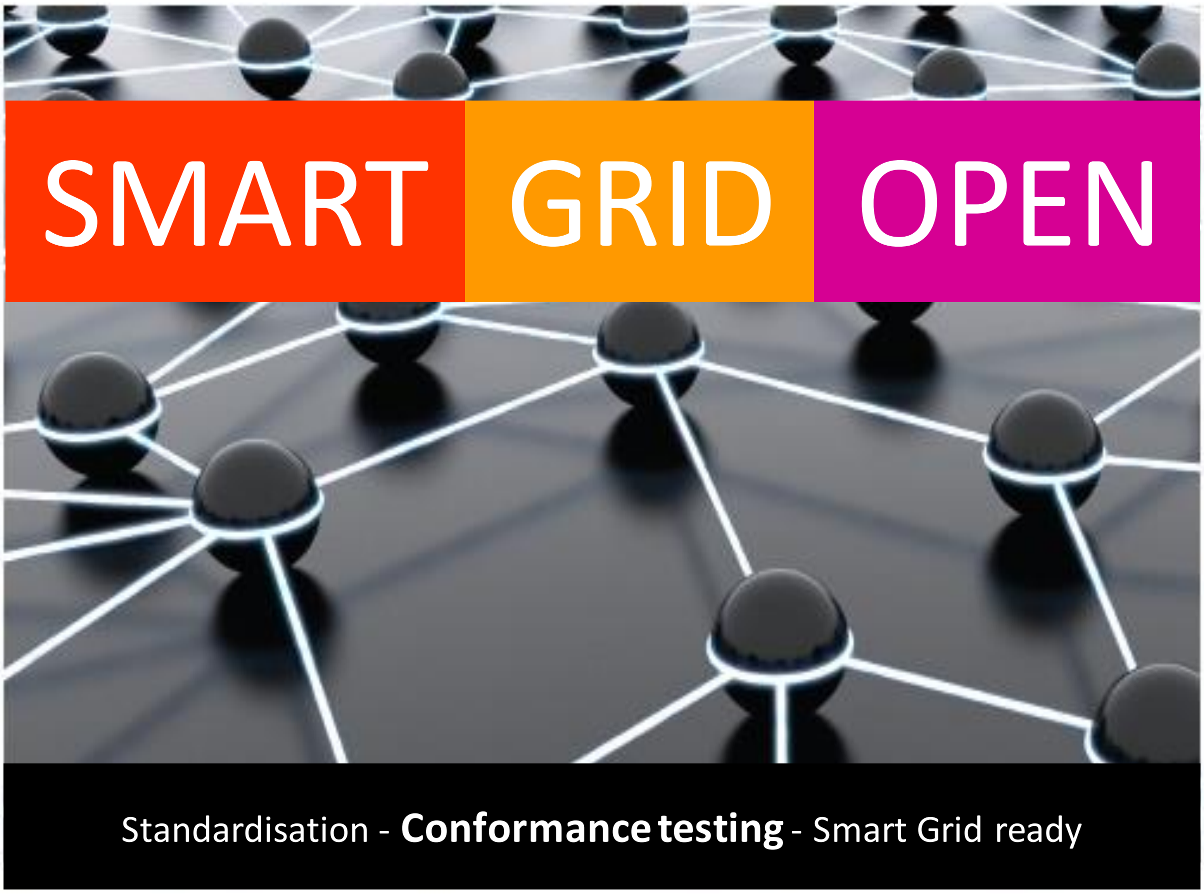
SGO Final Report



Smart Grid Open is a R&D project, supported by ForskEL (project no. 12100)

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SGO Final report 20160927 (*WP6* Deliverable D6-1)

1.1 Project details

Project title	**Smart Grid Open**
Project identification (program abbrev. and file)	**ForskEL project nr. 2013-1-12100**
Name of the programme which has funded the project	**ForskEL**
Project managing company/institution (name and address)	**Danish Technological Institute** **Kongsvang Alle 29** **8000 Aarhus, Denmark**
Project partners	**Eurisco, Danfoss, DTU, VE-Net og Varmepumpefabrikantforeningen**
CVR (central business register)	**56976116**
Date for submission	**27. September 2016**

Acknowledgements

The Smart Grid Open project wants to acknowledge the support from all people, institutions and companies that have contributed in different ways be it interview, advice or provision of hardware for testing.

Without funding there would be no project and the Smart Grid Open project has only been possible due to funding from the Danish PSO research program ForskEL, managed by the Danish TSO Energinet.dk. Thank you very much for the support all the way.

Danish Technological Institute has a performance contract with the Danish Ministry of Higher Education and Science, which has partly co-financed the project participation related to EV.

The project is also very grateful for valuable support from the heat pump manufacturers, which have kindly provided several heat pumps for smart grid testing and extensive technical support.

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1.2 Short description of project objective and results

1.2.1 Brief description of Smart Grid Open project

To help minimize add-on cost for Smart Grid ready high power products for the domestic domains like PV systems, Heat pumps, EV home chargers, the SGO project wanted to develop a Smart Grid ready conformance test method based on open standards (primary IEC 61850-10 Conformance testing standard). Based on proven tools and standards the test method was developed but no standard Smart Grid ready domestic equipment were found available for verification of the concept.

Instead, the SGO project found that a very simple Smart Grid control using two digital lines as implemented in Germany for grid control of Heat Pumps and PV systems may give 80% of the wanted Smart Grid effect for 20% complexity (and cost) for most domestic devises including Battery Energy Storage (BESS).

1.2.2 Kort beskrivelse af Smart Grid Open projektet

For at minimere ekstraomkostningen ved Smart Grid parat høj-effekt udstyr til privat segmentet f.eks. solceller, varmepumper og elbil hjemmeladere har SGO projektet ønsket at udvikle en Smart Grid parathedstest baseret på åbne standarder (primært IEC61850 Conformance testing standard). Ud fra afprøvede metoder og værktøjer blev testmetoden udviklet, men der blev ikke fundet standard Smart Grid parate apparater der kunne benyttes til verificering.

I stedet fandt SGO projektet, at det meget enkle Smart Grid styre koncept som benyttes i Tyskland til solcelleanlæg og varmepumper vha. 4 signaler (via 2 ledninger), måske kan tilbyde 80% af Smart Grid fleksibiliteten til 20% af kompleksiteten (og omkostningen). Anvendeligt for næsten alt effekttungt privat udstyr inkl. batteri lagre (BESS).

1.3 Summary

1.3.1 Project purpose and activities

To reach the ambitious Danish goal of not only fossil free electricity by 2035 but also supplying most of heating and transport energy from the electric grid by 2050 new flexible measures are needed to absorb the fluctuating energy efficiently. Even in the domestic domain, a need for demand side management is foreseen to integrate new electric devices like heat pumps (HP), electric vehicles (EV), Photos Voltaic (PV), Battery Energy Storage Systems (BESS) and the general domestic electric consumption.

Smart Grid technology enables smart management of a wide range of grid connected electricity consumers and DER (Distributed Energy Resources) such as PV, home wind turbines, microCHP, EVs, HPs, BESS and thus supports a smooth integration of increasing fluctuating renewable energy resources like solar and wind power. For the domestic domain, Smart Grid enables demand side management (DSM) and can enable virtual storage and virtual power plants using available flexibility.

For a full-scale Smart Grid role out, electricity customers must be willing to buy Smart Grid ready equipment in the shops. The domestic domain is a most price sensitive area. Without direct incentives, standardisation is the only way to bring down the extra cost of integrating a Smart Grid interface. Paying a premium price for a Smart Grid ready device today is a risky investment since the grid stakeholders have not yet decided on a standard for common exchange of Smart Grid information. Lack of an open agreed standardized information exchange between grid and consumer means that suppliers of the future smart equipment can only guess at requirements but hardly verify conformance.

The intention of the “Smart Grid Open” project was to offer actual guidelines and methods for testing protocols enabling conformance testing of Smart Grid control interfaces for Smart Grid ready products. The reality of the Danish Smart Grid market however is that very few products exist that claim to be Smart Grid ready to an open standard. Many product suppliers offer “Smart” products based on proprietary control through their own dedicated servers. Lack of Danish grid stakeholder recommendations on preferred Smart Grid standards means that Smart Grid functionality is not requested by domestic customers, nor offered by suppliers and not encouraged by grid operators and authorities. This forced the Smart Grid Open project to revise the problem statement slightly into looking at principles for possible reference testing on three domestic product domains: PV, Heat Pumps (HP) and domestic EV charging - all characterised by continuous high grid power for several hours compared to traditional domestic loads. Lacking actual Smart Grid ready products, this project suggests a possible alternative Danish way towards an open Smart Grid standard and a test method that follows the principles of recognised control standards like IEC 61850.

The SGO project found that a very simple Smart Grid control using two digital lines as implemented in Germany for grid control of Heat Pumps and PV systems may give 80% Smart Grid effect for 20% complexity and cost for most domestic devises including Battery Energy Storage (BESS).

1.3.2 Findings summary

- Roles and use cases developed for HP and EV domains in a Danish context in accordance with the Smart Grid 'reference architecture' (based on DANGRID work and the European M490 mandate), and Smart Grid relevant management functions identified for PV.
- Examples of formalised test procedures for the domestic product domain areas Electric Vehicles and Heat Pumps. These can be adapted to other domestic appliances like Distributed Energy Resources like e.g. PV, wind and microCHP.
- Developed reference test systems for selected 'pilot' test applications. I.e. reference test systems for EV domestic charging spot and Smart Grid ready heat pump.
- A Danish adaptation of the German heat pump SG-Ready label seems useable as Smart Grid control signals in a Danish context –
    - For heat pump aggregator control (Must Stop and Run Higher modes)
    - For DSO enabling DSO override control (Must Stop and Must Max).
    - Not only for heat pumps but also useful for **most other private product domains** like PV, EV home charge, battery storage etc.
- The compliance to the German SG-Ready seemed to be implemented in different ways by the suppliers. A certified verification of the actual heat pump characteristics and compliance to a Danish Smart Grid Open ready label could be relevant if any aggregator should expect to use standard control independent of the heat pump brand and type.
- Smart Grid Open concept is believed to offer an actual practical link between standardisation and conformance testing of Smart Grid ready products when available.

In hindsight, the project has been relevant and useful even though no advanced Smart Grid ready components have been identified. The project came to acknowledge that the simple SG Ready control might be enough to handle the Danish challenge. Even when things seem simple, there can be significant learning in actually testing real hardware, since the devil sticks in the details.

1.3.3 Recommendations

Grid stakeholders should urgently start negotiations on a Danish minimum Smart Grid requirement for power heavy domestic equipment. Several different aggregators may be operating equipment in the same domestic domain so a requirement for Interoperability and interchangeability seems highly relevant. There is beauty in simplicity and adapting the German four-mode control used for PV-systems and SG-Ready heat pumps gives immediate access to a large base of Smart Grid ready devices. Even with such a simple control, the local grid operator can overrule any Aggregator command without hindering advanced smart grid services.

Since voluntary action seem to have failed, legislation requiring standardised Smart Grid interface control should be considered. At minimum requiring standardised remote control inputs that enable: a minimal power mode and a maximum power mode supplemented with an optional Run Higher mode intended for Aggregator services. In popular terms such an SGO ready Smart Grid control may offer over 80% of the available flexibility in the domestic domain for 20% of the complexity (and cost) of an advanced solution with advanced web-based online management.

1.4 Project objectives

Denmark has set the ambition high with a national strategy to be independent of fossil fuel by 2050. This will require a substantial expansion of the renewable energy (RE) sources and green electricity will be the main alternative to fossil fuels.

To integrate much more fluctuating, renewable electricity into the future grid, a number of measures must be developed to secure the stable and reliable electricity supply which the Danish society is used to. Besides a massive rollout of RE generating facilities, part of the solution to the RE challenge, is a parallel deployment of Smart Grid control systems also for demand side management to create a much-needed flexible demand.

Danish electricity consumers are used to and depend on a very stable and reliable electricity supply. Since the consumers cannot yet be managed, the stability comes from clever management on the supply side combined with a shrinking base of central traditional thermal generation. For a 100% RE electricity scenario without traditional generation, new measures will be needed to ensure stability. To enable a massive rollout of RE generating facilities a parallel deployment of Smart Grid control systems can be a measure for demand side management to create a much-needed flexible demand.

Smart Grid technology enables smart management of a wide range of grid connected electricity consumers and DER (Distributed Energy Resources) such as Photo Voltaics (PV), home wind turbines, microCHP, Electrical Vehicles (EV), Heat Pumps (HP) and thus supports a smooth integration of increasing fluctuating renewable energy resources like solar and wind power. For the domestic domain, Smart Grid enables demand side management (DSM) and can enable virtual storage and virtual power plants using available flexibility.

Electricity Customers must be willing to buy Smart Grid ready equipment in the shops to achieve a full-scale Smart Grid role out. Without direct incentives, standardisation is the only way to bring down the extra cost of Smart Grid interface to an acceptable level in the domestic domain, that are a most price sensitive area. Paying a premium price for a Smart Grid ready apparatus today is a risky investment since the grid stakeholders have not yet decided on a common Smart Grid information exchange method. Lack of an open agreed standardized information exchange between grid and consumer means that suppliers of the future smart equipment can only guess at requirements but hardly verify conformance. Strong involvement in standardization work is needed by stakeholders together with a Danish smart grid reference architecture and a coordinated effort to secure a national testing and approval method for ‘Smart Grid Ready’ products.

The intention of the “Smart Grid Open” project was to offer actual guidelines and methods for testing protocols enabling conformance testing of Smart Grid control interfaces for Smart Grid Ready products. The reality of the Danish Smart Grid market however is that very few products exist that claim to be Smart Grid Ready to an open standard. Many product suppliers offer “Smart” products based on proprietary control through their own dedicated servers. Lack of Danish grid stakeholder recommendations regarding preferred Smart Grid standards means that domestic customers are not requesting Smart Grid functionality and suppliers are not offering it. This forced the Smart Grid Open project to revise the problem statement slightly into looking at principles for possible reference testing on three domestic product domains: PV, Heat Pumps (HP) and domestic EV charging - all characterised by continuous high grid power for several hours compared to traditional domestic loads. Lacking actual Smart Grid Ready products, this project instead suggests an alternative Danish way towards an open Smart Grid standard and a test method that follows the principles of recognised control standards like IEC 61850.

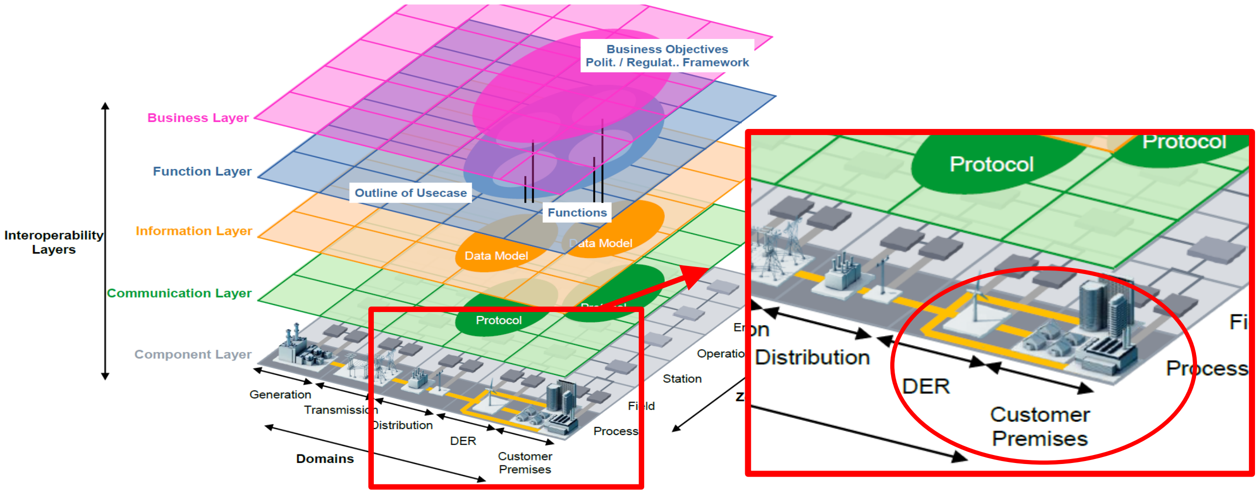


Figure 1 Project focus is on the cost sensitive Customer and low voltage DER domains illustrated by the encircled domain on the Component Layer of the European SGAM model from the M/490 EU mandate.

The initiative for Smart Grid Open project was taken in 2011 but due to a lack of commercial Smart Grid Ready products, the project start was postponed to 2013 expecting an imminent emerging market for Smart Grid Ready products.

Regarding ‘Smart Grid’ data communication, international standards are needed, but **a standard is not an implementation guideline**, which means that conformance test based on well-defined reference systems and test procedures has to be established and supported.[1]

Large product suppliers will typically drive the development and hereby define the ‘domain standards’ to be used, but since the driving force behind the Smart Grid implementation lies elsewhere a different approach seems logical. If **the ‘Smart Grid’ stakeholders could define the needs (reference architecture)**, define the technical interfaces and the specifications (Smart Grid Ready) that the products have to support – then the chance of a conform Smart Grid system will be much higher and the risk of proprietary solutions lower

International standardization can be stronger if the organization of user groups and conformance test specifications receive more focus. The feedback from demonstration projects, multi-vendor product testing (interoperability test) and conformance test from test organizations, could give the standardization a much stronger position in the industry. The Smart Grid Open project, will **feed knowledge back to the national standardization committee and international standardization groups**. This would allow the Danish industry to gain first-mover advantage, ‘set the agenda’ and benefit commercially.

[1] See appendix 1 in Focus areas for ForskEL 2012 call: http://www.energinet.dk/SiteCollectionDocuments/Danske%20dokumenter/Forskning/Udbud%202012%20ForskEL%20Call%20text.pdf

1.4.1 Project scope and organisation

This document is the final report from the Smart Grid Open (SGO) project.

Smart Grid Open is a R&D project, supported by ForskEL (project no. 12100).

This document will outline an architecture framework for identifying the data to be exchanged with a few domains with highest impact on domestic electric flexibility, which are:

- Heat pumps
- Electric vehicles
- Photovoltaic
- Home and building automation

Heat Pumps have been the 'reference' domain in the project for building the more generic test methods and SGO concept. This choice was made because of the expert knowledge from DTI laboratory and access to existing test facilities for running test on domestic heat pumps.

The work approach is in line with the methods developed in connection with the EU M/490 mandate.

1.4.1.1 Organisation

The SGO project was initiated with a strong and cost-effective lean organization with few core

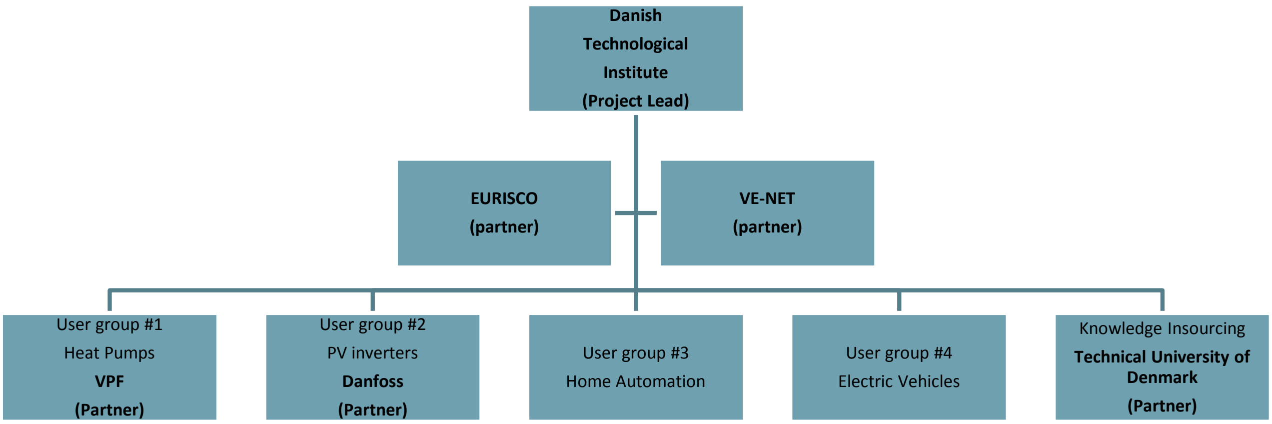


Figure 2 Project Organisation

partners (DTI, EURISCO, DTU, VE-Net) and two product domain partners (The Danish Association of Heat Pump Manufacturers and Danfoss) supported by important stakeholders such as Energinet.dk, Danish Energy Association and DI ITEK. The number of involved stakeholders was expected to increase via defined user groups (product manufacturers, system integrators and other related stakeholders) during the project period. The lack of Smart Grid ready equipment and strategic changes/priorities has forced the project into a slightly different approach than planned. Several partners were unable to contribute as expected.

1.4.1.1.1 The project lead

Danish Technological Institute, DTI, has lead the project. DTI is an independent, not-for-profit institution approved by the Danish authorities to provide technological services to businesses and the community. DTI provides approved technological services such as consultancy, tests, certification, education and training to companies, organisations and the community. Danish Technological Institute is active in a wide range of national and international projects and collaborates with a number of Danish and international research establishments, companies and organisations. DTI has existing dedicated test facilities in many fields including PV-systems, heat pumps, EVs and even an Energy Flex House integrating all of these domains and extensive house automation. The Institute contributes with technological knowledge and experience in projects on electric vehicles, heat pumps, house appliances, communication protocols, embedded data logging, control equipment, battery technology and various other technologies. DTI is currently a member in the Danish S/454 EV mirror committee and S/557 control of power systems and communication mirror committee.

1.4.1.1.2 Core project partners:

EURISCO Aps is a major project partner, which has demonstrated in-depth insight in the field of harmonization and standardization of grid-related communication in many grid related projects. EURISCO is an independent Danish development company. EURISCO has since 1994 developed hardware and software on a contract basis for customers within the energy, surveillance and defence industries. In close cooperation with its customers, EURISCO provides development services for specification of new product development, hardware and software design – basically from idea to prototype or final product. With many years of experience within international standardization, EURISCO also provides consultancy services within the technical domains of: Electric Vehicle (IEC TC69 and IEC/ISO JWG V2G), Power system (IEC TC57 WG17 for Distributed Energy Resources) and Security (TC57 WG15)

Technical University of Denmark DTU has tradition for central involvement in most major Danish and many international grid related R&D activities, resulting in deep and wide knowledge on grid management. At the responsible DTU unit, DTU Electrical Engineering, Centre for Electric Power and Energy (CEE), smart grid communication between power systems and DERs, including standards and open systems, are essential for the activities. CEE has been involved in several smart grid innovation and preparation projects, like FlexPower (ForskEl), EDISON (ForskEl), EcoGridDK (ForskEl), EcoGridEU (EU PF7), DERlab / DERri (EU FP7), SmoothPV (Nordic), INCAP (DSF) and iPower (SPIR). CEEs experimental research facilities include the PowerLabDK, a collection of smart grid laboratory facilities, ranging from single unit laboratories, over small-scale power system laboratory (SYSLAB) to full-scale live laboratory (Bornholm), and including the Nordic Electric Vehicle Interoperability Centre (NEVIC). Related to the electric grid DTU do represent unique research knowledge built over many years. However, DTU was unable to prioritise the knowledge transfer over other pending research activities within the project timeframe.

VE-Net (Renewable Energy Innovation Network) use their network and skills in the area of matchmaking and event organisation. The network had a focus on bringing research and innovation into the business community and in particular to the benefit of small and medium-sized companies (SMEs). VE-Net was a national Danish innovation network with major players in the Danish energy field such as companies, research establishments, approved technological service institutes, organizations and trade associations participated in the network. VE-Net aimed at creating synergy between and across the various energy forms and systems. The purpose was to contribute to the development of new technologies, promote the incorporation of renewable energy into the Danish energy system and contribute to promoting energy efficiency. Via project groups VE-Net focused on areas such as waste, bioenergy, district heating and cooling, intelligent integration of RE, intelligent energy cost effectiveness and PV. The financial support to VE-Net from the Danish Ministry of Higher Education and Science was terminated in the middle of the SGO project period, and the VE-Net was consequently closed down due to lack of funding. The remaining SGO tasks in the SGO project has been taken over by the project leader.

1.4.1.1.3 Domain project partners:

Danfoss (DSI = Danfoss Solar Inverters) was product domain representative for the PV inverter area – the only Danish manufacturer. With a very high share of export Danfoss Solar Inverters was a fast growing producer of PV inverters from domestic inverters at few kW to MW industrial range. DSI integrated new advanced functionalities and ancillary services into the inverters including IEC 61850 high-level grid control interface and smart grid functionalities. DSI was not able to put very much effort into the project before the solar inverter part of Danfoss was taken over by SMA. Fortunately, a successful workshop on PV systems were completed before the exit of Danfoss. This confirmed the methodical approach planned in the SGO project where product specialists, grid system specialists and research join their forces to identify the minimum essential information recommended for Smart Grid control of PV even at domestic level.

The **Danish Association of Heat Pump Manufacturers, (VPF)** was product domain representative for the heat pump area on behalf of manufactures. The Danish Association of Heat Pump Manufacturers counts as its members all the most important and biggest producers and suppliers of heat pump solutions on the Danish market. The basis for the branch collaboration is focusing intensively on delivering quality in all elements of the heat pump installation - from dimensioning and installation over the heat pump itself and to servicing after the installation. A key goal of the association is also to promote heat pump industry interests toward decision makers and authorities to ensure the best possible framework conditions. The Association is promoting continued research and development to further improve and make heat pumps even more effective and competitive. The Danish Heat Pump Association is member of the European Heat Pump Association (EHPA). Dealing mostly with commercial and legal issues the association struggled to find members willing to represent the association in the area of Smart Grid. In the end, a few members of the association offered their assistance on an individual basis offering their view on the future and more important offering heat pumps for Smart Grid ready testing.

1.4.1.1.4 Reference group

Representatives from the following entities have been invited for two reference group meetings:

- DI Energy (Danish Energy Industries Federation),
- UL International Demko A/S,

- Danish Energy Association, a non-commercial lobby organisation for Danish energy companies
- Danish Standards
- Aalborg University
- University of Southern Denmark
- Danish Safety Technology Authority
- EnergiNet.dk, the Danish TSO
- Insero Energy
- Danfoss
- DI ITEK (Danish ICT and Electronics Federation)
- Danish Technological Institute (DTI)

At the first meeting, the SGO idea was presented and comments on method or objectives were invited. The scope was extended to include security in Smart Grid Communication.

At the second reference group meeting, the issues with lack of Smart Grid ready equipment and lack of recommended standards was raised. The lack of market pull is the reason for the undeveloped Smart Grid market. The possible close down of Danfoss solar inverter development due to the merger with SMA in Germany was not yet announced. The recommendations from that meeting were complex:

- PV was recommended as first domain to work on.
- DSO level has no need for SG control but will not object to any smart products or services that may be offered. Any management of possible SG equipment will be through an Aggregator.
- DSO level do not see need for SG technical requirements for domestic equipment and will not drive any development.
- There was a hypothetical discussion on a Smart Grid label, maybe with two phases:
    - SG-ready 1.0 (grid-friendly) – maybe based on a limited use cases
    - SG-ready 2.0 (TSO friendly) – based on a full set of use cases
    - With reference to the little useful HD Ready labelling of flat screen TVs there were no clear recommendation for a smart grid labelling without agreed technical basis.
- Regarding EV charge,
    - DSOs prefer smaller one-phase chargers for EVs rather than higher-powered 3 phase chargers since many small chargers are less likely to peak at the same time.
    - There is no plan on including Vehicle to Grid (V2G) in SGO. If it comes, it is expected to have an inverter on the installation side so maybe solutions from PV side can be reused.
- Domestic Heat Pumps are considered customer equipment.
    - The critical scenario is a radial with Heat Pumps using electric top-up because of low temperatures.
    - After a power outage or load shed period it would be nice to manage Heat Pump starting
    - The SGO-project will look at Heat Pump Use Cases later.
- The reference group recommends the SGO Project to make a reference system, which could ease modelling work later.

It has been a challenge finding end users and manufactures of Smart Grid ready equipment. The original project plans have been revised dynamically throughout the project, and the project period was extended with more than a year hoping for development of a potential national Danish Smart Grid setup or a political decision on direction.

1.4.1.1.5 Change in partner status during the project:

Danfoss stopped active participation when their Danish Solar Inverter development was closed. Consequently, the project abandoned the planned test on PV systems.

VE-Net was closed down shortly after the funding from the Danish Ministry of Higher Education and Science terminated. The remaining task were taken over by the project leader.

DTU was having problems finding available qualified people to transfer knowledge to the project. Therefor DTU activities were set on hold for the remaining project period.

1.4.1.1.6 Funding

The Smart Grid Open project has only been possible due to funding from the Danish PSO research program ForskEL, managed by the Danish TSO Energinet.dk. Thank you very much.

The Danish Technological Institute project participation has been co-financed partly from a DTI performance contract with the Danish Ministry of Higher Education and Science.

1.4.1.1.7 Risk

The main risks anticipated relevant to this project were lack of user group support and lack of agreement on reference architecture.

- EURISCO has a good overview over the area and has extensive experience with IEC working groups and the relevant standards. The principles of the reference architecture were accepted by the project reference group and not questioned by the involved domain representatives.
- Commitment from stakeholders needed to implement the planned working method. The approach worked fine with Danfoss being represented by a highly qualified development specialist in an area where Danfoss had state of the art knowledge. The heat pump domain has many members in a strongly competitive situation. The domain was represented by sales people with limited understanding of the project scope and therefore limited successful in liaison between the company’s product development people and the project.
- Project dissemination has been handled with care respecting different interests in this field.

1.4.1.2 Background information

The main purpose of this document is to present the SGO project results and to collect and use already existing material from other R&D projects, standardizations groups and test specifications – which is to be considered ‘State-of-the-art’.

Unfortunately, the area for conformance and interoperability testing is a new and not very well covered area yet. Thus, a lot of the background material is work in process and there are also areas which are not covered at all.

Elements, which are new and developed specific for the purpose of SGO, like:

1. 'SGO Compatibility levels'
2. 'SGO Management Framework'
3. 'SGO Conformance test' definitions'

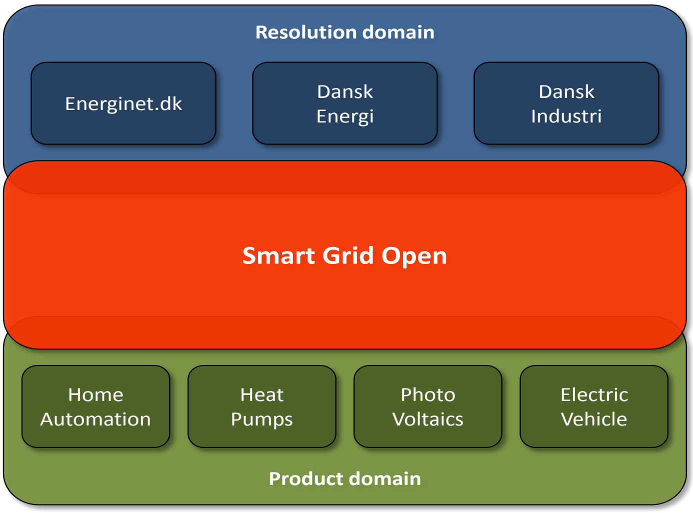
These new elements or concepts are not standardized and only used in this project as inspiration for further work. It is important to have very clear terms and definitions regarding 'interoperability' – but it is also a challenging area to harmonize.

1.5 Project results and dissemination of results

1.5.1 Challenges and findings

Conflict on the business model

One of the challenges regarding harmonization of terms and definitions for 'Conformance and Interoperability' is the business model that drives the process.



The 'Resolution domain' (blue area) may have an interest in harmonizing the interfaces for data exchange, because this gives limited technology bindings, open market opportunities and lower cost for products.

The 'Product domain' (green area) may on the other hand not be so interested in harmonizing the interfaces, because this will limit the technology bindings, make room for more market players and therefore lower the prices on the products.

Conclusion: It was not expected, that the producers of 'Smart Grid products' will be the main driver for the process of making new standards and concepts for interoperability standards and guidelines.

1.5.1.1 Interoperability, Conformance test and Compatibility levels

The definition of terms is important if we want to have a common understanding of what we are dealing with. In SGO we use the basic terms Interoperability and Conformance as two different, but also link definitions.

Conformance test is defined as a test to determine whether a component or system meets the required specification or standard.

Smart Grid Open defines **Interoperability** as the ability for components and systems to co-exist and operate together from a physical, logical and operational point of view.

SGO also defines several levels of **Compatibility** based on the ability for a given component or system to be compatible with another component or system of a different type (vendor).

The matrix in figure 2 illustrates the compatibility level definition versus the technical interface for a given component or system. The 'grey' colour means that e.g. two components can be defined as 'Interconnectable' if the physical interface match (connectors) and the protocol interface match (Ethernet and TCP/IP) – but they do not use the same service interface (REST vs. OPC UA). So basically they can 'see' each other on a network and coexist, but they are not able to work together or be 'Interworkable'.

SGO compatibility levels						
	Incompatible	Coexistent	Interconnectable	Interworkable	Interoperable	Interchangeable
Application interface						
Information interface						
Service interface						
Protocol interface						
Physical interface						

Figure 3: SGO compatibility levels

The SGO compatibility level definitions are based on the 'terms and definition' as defined by TC65 (ref.: 65/290A/DC) – but with a different set of device features.

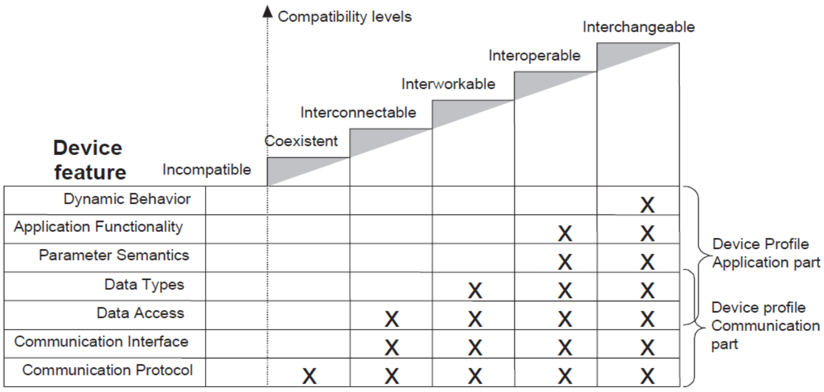


Figure 4: 65/290A/DC from IEC TC65: INDUSTRIAL PROCESS MEASUREMENT AND CONTROL. TC65 has made a 'Device Profile Guideline' where they define 5 Compatibility levels of Interoperability.

Incompatibility
Incompatibility is the inability of two or more devices to work together in the same distributed application. Incompatibility can result from differences in application functionality, data semantic, data types, and communications interface, or even communications protocols used by the affected devices. Incompatible devices may even interfere with or prevent each other's proper communication or functioning (possibly even destructively), if placed in the same distributed application network.

Coexistence
Coexistence is the ability of two or more devices, regardless of manufacturer, to operate independently of one another at the same communications network, or to operate together using some or all of the same communications protocols, without interfering with the functioning of other devices on the network.
NOTE there have not to be an agreement regarding the communication services.

Interconnectability
Interconnectability is the ability of two or more devices, regardless of manufacturer, to operate with one another using the same communication protocols, communication interface.
NOTE the devices allow data exchange without agreements about the data types. A data type conversion may be necessary.

Interworkability

Interworkability is the ability of two or more devices, regardless of manufacturer, to support transfer of device parameters between devices having the same communication interface and data types of the application data.
NOTE if a device is replaced with a similar one of a different manufacture, it can be necessary to reprogram the application.

Interoperability
Interoperability is the ability of two or more devices, regardless of manufacturer, to work together in one or more distributed applications. In case of replacement with a similar device of any manufacture, all distributed applications involving the replaced device will continue to operate as before the replacement, but with possible different dynamic responses. Interoperability is achieved when both a field device and a system support the same combination of mandatory and optional parts of the same standard.
NOTE Manufacturer-specific extensions in field devices or systems from different manufacturers may prevent interoperability.

Interchangeability
Interchangeability is the ability of two or more devices regardless of manufacturer to work together in one or more distributed applications. The devices will be using the same communication protocol and interface. The data and functionality of each device is defined so that any distributed applications involving a replaced device will continue to operate as before the replacement, including identical dynamic responses of the distributed applications.

1.5.1.2 Existing conformance test activities

The project has looked into existing conformance test activities and standardised methods of developing use cases with defined actors and roles for domains.

A note on existing conformance test activities can be found in ANNEX C together with an example of detailed 'Actor and Role definitions' used in the E-Mobility role model under CENELEC 'WG Smart Charging'.

A role model is essential for all the domains in SGO, so for the domains where a role model has not been developed by a standardization group or other organization representing the domain – SGO have provided this as part of WP2.

The role model with a clear definition of the actors is the basis for the use case definitions and functions in SGO.

1.5.1.3 Smart Grid Architecture Model – SGAM

One of the essential objectives in SGO is to define the different layers based on the M/490 SGAM model (Smart Grid Architecture Model). See SGAM model on figure XX.

In the figure, it is illustrated which layers areclosely covered by SGO (yellow and partly blue and green) and which is only partly covered (pink and grey).

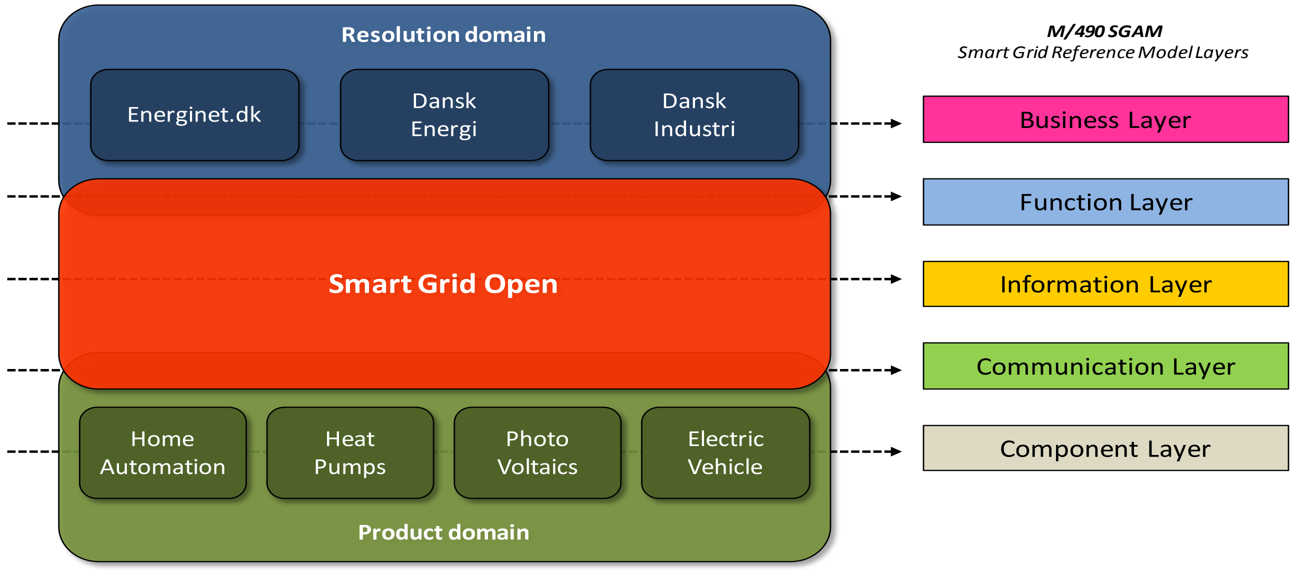


Figure 5: SGO architecture model overview

In WP2 a working process was established with key companies and organizations from the resolution domain, for localization and development of use cases (both business and functional related).

In WP3 a working process with key representatives from the product domain was established, to get a detailed view on the data communication interfaces to be supported in SGO, though only realized fully for the PV domain.

1.5.1.4 Dansk Standard – Forum for Smart Grid og Vedvarende Energi

Dansk Standard has since 2011 - as an extension to the National Committee work for Smart Grid standardization, facilitated a community called FSGVE (Forum for Smart Grid og Vedvarende Energi).

http://www.ds.dk/da/standardisering/fagomraader/forum-for-smart-grid-og-vedvarende-energi/

FSGVE has arranged a series of workshops with focus on SGAM and support of Smart Grid related topics with relation to the SGO project and scope.

The domains, which have been in focus, are similar to SGO, which are: EV, Heat pumps PV, Home and Building automation. In addition, other areas like Smart Metering are in focus for FSGVE.

1.5.1.5 Working Group Methodology

The work process follows the principles of the IntelliGrid Architecture methodology.

The overall systems engineering methodology for the Smart Grid Open project consists of the following project steps:

- Domain experts are tasked to support the project team. As one of the first undertakings of the project team, stakeholders (users) that could influence or be impacted by the project have been identified.
- Domain experts review existing Use Cases for applicability and ideas.
- Domain experts develop a list of Use Cases (functional descriptions), covering not only the specific business need but other user needs and future possibilities that could influence or might be impacted by the project.
- Domain experts, with possible assistance by project engineers who understand the Use Case process, draft the key Use Cases, capturing all of the necessary user requirements.
- Domain experts review and update these Use Cases to ensure their needs are captured correctly and to assess possible misunderstandings, overlaps, holes, and other inconsistencies.
- Project engineers assess and coordinate the Use Cases from which they develop a comprehensive and detailed user requirements document. This detailed user requirements document contains only user requirements.
- Information specialists apply the appropriate standards and technologies, based on the user requirements document. The strategic vision of the Architecture should be used to determine the key standards and technologies.
- Design engineers develop the Technical Specifications, which combine the user requirements from the domain experts, the strategic standards and technologies from the information specialists, and the tactical approach to system development recommended by the architecture.

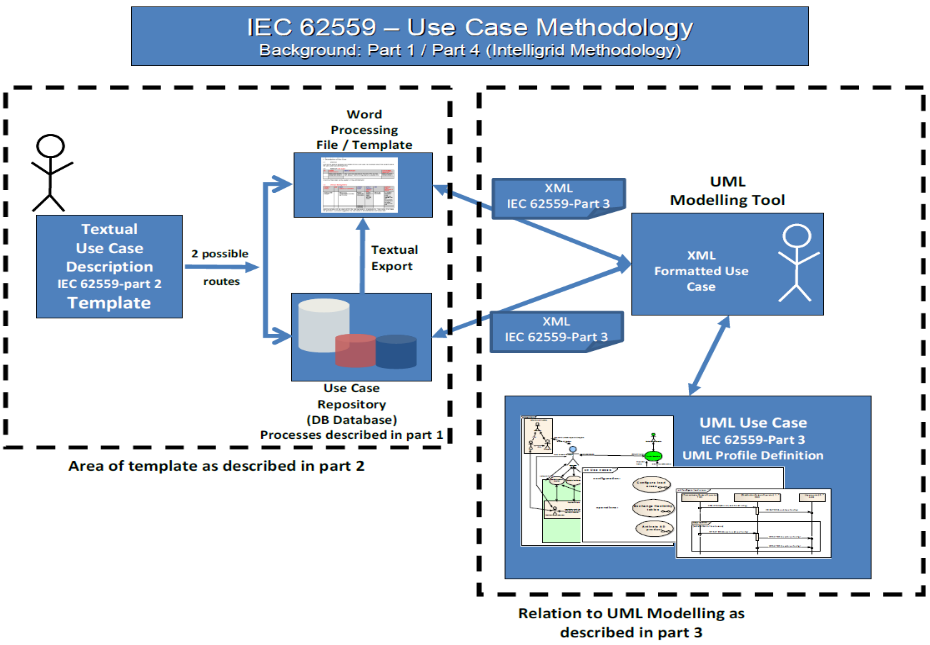


Figure 6: IEC 62559 Use Case Methodology

1.5.1.6 Use cases - template

Use cases were described in WP2 based on the basic idea of IEC 62559-2 standard, but with a more simplified structure and template.

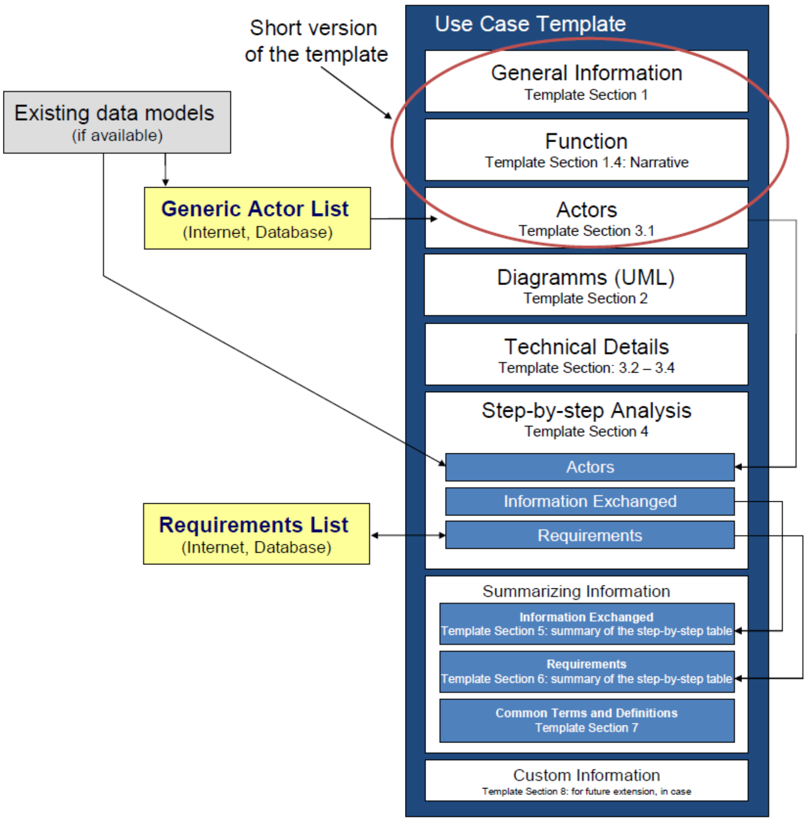


Figure 7: Use case template from IEC 62559-2 Ed1 (ref.: 8_1321e_CD.pdf)

The Use case template figure provides an overview of the use case template and its internal relation as well as the relation to the actor list and the requirement list, which are common for all use cases.

Existing use case descriptions from a Use Case Repository can be adapted into the project defined use cases as relevant.

The use case descriptions will start as short versions with the minimum mandatory fields:

- Name of use case
- Author and date
- Main goal – short narrative text
- Actors involved
- Sequence diagram to illustrate the steps

The short version is the basis for the complete use case which can be extended in a simple way with the addition of further information, i.e., without rewriting the use case. Being self-explaining, the short version is seen as an easy starting point for involving domain experts without going into every detail of the use case methodology and its complete use case template.

1.5.1.7 Use cases – examples from M/490

The use cases defined in M/490 is showed in the figure:

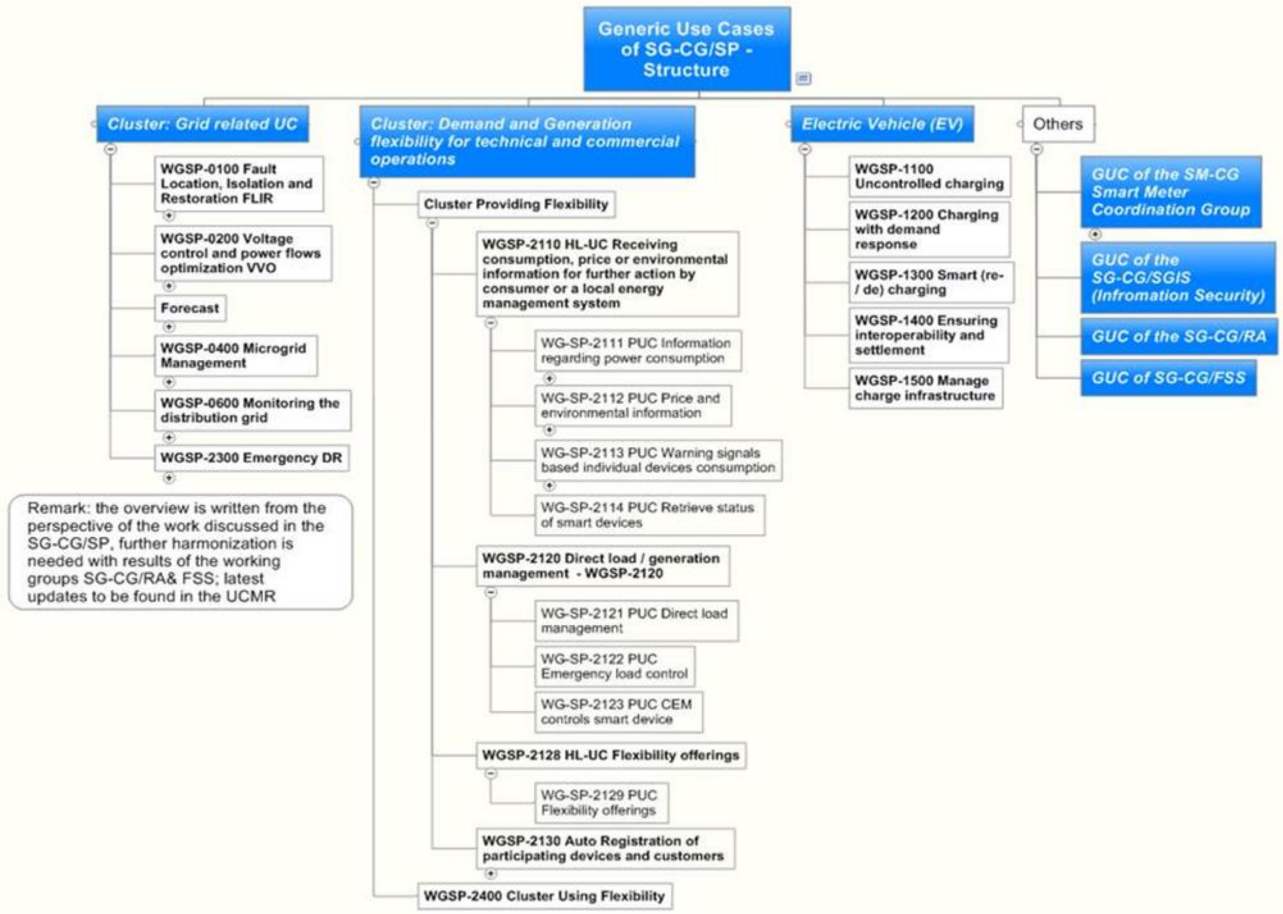


Figure 8: Use case overview from M/490

For more information about the use cases, please see this document.

http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/xpert_group1_sustainable_processes.pdf

1.5.1.8 SGO Management Framework

SGO management framework is the basic concept in SGO WP3 for merging the existing domain specific data communication standards (right side of the diagram), with the generic Smart Grid interface (on the left side of the diagram).

Similar concepts are in a working process in CENELEC WGI, IEC TC205 and IEC TC57 WG21, but at a very early stage – so SGO could not be used. The SGO Management Framework concept has been presented to CENELEC WGI under M/490 and will continuously be aligned with this work.

Basic illustration of the SGO Management Framework.

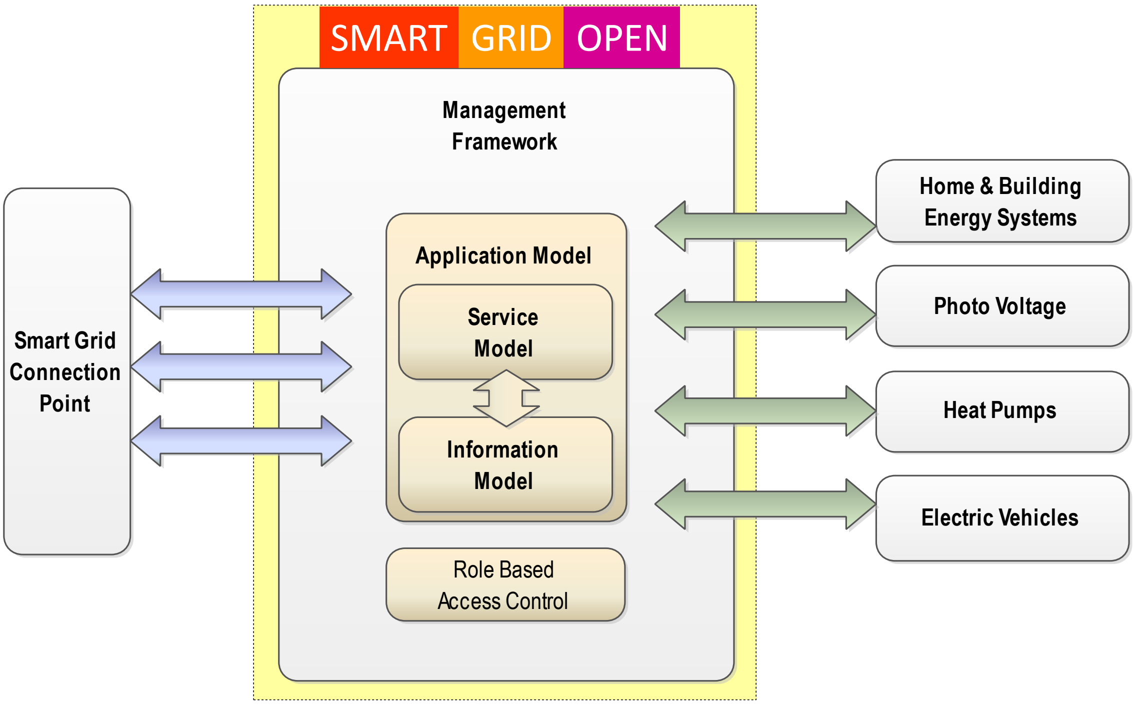


Figure 9: SGO assume a partly application specific Management Framework in Smart Grid Ready equipment that handles access control and information interchange. Service model is the equivalent functional SW model of the actual equipment function.

