Final report

INTELLIGENT ELECTRIC VEHICLE INTEGRATION

1. Project details

Project title	Nikola - Intelligent Electric Vehicle Integration
Project identification (program abbrev. and file)	12088
Name of the programme which has funded the project	ForskEl (2013 call)
Project managing company/institution (name and address)	Technical University Of Denmark, Department of Electrical Engineering Elektrovej 325, Kgs. Lyngby
Project partners	NUVVE, SEAS-NVE, EURISCO
CVR (central business register)	DK 30 06 09 46
Date for submission	2017-01-31

2. Short description of project objective and results

English

Nikola is a Danish research and demonstration project focusing on the synergies between the electric vehicle (EV) and the power system.

With sufficient control and communication it is possible to influence the timing, rate and direction of the power and energy exchanged between an EV battery and the grid.

This ability can be used in a set of "services" that bring value to the power system, the EV owner and society in general. Nikola thoroughly investigated such services, developed and investigated technologies that could support them and demonstrated them through both simulations and in-field testing.

Two vehicle OEMs joined the project, allowing the project to demonstrate and validate services on series produced electric vehicles.
The project has contributed to Danish R&D with more than 20 academic papers, 35 student projects and a PhD study.

Furthermore, the results of the project are used directly in commercial applications (Frederiksberg Forsyning Pilot) as well as upcoming R&D activities (ACES, Parker).

Dansk

Nikola er et dansk forsknings og udviklingsprojekt med fokus på forbindelsen mellem elbilen og elnettet.

Med den fornødne kontrol og kommunikation er det muligt at påvirke tidspunkt, størrelse og retning på den effekt og energi som udveksles mellem en elbils batteri og elnettet.

Denne mulighed kan udnyttes i en række "ydelser" som skal bringe værdi til både elnet, elbilsejer og samfundet som helhed.

Nikola projektet har gennemført en grundig og systematisk undersøgelse af disse ydelser, udviklet og forsket i de nødvendige og understøttende teknologier samt demonstreret ydelserne gennem både simulerede tests samt feltdemonstrationer.

Efter at to bilfabrikanter sluttede sig til projektet, blev det muligt at gennemføre tests på serieproducerede elbiler.

Nikola har bidraget til dansk FoU gennem publiceringen af mere end 20 videnskabelige artikler, gennemførslen af 35 studenterprojekter og uddannelsen af én PhD.

Resultater fra projektet bliver brugt direkte i kommericielle aktiviteter (Frederiksberg Forsyning Pilot) og har givet anledning til opfølgende FoU aktiviteter (ACES, Parker).

3. Executive summary

The project meet the objective described in the project description by identifying, prioritizing and evaluating a structured group of services through a number of theoretical and physical test and demonstration activities.

These activities included field testing, user testing, lab testing and software modelling. The physical tests were conducted using both series-produced vehicles and chargers as well as equipment developed by the project itself (Vehicles, chargers and supporting equipment)

The services, along with evaluations of each, are summarized in a service catalog and in more detail in a number of WP reports.

This work has produced more than twenty academic publications (Appendix 2) of which six are high-impact journal papers. A total of 35 student projects have been organised during the project to have students both learn from, and contribute to, the project. The ForskEl funding also supported a PhD study which made several important contributions to the project.

During the project vehicle OEMs Nissan and Groupe PSA joined the project as well as EVSE provider Enel. The equipment provided by the OEMs represented a substantial self-financed investment into the project.

Cooperating with Nissan and Enel, Nikola managed to execute the world's first demonstration of series-produced V2G cars providing ancillary services.

The project has carried out extensive dissemination activities including two seminars, presentations at large Danish and international events and mentions in large news outlets.

Nikola's results will directly carry into four follow-up activities and has helped pave the way for a large commercialization pilot for V2G in Denmark.

4. Project objectives

The main objective of the Nikola project was to

"..Systematically, consistently and thoroughly investigate the services that will make the EV an attractive asset for the end user and an active resource to the power system."

Such an investigation is necessary as part of the effort to make electric vehicles an asset in supporting a stable, economic power system based on renewable energy.

First, the project made a formal definition a "service". The following definition was made:

*"The act of influencing the **timing, rate and direction** of the power and energy exchanged between the **EV battery and the grid** to yield benefits for **user, system and society**."*

Based on this general definition, the project specified four topics needed to investigate such services. The project would explore different type of service both on the distribution grid level (1) and system-wide level (2), understand how they would be supported by contemporary technology and standards (3) and how they could be made understandable and attractive to the EV owner (4).

These four topics were each addressed by a work package.

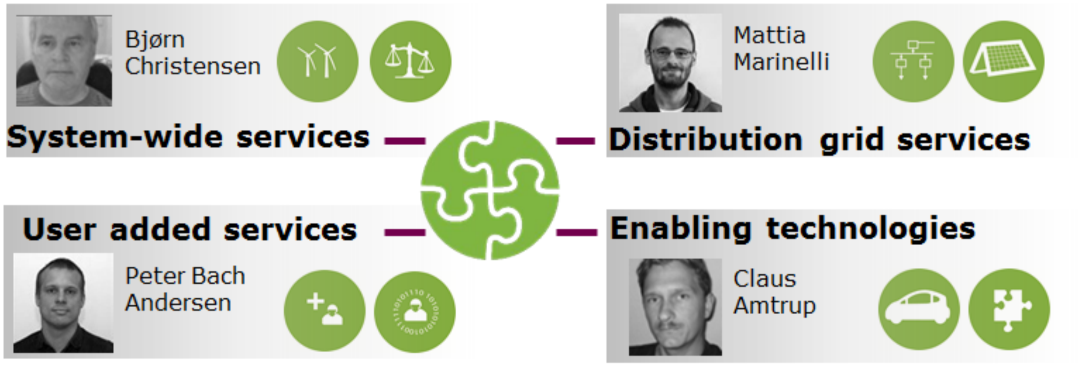


Figure 1 - The four core topics in Nikola and WP leaders

Each topic can be briefly described as follows:

System-wide services
Investigation of services applicable to the Danish power system, at transmission (>= 132 kV) level, and as part of the ancillary service markets. The services aid the TSO in running a cost efficient, secure power system with a high degree of renewable production.