For SGO to handle different domains with a similar approach SGO assume a common Management Framework with sub modular adaptation to the specific domain.

A SGO test setup will consist of a complex test-equipment, consisting of several sub functions:

1. that will act as a Smart Grid communications server
2. emulate the stimuli from the application process as needed
3. a measurement unit that monitor the process feedback to assess reactions.

An important auxiliary test device will be the reference system i.e. an equipment simulator

The reference system will include the Management Framework and the different application specific sub models to simulate the behaviour of the actual equipment.

1.5.1.9 Smart Grid Connection Point

The SGO Conformance test specification was developed in WP2, and was focused on the following elements:

- Standards in scope
- Test specifications
- Test reports
- Recommendations

The illustration below will give an overview of the defined term (SGCP) – Smart Grid Connection Point, which is the 'logical' coupling point between the Smart Grid resource and the Smart Grid operator.

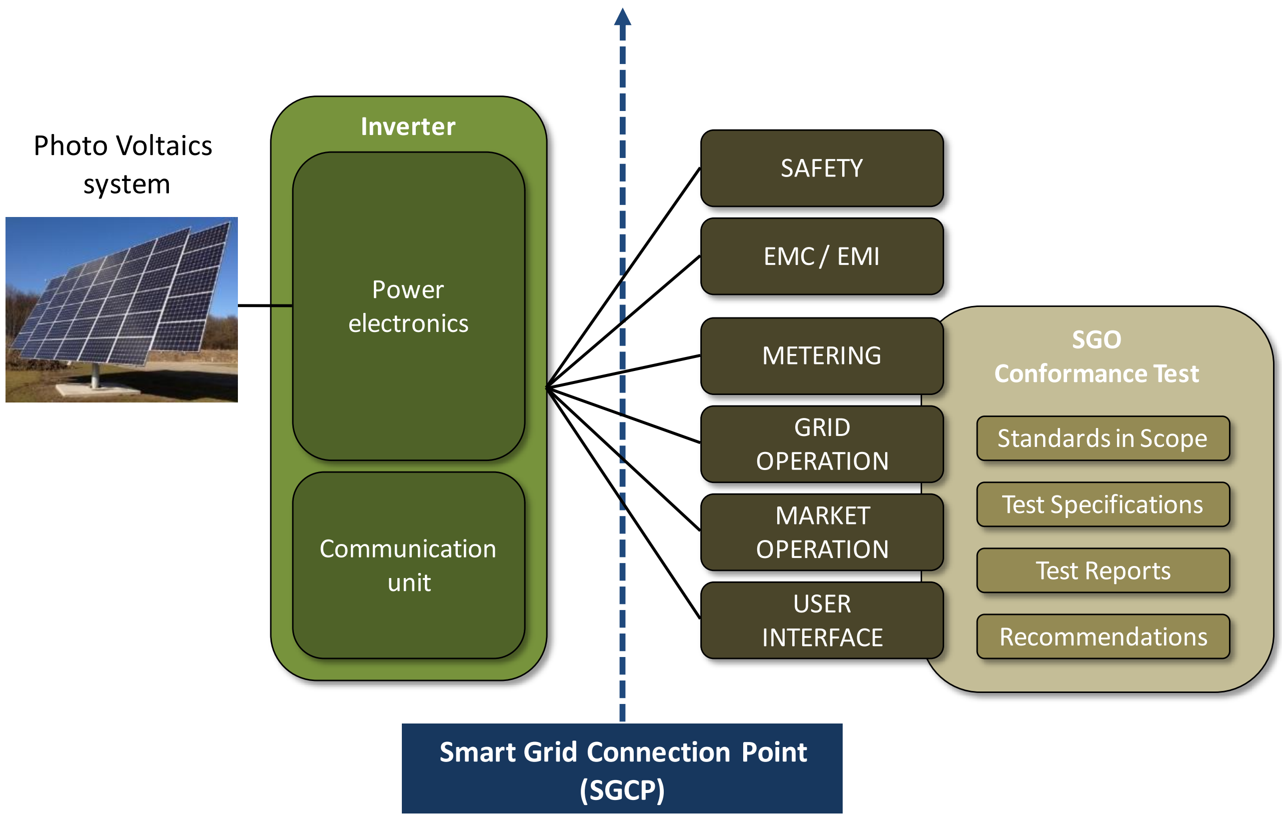


Figure 10: Smart Grid Connection Point illustrated with a PV inverter system. Left side is the embedded functions and hardware needed to operate. Right side shows 6 functional interface areas with external requirements of which 4 is addressed by the SGO test.

All grid-connected equipment has several requirements to fulfil. Some requirements are mandatory for safety and functional integrity of other systems and components. There must be some sort of user interface to allow for control or monitoring of the equipment's function. If an equipment should be able to offer flexibility to the grid, a further set of requirements must be fulfilled to accommodate management of the flexibility.

Safety requirements must be fulfilled by all equipment to ensure that nobody can be hurt by the operation of the equipment without deliberate action to bypass safety (Not Smart Grid relevant).

EMC/EMI (Electro Magnetic Compliance / Electro Magnetic Interference) requirements ensure that any equipment should not be adversely affected by electromagnetic noise and any equipment should not emit electromagnetic noise that can disturb function of other equipment and systems. (Not Smart Grid relevant).

Metering covered areas like e.g. actual power and energy flow, historic records of energy flow, voltage levels, frequency etc. (Is Smart Grid relevant).

Grid operation. Equipment must obey the local code of conduct on the grid in form of Grid-codes but can maybe even offer additional functionalities to the grid like e.g. reactive compensation or spinning reserve. (Is Smart Grid relevant).

Market operation covers functions that enable equipment to perform its basic function and possible grid services based on market conditions – participation in the market is normally via a trader /aggregator that will need (a standardized) communication to and from the equipment. The equipment must be able to signal the available flexibility and to react on external control from an aggregator/responsible system operator. (Is Smart Grid relevant).

User Interface can be anything from a very simple feedback indicator (a lamp showing the equipment is ON) to very advanced programmable functions with complex feedback options. (Is Smart Grid relevant).

The Smart Grid Connection Point is not a specific interface on the equipment but rather a information exchange interface between the embedded equipment internal management and a Smart Grid server or via point. The physical communications media can be any of several but the information and service model package definitions must be harmonized.

1.5.1.10 Domain area

Four equipment domains have been chosen as the focus in SGO. With Smart Grid control of these equipment domains, the essential part of critical electric consumption is taken care of.

Three equipment domains are characterized by a relatively high continuous electric load that could be active for hours:

1. Electric Vehicles (typical 2kW+ for 2 -12 hours)
2. Inverters e.g. PV-inverters (typical 4kW+ for 2 -10 hours)
3. Heat Pumps for house heating (typical 2 - 4kW intermittent for 0,5 to 24 hours)
4. Home Automation (Aggregate minor flexible loads at home-level)

The fourth equipment type in focus is Smart Grid ready home automation devices that should be able to aggregate some of the smaller flexible electric loads in buildings to emulate as a single larger load. The Home Automation equipment can work as a router and/or manage unintelligent equipment to act as Smart Grid ready. It is important to be aware that Home Automation equipment normally have other primary functions than Smart Grid services like e.g. comfort related controls or alarm functions.

Any Smart Grid management of individual electric hot water heaters is considered part of the Home Automation domain.

1.5.2 State of the art Test Equipment

1.5.2.1 Energy Flex House

Energy Flex House (EFH) is a highly flexible platform for testing building elements including control and energy assets. Two identical low-energy houses built in 2009 is used for test e.g. in form of side-by-side test combined with customer acceptance test. Both houses have more or less the same functionalities with respect to principal energy equipment. Two different brands of heat pumps; different types of HBES (Home and Building Electronic Systems); two different PV systems; each house has a garage where an EV can be charged. Virtually all energy systems in the EFH are monitored either by the integrated sensors or by dedicated sensors and many systems can be controlled externally by e.g. Smart Grid systems. The massive list of signals is used as inspiration for the SGO Home Automation domain.

Figure 11: Energy Flex House consist of the lab-house (to the left) and the family house (to the right). The right panel is a screen shot of the on-line display showing real time actual energy flow in the Energy Flex Family House. https://www.youtube.com/watch?v=bFHWTLHh5G4

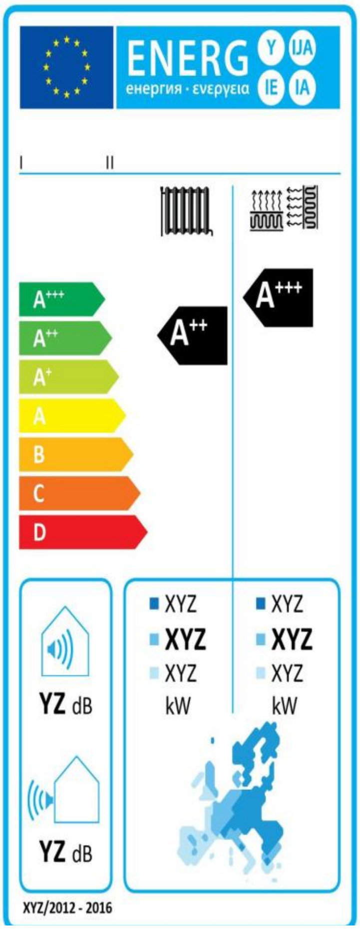


Figure 12 Heat Pumps must have an energy statement label.

The SGO project validates testing methods and test reference systems on selected products. The conformance pilot test is first conducted at lab level at the relevant DTI laboratories. If relevant, it has even been possible to validate one or more of the SGO test reference systems in full system context with some selected products as an extended conformance pilot test in connection with the DTI Energy Flex House set-up. A suitable environment for verifying interoperability between Smart Grid ready products in a pragmatic and realistic test set-up.

1.5.2.2 Heat pump test bed

To help customers select an energy efficient heating solution heat pumps must have an energy statement label. DTI conducts accredited conformance test of heat pumps according to

- EN 14511 (Basis);
- EN 14825 (Seasonal Coefficient of Performance (SCOP));
- EN 1647 (Hot water).

Heat pumps are tested under lab-conditions with simulated loads in a controlled environment. Depending on type of heat pump, different test facilities will be used. Air to air heat pumps are tested in calorimetric rooms to monitor energy flow.

DTI has a State of the Art test facility for air to water and water-to-water heat pumps, which can test heat pumps up to 40 kW. Two rooms each 100 m^3 simulate indoor and outdoor environmental conditions respectively. Simulated outdoor temperature can be regulated from -25°C to 50°C. The lab facility has integrated unique noise measurement equipment enabling noise measurement during operation. This facility fulfils the latest European standards and is EHPA certified.

The accredited heat pump testing is performed in a number of static operation points, and DTI test facilities are optimised for these accredited tests. Without interfering with the static core functions, the test strategy was to add a digital dynamic house simulation layer utilising the existing huge thermal load capacity. This was realized and tested on both on-off type of heat pump and frequency regulated heat pump. Nobody had expected that the heat pump house temperature regulation depended only partly on the air temperature but depended much more on water temperature feedback. This conflicted with the static water temperatures in the test setup. Making the water temperature dynamic would require changes into a system used for accredited test and was therefore given up within the SGO project frame. Still the test system was deemed capable with an upgrade.

1.5.2.3 'LabView' stimulations and measurements

The main purpose of WP3 was to develop a practical test system in LabView for 'Proof-of-Concept' of the SGO test methods.

This was the best way to evaluate the SGO test methods because a practical implementations will put focus on all the details and make sure that all end-to-end issues are addressed.

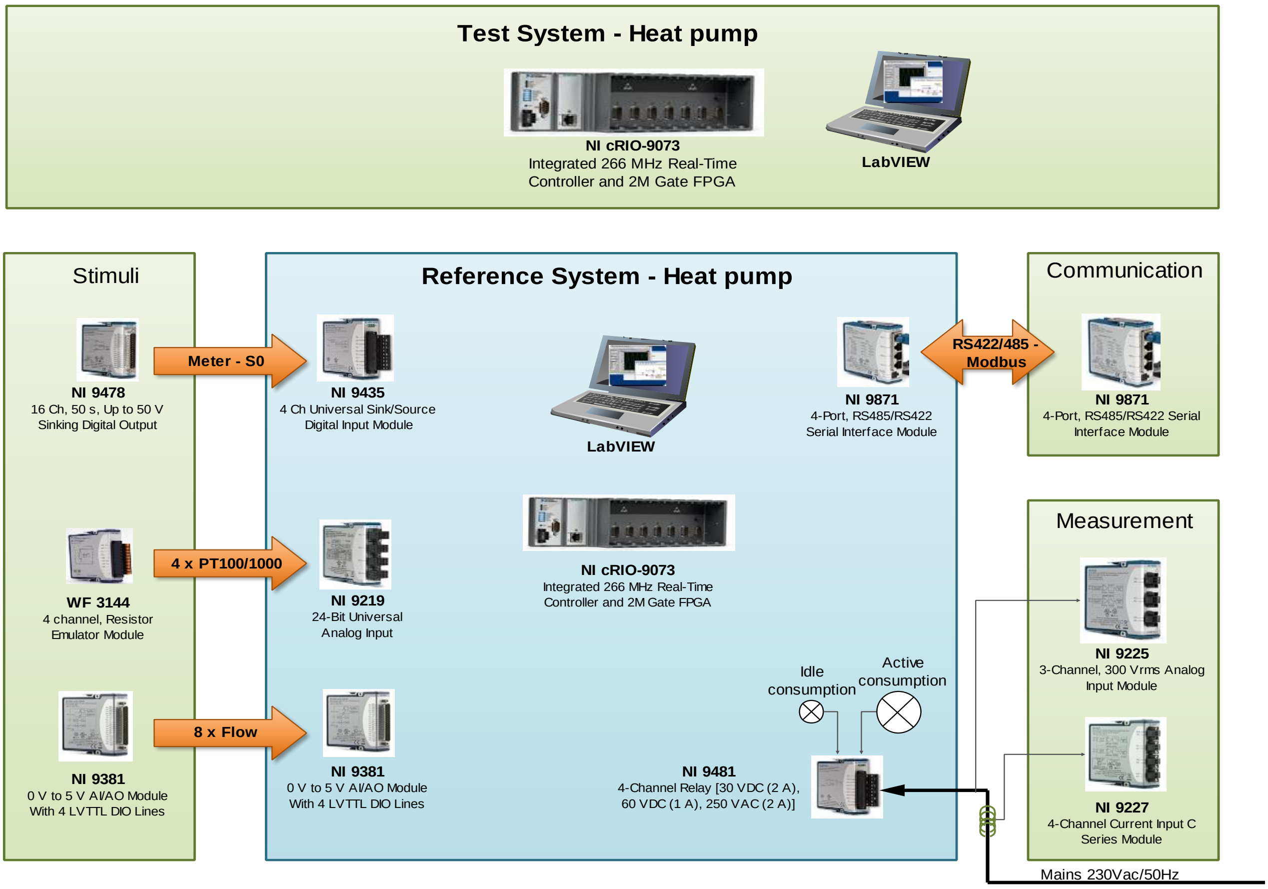


Figure 13: SGO LabView test platform

1.5.3 Information Security

1.5.3.1 Smart Grid Information Security - SGIS

The objective of the M/490 SGIS report is to support Smart Grid deployment in Europe providing Smart Grid Information Security guidance and SGIS standards landscape to Smart Grid stakeholders.

SGIS essential requirements presented, emphasize the importance of the CIA (Confidentiality, Integrity and Availability) triad for Information Security but also underline the varying weight of the Confidentiality, Integrity and Availability as essential requirements and the issue encountered to address Information Security topics for the Smart Grid as a whole.

Key SGIS elements like the SGAM (Smart Grid Architecture Model), SGIS-SL (SGIS Security Levels), Smart Grid Data Protection Classes (SG-DPC) and the Security View per layers are introduced and used to provide security requirements and recommendations on their implementations through a European Electrical Smart Grid stability scenario.

SGIS standards landscape illustrates the role of standards in requirements implementation and establishes a current picture and a target for this landscape.

SGIS Toolbox provides Smart Grid Use Case stakeholders an easy and pragmatic way to identify what might be their use case security needs.

In conclusion, the standards needed to establish the basis of the Smart Grid Information Security are available today. Nevertheless, there is a need for enhancement and for additional standards to integrate Smart Grid specific needs.

1.5.3.2 Intelligent Energy

The Danish Intelligent Energy Alliance is the largest Smart Grid platform for cooperation and partnerships in Denmark, The Alliance encompasses all key stakeholders (75 member companies by end of June 2016) in and around the energy sector to identify barriers and address the right conditions and environment for investments in new Smart Grid solutions. The Alliance has initiated work on how to deal with cyber security in a future Smart Grid.

1.5.3.3 CHPCOM

CHPCOM project aims to develop an IT communication solution, which should mature the Danish power system to Smart Grid. The method is to standardize data communication between CHP plants and other players in the electrical system.

When data communication is standardized, the barriers that prevent effective data exchange are broken down. This provides a wide range of opportunities and benefits for CHP plants and the other players, including:

- Automated data exchange of environmental and measurement data between power plants and other players via Internet - based communications.

- Secure access to data from other operators.
- Easier administration and higher data quality on CHP plants and at other operators.
- More flexible production and the possibility of providing new services.
- Lower costs when changing balance responsible party – for both power station and balance responsible

The CHPCOM solution prepares the Danish CHP sector for a future electricity market based on renewable energy, cooperative operation of power plants and an increased need for intelligent control of the operation.

One of the five work packages in CHPCOM aimed at developing a secure communication based on a so-called Public - Key Infrastructure (PKI) and an existing standardized Role based access control (RBAC) solution. Testing of the overall PKI / RBAC solution in CHPCOM context can be of general use when securing Smart Grid communication.

A prerequisite for a secure Smart Grid is that only the right devices and / or user can read data from and possibly affect the state of other devices in the network. This requires authentication and authorization:

- Authentication is about safely to determine from whom a given message in the grid derives. For Smart Grid the best solution is assessed to be a Public - Key Infrastructure (PKI) as described in Metke & EKL's article from 2010. PKI is also the recommended standard according to IEC TC57 technical specification for secure power system communication in the standard IEC 62351. Although IEC TC57 recommend PKI, detailed specification of the implementation of PKI in the electricity system and Smart Grid context lacks. Another example of a PKI is the Danish national digital signature NemID - which, however, due to a number of reasons, is not suitable for smart grid scenario.

- Authorization is about safely to determine the resources and functions which a given entity is authorized to access. This is often resolved using access control. Authentication is a prerequisite for meaningful authorization.

- CHPCOM is about the implementation of the fundamental information models and communication protocols in the standard IEC 61850 needed to establish a smart grid , as well as implementation of the related technical specifications in IEC 62351 for control over who has access to read and do what using IEC 61850 protocols. The project determined that there is a need for access control and that it should be "role-based" (RBAC - Role based access control).

1.5.4 Knowledge insourcing

Knowledge has been sourced into the SGO project from projects and organisations working with other smart grid communication between power systems and DERs, including standards and open systems.

The project has looked at e.g. OpenADR (Smart Grid concept US style) and VHPready versus IEC 61850 family and not found reason to look away from IEC 61850 as a preferred high level control method in Danish and European context. Please see more details in ANNEX B

1.5.5 Domain analysis

Guidelines for a potential SG-Ready Conformance Test Method for equipment that has an essential part of critical electric consumption in the customer premises, was designed and implemented in DTIs test equipment that is used for test of Heat Pumps. The test methods were the result of a deep analysis of the product domain Heat Pumps.

These test methods were in alignment with the EU mandate M/490.

This document contains guidelines for a potential SG-Ready Conformance Test Method, which can be used for equipment that has an essential part of critical electric consumption in the customer premises. The enclosed test method is in alignment with the EU mandate M/490.

By implementing both the SGAM model and the German SG-Ready label within the Conformance Test methodology, it has been possible to recommend a feasible and generic test method for test of SG readiness of selected component. The following equipment domains are of relevance for this conformance test, hence they have a relatively high continuous electric load that could be active for hours characterized by the three equipment domains:

- Electric Vehicles (typical 2kW+ for 2 -12 hours)
- Inverters e.g. PV-inverters (typical 4kW+ for 2 -10 hours)
- Heat Pumps for domestic use (typical 2 - 4kW intermittent for 0,5 to 24 hours)

These three domains are addressed in this document but at different detail level.

1.5.5.1 PV inverter systems

PV domain already has open and well-defined specifications (standards) for interoperability via the Sunspec Alliance. The SunSpec Alliance is a trade alliance of over 70 solar and storage distributed energy industry participants, together pursuing information standards to enable "plug & play" system interoperability.

The specifications describe models from components to complete plant, which allow operating different brands and types of PV systems under a common plant controller. A complete plant could be managed via Sunspec models but it is common that the communication with the DSO (or an aggregator) use the control methods preferred by the DSO.

While Danfoss was active in the SGO project the DSI PV development focus was on LSPV (large scale PV). Danfoss no longer developed for domestic use.

An example of a largescale Danfoss system: Möhring Energie GmbH has built a large PV 80 MW plant on the former NATO-airbase in Eggebek near Flensburg/Germany. More than 5.000 pcs TLX Pro inverters from Danfoss Solar Inverters are used for the plant.

Danfoss started the American and European certification of a new 60 kW MLX string inverter series in 2014. The MLX series use mainly same software core as the TLX and can be combined in the same topology.

Danfoss has observed that customers do not request Smart Grid ready or other future nice-to-have functionalities, but only mandatory functions to grid-connect and operate the PV system. Many of the SG functions are more important to DSO, TSO and aggregators.

Danfoss participation in the SGO project has its base at the LSPV system level. However, with the domestic focus in the SGO project Danfoss participation was still found relevant because experience shows that more expensive and comprehensive industrial system functionalities tend to migrate down to the domestic domain. It is more simple to reuse existing software from the large systems as the cost of more powerful embedded computers become marginal.

The Danfoss virtual development platform is a LSPV reference plant of 10MW

- 10 MW LSPV plants consisting of 4 subsections each 2,5MW
- 2,5MW consisting of 40 MLX inverters each 60kW connected to 10020 PV-panels of 250W
- One IM (Inverter Manager) aggregates 40 MLX inverters, to make a subsection appear as one 2.5MW unit.
- The Plant controller conforms to the relevant standards e.g. IEC61850-7-420; 61850-90-7; 61850-90-10 (schedules); 61850-8-1 (MMS mapping).
- Communication will typically be via TCP/IP. Behind the RTU, Modbus or TCP/IP protocol is used (according to the Sun-spec alliance).

At Plants larger than 2.5 MW a Closed loop plant controller (or RTU) will be used by the BRP (balance responsible) (for systems smaller than 2.5 MW interface can be direct to IM).

The Process network between MLX inverters are closed (proprietary), but the Plant Level Network implementation follow the IEC61850 recommendations regarding substation architecture. The Process network is based on Danfoss' own Message Independent Multicast Route.

	Smart Grid relevance of the Power Converter Functions (of IEC 61850-90-7 Section 5.4) were agreed in a SGO workshop with Energinet.dk, Danfoss, DTU, Eurisco and Danish Technological Institute (March 2014)	Need to have	Nice to have (e.g. sub-functions)	Not needed	Needed but with no data communication
Function INV1	connect / disconnect from grid (grid maintenance UC)	X			
Function INV2	adjust maximum generation level up/down (MUC2-5, SUC-3)	X			
Function INV3	adjust power factor (SUC1-2)	X			
Function INV4	request active power (charge or discharge storage) (MUC2-3)		X		
Function INV5	pricing signal for charge/discharge action			X	
	Volt-var management modes				
Volt-var mode VV11	available vars support mode with no impact on watts			X	
Volt-var mode VV12	maximum var support mode based on Wmax (SUC1)	X			
Volt-var mode VV13	static power converter mode based on settings (SUC1-2)	X			
Volt-var mode VV14	passive mode with no var support		X		
	Frequency-watt management modes				
Frequency-watt mode FW21	high frequency reduces active power (UC?)				X
Frequency-watt mode FW22	constraining generating/charging by frequency (MUC1)	X			

	Smart Grid relevance of the Power Converter Functions (of IEC 61850-90-7 Section 5.4) were agreed in a SGO workshop with Energinet.dk, Danfoss, DTU, Eurisco and Danish Technological Institute (March 2014)	Need to have	Nice to have (e.g. sub-functions)	Not needed	Needed but with no data communication
	Voltage Fault Ride Through				
Dynamic reactive current support TV31	support during abnormally high or low voltage levels (mandatory)				X
"Must disconnect"	MD curve	X			
Must remain connected"	"MRC curve (design requirements)				X
	Watt-triggered behaviour modes				
Watt-power factor WP41	feed-in power controls power factor			X	
Alternative Watt-power factor WP42	feed-in power controls power factor (SUC1)	X			
	Voltage-watt management modes				
Voltage-watt mode VW51	volt-watt management: generating by voltage (SUC1)	X			
Voltage-watt mode VW52	volt-watt management: charging by voltage (only with integrated storage function)		X		
	Non-power-related modes				
Temperature-function mode TMP	ambient temperature indicates function			X	
Pricing signal-function mode PS	pricing signal indicates function to execute			X	
	Parameter setting and reporting				
Function DS91:	modify power converter-based DER settings				X
Function DS92:	event/history logging (TUC1, TUC4)	X			
nction DS93:	Fustatus reporting (TUC1)	X			
on DS94:	Functitime synchronization	X			
Scheduled commands	a schedule is sent to the power converter with commands scheduled for particular times. These commands can also invoke pre-established parameters. (MUC1-5, SUC1-3)	X			
	Extended functions				
	Examples include:				
	Week-day schedule for volt-var actions				
	Weekly schedule for frequency-watt actions				
	1. (TF3.2.2) Spinning reserves (MUC1)	X			
	a. Delta effektbegrænser	X			
	b. PF (P,U) (SUC1)		X		
	2. Regulering af S (tilsyneladende effekt) (SUC3)		X		
	3. Aktuel kommunikationsstatus (TUC5)	X			
	a. Applikationsniveau	X			

Danfoss had not implemented role-based access control in the process network side since all high voltage installations must be kept protected behind fence and lock. In Denmark, the preferred control interface for a large plant will normally be in accordance with IEC 61850.

DER management functions for power converters are defined in e.g. IEC 61850-90-7 but not all functions are found to be relevant for Smart Grid management.

1.5.5.2 Home Automation domain

Many have seen Home Automation as, if not an easier way, at least a possible way to enable some level of demand side management in the domestic domain. Demand side management of washing machines, dishwashers, freezers etc. is a first step to enable Smart Grid management of domestic flexibility.

The SGO project has looked for any potentially Home Automation platforms with a major support base and widely acceptance from equipment suppliers and service providers. Even with the help from other concurrent R&D projects, no candidate was found to be even close to the primary criteria: Open standards and wide support. On the contrary, the whole area seems strongly competitive - dominated by many different individual proprietary solutions trying to compete for the same marginal share of a very slowly evolving market. The few potential Home Automation platforms claiming to be based on open standards are struggling to gain followers.

The industrial building control protocol KNX is considered too complex to become a domestic technology.

1.5.5.2.1 SGO project investigation of product EviShine relevance and potential for involving Evikali.

An interview with key persons from Evikali was arranged with the purpose to investigate relevance of EviShine and potential for involving Evikali in the SGO project.

EviShine focus on data-collection and data-distribution. EviShine accepts some 40 communication protocols to/from different equipment where PV inverters were mentioned as primary examples. The solution typically use a local dedicated box for interface and 5-second sample rate. Collected and processed data is made available via a cloud-service – also available for smartphones etc. The EviShine solution as such is not an open product but works with whatever protocol their customers specify. Data from PV systems are uploaded to the TSO at hourly basis as documentation of PV-production. It was concluded that involving Evikali in the SGO project was not relevant. Evikali did not see any SGO relevant products or platforms in the market based on open standards.

1.5.5.2.2 OpenHAB - an open source home automation software

OpenHAB is a vendor and technology agnostic open source automation software for domestic homes.

Open Home Automation Bus (OpenHAB) started in 2010 under the umbrella of
Eclipse Foundation with the objective of creating an open source platform for home automation.

Even though several huge global companies (e.g. CA Technologies, Ericsson AB, Google Inc., IBM, Oracle, Red Hat, Inc., Robert Bosch GmbH and SAP SE) are strategic members of the Eclipse Foundation. Currently OpenHAB seems to be driven mostly by geeks designing all levels of home automation. The SGO project ignore OpenHAB for now but with the expressed focus on open source and open standards, it may be worth monitoring in future for an increased support base.

1.5.5.3 Heat Pumps

Guidelines for a potential SG-Ready Conformance Test Method was designed and implemented in DTIs test stand used for certified testing of Heat Pumps. The test methods were the result of a deep analysis of the product domain Heat Pumps. These test methods were in alignment with the EU mandate M/490.

The SGO project was focusing on implementing a SG-Ready test for Heat Pumps used for domestic use. These pumps are defined by the following parameters: The power is typical 2 - 4kW, and the Heat Pump is operating on a sporadic basis, normally between 0.5 to 24 hours' basis.

By implementing both the SGAM model and the German SG-Ready label within the Conformance Test methodology, it has been possible to recommend a feasible and generic test method for test of SG readiness of Heat Pumps of the above type.

SGO analysed three Use Cases, one commercial Use Case and two technical Use Cases. The Use Cases, which have been analysed, are as follows:

- The Price for electricity is low.
- Voltage on DSO level is low.
- Voltage on DSO level is high.

Below is the example of the Use Case "Voltage on DSO level is low"

<table>
<tr><th colspan="5">Use Case Identification</th></tr>
<tr><td>ID</td><td colspan="2">Domain(s)/Zone(s)</td><td colspan="2">Name of Use Case</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="2">Voltage on DSO level is low</td></tr>
<tr><th colspan="5">Version Management</th></tr>
<tr><td>Version No</td><td>Date</td><td>Name of Author(s)</td><td>Changes</td><td>Approval Status</td></tr>
<tr><td></td><td>2015-07-24</td><td>Steffen Lind Kristensen</td><td></td><td></td></tr>
<tr><th colspan="5">Narrative of Use Case</th></tr>
<tr><td colspan="5">Short Description</td></tr>
<tr><td colspan="5">Controlling the SG-Ready signal of the Heat Pump based on the signal received from the DSO indicating the Voltage is low.</td></tr>
<tr><td colspan="5">Long Description</td></tr>
<tr><td colspan="5">Signal sent from the DSO informing the Smart Grid Controller, that the voltage level is lower than the defined nominal voltage level and the DSO need the Heat Pump to stop operating.

Control signal sent from the Smart Grid Controller to the SG-Ready Controller, informing that the voltage is low.

Information from the SG-Ready Controller to the Heat Pump, informing it to go in SG-Ready Must Stop Mode. E.g., the SG-Ready bit A set to "OFF", SG-Ready bit B is set to "ON".</td></tr>
</table>

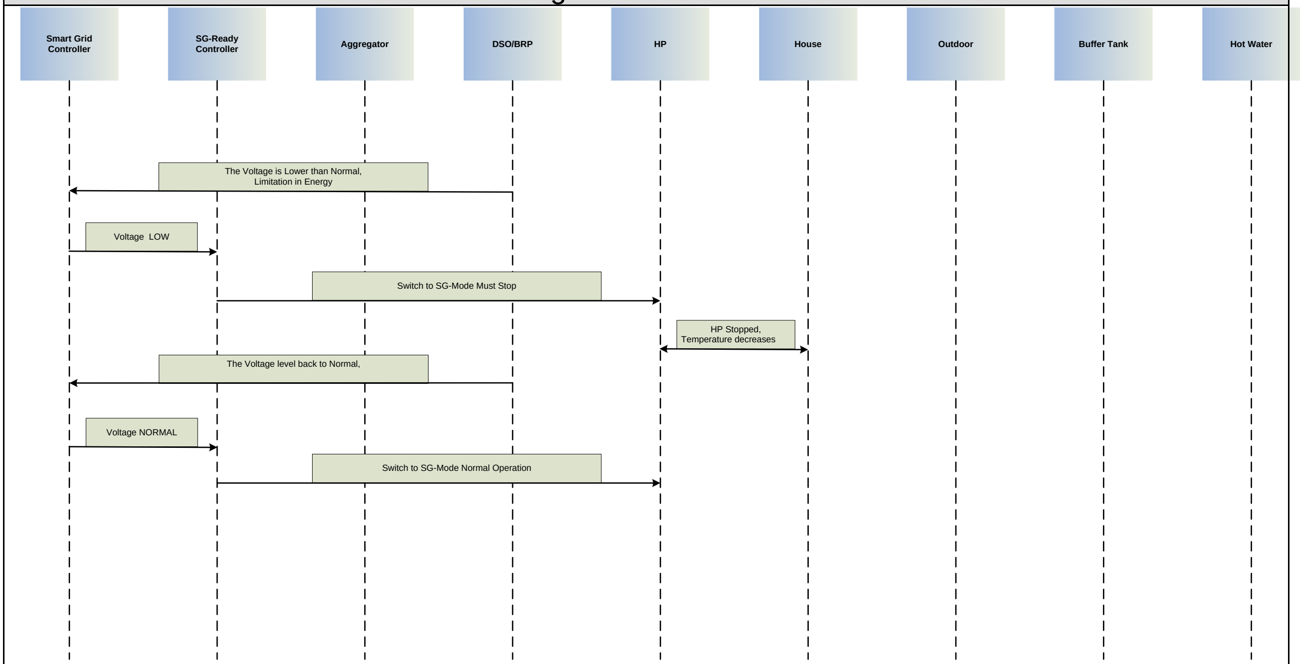
The Heat Pump stops to run hence decreasing the temperature in the house.

Signal sent from the DSO informing the Smart Grid Controller that the voltage level is back to normal level.

Control signal sent from the Smart Grid Controller to the SG-Ready Controller, informing the voltage is Normal.

Information from the SG-Ready Controller to the Heat Pump, informing it to go in SG-Ready Normal Operation Mode. E.g., the SG-Ready bit A set to “OFF”, SG-Ready bit B is set to “OFF”.

Table 1 Example of Use cases; Voltage on DSO level is low

<table>
<tr><th colspan="4">Use Case Identification</th></tr>
<tr><td>ID</td><td colspan="2">Domain(s)/Zone(s)</td><td>Name of Use Case</td></tr>
<tr><td></td><td colspan="2"></td><td>Voltage on DSO level is low</td></tr>
<tr><th colspan="4">Diagram of Use Case</th></tr>
<tr><td colspan="4">
</td></tr>
<tr><th colspan="4">Actors</th></tr>
<tr><td>Actor Name</td><td>Actor Type</td><td>Actor Description</td><td>Further Information specific to this Use Case</td></tr>
<tr><td>Smart Grid Controller</td><td>Device</td><td>Operates the Heat Pump. Receives Heat Pump operation plans and is responsible for the execution of a Heat Pump operation plan. Other responsibilities: Authenticate or relay to Aggregator for authentication, negotiation of Heating capabilities and finally executing Heating service</td><td>NEW</td></tr>
</table>

		request within boundaries (grid capabilities, HP-availability)	
SG-Ready Controller	Device	Implementing the function for Smart Grid readiness. Performs state estimation based on real-time information from the Smart Grid Controller	NEW
Aggregator	Role	See IEC 62559-2	
DSO/BRP	Role	See IEC 62559-2	
HP	Device	Heat Pump, device that converts electrical power to heat.	NEW
House	Role	End User of heat	NEW
Outdoor	Role	End User of heat	NEW
Buffer Tank	Role	End User of heat	NEW
Hot Water Tank	Role	End User of heat	NEW

Table 2 Example of Use cases; Voltage on DSO level is low

For details of the above Use Cases, please refer to the document WP4 SGO Documentation of Test Methods D4-1 in Annex D

Throughout the entire project the aim was to find an open and standardised test method, therefore a schematic test setup based on the IEC 61850-10 has been designed. The intention is to follow the IEC 61850-10 naming structure, hereby creating a test setup which is in alignment with the IEC 61850-10 standard. Based on this structure it has been possible to design an example of a Test Report, which also is in alignment with the philosophy of the IEC 61850-10 recommendations. Moreover, in case the SG-Ready interface is via a communication interface, the Test Report will be easily adjusted.

During the SGO project the approach of the Conformance Test methodology was to verify if the Device under test (DUT) was SG-Ready or not. It has been of most importance that the original equipment, e.g. thermostats etc., was not tampered potentially influencing the internal logic controller of the DUT during the test sequence. Consequently, an “Intelligent” house simulator was created, consisting of two cooling units, in which the external temperature sensors/controllers for the heat pump was installed during test. One cooling unit was for the indoor temperature sensors/controllers, and the other was for the outdoor temperature sensors/controllers of the Heat Pump.

A basic logic programme was programmed in LabVIEW which controlled the two cooling units. The outdoor unit should have a constant temperature level at all times during the test, and the indoor unit should simulate a “house”. In order to make the indoor cooling unit to act as a “house” a Dynamic house model was designed and programmed in LabVIEW. For more details of the Dynamic house model, see document WP4 SGO Documentation of Test Methods in Annex D.

A feasible approach was documented as to analyse and verify if the tested equipment is SG-Ready according to the German SG-Ready label. The challenge is to be able to distinguish between the two SG-Ready modes; Run Higher and Must Max Mode. The method is to test the Heat Pump in the different SG-Ready Modes and then measure the amount of energy which the Heat Pump delivers to the heating system over time in the various modes. These measured values are compared; the energy provided in the Must Max Mode must be larger than the energy provided in

Run Higher Mode. The same comparison can be done for all possible modes, which is described in detail in the document WP4 SGO Documentation of Test Methods D4-1 in Annex D.

1.5.6 Implemented Domain Test methods

1.5.6.1 Basic Concept

A standardised approach has been used for the SG-Ready Conformance Test of the Heat Pump. All Heat Pumps are installed in the test setup as “Black Boxes” tested in the various SG-Ready modes, and the reaction of the Heat Pump is monitored accordingly.

To find a test method, which can verify if the Heat Pump is SG-Ready in the Smart Grid Connection Point, the test setup must consist of the following elements.

- Static Simulator
- Dynamic Stimulator
- Analyser

1.5.6.2 Static Simulator

The Static Simulator monitors and controls the thermal energy system connected to the Heat Pump. In addition, it will be possible to monitor any electrical power measurement needed, in order to operate the thermal circuits, the Heat Pump is connected to the DTI Test Stand.

The Static Simulator logs the energy flow, temperature measuring and power measuring. Subsequently these are sent to the analyser of the test setup for analysing and documentation of the test.

The Static Simulator will allow the Heat Pump to operate in its normal mode, as well as the SG-Ready Modes defined by the Dynamic Simulator, without any interruption of the internal control algorithm of the Heat Pump.

The Static Simulator consist of the following modules.

1.5.6.2.1 DTI Test Stand

The DTI Stand monitor, controls and operate the thermal circuit of the Heat Pump, DTI Test Stand ensures the Heat Pump to operate in a proper manner.

1.5.6.2.2 Energy flow measuring

The Energy flow measuring monitors all relevant values relating to the thermal circuit of the Heat Pump.

1.5.6.2.3 Temperature measuring

The Temperature measuring monitors all relevant values relating to temperatures in the thermal circuit of the Heat Pump.

1.5.6.2.4 Power measuring

The Power measuring monitors all relevant values relating to the electric circuit of the Heat Pump.

1.5.6.3 Dynamic Simulator

The Dynamic Simulator has two main tasks, to control and operate the switching between the different SG-Ready Modes, and to provide the test setup with the capability to simulate a house and the environments of this house.

The Dynamic Simulator logs the SG-Ready Modes in real time, and these values are subsequently sent to the analyser for further analysing and documentation of the test. Likewise, in the Static Simulator all data points must be time stamped to enable proper analysis of the data.

The Dynamic Simulator consist of the following modules.

1.5.6.3.1 SG-Ready Mode Logic

The SG-Ready Mode Logic ensures timely switching between the various SG-Ready Modes, e.g. Normal Operation, Must Stop, Run Higher and Must Max.

The SG-Ready logic must also ensure to send/provide the switching between modes with the correct timestamp, ensuring proper analysing of the test.

1.5.6.3.2 Dynamic House Logic

The Dynamic House Logic will send the Temperature set points to both House simulator and the Outdoor simulator, hereby ensuring the temperatures to be correct during the test sequence.

In addition, it is the responsibility of the Dynamic House Logic to ensure the house simulator are as per described in the equivalent model for the intelligent house simulation. In short, if the Heat Pump is running, the temperature in the House simulator is increasing. If the Heat Pump is stopped, the temperature will drop, in accordance to the basic dynamic house model, implemented as an equivalent model based on the following assumptions:

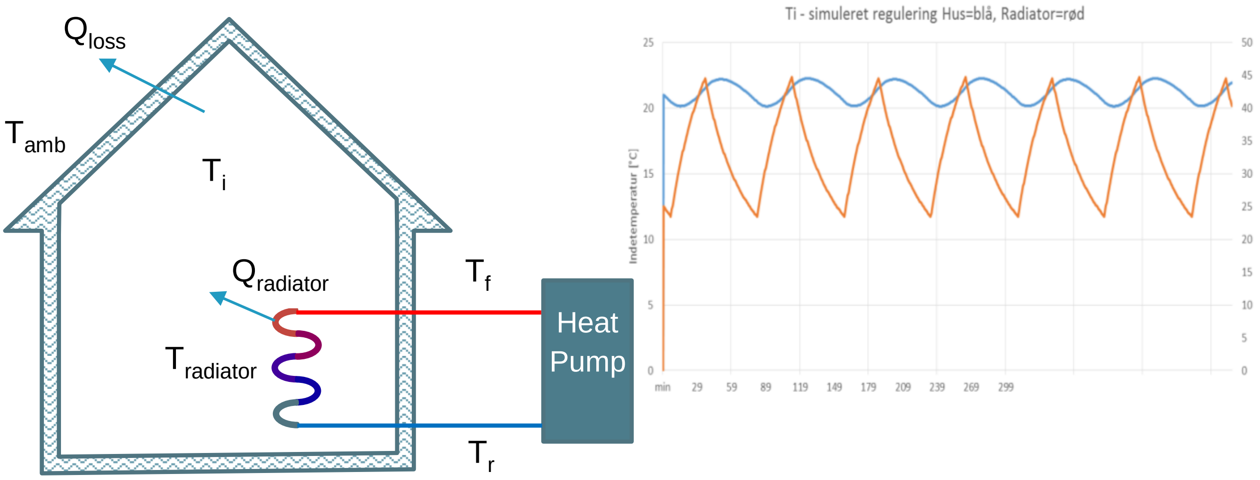


Figure: 14 Simplified house model and an example of the simulated regulation of the indoor temperature (blue) via a very simple radiator model (radiator temperature in red on right hand side scale).

The equivalent model is based on the simplified house model showed in figure 25. The model is based on all types of Heat Pumps, but the following calculations are based on Heat Pumps of type "ON / OFF".

As it is illustrated in figure 25, the running of the Heat Pumpcauses increase in the inside temperature T_i which also increases the thermal energy in the house. If the outside temperature T_{amb} is constant, the loss to the surroundings increases when T_i increases.

Likewise, T_i falls if the Heat Pump is stopped, whereby the thermal energy in the house decreases. If the outside temperature T_{amb} is constant, the loss to the surroundings decreases when T_i decreases.

The heat loss of the house, Q_{loss} can be considered as a linear function of the temperature difference between the inside temperature and the outside temperature and heat conduction from the house to the outside, giving us following formula where R_h is heat transfer to the surrounding.

$$Q_{loss} = (T_i - T_{amb})*R_h$$

All heating of the house comes solely from the radiator system. Qradiator. Qradiator can be considered as a linear function of the temperature difference between the indoor temperature and heating temperature, and the heat conducting between the radiator and the house (Rradiator), resulting in the following formula:

$$Qradiator = (Tradiator - Ti)*Rradiator$$

The temperature in the house increases/decreases exponentially over time, depending on heat transfer to the surroundings (R_h) and the heating capacity (C_h).

Thus, the following formula can be derived:

$$T(t) = Tstart (1-e(-t/ RhCh))$$

Based on above assumptions the following equivalent model can be designed.

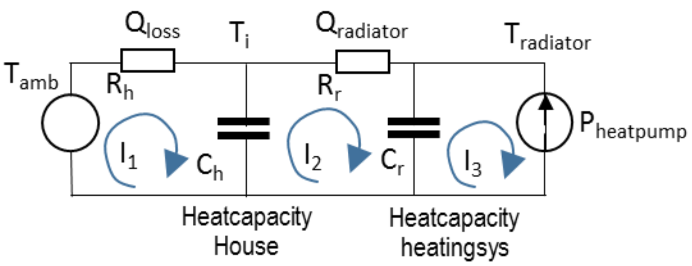


Figure 15 Equivalent model

It is possible to create an equivalent model for both the Hot Water Tanks and the Buffer Tanks; however, this is not part of this house model.

1.5.6.3.3 Analyser

In order to verify the Smart Grid readiness of the Heat Pump, the Analyser receives the relevant data, which are analysed and processed for SG-Ready Conformance Verification and Reporting.

The Analyser consist of the following modules.

1.5.6.3.4 Data Logging

The Data logging module will ensure that all data points needed for reporting and the conformance verification are assessable for these modules.

All data points are logged with timestamp to ensure proper analysing of the data.

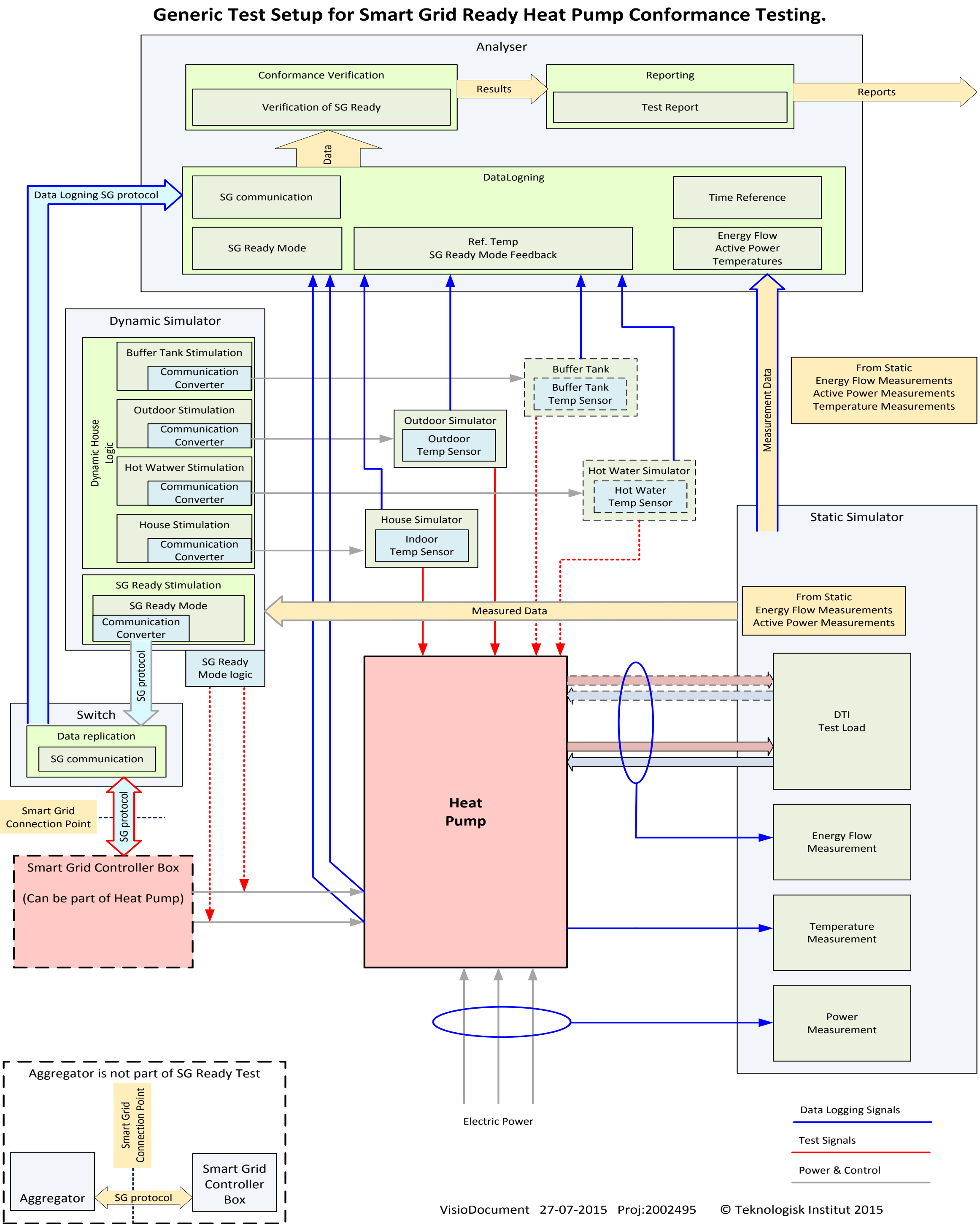


Figure 16: Test Setup for SG-Ready verification

1.5.6.3.5 Conformance Verification

The Conformance Verification module must provide the Analyser with the capability to verify if the DUT (Device Under Test) are SG-Ready compliant. To verify the Smart Grid readiness, the Conformance Verification module makes a comparing of the integrated energy flow over time for the different SG-Ready Modes. The integral for normal operation is considerably smaller than Run Higher Mode and the integral of Run Higher mode is smaller than the Integral of Must Max Mode.

Finally, the integral of Must Stop is expected to be close to Zero.

1.5.6.3.6 Reporting

The Reporting Module is a report generator, providing the test result in a report. In addition, it will provide graphs and Excel based data of the test for additional future analysing.

The Report module will document if the test of the DUT was approved, failed or if the test was inconclusive.

In Figure 27 the basic test setup is illustrated, showing the interaction between the various function elements, the location of the various test modules and how the data is exchanged between test elements, insuring a proper evaluation of the Smart Grid readiness, of the Heat Pump.

1.5.7 "LabVIEW" stimulations and measurement

Testing the Heat Pump in relation to SG Ready requires that the heat pump is operating in a 'normal' condition. This means that the Heat Pump must act as if it was installed in a normal house and not in a test stand as it is.

The test stand is capable of simulating heat dissipation to the surroundings by cooling the water flowing in the heating circuit. What the test stand needs is a way to change the indoor temperature seen from the Heat Pump and likewise with the outdoor temperature. This has been accomplished by modifying a consumer cooling box by adding a more intelligent PID regulator which can be controlled by LabVIEW.

The heat pump's temperature sensors then go into the cooling box and the heat pump will now see the temperature inside the cooling box, after a settling time.

This section will show how the cooling box is controlled by LabVIEW and how another LabVIEW program is simulating a house for changing the temperature in realistic manner.

The LabVIEW programs is called Virtual Instruments, shortened VI.

1.5.7.1 Controlling the temperature boxes

The PID regulator is a Laird PR-59 regulator. It has a serial (RS232) interface where all its parameters can be changed and read out. Laird supplies a protocol description for the regulator and for this protocol, a handler was created in LabVIEW, as seen in Figure 17.

This protocol handler is based on the documentation from Laird and the structure in Figure 18. When a command or parameter is sent, the regulator echoes back the single characters and answers back with an acknowledge signal.

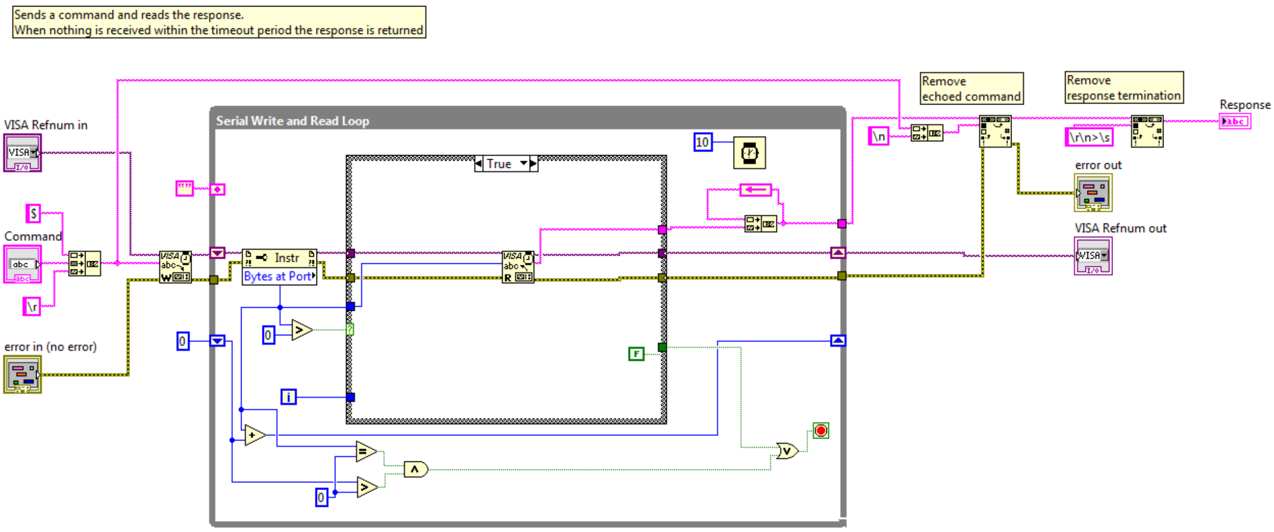


Figure 17 Laird PR-59 protocol handler VI

start char	*command*	*data*	*stop char*
$	R4 1=	23.5	<CR>

Figure 18 The Laird protocol

The protocol handler is a single VI which is a cable sending a single command to the Laird controller. For sending multi commands, which is needed for starting the regulator and changing the set point, a controller VI was implemented.

This VI sends all the commands listed in the 'Initialization commands' text box, when the VI is started. After the initialization process the VI keeps reading the temperature from the regulator which can be used for logging.

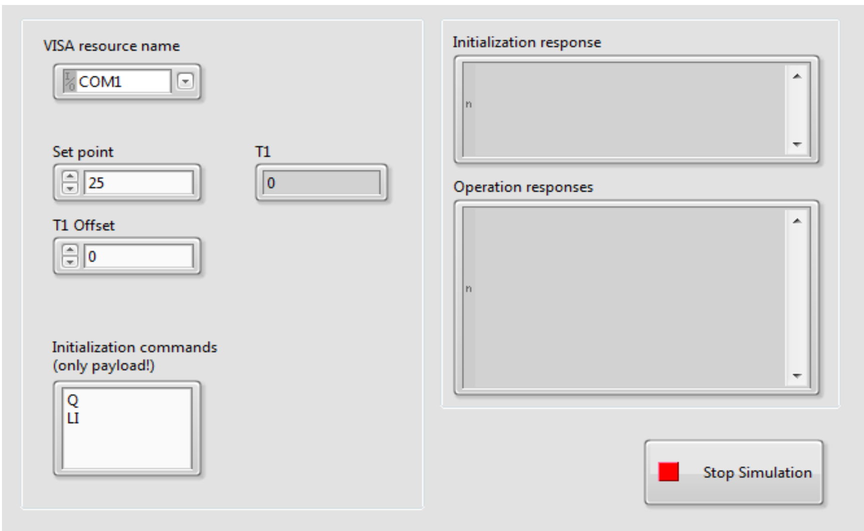


Figure 19 The VI that is controlling the Laird regulator by calling the protocol handler

If the set point, in the VI, is changed during run-time it is updated on the regulator by sending the corrosponding command with the new value included.

The VI is constructed by using a sequence where the initialization process has to be finished before the operation process is started.

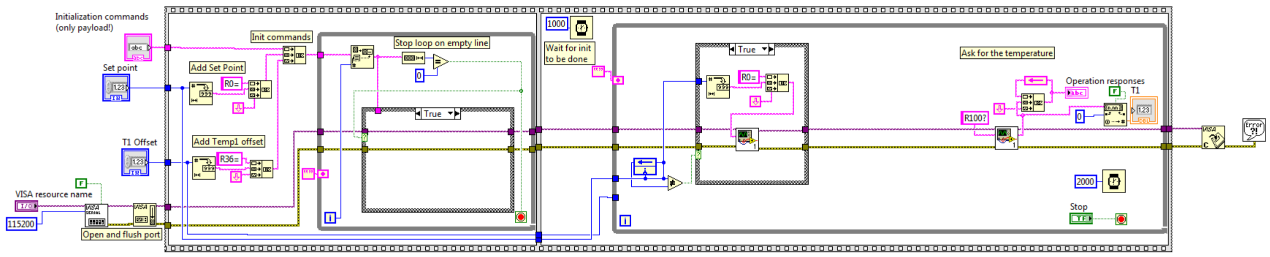


Figure 20 The wires behind the controlling VI

Figure 21 A heat pump installed in the conventional test rig with the additional dynamic test equipment placed on the table. SG Ready and the dynamic house simulation running on the labtop.

1.5.7.2 House Heating Simulation

Being able to change the temperature for the Heat Pump sensors is fine but it has to be done in a manner that looks realistic due to the internal logic of the heat pump that might think something is wrong if the temperature is changing too fast.

Figure 22 Two remotely temperature controlled cabinets for simulating house in-door temperature (left) and out-door temperature (right) used for manipulating the heat pump original sensors.

A VI was created for simulating the house. The basis of this VI is to simulate a heat transfer from the house to the surroundings and in-/decreasing the temperature inside the house based on state of the Heat Pump.

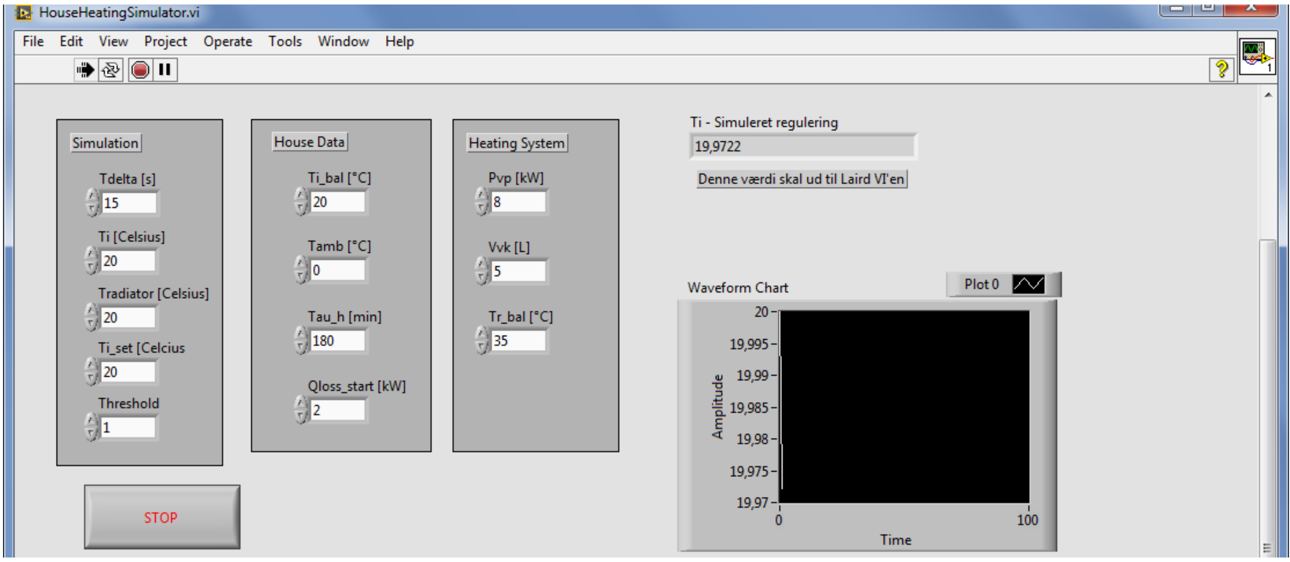


Figure 23 HouseHeatingSimulation VI

The parameters for this VI and the formulas behind it is supplied by DTI.

The formulas were given in a spreadsheet where the resulting formula was divided into multiple simple formulas across multiple columns. These formulas were taken into LabVIEW one by one, resulting in the VI shown in Figure 23 which is created by the diagram in Figure 24.

The resulting VI was able to create the same chart as presented in the spreadsheet.

The VI takes the Heat Pumps electrical power consumption as an input and then determines if the temperature of the house is increasing or decreasing.

For example if the Heat Pump is off and the indoor temperature is higher than the outdoor temperature. The result is heat dissipation from the house and the fact that the Heat Pump must see a falling indoor temperature. This is done by the HouseHeatingSimulation VI by changing the Set Point of the Controller VI, which then sends a ‘change-set-point’ command to the Laird regulator. The regulator then starts to cool down the cooling box until the set point is reached. Due to the thermal storage in the cooling box and the heat pump’s temperature sensor, the temperature read out on the heat pump may lag slightly relative to the regulator’s temperature.

The diagram of the HouseHeatingSimulation VI is shown in Figure 24. The diagram is created by many small calculations that are exactly like the calculations from Excel. Another way was to create a transfer function with the same functionality but this could lead to more problems in case that the resulting chart did not look the same as the one in Excel and debugging was needed.

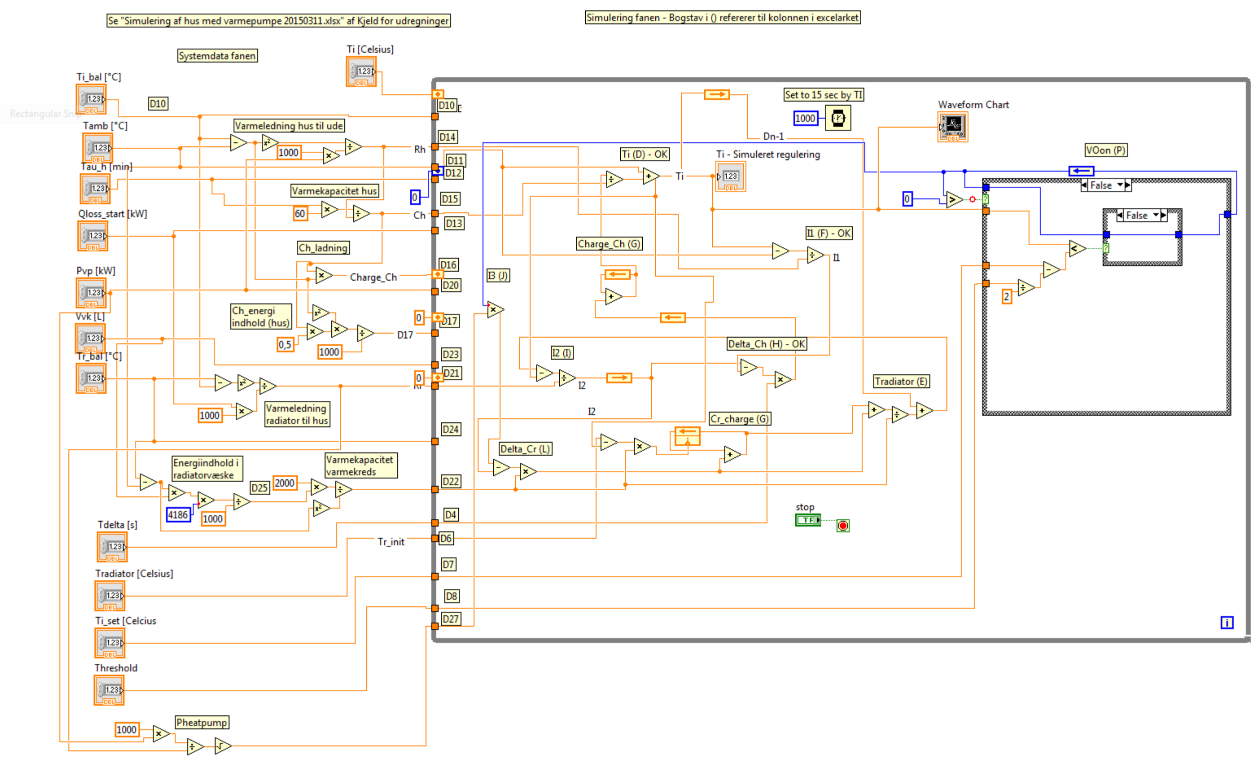


Figure 24 The diagram behind the HouseHeatingSimulation VI

1.5.8 Controlling and power consumption measurement

Controlling the Heat Pump is done by DTI standard test equipment which has the available I/O’s and is already well integrated into their test system.

Likewise with the power consumption which is already logged, it just needs to be forwarded to the House Heating Simulation.

1.5.9 Heat Pump Example test setup

The goal is to build a test platform where it is possible to simulate a random house from programmable characteristics. The system is tested in connection with tests of SG-Ready control signals to the SG-Ready certification of Heat Pumps. To achieve a standardized approach a test setup in alignment with IEC 61850-10s testing methods have been designed.

IEC 61850-10 consists of the following main components: DUT, Analyser, Simulator and Equipment Simulator.

1.5.9.1 DUT (Device Under Test)

The DUT is the device under test, in this case the Heat Pump, which is desired for test.

The Heat Pump mounted in one of DTI's test stands in Aarhus will be connected to the heating/cooling circuit; this includes the Brine, indoor/ House installation and Hot Water Tank and Buffer Tank circuit as specified.

The DUT is connected to the simulators, enabling SG-Ready signals and temperatures to be simulated. Based on the Heat Pump reaction, the Heat Pump SG-Ready conformity can be verified.

1.5.9.2 Analyser

The Analyser is connected to the DUT during the entire test, to verify the SG-Ready conformity. The Analyser consists of DTI LabVIEW equipment with underlying program codes used for the certification of Heat Pumps. The Excel platform is used for analysing the test, and ultimate reporting the result of the test.

The Analyser provides detailed logs of measurements from equipment simulators including, temperature measurement, voltage and current measurements in all three phases, the active and reactive power. Based on these logs the Analyser provides data to verify the Device Under Test Smart Grid readiness.

This analysis consists of comparison of the real-time data for SG-Ready Modes with power, Energy Flow and temperature measuring, in order to verify if the DUT is SG-Ready.

1.5.9.3 Simulator

The Simulator is the component, which will affect the DUT during the controlled test, hereby enabling the system the possibility to analyse and verify if the test of the DUT is passed, failed or inconclusive.

In order to verify whether the tested Heat Pump is SG-Ready according to the German definition, it has been necessary to extend the static test setup (DTI Test load) with a dynamic "house" simulation and SG-Ready simulation. In order to build a dynamic test platform, the test setup consists of two simulators, a static simulator and a dynamic simulator, unlike the standard IEC 61850-10 conformance test systems which normally only consist of one simulator.

1.5.9.3.1 Static Operation.

The Simulator for Static Operation is the existing test Stand located at Technological Institute in Aarhus. This is based on LabVIEW control with underlying program codes that is already used for certification of Heat Pumps. This simulator controls and regulates the flow and temperature in House Installation, Hot Water Tank and Buffer Tank circuits. The system provides a constant flow in any of the used circuits, and provides a fixed return temperature in the house installation circuit, so it simulates that heat is released into the "house”.

1.5.9.3.2 Dynamic Operation.

The Dynamic Operation Simulator is based on LabVIEW equipment with underlying program code; this platform extends the Static Operation Simulator with dynamic set points depending on the Heat Pump's current operation. The dynamic simulator controls the external “Cooling Boxes” used for manipulating the internal control and regulation of the Heat Pump to believe the Heat Pump is installed inside a “real” house.

The simulator sends temperature set points to the temperature controller that is located in Outdoor- and Indoor Equipment devices. Optionally, the Dynamic Operation will simulate the temperature set points for the Buffer Tank- and Hot Water Equipment devices.

The Dynamic Simulator also controls and operates the simulation of the transitions between various SG-Ready Modes. This is done by setting the appropriate Smart Grid bit high or low on the two binary inputs on the Heat Pump, depending on the requested SG-Ready Mode. Optional, this can be done over a communication interface.

The simulator calculates the temperature increases/decrease to be sent to the Outdoor- and Indoor Equipment devices. These calculations are based on the used thermal power of the Heat Pump and the Dynamic House Model used. The Dynamic House model logic is described in section Description of dynamic house model.

1.5.9.3.3 Description of dynamic house model Logic

In order to be able to verify the Smart Grid readiness of the Heat Pump, it is important that the Heat Pumps respond correctly to the SG-Ready signals therefore, the test system must act and react in the same way, as a house would do. That is, if the Heat Pump and/or immersion heater runs the temperature is increased in the ”housing”, and when the Heat Pump and/or immersion heater is not running, the temperature will fall. The variation in temperature will depend on the thermal capacity of the system. The thermal loss to the surroundings depends on the thermal envelope of the house and the outdoor temperature.

In the event that the Heat Pump is fitted with a Hot Water Tank or a Buffer Tank, the test system must act and react similarly as those devices would. That is, a Heat Pump and/or immersion heater running in the tanks increases the temperature . If the Heat Pump and/or immersion heater is not running, or a hot water outlet is open, then temperature will drop depending on the insulation and the thermal capacity of the system. The thermal loss to the surroundings depends on how fast the water is drained from the tanks and the ambient temperature of the system. The Heat Pumps increases the thermal energy delivery by either increasing the flow or temperature in the system, or both.

When there is a constant water flow in the output circuit, the Heat Pump will increase/decrease the temperature of the output circuits when affected by SG-Ready signals. Subsequently, cause changes in energy supply, which in turn causes an increase respectively a decrease of the Heat Pump power consumption, which can be read on the electricity meter. **We can therefore conclude that the electricity consumption is influenced by the SG-Ready control signal, hence the change in electricity consumption can determine if the Heat Pump is SG-Ready or not.**

1.5.9.3.4 SG-Ready simulation

The primary Solution Method; “The Dynamic House”. The indoor temperature in the "house" rises and falls as described in equivalent model, the Heat Pump will perform as if it was installed in a real house. Therefore, the power consumption of the Heat Pump must match the selected SG-Ready Mode, hereby enabling the verification of the selected SG-Ready Mode.

1.5.9.3.5 Logic for SG-Ready Mode:

Regardless, which solution method is used, it is required, that the simulator controls the switching between the various SG-Ready Modes; this is done by setting the two Smart Grid-bit outputs high or low depending of the SG-Ready Mode required.

In order to verify the Smart Grid readiness of the Heat Pump, the logic for Smart Grid readiness switches the Heat Pump from SG-Ready Mode A to Mode B. After a delay time of 2 hours, the logic switches to Mode C, again a delay time of 2 hours is implemented. This sequence is performed until the Heat Pump has done transitions to/from all relevant SG-Ready Modes.

The delay time is set to 2 hours, but it is expected that this can be optimized for smaller delays; this may depend on the different Heat Pump types and brands.

1.5.9.4 Equipment Simulator

Equipment Simulator is distributed into the following sub simulators, Equipment Simulator Heat Pump Stand, Outdoor Equipment Simulator, Indoor Equipment Simulator, Buffer Tank Equipment Simulator (Optional) Hot Water Equipment Simulator (Optional).

All relevant information is logged in, respectively, temperature measuring, measuring power and energy flow measuring, and then they can be used for analysis and verification of the component’s Smart Grid readiness.

1.5.9.4.1 Equipment Simulator Heat Pump Stand

The Equipment Simulator Heat Pump Stand is the test stand at the Danish Technological Institute's test in Aarhus; here the Heat Pump will be installed for testing.

All heating/cooling circuits, as the specific Heat Pump is equipped with, is connected, whereby the Heat Pump SG-Ready conformity can be tested.

Heating/cooling circuits for Brine/House and optional, Hot Water Tank and Buffer Tank, are controlled by DTI LabVIEW equipment with underlying program code, described in Simulator Static Operation and Analyser.

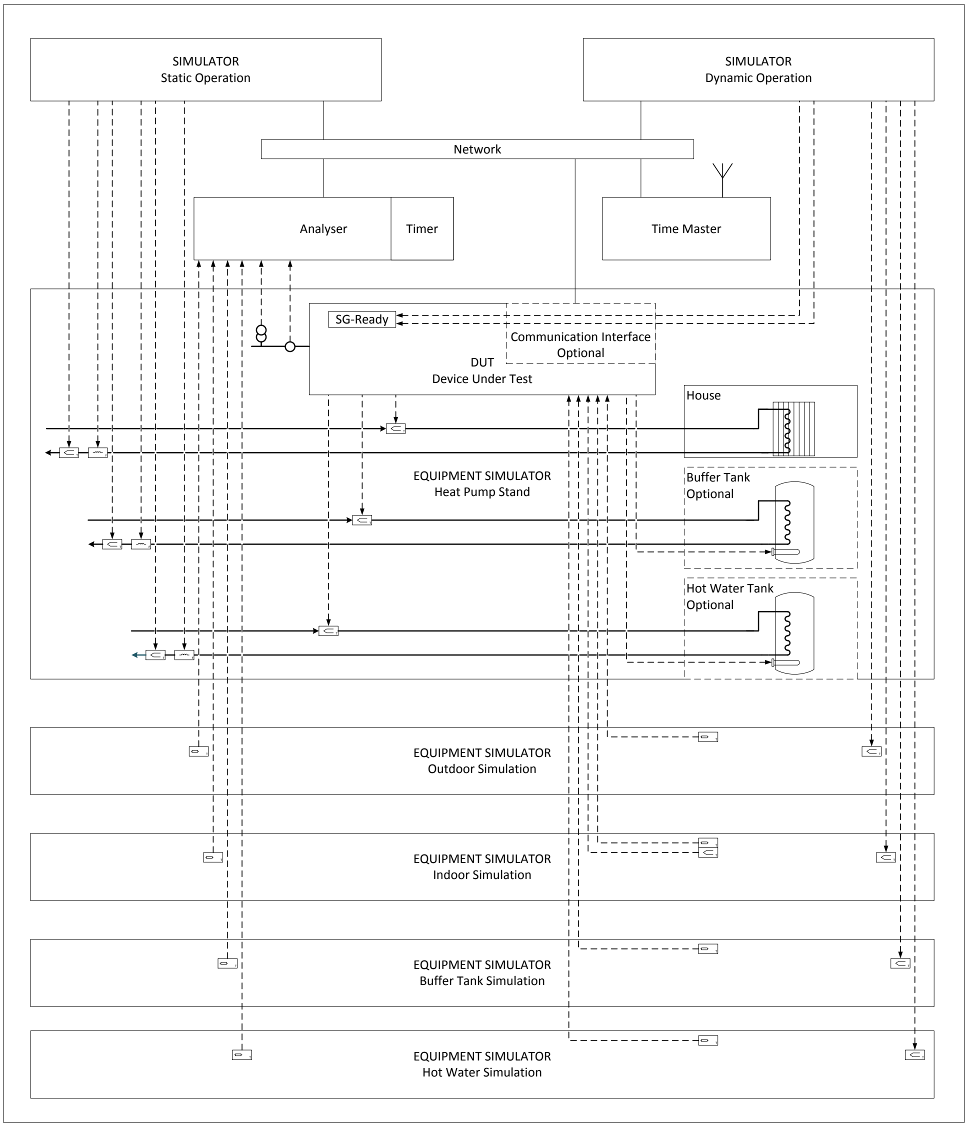


Figure 25 Schematic Test Setup based on IEC 61850-10 model

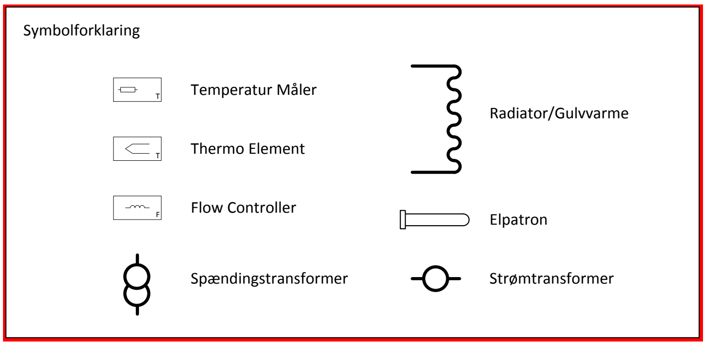


Figure 26 Legend of Figure 25

1.5.9.4.2 Equipment Simulators "Dynamic House Platform"

The goal is to build a test platform where it is possible to simulate a random house from programmable characteristics. The DUT is tested by manipulating the SG-Ready control signals to the SG-Ready Heat Pumps, and by manipulating the surroundings of the Heat Pump according to the operation of the Heat Pump.

Using the following equipment Simulators, it will be possible to simulate the thermal load in a house, with variable programmable house designs.

- Indoor Equipment Simulator.
- Outdoor Equipment Simulator.
- Buffer Tank Equipment Simulator (Optional).
- Hot Water Tank Equipment Simulator (Optional).

In order to ensure the Indoor Equipment Simulator simulates the increase/decrease in temperature, depending of the operation of the Heat Pump, a calculated set point of the indoor temperature are sent from the Dynamic Simulator to the Indoor Equipment Simulator via suitable communication.

There will be installed a reference measurement of the temperature in all Equipment Simulators.

Similar logic could be added to both Buffer Tank Equipment Simulator and Hot Water Tank Equipment Simulator this was not part of the scope of this document.

1.5.9.5 Schematic test setup based on IEC 61850-10 reference model.

Following the previous described partitions, which are using the IEC, 61850-10 naming structure, and the possibility of creating a test setup for testing the SG-Readiness of Heat Pumps in accordance to the EIC 61850-10 reference model.

A schematic layout vision by the SGO for an IEC 61850-10 test setup is showed in Figure 34.

1.5.9.6 Evaluation of HP testing using SG Ready signals-

Lacking any common Smart Grid standard for Heat Pump control, the compliance with the German two signal SG-Ready label was tested instead as part of the SGO project.

A Heat Pump is a very complex product to test because many external conditions must be in place to simulate the environment a Heat Pump is normally working in. Danish Technological Institute (DTI) has several dedicated test rigs for Heat Pumps with accreditation but all designed to test in static operation as required by efficiency test standards. To test Smart Grid control interface from a "Black Box" perspective the Heat Pump's own control must be active and this requires a new dynamic test setup. A minimalistic dynamic house simulation with an indoor room temperature chamber and an outdoor air temperature chamber was added to an existing static test rig without interfering with parts relevant for the test accreditation.

Since the German SG-Ready was the only open defined Smart Grid interface for Heat Pumps, SGO designed a test setup to demonstrate conformance test method. Testing the combination of two discrete signals may sound simple but the devil sticks in the details. Four modes folds into 16 transitions combined with a 2 hours' limit and dependence on Heat Pump running or not resulting in 64+ possible transitions to verify. Different test approaches may be needed for frequency controlled Heat Pumps compared too ON-OFF types.

To allow Heat Pump to work as in a house, the existing static test setup at DTI (with accreditation) was extended with simulators for indoor and outdoor air temperatures.

Both an ON-OFF type and an inverter-controlled Heat Pump was installed and attempted tested. The test was only partly successful:

Even using the Heat Pump’s own air temperature sensors for indoor and outdoor temperatures, the Heat Pump shows little reaction to air temperature even with maximum sensitivity setting. This proves that the Heat Pumps tested uses water temperature as primary regulation feedback.

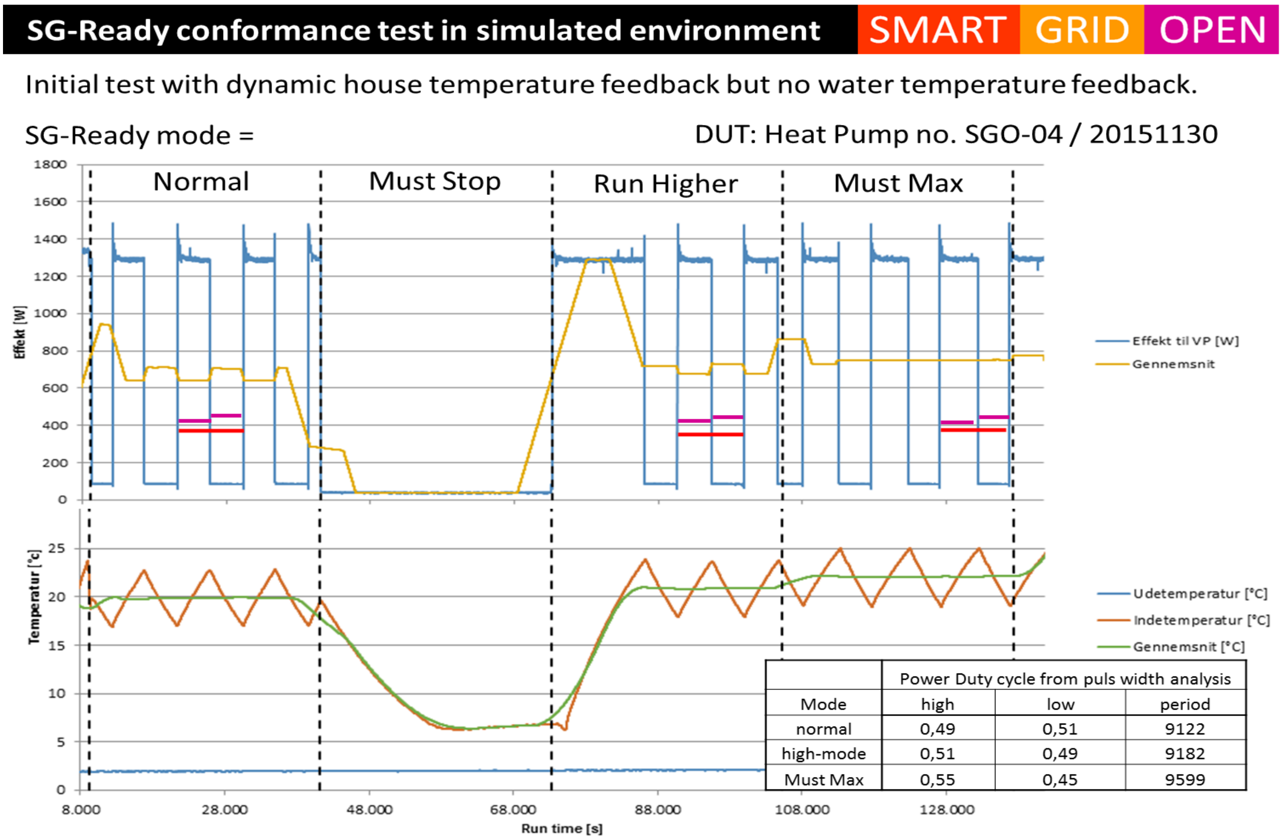


Figure 27 Results from test on claimed SG Ready on-off heat pump. Because of air temperature feedback only for the heat pump the reaction may be very slow but stable. Reactions can be seen to all 4 DG Ready modes by pulse width analysis. No 2 hour fault detection.

Some Heat Pumps do not use room temperature feedback at all. In the annex of this report a description of test methods and an examples of a Heat Pump test report can be found. None of the tested Heat Pumps performed completely as expected from the SG-Ready description so it seems relevant to verify the function before aggregators depend on the Smart Grid ready interface for a specific function.

For further SG-Ready testing, the dynamic simulation must also include water temperature control. The current proprietary regulation system is designed for constant water temperature performance, and because of accreditation, this system has not been touched in connection with temporary SGO tests.

Still the SGO project has proved that testing e.g. of the German SG-Ready is possible and recommendable.

Some of the claimed SG-Ready heat pumps do not conform fully to the expected Smart Grid performance.

SGO project also conclude that the simple two signal German SG-Ready control can be used as low cost Smart Grid control in the domestic domain for heat pumps, EV, PV and other DER.

The SGO mode 1 and mode 2 are well suited as aggregator signals for remote management, and SGO mode 1 and mode 3 will still be available for optional future local DSO control.

1.5.9.7 Electric Vehicles

The product domain Electrical Vehicles can be divided into the following subdomain, charging in the public domain and domestic (home) charging of EVs. In this respect, Nordic Electric Vehicle Interoperability Centre (NEVIC) are one of the leading authorities in regard to EV charging in the public domain, consequently SGO have focused on investigating the possibilities of standardising the home charging of EVs in more details.

Based on several workshops relating to the subject, Eurisco, and DTI realised the following concept, of how the SG-Ready Modes could be mapped to the various settings of the home charger of an EV.

Inspired by the German SG-Ready label, issued by the BWP, German National Heat Pump Association (Bundesverband Wärmepumpe), it is possible to design a feasible SG-Ready labelling concept for home charging of EVs in accordance to IEC 61851-1. The described method applies to AC charging only.

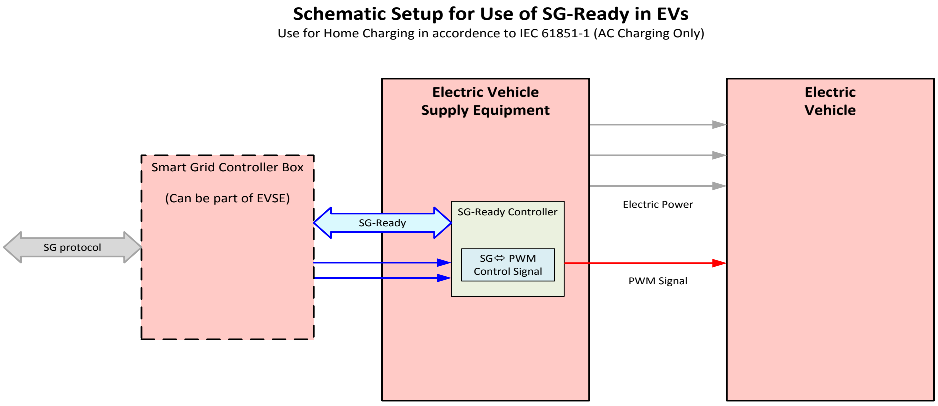


Figure 28: Possible SG-Ready Setup for EVs, based on IEC 61851-1 (Blue SG Ready signals, Red PWM signal, Grey Control signals)

The philosophy behind the setup is to align the conformance test setup of the HP, with a feasible conformance test setup of home charging of EVs. The Smart Grid Controller Box receives Smart Grid signals from the actor e.g. an aggregator. This signal could be a price signal, SG-Ready Mode or any other Smart Grid indicating signal. The Smart Grid Controller Box converts the signal into the appropriate SG-Ready Mode according to the German SG-Ready label.

By converting the SG-Ready Modes, i.e. Normal Operation Mode, Run Higher Mode, Must Max Mode to the Pulse-width modulation (PWM) control signal specified in the IEC 61851, it has been possible to suggest a possible use of SG-Ready signals for charging EVs.

In case the Must Stop Mode is received, the ESVE (see figure 6 page XX) ensures the charging of the EV to be terminated in a secure manner.

The SGO suggest mapping the SG-Ready Modes as specified in below table.

The table was designed based on the electrical installation of the majority of the Danish houses. Normally the installations have 1-phase 10 A capacity, 3-phases 16 A capacities and in case the house owner wishes more power when charging the EV, 32 A installation can be installed. However, the majority of the Danish houses are limited to maximum 32 A at the point of connection to the grid.

SG-Ready Mode	Proposed Duty Cycle PWM Signal	Maximum Current to be Drawn from Vehicle
Normal Operation	9 %	6 A
Run Higher Mode	26,6 %	16 A
Must Max Mode	53,3 %	32 A

Table 3 SG-Ready mode in an EV context – PWM signals to set the suggested current limits.

It must be noted that the maximum current to be drawn from the vehicle, is dependent of the installation of the Home Charger unit.

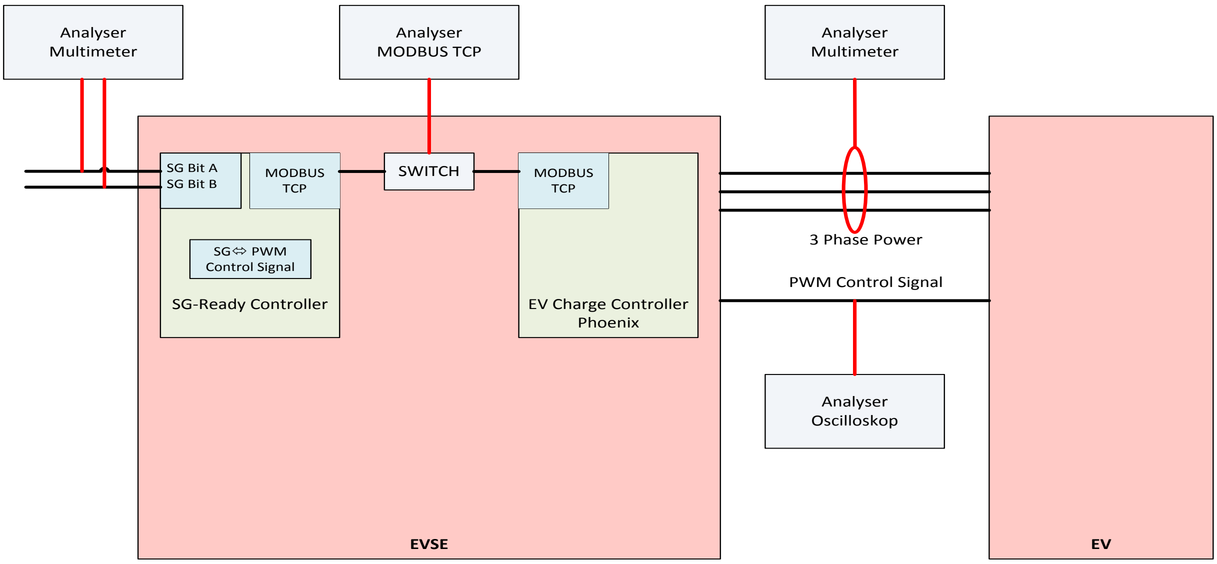


Figure 29: Example Test Setup

Although the DSO/BRP or Aggregator wishes to charge the EV with maximum capacity, i.e. Must Max Mode, which in this case equals 32 A, the installation within the house itself, may limit these demands, enabling the charger only to operate at a “lower” level, i.e. Run Higher Mode or Normal

Operation Mode. It is of importance that these limitations are forwarded to the relevant actors, for possible use and data processing in the relevant system.

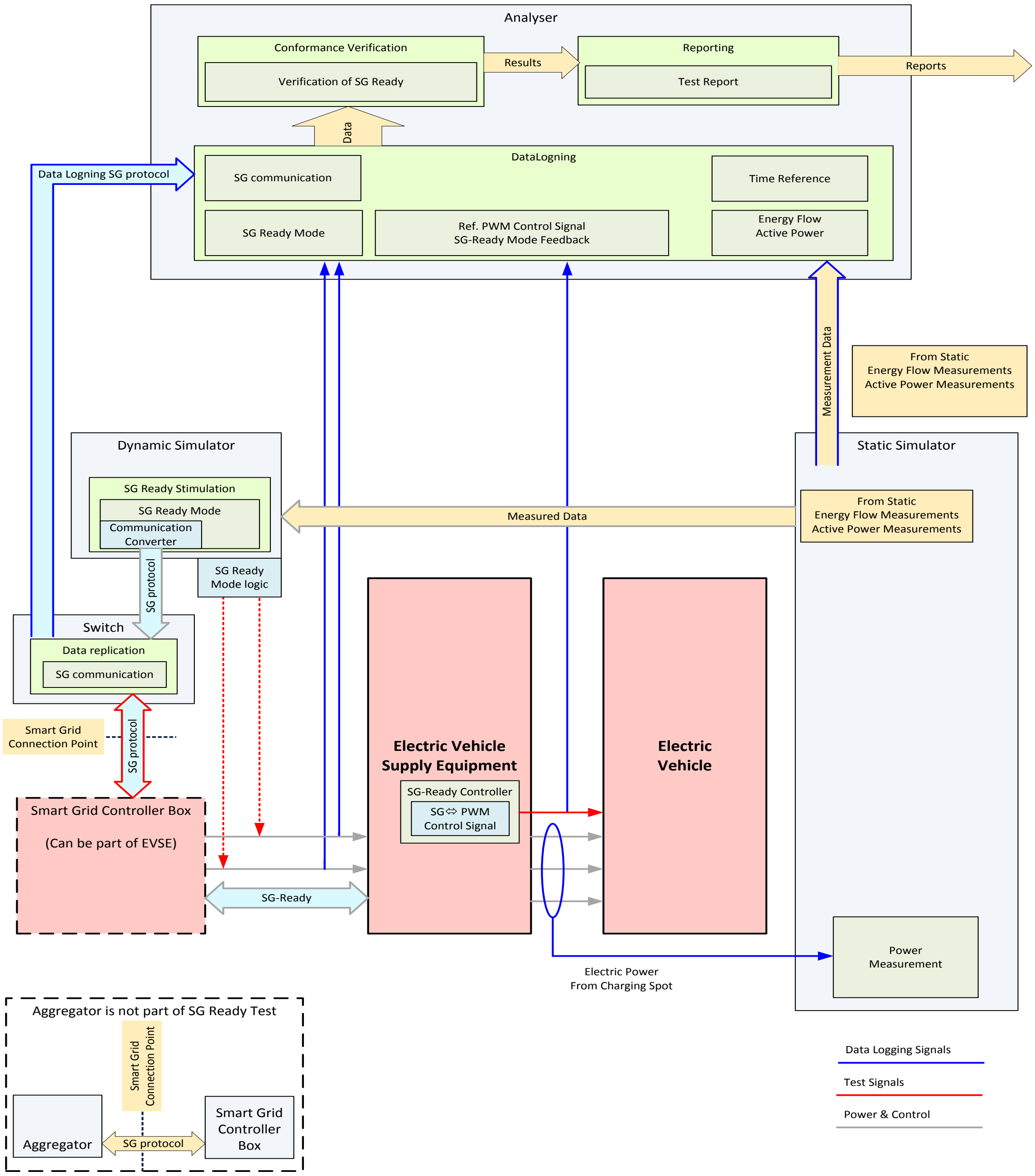


Figure 30: Proposed Generic Test Setup for SG-Readiness of EVs

By combining the SGAM model, the German SG-Ready label and the IEC 61851, it has been possible to design a feasible and generic test setup for the test of Smart Grid readiness of EVs. This setup, may serve as a base for a future hardware/software platform to be developed.

The SGO project has not realised nor tested the suggested hardware/software, however the concept is in alignment with the other ongoing R&D projects in this area, such as the EVCOM project where Danish Energy Association as project holder.

1.5.10 Dissemination

The SGO project has disseminated information and results via different channels.

1.5.10.1 Articles

Contributions to articles in different media:

- HVAC no. 13 December 2014: Article: Når varmepumpen skal kommunikere med nettet – hvilket sprog skal benyttes?
- Ingeniøren 20. February 2015: Feature Article: Skal danske varmepumper mærkes Smart Grid Ready?

1.5.10.2 Relevant workshops

- ”Smart Grid i samfundet” Energinet.dk 30. sep. 2013
- Benefits from International Standardization. iPower International Conference 6. Nov. 2013
- “2-days workshop for PV domain” Smart grid Open 13-14. March 2014,
- ”Business in Demand Response” Energinet.dk 12. May 2014

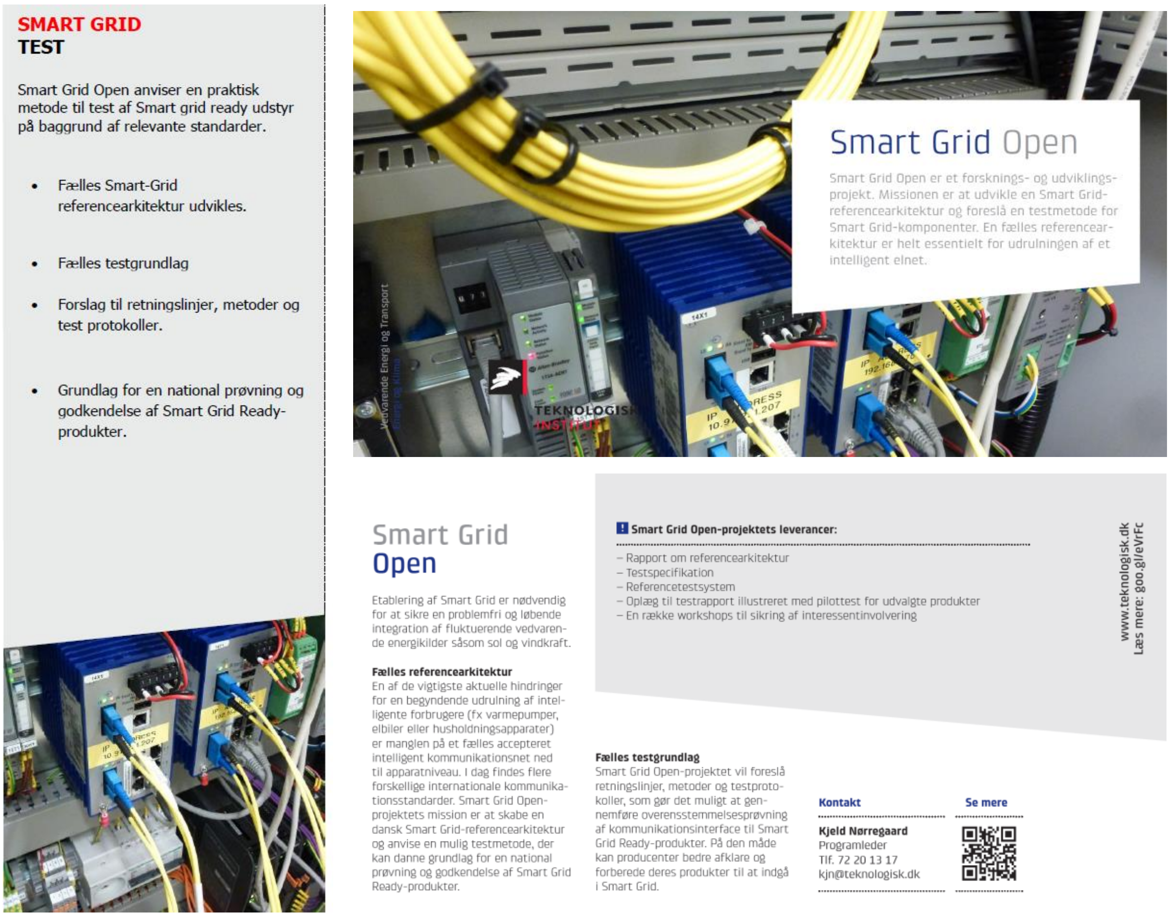


Figure 31 Roll-up and product card used at different evets.

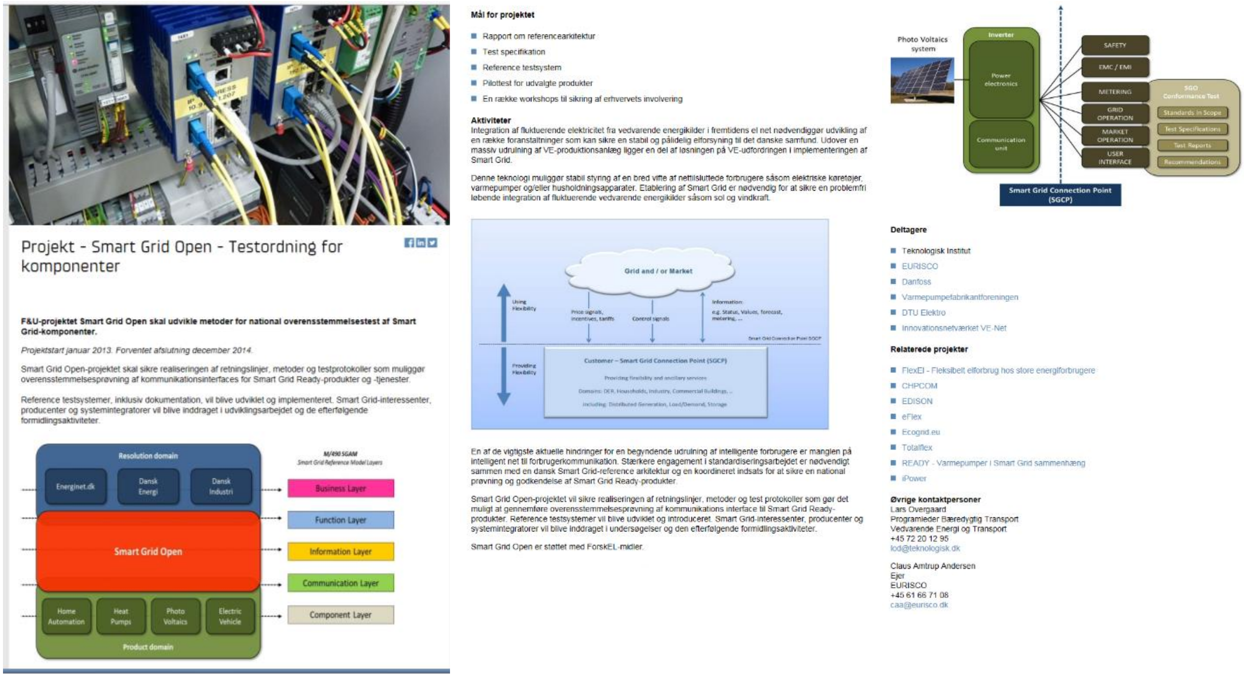
1.5.10.3 Public presentations

- Participation with exhibition boot at “Energiens Topmøde 6. June 2013”
- Presentations for HPCOM project 3. February 2015 at Green Tech Centre, Vejle
  - SGO summary – Heat pump Smart Grid Conformance test 2016
  - SGO SG-Ready interpretation 2015-02-03
- Presentations at Energy conference 1. December 2015 at DTI, Aarhus
  - “Projekt intro og resultater”
  - ”Smart Grid Ready Label – eksempel på Smart Grid Open- testmetode“

1.5.10.4 Further dissemination

A short folder in Danish has been produced with the purpose of a broader dissemination to Heat Pump manufacturers and other domain producers.

WEB



Projekt - Smart Grid Open - Testordning for komponenter

F&U-projektet Smart Grid Open skal udvikle metoder for national overensstemmelsestest af Smart Grid-komponenter.

Projektstart januar 2013. Forventet afslutning december 2014.

Smart Grid Open-projektet skal sikre realiseringen af retningslinjer, metoder og testprotokoller som muliggør overensstemmelsesprøvning af kommunikationsinterfaces for Smart Grid Ready-produkter og -tjenester.

Reference testsystemer, inklusiv dokumentation, vil blive udviklet og implementeret. Smart Grid-interessenter, producenter og systemintegratorer vil blive inddraget i udviklingsarbejdet og de efterfølgende formidlingsaktiviteter.

Mål for projektet

- Rapport om referencearkitektur
- Test specifikation
- Reference testsystem
- Pilottest for udvalgte produkter
- En række workshops til sikring af erhvervets involvering

Aktiviteter
Integration af fluktuerende elektricitet fra vedvarende energikilder i fremtidens el net nødvendiggør udvikling af en række foranstaltninger som kan sikre en stabil og pålidelig elforsyning til det danske samfund. Udover en massiv udrulning af VE-produktionsanlæg ligger en del af løsningen på VE-udfordringen i implementeringen af Smart Grid.

Denne teknologi muliggør stabil styring af en bred vifte af nettilsluttede forbrugere såsom elektriske køretøjer, varmepumper og/eller husholdningsapparater. Etablering af Smart Grid er nødvendig for at sikre en problemfri løbende integration af fluktuerende vedvarende energikilder såsom sol og vindkraft.

En af de vigtigste aktuelle hindringer for en begyndende udrulning af intelligente forbrugere er manglen på intelligent net til forbrugerkommunikation. Stærkere engagement i standardiseringsarbejdet er nødvendigt sammen med en dansk Smart Grid-reference arkitektur og en koordineret indsats for at sikre en national prøvning og godkendelse af Smart Grid Ready-produkter.

Smart Grid Open-projektet vil sikre realiseringen af retningslinjer, metoder og test protokoller som gør det muligt at gennemføre overensstemmelsesprøvning af kommunikations interface til Smart Grid Ready-produkter. Reference testsystemer vil blive udviklet og introduceret. Smart Grid-interessenter, producenter og systemintegratorer vil blive inddraget i undersøgelser og den efterfølgende formidlingsaktiviteter.

Smart Grid Open er støttet med ForskEL-midler.

Deltagere

- Teknologisk Institut
- EURISCO
- Danfoss
- Varmepumpefabrikantforeningen
- DTU Elektro
- Innovationsnetværket VE-Net

Relaterede projekter

- FlexEl - Fleksibelt elforbrug hos store energiforbrugere
- CHPCOM
- EDISON
- eFlex
- Ecogrid.eu
- Totalflex
- READY - Varmepumper i Smart Grid sammenhæng
- iPower

Øvrige kontaktpersoner
Lars Overgaard
Programleder Bæredygtig Transport
Vedvarende Energi og Transport
+45 72 20 12 95
lod@teknologisk.dk

Claus Amtrup Andersen
Ejer
EURISCO
+45 61 66 71 08
caa@eurisco.dk

Figur 32 www.smartgridopen.dk – A web page with general information about the project

1.6 Utilization of results

1.6.1 Suggested 2 line Smart Grid control for Denmark.

After reflections on the possible relevance of the German SG Ready control for Heat Pumps it was decided to extend the project with a small study into the possible use of the same two SG Ready signals for other equipment than Heat Pumps.