Distribution grid services
Investigate services that aid the integration of the electric vehicle (EV) in the distribution grids (< 132 kV) as part of the operational and strategic targets of a distribution system operator including parameters such as voltage, thermal and reactive power limits.

User added services
This topic address the services needed to interface the EV owner with the power and energy services. This includes investigating behavioural patterns of EV owners to determine how much the charging process can be altered without adverse effects to the owners driving needs as well as the user interfaces, and associated functionalities, needed to kindle the owner's interest in grid service participation.

Enabling technology
This topic covers the technologies, and associated standards, needed to enable electric vehicles, charging spots and backend systems for power and energy services. Special attention is given to the intelligent controllers that will influence the (dis-)charging of EV batteries, their soft- and hardware and the communication between them. The topic also covered the development of a few retrofitted electric vehicles to validate power and energy services.

Besides from the "enabling technologies" topic, all topics were tasked with defining a first list of possible services – each described with a short service description document.

The services were then sent to a number of external reviewers relevant for each topic. This included experts within both industry and academia.
Based on the input from the external review, and internal literature reviews, each service was given an initial priority – low, medium or high – based on the potential and value the service was deemed to have.

The high-priority services would be the primary target of the investigations. Being a relative small project this allowed the participants to better focus project resources.

The result of this work became the **Nikola service catalog** which provides an overview of all services considered by the project.

All high or medium priority services were evaluated based on common criteria – **Value proposition and economics**, **Technical feasibility and standardization support** and **Market or regulatory challenges**.

The services investigated are listed in figure 2.

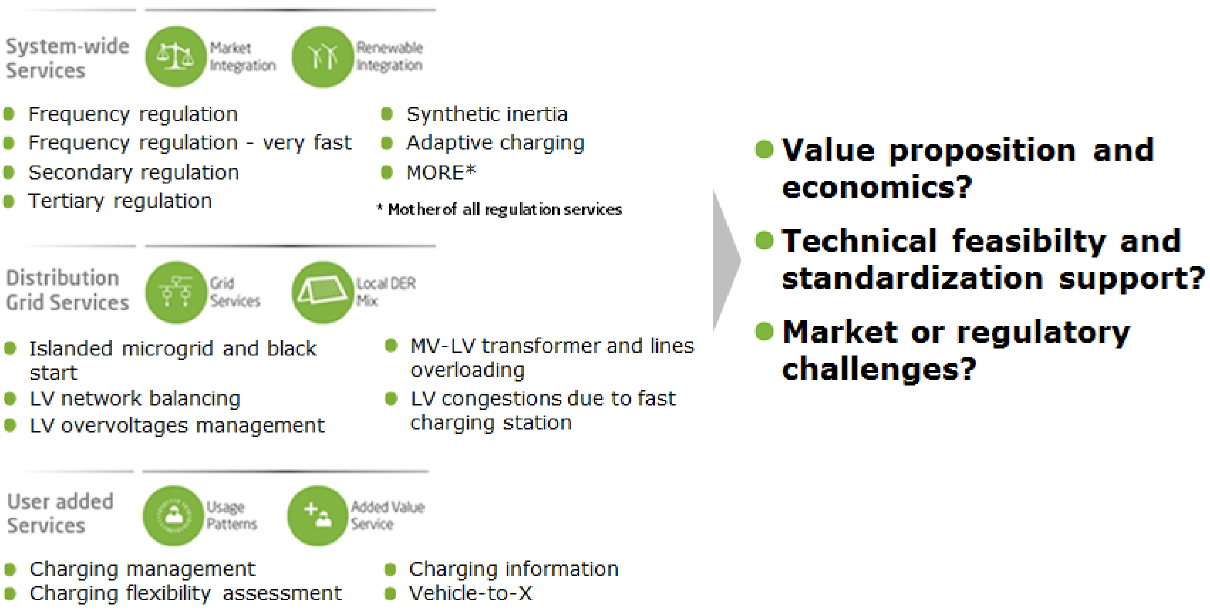


Figure 2 - Evaluation of services

The catalog, where services have received their final evaluation, can be seen in appendix 1.

Work package leaders planned a number of service evaluation activities to be carried out during the project. The "enabling technologies" work package was to prepare the available technical equipment (EVs, chargers) as to support these activities.

5. Project results and dissemination of results

5.1 Technical results of work packages

The sections below describe the main technical results from each of the four core topics, each covered by a work package, of Nikola. Each section will in turn describe the activities undertaken and the conclusions made.

The first three topics, dealing directly with services, will describe the identification and evaluation of the services relevant to the topic in question.

5.1.1 System-wide services (WP1)

Process and activities

The System-wide services work package in Nikola identified a total of seven services (Table 1). The services were then analysed in more detail and documented in a detailed service description.

The descriptions focused on 4 major aspects:

- Technology
- Market
- Economy
- User

Special emphasis was put on the highest value and easiest to market service Frequency regulation (FCR-N).

Using the technology platform from WP4 i.e. Two Nissan Leafs, two Endesa V2G charging stations, a Nuvve aggregator platform and a DEIF frequency measuring device the project set out to validate the FCR-N service through actual tests (figure 3).