Using the following assumptions:

An Aggregator wants to control “Must stop” and “Run higher” in order to manage the available energy flexibility of the component while maintaining a level of comfort or function as agreed with the user of the equipment.

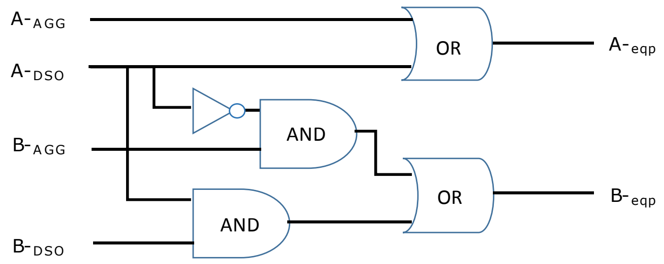
The local DSO has an interest in a fast and simple way of sheeding load during unusable peak loads and increase load during a high voltage situation on a radial or substation.

The user of any equipment wants to have the full level of comfort or function available. If any degradation of comfort or function due to Smart Grid management should be accepted by the user, it will require a business case showing short payback time for the combined initial cost and operational cost.

Technical perspectives of 2 line Smart Grid control

A very simple logic interface allows an Aggregator to control “Must stop” and “Run higher” in normal situations, while the DSO can always command “Must stop” and “Run Max” in case of local voltage quality issues.

The Aggregator must have a local interface box with two signal outputs capable of activating relay coils. The aggregator control signals are normally less time critical than DSO protection commands. The two DSO signals can come from the domestic meter and be connected to the interface by wires or wireless via a driver circuit. The DSO can broadcast the override commands to meters selected meters, along a radial or a whole substation as needed.



	Signal	
Mode	B	A
Normal	0	0
Must stop	0	1
Run higher	1	0
Must max	1	1

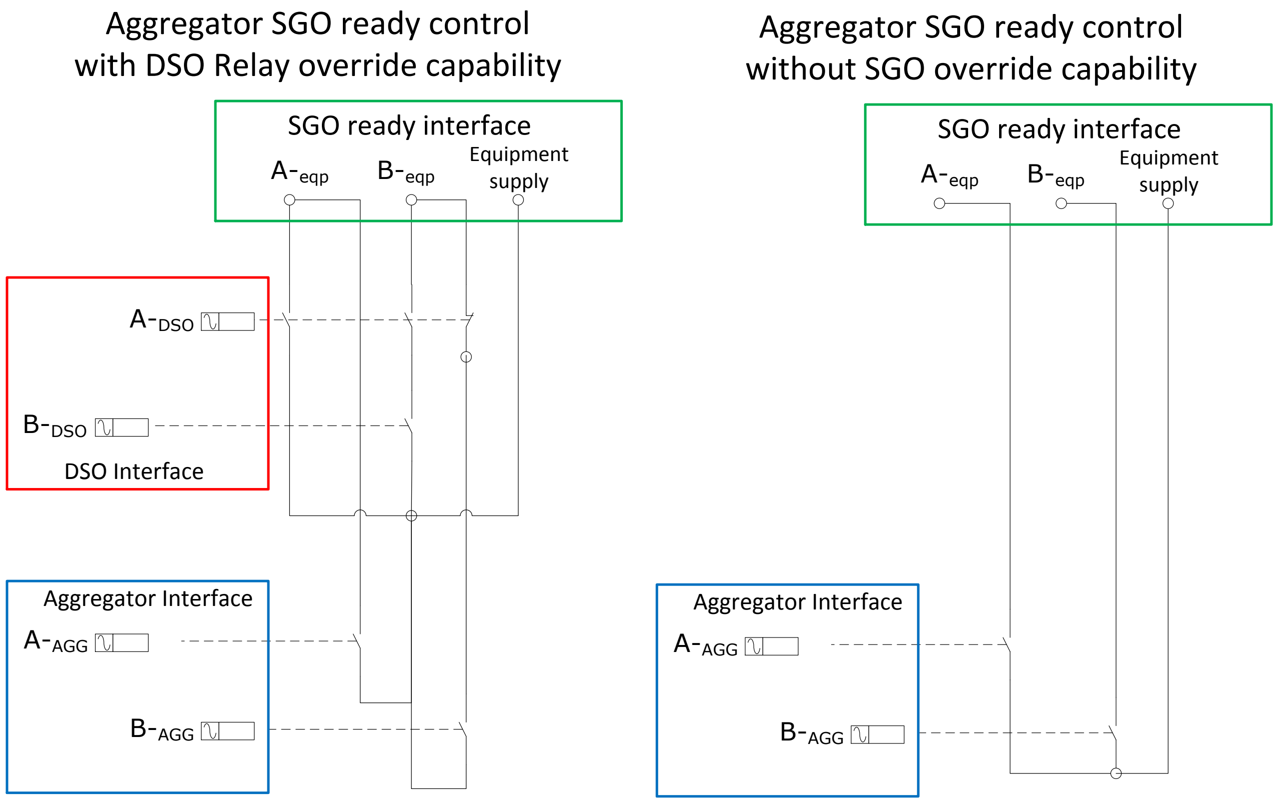


Figure 33 A simple relay logic provide good galvanic separation and combines the two Smart Grid signals from an Aggregator and a DSO, enabling the DSO to overrule any Aggregator command. When there is no need for DSO override capability the circuit becomes even simpler.

The generic example illustrated in Figure 34 Generic example suggests how different domestic equipment (assumed SGO Ready) can be managed individually by different aggregators all with the same very simple DSO override capability via meter-distributed outputs. Figure 34 shows 5 different equipment types - all behind the electricity-meter on a single domestic electric installation. Reducing the Smart Grid control to a very simple hardware level can greatly simplify also the need for consistent standardization across different equipment types each having their own traditional communication protocols. It possible to start rolling out equipment with a relative simple conformance test. Using relay interface will create good galvanic barriers reducing risk of compatibility and interoperability issues.

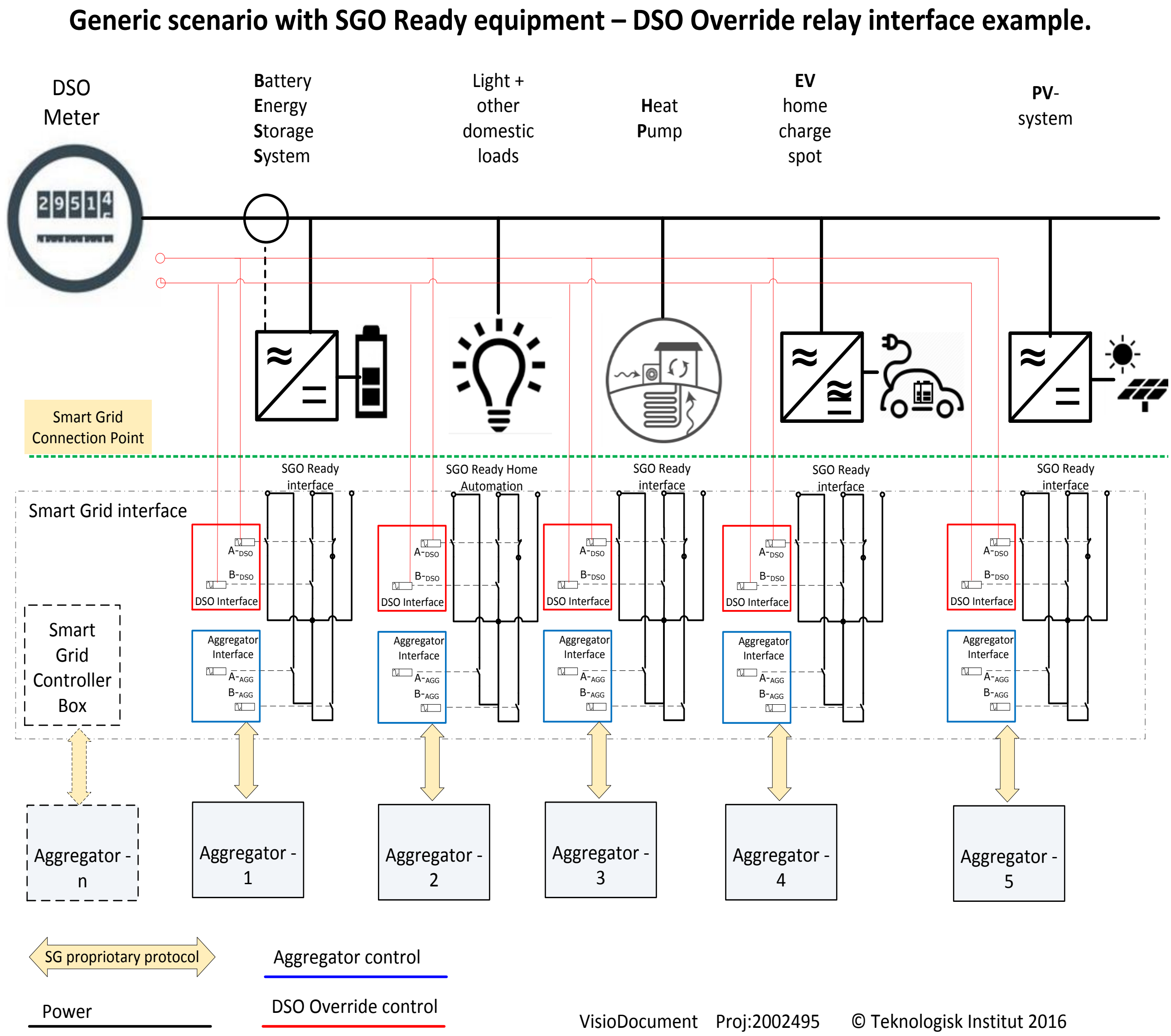


Figure 34 Generic example suggests how different domestic equipment (assumed SGO Ready) can be managed individually by different aggregators all with the same very simple DSO override capability via meter-distributed outputs.

Experience from the heat pump tests indicate a need for a minimal level of conformance testing to ensure consistent reaction to the SG Ready control signals and to identify the core characteristic time constants to the aggregator. “SGO ready” in this context refer to a passed conformance test equipment meeting automatic fault detection (maximum 2 hours active limit signal allowed) and the two wire control reaction suggested in Table 4 Suggested SGO Ready interpretation vs different equipment..

It seems reasonable to investigate the potential further for the simple two line Smart Grid ready interface.

Table 4 Suggested SGO Ready interpretation vs different equipment.

SGO mode = Load on grid	0 = normal	1 = Must Stop (or minimal load)	2 = Run Higher (or normal operation)	3 = Must Max (maximum load)
SGO Ready Signal B	0	0	1	1
SGO Ready Signal A	0	1	0	1
PV Germany	100% No limit	60%	30%	0
PV DK	100% No limit	100% ride-through	30% / 100%	0
VP DK	No limit	Min	More	Max
EV DK	No limit	Min / 6A	Max / charge max allowed by car	Max / charge max allowed by car
Home storage DK	No limit	Max discharge / no charge ride-through	Max charge / no discharge (not even local)	Max charge / no discharge (not even local)
Electric heating DK	No limit	Frost protection only / min comfort limit	Temperature set = maximum allowed	Temperature set = maximum allowed
Freezer/refrigerator	No limit	Stop until temperature reach maximum allowed	Temperature set = minimum allowed	Temperature set = minimum allowed
Washing	No limit	Stop if accepted by user	No limit	No limit
Dishwasher	No limit	Stop if accepted by user	Start if postponed by timer	Start if postponed by timer
Stove / Oven	No limit	Stop the time accepted by user	No limit	No limit
Drainpump / Waterpump	No limit	Stop time-limit accepted by user	Start and run until stop criteria	Start and run until stop criteria
Street lighting	No limit	Switch off / minimise light for 5 minutes	No limit	Switch on all light
Ventilation	No limit	Stop for 5 minuts / Minimised air flow	No limit	Maximum air flow
UPS	No limit	Switch to UPS power per agreement	Charge max	Charge max
Micro CHP	No limit	Maximum electric production	Price or Aggregator managed higher/normal operation	Stop microchip; switch on electric submersion heaters
Forklift charged locally	Smart charge	Stop charging / minimum charge until limit SoC	Charge maximum	Charge maximum
Cooling container	No limit	Stop until temperature reach maximum allowed	Temperature set = minimum allowed	Temperature set = minimum allowed

1.7 Conclusion and perspective

Green electricity will be the main path to realise the Danish 2050 fossil independence plan including the heating and transport areas. A substantial expansion of Danish electric power consumption supplied primarily by renewable fluctuating electric energy calls for new measures to secure a stable and reliable future electricity supply. Distributed Energy Resources, DER (e.g. Photo Voltaics) and electric consumers must be much more flexible to allow for the fluctuating supply and limited capacity in the grid. Deployment of Smart Grid control systems for flexibility management also at the low voltage end of the electric grid seems imminent relevant and maybe unavoidable to fully implement the Danish climate objectives.

Smart Grid technology enables smart demand side management of electricity consumers and DER such as Photo Voltaics, electrical vehicles and heat pumps supporting a smooth integration of increasing fluctuating energy. Getting a massive Smart Grid deployment started may require either regulation or attractive incentives. To achieve a large-scale role out electricity Customers must be willing to invest in Smart Grid equipment. Smart Grid ready equipment will not be accepted by the domestic domain if the prices are higher than conventional goods. Standardisation and mass produced standard products are likely the best means to drive down the add-on cost by including Smart Grid functionality. Lacking an open agreed standardized information exchange between grid and consumer, the suppliers of the future smart equipment can only guess at requirements, but hardly verify conformance. At the end of the Smart Grid Open project, the expected emerging market for Smart Grid Ready products still awaits the grid stakeholders to decide on a common Smart Grid information exchange method.

Without any agreed or even suggested Smart Grid standards, the frame conditions for developing specific conformance tests has been challenging. Without any commercial Smart Grid Ready domestic equipment, the “Smart Grid Open” project (SGO) has changed focus towards guidelines and methods for realization of testing protocols enabling conformance testing of Smart Grid Ready interface on products. Many product suppliers offer “Smart” products based on proprietary control through their own dedicated servers. Lack of Danish grid stakeholder recommendations regarding preferred Smart Grid standards means that domestic customers are not requesting Smart Grid functionality and suppliers are not offering it. Still the SGO project has looked at possible reference testing on three domestic product domains: PV, Heat Pumps (HP) and domestic EV charging - all characterised by continuous high grid power for several hours compared to traditional domestic loads. Lacking actual Smart Grid Ready products, the project looked at the German SG-Ready interface on heat pumps and suggests this used in Denmark as a simple intermediate interface. The SGO project suggests extending the use of this very simple four-mode control to other domestic products. This can be a first step towards Smart Grid control in an alternative Danish way allowing both an Aggregator and the local DSO to control the power-critical products in a simple way. The SGO project developing test equipment and a test method that follows the principles of recognised control standards like IEC 61850 to look at some Heat Pumps claiming to be Smart Grid ready according to the German National Heat Pump association (Bundesverband Wärmepumpe BWP).

An important objective in the SGO project was building knowledge within the area of Smart Grid control and conformance testing, including mapping the most relevant contenders for Smart Grid control like IEC 61850, OpenADR, USEF, VHPready, the German heat pump SG-Ready label and

Smart Grid ready home automation. Many different initiatives compete for a dominating position, but for the domestic domain, none seems to have noticeable support from the major product suppliers. **Only the German SG-Ready label can present a list of 900+ heat pump products, making it the only Smart Grid interface with a wide acceptance across the suppliers enabling demand side management of domestic equipment.**

Danfoss was an active partner of the SGO project until their Solar Inverter division was merged with SMA. Danfoss could see that in the near future even domestic inverters will likely have computing power to handle complex control like IEC 61850. A project workshop involving Energinet.dk identified a subset of IEC 61850 functions relevant for Smart Grid control of power converters including smaller PV systems. Danfoss had to leave the project shortly after so no conformance test has been done on PV inverters.

Denmark hope for heat pumps to take over most individual heating solutions if/when oil and gas are phased out eventually and electric power is used for efficient heating. This will increase the electric load significantly and call for smart grid control. The only current Danish business opportunity for aggregated control is by forming Virtual Power Plants and trade power and energy. Heat pump suppliers offer individual proprietary Smart Grid solutions but independent aggregators request open standards. A Heat Pump is a very complex product to test because many external conditions must be in place to simulate the environment a Heat Pump is normally working in. Danish Technological Institute (DTI) has several dedicated test rigs for Heat Pumps with accreditation but all designed to test in static operation as required by efficiency test standards. To test Smart Grid control interface from a “Black Box” perspective, the Heat Pump’s own control must be active and this requires a new dynamic test setup. A minimalistic dynamic house simulation with an indoor room temperature chamber and an outdoor air temperature chamber was added to an existing static test rig without interfering with parts relevant for the test accreditation.

Since the German SG-Ready was the only open defined Smart Grid interface for Heat Pumps, SGO designed a test setup to demonstrate conformance test method. Testing the combination of two discrete signals may sound simple but the devil sticks in the details. Four modes folds into 16 transitions combined with a 2-hour limit detection and testing for possible dependence on Heat Pump running or not when limit occurs, results in more than 64 possible transitions to verify. A different test approach may be needed for frequency controlled Heat Pumps compared too ON-OFF types.

Some Heat Pumps do not use room temperature feedback at all. The SGO final report include a description of test methods and an example of a Heat Pump test report. None of the tested Heat Pumps performed completely as expected from the SG-Ready description so it seems relevant to verify the function before aggregators depend on the Smart Grid ready interface for a specific function.

The two discrete Smart Grid ready signals form four modes: Normal, Must Stop, Must Max, and Run Higher.

The Must Stop and Must Max signals can be used locally by the DSO via a meter-interface in case of e.g. extreme load or very low load and high PV generation causing critical voltage levels at specific radials or substations. The Must Stop and Run Higher signals can be relevant for an aggregator, which can operate the Heat Pump as a “heat actuator” offering the customer external comfort control while trading power and energy. With a minimal logic setup, the DSO control can always overrule aggregator control offering independent dual access to demand side management of Heat Pumps. SGO has analysed the use of the same simple interface on other domestic products and actually tested the concept on a Domestic EV charger. **It seems feasible to use the same two discrete control signals to manage a number of domestic equipment paralleled – this could be a new cost effective and simple approach to stepwise implementing a Danish Smart Grid control as needed.**

Regarding the lack of commercial Smart Grid ready equipment, the SGO project has produced relevant results already included in the HPCOM project.

1.7.1 Findings

- Roles and use cases in a Danish context developed for two domains in accordance with the Smart Grid ‘reference architecture’ –The DANGRID work and the European M490 mandate has formed a basis for the framework.
- Smart Grid relevant management functions identified for PV.
- Examples of formalised test procedures for the domestic product domain areas Electric Vehicles and Heat Pumps. These can be adapted to other domestic appliances like Distributed Energy Resources e.g. PV, wind and microCHP.
- Developed reference test systems for selected ‘pilot’ test applications. I.e. reference test system for EV charging spot and a Smart Grid ready heat pump.
- A Danish adaptation of the German heat pump SG-Ready label seems useable as Smart Grid control signals in a Danish context for following purposes
    - Heat pump aggregator control (Must Stop and Run Higher modes)
    - A simple future possible DSO override control (Must Stop and Must Max).
    - Heat pumps and
    - Most other private product domains like PV, EV home charge, battery storage etc.
- The compliance to the German SG-Ready seemed to be implemented in different ways by the suppliers. A certified verification of the actual heat pump characteristics and compliance to a Danish SGO ready label could be relevant if any aggregator should expect to use standard control independent of the heat pump brand and type.
- Smart Grid Open concept is believed to offer an actual practical link between standardisation and conformance testing of Smart Grid ready products when available.

Lacking any common Smart Grid standard for Heat Pump control, compliance with two German signal SG-Ready label were tested as part of the SGO project.

To allow Heat Pump to work as in a house, an existing static test setup at DTI (with accreditation) was extended with simulators for indoor and outdoor air temperatures.

Both an ON-OFF type and an inverter-controlled Heat Pump was installed and attempted tested. The test was only partly successful:

Even using the Heat Pump's own air temperature sensors for indoor and outdoor temperatures, the Heat Pump shows little reaction to air temperature even with maximum sensitivity setting. This proves that the Heat Pumps tested uses water temperature as primary regulation feedback.

For further SG-Ready testing, the dynamic simulation must also include water temperature control.

The current proprietary regulation system is designed for constant water temperature performance, and because of accreditation, this system has not been touched in connection with temporary SGO tests.

Still the SGO project has proved that testing e.g. of the German SG-Ready is possible and recommendable.

Some of the claimed SG-Ready heat pumps do not conform fully to the expected Smart Grid performance.

SGO project also conclude that the simple two signal German SG-Ready control can be used as low cost Smart Grid control in the domestic domain for heat pumps, EV, PV and other DER.

The SGO mode 1 and mode 2 are well suited as aggregator signals for remote management, and SGO mode 1 and mode 3 will still be available for optional future local DSO control.

1.7.2 Relevance of the project with the wisdom of hindsight?

In hindsight, the project has been relevant and useful even though no Smart Grid ready components have been identified. As always, the devil sticks in the details. Without working with real hardware, the tricky challenges are easily overlooked. Even when things seem simple, there can be significant learning in actually testing.

At project start there was an understanding across the business that Smart Grid was needed and therefore just around the corner, but the reality at project closure was:

- No smart grid ready requirements
- No standardized smart grid ready equipment
- If and when a Smart Grid approach is agreed in Denmark conformance testing is relevant – even at a basic level

1.7.3 Recommendations

- Grid stake holder's agreement for smart grid is a minimum requirement
- Grid stakeholders should design and agree on requirements for switchable equipment
- Legislation requiring standardised Smart Grid recommended. At minimum requiring standardised remote control inputs enabling
    - a minimal power mode and
    - a maximum power mode and
    - an optional.Run Higher intended for Aggregator services.
- There is beauty in simplicity. Adapting the German four-mode control used for PV-systems and SG-Ready heat pumps gives access to a large base of Smart Grid ready devices.
    - German SG-Ready can be a quick shortcut to new standards for heat pumps
    - Local grid operator can overrule Aggregator with very simple relay logic

- Simple control does not hinder advanced smart grid services
    - Usable in most equipment domains
    - A Smart Grid ready label to prove verified conformance in Denmark
- Using SG Ready Must Stop control should include both heat pump compressor and electric heatcoil since many heat pumps run without enabled heatcoil.
- In SG Ready Must Max mode the best chance of a quick predictable reaction is to activate the heatcoil only

In popular terms an SGO ready Smart Grid control may offer over 80% of the available flexibility in the domestic domain for 20% of the complexity (and cost) of an advanced solution with web-based online management.

Table 5 Different devices suggested reaction to SGO ready modes.

SG-Ready	SGO Mode	SGO Mode Description	Heat Pump	EV Home-charger	PV System (no storage)	PV inverter with local battery
Normal	0	Normal Operation	Normal Operation	No limit	Normal Production	Normal Production
Must Stop	1	Stop/Minimum Load	Min Consumption	Min Charge (? A)	Max Production	No grid limit (PV+BAT)
Run Higher	2	Increase load	Increase temp set	No limit	Cap Production	Grid limit, Charge battery
Must Max	3	Maximum Load	Max Consumption	No limit	Stop Production	Stop PV, Max BAT charge

ANNEX A1 Abbreviations

API	Application Programming Interfaces
ASN.1	Abstract Syntax Notation One
ATM	Abstract Test Method
ATS	Abstract Test Suite
CDD	Component Data Dictionary (IEC / SC 3D)
CEN	The European Committee for Standardization
CENELEC	European Committee for Electro Technical Standardization
CIM	Common Information Model
CIMug	CIM User Group
CIS	Component Interface Specifications
COSEM	Companion Specification for Energy Metering
CoC	Certificate of Conformance
CSN	Concrete Syntax Notation
CSP	Concentrated Solar Power
CTI	Conformance test information
CTT	Conformance test tool
DER	Distributed Energy resources
DIN	Deutsches Institut für Normung
DLMS	Device Language Message specification
DMS	Distribution Management System
DSO	Distribution System Operator
DTI	Danish Technological Institute, an independent research and test institution
DTU	Technical University of Denmark
DUT	Device Under Test
EC	European Commission
EFH	Energy Flex House, a lab facility at Danish Technological Institute
EMC	Electro Magnetic Compatibility
EMS	Energy Management System
ENTSO-E	European Network of Transmission System Operators for Electricity
EBSII	European Business System Integration and Interoperability
ESO	European Standard Organization
Ethernet	Common computer-networking components
ETSI	European Telecommunications Standards Institute
EUT	Equipment Under Test
EV	Electric Vehicle
FSS	(Working Group) First set of standards
FTP	File transfer protocol
GID	Generic Interface Definition
GIS	Geographic Information System
GridWise	Project to modernize the US electric grid system
GSM	Global System for Mobile Communications (G2)
GOOSE	Generic Object Oriented Substation Events
GWAC	GridWise Architecture Council
HBES	Home and Building Electronic System
HES	Head-End System
HMI	Human Machine Interface
HTML	HyperText Markup Language

ICS	Implementation Conformance Statement
ICT	Information and Communication Technology
IEC	International Electro Technical Commission
IECEE	International Electro Technical Commission for Electrical Equipment
IED	Intelligent Electronic Devices
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IFS	Interoperable Function Statement
ILAC	International Laboratory Accreditation Cooperation
IOP	Interoperability
IP(v6)	Internet Protocol version 6
ISO	International Organization for Standardization
ISO/OSI	Open Systems Interconnection Reference Model
IT	Information Technology
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
IUT	Implementation under test
MICS	Model Implementation Conformance Statement
MoC	Means of Communication
MoT	Means of Test
NGN	Next Generation Networks
NWIP	New Work Item Proposal
OpenADR	Open Automated Demand Response
PDU	Protocol data units
PICS	Protocol Implementation Conformance Statement
PIXIT	Protocol Implementation eXtra Information for Testing
PPP	Point-to-Point Protocol
PV	Photo Voltaic
QE	Qualified Equipment
RAWG	Reference Architecture Working Group under the CEN/CENELEC/ETSI SGCG
RFC	Request for Comments, publication of the IETF and the Internet Society
SCADA	Supervisory Control and Data Acquisition
RP	Reference Point
SAS	Substation Automation Systems
SDLC	System development life cycle
SGAM	Smart Grid Architecture Model
SGO	Smart Grid Open, an open source proposed conformance test method
SG-Ready	German Heat Pump certification by Bundesverband Wärmepumpe e.V.
SG-CG	Smart Grid Coordination Group
SGIMM	Smart Grid Inter-Operability Maturity Model
SGIS	Smart Grid Information Security
SOAP	Simple Object Access Protocol
SUT	System Under Test
TC	Technical Committee
TCP	Transmission Control Protocol
TCP/IP	Communication protocol for the internet.
TD	Test Description
TOGAF	The Open Group Architecture Framework
TP	Test Purpose
TR	Technical Report
TS	Technical Specification
TSO	Transmission System Operator
TSS&TP	Test Suite Structure and Test Purposes

TTCN-3	Testing and Test Control Notation version 3
UCALug	UCA International Users Group
UDP	User Datagram Protocol
UML	Unified Modelling Language
V2G	Vehicle-To-Grid
WG FSS	Working Group First set of standards within the SG-CG
WG RA	Working Group Reference Architecture within the SG-CG
WG SGIS	Working Group SGIS within the SG-CG
WG SP	Working Group Sustainable Processes within the SG-CG
WGI	Working Group Interoperability
WiFi	Technology that allows an electronic device to exchange data wirelessly
XML	Extensible Markup Language
XMPP	Extensible Messaging and Presence Protocol – a XML streaming protocol
XSF	XMPP Standards Foundation

ANNEX A2 Terms and Definitions

Term	Definition	Reference
Accreditation	Accreditation is the independent evaluation of conformity assessment bodies against recognized standards to carry out specific activities to ensure their impartiality and competence. Through the application of national and international standards, government, procurers and consumers can have confidence in the calibration and test results, inspection reports and certifications provided	ILAC International Laboratory Accreditation Cooperation
Coexistence	The ability of two or more devices, regardless of manufacturer, to operate independently of one another at the same communications network, or to operate together using some or all of the same communication protocols and processes, without interfering with the functioning of other devices in the same system.	Adapted from IEC TC65/920/DC
Companion Specifications	Project specific companion specifications will be required to achieve product level interoperability, that specify what standards are used, what alternatives have to be taken and which options need to be supported by communication entities used in the given system.	TR 50572
Compliance	Accordance of the whole implementation with specified requirements or standards. However, some requirements in the specified standards may not be implemented. Note: most related to standards	Adapted from TOGAF 9.1 section 48.2 See Figure 22 of this report
Component	An object used in the SG, representing part of the total SG functionality required in a specific and distinctive situation. An object can represent hardware as well as software. Software can be seen as an integral part of a component or it can add functionality to the SG system.	As used by WGI
Conformance	Accordance of the implementation of a product, process or service with all specified requirements or standards. Additional features to those in the requirements / standards may be included. All features of the standard/specification are implemented and in accordance, but some additional features are not covered by the standard/specification	Adapted from TOGAF 9.1 section 48.2 See Figure 22 of this report

Conformity assessment	Processes that are used to demonstrate that a product (tangible) or a service or a management system or body meets specified requirements. Assessment may be conducted by 1st, 2nd or 3rd parties depending if the activities are performed by the vendor, the purchaser/user or by a party independent from the vendor and from the purchaser/user respectively.	ITU-T
Conformance testing	The act of determining to what extent a single implementation conforms to the individual requirements of its base standard. An important condition in achieving interoperability is the correct implementation of the standards. This can be verified by conformance testing. Determines whether an implementation conforms to a profile as written in the PICS. The latter testing can be interoperability testing if profile covers the interoperability requirements additional to the conformance testing requirements of standards applied. Conformance testing is a prerequisite for interoperability testing.	Adapted from TR 50572 Clarification of WGI
Data integrity	Ability of a communications system to deliver data from its source to its destination with an acceptable and measurable residual error rate.	IEC 62051 TR 50572
Deployment of methodology	The way in which the IOP methodology will be implemented and applied in praxis	As used by WGI
Data security	Prevention of one or more of the following: - unauthorized access to information within a data stream; - unauthorized alteration of information within a data stream; - unauthorized generation of messages which could be taken as valid by the receiving equipment; - denial of service. See also: ‘Security’.	TR 50572 (1)
Function	Process which constantly or at defined intervals, automatically or on demand, performs specific activities. It is defined by its input, behaviour and output. An application is composed of one or more functions. A function can be basic (mandatory) or optional.	Adapted from TR 50572

Functional requirements	A statement that identifies what a device or system must accomplish to produce required behaviour and/or results	IEEE
GWAC (GridWise) Interoperability Framework	Also known as the GWAC Stack, addresses the different layers identifying all interfaces that can have IO issues	GridWise Architecture Council
Incompatibility	The inability of two or more objects to work together in the same system.	Adapted from IEC TC65/920/DC
Interchangeability	The ability of two or more devices or objects to be interchanged without making changes to other devices or objects in the same system without degradation in system performance.	Adapted from IEC TC65/920/DC
Inter-connectability	The ability of two or more devices, regardless of manufacturer, to operate with one another using the same communication protocols, communication	Adapted from IEC TC65/920/DC
Interoperability (IOP)	The ability of two or more networks, systems, devices, applications, or components to interwork, to exchange and use information in order to perform required functions	TR 50572 (Glossary)
IOP certification	The process that will provide a certificate by an accredited body if IOP is according to a distinct profile	As used by WGI
IOP concept	Generic arrangement (principles applied) how to realize IOP in a specific situation (refer to the layers in GWAC Stack)	GWAC Stack
IOP level	Maturity levels explained in the SGIMM	SGIMM
IOP methodology	Methods and steps that can be applied to realize Inter-Operability in a given situation	To be developed by WGI. See WGI Scope and WGI Targets

IOP profile	An IOP profile is a document that describes how standards or specifications are deployed to support the requirements of a particular application, function, community, or context A profile defines a subset of an entity (e.g. standard, model, rules). It may contain a selection of Data models and Services. Furthermore, a profile may define Instances (e.g. specific device types) and Procedures (e.g. programmable logics, message sequences)	As used by WGI SGRA report, November 2012
IOP testing	Interoperability testing should be performed to verify that communicating entities within a system are interoperable, i.e. they are able to exchange information in a semantically and syntactic correct way. During interoperability testing, entities are tested against peer entities known to be correct. (profiles)	As used by WGI
IOP testing process	Describing Workflow of testing from input to output and the actual procedures, tasks and responsibilities	IECEE
Interworkability	The ability of two or more devices, regardless of manufacturer, to support transfer of device parameters between devices having the same communication interface and data types of the application data. NOTE: If a device is replaced with a similar one of a different manufacture, it can be necessary to reprogram the application.	IEC TC65/920/DC
Interface	Point or means of interaction between two systems interface. NOTE: The devices allow data exchange without agreements about the data types. A data type conversion may be necessary.	IEC 62051
MICS	Model implementation conformance statement. Statement that details the standard data object model elements supported by the system or device	IEC 61850-10

Object	Entity treated in a process of design, engineering, realization, operation, maintenance, dismantling and disposal. NOTE 1 The object may refer to a physical or non-physical ”thing” that might exist, exists or did exist.	IEC 81346/1
PICS	Protocol implementation conformance statement. Statement with the summary of the communication capabilities of the system or device to be tested.	IEC 61850-10
Plug and Play	The ability to add a new component to a system and have it work automatically without having to do any technical analysis or manual configuration.	SGIMM
PIXIT	Protocol Implementation eXtra Information for Testing. Statement with system or device specific information regarding the communication capabilities of the system or device to be tested which are outside the scope of the IEC 61850 series. The PIXIT is not subject to standardization.	IEC 61850-10
Process	Logically linked sequence of tasks that enables a system to achieve particular objectives. NOTE A process may interact with other processes. Processes may be business processes or support processes.	TR 50572 (12)
Quality Assurance Process	Working process around achieving the state of Inter-Operability of components, (sub) systems connected to each other (the process secures transparency and witness-ability that everything went according to the rules).	As used by WGI
Requirement	Statement that identifies a necessary attribute, capability, characteristic or quality of a system in order for it to have value and utility to a user. NOTE 1 In systems engineering, a requirement can be a description of what a system must do, referred to as a Functional Requirement. A requirement may alternatively specify something about the system itself and how well it should perform its functions. Such requirements are often called Non-Functional Requirements, or 'Performance	TR 50572 (7)

	Requirements' or 'Quality Of Service Requirements'. NOTE 2 One common way to document a requirement is stating what the system shall do by, for example, generating a Use Case.	
Security	Measures that protect and defend information and information systems by assuring their confidentiality, integrity, access controls, availability and accuracy. As defined in ISO/IEC 27002:2005 "Information security is the protection of information from a wide range of threats in order to ensure business continuity, minimize business risk, and maximize return on investments and business opportunities." See also "Data Security".	TR 50572 (4) SGIS
Security requirements (IOP)	Methods and measures to be applied in systems connected and how these should be handled in the IOP Methodology	As used by WGI
SGAM	The Smart Grid Architecture Model, the 3D- Model for SG mapping. High level conceptual model of the Smart Grid developed by the M/490 Reference Architecture working group describing the main actors of the Smart Grid and their main interactions.	SGCG, RAWG
SICS	SCL implementation Conformance Statement. Statement with the summary of the capabilities of the SCL engineering tool.	IEC 61850-10
Smart Grid	Electricity network that intelligently integrates the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to efficiently ensure a more sustainable, economic and secure electricity supply. A Smart Grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety.	EURELECTRIC (modified) Glossary TR 50572 SGCG matrix of terms

Smart Grid Application (Domain)	The different (sub) systems that can be identified where SG technologies are applied, i.e.: Generation, Transmission, Distribution, DER and Customer premises.	FSS Report and SGRA Report
Standard type 1 Standard type 2 Standard type 3	Type 1 - Requirement Standards are high level requirement standards, neutral from technology. Those requirements do not provide technical implementation options. So WGI uses the term Standard / Specification for type 1 standards Type 2 - Implementation Standard - Implementation option standards describe many specific implementation options depending on domain and technologies used. So WGI is using the term Profile as defined by WG methods Type 3 - To achieve interoperability – it is often required to limit (profile) the implementation options provided by Type 2 standards. WGI is using the term Implementation profile for those type 3 standards	SGCG - WG SGIS
System	Set of interrelated objects considered in a defined context as a whole and separated from their environment performing tasks under behave of a service. a typical industry arrangement of components and systems, based on a single architecture, serving a specific set of use cases.	Adapted from IEC 81346/1 FSS definition
Subsystem	Part of the total system which contributes to a certain functionality.	Adapted from IEC 62425
SGIMM	The Smart Grid Inter-Operability Maturity Model applied together with the GWAC Stack IOP Layers.	GridWise Architecture Council
Technical Requirements	Specify the technical characteristics of single component/object and/or single (sub) systems and/or specify the way systems exchange information and interact (control or are controlled).	As used by WGI
Test specifications	Document describing the requirements of testing process and specific tests to be performed.	As used by WGI

TICS	Technical Issues Conformance Statement. Statement with device specific information regarding the implemented technical issues detected after publication of the standard. The TICS is not subject to standardization.	IEC 61850-10
Use Case	Description of the interaction between one or more actors, represented as a sequence of simple steps. NOTE 1 Actors are entities that exist outside the system ('black box') under study, and which take part in a sequence of activities in a dialogue with the system to achieve a specific goal. Actors may be end users, other systems, or hardware devices. NOTE 2 Each Use Case is a complete series of events, described from the point of view of the actor. Class specification of a sequence of actions, including variants, that a system (or other entity) can perform, interacting with actors of the system [SOURCE: IEC 62559, ed.1 2008-01 - IEC 62390, ed 1.0:2005-01] Alternative: description of the possible sequences of interactions between the system under discussion and its external actors, related to a particular goal Note: A use case is the description of one or several functions performed by the respective actors.	TR 50572 (7) SGCG matrix on terms [SOURCE: A. Cockburn "Writing effective use cases"]
Use Case Actor	Entity involved in a Use Case, e.g. organizations (Consumer, Distribution Network Operator, Read Data Recipient, etc.) and/or systems (HES, CIS, DC, Meter, Gateway, etc).	TR 50572
Use Case Diagram	Type of behavioural diagram generated using the Unified Modelling Language (UML) and defined by and created from a Use-case analysis. NOTE 1 The purpose of a Use Case Diagram is to present a graphical overview of the functionality provided by a system in terms of actors, their goals (represented as use cases), and any dependencies between those use cases. NOTE 2 The main function of a use case diagram is to demonstrate what system functions are performed for which actor. Roles of the actors in the system can thus be depicted.	TR 50572

WGI Scope	Sets the boundaries of the work for Inter-Operability Working Group.	As used by WGI
WGI Targets	What WGI wants to obtain/deliverables related to time schedule.	As used by WGI

ANNEX B.Knowledge insourcing

Knowledge has been sourced into the SGO project from projects and organisations working with other smart grid communication between power systems and DERs, including standards and open systems.

Several Danish based smart grid innovation and preparation projects, like e.g. FlexPower (ForskEl), EDISON (ForskEl), EcoGridDK (ForskEl), EcoGridEU (EU PF7) and iPower (SPIR) has contributed knowledge through their disseminations occasionally supplemented by interviews.

Existence of Danish experimental research facilities at DTI and the DTU CEE PowerLabDK, a collection of Smart Grid laboratory facilities, ranging from single unit laboratories, over small-scale power system laboratory (SYSLAB) to full-scale live laboratory (Bornholm), and including the Nordic Electric Vehicle Interoperability Centre (NEVIC) is a national asset of international class.

The range of Smart Grid ready equipment in Denmark have been very slim indeed, but the area of Smart Grid control has international focus and several proposals for new standards has been introduced. Here follows a few that the SGO project has found relevant to look further into, to assess relevance in a Danish context.

Smart Grid Concepts in EU vs US

First a short analysis of Smart Grid Concepts in EU vs US. USA is struggling with slightly different challenges than EU and may therefore be looking for different solutions more suitable for the grid structures.

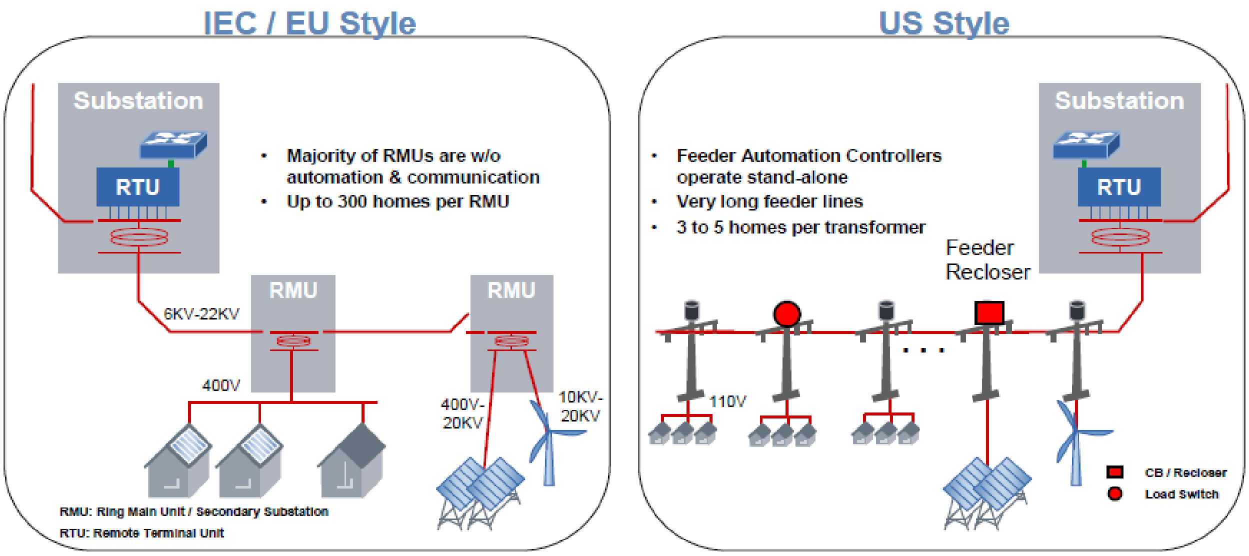


Figure 35: Grid topology EU vs US style Networks

In US some of the major challenges are:

- Blackout/Brownout
- Long transmission lines
- Large generation plants and large loads/consumers
- Old, overloaded network infrastructure (which can be more evenly loaded with a Smart Grid)

- Applications for Distribution Automation implemented today comprise
    - Volt/VAR control,
    - Voltage regulation through tab changers or
    - Remote control of transformer stations mainly in US Style environment.

Those applications have tougher requirements on latency and availability but the amount of data to be transported is rather limited.

The solution is normally shedding load based on the balance using Open Automated Demand Response (OpenADR) communication.

US requirements for Applications for Distribution Automation implemented today comprise Volt/VAR control, Voltage regulation through tab changers or remote control of transformer stations mainly in US Style environment. Those applications have tougher requirements on latency and availability but the amount of data to be transported is rather limited.

In EU some of the major challenges are:

- Large share of renewable energy.
- Fluctuating generation from renewable sources
- High and still increasing proportion of renewable energy sources (which do not continuously generate power).
- The vast majority of Smart Grid Applications implemented in EU are related to
    - Remote Metering reading
    - Transferring Meter readings to the Meter Data Management System,
    - Remote Connect/ Disconnect installations at the Meter
    - Outage Detection at the Meter.
- From a communication network perspective the mentioned applications do not place very stringent latency or high throughput requirements against the network but a significant amount of data needs to be transported that can be a challenge for certain traditional communication technologies.

The solution is shedding load or generation – even renewable generation - based on actual price determined from stability and at the energy exchange.

Communication at grid level is IEC 61850-7-420

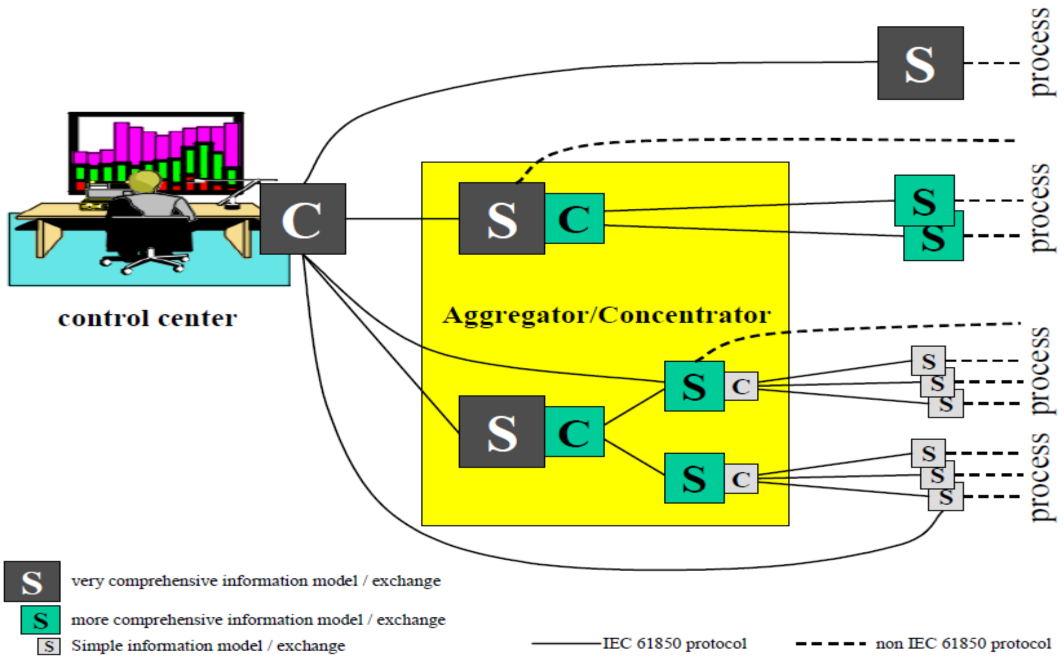


Figure 36: Using IEC 61850 enable faster dispatch of Demands and full acknowledgement of the Reaction from the process.

EU requirements for the vast majority of Smart Grid Applications implemented today are related to transferring Metering Data and backhauling them to the Meter Data Management System, Remote Connect/ Disconnect or Outage Detection. From a communication network perspective those applications do not place very stringent latency or high throughput requirements against the network but a significant amount of data needs to be transported that might be a challenge for certain communication technologies.

OpenADR vs IEC61850-7-420 (OpenADR differences from IEC 61850-7-420)

- One-way communication (transmitting Demand and hoping for Reaction)
- National Standard
- Small amounts of data for fast reaction time on the network (latency)
- Only master slave communication and only Demand from the grid and Reaction from the process.
- Starts logic sequences at the consumer
- Not-"Open standard" – must be a member of OpenADR Alliance to influence the norms
- Data model based on XML, but variable names are not defined systematically like in IEC 61850- 7-420

OpenADR 2.0

An American commonly used Smart Grid protocol OpenADR 2.0 Profile Specification was analysed in some depth.

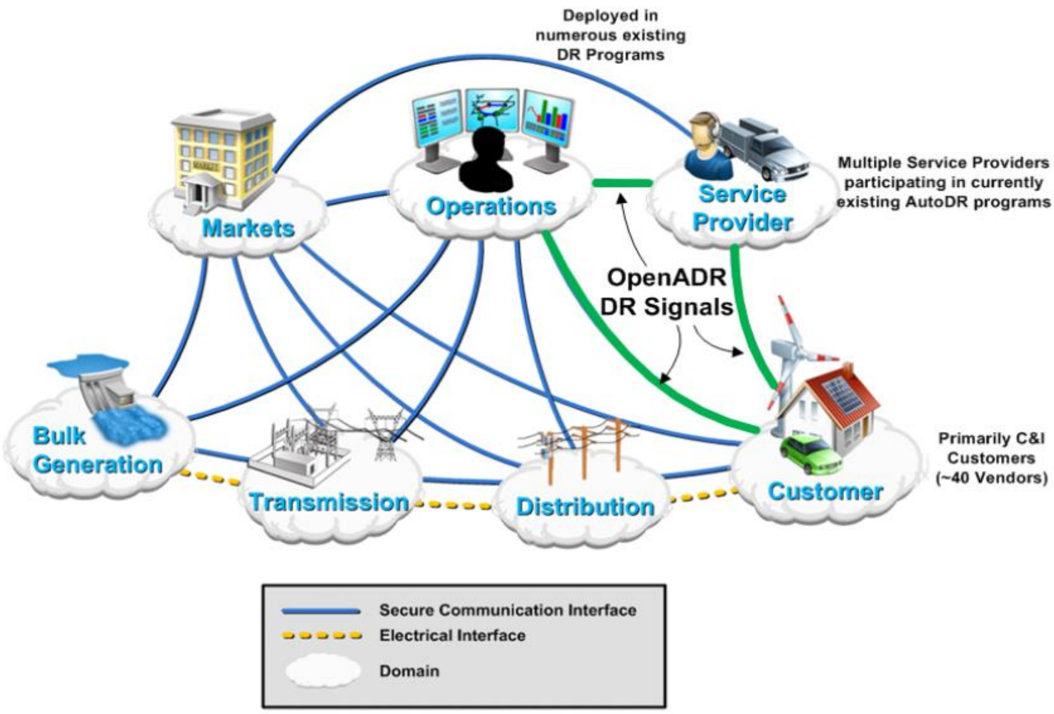


Figure 37: OpenADR Smart Grid Domain, source Berkeley Lab

The OpenADR 2.0 profile specification is a flexible data model to facilitate common information exchange between electricity service providers, aggregators, and end users. An open specification of implementing a two-way signalling systems, providing specifications for the servers (Virtual Top Nodes or VTNs) and the automated clients (Virtual End Nodes, or VENs), is included in the OpenADR specifications.

OpenADR 2.0 covers the data models including specific DR information, which are transmitted between VTN and VEN (or VTN/VEN pairs). Currently OpenADR 2.0 supports the following functionality defined by OASIS EI Version 1.0 standard:

- Registration
- Event
- Quote or Dynamic Prices
- Reporting/Feedback and Override.

By using the above functions/services it is possible to specify the information that is relevant to DR, pricing, and DER communication requirements.

OpenADR uses an application-level data model, which is independent of transport mechanisms, enabling the use of both HTTP and Extensible Messaging and Presence Protocol (XMPP) as Transport Layer.

OpenADR 2.0 specifies the necessary level of security that is essential to meet the U.S. Cyber Security requirements for such purposes as data confidentiality, integrity, authentication and message-level security. Such security requirements are essential for nonrepudiation and to mitigate any resulting Cyber Security risks. Nonrepudiation is a method of guaranteeing message transmission between parties via digital signature and/or encryption.

OpenADR 2.0 offers a clear set of mandatory and optional attributes, to be able to meet the requirements of today as well as the future market needs, for interoperability requirements for Smart Grid standards.

Although, the OpenADR 2.0 is widely used, it is based on a Demand/Respond philosophy, which requires the following control of the electricity system. OpenADR means Open Automated Demand/Respond, hence the unit located at customer/user side is a fully automated unit, which responds to the price signal, transmitted by the DRMS (Demand Respond Management System). The Demand/Respond philosophy is focusing on the load sheading/shifting of energy, which is one of the biggest challenges meeting the US market, hence the development of the OpenADR 2.0 is more associated with the US markets than the Danish. The US market needs Demand/Response due to mainly lack of power where the Danish market needs to solve the transition of the grid to be able to accommodate more Renewable Energy (RE) in the Grid, main Wind Power, more RE means more fluctuating energy production.

Based on the above analysis it was decided in the SGO project, not to use the OpenADR as the Smart Grid control platform but to investigate further options.

VHPready

In parallel with the SGO project period the Industry Alliance VHPready e.V. in Germany became operational in May 2014. The alliance, which is issuing the VHPready certification, is committed to the realization of the energy transition by creating and using an open industry standardized network of decentralized energy systems. Combining the production of thermal (Heat) and electrical energy (Power), based on the production of renewable energy e.g. wind power, it is possible to contribute to integration of renewable energies in the energy markets.

The Industry forum VHPready is currently working as cross-sector and manufacturer-independent alliance to implement VHPready 4.0, which will facilitate the opportunity for participation in the energy balancing market for the following system types:

- Battery storage systems
- Combined heat and power units (CHP)
- Process heaters and Heat pumps

In order to facilitate implementation of VHPready 4.0, the Industry Alliance VHPready e.V. established working groups, in which the following topics are currently being addressed in detail:

- WG1: Advancement of VHPready
- WG2: Certification/prequalification
- WG3: Marketing and internationalization
- WG4: Cooperation and standardization

A VHPready 4.0 White Paper, from WG1 are currently available at the homepage of Alliance VHPready e.V. (https://www.vhpready.com/2015/04/07/vhpready-4-0-white-paper/)

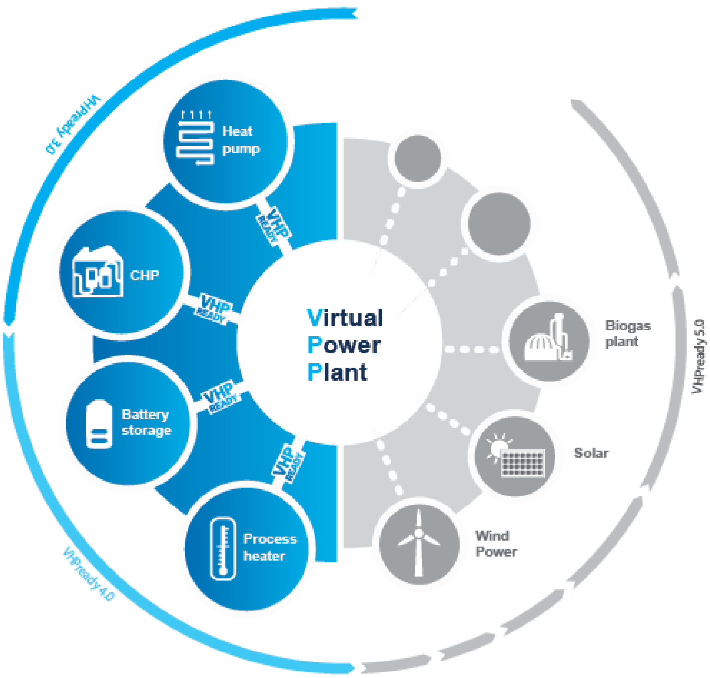


Figure 38: VHPready implementation of system types participation in the energy balancing market

VHPready 3.0

Currently, Technical Requirements Specifications Version 3.0, are the only available specifications these have been specified by Vattenfall Europe Wärme AG, however several different partners were part of the specifications, among others, Fraunhofer FOKUS and Stiebel Eltron.

Storing of energy in the form of heat is one of many ways to solve the problem of integrating renewable energies into the power system successfully. Using Virtual Power Plant (VPP) technology, is another modern and cost-efficiently way of doing so.
The VPP Virtual Power Plant combines BCHPs (Block-type Combined Heat and Power plants) and HP (Heat Pumps) to create a flexible system with a centralised control. It controls generation of power during heat generation using the connected BCHP plants and using the excess wind and solar electricity in the HP. For example, if there is surplus electrical energy in the grid, the control room activates Heat Pumps to produce heat and store this heat in storage facilities for future consumption.
If the amount of wind-generated electricity in the system is not enough, the BCHP plants will produce power, hereby avoiding conventional power generation. The co-generated heat is stored for future consumption.

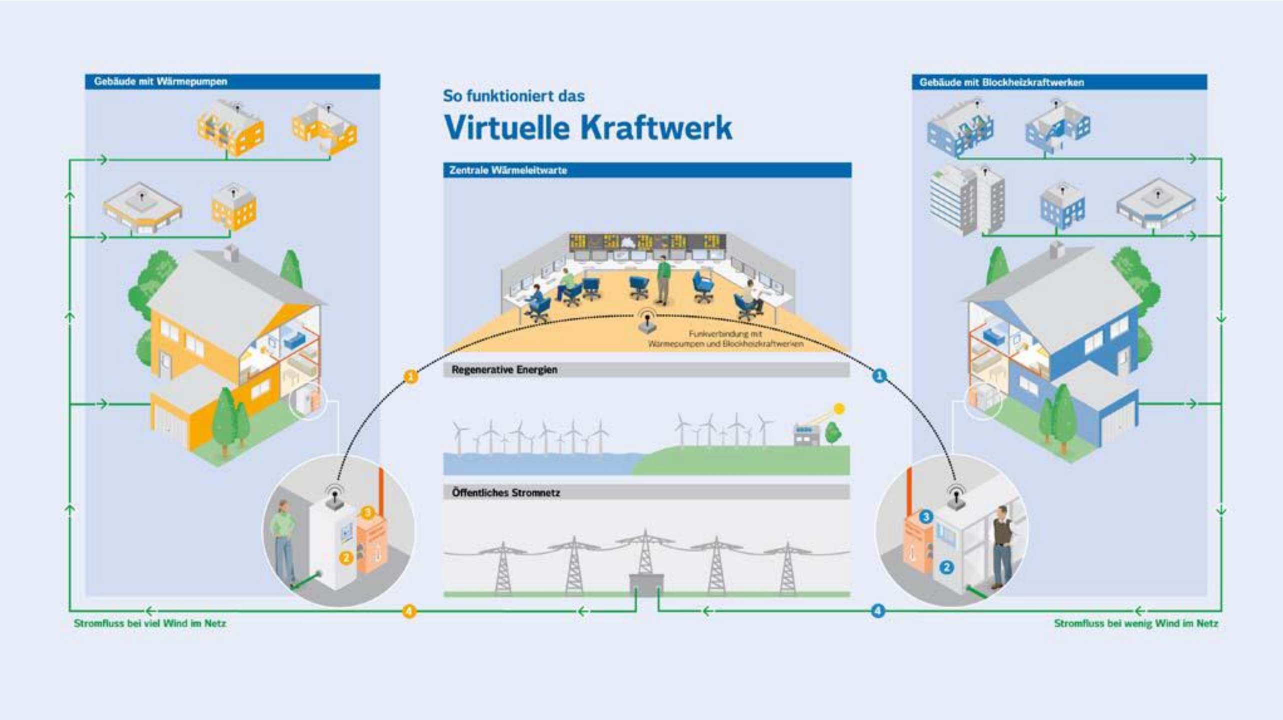


Figure 39: VPP concept for VHPready, source Vattenfall Europe Wärme AG

Plants and systems which meet the demands and technical requirements of the VHPready specification can be connected to the VPP, the technical requirements for the plant, data communication and heating system are defined as a whole in the VHPready specifications. The main focus is on the following objectives:

- Continuous reliability of local heat supply
- Optimum use of thermal storage capacity in the system
- Scheduled and spontaneous plant control
- Safe and reliable data communication.

To ensure safe and reliable communication the tele control protocols (IEC 60870-5-104, IEC 61850-7-420), and number of security features (SSL/TLS, PKI) have been implemented.

For a secure and reliable operation of the VPP system behaviour and time limits (for example, the reaction time in the event of a change in set point) has been defined in details. Moreover, in case the standardised protocol IEC 61850-7-420 is chosen a well-defined switching operation are specified, by VHPready 3.0.

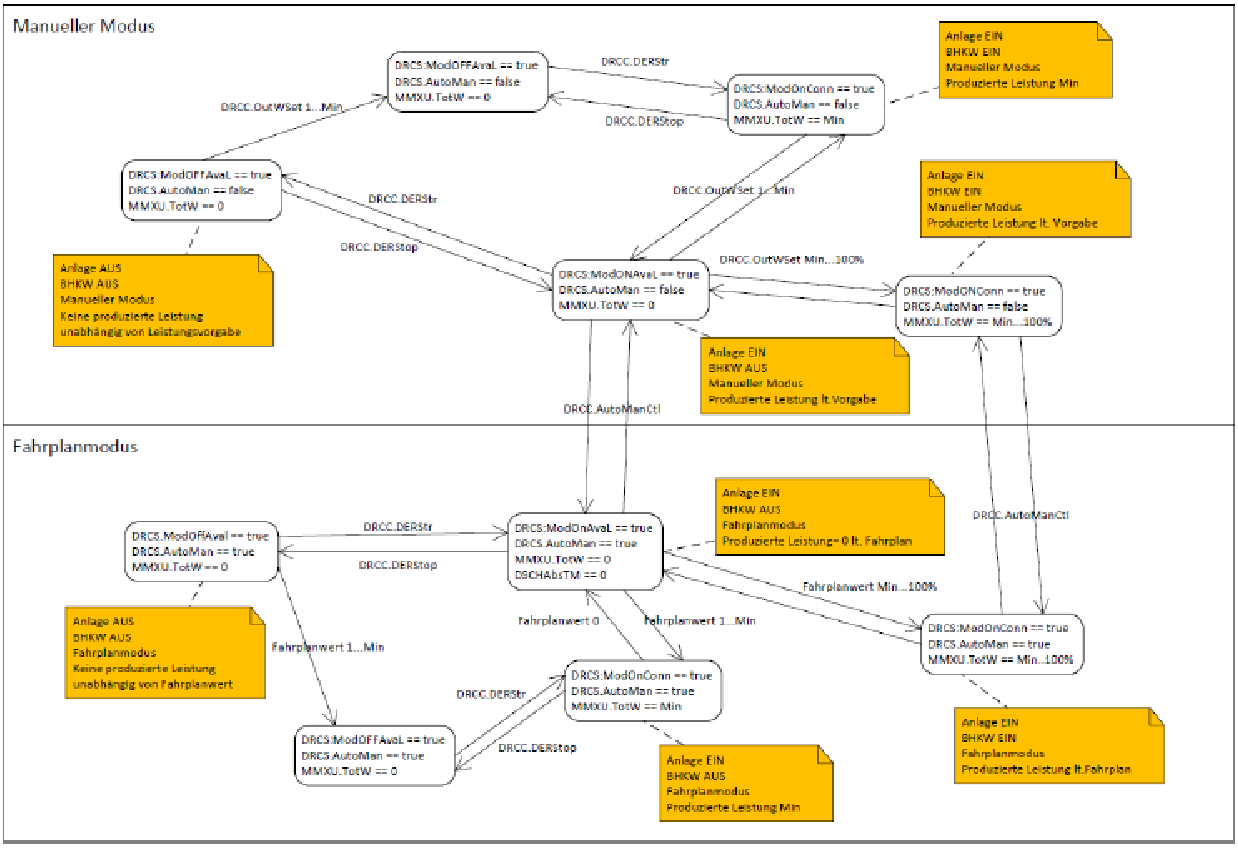


Figure 40: Status chart priorities during switching operations, defined by VHPready 3.0

Although the ideas behind the VHPready label is promising, when the SGO project started to investigate the VHPready label, only few companies present. Only one Heat Pump manufacturer was participating and the remaining companies where located in Germany. In addition, the Heat Pump industry was using the German SG-Ready label, which at that time contained more than 400 various Heat Pump on the list of SG-Ready certified Heat Pumps.

In view of this, it was decided to follow the development of the VHPready label during the remaining part of the SGO project.

VHPready is an interesting initiative. It is a cross-sector and manufacturer-independent alliance. It works with standardised communication, such as IEC 61850 and IEC 60870. VHPready combines CHPs, Heat Pumps, Battery storage systems, and process heaters, which gives the possibilities for Smart Grid operation and energy storage, both as thermal and electrical storage.

SG Ready

SG Ready label til varmepumper SMART GRID OPEN

På det 10. Forum Wärmepumpe i Berlin 9. November 2012 præsenterede Bundesverband Wärmepumpe e.V. „SG Ready"-certificering af varmepumper i Tyskland.

Forbrugeren kan i fremtiden kende en Smart Grid egnet varmepumpe på SG Ready-logo mærket

17 leverandører står bag og vil benytte mærket.

Pressebilleder fra BWP:
http://www.waermepumpe.de/presse/pressemitteilungen/details/details/waermepumpe-goes-smart/

De første modeller med SG Ready label fremvist på ISH i marts 2013.

878 varmepumper er optaget på listen*) som SG Ready per 17. aug. 2015
951 varmepumper er optaget på listen*) som SG Ready per 23. jun. 2015
*) BWP Modell-Liste "SG Ready"-Label für Smart-Grid-fähige Wärmepumpen (Stand: 17.08.2015)

SG Ready 2-bit protokol SMART GRID OPEN

For at være SG Ready skal varmepumpen ifølge Bundesverband Wärmepumpe (BWP) kunne styres af to styresignaler, til at arbejde i fire forskellige tilstande

- **4 forskellige SG Ready modes bestemmes af 2 styresignaler**
  Normal drift og 3 unormale SG Ready styrede tilstande:
  Stop i op til 2 timer, Øget drift, Kør maximum

- **Betriebszustand 1** (1 Schaltzustand, bei Klemmenlösung: 1:0):
  Dieser Betriebszustand ist abwärtskompatibel zur häufig zu festen Uhrzeiten geschalteten **EVU-Sperre** und umfasst maximal **2 Stunden „harte" Sperrzeit**.
  *"**Must Stop**". Denne indstilling **slukker** for varmepumpen, bagudkompatibel til tidsbestemt EVU signal anvendt af tyske **energileverandører**, og inkluderer højest **to timers "hård" slukning.***
- **Betriebszustand 2** (1 Schaltzustand, bei Klemmenlösungen: 0:0):
  In dieser Schaltung läuft die Wärmepumpe im energieffizienten **Normalbetrieb** mit anteiliger Wärmespeicher-Füllung für die maximal zweistündige EVU-Sperre.
  *"**Normal drift**". I denne indstilling kører varmepumpen efter energieffektive **normale** grænser, med varmefylde-rata for højest 2 timers off.*

Kilde: Bundesverband Wärmepumpe (BWP) *med SGO kommentarer*:

SG Ready 2-bit protokol

SMART GRID OPEN

- **Betriebszustand 3** (1 Schaltzustand, bei Klemmenlösung 0:1)
  In diesem Betriebszustand läuft die Wärmepumpe innerhalb des Reglers im **verstärkten** Betrieb für Raumheizung und Warmwasserbereitung.
- Es handelt sich dabei **nicht** um einen **definitiven Anlaufbefehl**, sondern um eine Einschaltempfehlung entsprechend der heutigen Anhebung.

*"High". Med denne indstilling kører varmepumpen indenfor gængse regler med **forøget** opvarmning af rum og varmandsbeholder.*

*Dette **forcerer IKKE** varmepumpen til at køre, men øger opvarmning i henhold til en effekt-anbefaling.*

Kilde: Bundesverband Wärmepumpe (BWP) *med SGO kommentarer:*

SG Ready 2-bit protokol

SMART GRID OPEN

- **Betriebszustand 4** (1 Schaltzustand, bei Klemmenlösung 1:1)
  Hierbei handelt es sich um einen **definitiven Anlaufbefehl**, insofern dieser im Rahmen der Regeleinstellungen **möglich** ist.
  Für diesen Betriebszustand müssen für verschiedene Tarif- und Nutzungsmodelle verschiedene Regelungsmodelle am Regler einstellbar sein:
  Variante 1: Die Wärmepumpe (Verdichter) wird **aktiv** eingeschaltet.
  Variante 2: Die Wärmepumpe (Verdichter und **elektrische Zusatzheizungen**) wird aktiv eingeschaltet, optional: **höhere Temperatur** in den Wärmespeichern

*"**Must Max**". Her omhandles en indstilling, der **forcerer** varmepumpen til at køre, så længe dette er **muligt** indenfor reglerne. For denne indstilling skal der være forskellige tarif- og anvendelsesmodeller til forskellige reguleringsmodeller for regulatoren.:*
*Version 1: Varmepumpen (kompressoren) bliver tændt **aktivt***
*Version 2: Varmepumpen (kompressoren og **elvarmepatron**) bliver aktivt tændt*
*Valgfrit: **højere temperatur** i varmelageret.*

Kilde: Bundesverband Wärmepumpe (BWP) *med SGO kommentarer:*

SG Ready 2-bit protokol

SMART GRID OPEN

SGO forståelse af hhv

Kommando

SG-Mode

Forced / normal	Bit 0 \ Bit 1	Low / High 0	Low / High 1
	0	Normal Operation	Run Higher
	1	Must Stop	Must Max

Forventet reaktion

SG-Mode-reaktion

Tvang / Normal	Bit 0 \ Bit 1	Lav / Øget 0	Lav / Øget 1
	0	Normal Operation	VP optager midlertidigt (<2 timer) mere elektrisk effekt end i Normal Operation. Komfort grænser har prioritet **Formål:** På grund af priser anbefales oplagring af varme i rum og akkumuleringstanke.
	1	Varmepumpen stoppes midlertidigt (<2 timer). Frostsikring eller minimum komfort grænse har prioritet **Formål:** Problemer i elnettet (f.eks. manglende produktion, lokal underspænding) eller deltagelse i aggregeret salg (VPP) kræver varmepumpen stoppet.	VP optager midlertidigt (<2 timer) mere elektrisk effekt end i Normal Operation. Høje sikkerhedsgrænser har prioritet **Formål:** På grund af problemer med overspænding i elnettet lokalt kræves højeste last

SG Ready 2-bit protokol

SMART GRID OPEN

SGO forståelse af kommando

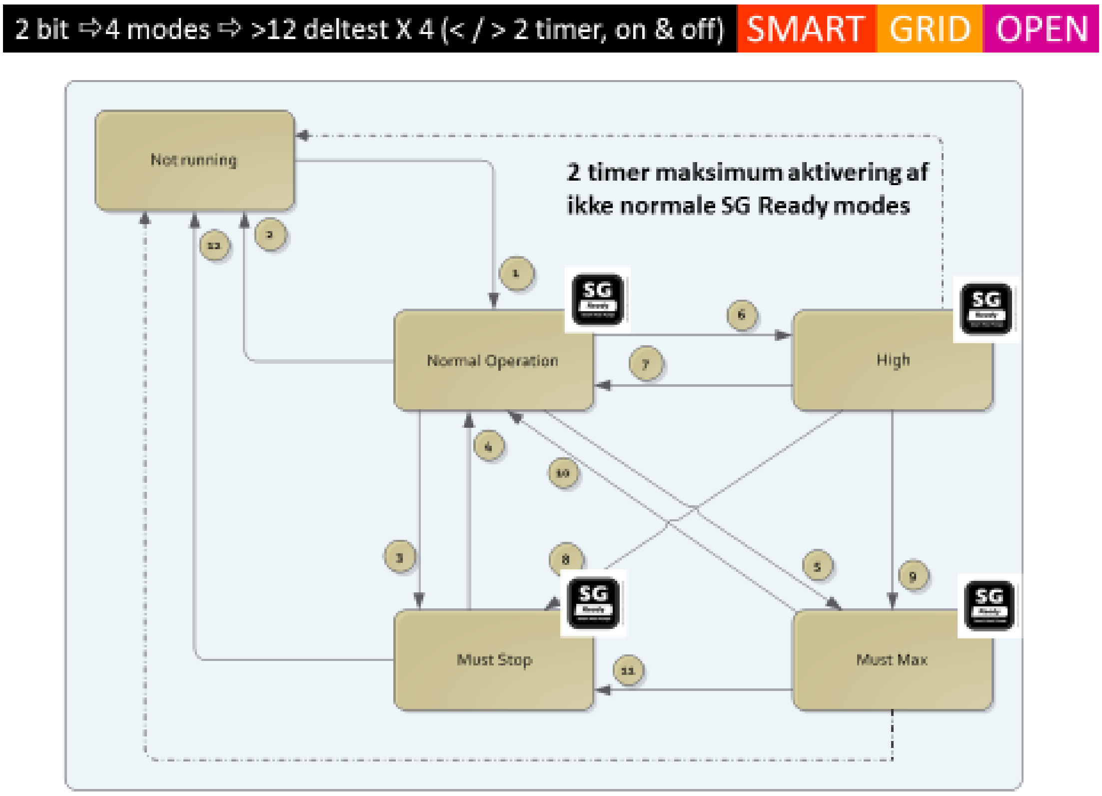
SG-Mode

Forced / normal	Bit 0 \ Bit 1	Low / High 0	Low / High 1
	0	Normal Operation	Run Higher
	1	Must Stop	Must Max

Forslag til forståelse af forventet reaktion

SG-Mode-reaktion?

Tvang / Normal	Bit 0 \ Bit 1	Lav / Øget 0	Lav / Øget 1
	0	Normal Drift	Anbefalet øgning af setpunkter med f.eks. 1-3°
	1	Setpunkter ændres midlertidigt til frostsikring eller minimum komfort grænse	Setpunkter øges midlertidigt til maximum indenfor sikkerhedsgrænser



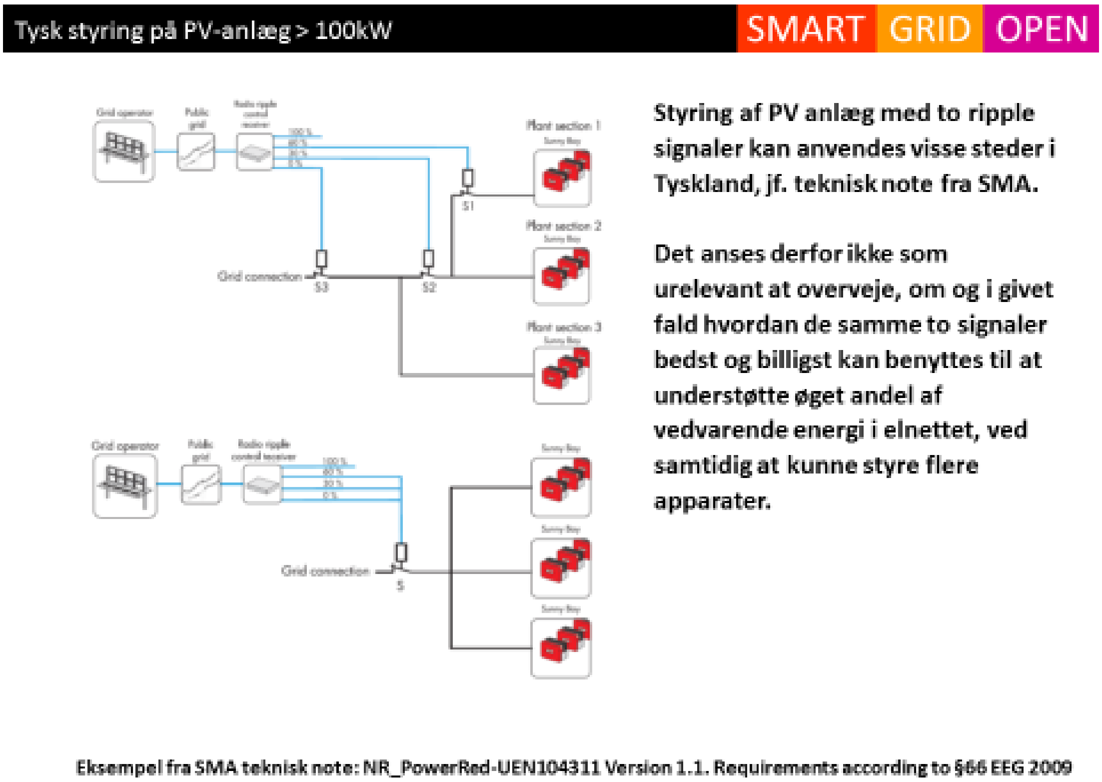


Figure 41 Example on German grid broadcast of of 4 mode Ripple signals to derate PV generation

ANNEX C. Actor and role definitions for E-mobility (example)

Existing conformance test activities

Interoperability

A Working Group Interoperability (WGI) has been working under the Smart Grid Coordination Group (SG-CG) established by the European Standardization Organizations CEN, CENELEC and ETSI. The tasks for the WGI laid down in the European Commission's Smart Grid Mandate M/490 were meant for experts who should be looking at e.g. methods, maps and profiles.

The first task: "A system interoperability method". A methodology to achieve system interoperability. In this methodology conformance testing, profiles, use cases etc. are introduced. The methodology describes how these aspects will contribute towards interoperability. The methodology has a focus on smart grids (incl. smart metering) and is generic as it can be applicable for all kinds of smart grid standards.

Interoperability can be achieved on different levels of the SGAM (Smart Grid Architecture Model M/490). The methodology describes how to achieve interoperability on all levels. It is important to note that interoperability can also mean interoperability on SGAM communication level only. It is up to users to use the methodology to achieve the desired level of interoperability applicable for them.

The second task: "Conformance testing map" a more detailed exploration of the item 'Conformance testing' in the Interoperability methodology.

The third task: "Assessment of needed profiles' is a more detailed exploration of the item 'Profiles'. An inventory of profiles that is already available based on the first set of standards, and a gap analyses.

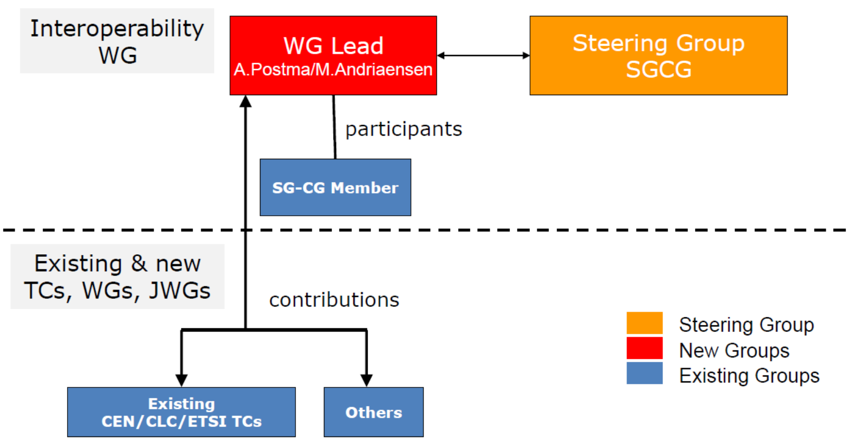


Figure 42: Organization diagram from M/490 SG-CG

NEMA – Smart Grid Interoperability and Conformance

SG-IC: A Smart Grid Standard for Interoperability and Conformance

ANSI/NEMA SG-IC 1 *Smart Grid Interoperable & Conformant Testing and Certification Scheme Operator Guidelines* addresses a challenge defined by the National Institute of Standards and Technology (NIST) in implementing Smart Grid. Phase three of the NIST roadmap for Smart Grid interoperability standards is to "develop a plan for testing and certification to ensure that Smart Grid equipment and systems conform to standards for security and interoperability." SG-IC accomplishes that.

These guidelines bring consistency and portability to the interoperability testing process in much the same way the industry has performed safety testing for the last century. To maintain uniformity, contributors to the scheme include internationally-accredited testing bodies that are also nationally recognized testing laboratories (NRTLs). The NRTL Program is part of OSHA's Directorate of Technical Support and Emergency Management.

SG-IC describes the roles and responsibilities for each of the four main participants in the testing scheme. Together, they create the necessary levels of checks and balances for the overall process:

Interoperability Testing and Certification Authority (ITCA)

ITCA is the scheme operator. This person or company owns the responsibility for the testing process. ITCA will:

- identify the standard that forms the basis for the testing;
- prepare the test specification that describes the type and purpose of the testing that will be conducted; and
- ensure there is industry consensus around the test specification and how it fulfills the needs of Smart Grid.

Accreditation Body (AB)

As an agent of ITCA, AB validates credentials and qualifications of each person involved in the testing process.

Testing Lab (TL)

The TL performs hands-on testing of electrical products. It may also perform market surveillance after the test to verify that manufacturers continue to conform to the requirements of the test specification.

Certifying Body (CB)

As an independent body that examines the test results from the TL, CB oversees adherence to the test specification.

The SG-IC testing and certification scheme operator guidelines represents a major step in delivering on the promise of Smart Grid. The standard is available from NEMA at *www.NEMA.org/SG-IC1*.

NEMA

The Association of Electrical and Medical Imaging Equipment Manufacturers
1300 North 17th Street, Suite 900, Rosslyn, Virginia 22209 • www.nema.org

Figure 43 NEMA SG-IC

http://www.nema.org/News/Pages/NEMA-Smart-Grid-Interoperability-Standard-Receives-ANSI-Approval.aspx

In 2013, the National Electrical Manufacturer's Association (NEMA) received approval from the American National Standards Institute (ANSI) for ANSI/NEMA SG-IC 1-2013 Smart Grid Interoperable and Conformant Testing and Certification Scheme Operator Guidelines.

NEMA has led an effort to develop SG-IC 1, an American standard that describes the roles and responsibilities for each of the four main participants in the testing scheme for interoperability and security among Smart Grid products. The SG-IC 1 guideline brings uniformity and portability to the process, as well as creating the necessary levels of checks and balances for the overall testing process. Contributors include internationally accredited testing bodies that are also nationally recognized testing laboratories.

Stakeholders in Smart Grid can validate the interoperability and security of individual grid elements on a consistent, industry-wide basis. The implementation of the guideline promotes testing and certification, governance, harmonization, and backward compatibility.

NEMA President and CEO claim, "The goal of the utilities is to ensure that products are interoperable the day they are installed."

NEMA is an association of electrical equipment and medical imaging manufacturers with headquarter in Virginia, USA.

KEMA – IEC 61850 conformance testing and certification

In Europe KEMA is offering Smart Grid testing in accordance with IEC 61850-10 using their own UniCA 61850 Conformance Test-set.

The UniCA set sends/receives analyses and stores IEC 61850-8-1 communication messages and checks SCL files. UniCA is a tool for protocol development, system and conformance testing, trouble shooting, factory and site acceptance testing and is easy to use. The test set consists of the UniCA 61850 protocol analyser, the UniCAsim 61850 Client conformance test simulator, the UniCAsim GOOSE conformance test simulator and the UniCA SCL Checker.

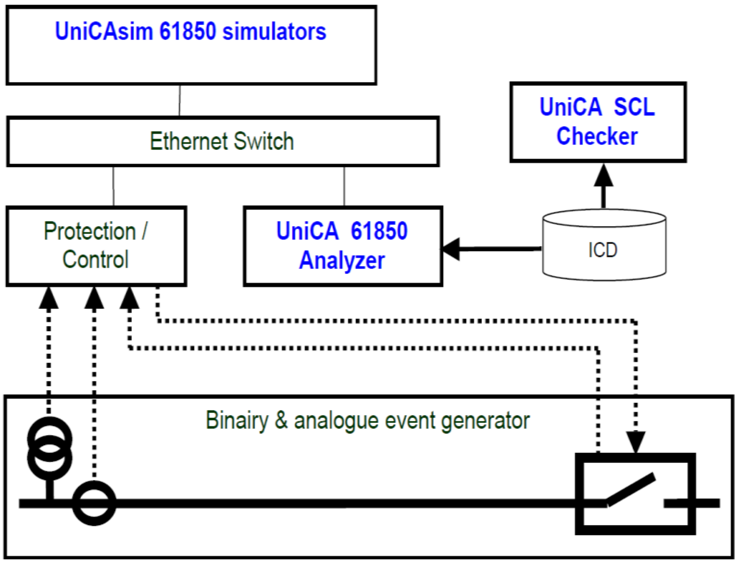


Figure 44 KEMA UniCA 61850 test equipment illustration

The figure shows the typical conformance test configuration. The system is designed for grid components at substation level. KEMA uses the same test set to perform its own conformance tests, but is also selling the solutions to OEMs, where e.g. ABB has published CoCs on their own substation equipment performed in-house using the UniCA 61850 test equipment.

Two different but similar substation equipment tested positive for conformance to the same specification may not be interchangeable as experienced by the Danish TSO Energinet.dk.

Test steps in a conformance test

1. Preparation.
   1.1. Applicable requirements identified
   1.2. Needed signals and power from grid side
   1.3. Needed interface on equipment side
   1.4. Risk assessment of set up – with mitigation plan and unexpected event handling strategies.
2. Setting up equipment
3. Commissioning
4. Testing
5. Decommissioning
6. Reporting

Role Model and Actor definitions

E-Mobility role model (example)

A single role model for all Smart Grid domains is not available, but IEC TC8 is working on a UML-based role model for different domains e.g. E-mobility domain. This role model is not public available at the moment, but a preliminary role model developed by WG Smart Charging under CENELEC, will give a good illustration of what a role model is:

CENELEC EM-CG role model for E-mobility.

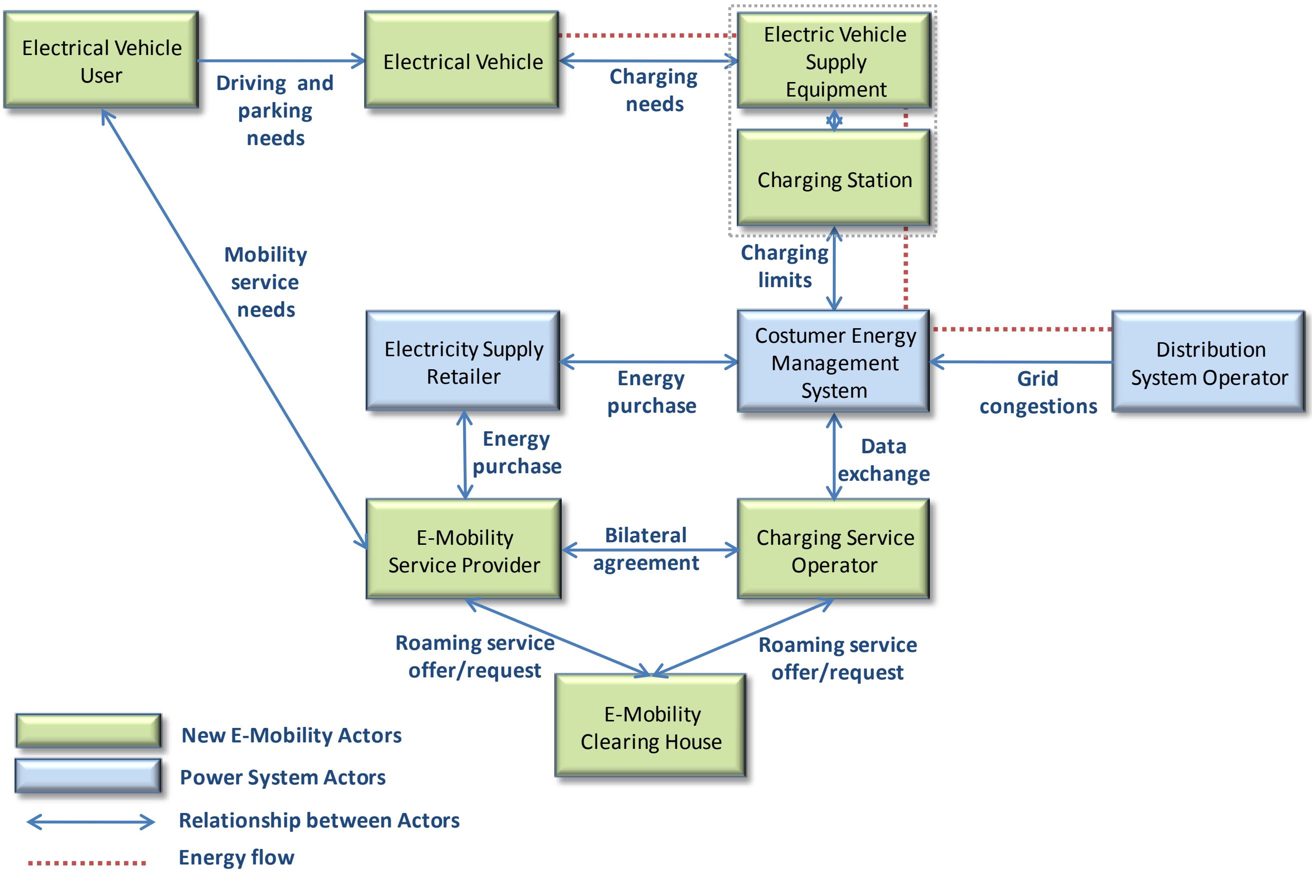


Figure 45: CENELEC WG Smart Charging (EM-WG) role model for E-Mobility. Customer Energy Management System can have an aggregating function.

Actor and role definitions for E-mobility (example)

Actor name	Definition of actor	Role of actor
Electric Vehicle User (EVU)	Person or legal entity using the vehicle and providing information about driving needs and consequently influences charging patterns. NOTE: Driving needs, such as range and time of availability are necessary to achieve the most appropriate charging scenario. [ISO/IEC 15118-1]	**Driving from A to B** The basic role of the user is to drive from A to B and give information about the trip (e.g. driving distance, route, estimated time of arrival) to the E-Mobility Service Provider **Parking where needed** Driving urban areas with high traffic density - parking with the possibility to charge, can be very important for the EV user. Information about location and availability of the charging supply equipment is an important part of 'Smart Charging' and therefore it is beneficial to spread this information to the EV user. **Charging when needed and optimal** The need for charging depends on factors like: User needs, availability of Charging Supply Equipment, price of energy and grid constrains.

Actor name	Definition of actor	Role of actor
		'Smart Charging' is the definition of a concept where all these issues are optimized automatically. The EV user can sign a contract with the E-Mobility Service Provider, which can provide the best solution for the user. Depending on the solution (e.g. charging instantly, according to price/green energy or grid friendly) the needed information has to be exchanged between the EV user and the E-Mobility Service Provider. *NOTE: There shall be a relationship/association between the EVU and the E-mobility Customer (EC). However, the exact nature of this relationship/association depends on the underlying business models and use cases*
Electrical Vehicle (EV)	Any vehicle propelled by an electric motor drawing current from a rechargeable storage battery or from other portable energy storage devices (rechargeable, using energy from a source off the vehicle such as a residential or public electric service), which is manufactured primarily for use on public streets, roads or highways. [ISO 8713, ISO/IEC 61851 and 15118-1]	**Driving the user from A to B** The main role for the EV will always be to drive the user from A to B. If for some reason this cannot be fulfilled (e.g. need for emergency cooling or heating of battery, empty battery, emergency repairs) the EV might provide this information to the user. **Charging according to the EV, user and grid needs** The energy needed to fulfil a specific driving demand, should always be available. First step is always to know the driving needs and constrains and next step for the EV to get the required energy. The EV will need information about grid congestions and market demands (Local Limit Profile). Locally measurable grid parameters such as frequency and voltage can serve as an indicator for the grid's local and overall system state. The E-Mobility Service Provider will need information about energy needs and user requirements (Target Settings) to fulfil the needs of 'Smart Charging'.
Electric Vehicle Supply Equipment (EVSE)	Conductors, including the phase, neutral and protective earth conductors, the EV couplers, attachment plugs, and all other accessories, devices, power outlets or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the EV and allowing communication between them if required [Ref: IEC61851-1]	**Charging the EV safely** The main role of the EVSE is to deliver power to the EV Independent of infrastructure used, user, smart grid or market needs, the charging should always be safe and secure for the user and equipment. The Charging Supply Equipment should signal to the E-Mobility Infrastructure Operator if something is wrong.
Charging Station (CS)	All equipment for delivering current to EVs, installed in an enclosure and with special control functions. [ISO/IEC 61851-1]	**Charging the EV efficiently and effectively** The Charging Station should always try to adjust the charging behaviours in a smart way to stabilize the grids and optimize the charging operations. The CS should

Actor name	Definition of actor	Role of actor
	One or several Electric Vehicle Supply Equipment (EVSE according ISO/IEC 61851) are enclosed within a charging station.	always charge the EV as requested within the given limitations or constraints. When an EV has charged at a public charging supply, the information about amount of energy, tariff and operators will be stored, validated and send to the operator who needs the information.
Costumer Energy Management System (CEMS)	The CEM is a logical function optimizing energy consumption and or production based on signals received from the grid, consumer's settings and contracts, and devices minimum performance standards. The Customer Energy Manager collects messages sent to and received from connected devices; especially the in-home/building sector has to be mentioned. It can handle general or dedicated load and generation management commands and then forwards these to the connected devices. It provides vice versa information towards the "grid / market". Note that multiple loads/generation resources can be combined in the CEM to be mutually controlled. When the CEM is integrated with communication functionalities it is called a Customer Energy Management System or CEMS. [M/490]	**Saving energy cost for the costumer** It could also have the role of monitoring and managing the information exchange between the EVSE/CS and the Operators, like DSO, CSO, ESR.
Charging Service Operator (CSO)	A party offering charging service for electric vehicles. May be investor (owner) and operator of CS and of the private electricity networks to which they are connected. If these roles are organised separately, the CSO is responsible for the service management with the EVSE.	**Operate and maintain the data communication** and information exchange between the EV, user and supply equipment on the one side – and the E-mobility Service Providers on the other side, directly or through the EMCH. The CSO operates its charging stations through a Charging Service Management System or Costumer Energy Management System (CEMS)**.**
E-mobility Service Provider (EMSP)	Provider of services in relation with the use of EV. For example: EV rental including access to any shareable EVSE, multi-mode transportation including EV, Charging service management etc.	**Providing E-mobility services to the EV user** The user signs up with one or more of these actors. The role of the E-mobility Service Provider is to manage all or some of the E-mobility services, like payment for the energy, location and reservation of Charging Supply Equipment and other value added services.

Actor name	Definition of actor	Role of actor
	Also called EMO and defined in ISO-IEC 15118-1. Also called EVSP within Green e-Motion project.	
E-mobility Clearing House (EMCH)	Managing exchange of data between operators in relation with mobility services so as to ensure interoperability and open access of EV users to these services.	**Clearing charging activities** The role of the E-Mobility Clearing House will be to establish an open and neutral service for making the charging activities available between different operators. **Providing interoperability between operators** When charging in public, the user should be able to use all the charging facilities available, including cross-board charging facilities. To support the interoperability of information exchange between the E-mobility actors, a clearing house service or an onboard smart meter could provide the needed exchange of information (e.g. ID of user, EV and operators, location and availability of charging supplies, charging profiles) Alternative: Entity mediating between two clearing partners to provide validation services for roaming regarding contracts of different E-mobility Service Providers with the purpose to: — collect all necessary contract information like Contract ID, E-mobility Service Provider (ESP), communication path to E-mobility Service Provider, roaming fees, begin- and end-date of contract, etc. Provide CSO with confirmation that an E-mobility Service Provider (ESP) will pay for a given Contract ID (authentication of valid contract) and transfer a corresponding Service Detail Record (SDR) after each charging session to the corresponding E-mobility Service Provider (ESP). *Note: This actor is important in relation to information security and data privacy issues.*
Electricity Supply Retailer (ESR)	Entity on the market selling electrical energy to consumers, in compliance with the regulation for market organisation. It can also have a grid access contract with the TSO or DSO.	In addition, multiple combinations of different grid user groups (e.g. those grid users that do both consume and produce electricity) exist. An ESR is in relation with a Balance Responsible Party according to the electricity market organisation.
Distribution System Operator (DSO)	According to European Directive: "a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given	**Safety of supply (no congestions)** Important for the DSO, will always be to secure access to energy and 'safety of supply' either by a smart grid or by

Actor name	Definition of actor	Role of actor
	area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity". Moreover, the DSO is responsible for regional grid access and grid stability, integration of renewable at the distribution level and regional load balancing.	a combination of a smart grid and manageable load, like shifting the EV charge to 'off-peak' hours. Information about forecast of possible grid congestions in the local distribution grid or a direct 'brown-out' signal in emergency situations, could be useful for the E-Mobility Service Provider, if this is part of the 'Smart Charging' concept. Also described in ISO-IEC 15118-1 as responsible for the voltage stability in the distribution grid (medium and low voltage power grid). - Electricity distribution is the final stage in the physical delivery of electricity to the delivery point (e.g. end-user, EVSE or parking operator). - A distribution system's network carries electricity from the transmission grid and delivers it to consumers. Typically, the network would include medium-voltage power lines, electrical substations and low-voltage distribution wiring networks with associated equipment. Depending on national distribution regulations, the DSO may also be responsible for metering the energy (MO).

ANNEX D. SGO Documentation of Test Methods domestic heat pumps

- **follow on the next pages.**

Summary of the annex

The document contains guidelines for a potential SG-Ready Conformance Test Method, which can be used for equipment that has an essential part of critical electric consumption in the customer premises. The enclosed test method are in alignment with the EU mandate M/490.

With the SGAM model background and the German SG-Ready label functions a Conformance Test methodology was applied. A feasible and generic test method for test of SG readiness of selected components has been developed. The following equipment is of relevance for a Smart Grid ready conformance test, hence they have a relatively high continuous electric load that could be active for hours:

• Heat Pumps for domestic use (typical 2 - 4kW intermittent for 0,5 to 24 hours)

Only the domain Heat Pumps are covered in this document.

The document also analyses three Use Cases, one commercial Use Case and two technical Use Cases. The Use Cases, which have been analysed are as follows:

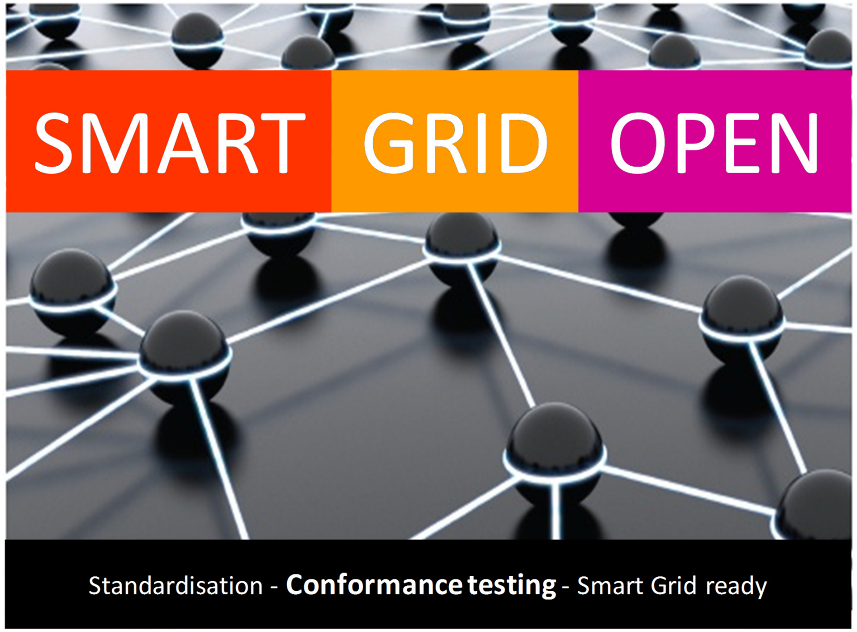
• The Price for electricity is low.
• Voltage on DSO level is low.
• Voltage on DSO level is high.

For details of the above Use Cases, please refer to the chapter Use Case Study. In addition, more examples of Use Cases are showed, in the chapter The SGO definition of the SG-Ready signal.

Throughout the entire project the aim was to find an open and standardised test method, therefore a schematic test setup based on the IEC 61850-10 has been designed. The intention is to follow the IEC 61850-10 naming structure, hereby create a test setup which is in alignment with the IEC 61850-10 standard. Based on this structure it has been possible to design an example of a Test Report, which also is in alignment with the philosophy of the IEC 61850-10 recommendations. Moreover, in case the SG-Ready interface is via a communication interface, the Test Report will be easily adjusted.

During the SGO project, the approach of the Conformance Test methodology was to verify if the DUT was SG-Ready or not. It has been of most importance that the original equipment, e.g. thermostats etc., were not tampered with hereby potentially influencing the internal logic controller of the DUT during the test sequence. Consequently, an “Intelligent” house simulator was created, consisting of two cooling units, in which the external temperature sensors/controllers for the heat pump were installed during testing. One cooling unit was for the indoor temperature sensors/controllers, and the other was for the outdoor temperature sensors/controllers of the Heat Pump.

WP4 SGO Documentation of Test Methods



Deliverable D4-1

ANNEX D –SGO Documentation of Test Methods domestic heat pumps

Contents

Figures

Tables

Scope

The purpose of this document is to outline the ideas, test methods and recommendation relating conformance testing of Heat Pumps. This document also include a proposed layout of Final Test Report.

The work approach is in line with the methods developed in connection with the EU M/490 mandate.

Terms and Definitions

General Terms and Definitions

Term	Definition
A2W	Air-to-Water Heat Pump
BWP	German National Heat Pump Association (Bundesverband Wärmepumpe)
DTI	Danish technological Institute
DUT	Device under Test
EV	Electrical Vehicle
HP	Heat Pump
PV	Photo Voltage
SG	Smart Grid
SGAM	Smart Grid Architecture Model
SGO	Smart Grid Open Project
SG-Ready	Smart Grid Ready according to the German SG label from BWP
W2W	Water-to-Water Heat Pump

Table 1 General Terms and Definitions

Temperature Terms and Definitions

Term	Definition
$T_{outdoor}$	Outdoor temperature, measured by the Outdoor temperature sensors of HP
T_{indoor}	Indoor temperature, measured by the Indoor temperature sensors of HP
$T_{indoor\_MustMax}$	The Upper temperature level for which the HP are allowed to switch to Must Max; Measured by the indoor temperature sensor of HP
T_{indoor_High}	The Upper temperature level for which the HP are allowed to switch to Run Higher; Measured by the indoor temperature sensor of HP
$T_{indoor\_MustStop}$	The Lower temperature level for which the HP are allowed to switch to Must Stop; Measured by the indoor temperature sensor of HP
$T_{indoor\_UpperComfort}$	The Max Comfort temperature setpoint, which is currently set by the End-User; Provided to the HP by the indoor temperature panel(s)
$T_{indoor\_LowerComfort}$	The Min Comfort temperature setpoint, which is currently set by the End-User; Provided to the HP by the indoor temperature panel(s)
T_{MAX_indoor}	The Maximum temperature level for which the HP are allowed to operate; Provided by the HP "Security" Settings
T_{MIN_indoor}	The Minimum temperature level for which the HP are allowed to operate; Provided by the HP "Security" Settings (could be the defrosting level e.g. 5 Deg. C)
$T_{Forward\_MIN}$	The minimum forward temperature of the indoor heater. This temperature defines the heat curve used by the internal heat controller of the Heat Pump.
$T_{Forward\_MAX}$	The maximum forward temperature of the indoor heater. This temperature defines the heat curve used by the internal heat controller of the Heat Pump.
T_{Return}	The return temperature of the indoor heater. This temperature defines and controlled by the DTI test stand.

Table 2 Temperature Limits Terms and Definitions

Terms and Definitions Dynamic House Model

Term	Definition
Simulating	
T_i	Start Indoortemp
$T_{radiator}$	Start Temp Heater
T_{i_set}	Setpoint Indoor Temperature
House Data	
T_{i_bal}	Setpoint Indoor Temperature for balance
T_{amb}	Setpoint Outdoor Temperature for balance
$Tau_{\_h}$	Setpoint Time Constant for House
Q_{loss}	Setpoint Heat Loss balancing
R_h	Heat Conducting House/Outdoor
C_h	Heat Capacity House
Charge_C_h	Capacitor charge (House)
Heating System	
P_vp	Setpoint Power of Heat Pump
R_r	Heat Conducting Heater/ House
C_r	Heat capacity heating circuit
$T_{radiator\_\_bal}$	Heating temperature where the house is in balance
$P_{heatpump}$	Heat Pump nominal " power "

Table 3 Terms and Definitions Dynamic House Model

Summary

This document contain guidelines for a potential SG-Ready Conformance Test Method, which can be used for equipment that have an essential part of critical electric consumption in the customer premises. The enclosed test method are in alignment with the EU mandate M/490.

By implementing both the SGAM model and the German SG-Ready label within the Conformance Test methodology, it has been possible to recommend a feasible and generic test method for test of SG readiness of selected component. The following equipment domains are of relevance for this conformance test, hence they have a relatively high continuous electric load that could be active for hours characterized by the three equipment domains:

- Electric Vehicles (typical 2kW+ for 2 -12 hours)
- Inverters e.g. PV-inverters (typical 4kW+ for 2 -10 hours)
- Heat Pumps for domestic use (typical 2 - 4kW intermittent for 0,5 to 24 hours)

However, only the domain Heat Pumps are covered in this document.

The document also analyses three Use Cases, one commercial Use Case and two technical Use Cases. The Use Cases, which have been analyse are as follows:

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For details of the above Use Cases, please refer to the chapter Use Case Study. In addition, more examples of Use Cases are showed, in the chapter The SGO definition of the SG-Ready signal.

Throughout the entire project the aim was to find an open and standardised test method, therefore a schematic test setup based on the IEC 61850-10 have been designed. The intention is to follow the IEC 61850-10 naming structure, hereby create a test setup which is in alignment with the IEC 61850-10 standard. Based on this structure it has been possible to design an example of a Test Report, which also is in alignment with the philosophy of the IEC 61850-10 recommendations. Moreover, in case the SG-Ready interface is via a communication interface, the Test Report will be easily adjusted.

During the SGO the approach of the Conformance Test methodology was to verify if the DUT was SG-Ready or not. It have been of most importance that the original equipment, e.g. thermostats etc., was not tampered with hereby potentially influencing the internal logic controller of the DUT during the test sequence. As a consequence an “Intelligent” house simulator was created, consisting of two cooling unit, in which the external temperature sensors/controllers for the heat pump was installed during test. One cooling unit was for the indoor temperature sensors/controllers, and the other was for the outdoor temperature sensors/controllers of the Heat Pump.