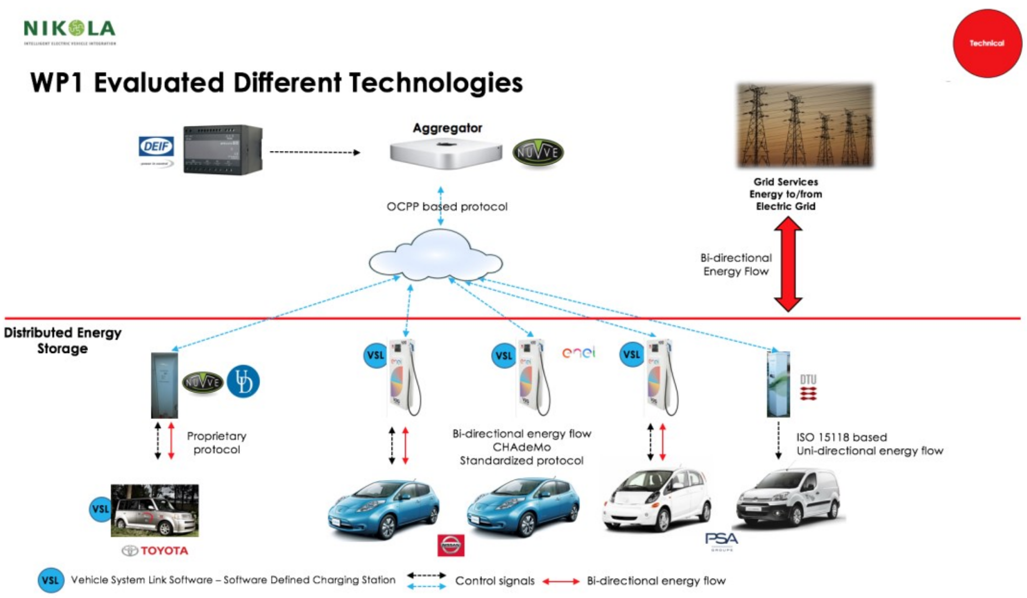


Figure 3 - Nikola technology platform

Tests were conducted within Nikola and confirmed the technical feasibility of supporting the FCR-N service.

At the beginning of 2015 Nikola partners started a dialog with Energinet.dk with the aim of paving the way for an actual trial with Energinet.dk in their DK2 grid. We were selected for a

ENDK emerging technology trial and the first phase of this trial was conducted in May and June 2016.

An extensive set of tests were then conducted at the Frederiksberg Forsyning site with aggregation of five Nissan e-NV 200, five Endesa VG chargers, a Nuvve aggregator and a MTR-3 measuring device.

The validations were done on all 4 aspects mentioned above. The aggregated EVs responded well and with high fidelity to the requirements for the FCR-N service.

The economy was shown to be good i.e. a positive business plan can be made. There exists an open market where bids can be made and a customer (Frederiksberg Forsyning) has bought into the concept.

Evaluation results

In summary Nikola has concluded a positive validation of the FCR-N service. While investigated in Nikola, other services identified still need further validation in subsequent R&D efforts.

Name	Short description	Value for system	Value for owner	Tech./ standard support	Market/ regulatory support
Frequency regulation	Keeps the frequency in an interval around 50 Hz	High	High	Medium/High	High
Frequency regulation - very fast	Frequency regulation with ramping times and precision that go beyond what traditional generators can provide	High	High	Medium/High	Low
Secondary regulation	Replaces frequency regulation and restores the frequency to 50 Hz	Medium	Low	Medium/High	Low
Tertiary regulation	Replaces secondary regulation and fulfills a higher requirement to energy capacity and delivery timescale	Low	Low	Low	Low
Synthetic inertia	Mimics rotational inertia by taking advantage of the fast chemical reaction of batteries	Medium/High	Low	Low	Low
Adaptive charging	Delays or advances charging in time based on e.g. energy costs or renewable contents	High	High	Medium/High	Low
MORE - Mother of all regulation	Includes all the abovementioned traditional types of regulation in one - assuming a large fleet of EVs.	Low	Low	Low	Low

Table 1 –Evaluation results of system-wide services

Conclusions

- ✓ WP1 showed that the FCR-N Service can be performed by aggregated series produced EVs:
  - 24 hours' test duration following DK2 grid frequency
  - Extreme frequency (canned) to stress test configuration
  - Very fast response: 5 - 6 seconds delay
  - High accuracy and precision
- ✓ WP1 has successfully tested V2G capabilities on different EV brands:
  - Nissan Leaf
  - PSA iOn
  - Toyota E-Box (proprietary technology)
- ✓ WP1 has successfully tested Uni-directional capabilities and shown that EVs with V2G capabilities have a substantially higher earnings potential than uni-directional EVs. This is a strong argument for EV OEMs to consider this technology in their standard series electric cars.

- ✓ The use of the CHAdeMO protocol for V2G based services across different vehicle models is a strong step towards cross-OEM support of this technology.

- ✓ WP1 was a driving force in getting Nissan, Enel and PSA into the project, all providing equipment used by the work package, in 2015 – this was done in competition with other European projects.

- ✓ WP1 was the driving force behind the dialogs with Energinet.dk (ENDK) in 2014 to argue for an actual test in the DK2 grid. This dialog continued through 2015 and 2016 and has resulted in that the project was selected for the Emerging Technology Pilot Project with ENDK.

- ✓ Extensive tests were performed with 5 Nissan e-NV 200 cars, 5 V2G chargers and a Nuvve aggregator for a full 7-day period from 23/06/2016 to 30/06/2016. The results were very positive showing that the aggregated cars can provide the FCR-N service fulfilling the ENDK requirements. Furthermore, that a solid business case can be made and lastly that the customer – Frederiksberg Forsyning – has bought into the concept.

5.1.2 Distribution grid services

Process and activities

Work package two has, based on previous relevant projects and the input from external reviewers, identified and prioritized a total of five services which EVs can provide to support the local distribution grid (Table 2).
Three of these services, namely **LV overvoltage management, MV-LV transformer and lines overloading, and LV network balancing,** were recognized as the most relevant ones and singled out for further investigation. Therefore, they have been the subject of various evaluation activities.