A basic logic programme was programmed in LabVIEW which controlled the two cooling unit, the outdoor unit must be held at a constant temperature level at all time during test, and the indoor unit was to simulate a “house”. In order to make the indoor cooling unit to act as a “house” a Dynamic

house model was designed and programmed in LabVIEW. For more details of the Dynamic house model, see chapter Dynamic house model as an equivalent model.

Finally, the document provides a feasible approach to analyse and verify if the tested equipment is SG-Ready according to the German SG-Ready label. The challenge is to be able to distinguish between the two SG-Ready modes; Run Higher and Must Max Mode. The method is to test the Heat Pump in the different SG-Ready Modes and then measure the amount of energy the Heat Pump delivers to the heating system over time in the various mode. These measured values are compared, the energy provided in the Must Max Mode must be larger than the energy provided in Run Higher Mode. The same comparison can be done for all possible modes, which is described in details in the chapter "Real Life" power consumption and SG-Ready Mode.

Background information

What is Interoperability, Conformance test and Compatibility levels?

In order to get a common understanding, the definition of terms is important. In SGO, we use the basic terms Interoperability and Conformance as two different, but also link definitions.

Conformance test is defined as a test to determine whether a component or system meets the required specification or standard.

Smart Grid Open defines **Interoperability** as the ability for components and systems to co-exist and operate together from a physical, logical and operational point of view.

SGO also defines a level of **Compatibility** as the ability for a given component or system to be compatible with another component or system of a different type (vendor).

This document describes a potential test method used when performing a SG-Ready Conformance test of equipment.

Reference Architecture – SGAM

The aim of the SGO project is to show a potential test method based on the SGAM model. A series of workshops with focus on SGAM and support of Smart Grid related topics has been conducted with relation to the SGO project and scope.

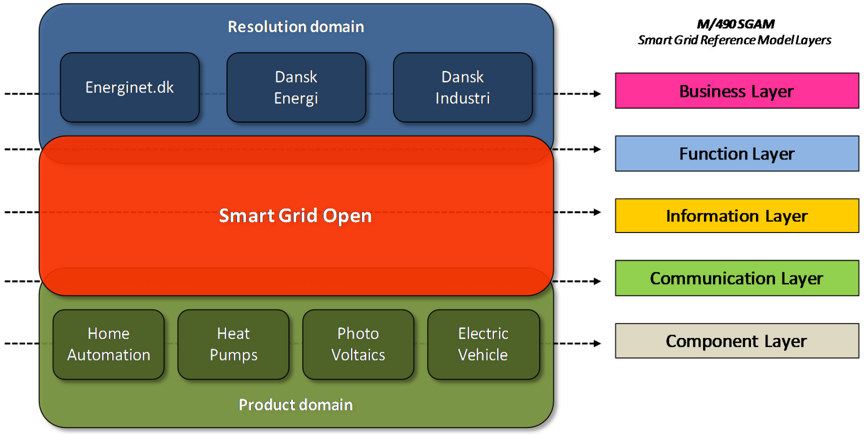


Figure 1 SGAM Model in accordance to the M/490 Mandate

The domains that has been in focus is similar to SGO, which are EV, Heat Pumps PV, Home and Building automation.

This document describes test methods within the component layer of the SGAM model. All components are located in the quadrant Customer Premise and Process/Field of the SGAM model.

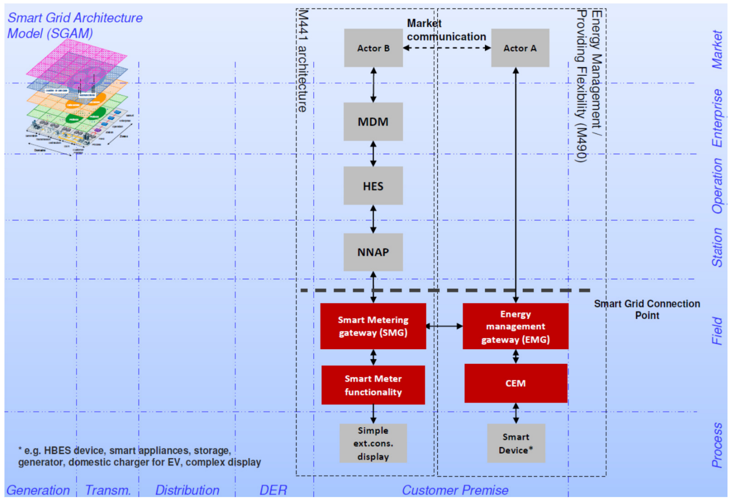


Figure 2 Example - Mapping of Flexibility Functional Architecture on SGAM

Smart Grid Connection Point

All grid-connected equipment has several requirements to fulfil. Some requirements are mandatory for safety and functional integrity of other systems and components. There must be some sort of user interface to allow for control or monitoring of the equipment's function. If an equipment should be able to offer, flexibility to the grid a further set of requirements must be fulfilled to accommodate management of the flexibility.

The Smart Grid Connection Point is not a specific interface on the equipment but rather an information exchange interface between the embedded equipment internal management and a Smart Grid server or via point.

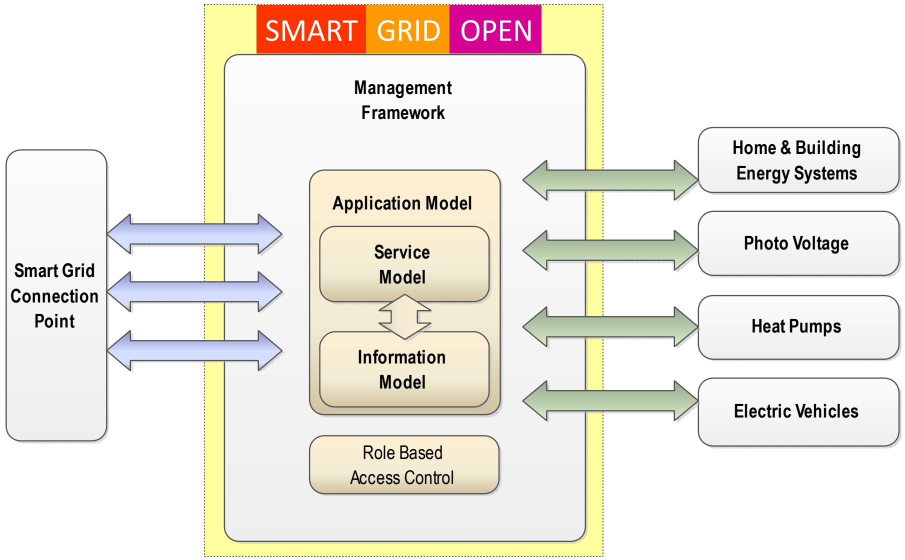


Figure 3 Link between Domain areas and Smart Grid Connecting Point

SGO assume a partly application specific Management Framework in Smart Grid Ready equipment that handle access control and information interchange. Service model is the equivalent functional SW model of the actual equipment function.

For SGO to handle different domains with a similar approach SGO assume a common Management Framework with submodular adaptation to the specific domain.

The test setup will consist of a complex test-equipment, consisting of several sub functions:

- Emulate the stimuli from the application process as needed
- A measurement unit that monitor the process feedback to assess reactions.

An important auxiliary test device will be the equipment simulator i.e. the intelligent house simulator

Based on the SG-Ready label from the German National Heat Pump Association (BWP Bundesverband Wärmepumpe), this document describes a possible test method for Heat Pumps only, however it might be possible to use the SG-Ready label defined by BWP in other domains, see SGO Final Report for details.

Domain area

Four equipment domains has been chosen as the focus in SGO. With Smart Grid control of these equipment domains, the essential part of critical electric consumption is taken care of.

A relatively high continuous electric load that could be active for hours characterizes three equipment domains:

- Electric Vehicles (typical 2kW+ for 2 -12 hours)
- Inverters e.g. PV-inverters (typical 4kW+ for 2 -10 hours)
- Heat Pumps for house heating (typical 2 - 4kW intermittent for 0,5 to 24 hours)
- Home Automation (Aggregate minor flexible loads at home level)

The fourth equipment type is a Smart Grid tested home automation unit able to aggregate some of the smaller flexible electric loads in the building to serve as a single larger load. The Home Automation equipment can work as a router and/or manage unintelligent equipment to act as Smart Grid ready. It is important to be aware that the Home Automation equipment may have other primary functions than Smart Grid services like e.g. comfort related controls or alarm functions.

Smart Grid management of electric hot water heaters will be covered by either Heat Pump control or Home Automation.

This document describes a potential test method for the equipment domain Heat Pump only.

Test Use Case Headlines

Background

The Use case describes the relation to the actor list and the requirement list, which are common for all, Use Cases.

Existing Use Case descriptions from a Use Case Repository can be migrated into the projects defined Use Cases as appropriate.

The Use Case descriptions will start as short versions with the minimum mandatory fields:

- Name of Use Case, Author, Date, Narrative, Actors.

The short version is the basis for the complete Use Case and can be simply extended with the addition of further information, i.e., without rewriting the Use Case. Being self-explaining the short version is seen as an easy starting point for involving domain experts without going into every detail of the Use Case methodology and its complete Use Case template.

Use Case Study

Use Case 1: Price is low

<table>
<tr><th colspan="5">Use Case Identification</th></tr>
<tr><td>ID</td><td colspan="2">Domain(s)/Zone(s)</td><td colspan="2">Name of Use Case</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="2">Price is low</td></tr>
<tr><th colspan="5">Version Management</th></tr>
<tr><td>Version No</td><td>Date</td><td>Name of Author(s)</td><td>Changes</td><td>Approval Status</td></tr>
<tr><td></td><td>2015-05-18</td><td>Steffen Lind Kristensen</td><td></td><td></td></tr>
<tr><th colspan="5">Narrative of Use Case</th></tr>
<tr><td colspan="5">Short Description</td></tr>
<tr><td colspan="5">Controlling the SG-Ready signal of the Heat Pump based on the price signal received from the Aggregator. Heat Pump has possibility to store thermal energy in the building.</td></tr>
<tr><td colspan="5">Long Description</td></tr>
<tr><td colspan="5">Price signal scheme are downloaded from the Aggregator to the Smart Grid Controller

Price signal sent from the Aggregator informing the Smart Grid Controller, that the price is low.

Price signal sent from the Smart Grid Controller to the SG-Ready Controller, that the price is low.

Information from the SG-Ready Controller to the Heat Pump, informing it to go in SG-Ready Run Higher Mode. E.g., the SG-Ready bit A set to “ON”, SG-Ready bit B is set to “OFF”.

When the compressor delay time is “OFF”, the Heat Pump starts to run hence increasing the temperature in the house.

Price signal sent from the Aggregator informing the Smart Grid Controller, that the price is Normal.

Price signal sent from the Smart Grid Controller to the SG-Ready Controller, that the price is Normal.

Information from the SG-Ready Controller to the Heat Pump, informing it to go in SG-Ready Normal Operation Mode. E.g., the SG-Ready bit A set to “OFF”, SG-Ready bit B is set to “OFF”.</td></tr>
</table>

Table 4 Example of Use cases; Price is low

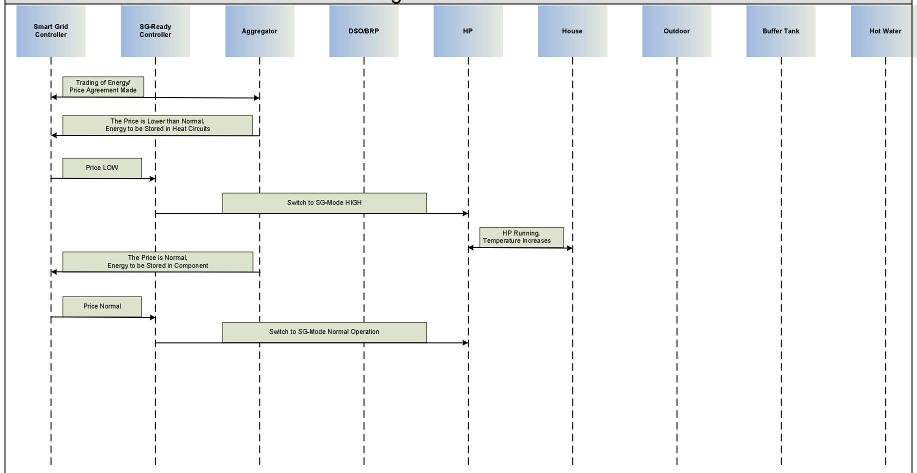
<table>
<tr><th colspan="3">Use Case Identification</th></tr>
<tr><td>ID</td><td>Domain(s)/Zone(s)</td><td>Name of Use Case</td></tr>
<tr><td></td><td></td><td>Price is low</td></tr>
<tr><th colspan="3">Diagram of Use Case</th></tr>
<tr><td colspan="3"></td></tr>
</table>

Table 5 Example of Use cases; Price is low

Use Case Identification			
ID	Domain(s)/Zone(s)	Name of Use Case	
		Price is low	
Actors			
Actor Name	Actor Type	Actor Description	Further Information specific to this Use Case
Smart Grid Controller	Device	Operates the Heat Pump. Receives Heat Pump operation plans and is responsible for the execution of a Heat Pump operation plan. Other responsibilities Authenticate or relay to Aggregator for authentication, negotiation of Heating capabilities and finally executing Heating service request within boundaries (grid capabilities, HP-availability)	NEW
SG-Ready Controller	Device	Implementing the function for SG-Readiness. Performs state estimation based on real-time information from the Smart Grid Controller	NEW
Aggregator	Role	See IEC 62559-2	
DSO/BRP	Role	See IEC 62559-2	
HP	Device	Heat Pump, device that converts electrical power to heat.	NEW
House	Role	End User of heat	NEW
Outdoor	Role	End User of heat	NEW
Buffer Tank	Role	End User of heat	NEW
Hot Water Tank	Role	End User of heat	NEW

Table 6 Example of Use cases; Price is low

Use Case 2: Voltage on DSO level is low

Use Case Identification				
ID	Domain(s)/Zone(s)	Name of Use Case		
		Voltage on DSO level is low		
Version Management				
Version No	Date	Name of Author(s)	Changes	Approval Status
	2015-07-24	Steffen Lind Kristensen		
Narrative of Use Case				
Short Description				
Controlling the SG-Ready signal of the Heat Pump based on the signal received from the DSO indicating the Voltage is low.				
Long Description				
Signal sent from the DSO informing the Smart Grid Controller, that the voltage level is lower than the defined nominal voltage level and the DSO need the Heat Pump to stop operating. Control signal sent from the Smart Grid Controller to the SG-Ready Controller, informing the voltage is low. Information from the SG-Ready Controller to the Heat Pump, informing it to go in SG-Ready Must Stop Mode. E.g., the SG-Ready bit A set to "OFF", SG-Ready bit B is set to "ON". The Heat Pump stops to run hence decreasing the temperature in the house. Signal sent from the DSO informing the Smart Grid Controller that the voltage level is back to normal level. Control signal sent from the Smart Grid Controller to the SG-Ready Controller, informing the voltage is Normal. Information from the SG-Ready Controller to the Heat Pump, informing it to go in SG-Ready Normal Operation Mode. E.g., the SG-Ready bit A set to "OFF", SG-Ready bit B is set to "OFF".				

Table 7 Example of Use cases; Voltage on DSO level is low

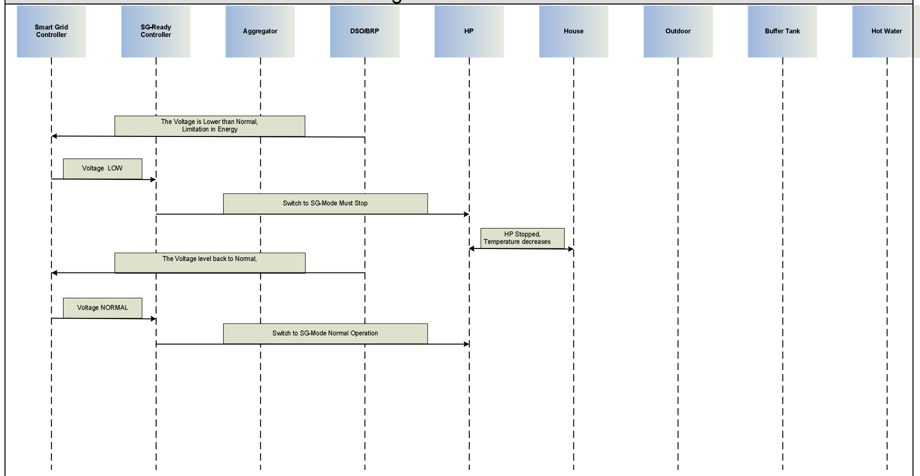
Use Case Identification		
ID	Domain(s)/Zone(s)	Name of Use Case
		Voltage on DSO level is low
Diagram of Use Case		
		

Table 8 Example of Use cases; Voltage on DSO level is low

Use Case Identification			
ID	Domain(s)/Zone(s)	Name of Use Case	
		Voltage on DSO level is low	
Actors			
Actor Name	Actor Type	Actor Description	Further Information specific to this Use Case
Smart Grid Controller	Device	Operates the Heat Pump. Receives Heat Pump operation plans and is responsible for the execution of a Heat Pump operation plan. Other responsibilities: Authenticate or relay to Aggregator for authentication, negotiation of Heating capabilities and finally executing Heating service request within boundaries (grid capabilities, HP-availability)	NEW
SG-Ready Controller	Device	Implementing the function for SG-Readiness. Performs state estimation based on real-time information from the Smart Grid Controller	NEW
Aggregator	Role	See IEC 62559-2	
DSO/BRP	Role	See IEC 62559-2	
HP	Device	Heat Pump, device that converts electrical power to heat.	NEW
House	Role	End User of heat	NEW
Outdoor	Role	End User of heat	NEW
Buffer Tank	Role	End User of heat	NEW
Hot Water Tank	Role	End User of heat	NEW

Table 9 Example of Use cases; Voltage on DSO level is low

Use Case 3: Voltage on DSO level is high

Use Case Identification				
ID	Domain(s)/Zone(s)		Name of Use Case	
			Voltage on DSO level is High	
Version Management				
Version No	Date	Name of Author(s)	Changes	Approval Status
	2015-07-24	Steffen Lind Kristensen		
Narrative of Use Case				
Short Description				
Controlling the SG-Ready signal of the Heat Pump based on the signal received from the DSO indicating the Voltage is High.				
Long Description				
Signal sent from the DSO informing the Smart Grid Controller, that the voltage level is higher than the defined nominal voltage level and the DSO need the Heat Pump to operating at maximum capacity. Control signal sent from the Smart Grid Controller to the SG-Ready Controller, informing the voltage is high. Information from the SG-Ready Controller to the Heat Pump, informing it to go in SG-Ready Must Max Mode. E.g., the SG-Ready bit A set to "ON", SG-Ready bit B is set to "ON". The Heat Pump start all possible heating circuits, hence increasing the temperature in the house, Buffer Tank and the Hot Water Tank if these are installed in the heating installation. Signal sent from the DSO informing the Smart Grid Controller that the voltage level is back to normal level. Control signal sent from the Smart Grid Controller to the SG-Ready Controller, informing the voltage is Normal. Information from the SG-Ready Controller to the Heat Pump, informing it to go in SG-Ready Normal Operation Mode. E.g., the SG-Ready bit A set to "OFF", SG-Ready bit B is set to "OFF".				

Table 10 Example of Use cases; Voltage on DSO level is high

Use Case Identification		
ID	Domain(s)/Zone(s)	Name of Use Case
		Voltage on DSO level is High
Diagram of Use Case		

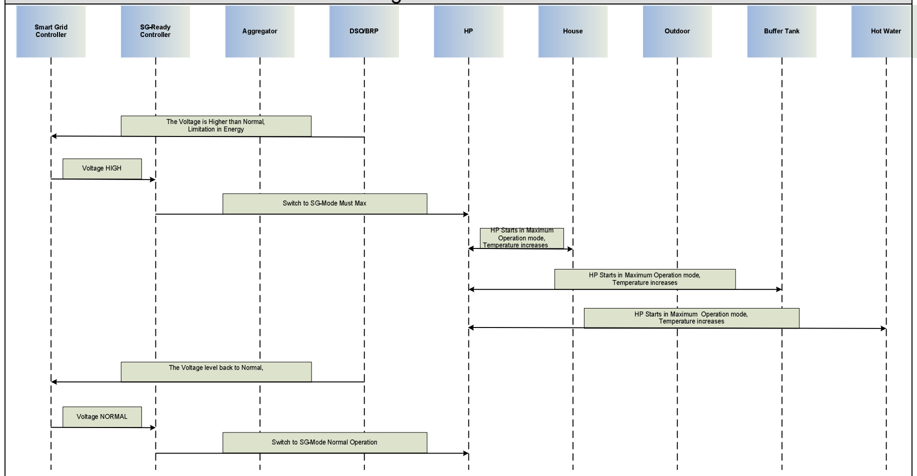


Table 11 Example of Use cases; Voltage on DSO level is high

Use Case Identification			
ID	Domain(s)/Zone(s)		Name of Use Case
			Voltage on DSO level is High
Actors			
Actor Name	Actor Type	Actor Description	Further Information specific to this Use Case
Smart Grid Controller	Device	Operates the Heat Pump. Receives Heat Pump operation plans and is responsible for the execution of a Heat Pump operation plan. Other responsibilities: Authenticate or relay to Aggregator for authentication, negotiation of Heating capabilities and finally executing Heating service request within boundaries (grid capabilities, HP-availability)	NEW
SG-Ready Controller	Device	Implementing the function for SG-Readiness. Performs state estimation based on real-time information from the Smart Grid Controller	NEW
Aggregator	Role	See IEC 62559-2	
DSO/BRP	Role	See IEC 62559-2	
HP	Device	Heat Pump, device that converts electrical power to heat.	NEW
House	Role	End User of heat	NEW
Outdoor	Role	End User of heat	NEW
Buffer Tank	Role	End User of heat	NEW
Hot Water Tank	Role	End User of heat	NEW

Table 12 Example of Use cases; Voltage on DSO level is high

The SGO definition of the SG-Ready signal

In Smart Grid Open the following definition of SG-Ready, based on the German SG-Ready label, have been defined.

The German SG-Ready label consists of 2-Bit providing four different modes; Normal Operation Mode, Run Higher Mode, Must Max Mode and Must Stop Mode.

Normal Operation Mode:

The Heat Pump's internal logic regulate the Heat Pump thermal energy supply.

Run Higher Mode:

In the “Run Higher” mode (= “High” mode) the Heat Pump’s thermal energy supply increases, this increase is, however, depending on whether it is possible to ”store” the extra heat in the building and any water storage containers.

Example of Use Case:

The price is low, and the Heat Pump have the possibility to store thermal energy.

Must Max Mode:

The Heat Pump will run in forced operation, causing it to increase its thermal energy supply. In this mode, the Heat Pump will run according to the safety limits specified by the supplier/installation.

Example of Use Case:

The upper grid have a need to start the Heat Pump in order to maintaining stability of the grid due to higher voltage in the grid than the defined nominal voltage level.

Must Stop Mode:

In this mode, the Heat Pump will stop its thermal energy supply. It will remain in stopped for a maximum of 2 hours.

Examples of Use Cases:

The upper grid have a need to start the Heat Pump to assist maintaining stability of the grid due to lower voltage in the grid than the defined nominal voltage level.

Aggregator disconnects Heat Pumps, due to High Price.

Aggregator disconnects Heat Pumps, to obtain contractual obligations of delivery of power later.

The correlation between the 2-Bit and 4 SG-Ready Modes seen in Figure 4.

Figure 5 shows the correlation between SG-Ready Modes and the expected reaction in the Heat Pump.

SG-Mode

Forced/Normal Mode (Bit 0) \ Low/High Mode (Bit 1)	0	1
0	**Normal Operation**	**High**
1	**Must Stop**	**Must Max**

Figure 4 2-Bit combination for the 4 SG-Ready Modes.

SG-Mode Reaction

Forced/Normal Mode (Bit 0) \ Low/High Mode (Bit 1)	0	1
0	**Normal Operation**	**Recommended adjustment of the Setpoint of the internal heat controller by for example +10%**
1	**Setpoint of the internal heat controller set to minimum comfort level or defrosting level**	**Forced adjustment of the Setpoint of the internal heat controller to the upper "Security" limits**

Figure 5 Expected reaction of the Heat Pump in the 4 SG-Ready Modes.

In order to verify that the Heat Pump is SG-Ready, it shall be possible to test the response of the Heat Pump when making transitions between the various SG-Ready Modes. These transitions,

occurs by switching from one SG-Ready Mode to the next, this is done by switching the bit combination to obtain the new combination that equals the desired SG-Ready Mode.

It must be possible to switch between the different modes and remain in the selected mode, in order to verify every single step of the test.

The relationship of the transition between different SG-Ready Modes seen in Figure 6.

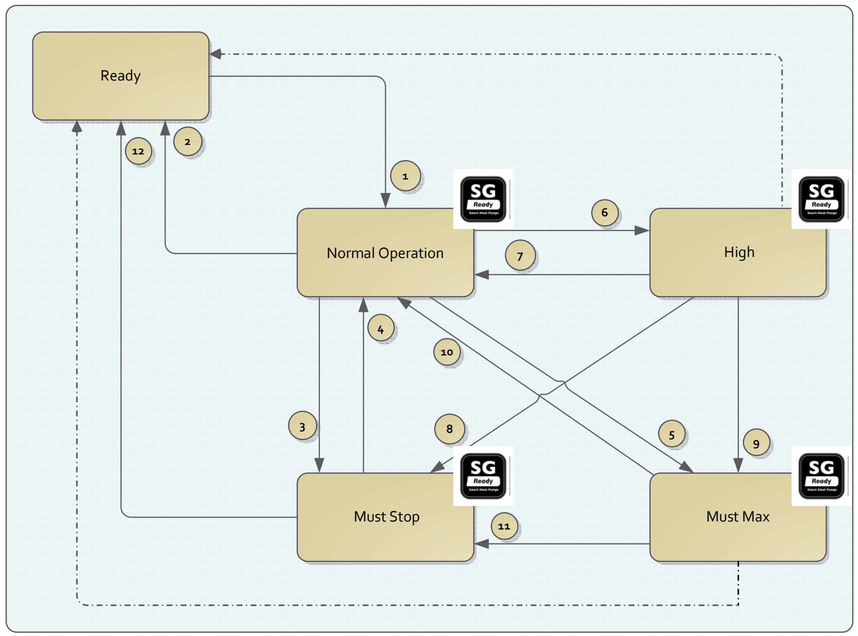


Figure 6 Recommended transitions between various SG-Ready Modes

Test Methodology

Basic Concept

To make the SG-Ready Conformance Test of the Heat Pump, a standardised approach have been used. All Heat Pumps are installed in the test setup as “Black Boxes” tested in the various SG-Ready modes, and the reaction of the Heat Pump is monitored accordingly.

To find a test method, which can verify if the Heat Pump is SG-Ready in the SG Connection Point, the test setup must consist of the following elements.

- Static Simulator
- Dynamic Stimulator
- Analyser

In this chapter the functionality of the above elements are described.

In the chapter System Description – Laboratory, the various components and systems needed to fulfil the below required functionality are described in details.

Static Simulator

The Static Simulator monitors and controls the thermal energy system connected to the Heat Pump. In addition, it will be possible to monitor any electrical power measurement needed, in order to operate the thermal circuits the Heat Pump is connected to the DTI Test Stand.

The static Simulator logs the energy flow, temperature measuring and power measuring. Subsequently these are sent to the analyser of the test setup for analysing and documentation of the test. Moreover, all data points must be time stamped enabling proper analysing of the data.

The static Simulator will allow the Heat Pump to operate in its normal mode, as well as the SG-Ready Modes defined by the Dynamic Simulator, without any interruption of the internal control algorithm of the Heat Pump.

Dynamic Simulator

The dynamic Simulator has two main task, to control and operate the switching between the different SG-Ready Modes, and to provide the test setup with the capability to simulate a house and the environments of this house.

The dynamic Simulator logs the SG-Ready Modes in real time, and these values are subsequently sent to the analyser for further analysing and documentation of the test. Likewise, the Static Simulator all data points must be time stamped enabling proper analysing of the data.

Analyser

In order to verify the SG Readiness of the Heat Pump, the Analyser receives the relevant data, which are analysed and processed for SG-Ready Conformance Verification and Reporting.

Static Simulator

The Static Simulator consist of the following modules.

DTI Test Stand

The DTI Stand monitor, controls and operate the thermal circuit of the Heat Pump, DTI Test Stand ensures the Heat Pump to operate in a proper manner.

Energy flow measuring

The Energy flow measuring monitor all relevant values relating to the thermal circuit of the Heat Pump.

Temperature measuring

The Temperature measuring monitor all relevant values relating temperatures in the thermal circuit of the Heat Pump.

Power measuring

The Power measuring monitor all relevant values relating to the electric circuit of the Heat Pump.

Dynamic Simulator

The Dynamic Simulator consist of the following modules

SG-Ready Mode Logic

The SG-Ready Mode Logic ensures timely switching between the various SG-Ready Modes, e.g. Normal Operation, MUST Stop, Run Higher and MUST Max.

The SG-Ready logic must also ensure to send/provide the switching between modes with the correct timestamp, ensuring proper analysing of the test.

Dynamic House Logic

The Dynamic House Logic will send the Temperature setpoints to both House simulator and the Outdoor simulator, hereby ensuring the temperatures to be correct during the test sequence. It is possible to create an equivalent model for both the Hot Water Tanks and the Buffer Tanks; however, this is not part of this house model.

In addition, it is the responsibility of the Dynamic House Logic, to ensure the house simulator are as per described in the equivalent model for the intelligent house simulation. In short, if the Heat Pump is running the temperature in the House simulator is increasing and if the Heat Pump is stopped the temperature will drop, in accordance to the model.

Dynamic house model as an equivalent model

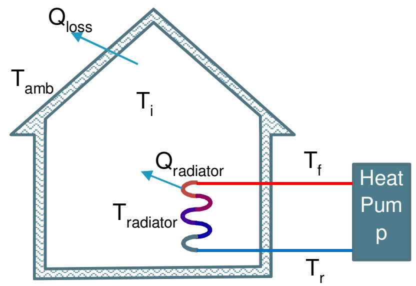


Figure 7 Simplified house model

To derive the equivalent diagram the following relationship between thermal and electrical devices is assumed.

Thermal Value	Thermal Unit	Electrical equivalent Unit
Temperature	℃	Volt
Temperature flow	Q	Ampere
Heat Capacity	Joule	Farad
Thermal conductivity	W/(m²K)	Siemens
Isolation	m²K/W	Ohm
Power	W	W

Table 13 Correlation between thermal values in relation to the electrical equivalent formulas

The equivalent model is based on the above simplified house model. The model is based on all types of Heat Pumps, but the following calculations are based on Heat Pumps of type "ON / OFF".

As it is seen in Figure 7, then when the Heat Pump is running, the inside temperature T_i increase, thus increasing the thermal energy in the house. If the outside temperature T_{amb} is constant, the loss to the surroundings increases when T_i increases.

Likewise, T_i fall if the Heat Pump is stopped, whereby the thermal energy in the house decreases. If the outside temperature T_{amb} is constant, the loss to the surroundings decreases when T_i decreases.

The heat loss of the house, Q_{loss} can be considered as a linear function of the temperature difference between the inside temperature and the outside temperature and heat conduction from the house to the outside, giving us following formula:

$$Q_{loss}= (T_i-T_{amb})*R_h$$

All heating of the house comes solely from the radiator system, $Q_{radiator}$. $Q_{radiator}$ can be considered as a linear function of the temperature difference between the indoor temperature and heating temperature, and the heat conducting between the radiator and the house, resulting in the following formula:

$$Q_{radiator}= (T_{radiator}-T_i)*R_{radiator}$$

The temperature in the house increases/decreases, as exponential function over time, of heat transfer to the surroundings (R_h) and the heating capacity (C_h).

Thus, the following formula can be derived.

$$T\ (t) = T_{start}\ (1-e^{(-t/\ RhCh)})$$

The following constants and formulas are used in the equivalent diagram.

	Label	value	unit	formula
Simulating				
Time step	Delta-tid	15	sec	Charge_C_h/C_h
Start Indoortemp	T_i	20	℃	
Start Temp Heater	$T_{radiator}$	20	℃	
Setpoint Indoor Temperature	T_{i_set}	20	℃	
Threshold	Threshold	1	°K	
House Data				
Setpoint Indoor Temperature for balance	T_{i_bal}	20	℃	
Setpoint Outdoor Temperature for balance	T_{amb}	0	℃	
Setpoint Time Constant for House	Tau_h	180	min	
Setpoint Heat Loss balancing	Q_{loss}	2	kW	Joule lost per sec at balance
Heat Conducting House/Outdoor	R_h	0,2	ohm	$(T_i-T_{amb})^2/Q_{loss}$
Heat Capacity House	C_h	54000	farad	Tau_h/R_h
Capacitor charge (House)	Charge_C_h	1080	kAs	$C_h*(T_i-T_{amb})$
Capacitor energy content (House)		10800	kJ	$0,5*Ch*(T_i-T_{amb})^2$
W (Work House)		3	kWh	$0,5*C*V^2$

Heating System				
Setpoint Power of Heat Pump	P_vp	8	kW	
Heat Conducting Heater/ House	R_r	0,1125	ohm	$(T_{radiator}\_bal-T_i\_bal)^2/P\_vp$
Heat capacity heating circuit	C_r	1196	farad	
Liquid volume in the heating system		5	l	
Heating temperature where the house is in balance	$T_{radiator}\_bal$	35	°C	
The energy content of heater fluid [kJ]		732,55	kJ	
The energy content of heater fluid [kWh]		0,2	kWh	
Heat Pump nominal " power "	$P_{heatpump}$	267	A	

Table 14 Constants and formulas for Figure 7 Simplified house model

Based on above assumptions the following equivalent model can be designed.

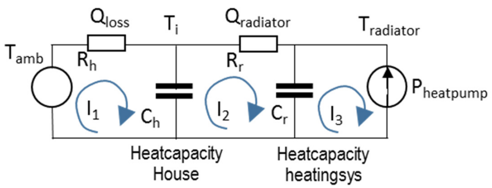
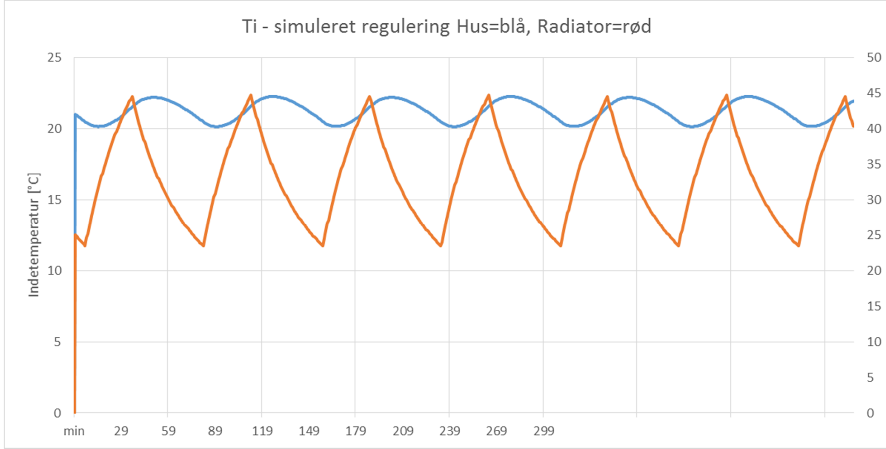


Figure 8 Equivalent model

Based on the formulas and constants specified in Table 14, it is possible to create a simulation of the "house model". The comfort zone has been specified between 19.9° C and 23.3° C. The Heat Pump runs twice within this comfort zone, after which the Heat Pump is stopped, hence providing the following temperature curve inside the "house".



Figur 9 Indoor Temperature based on Dynamic house model as an equivalent model (Blue = indooor temperature; Red=radiator temperature on right hand scale)

Analyser

The Analyser consist of the following modules.

Data Logging

The Data logging module will ensure that all data points needed for reporting and the conformance verification are assessable for these modules.

All data points are logged with timestamp to ensure proper analysing of the data.

Conformance Verification

The Conformance Verification module must provide the Analyser the capability to verify if the DUT (Device Under Test) are SG-Ready compliant. To verify the SR Readiness, the Conformance Verification module makes a comparing of the integrated energy flow over time for the different SG-Ready Modes. The integral for normal operation is considerably smaller than Run Higher Mode and the integral of Run Higher mode is smaller than the Integral of Must Max Mode.

Finally, the integral of MUST Stop is expected to be close to Zero.

Reporting

The Reporting module is a report generator, providing the test result in a report. In addition, it will provide graphs and excel based data of the test for additional future analysing.

The Report module will document if the test of the DUT was approved, failed or if the test was inconclusive.

In Figure 10 the basic test setup is illustrated, showing the interaction between the various function elements, the location of the various test modules and how the data is exchanged between test elements, insuring a proper evaluation of the SG readiness, of the Heat Pump.

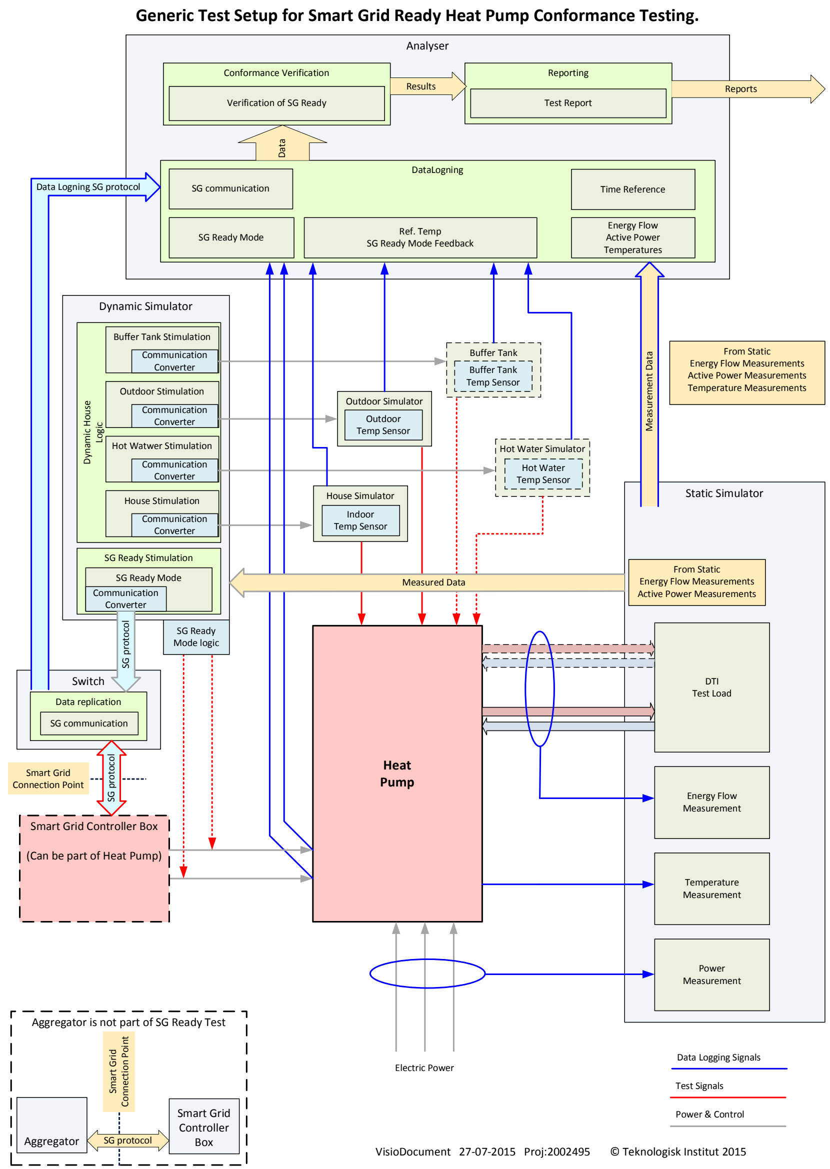


Figure 10 Test Setup for SG-Ready verification

Unit Description – Technical Fact Sheet

A Heat Pump is a device that provides heat energy from a source of heat to a destination called a "heat sink". Heat Pumps are designed to generate thermal energy by the use of electrical power. The electrical power used is significantly smaller than the thermal energy produced in the system.

Operating principles

There are several type of Heat Pumps however; we look only at the Water-to-Water (W2W) and the Air-to-Water (A2W) types.

We design the test programme for both the "ON/OFF" compressed type of Heat Pump and the frequency controlled type of Heat Pump, but in the chapter System Description – Real Life we focus on describing the functionality of the Heat Pump, based on the "ON/OFF" compressed type of Heat Pump.

Based on the configuration of the heat curve programmed into the Heat Pump, the temperature of the indoor heater is defined.

Pre-Test Configuration of Heat Pump

In order to verify if the tested DUT is SG-Ready the following settings must be set in the software of the Heat Pump internal logic.

- Setpoint of Indoor Temperature: 20℃
- Time Schedules: Ensure that any type of time schedules are disabled

Configure the Heat Curve as follows

- Heat Curves: Ensure linear curves (e.g. Floor Heating)
- $T_{Outdoor\_MAX}$, $T_{Forward\_MIN}$: 10℃, 35℃
- $T_{Outdoor\_MIN}$, $T_{Forward\_MAX}$: - 10℃, 55℃

The following conditions to be configured in the DTI test stand, before testing the DUT.

- Flow: 1000 l/hour
- T_{Return}: 29℃
- SG-Ready Bit: Wired to SG Bit A and SG Bit B

System Description – Real Life

When the Heat Pump is installed in the housing installation, it will operate in accordance to the desired temperature within the house and the real temperature outside the building.

Based on the configuration of the heat curve programmed into the Heat Pump, the temperature of the indoor heater is defined.

When commissioning a Heat Pump, one of the final test is to optimize the heat curve configuration of the Heat Pump to match the building in which the Heat Pump is installed.

Expected indoor temperature curve as a function of SG-Ready Mode

It is expected that if the Heat Pumps are SG-Ready, and are tested according to the various SG-Ready Modes, the Heat Pump will start and stop according the SG-Ready Mode of which it is operating.

Throughout the SG-Ready verification test, the outdoor temperature is kept on a constant 2° C. hereby realising the Heat Pump starts/stops in accordance to the SG-Ready Mode of which it is operated. In case the outdoor temperature is above 20° C, the Heat Pump is functioning falsely in the various SG-Ready Modes. The reason is the Heat Pump internal logic will not provide thermal energy to the system when the outdoor temperature is too high.

The Heat Pump start/stops according to the desired SG operation mode, forcing the indoor temperature to be raise/fall according to the operation mode.

Figure 11 shows the expected operation of the Heat Pump and subsequently indoor temperature as defined by the various SG-Ready Modes, in the figure it is showed how the indoor temperature curve raises and fall as a function of the SG-Ready Mode.

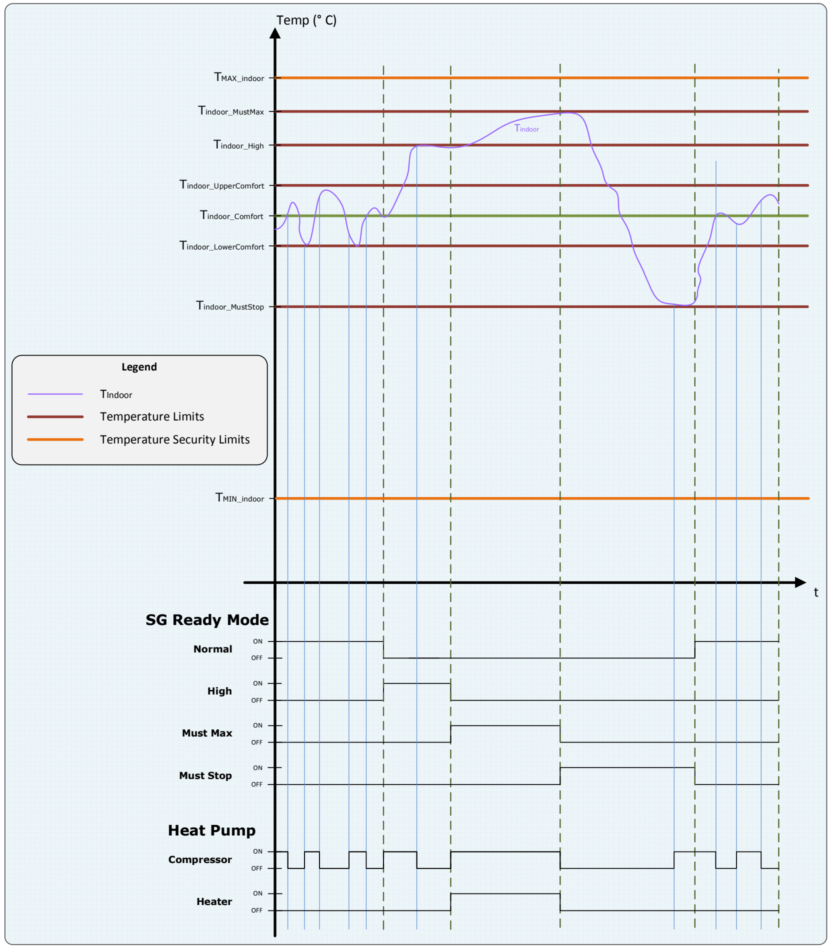


Figure 11 Indoor Temperature curve showed as a function of the various SG-Ready Modes

"Real Life" power consumption and SG-Ready Mode

The following graphs, shows how the DUT B (Device under Test, test object B), regulate the Heat Pump as a function of the measured indoor temperature. The desired indoor temperature is set to 20° C while the outdoor temperature is kept at 3,6°C.

As soon as the Heat Pump is running at full power, the "house" temperature is increased with 0,5°C/min, while down regulated by 0,5°C/min if the Heat Pump is stopped. If the power of the

Heat Pump is 125 W, the Heat Pump is running with the circulation pump only and than the temperature is kept at a constant value.

The Heat Pump is now tested in the different SG-Ready Modes and it is recognised that the difference between Normal Operation Mode and Run Higher is that the Heat Pump delivers a larger amount of energy in Run Higher Mode than in Normal Operation Mode.

The difference between the Run Higher Mode and Must Max Mode is a decrease in delay time of the compressor start and the Heat Pump allows larger production of energy in Must Max Mode than in Run Higher Mode.

Analysing the above observations it is possible to differentiate between the Run Higher Mode and Must Max Mode by analysing the integrated energy produced in the Heat Pump over time. The same applies to Normal Operation Mode here the integral of energy produced in the Heat Pump over time, also show that the Heat Pump is operating in Normal Operation Mode.

The following graphs are based on manual "simulation" of the indoor temperature, outdoor temperature is kept constant 3,6°C by use of ice.

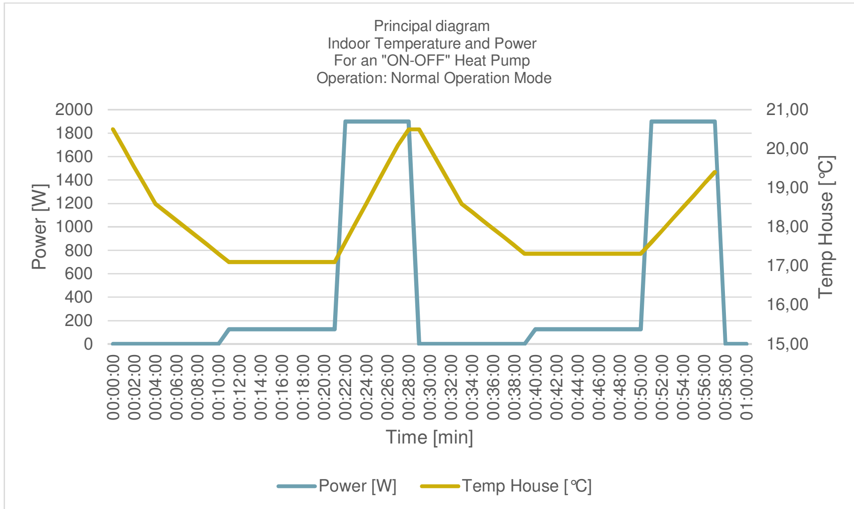


Figure 12 Expected power flow of Heat Pump running in Normal Operation Mode

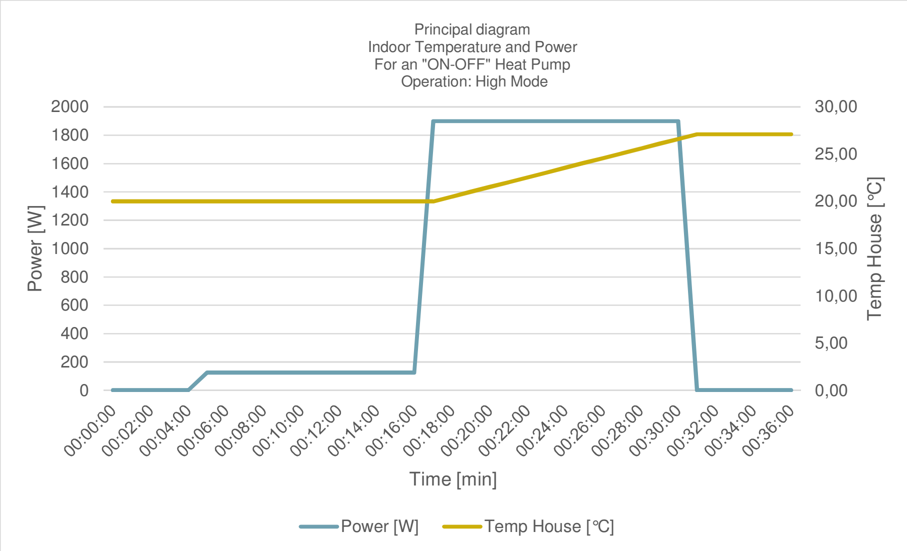


Figure 13 Expected power flow of Heat Pump running in Run Higher Mode

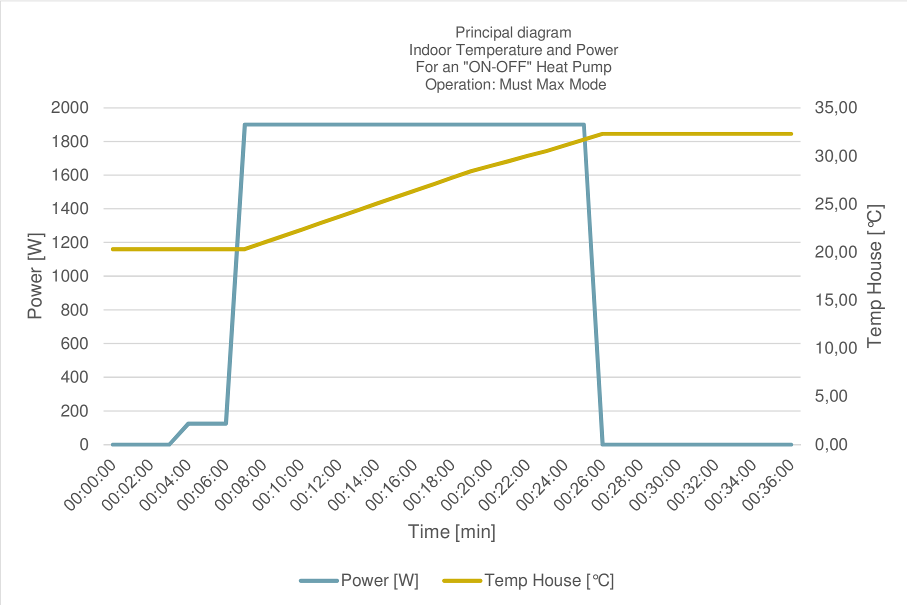


Figure 14 Expected power flow of Heat Pump running in Must Max Mode

System Description – Laboratory

In order to provide a “Black Box” test the following test conditions is needed. By using both simulation and monitoring tools it will be possible to simulate and monitor various temperature curves and their impact on the Heat Pump’s internal control and regulation.

The goal is to build a test platform where it is possible to simulate a random house from programmable characteristics. The system is tested in connection with tests of SG-Ready control signals to the SG-Ready certification of Heat Pumps.

To achieve a standardized approach a test setup in alignment with IEC 61850-10s testing methods have been designed.

IEC 61850-10 consists of the following main components:

DUT, Analyser, Simulator and Equipment Simulator.

DUT (Device Under Test)

The DUT is the device under test, in this case the Heat Pump, which is desired for test.

The Heat Pump mounted in one of DTI's test stands in Aarhus. The Heat Pump will be connected to the heating/cooling circuit; this includes the Brine, indoor/ House installation and Hot Water Tank and Buffer Tank circuit as per the specification of the installed Heat Pump.

The DUT is connected to the simulators, enabling SG-Ready signals and temperatures to be simulated. Based on the Heat Pump reaction, the Heat Pump SG-Ready conformity can by verified.

Analyser

The Analyser is connected to the DUT during the entire test, to verify the SG-Ready conformity. The Analyser consists of DTI LabVIEW equipment with underlying program codes used for the certification of Heat Pumps. The Excel platform is used for analysing the test, and ultimate reporting the result of the test.

The Analyser provides detailed logs of measurements from equipment simulators including, temperature measurement, voltage and current measurements in all three phases, the active and reactive power. Based on these logs the Analyser provides data to verify the Device Under Test SG Readiness.

This analysis consists of comparing the real-time data for SG-Ready Modes with power, Energy Flow and temperature measuring, in order to verify if the DUT is SG-Ready.

Simulator

The Simulator is the component, which will affect the DUT during the controlled test, hereby enabling the system the possibility to analyse and verify if the test of the DUT is passed, failed or inconclusive.

In order to verify whether the tested Heat Pump is SG-Ready according to the German definition of this, it has been necessary to extend the static test setup (DTI Test load) with a dynamic "house" simulation and SG-Ready simulation. In order to build a dynamic test platform, the test setup consists of two simulators, a static simulator and a dynamic simulator, unlike the standard IEC 61850-10 conformance test systems which normally only consist of one simulator.

Static Operation.

The Simulator for Static Operation is the existing test Stand located at Technological Institute in Aarhus. This is based on LabVIEW control with underlying program codes that is already used for certification of Heat Pumps. This simulator controls and regulates the flow and temperature in House Installation, Hot Water Tank and Buffer Tank circuits. The system provide a constant flow in any of the used circuit, and provides a fixed return temperature in the house installation circuit, so it simulates that heat is released into the "house".

Dynamic Operation.

The Dynamic Operation Simulator is based on LabVIEW equipment with underlying program code; this platform extends the Static Operation Simulator with dynamic setpoints depending on the Heat Pump's current operation. The dynamic simulator controls the external "Cooling Boxes" used for manipulating the internal control and regulation of the Heat Pump to believe the Heat Pump is installed inside a "Real" House.

The simulator sends temperature setpoints to the temperature controller that is located in Outdoor- and Indoor Equipment devices. Optionally, the Dynamic Operation will simulate the temperature setpoints for the Buffer Tank- and Hot Water Equipment devices.

The dynamic simulator also controls and operates the simulation of the transitions between various SG-Ready Modes. This is done by setting the appropriate SG bit high or low on the two binary inputs on the Heat Pump, depending on the requested SG-Ready Mode. Optional, this can be done over a communication interface.

The simulator calculate the temperature increases/decrease to be sent to the Outdoor- and Indoor Equipment devices, these calculations are based on the used thermal power of the Heat Pump and the Dynamic House Model used. The dynamic House model logic is decribed in section Description of dynamic house model.

Description of dynamic house model Logic

In order to be able to verify the SG readiness of the Heat Pump, it is important that the Heat Pumps responds correctly to the SG-Ready signals therefore, the test system must act and react in the same way, as a house would do. That is, if the Heat Pump and/or immersion heater runs the temperature is increased in the "housing", and when the Heat Pump and/or immersion heater is not running, the temperature will fall. The variation in temperature will depending on the thermal capacity of the system. The thermal loss to the surroundings depends on the thermal envelope of the house and the outdoor temperature.

In the event that the Heat Pump is fitted with a Hot Water Tank or a Buffer Tank, the test system must act and react similarly as those devices would. That is, if the Heat Pump and/or immersion heater runs the temperature in the tanks increases. If the Heat Pump and/or immersion heater is not running, or a hot water outlet is open, then temperature will drop depending on the insulation and the thermal capacity of the system. The thermal loss to the surroundings depends on how fast the water is drained from the tanks and the ambient temperature of the system.

Heat Pumps increases the thermal energy delivery by either increasing the flow or temperature in the system, or both.

When there is a constant water flow in the output circuit, the Heat Pump will increase/decrease the temperature of the output circuits when affected by SG-Ready signals. Subsequently, cause changes in energy supply, which in turn causes an increase respectively a decrease of the Heat Pump power consumption, which can be read on the electricity meter. We can therefore conclude that the electricity consumption in influenced by the SG-Ready control signal, hence the change in electricity consumption can determine if the Heat Pump is SG-Ready or not.

SG-Ready simulation

The primary Solution Method; "the dynamic house".

The indoor temperature in the "house" rises and falls as described in equivalent model, the Heat Pump will perform as if it was installed in a real house. Therefore, the power consumption of the Heat Pump must match the selected SG-Ready Mode, hereby enabling the verification of the selected SG-Ready Mode.

Alternative Solution Method; temperature setpoint as a function of SG-Ready Modes.

The indoor temperature of the "house" rise and fall depending on the SG-Ready Modes. The Heat Pump internal control system regulate the internal offset of the forward temperature in the output circuit, up or down depending of the SG-Ready Mode. The indoor temperature of the "house" is adjusted up/down to the setpoint of the selected SG-Ready Mode, where it is held steady, while it is checked if the internal automatic control system in the Heat Pump, starts or stops Heat Pump accordingly, alternatively the timeout on the 2 timer expires.

Logic for SG-Ready Mode:

Regardless, which solution method is used, it is required, that the simulator controls the switching between the various SG-Ready Modes; this is done by setting the two SG-bit outputs high or low depending of the SG-Ready Mode required.

In order to verify the SG-Readiness of the Heat Pump, the logic for SG-Readiness switches the Heat Pump from SG-Ready Mode A to Mode B. After a delay time of 2 hours, the logic switches to Mode C, again a delay time of 2 hours is implemented, this sequence is done until the Heat Pump have done transitions to/from all relevant SG-Ready Modes.

This delay time is set to 2 hours, but it is expected that this can be optimized for smaller delays; this may depend on the different Heat Pump types and brands.

Figure 15 shows the transitions to be tested, indicated by grey are the illegal states.

Før			Action		Forventet Resultat		
HP	Ønsket FremløbsTemperatur	Målt Aktiv Effekt på HP	Fra Mode	Til Mode	HP	Ønsket FremløbsTemperatur	Målt Aktiv Effekt på HP
Kører	Normalt level	Normalt niveau	Normal Operation	Must Stop	Stopper	Ingen Ændring	Faldende til lav
Kører Ikke	Normalt level	Lavt Niveau	Normal Operation	Must Stop	Kører Ikke	Ingen Ændring	Ingen Ændring
Kører	Normalt level	Højt niveau	Normal Operation	High	Kører	Stigning til High Level	Stigende til høj
Kører Ikke	Normalt level	Lavt Niveau	Normal Operation	High	Starter	Stigning til High Level	Stigende til høj
Kører	Normalt level	Højt niveau	Normal Operation	Must Max	Kører	Stigning til Must Max Level	Stigende til høj
Kører Ikke	Normalt level	Lavt Niveau	Normal Operation	Must Max	Starter	Stigning til Must Max Level	Stigende til høj
Kører Ikke	Normalt level	Lavt Niveau	Must Stop	Normal Operation	Starter	Ingen Ændring	Stigende til høj
Kører Ikke	Normalt level	Lavt Niveau	Must Stop	High	Starter	Stigning til High Level	Stigende til høj
Kører Ikke	Normalt level	Lavt Niveau	Must Stop	Must Max	Starter	Stigning til Must Max Level	Stigende til høj
Kører	Normalt level	Normalt niveau	Must Stop	Normal Operation	Kører Ikke	Ingen Ændring	Ingen Ændring
Kører	Normalt level	Højt niveau	Must Stop	High	Kører Ikke	Stigning til High Level	Ingen Ændring
Kører	Normalt level	Højt niveau	Must Stop	Must Max	Kører Ikke	Stigning til Must Max Level	Ingen Ændring
Kører	High level	Normalt niveau	High	Normal Operation	Kører	Falder til Normalt level	Faldende til lav
Kører Ikke	High level	Lavt Niveau	High	Normal Operation	Kører Ikke	Falder til Normalt level	Faldende til lav
Kører	High level	Højt niveau	High	Must Max	Kører	Stigning til Must Max Level	Stigende til høj
Kører Ikke	High level	Lavt Niveau	High	Must Max	Starter	Stigning til Must Max Level	Stigende til høj
Kører	High level	Normalt niveau	High	Must Stop	Stopper	Falder til Normalt level	Faldende til lav
Kører Ikke	High level	Lavt Niveau	High	Must Stop	kører Ikke	Falder til Normalt level	Faldende til lav
Kører	Must Max level	Normalt niveau	Must Max	Normal Operation	Kører	Falder til Normalt level	Faldende til lav
Kører	Must Max level	Højt niveau	Must Max	High	Kører	Falder til High Level	Faldende til lav
Kører	Must Max level	Normalt niveau	Must Max	Must Stop	Stopper	Falder til Normalt level	Faldende til lav
Kører Ikke	Must Max level	Lavt Niveau	Must Max	Normal Operation	Kører	Falder til Normalt level	Stigende til høj
Kører Ikke	Must Max level	Lavt Niveau	Must Max	High	Kører	Falder til High Level	Stigende til høj
Kører Ikke	Must Max level	Lavt Niveau	Must Max	Must Stop	Kører Ikke	Falder til Normalt level	Ingen Ændring

Figure 15 The transition steps for verifying SG-Ready Modes.

Equipment Simulator

Equipment simulator is distributed into the following sub simulators, Equipment Simulator Heat Pump Stand, Outdoor Equipment Simulator, Indoor Equipment Simulator, Buffer Tank Equipment Simulator (Optional) Hot Water Equipment Simulator (Optional).

All relevant information is logged in, respectively, temperature measuring, measuring power and energy flow measuring, and then they can be used for analysis and verification of the component's SG-Readiness.

Equipment Simulator Heat Pump Stand

The Equipment Simulator Heat Pump Stand is the test stand at the Danish Technological Institute's test in Aarhus; here the Heat Pump will be installed for testing.

All heating/cooling circuits, as the specific Heat Pump is equipped with, is connected, whereby the Heat Pump SG-Ready conformity can be tested.

Heating/cooling circuits for Brine/House and optional, Hot Water Tank and Buffer Tank, are controlled by DTI LabVIEW equipment with underlying program code, described in Simulator Static Operation and Analyser.

Equipment Simulators "Dynamic House Platform"

The goal is to build a test platform where it is possible to simulate a random house from programmable characteristics. The DUT is tested by manipulating the SG-Ready control signals to the SG-Ready Heat Pumps, and by manipulating the surroundings of the Heat Pump according to the operation of the Heat Pump.

Using the following equipment Simulators it will be possible to simulate the thermal load in a house, with variable programmable house designs.

- Indoor Equipment Simulator.
- Outdoor Equipment Simulator.
- Buffer Tank Equipment Simulator (Optional).
- Hot Water Tank Equipment Simulator (Optional).

In order to ensure the Indoor Equipment Simulator simulates the increase/decrease in temperature, depending of the operation of the Heat Pump, a calculated setpoint of the indoor temperature are sent from the Dynamic Simulator to the Indoor Equipment Simulator via suitable communication.

The Dynamic Simulator transmit temperature setpoint based on the temperature calculations computed in the Dynamic House Logic module. These values are transmitted to the external temperature sensor/controller located inside the Indoor Equipment Simulator. Equivalent, for the Outdoor Equipment Simulator, here the Dynamic Simulator dispatched the outdoor temperature setpoint calculated in the Dynamic House Logic module. The outdoor temperature is simulated 2º continuously, hereby ensured that the Heat Pump starts and stops by the influence of SG-Ready Modes. It will, however be possible to calculate and transmit various outdoor temperature setpoint values to the Outdoor Equipment Simulator, if requested (e.g. weather forecast).

It is possible to set different temperature setpoints to the different Equipment Simulators simultaneously. The Equipment Simulators receive the temperature setpoints and regulate the temperature of the Equipment Simulators using cooling, heating and ventilation until the requested setpoint temperature is reached. The regulation of the Equipment Simulators must be able to regulate with 0,1° resolution, but 0,2° absolute accuracy. The logic should be designed so that the slope of the setpoints can be adjusted, however, are expected to have a slope of 1° C per minute for the Equipment Simulators. It is desired that these gradient coefficients can be set individually for each Equipment Simulators.

There will be installed a reference measurement of the temperature in all Equipment Simulators.

Similar logic could be added to both Buffer Tank Equipment Simulator and Hot Water Tank Equipment Simulator, this was not part of the scope of this document.

Schematic test setup based on IEC 61850-10 reference model.

Following the previous described partitions which are using the IEC 61850-10 naming structure, and will it be possible to create a test setup for testing the SG-Readiness of Heat Pumps in accordance to the EIC 61850-10 reference model.

A schematic layout vision by the SGO for a IEC 61850-10 test setup is showed in Figure 16.

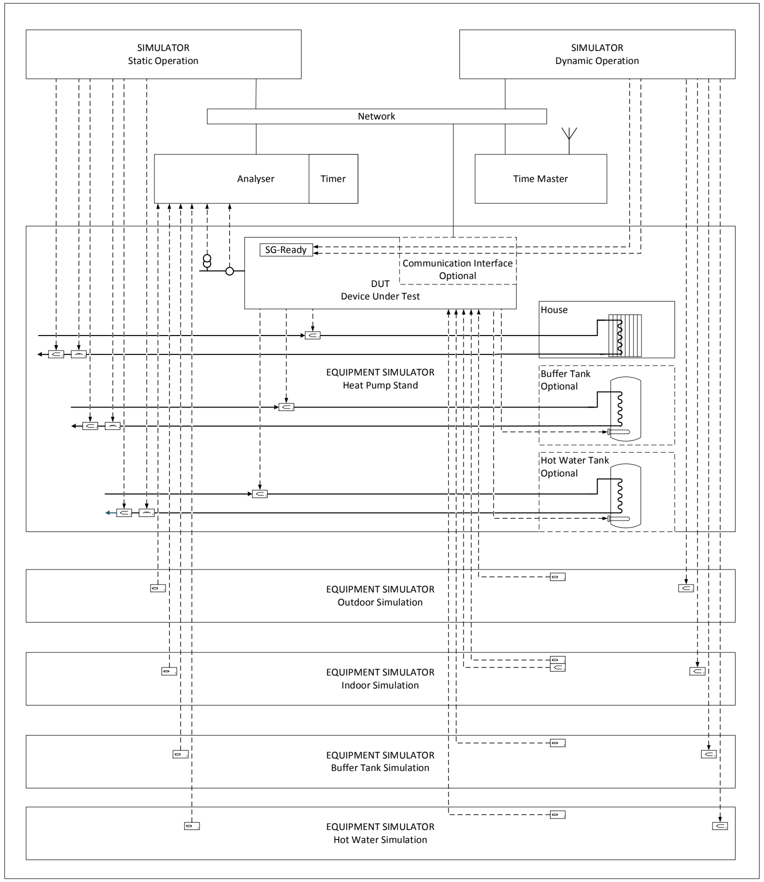


Figure 16 Schematic Test Setup based on IEC 61850-10 model

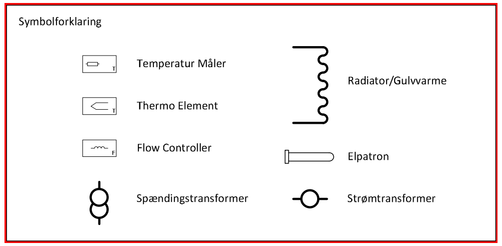


Figure 17 Legend of Figure 16

Test specification and requirements

In connection with the testing of the functionality of the Heat Pump, which will include the Smart Grid Ready functionality, install the Heat Pump in a test environment that simulates the thermal load of a house, with programmable characteristics for these.

The essential test equipment is the certified test system, which stresses the Heat Pump thermally in programmable static operating points over a wide temperature range and power range, targeted efficiency measurement according to DS/EN16147, DS/EN12102, DS/EN14511, DS/EN14825 amongst other.

The test system used for the Heat Pump normally apply to operational excellence, for test of the SG-Readiness temperature sensors have been added to the Heat Pump, and comfort control of the indoor temperature of a house is being simulated.

Heat Pumps are offered with a dedicated inside temperature sensor often with proprietary communication, an outdoor temperature sensor, and in some cases also additional sensors for example. used in Buffer Tank.

Since the original temperature sensors from different Heat Pump suppliers may have different physical form and function, it has been decided that for the simulation of a house to allow the use of the original sensors rather than disrupt the sensors that the supplier has already approved.

The test system consequently added two programmable temperature chambers, which simulate respectively indoor and outdoor temperature.

To the test system a dynamic simulation manager is added, based on a simulation model of a house, the dynamic simulation manager can control the periphery settings for the Heat Pump. The dynamic simulator will measure power supply and calculate the change in the housing indoor temperature as a function of the heat balance with the surroundings.

The test system will initially be used to analyse Heat Pumps response to Smart Grid control signals as agreed by the BWP under SG-Ready predicate.

It is desired that the test system can collect all necessary data from analyses, such as the electric power consumption, the use of activation/deactivation of the various SG-Ready Modes. Based on the thermal power of the Heat Pump, the house temperature increase/decrease is calculated.

The primary method for verifying SG-Ready Modes, based on thermal energy supply

Verification of SG-Ready function will be achieved partly as confirmation of the operation of individual modes for up to two hours, partly by monitoring expected change between various SG-Ready Modes. Recognition of change between SG-Ready modes is primarily recognized through changes in thermal energy supply of the Heat Pump. This requires first a verification and characterization of the Heat Pump's normal operation, so that the deviation can be recognized and attributed to specific SG-Ready Modes.

The way to verify if the Heat Pump switches to specific SG-Ready Modes, is to monitor if the thermal energy flow to the Heat Pump, follows the desired SG-Ready Mode.

Test of Normal Operation Mode:

Heat Pump starts in Normal Operation and indoor temperature in Indoor Equipment Simulator (T_{Indoor}) set to the same value as the heat inside temperature setpoint of the Heat Pump ($T_{Indoorsetpoint}$), (f. Ex. $T_{Indoor} = T_{Indoorsetpoint} = 20°C$.)

Outdoor Equipment Simulator temperature ($T_{outdoor}$) is fixed at 2°C.

When the Heat Pump is running, which is measured on thermal energy supply, indoor temperature in house simulation increases the T_{Indoor} with the temperature increase as the equivalent model prescribes.

When the Heat Pump has stopped, T_{Indoor} falls as the model prescribes. This means the Heat Pump will start and stop in the same interval which is seen in power consumption, thus it can be verified that the Heat Pump is in Normal Operation Mode. Moreover, it is verified that the house the simulation is configured correctly according to the internal temperature logic manager of the Heat Pump.

It will be possible to log the integral of the thermal energy supply of the Heat Pump during Normal Operation Mode; this is later used to test the Run Higher Mode and Must Max Mode.

Test of transition from Normal Operation Mode to Run Higher Mode:

Heat Pump starts in Normal Operation and indoor temperature in Indoor Equipment Simulator (T_{Indoor}) set to the same value as the heat inside temperature setpoint of the Heat Pump ($T_{Indoorsetpoint}$), (f. Ex. $T_{Indoor} = T_{Indoorsetpoint} = 20°C$.)

Outdoor Equipment Simulator temperature ($T_{outdoor}$) is fixed at 2°C.

When the Heat Pump stops after 2 hour of Normal Operation, it is switched in Run Higher Mode and it is expected that the Heat Pump start, this is seen in an increase in thermal energy supply.

When the Heat Pump is running, which is measured on thermal energy supply, indoor temperature in house simulation increases the T_{Indoor} with the temperature increase as the equivalent model prescribes. When the Heat Pump has stopped, T_{Indoor} falls as the model prescribes.

It will be possible to log the integral of the thermal energy supply of the Heat Pump during Run Higher Mode operation.

It is expected that the Heat Pump will allow a larger energy intake and will therefore run longer than in Normal Operation Mode before it stops (cycle time and/or the duty cycle is increased relative to Normal Operation Mode), thus being active for longer than in Normal Operation Mode and that cooling compressor timeout is the same as in Normal Operation Mode.

The time delay between the running's of the Heat Pump is similar to the one in Normal Operation Mode, but the integral of the thermal energy supply will be higher than the thermal energy supply in Normal Operation, hereby it can be verified that the Heat Pump operates in Run Higher Mode.

Test of transition from Normal Operation Mode to Must Max Mode:

Heat Pump starts in Normal Operation Mode and indoor temperature in house simulator controller (T_{Indoor}) set to the same value as the heat inside temperature gauge ($T_{Indoorsetpoint}$), (f. Ex. $T_{Indoor} = T_{Indoorsetpoint} = 20°C$.)

Outdoor Temperature ($T_{outdoor}$) is fixed at 2°C.

When the Heat Pump stops after 2 hour of Normal Operation, it is switched in Must Max Mode and it is expected that the Heat Pump start, this is seen in an increase in thermal energy supply.

When the Heat Pump is running, which is measured on thermal energy supply, indoor temperature in house simulation increases the T_{Indoor} with the temperature increase as the equivalent model prescribes. When the Heat Pump has stopped, T_{Indoor} falls as the model prescribes.

It will be possible to log the integral of the thermal energy supply of the Heat Pump during Must Max operation.

It is expected that the Heat Pump will allow a larger energy intake and will therefore run longer than in Normal Operation Mode before it stops (cycle time and/or the duty cycle is increased relative to Normal Operation Mode), thus being active for longer than in Normal Operation Mode. The cooling compressor timeout is forced in relation to the normal operation mode and therefore the interval between the start-up of the compressor to be shorter than the normal operation mode, hereby verifying the heat operates in Must Max Mode.

Test of transition from Normal Operation Mode to Must Stop Mode:

Heat Pump starts in Normal Operation Mode and indoor temperature in house simulator controller (T_{Indoor}) set to the same value as the heat inside temperature gauge ($T_{Indoorsetpoint}$), (f. Ex. $T_{Indoor} = T_{Indoorsetpoint} = 20°C$.)

Outdoor Temperature ($T_{outdoor}$) is fixed at 2°C.

When the Heat Pump is put in Must Stop Mode, it is expected that the Heat Pump stop. Which seen a decrease in thermal energy supply. When the Heat Pump has stopped, T_{Indoor} falls as the model prescribes.

It is expected that the Heat Pump starts again when TIndoor reach the critical level for the facility (5°C/defrosting level) or after 2 hours, whichever comes first, thus it can be verified that the Heat Pump run in Must Stop Mode.

It will be possible to test the remaining transition shifts according to the same method.

Specification

Simulator/Analyser

The Simulators both Dynamic and Static and the Analyser is installed on a dedicated PC.

- 2 x RS-232 (could be a USB to RS-232 converter)
- Installed with the following LabVIEW Software
  - NI SignalExpress

        - Windows 8/Windows 7/Vista/XP SP3/Server 2003 R2 (32-bit)/Server 2008 R2 (64-bit)
        - 1 GB of RAM
        - 2 GB of free disk space
        - Pentium 4 processor or equivalent
    - LabVIEW Real-Time Module
        - LabVIEW Full or Professional development system (32-bit) for Windows plus the following:
        - 200 MB additional available disk space
        - Real-time target hardware and driver software
        - You might need more memory than the recommended minimum for LabVIEW depending on the size of the application you design in LabVIEW on the host computer
    - LabVIEW Datalogging and Supervisory Control Module
        - LabVIEW Base, Full, or Professional development system (32-bit) for Windows plus the following:
        - 2.5 GB additional available disk space
        - 512 MB of RAM. National Instruments recommends 1 GB of RAM
        - Internet Explorer 6 Service Pack 1 or later

SG-Ready Simulation

The SG-Ready Simulation consist of two controllable output, wired to the DUT as potential free contacts. These contacts are located in the Agilent, which is a standard part of the DTI test system.

- 2 potential free contacts
    - One for SG-Ready A
    - One for SG-Ready B

Indoor Equipment Simulator.

- Must be able to regulate the temperature range + 2° - + 40º, the adjustment happens in steps of 0,1º
- Interior dimensions minimum (B/D/H mm) 250x250x100
- Glass Door
- Through wiring in connection with the doorway as wire, separation is not required.
- The box is desired mobile so that it can be moved rounded as required.
- Ensure that there is adequate air circulation so that temperature measurements are accurate
- External control of temperatures by means of cooling Controller of the type Laird PR57, using serial communications.
- Communication Interface
    - RS232
    - 115200 baud, 1 start, 8 bits, 1 stop, no parity
    - Master/Slave implementation where Simulator Dynamic Operation Master and Laird controls are slaves.
    - Communication protocol Super Cool Serial Command Interface (SSCI_v1.6c)
- Signals

    - Reference Temperature, to be connected to the DTI LabVIEW via the Agilent system.
    - Temperature setpoint, to be sent to the Laird Controller periodically every 10 seconds. This sampling rate must be changeable as a parameter for optimizing any test sequences.

Outdoor Equipment Simulator.

- Must be able to regulate the temperature range - 35° - +35º, the adjustment happens in steps of 0,1º
- Interior dimensions minimum (B/D/H mm) 250x250x100
- Through wiring in connection with the doorway as wire, separation is not required.
- The box is desired mobile so that it can be moved rounded as required.
- Ensure that there is adequate air circulation so that temperature measurements are accurate
- External control of temperatures by means of cooling Controller of the type Laird PR57, using serial communications.
- Communication Interface
    - RS232
    - 115200 baud, 1 start, 8 bits, 1 stop, no parity
    - Master/Slave implementation where Simulator Dynamic Operation Master and Laird controls are slaves.
    - Communication protocol Super Cool Serial Command Interface (SSCI_v1.6c)
- Signals
    - Reference Temperature, to be connected to the DTI LabVIEW via the Agilent system.
    - Temperature setpoint, to be sent to the Laird Controller periodically every 10 seconds. This sampling rate must be changeable as a parameter for optimizing any test sequences.

Timer/Time Master

To verify that SG-Ready Mode Must Stop is active in max 2 hours timer a timer must be used. This timer has an accuracy of 1 second. In the test specified in section The primary method for verifying SG-Ready Modes, based on thermal energy supply, a 2 hour timer also have been specified.

Time master is used to synchronize the test system to ensure the accuracy of the test platform. An NTP server is used for time master.

- Accuracy
    - Free run, one day
        - $\pm 1 \cdot 10^{-7}$, ±1Hz (The accuracy in Hertz is based on the standard frequency of 10 MHz. For example: Accuracy free run one day is $\pm 1 \cdot 10^{-7} \cdot 10$MHz = ± 1 HZ)
    - Free run, one year
        - $\pm 1 \cdot 10^{-6}$, ±10 Hz
    - GPS-synchronous, averaged 24h,
        - $\pm 1 \cdot 10^{-11}$

- Communication Interface
    - RJ-45 Network Connection 10/100 Mbit
    - Internet Protocol (IP)
        - IP v4, IP v6
    - Network Time Protocol (NTP)
        - NTP v2 (RFC 1119), NTP v3 (RFC 1305), NTP v4 (RFC 5905), SNTP v3 (RFC 1769), SNTP v4 (RFC 2030)
    - Time Protocol (TIME)
        - Time Protocol (RFC 868)
    - Daytime Protocol (DAYTIME)
        - Daytime Protocol (RFC 867)

Test Reports

This document covers a feasible method to be able to test if a Heat Pump is SG Ready in accordance to the German SG-Ready label. A template for a Test Report, which is in alignment with the IEC 61850-10, conformance testing of communication networks and systems for power utility automation, have been designed during the project.

Reference System

A reference system was designed during the project for more details of the reference system please see ***"WP 3 Report CAA?"***.

Unit/System Test

In the enclosed document, principles behind a SG-Ready conformance test of Heat Pumps have been described in details. In the document ***"WP4 Example of Test Report SG-Ready Test of Heat Pumps D4-2 revision 2015-07-24"*** a more detailed test procedure is described.

Final Result

Currently we have made several "hand test" of various Heat Pumps, and as such, do not have a conclusion of the test. However, in chapter "Real Life" power consumption and SG-Ready Mode, the result of test item B is shown.

Recommendation

During the project, the focus was to define a conformance test for SG-Ready components. We have noted considerable difficulties in designing a test setup, in which it was possible to put the DUT in a test environment as a "Black Box". The reason for the "Black Box" test was to avoid tampering with already approved hardware delivered by the supplier. In order to ensure proper responds from the DUT, when executing the SG-Ready Modes, an "intelligent" house had to be designed. As explained in the document this was done by adding two controllable cooling/heating units to the test bench at DTI in Aarhus.

Hereafter, it was possible to detect the response from a tested on-off Heat Pump as a result of the enforced SG-Ready modes. But similar results could not be detected on an inverter driven heat

pump. The evaluation from the tests is that both air and water circuits must be dynamically simulated to create a realistic scenario for the heat pump to operate in. The dynamic house model already has basic water temperature simulation that can be used to control the test setup. Unfortunately only a manual entry of set temperatures is possible for the accredited static heat pump test core system, that is designed to keep the water temperature very stable. A long time was used in an attempted to acquire Labview drivers for the constant temperature control equipment without luck. DTI specialists has claimed it technically possible to design a completely new Labview water-temperature control system instead of the current proprietary system but assessed not feasible within the frames of the project. It would require a complete mapping of current temperature sensors and proprietary actuators in the regulation system to design a completely new water-temperature control loop and a new control display interface. Additional a very thorough test would be needed to demonstrate stability with tight limits to maintain the accreditation of the system. Only after completion of the stability test could an interface to the dynamic house simulation be added and tested with a SG Ready heat pump.

Standardisation

Although we have faced challenges in the test setup, we recommend to continue the exploitation of the SG-Ready bits defined by BWP. We see the great potential to use these bit in other applications then Heat Pumps, e.g. EVs. However, there is a need for a clear definition of the four SG-Ready Modes, in the chapter The SGO definition of the SG-Ready signal, we have described our interpretation of the SG-Ready bits. We see a considerable need for a clear and uniform definition of the SG-Ready bits; it would be a great use if this could be added to the ongoing standardisation work.

Based on our work we strongly recommend the future communication interface, which is a must for the implementation of Heat Pumps in the future grid, to be standardised.

We have investigated both the OpenADR and the IEC 61850 protocols and our strong recommendations are to implement the IEC 61850 standard.

Power system

One of the aspects, we have realised during SGO, is that the delay in compressor start makes a challenge for future grid operators. The current challenge is that the delay is different between the various manufactures and types; this puts forward a challenge when DSO/BRP or an aggregator wishes to use these components for grid supporting activities.

We have also realised a potential conflict of how, the owner of the Heat Pump and the actors on a upper level e.g. DSO/BRP aggregator, wishes to operate the Heat Pump.

We therefore recommend that more information to be provided upwards in the grid topology, for possible usage at DSO/BRP or aggregator level.

Product

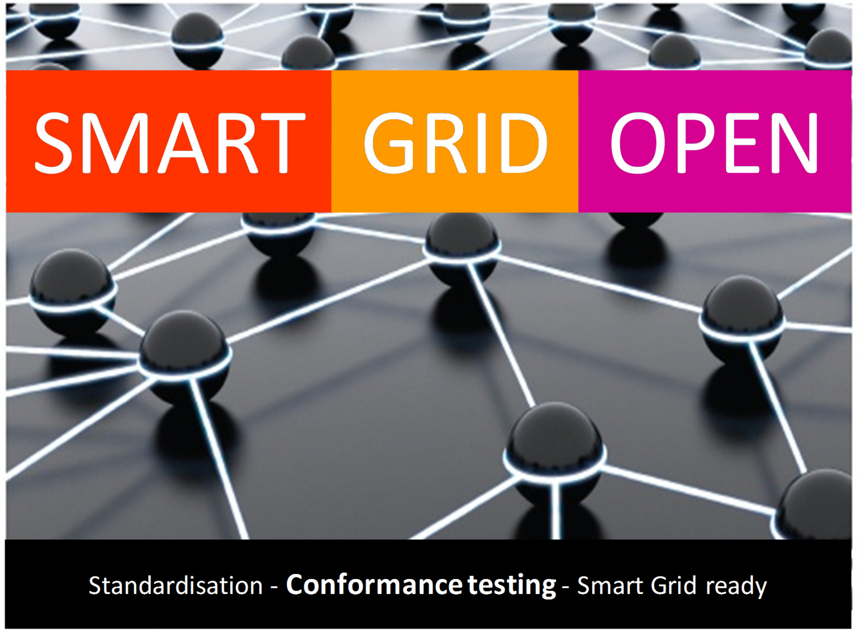
We have during the SGO project defined the meaning of the SG-Ready Modes. In this process we took special care of the definition of the SG-Ready Run Higher Mode and the SG-Ready Must Max Mode. We recommend the industry to implement these definitions or acknowledgement another definition of the SG-Ready modes.

ANNEX E. SGO Test Report example - SG-Ready Heat Pump Test

- **follow on the next pages.**

Example of Test Report for SG-ready conformance test on on/off-type of Heat Pump.

SGO Test Report example - SG-Ready Heat Pump Test



Deliverable D4-2

ANNEX E – SGO Test Report example - SG-Ready Heat Pump Test

Conformance Test Report on on/off-type of SG-ready Heat Pump

Contents

Figures

Tables

Scope

The purpose of this document is to give an example of a proposed layout of final Test Report, used when testing the conformance of Heat Pumps, in relation to the SG-Ready specification.

The layout of the Test Report is based on the IEC 61850-10, conformance testing of communication networks and systems for power utility automation.

The work approach is in line with the methods developed in connection with the EU M/490 mandate.

Anglebrackets "<" and ">" are used to indicate information to be entered at time of test.

1. Introduction

The document Test Report Methods Heat Pumps (Smart grid Open deliverable D4-1) Outline test methods and recommendations relating to conformance testing.

This document is an example only of systematic test and it is not intended to include all aspects addressed in the Test Report Methods Heat Pumps (SGO D4-1). This document example is designed for on/off-type of heat pumps. Tests to characterise the heat pump for aggregation is not included e.g. typical power change from step to step; typical reaction time from command to result etc.

1.1. Identifications

The following table gives the exact identification of tested equipment and test environment used for this conformance test.

DUT	<complete description of the device under test, type, hardware / software version>
MANUFACTURER	<name, location of the manufacturer of the DUT>
TEST INITIATOR	<the initiator of the test, name, address, contact person>
TEST FACILITY	<test facility name> <accredited/recognized to issue Level A/B/C Certificates>
TEST ENGINEER	<name and e-mail address of test engineer>
TEST SESSION	<date and location(s) of the test session>
SIMULATOR	<name and type conformance test simulator version X.Y with reference test suite, version X.Y and Test parameters file>
ANALYSER	<name and type analyzer, version X.Y>
EQUIPMENT SIMULATOR/	<name and type equipment simulator>

HEAT PUMP SIMULATION STAND	
INTELLIGENT HOUSE SIMULATORS/INDOOR SIMULATION	<name, type, hardware / software version>
INTELLIGENT HOUSE SIMULATORS/OUTDOOR SIMULATION	<name, type, hardware / software version>
TIMER	<name and type of time master>
TIME MASTER	<name and type of time master>

NOTE; the TEST FACILITY or MANUFACTURER can provide the documents in digital or printed format

1.2. Background

<OPTIONAL, short description on the environment where the *DUT* will be used>

The *TEST FACILITY's* assignment was to answer the following question:

"Does the implementation of the DUT, conform to the SG-Ready label?"

To answer this question, *TEST FACILITY* has performed a **conformance test** of the SG-Ready implementation in the *DUT*. This test has been performed according to procedures and conditions set forth by the SGO Project.

TEST FACILITY is accredited/recognized to perform formal conformance tests and issue the certificate.

1.3. Purpose of this document

The purpose of this document is to describe the conformance test procedure and results of the *TEST SESSION* concerning the SG ready implementation in the *DUT*.
The test results are the basis of the conformance statement.

1.4. Contents of this document

Chapter 2 shows the list of relevant normative and other references, used to provide input for the conformance test.

Chapter 3 describes the various relevant components for the conformance test and their configuration as used in the conformance test, including the DUT. This chapter also gives an overview and introduction to the various test groups that together constitute the conformance test.

Chapter 4 and 5 give an overview and summary of the test results, the conclusion(s) and recommendations.

1.5. Glossary

DUT Device Under Test

2. REFERENCES

2.1. Normative

The tests defined in this document are based on the following IEC 61850 documents.

IEC 61850-10, *Communication networks and systems in substations – Part 10: Conformance testing; First edition 2005-05*

2.2. Other

IS 9646 – OSI – Conformance testing methodology and framework.

3. THE CONFORMANCE TEST

3.1. Components in the test environment

The test environment consists of the following components:

- DUT
- SIMULATOR
- ANALYSER
- EQUIPMENT SIMULATOR/HEAT PUMP SIMULATION STAND
- INTELLIGENT HOUSE SIMULATORS
- Ethernet switching HUB (future option for web-based SG ready signals)
- Time master
- Timer

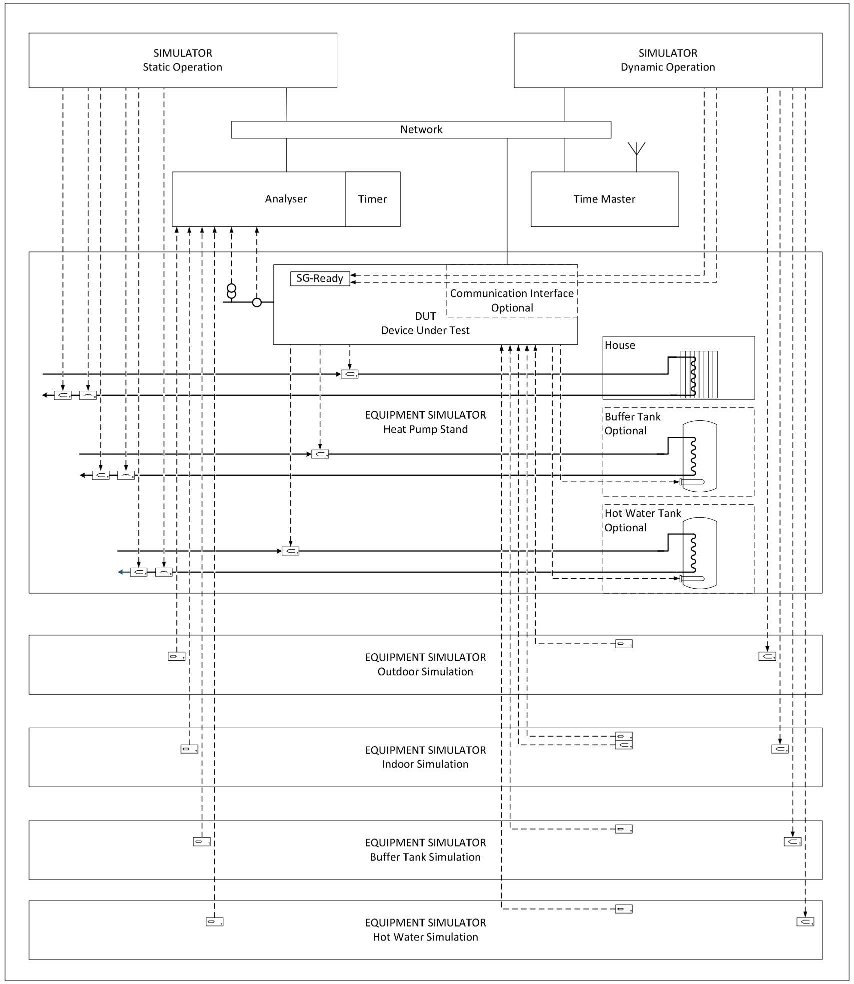


Figure 1: Principle Test Environment including optional DUT-system components

3.2. Overview of the test suite

The SG-Ready test cases are structured as follows:

- Documentation and version control
- Configuration file
- Mapping of SG-Ready model and services
    - Control

4. TEST RESULTS

Tables Table 1 and Table 2 in this Chapter give an overview of the conformance test results. References shown in the table columns refer to the individual test procedures in Annex A.
The Mandatory column indicates the mandatory test cases and the Conditional column indicates the same for the conditional test cases. The Inconclusive column indicates those test cases that did not pass nor fail.

Table 1: Overview of applicable test cases passed for DUT

Conformance Block	Mandatory	Conditional
1:Documentation	Doc1, Doc2, Doc3	
2: Configuration	Cnf1	
3: Control	Ctl1, Ctl2, Ctl3 ETC CtlN1, CtlN2, CtlN3 ETC….	

Table 2: Overview of applicable test cases failed, inconclusive or comments for DUT

Conformance Block	Inconclusive	Failed	Comment
<block>	<testcase>	<testcase>	<testcase>

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the test results described in this report, TEST FACILITY declares the tested SG-Ready implementation in the DUT has **shown/not shown to be non-conforming** to SG-readiness as specified in the SG-Ready Label.
.

5.1. Recommendations following from the test

The following comments and recommendations apply for the *DUT*:
<Comments and Recommendations from *TEST FACILITY*>

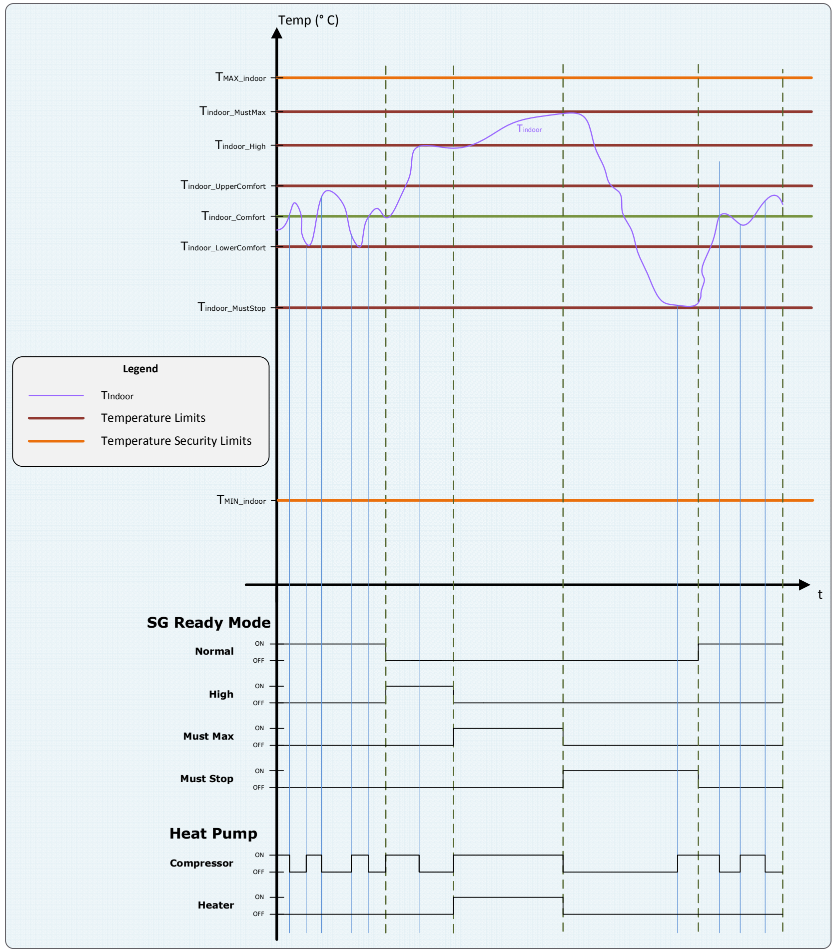


Figure 2: Temperature Definitions (Tindoor is not actual but only to illustrate relation)

Precondition

Check firmware status and system setup ☐

Test of indoor temperature measuring ☐

Check the HP is regulating as a function of the temperature in the simulated house ☐

Annex A. Detailed Test Procedures and Result

Annex A.1. Documentation

ID	Test Procedure	Verdict
Doc1	Check if the manufacturer documentation and hardware/software versions of the DUT do match: a) SG-Readiness b) Indoor temperature thermostat c) Outdoor temperature thermostat d) Hardware/software version match	Passed ☐ Failed ☐ Inconclusive ☐
Doc2	Verify the wiring is according to the manufacturer documentation of the DUT do match: a) SG-Readiness b) Indoor temperature thermostat c) Outdoor temperature thermostat d) Buffertank temperature thermostat (option)	Passed ☐ Failed ☐ Inconclusive ☐
Doc3	Verify the heat pump system connection is according to the manufacturer documentation of the DUT do match: a) Indoor unit b) Outdoor unit c) Buffertank (option)	Passed ☐ Failed ☐ Inconclusive ☐

Annex A.2. Basic Configuration

ID	Test Procedure	Verdict
Cnf1	Test if the heat pump configuration file conforms to expected normal behaviour in the house simulation system during normal operation a) Indoor temperature increase/decrease b) Outdoor temperature increase/decrease	Passed ☐ Failed ☐ Inconclusive ☐

Annex A.3. Mapping of object models and services

Table 3: Mapping of object models and services per conformance blocks

Conformance Block	**Mandatory**	**Conditional**
3: Control	Operate	

Table 4: Test procedures per conformance blocks

Conformance Block	**Mandatory**	**Conditional**
3: Control	Ctl1, Ctl2, Ctl3 etc. CtlN1, CtlN2, CtlN3 etc.	

Annex A.3.1. Control

Test Reference	Test Purpose	Test Result
Ctl1	To test if the Heat Pump is affected when switching from Normal Operation to Must Stop when the Heat Pump is Running	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Dropping to Lower level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: Normal Operation 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Stop 3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: Must Stop 5. Let the Heat Pump run in SG Mode: Must Stop for 3 hours. 6. Switch back to Normal Operation		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl2	To test if the Heat Pump is affected when switching from Normal Operation to Must Stop when the Heat Pump is Not Running	☐ Passed ☐ Failed ☐ Inconclusive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Not Changed after step 4.		
Test Description 1. Heat Pump operating in SG Mode: Normal Operation 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Stop 3. Ensure the Heat Pump is Not Running. This can be verified by measuring the active power to be Low Level 4. Switch the Heat Pump into SG Mode: Must Stop 5. Let the Heat Pump run in SG Mode: Must Stop for 3 hours. 6. Switch back to Normal Operation		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl3	To test if the Heat Pump is affected when switching from Normal Operation to High when the Heat Pump is Running	☐ Passed ☐ Failed ☐ Inconclusive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Increasing to Higher Level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: Normal Operation 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: High 3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: High 5. Let the Heat Pump run in SG Mode: High for 3 hours. 6. Switch back to Normal Operation		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl4	To test if the Heat Pump is affected when switching from Normal Operation to High when the Heat Pump is Not Running	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Increasing to Higher Level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: Normal Operation 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: High 3. Ensure the Heat Pump is Not Running. This can be verified by measuring the active power to be Low Level 4. Switch the Heat Pump into SG Mode: High 5. Let the Heat Pump run in SG Mode: High for 3 hours. 6. Switch back to Normal Operation		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl5	To test if the Heat Pump is affected when switching from Normal Operation to Must Max when the Heat Pump is Running	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Increasing to Higher Level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: Normal Operation 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Max 3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: Must Max 5. Let the Heat Pump run in SG Mode: Must Max for 3 hours. 6. Switch back to Normal Operation		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl6	To test if the Heat Pump is affected when switching from Normal Operation to Must Max when the Heat Pump is Not Running	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Increasing to Higher Level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: Normal Operation 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Max 3. Ensure the Heat Pump is Not Running. This can be verified by measuring the active power to be Low Level 4. Switch the Heat Pump into SG Mode: Must Max 5. Let the Heat Pump run in SG Mode: Must Max for 3 hours. 6. Switch back to Normal Operation		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl7	To test if the Heat Pump is affected when switching from Must Stop to Normal Operation when the Heat Pump is Not Running	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Increasing to Higher Level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: Must Stop 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Normal Operation 3. Ensure the Heat Pump is Not Running. This can be verified by measuring the active power to be Low Level 4. Switch the Heat Pump into SG Mode: Normal Operation 5. Let the Heat Pump run in SG Mode: Normal Operation for 3 hours. 6. Switch back to Must Stop		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl8	To test if the Heat Pump is affected when switching from Must Stop to High when the Heat Pump is Not Running	☐ Passed ☐ Failed ☐ Inconclu-sive

Reference to Clause and Subclause in Standardization Document
"PREPARED"

Expected Result
It is expected that the Active Power measured for the Heat Pump is Increasing to Higher Level after step 4.

Test Description
1. Heat Pump operating in SG Mode: Must Stop
2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: High
3. Ensure the Heat Pump is Not Running. This can be verified by measuring the active power to be Low Level
4. Switch the Heat Pump into SG Mode: High
5. Let the Heat Pump run in SG Mode: High for 3 hours.
6. Switch back to Must Stop

Comments
"BLANK"

Test Reference	Test Purpose	Test Result
Ctl9	To test if the Heat Pump is affected when switching from Must Stop to Must Max when the Heat Pump is Not Running	☐ Passed ☐ Failed ☐ Inconclu-sive

Reference to Clause and Subclause in Standardization Document
"PREPARED"

Expected Result
It is expected that the Active Power measured for the Heat Pump is Increasing to Higher Level after step 4.

Test Description
1. Heat Pump operating in SG Mode: Must Stop
2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Max
3. Ensure the Heat Pump is Not Running. This can be verified by measuring the active power to be Low Level
4. Switch the Heat Pump into SG Mode: Must Max
5. Let the Heat Pump run in SG Mode: Must Max for 3 hours.
6. Switch back to Must Stop

Comments
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CtIN1</td><td><u>Test Purpose</u>
To test if the Heat Pump is affected when switching from Must Stop to Normal Operation when the Heat Pump is Running</td><td><u>Test Result</u>
☐ <u>Passed</u>
☐ <u>Failed</u>
☐ <u>Inconclu-sive</u></td></tr>
<tr><td colspan="3"><u>Reference to Clause and Subclause in Standardization Document</u>
"PREPARED"</td></tr>
<tr><td colspan="3"><u>Expected Result</u>
It is expected that the Active Power measured for the Heat Pump is Not Changed after step 4.</td></tr>
<tr><td colspan="3"><u>Test Description</u>
1. Heat Pump operating in SG Mode: Must Stop
2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Normal Operation
3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be Low Level
4. Switch the Heat Pump into SG Mode: Normal Operation
5. Let the Heat Pump run in SG Mode: Normal Operation for 3 hours.
6. Switch back to Must Stop</td></tr>
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<table>
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CtIN2</td><td><u>Test Purpose</u>
To test if the Heat Pump is affected when switching from Must Stop to High when the Heat Pump is Running</td><td><u>Test Result</u>
☐ <u>Passed</u>
☐ <u>Failed</u>
☐ <u>Inconclu-sive</u></td></tr>
<tr><td colspan="3"><u>Reference to Clause and Subclause in Standardization Document</u>
"PREPARED"</td></tr>
<tr><td colspan="3"><u>Expected Result</u>
It is expected that the Active Power measured for the Heat Pump is Not Changed after step 4.</td></tr>
<tr><td colspan="3"><u>Test Description</u>
1. Heat Pump operating in SG Mode: Must Stop
2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: High
3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be Low Level
4. Switch the Heat Pump into SG Mode: High
5. Let the Heat Pump run in SG Mode: High for 3 hours.
6. Switch back to Must Stop</td></tr>
<tr><td colspan="3"><u>Comments</u>
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</table>

Test Reference	Test Purpose	Test Result
CtlN3	To test if the Heat Pump is affected when switching from Must Stop to Must Max when the Heat Pump is Running	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Not Changed after step 4.		
Test Description 1. Heat Pump operating in SG Mode: Must Stop 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Max 3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be Low Level 4. Switch the Heat Pump into SG Mode: Must Max 5. Let the Heat Pump run in SG Mode: Must Max for 3 hours. 6. Switch back to Must Stop		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl10	To test if the Heat Pump is affected when switching from High to Normal Operation when the Heat Pump is Run-ning	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Dropping to Lower level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: High 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Normal Operation 3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: Normal Operation 5. Let the Heat Pump run in SG Mode: Normal Operation for 3 hours. 6. Switch back to High		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl11	To test if the Heat Pump is affected when switching from High to Normal Operation when the Heat Pump is Not Running	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Dropping to Lower level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: High 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Normal Operation 3. Ensure the Heat Pump is Not Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: Normal Operation 5. Let the Heat Pump run in SG Mode: Normal Operation for 3 hours. 6. Switch back to High		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl12	To test if the Heat Pump is affected when switching from High to Must Max when the Heat Pump is Running	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Increasing to Higher Level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: High 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Max 3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: Must Max 5. Let the Heat Pump run in SG Mode: Must Max for 3 hours. 6. Switch back to High		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl13	To test if the Heat Pump is affected when switching from High to Must Max when the Heat Pump is Not Running	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Increasing to Higher Level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: High 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Max 3. Ensure the Heat Pump is Not Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: Must Max 5. Let the Heat Pump run in SG Mode: Must Max for 3 hours. 6. Switch back to High		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl14	To test if the Heat Pump is affected when switching from High to Must Stop when the Heat Pump is Running	☐ Passed ☐ Failed ☐ Inconclu-sive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Dropping to Lower level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: High 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Stop 3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: Must Stop 5. Let the Heat Pump run in SG Mode: Must Stop for 3 hours. 6. Switch back to High		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl15	To test if the Heat Pump is affected when switching from High to Must Stop when the Heat Pump is Not Running	☐ Passed ☐ Failed ☐ Inconclusive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Dropping to Lower level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: High 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Stop 3. Ensure the Heat Pump is Not Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: Must Stop 5. Let the Heat Pump run in SG Mode: Must Stop for 3 hours. 6. Switch back to High		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl16	To test if the Heat Pump is affected when switching from Must Max to Normal Operation when the Heat Pump is Running	☐ Passed ☐ Failed ☐ Inconclusive
Reference to Clause and Subclause in Standardization Document "PREPARED"		
Expected Result It is expected that the Active Power measured for the Heat Pump is Dropping to Lower level after step 4.		
Test Description 1. Heat Pump operating in SG Mode: Must Max 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Normal Operation 3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: Normal Operation 5. Let the Heat Pump run in SG Mode: Normal Operation for 3 hours. 6. Switch back to Must Max		
Comments "BLANK"		

Test Reference	Test Purpose	Test Result
Ctl17	To test if the Heat Pump is affected when switching from Must Max to High when the Heat Pump is Running	☐ Passed ☐ Failed ☐ Inconclu-sive

Reference to Clause and Subclause in Standardization Document
"PREPARED"
Expected Result
It is expected that the Active Power measured for the Heat Pump is Dropping to Lower level after step 4.
Test Description
1. Heat Pump operating in SG Mode: Must Max 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: High 3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: High 5. Let the Heat Pump run in SG Mode: High for 3 hours. 6. Switch back to Must Max
Comments
"BLANK"

Test Reference	Test Purpose	Test Result
Ctl18	To test if the Heat Pump is affected when switching from Must Max to Must Stop when the Heat Pump is Running	☐ Passed ☐ Failed ☐ Inconclu-sive

Reference to Clause and Subclause in Standardization Document
"PREPARED"
Expected Result
It is expected that the Active Power measured for the Heat Pump is Dropping to Lower level after step 4.
Test Description
1. Heat Pump operating in SG Mode: Must Max 2. After >2 hours stable operation, look out for step 3 condition before switching into SG Mode: Must Stop 3. Ensure the Heat Pump is Running. This can be verified by measuring the active power to be High Level 4. Switch the Heat Pump into SG Mode: Must Stop 5. Let the Heat Pump run in SG Mode: Must Stop for 3 hours. 6. Switch back to Must Max
Comments
"BLANK"

ANNEX F. SGO Documentation of Test Methods Domestic EV charge

- follow on the next pages.