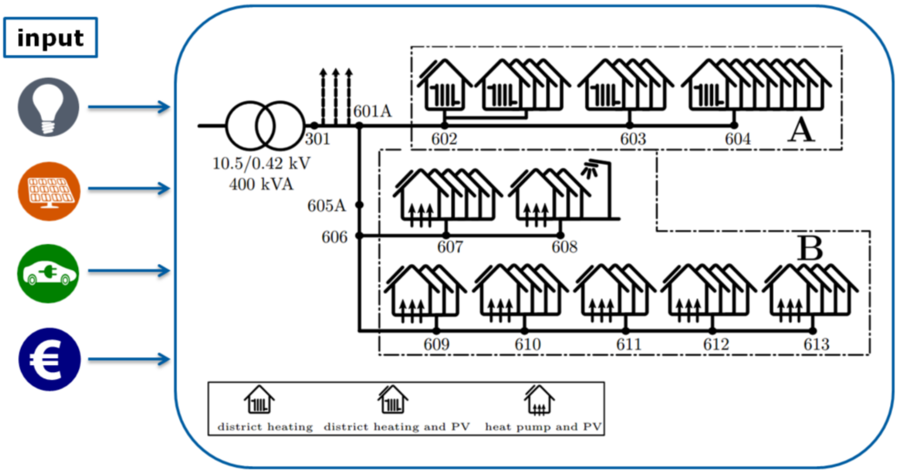


Figure 4 - Borup distribution grid

The work package has performed a number of simulation studies to evaluate the impact of uncontrolled EV charging to the local distribution grid, as well as to investigate the potential benefits of different control strategies. In addition, several experiments have been conducted in the laboratory environment to prove the technical feasibility of an EV providing distribution grid services. Finally, the WP has also performed a small field test experiment where a single EV providing various services has been tested in a real environment with a limited amount of equipment and no controllability of other residential load.
Base on the activities in WP2, the five identified services have been given a final evaluation.

Evaluation results

Both the **LV overvoltage management** and **MV-LV transformer and lines overloading** services are evaluated to be of high value to the distribution grid operator and very important for integration of high EV numbers in the local grid. In addition, **LV congestion due to fast charging stations** service is also of high importance for the distribution grid as the EVs could partially mitigate the self-induced congestion problems by different control strategies. However, all of these services need continued development as, to the authors' knowledge, neither is yet available in contemporary grid operation.
The **LV network balancing** is evaluated to have a medium value for the system operator as it can help in reducing the unbalances and therefore the impact on three-phase connected equipment, but a low value for the EV domestic user, since it is not his main interest to have a perfectly balanced supply voltage. The service may become more interesting for larger LV-supplied customers with higher 3-phase power supply and presence of 3-phase rotatory machines.
On the other hand, **Islanded micro grid and black start** has a low value for the system, but a high value for the EV user since it enables him to maintain a small power system and ensures that power and energy are available even when the main grid is disconnected. Although this may not be common in highly populated areas, it may be of particular use for remote locations where the grid outages are common.

Name	Short description	Value for system	Value for owner	Tech./ standard support	Market/ regulatory support
Islanded micro grid and black start	Enables one or a set of EVs to sustain a small power system	Low	High	Low	Low
LV network balancing	Mitigates unbalances between phases of LV network	Medium	Low	Low	Low
LV overvoltage management	Mitigates overvoltage of LV feeders	High	Medium	Medium	Medium
MV-LV transformer and lines overloading	Mitigates overloading of transformers and cables of LV network	High	Medium	Medium	Low
LV congestion due to fast charging stations	Manages EV fast charging to keep within operational limits of LV network	High	Medium	Medium	Low

Table 2 - Evaluation results of distribution grid services

Conclusions

WP2 have successfully met its goal of investigating services relevant to the distribution system through simulations, experimental laboratory testing, field trials and consistent amount of internationally peer reviewed publications.

The main outcomes of the investigations are as follows:

- ✓ Current series-produced EVs can provide ancillary services at the distribution level.
- ✓ EV reactive power control improves the grid voltage conditions, however grid codes are needed (similarly to the ones for Photovoltaic adopted in Germany and Italy) in order to oblige the OEM to implement such capabilities.
- ✓ Including EV reactive power flexibility in multi-objective scheduling provides DSO benefits while not affecting the EV aggregator 's charging cost.
- ✓ Overall delay, including all communication and measurements, amounts to between 2-4 seconds for the specific tested droop controller and considering the most recently manufactured EVs.
- ✓ Current "undershooting" up to 1 A, which may lead to consistent inaccuracies while providing services.
- ✓ Regulatory and policy barriers present a greater challenge than the technology and infrastructure related ones due to large diversity of distribution systems and respective regulations across Europe.

Work package two has therefore identified the gaps with the following recommendations:

- National grid codes should include reactive power capability for voltage support similar to the ones existing for PVs in several European countries, e.g. Germany and Italy.
- Observability of distribution grids should be increased under different aspects in order to fully deploy the EV potential al low voltage level: 1) low voltage grid topology and equipment specification; 2) relevant consumption and production data collected on individual residential units with at least a quarterly of hour sampling rate; 3) initial and end of line single phase voltage measurements at least every minute; 4) phase current (including neutral) al the low voltage side of the MV/LV transformer every minute.
- Updating EV standard (such as IEC 61851) which would oblige the EV manufacturers to optimize the EV battery management system in terms of response accuracy, and potentially decrease the discrete 1 A response requirement to get a more smooth and precise transition in the operating range.
- Thorough investigation of technical feasibility on different EV brands and models to provide distribution grid services, including experimental testing on various vehicles and development of controllers for mass roll-out of EVs.
- Remove regulations which forbid aggregation and explicitly allow flexibility procurement at the distribution level.
- Remunerate current DSO services to provide basis for comparing different solutions and estimating the flexibility price.
- Define standards for interface and data exchange between DSO and TSO as well as clear priorities between them for normal operation and various emergency situations.
- Defining standards and regulations for deploying EV supply equipment with control and communication capabilities.
- Deployment of robust back-end communication system for effective controlling capability of the vehicle across different power system stakeholders (i.e., DSO, TSO, fleet operator)
- Educate the users about the benefits of such services and the potential earnings, including the importance of having the vehicle plugged-in whenever it is not driven and guaranteeing the possibility of having grid services without compromising primary transportation purposes.

5.1.3 User added services

Process and activities

Work package three have, based on previous projects and the input from external reviewers, identified and prioritized a total of four services (Table 3) that may aid in involving EV owners in power and energy services.

Two of these services, ***charging management*** and ***charging flexibility assessment***, where deemed the most relevant to investigate further (high initial priority) and have been subject to a total of five evaluation activities.

The work package has used two different data sources representing both private and workplace charging, as a valuable input to the charging flexibility evaluations. A number of studies have analyzed this data to both uncover the flexibility available in each scenario and to propose approaches to automatically assess the degree of such flexibility.

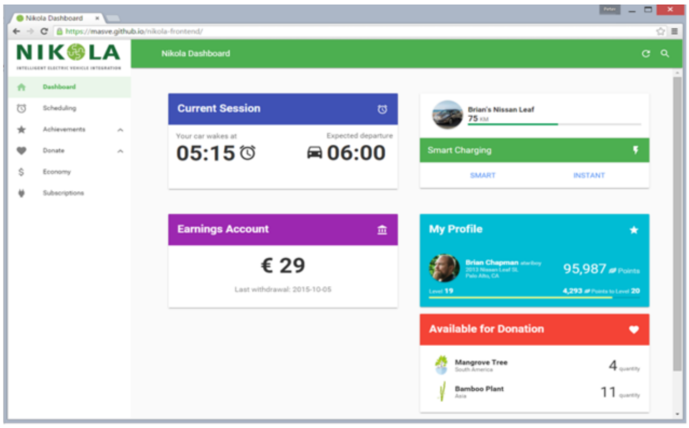


Figure 5 - Demonstration interface (EVUI.elektro.dtu.dk)

The WP has also organized the development of a demonstration user interface implementing functionalities to support the EV owners willingness to participate in grid services. The functionalities have been subject to a small user test and have received input from Nissan Motors. The interface developed has given new insights and learnings applicable to the WPs objective.
Based on the activities in WP3 the four identified services have been given a final evaluation.

Evaluation results

Both the ***Charging management*** and ***Charging flexibility assessment*** services are evaluated to be of high value to the EV owner and very important in the deployment of EV based energy services. However both of these services requires continued development as no such system, to the authors knowledge, is yet available.

The ***Vehicle-to-load service*** is evaluated to have a medium interest to the EV owner since only a single application has been identified in a Danish context – namely vehicle-to-equipment. Technical support for this service is also limited (available in few vehicles).

Finally the ***Charging information*** service is deemed to have low value to the owner since it will likely only appeal to a small number of users. Technology support however, is set to medium since OEM developed apps already allow EV owners access to the most essential information such as SOC and charging status.

Name	Short description	Value for system	Value for owner	Tech./ standard support	Market/ regulatory support
Charging management	Support EV service participation for the EV owner through interface.		High	Low	
Charging flexibility assessment	Estimates whether sufficient charging flexibility exists in order to participate in services.		High	Low	
Charging information	Presents the EV user with the information most relevant when controlling (dis)charging of the EV		Low	Medium	
Vehicle-to-Load	Enables the EV to supply electric energy to the EV user in places where access to the general electric grid is impossible or impractical		Medium	Medium	

Table 3 - Evaluation results of user added services

Conclusions

Work package three have successfully met its goal of investigating services relevant to the EV owner through both real-world data, interface development, user involvement and field testing.

The investigation found that:

- ✓ Charging management and flexibility analysis software needs to be further developed and tested with a larger sample of testers than was available to the Nikola project.
- ✓ The identified functionalities (Scheduled charging windows, charging status etc) show promise in bridging the user to smart grid services.
- ✓ Usage pattern analysis may aid in simplifying the EV owners involvement in smart grid services – eliminating the users need to provide detailed and continuous input to the aggregator.
- ✓ An emphasis on economic and feel-good incentives as well as gamification may attract users and increase willingness to participate in services.
- ✓ Smart grid services, besides from adaptive charging, may be complicated to understand and the user needs to understand the tradeoffs/consequences.
- ✓ The EVs charging flexibility depends on sufficiently long, and predictable, plugin sessions, which again can vary greatly between different user groups and cases.
- ✓ The support of V2L will likely depend on the ability to identify new and valuable applications.

The following recommendations for user added services are made:

- ! It is recommended to undertake large-scale user tests where EV owners have access to charging control systems. This will allow for a better understanding of the users attitude and requirements towards the system taking care of charging their vehicles.
- ! There is a need for ways to convey, and perhaps abstract, the complexities of grid services – e.g. explaining V2G and ancillary services.
- ! It may make sense with an initial emphasis on fleet owners. This because usage patterns tends to be simpler and the concentration of equipment may make deployment easier. Learnings can then be applied to private owners.
- ! Complexity for the end-user must be minimized. Trust must be placed with a 3rd party that has (possibly through data analytics) a deep understanding of the users usage patterns.
- ! Use all the incentives available (economic and otherwise) to appeal to as many users as possible. Both environmental and economic benefits should be quantified and clearly presented.
- ! Encourage frequent plug-ins, the user must understand that earning/value is proportional with the EVs time spent connected to the grid.

5.1.4 Enabling technology

The WP Enabling technology didn’t directly address services – rather it did investigations and development needed to technically support the services described by the other work packages.

Before the project could start demonstrating services it needed access to both vehicles and chargers which would provide open research platforms in that the (dis-)charging process could be closely monitored and controlled.

Project vehicles

Since the project needed vehicles for testing the various services it was decided to acquire and upgrade a number of converted Citroen C1’s for the project. This would provide the project with an open platform, with full control of the charging process and access to all needed data.

The vehicles purchased by the project were already converted to EVs prior to the project. However the vehicles were both in need of mechanical and electrical upgrades (motor couplers, BMS system, charger, charging inlet etc) to ensure sufficient reliability and safety.

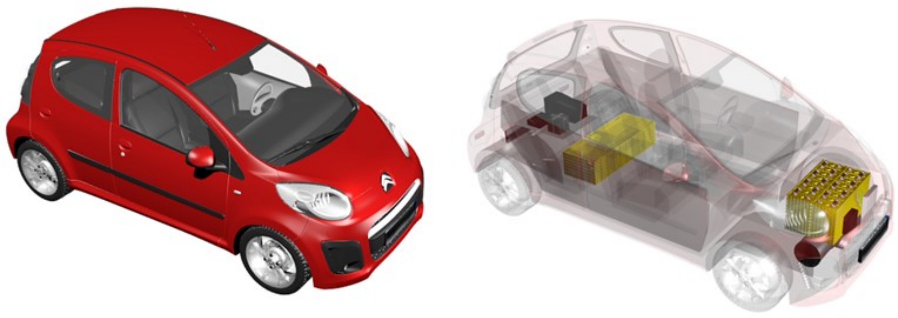


Figure 6 - Retrofitted C1 vehicles

The vehicles where equipped with a control system that allowed the project to control the charging process with the IEC 61851 standard. The vehicles where used for demonstration in conjunction with the OEM cars later available to the project, and gave the participants valuable insights on EV technology.