Summary of the annex

The following equipment domain is of relevance for this conformance test, hence it is characterized by a relatively high continuous electric load that could be active for hours:

- Electric Vehicles (typical 2kW+ for 2 -12 hours)

Only the domain EV Home Chargers are covered in this document.

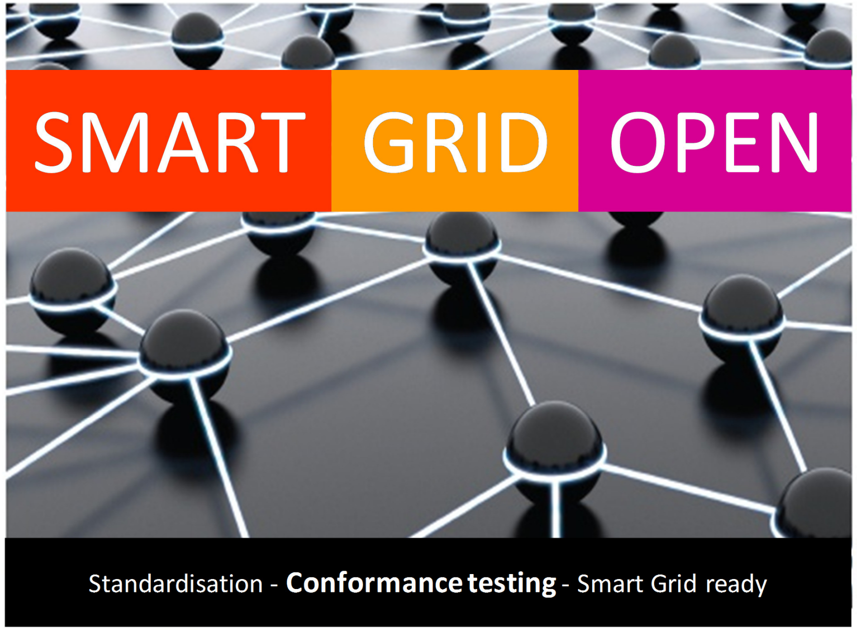
The document analyses four selected Use Cases, two commercial Use Cases and two technical Use Cases. The Use Cases, which have been analysed are as follows:

- The Price for electricity is low.
- Voltage on DSO level is low.
- Voltage on DSO level is high.
- The price for electricity is high.

Throughout the entire project the aim was to find an open and standardised test method, therefore a schematic test setup based on the IEC 61850-10 methodology have been designed. The intention is to follow the principles of IEC 61850-10 naming structure and hereby create a test setup, which is structurally aligned with the standard. Likewise, the Test Report is structured after the philosophy of the IEC 61850-10 recommendations.

During the SGO project, the approach of the Conformance Test methodology was to verify if the DUT was SG-Ready or not. Normally it is important that the original equipment, e.g. sensors etc., is original and not modified for the test, since this could potentially influence the internal logic controller of the DUT during the test sequence. Therefore, a realistic test environment is built and used during the tests.

Unfortunately, no SG Ready EV Home Charger was available on the market, and therefore a standard Pod-point charger was electronically modified to accept the two SG Ready signals and adjust the allowable charge current to the Electric Vehicle accordingly. A standard electric vehicle, Nissan Leaf was used to verify the SG Ready function and proper reaction to transitions between modes and faulty limiting signals lasting more than 2 hours. The test was successful and the developed SG Ready home charger can serve as reference system for future tests.



Deliverable D4-1

ANNEX F – SGO Documentation of Test Methods Domestic EV charge

Contents

Scope

The purpose of this document is to outline ideas, test methods and recommendation relating conformance testing of SG Ready EV Home Chargers.

The work approach is in line with the methods developed in connection with the EU M/490 mandate.

Since no SG Ready EV Home Chargers was found on the Danish market a prototype SG Ready EV Home Charger has been developed and tested to verify proof of concept.

Terms and Definitions

General Terms and Definitions

Term	Definition
BWP	German National Heat Pump Association (Bundesverband Wärmepumpe)
DTI	Danish technological Institute
DUT	Device under Test
EV	Electrical Vehicle
Home Charger	EV Home Charger
PV	Photo Voltage
SG	Smart Grid
SGAM	Smart Grid Architecture Model
SGO	Smart Grid Open Project
SG-Ready	Smart Grid Ready according to the German SG label from BWP
V2G	Vehicle to Grid, sending power from EV battery to the grid

Table 1 General Terms and Definitions

Summary

This document contains guidelines for a potential SG-Ready Conformance Test Method, which can be used for equipment that has an essential part of critical electric consumption in the customer premises. The enclosed test method are in alignment with the EU mandate M/490.

By implementing both the SGAM model and the German SG-Ready label within the Conformance Test methodology, it has been possible to recommend a feasible and generic test method for test of SG readiness of selected components. The following equipment domains are of relevance for this conformance test, hence they have a relatively high continuous electric load that could be active for hours characterized by the three equipment domains:

- Electric Vehicles (typical 2kW+ for 2 -12 hours)
- Inverters e.g. PV-inverters (typical 4kW+ for 2 -10 hours)
- Heat Pumps for domestic use (typical 2 - 4kW intermittent for 0,5 to 24 hours)

However, only the domain EV Home Chargers are covered in this document.

The document analyses four selected Use Cases, two commercial Use Cases and two technical Use Cases. The Use Cases, which have been analysed are as follows:

- The Price for electricity is low.
- Voltage on DSO level is low.
- Voltage on DSO level is high.
- The price for electricity is high.

For details of the above Use Cases, please refer to the chapter Use Case Study. In addition, more examples of Use Cases are showed, in the chapter The SGO definition of the SG-Ready signal.

Throughout the entire project the aim was to find an open and standardised test method, therefore a schematic test setup based on the IEC 61850-10 methodology have been designed. The intention is to follow the principles of IEC 61850-10 naming structure, hereby create a test setup which is structurally aligned with the standard. Likewise, the Test Report is structured after the philosophy of the IEC 61850-10 recommendations.

During the SGO project, the approach of the Conformance Test methodology was to verify if the DUT was SG-Ready or not. Normally it is important that the original equipment, e.g. sensors etc., is original and not modified for the test, since this could potentially influencing the internal logic controller of the DUT during the test sequence. Therefore, a realistic test environment is built and used during the tests.

Unfortunately, no SG Ready EV Home Charger was available on the market, and therefore a standard Pod-point charger was electronically modified to accept the two SG Ready signals and adjust the allowable charge current to the Electric Vehicle accordingly. A standard electric vehicle, Nissan Leaf, was used to verify the SG Ready function and proper reaction to transitions between modes and faulty limiting signals lasting more than 2 hours. The test was successful and the developed SG Ready home charger can serve at reference system for future tests.

Background information

What is Interoperability, Conformance test and Compatibility levels?

In order to get a common understanding, the definition of terms is important. In SGO, we use the basic terms Interoperability and Conformance as two different terms, but also linked definitions.

Conformance test is defined as a test to determine whether a component or system meets the required specification or standard.

Smart Grid Open defines **Interoperability** as the ability for components and systems to co-exist and operate together from a physical, logical and operational point of view.

SGO also defines a level of **Compatibility** as the ability for a given component or system to be compatible with another component or system of a different type (vendor).

This document describes a potential test method used when performing a SG-Ready Conformance test of equipment.

Reference Architecture – SGAM

The aim of the SGO project is to show a potential test method based on the SGAM model. A series of workshops with focus on SGAM and support of Smart Grid related topics has been conducted with relation to the SGO project and scope.

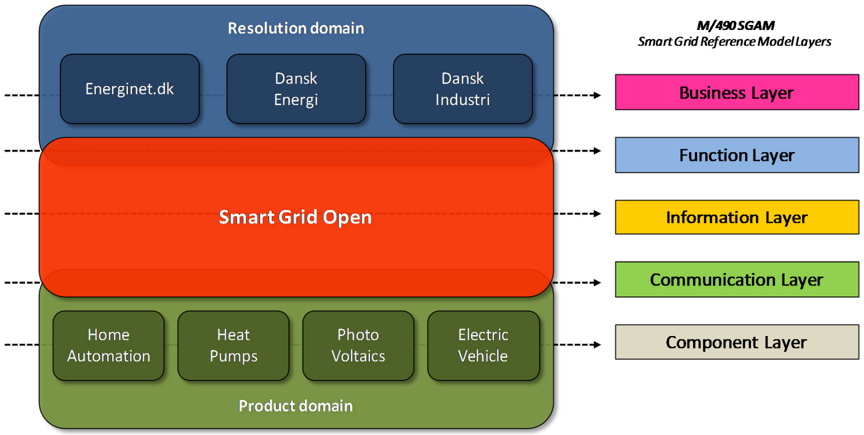


Figure 1 SGAM Model in accordance to the M/490 Mandate

The domains that has been in focus is similar to SGO, which are EV, Heat Pumps PV, Home and Building automation.

This document describes test methods within the component layer of the SGAM model. All components are located in the quadrant Customer Premise and Process/Field of the SGAM model.

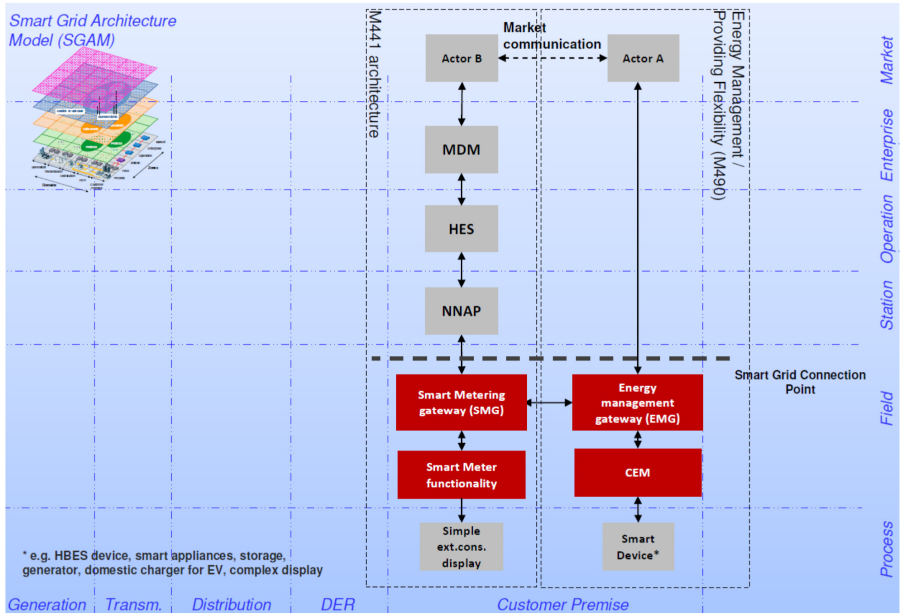


Figure 2 Example - Mapping of Flexibility Functional Architecture on SGAM

Smart Grid Connection Point

All grid-connected equipment has several requirements to fulfil. Some requirements are mandatory for safety and functional integrity of other systems and components. There must be some sort of user interface to allow control or monitoring of the equipment's function. If an equipment should be able to offer flexibility to the grid a further set of requirements must be fulfilled to accommodate management of the flexibility.

The Smart Grid Connection Point is not a specific interface on the equipment but rather an information exchange interface between the embedded equipment internal management and a Smart Grid server or via point.

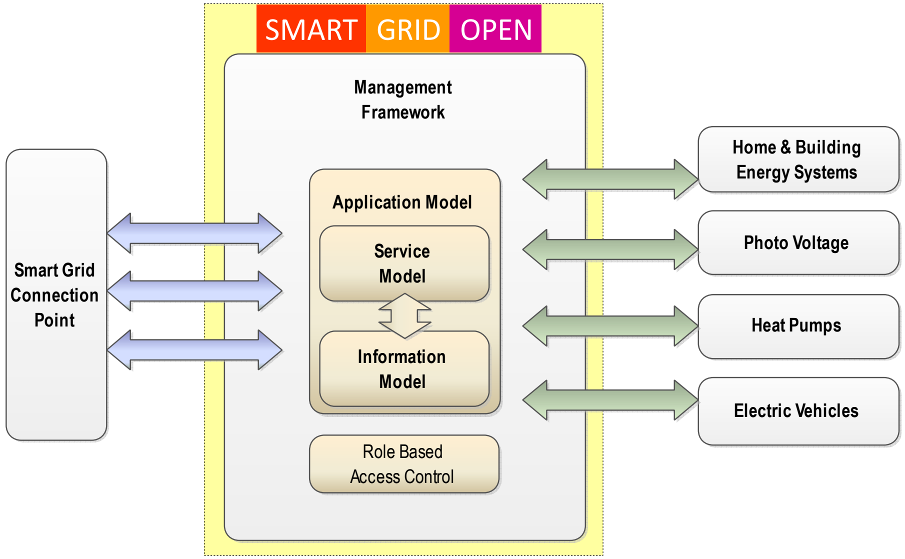


Figure 3 Link between Domain areas and Smart Grid Connecting Point

SGO assume a partly application specific Management Framework in Smart Grid Ready equipment that handles access control and information interchange. The service model is the equivalent functional SW model of the actual equipment function.

For SGO to handle different domains with a similar approach, SGO assume a common Management Framework with submodular adaptation to the specific domain.

The test setup will consist of a complex test-equipment, consisting of several sub functions:

- Emulate the stimuli from the application process as needed
- A measurement unit that monitor the process feedback to assess reactions.

An important auxiliary test device will be the equipment simulator i.e. the intelligent house simulator. Based on the SG-Ready label from the German National Heat Pump Association (BWP Bundesverband Wärmepumpe), this document describes a possible test method for Heat Pumps only, however it might be possible to use the SG-Ready label defined by BWP in other domains, see SGO Final Report for details.

Domain area

Four equipment domains have been chosen as the focus in SGO. With Smart Grid control of these equipment domains, the essential part of critical electric consumption is taken care of.

A relatively high continuous electric load that could be active for hours characterizes three equipment domains:

- Electric Vehicles (typical 2kW+ for 2 -12 hours)
- Inverters e.g. PV-inverters (typical 4kW+ for 2 -10 hours)
- Heat Pumps for house heating (typical 2 - 4kW intermittent for 0,5 to 24 hours)
- Home Automation (Aggregate minor flexible loads at home level)

The fourth equipment type is a Smart Grid tested home automation unit able to aggregate some of the smaller flexible electric loads in the building to serve as a single larger load. The Home Automation equipment can work as a router and/or manage unintelligent equipment to act as Smart Grid ready. It is important to be aware that the Home Automation equipment may have other primary functions than Smart Grid services like e.g. comfort related controls or alarm functions.

Smart Grid management of electric hot water heaters will be covered by either Heat Pump control or Home Automation.

This document describes a potential test method for the equipment domain EV Home Chargers only.

Test Use Case Headlines

Background

The Use case describes the relation to the actor list and the requirement list, which are common for all Use Cases.

Existing Use Case descriptions from a Use Case Repository can be migrated into the projects defined Use Cases as appropriate.

The Use Case descriptions will start as short versions with the minimum mandatory fields:

- Name of Use Case, Author, Date, Narrative, Actors.

The short version is the basis for the complete Use Case and can be simply extended with the addition of further information, i.e., without rewriting the Use Case. Being self-explaining the short version is seen as an easy starting point for involving domain experts without going into every detail of the Use Case methodology and its complete Use Case template.

Use Case Study

Use Case 1: Price is low

<table>
<tr><td colspan="5">Use Case Identification</td></tr>
<tr><td>ID</td><td colspan="2">Domain(s)/Zone(s)</td><td colspan="2">Name of Use Case</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="2">Price is low</td></tr>
<tr><td colspan="5">Version Management</td></tr>
<tr><td>Version No</td><td>Date</td><td>Name of Author(s)</td><td>Changes</td><td>Approval Status</td></tr>
<tr><td></td><td>2015-05-18</td><td>Simon Møiniche Skov,
Kjeld Nørregaard</td><td></td><td></td></tr>
</table>

Narrative of Use Case
Short Description
Controlling the SG-Ready signal of the EV Home Charger based on the price signal received from the Spot-market. Home Charger offer higher charge current to EV.
Long Description
Price signal scheme are downloaded by the Aggregator. Aggregator signal is pushed to the Smart Grid Controller. High signal sent from the Aggregator to Smart Grid Controller. High signal sent from Smart Grid Controller to SG-Ready Controller. A Run Higher demand from Aggregator could be a result of e.g. price being lower now and not later or to enable an Aggregator controlled load time shift e.g. postponing next consumption. Information from the SG-Ready Controller to the EV Home Charger, informing it to go in SG-Ready Run Higher Mode. E.g., the SG-Ready bit A set to “OFF”, SG-Ready bit B is set to “ON”. Normal signal sent from Smart Grid Controller to SG-Ready Controller. Price signal sent from the Smart Grid Controller to the SG-Ready Controller, that the price is Normal. Information from the SG-Ready Controller to the EV Home Charger, informing it to go in SG-Ready Normal Operation Mode. E.g., the SG-Ready bit A set to “OFF”, SG-Ready bit B is set to “OFF”.

Table 2 Example of Use cases; Price is low

Use Case Identification		
ID	Domain(s)/Zone(s)	Name of Use Case
		Price is low
Diagram of Use Case		

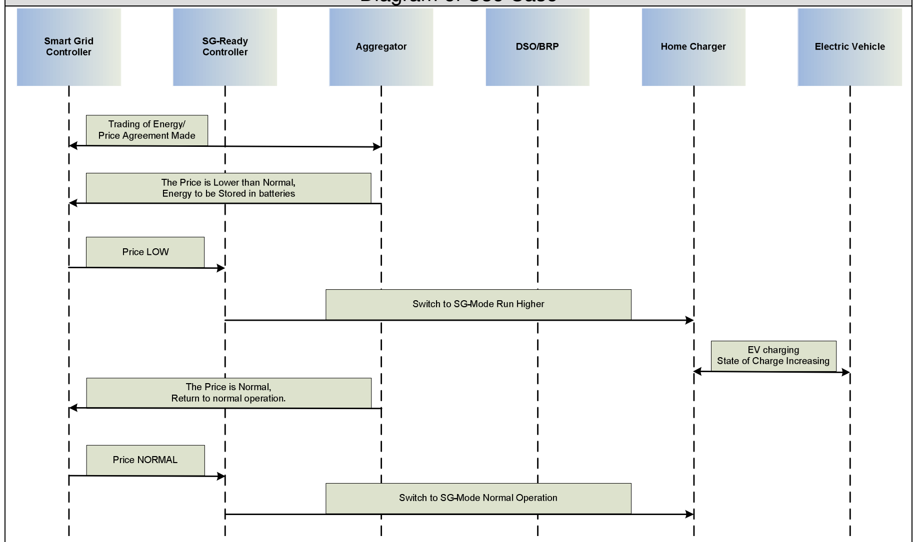


Table 3 Example of Use cases; Price is low

Use Case Identification			
ID	Domain(s)/Zone(s)	Name of Use Case	
		Price is low	
Actors			
Actor Name	Actor Type	Actor Description	Further Information specific to this Use Case
Smart Grid Controller	Device	Operates the EV Home Charger. Receives EV Home Charger operation plans and is responsible for the execution of a EV Home Charger operation plan. Other responsibilities Authenticate or relay to Aggregator for authentication, negotiation of State of Charge and finally executing charging service request within boundaries (grid capabilities, Energy to fill the EV battery)	NEW
SG-Ready Controller	Device	Implementing the function for SG-Readiness. Performs state estimation based on real-time information from the Smart Grid Controller	NEW
Aggregator	Role	See IEC 62559-2	
DSO/BRP	Role	See IEC 62559-2	
HP	Device	EV Home Charger, device that conducts electrical power to an Electric Vehicle (battery charge).	NEW
Electric Vehicle	Role	Receive power (for V2G even supply power)	NEW

Table 4 Example of Use cases; Price is low

Use Case 2: Voltage on DSO level is low

Use Case Identification				
ID	Domain(s)/Zone(s)	Name of Use Case		
		Voltage on DSO level is low		
Version Management				
Version No	Date	Name of Author(s)	Changes	Approval Status
	2015-07-24	Simon Møiniche Skov, Kjeld Nørregaard		
Narrative of Use Case				
Short Description				
Controlling the SG-Ready signal of the EV Home Charger based on the signal received from the DSO indicating the Voltage is low.				
Long Description				
Signal sent from the DSO informing the Smart Grid Controller, that the voltage level is lower than the defined nominal voltage level and that the DSO need the EV Home Charger to stop operating. Control signal sent from the Smart Grid Controller to the SG-Ready Controller, informing the voltage is low. Information from the SG-Ready Controller to the EV Home Charger, informing it to go in SG-Ready Must Stop Mode. E.g., the SG-Ready bit A set to “ON”, SG-Ready bit B is set to “OFF”. The EV Home Charger stops to run hence decreasing the temperature in the house. Signal sent from the DSO informing the Smart Grid Controller that the voltage level is back to normal level. Control signal sent from the Smart Grid Controller to the SG-Ready Controller, informing the voltage is Normal. Information from the SG-Ready Controller to the EV Home Charger, informing it to go into SG-Ready Normal Operation Mode. E.g., the SG-Ready bit A set to “OFF”, SG-Ready bit B is set to “OFF”.				

Table 5 Example of Use cases; Voltage on DSO level is low

Use Case Identification		
ID	Domain(s)/Zone(s)	Name of Use Case
		Voltage on DSO level is low
Diagram of Use Case		

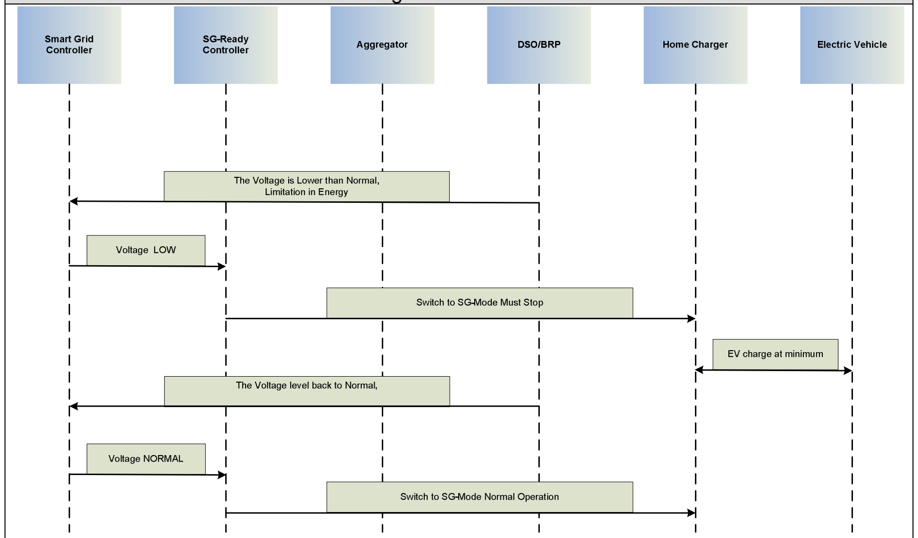


Table 6 Example of Use cases; Voltage on DSO level is low

Use Case Identification			
ID	Domain(s)/Zone(s)	Name of Use Case	
		Voltage on DSO level is low	
Actors			
Actor Name	Actor Type	Actor Description	Further Information specific to this Use Case
Smart Grid Controller	Device	Operates the EV Home Charger. Receives EV Home Charger operation plans and is responsible for the execution of a EV Home Charger operation plan. Other responsibilities Authenticate or relay to Aggregator for authentication, negotiation of State of Charge and finally executing charging service request within boundaries (grid capabilities, Energy to fill the EV battery)	NEW
SG-Ready Controller	Device	Implementing the function for SG-Readiness. Performs state estimation based on real-time information from the Smart Grid Controller	NEW
Aggregator	Role	See IEC 62559-2 Use case methodology	
DSO/BRP	Role	See IEC 62559-2	
EV Home Charger	Device	EV Home Charger, device that conducts electrical power to an Electric Vehicle (battery charge).	NEW
Electric Vehicle	Role	Receive power (for V2G even supply power)	NEW

Table 7 Example of Use cases; Voltage on DSO level is low

Use Case 3: Voltage on DSO level is high

Use Case Identification				
ID	Domain(s)/Zone(s)		Name of Use Case	
			Voltage on DSO level is High	
Version Management				
Version No	Date	Name of Author(s)	Changes	Approval Status
	2015-07-24	Simon Møiniche Skov, Kjeld Nørregaard		
Narrative of Use Case				
Short Description				
Controlling the SG-Ready signal to the EV Home Charger based on the signal received from the DSO indicating the Voltage is High.				
Long Description				
Signal sent from the DSO informing the Smart Grid Controller, that the voltage level is Higher than the defined nominal voltage level and the DSO need the EV Home Charger to operating at maximum capacity. Control signal sent from the Smart Grid Controller to the SG-Ready Controller, informing the voltage is high. Information from the SG-Ready Controller to the EV Home Charger, informing it to go into SG-Ready Must Max Mode. E.g., the SG-Ready bit A set to “ON”, SG-Ready bit B is set to “ON”. The EV Home Charger offers maximum current to the electric vehicle. Maximum charge can only take place until the battery in the electric vehicle is nearly full. Signal sent from the DSO informing the Smart Grid Controller that the voltage level is back to normal level. Control signal sent from the Smart Grid Controller to the SG-Ready Controller, informing that the voltage is Normal. Information from the SG-Ready Controller to the EV Home Charger, informing it to go into SG-Ready Normal Operation Mode. E.g., the SG-Ready bit A set to “OFF”, SG-Ready bit B is set to “OFF”.				

Table 8 Example of Use cases; Voltage on DSO level is high

Use Case Identification		
ID	Domain(s)/Zone(s)	Name of Use Case
		Voltage on DSO level is High
Diagram of Use Case		

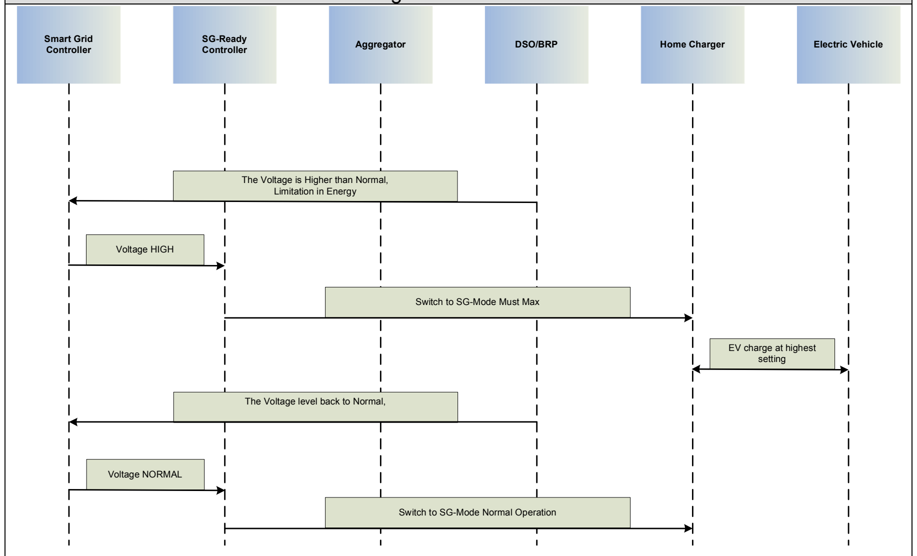


Table 9 Example of Use cases; Voltage on DSO level is high

Use Case Identification			
ID	Domain(s)/Zone(s)	Name of Use Case	
		Voltage on DSO level is High	
Actors			
Actor Name	Actor Type	Actor Description	Further Information specific to this Use Case
Smart Grid Controller	Device	Operates the EV Home Charger. Receives EV Home Charger operation plans and is responsible for the execution of a EV Home Charger operation plan. Other responsibilities Authenticate or relay to Aggregator for authentication, negotiation of State of Charge and finally executing charging service request within boundaries (grid capabilities, Energy to fill the EV battery)	NEW
SG-Ready Controller	Device	Implementing the function for SG-Readiness. Performs state estimation based on real-time information from the Smart Grid Controller	NEW
Aggregator	Role	See IEC 62559-2 Use case methodology	
DSO/BRP	Role	See IEC 62559-2	
Home Charger	Device	EV Home Charger, device that conducts electrical power to an Electric Vehicle (battery charge).	NEW
Electric Vehicle	Role	Receive power (for V2G even supply power)	NEW

Table 10 Example of Use cases; Voltage on DSO level is high

Use Case 4: Price is high

Use Case Identification				
ID	Domain(s)/Zone(s)	Name of Use Case		
		Price is high		
Version Management				
Version No	Date	Name of Author(s)	Changes	Approval Status
	2015-05-18	Simon Møiniche Skov, Kjeld Nørregaard		
Narrative of Use Case				
Short Description				
Controlling the SG-Ready signal of the EV Home Charger based on the price signal received from the Spot-market. Home Charger offer minimum charge current to EV.				
Long Description				
Price signal scheme are downloaded by the Aggregator. Aggregator signal is pushed to the Smart Grid Controller. Stop signal sent from the Aggregator to Smart Grid Controller. Must Stop signal sent from Smart Grid Controller to SG-Ready Controller. A Must Stop demand from Aggregator could be a result of e.g. price is higher now than later or e.g. contributing to peak load reduction Information from the SG-Ready Controller to the EV Home Charger, informing it to go in SG-Ready Must Stop Mode. E.g., the SG-Ready bit A set to “ON”, SG-Ready bit B is set to “OFF”. Normal signal sent from Smart Grid Controller to SG-Ready Controller. Price signal sent from the Smart Grid Controller to the SG-Ready Controller, that the price is Normal. Information from the SG-Ready Controller to the EV Home Charger, informing it to go in SG-Ready Normal Operation Mode. E.g., the SG-Ready bit A set to “OFF”, SG-Ready bit B is set to “OFF”.				

Table 11 Example of Use cases; Price is high

Use Case Identification		
ID	Domain(s)/Zone(s)	Name of Use Case
		Price is high
Diagram of Use Case		

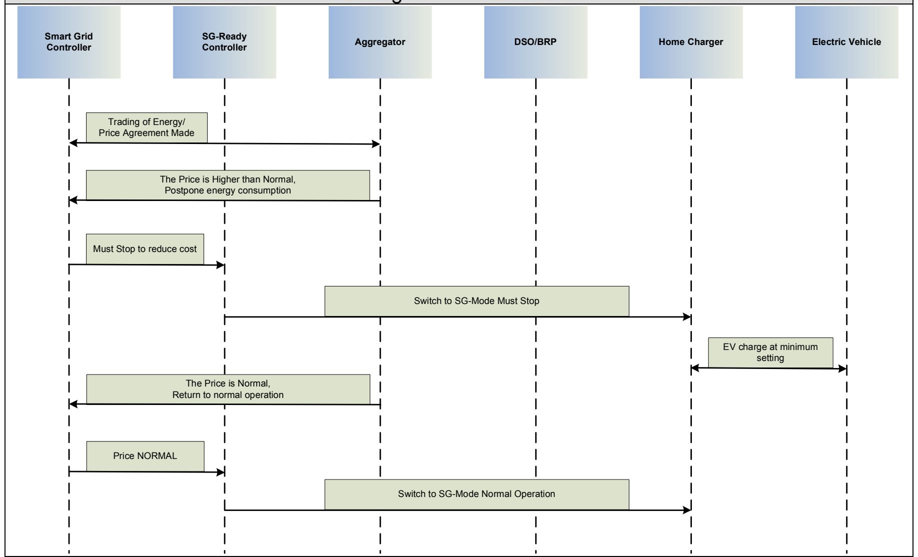


Table 12 Example of Use cases; Price is high

Use Case Identification			
ID	Domain(s)/Zone(s)	Name of Use Case	
		Price is high	
Actors			
Actor Name	Actor Type	Actor Description	Further Information specific to this Use Case
Smart Grid Controller	Device	Operates the EV Home Charger. Receives EV Home Charger operation plans and is responsible for the execution of a EV Home Charger operation plan. Other responsibilities Authenticate or relay to Aggregator for authentication, negotiation of State of Charge and finally executing charging service request within boundaries (grid capabilities, Energy to fill the EV battery)	NEW
SG-Ready Controller	Device	Implementing the function for SG-Readiness. Performs state estimation based on real-time information from the Smart Grid Controller	NEW
Aggregator	Role	See IEC 62559-2 Use case methodology	
DSO/BRP	Role	See IEC 62559-2	
EV Home Charger	Device	EV Home Charger, device that conducts electrical power to an Electric Vehicle (battery charge).	NEW
Electric Vehicle	Role	Receive power (for V2G even supply power)	NEW

Table 13 Example of Use cases; Price is high

The SGO definition of the SG-Ready signal

In Smart Grid Open the following definition of SG-Ready, based on the German SG-Ready label, have been defined.

The German SG-Ready label consists of 2-Bit providing four different modes; Normal Operation Mode, High Mode, Must Max Mode and Must Stop Mode.

Normal Operation Mode:

The EV Home Chargers internal logic regulates the EV charge current.

Run Higher Mode:

In this mode the EV Home Charger increases the charge current, this increase is, however, depending on whether it is possible for the EV to accept the offered charge current.

Example of Use Case:

The price is low, and the EV can accept higher charge current.

Must Max Mode:

The EV Home Charger will charge the EV with maximum charge current.

Example of Use Case:

The local grid voltage is high, hence a need to increase load in order to maintain an acceptable voltage quality on the grid.

Must Stop Mode:

In this mode, the EV Home Charger will stop charging. It can remain stopped for a maximum of 2 hours.

Examples of Use Cases:

The local grid voltage is low, and load reduction is required. Sending a Must Stop command to the SG Ready EV Home Charger minimise the charge current to the electric vehicle to assist maintaining maintain an acceptable voltage quality on the grid.

Must Max Mode:

Aggregator postpone EV charging, due to High Price.

Aggregator minimise charge from EV Home Charger, to obtain contractual obligations of delivery of power later or e.g. contributing to peak load reduction.

The correlation between the 2-Bit and 4 SG-Ready Modes is seen in Figure 4.

Fejl! Henvisningskilde ikke fundet. shows the correlation between SG-Ready Modes and the expected reaction in the EV Home Charger.

In order to verify that the EV Home Charger is SG-Ready, it shall be possible to test the response of the EV Home Charger when making transitions between the various SG-Ready Modes. These transitions, occurs by switching from one SG-Ready Mode to the next, this is done by switching the bit combination to obtain the new combination that equals the desired SG-Ready Mode.

It must be possible to switch between the different modes and remain in the selected mode, in order to verify every single step of the test.

The relationship of the transition between different SG-Ready Modes is seen in Figure 5

SG-Mode			
Bit 1 / Bit 0		Low/High Mode	
		0	1
Forced/Normal Mode	0	**Normal Operation**	**High**
	1	**Must Stop**	**Must Max**

Figure 4 2-Bit combination for the 4 SG-Ready Modes. High = Run Higher.

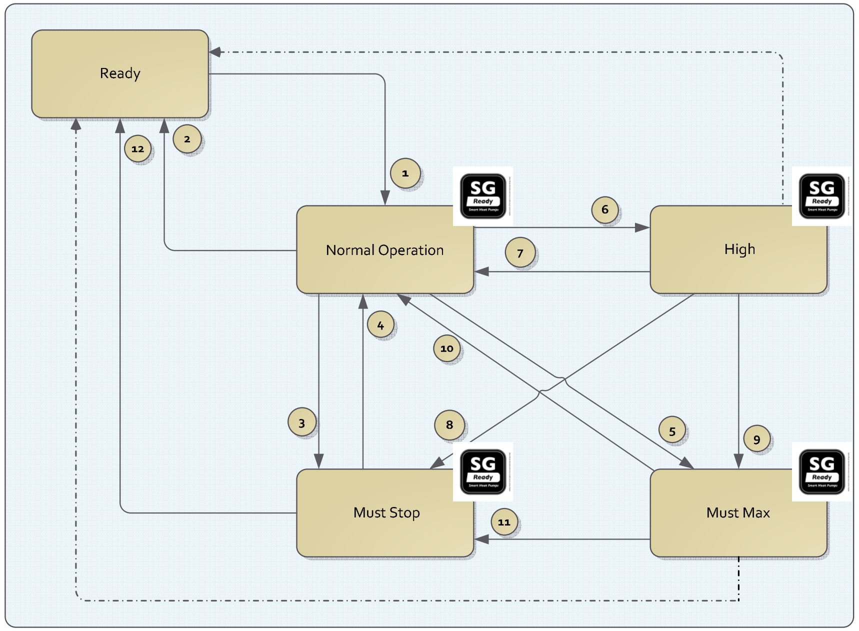


Figure 5 Recommended transitions between various SG-Ready Modes

Test Methodology

Basic Concept

To make the SG-Ready Conformance Test of the EV Home Charger, a standardised approach has been used. All EV Home Chargers are installed in the test setup as “Black Boxes” tested in the various SG-Ready modes, and the reaction of the EV Home Charger is monitored accordingly.

To find a test method, which can verify if the EV Home Charger is SG-Ready in the SG Connection Point, the test setup must consist of the following elements.

- Static conformance review
- Dynamic test
- Analysis of results

In this chapter the functionality of the above elements are described.

In the chapter System Description – Laboratory, the various components and systems needed to fulfil the below required functionality are described in details.

Static conformance review

The Static conformance review ensures that the specification of SGO EV home charger meets the SGO requirements. Furthermore, it clarifies how to install the SGO EV home charger and how it is programmed, if possible.

The Static conformance review must verify that the SGO EV home charger can be installed according to the product specification. If it is programmable, any fault during programming must not course a hazardous setup of the SGO EV home charger.

Furthermore, it must be verified that the SGO EV home charger reacts on SGO signals according to the standard.

Dynamic Simulator

The dynamic Simulator has two main tasks, to control and operate the switching between the different SG-Ready Modes, and to provide the test setup with the capability to simulate the load and the active subsystems of an EV during charging.

The dynamic Simulator logs the SG-Ready Modes in real time, and these values are subsequently sent to the analyser for further analysing and documentation of the test. All data points must be time stamped enabling proper analysing of the data.

Analyser

In order to verify the SG Readiness of the SGO EV home charger, the Analyser receives the relevant data, which are analysed and processed for SG-Ready Conformance Verification and Reporting.

In Figure 6 the basic test setup is illustrated, showing the interaction between the various function elements, the location of the various test modules and how the data is exchanged between test elements, insuring a proper evaluation of the SG readiness, of the SGO EV home charger.

Generic Test Setup for Smart Grid Ready EV Conformance Testing.

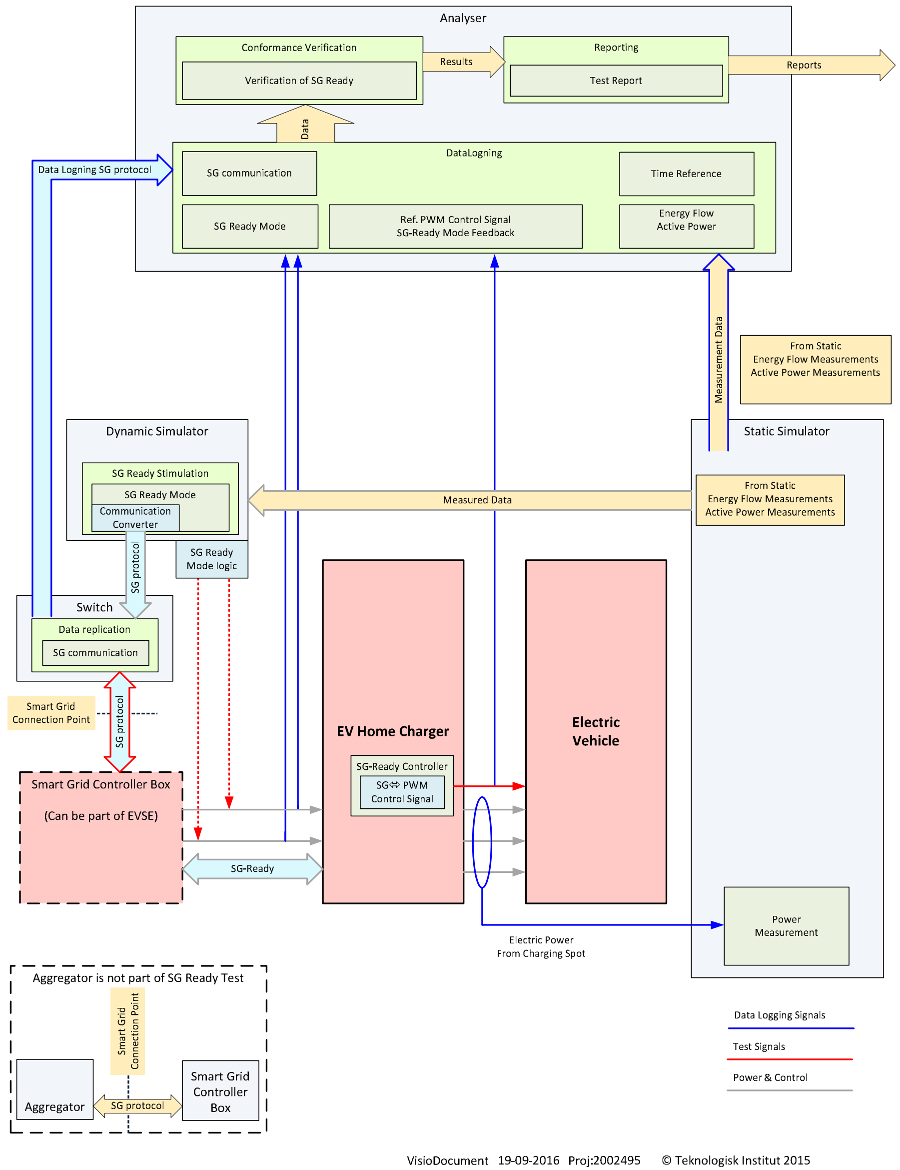


Figure 6 Test Setup for SG-Ready verification

Unit Description – Technical Fact Sheet

A SGO EV Home Charger is a device supplying electric energy for the recharging an EV. It ensures safe connection and disconnection of the charge plug. Furthermore, it ensures that the EV is not charged with more power than the house installation can supply.

Operating principles

There are several types of EV home chargers however, only IEC 61851 – type 3 chargers have been considered for this proof of concept.

IEC 61851 – type 3 EV chargers allow a safe connection and disconnection of the charge plug. It is also capable of communicating with the EV's internal charge controller via a PWM signal. It can tell the EV how much current it is allowed to draw from the charger.

Pre-Test Configuration of SGO EV home charger

In order to verify if the tested DUT is SG-Ready the following settings must be set in the software of the SOG EV home charger internal logic.

- Max current: 16A
- Run Higher current: 12A/16A
- Normal current: 8A/10A
- Min current: 0A
- Time Schedules: Ensure that any type of time schedules are disabled

Figur 7 EV test charge using EV Home charger made "SG Ready" via remote control of charge current from Labview SW also emulating control from SG Ready inputs

System Description – Laboratory

In order to provide a "Black Box" test the following test conditions is needed. By using both simulation and monitoring tools it will be possible to simulate and monitor various EV's and their impact on the SGO EV home chargers internal control and regulation.

The goal is to build a test platform where it is possible to simulate a random EV from programmable characteristics. The system is tested in connection with tests of SG-Ready control signals to the SG-Ready certification of Heat pumps (since no SG Ready chargers was found).

To achieve a standardized approach a test setup in alignment with IEC 61850-10s testing methods has ben designed.

IEC 61850-10 consists of the following main components:

DUT, Analyser, Simulator and Equipment Simulator.

DUT (Device Under Test)

The DUT is the device under test, in this case the SGO EV home charger, which is desired for test.

The DUT is connected to the simulators, enabling SG-Ready signals to be simulated. Based on the SGO EV home chargers reaction, the home charger SG-Ready conformity can by verified.

Analyser

The Analyser is connected to the DUT during the entire test, to verify the SG-Ready conformity. The Analyser consists of DTI LabVIEW equipment with underlying program codes used for the certification of SGO EV home charger. The Excel platform is used for analysing the test, and ultimate reporting the result of the test.

The Analyser provides detailed logs of measurements from equipment simulators including, temperature measurement, voltage and current measurements in all three phases, the active and reactive power. Based on these logs the Analyser provides data to verify the Device Under Test SG Readiness.

This analysis consists of comparing the real-time data for SG-Ready Modes with power, in order to verify if the DUT is SG-Ready.

Simulator

The Simulator is the component, which will affect the DUT during the controlled test, hereby enabling the system the possibility to analyse and verify if the test of the DUT is passed, failed or inconclusive.

In order to verify whether the tested EV Home Charger is SG-Ready according to the SGO project interpretation, a dynamic SG-Ready simulation has been prepared together with logging of signals and charge power vs. time.

Dynamic Operation.

The dynamic simulator controls and operates the simulation of the transitions between various SG-Ready Modes. This is done by setting the appropriate SG Ready bits high or low on the two binary outputs going to the SGO EV home charger, depending on the requested SG-Ready Mode.

Optional, this can be done over a communication interface via a local Smart Grid interface box with digital outputs.

Test specification and requirements

Power consumption is the primary method for verifying SG-Ready Modes

Verification of SG-Ready function will be achieved partly as confirmation of the operation of individual modes for up to two hours, partly by monitoring expected change between various SG-Ready Modes. Recognition of change between SG-Ready modes is recognized through changes in energy supply to the SGO EV Home Charger. This can be done because the charge current has been defined for all SG-Ready modes.

The way to verify if the SGO EV home charger switches to specific SG-Ready Modes, is to monitor if the charge power, follows the desired SG-Ready Mode.

Test of Normal Operation Mode:

Test of transition from Normal Operation Mode to High Mode:

Test of transition from Normal Operation Mode to Must Max Mode:

Test of transition from Normal Operation Mode to Must Stop Mode:

It will be possible to test the remaining transition shifts according to the same method.

Test Reports

This document covers a feasible method to be able to test if a SGO EV home charger is SG Ready according to the SGO project interpretation. See SGO EV home charger feasibility test below.

Recommendation

During the project, the focus was to define a conformance test for SG-Ready components.

Standardisation

After having verified the SG Ready concept on an EV Home Charger, a potential use of the simple control method seems very realistic. However, there must be a common understanding of the SG Ready functions for each product domain, hence a need for a clear definition of the four SG-Ready Modes. The reaction can be different between different product domains but the change in load must have the same tendency on the grid.

Based on this little proof of concept SG ready EV Home Charger is can be recommended to seek wider acceptance for the simple two line Smart Grid control. Implementation of future SGO Ready EV Home Chargers should be standardised or at least gain wide industry acceptance (De facto standard).

SGO EV home charger feasibility test

SGO EV home charger specifications:

- Supply 230V 16A
- PC interface Serial RS-422 9600,N,8,1
- SGO input signal levels 0 = 0 VDC, 1 = 12 VDC
- Output max = 16A
- Output more = 12A
- Output normal = 10A
- Output stop = 0A

The output current for each SGO mode is programmable in the implemented SGO EV home charger. Values have been chosen to be able to identify each SGO mode on power readings in the test setup. SGO “more” could as well be 16A since there will only be a small changes in efficiency if any.

A SGO EV home charger must be able to enter all modes regardless the current mode. Verification of this functionality is done according to following test procedure.

Pre test conditions: The SGO EV home charger must have grid supply and be connected to an EV supporting “mode 3” charging. The LabView application is running, the SGO EV home charger and PC must be connected.

Step	Action	Expected result	Comment	Approved by
1	Start charging	Charger starts in “normal” mode	10A	SIMS
2	Change mode to “stop”	Charger enters “stop” mode	0A	SIMS
3	Change mode to “normal”	Charger enters “normal” mode		SIMS
4	Change mode to “more”	Charger enters “more” mode	12A	SIMS
4	Change mode to “normal”	Charger enters “normal” mode		SIMS
5	Change mode to “max”	Charger enters “max” mode	16A	SIMS
6	Change mode to “normal”	Charger enters “normal” mode		SIMS
7	Change mode to “stop”	Charger enters “stop” mode		SIMS
8	Change mode to “more”	Charger enters “more” mode		SIMS
9	Change mode to “stop”	Charger enters “stop” mode		SIMS
10	Change mode to “max”	Charger enters “max” mode		SIMS
11	Change mode to “stop”	Charger enters “stop” mode		SIMS
12	Change mode to “more”	Charger enters “more” mode		SIMS

13	Change mode to “max”	Charger enters “max” mode		SIMS
14	Change mode to “more”	Charger enters “more” mode		SIMS
15	Change mode to “normal”	Charger enters “normal” mode		SIMS

A SGO EV home charger shall ignore SGO “stop” signal if it have been present for more than 2 hours. The SGO EV home charger must return to “normal” mode if SGO “stop” signal exceeds the 2-hour limit. The 2-hour timer is reset when SGO signal changes. Verification of this functionality is done according to following test procedure.

Pre test conditions: The SGO EV home charger must have grid supply and be connected to an EV supporting “mode 3” charging. The LabView application must run the SGO EV home charger and PC must be connected.

Step	Action	Expected result	Comment	Approved by
1	Start charging	Charger starts charging in “normal” mode	10A	SIMS
2	Change mode to “stop”	Charger enters “stop” mode	0A	SIMS
3	Wait for 2 hours and verify that charger returns to “normal” mode	Charger enters “normal” mode 2 hours after the “stop” command was given	10A	SIMS
4	Change mode to “more”	Charger enters “more” mode and the 2 hour timer is reset	12A	SIMS

A SGO EV home charger shall not course a fault if connected when in “stop” mode.

Pre test conditions: The SGO EV home charger must have grid supply. The LabView application must run the SGO EV home charger and PC must be connected. The SGO EV home charger is in “stop” mode.

Step	Action	Expected result	Comment	Approved by
1	Plug the J1772 connector into the EV	EV registers that a charger is present. The charge current is 0A	0A, no fault	SIMS
2	Change SGO mode to “normal”	Charger enters “normal” mode and EV starts charging	10A	SIMS

A SGO EV home charger must continue charging after a power failure.

Pre test conditions: The SGO EV home charger must have grid supply and be connected to an EV supporting “mode 3” charging. The LabView application must run the SGO EV charger and PC must be connected. The SGO EV home charger is in “normal” mode.

Step	Action	Expected result	Comment	Approved by
1	Cut off grid supply in 30 sec.	The charger stops charging		SIMS
2	Reconnect grid supply	The charger starts charging		SIMS