In the last part of the project, one of the vehicles was equipped with small solar inverters in order to test AC based V2G (as opposed to the DC based V2G used by the Enel chargers in the project).

Project charging spots and light cables

To support the services the WP developed a number of charging solutions including portable charging spots and a phase splitter.

The portable AC chargers (3P, 32A), where equipped with a IEC 61851 controller developed by Phoenix that, through an Ethernet connection, allowed for external control of the charging rate. This equipment was primarily used by WP2 (Distribution grid services) in the DTU laboratory tests (Syslab) and in the field tests (Borup).

Another piece of equipment, a three-phase splitter, allowed three one-phase AC charging vehicles to connect to the same three-phase connection. This allowed for WP2 services focusing on phase balancing i.e. pr phase load could be controlled independently.

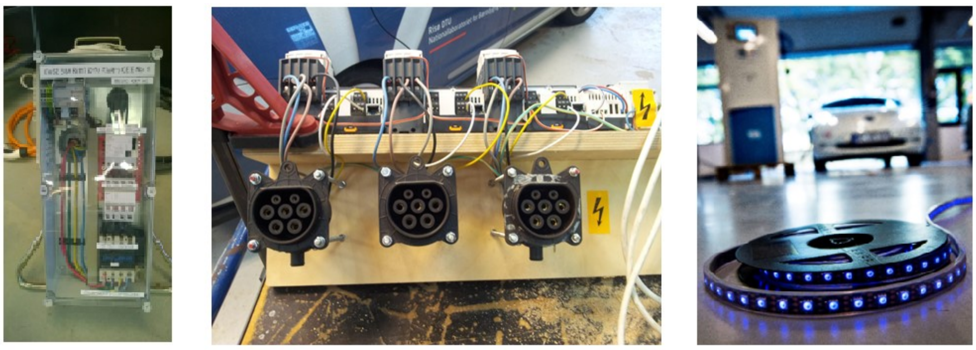


Figure 7 - Phoenix-based charger (left) Phase splitter (right)

In order to better visualize the charging control toward a non-technical audience a number of “light cables” were developed and brought to various networking events. The cables use colours and animation to show size and direction of the current flowing between the vehicle and the grid. The cables are controlled by a small computer that receives real-time power measurements either from local measurements or via a connection to an online source of such data.

Besides from the above, additional supporting equipment was developed such as a portable measurement unit (Based on DEIF unit).

Standards

An important part of the enabling technologies WP are the communication standards applicable for connecting EV, EVSE and a backend for the purpose of service provision.

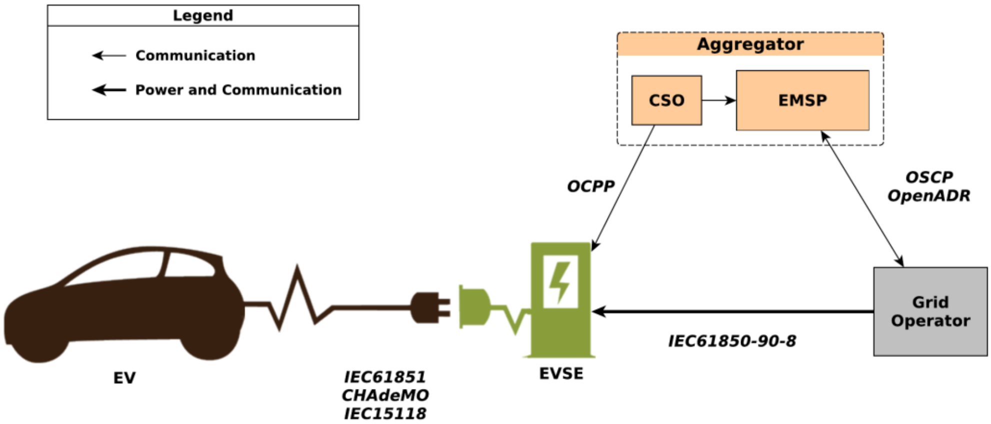


Figure 8 - Standards for service provision

A number of the standards shown in figure 8 have been selected for a more thorough study by the project:

<u>IEC/ISO 15118</u>

The 15118 standard is used to support advanced communication between an EV and EVSE. A reference implementation of the 15118 standard was developed (test bench). The goal has been to evaluate the standard in terms of difficulty of implementation, interoperability with existing devices, security and the support of power and energy services described in Nikola.

The testbench was successfully built and tested towards a computer – although tests towards a real EV or EVSE proved not to be possible.

The conclusions of this study were that the implementation is non-trivial due to features such as SLAC (EV-EVSE identification) and the many levels of implementation required. It was also found that interoperability was still lacking and there was, at the time of the study, a very limited amount of EVs and EVSEs supporting 15118.

It was found that 15118 could still only support a rather limited amount of services – not much beyond what is already possible through simple IEC 61851 PWM control. Finally some possible security flaws were also identified.

In general the standard is found to have potential- but further development is still needed.

<u>61850-90-8</u>

The scope of TR61850-90-8 is to show how IEC 61850-7-420 can be used to model the essential parts of the E-mobility standards related to Electric Vehicle and Electric Vehicle Supply Equipment (IEC 62196, IEC 61851, IEC 15118) and the Power system (IEC 61850-7-420), in order to secure a high level of safety and interoperability.

Nikola has directly supported the development of this standard and tested its application in a test bench setup.

<u>IEC 61851</u>

The IEC 61851 "Electric vehicle conductive charging system" establishes general characteristics, including charging modes and connection configurations, and requirements for specific implementations (including safety requirements) of both electric vehicle (EV) and electric vehicle supply equipment (EVSE) in a charging system.

The most relevant feature of the standard is the possibility to limit the charging current. This allows simple charging control on a most current-day EVs. Nikola has tested how (speed and accuracy) different EVs respond to the PWM duty cycle used by IEC 61851.

EV nr.	Minimum delay	Average delay	Maximum delay	Average Response Error
I	0.4 s	1.1 s	2.0 s	0.8 A
II	0.2 s	0.3 s	0.6 s	0.4 A
III	0.5 s	1.5 s	2.5 s	1.0 A

Table 4 - EV response comparison

It was found that most current EV brands provide a pretty fast and accurate response to this type of charging control (see table 4). The speed (delay) of the response varies between the brands.

In conclusion, the standard support the more simple services explored in Nikola and has been used in several experiments.

<u>Comparison between standards for grid services</u>

Another important WP activity was the comparison between some of the identified services in terms of their ability to support services.

The standards and their features where compared in terms of support of the most demanding service in the Nikola service catalog – frequency regulation. The standards were compared in two groups – between EV and EVSE and between EVSE and backend.

EV to EVSE

Standard/ Specification	Power Control	V2G	SOC	Charging Schedule	Identification	Response Time
IEC61851	+	-	-	-	-	< 3s
IEC15118	+	(+)	(+)	+	+	< 60s
CHAdeMO	+	(+)	+	-	-	< 1s

EVSE to Back-end

Standard/ Specification	Power Control	V2G	SOC	Charging Schedule	Identification
OCPP	+	-	-	+	-
IEC61850-90-8	+	(+)	+	+	-

Table 5 - Standards and their support of frequency regulation

In the figure above '+' denotes support of the a number of needed functionalities (Power control, V2G, SOC, etc), '-' means a lack of support and '()' means limited/future support.

The conclusion is that CHAdeMO and IEC 15118 are in the best position to support frequency regulation, at the EV-EVSE level, as of this writing.

Currently IEC 61850-90-8 is closest to supporting frequency regulation. However the OCPP standard is more wide-spread and new versions are likely to better support the needed features.

Conclusions

The enabling technologies work package in Nikola has successfully been able to support the services investigated in the project through the project vehicles and charging equipment.

That being said, the project vehicles have required much more work than expected and problems with the first subcontractor tasked with doing the updates, delayed the development considerably.

The cars were ultimately delivered in time to be included in project services, but mostly due to hard work and "interest hours" given by Elektro Fyn and staff at DTU. A learning from this project is the risk associated with technology development - even though the development process is planned in detail.

Other equipment (chargers, splitters, measurement, light cables) were less complex but still became great assets to the project.

Besides from technology development, the work package also contributed with research on service support by contemporary standards. Some of these finding have been used to give input for the revision of the ISO/IEC 15118 standard.

Main conclusions are as follows:

- ✓ EVs are currently able to provide grid services, using:
  - ➢ IEC 61851 with dynamic charging limits
  - ➢ CHAdeMO with bidirectional charging control
- ✓ V2G support is still missing for all communication protocols other than CHAdeMO 2.0.
- ✓ Most protocols need improvements in security.
- ✓ Grid services are dynamic in nature which means that protocols should exhibit speed and accuracy in the controllability of the charging process.
- ✓ Communication standards should ideally support a broad range of grid services.

5.2 Collaboration with OEMs

Dissemination and networking activities by the project partners brought the project in contact with Nissan Europe. When Nissan Europe later announced that they, together with Enel, would start supporting V2G in their vehicles – an opportunity for collaboration presented itself.

The work by Nikola, the experience within aggregation software of Nuvve and good market conditions in Denmark convinced Nissan and Enel to choose Denmark as the first test-site for commercial V2G operation.

The first two Nissan vehicles arrived at DTU in the spring of 2015.

Figure 9 - Nissan joining Nikola early 2015

After Nissan had joined the project, discussions with Groupe PSA (Peugeot and Citroën) on a similar arrangement started. Groupe PSA later also decided to provide two vehicles to the project.

In total the following equipment was made available to the project:

- Two 2015 model Nissan Leafs
- One electric Berlingo
- One Peugeot Ion
- Two 1st gen Enel DC 10 kW V2G charging stations
- Four 2nd gen Enel DC 10 kW V2G charging stations

The above equipment was provided without cost by OEMs in order to participate in EV power and energy service validations.

Figure 10 - New Nikola partners and equipment

The involvement and equipment provided by Nissan, Enel and Groupe PSA extended the scope of Nikola considerably – but also the impact and results of the project.

Ultimately it allowed for the first demonstration of OEM V2G vehicles providing FNR services (frequency regulation) carried out as part of an IEA (International Energy Agency) workshop at DTU at the end of October 2015.

Figure 11 - First validation of series produced V2G cars providing FNR

The OEM equipment have primarily been used for ancillary service validations as part of WP1 – but also to some extend for services as part of the distribution grid services tested at Syslab in WP2.

5.3 Dissemination activities

Besides from the academic publications produced by the project (appendix 2) the project has undertaken a number of dissemination activities.

5.3.1 News articles

The project has had several mentions in news articles both inside and outside academic news outlets.

Among the larger news outlets to describe the project, following the first work on Nissan vehicles that was presented by Nikola in October 2015, are:

- Ingeniøren, Dec 2015 ”Nissan gør bilbatteri til kraftværk”
- Dynamo, Dec 2015 ”ELBILEN”
- Børsen, Jan 2016 “Nissan vil opbevare strøm fra hele Danmark”
- Motor magasinet, Dec 2016 ”Leaf er klar til intelligent el”

Figure 12 - News articles on Nikola activities

5.3.2 Web page

A project webpage (www.nikolaproject.info) was created to present and describe the project.

Throughout the project the webpage was updated to reflect the status of the project and link to material such as the service catalog, the developed user interface and presentation material from the seminars.

Figure 13 - Project webpage (left) google analytics (right)

The webpage traffic was tracked using google analytics (figure 13 / right) and was evaluated at project meetings.

5.3.3 Seminars

The Nikola partners decided to arrange two seminars during the project. First a half-way seminar was arranged in November 2014 with 55 participants and then later, in June 2016, an end seminar attended by a hundred participants including representatives from seven different vehicle manufacturers.

The seminar included a first-of-its kind demonstration where it was shown that EVs can dynamically adjust to the needs of the power system by seamlessly transitioning from one service to another. A Syslab test showed six EVs (of different brands) providing local voltage support when connected to the public distribution grid, transitioning to frequency regulation once the system becomes islanded.

Figure 14 - Nikola end seminer

Both seminars allowed the Nikola partners to present project results and were an important part of the projects dissemination and networking activities.

Presentation material was made available to participants after the events through the project webpage.

5.3.4 Events

A number of larger events allowed the Nikola partners to disseminate on the project.

The project has been described at numerous meetings, visits and conferences both in Denmark and abroad.

Among the larger of these events were:

- **Armand Peugeot Chair, Electromobility: Challenging Issues (ECI) conference, Paris 2014 and Singapore 2015**
  Presentation of the Nikola project (2014, Paris) and User involvement in EV smart grid services (WP3) (2015, Singapore). Each event attracted 75-100 participants.
- **The solar and electrical mobility revolution conference, Amsterdam 2015.**
  Invitation to present the activities of the Nikola project and the ties to renewables in Demark. The event was attended by approximately 100 technical experts, city/government and industry representatives.
- **United Nations Industrial Development Organization (UNIDO) meeting, Vienna 2016**
  Invited as EV integration expert in a Consultative Expert Group Meeting (EGM) on "Interoperability between the electric vehicles and the grid in the urban context". The meeting brought together experts and ~50 international policy makers.
- **International Energy Agency (IEA) Task 28 – V2X and the grid workshop, Copenhagen 2015.**
  The Nikola team was responsible for the hosting of the IEA task 28 meeting in Copenhagen. The event took place both at Danish Standards in Nordhavn and at the Lyngby Campus north of Copenhagen. The event consisted of 50-60 industry and academy participants.
- **Folkemødet, Nissan press event on the future of cars, Bornholm 2016**
  Presentation of project results for ~ 50 participants at panel discussion arranged by Nissan Denmark.
- **Launch event at the Frederiksberg forsyning for the commercial V2G Pilot**
  ~50 Participants with roughly half being from the press. The event showcased the Nissan/Enel/Nuvve technology validated in Nikola and got extensive press coverage.

The launch event at Frederiksberg forsyning was covered by several large news outlets. The screenshots below is from the DR1 evening news the 28th of September 2016.

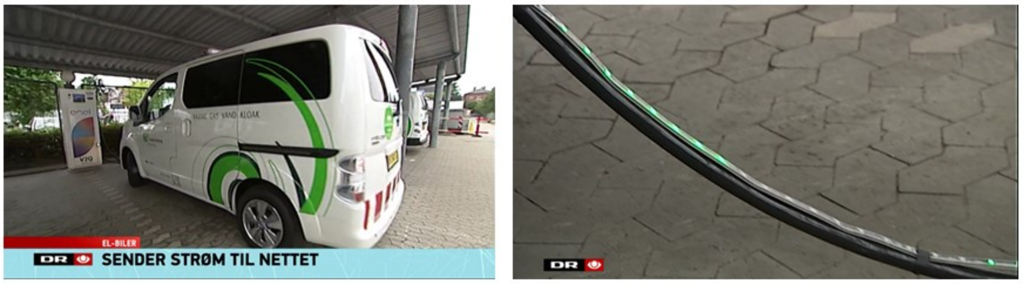


Figure 15 - DR1 evening news (Nikola light cables to the right)

5.3.5 PhD study

As part of the project, ForskEl funded a PhD student which made several and considerable contributions to the project.

The thesis investigated how EVs could mitigate the self-induced adverse effects and actively help the distribution grid operation, either autonomously or in coordination, e.g., with an EV aggregator. The general framework for EV integration was presented, including the contemporary technology, the relevant stakeholders and the most important challenges. EV flexibility provision to DSOs was studied both from the technical and the regulatory perspective in order to identify the barriers for active EV involvement, and provide a set of policy recommendations for overcoming them.

The potential benefits and drawbacks of introducing EV reactive power capability for voltage support were analysed. A decentralised reactive power control was proposed which could, given the appropriate equipment sizing, support the distribution grid independent of the active power modulation. Such an autonomous controller relied only on the local voltage measurement and can be implemented in the short-term future by using the inherent functionality of the EV power electronics. The impact of the proposed control was investigated on a Danish low-voltage grid with the assessment of grid parameters in various conditions.

A multi-objective framework was developed for the optimal EV day-ahead scheduling in unbalanced distribution grids. The framework assessed the trade-off between the DSO's and the EV aggregator's economic concerns, and used a fuzzy-satisfying method to balance the interest of both parties. Moreover, the impact of the additional EV reactive power support was analysed when EVs are the only flexible resource, as well as when combined with other demand response.

Experimental activities were conducted to validate the technical feasibility of contemporary EVs to provide flexibility services, both in a laboratory environment and in a real distribution grid. The emphasis was put on assessing several EV parameters, such as EV responsiveness and EV accuracy, to provide basis for future theoretical work, as well as recommendations for improvement.

Overall, it was shown that EVs can actively support the distribution grid operation, but also that there is a critical gap between the political sustainability plans, and the implemented standards and regulatory framework. Moreover, it was demonstrated that DSOs can benefit from the potential EV reactive power control without substantially influencing the losses or the EV aggregator’s cost. Finally, it was proven that series-produced EVs are capable of providing various flexibility services within several seconds, but their accuracy might arise as a topic of concern.

6. Utilization of project results

The Nikola project has contributed directly to four follow up activities:

6.1 EV group within Energinet.dk’s “Pilot project for emerging technologies in the ancillary services markets”

After close discussions with Enenrginet.dk regarding the support of System-wide services, the project applied to become part of a new pilot project arranged by EnerginetDK as part of the Market model 2.0 strategy.

Nikola was chosen to become one of four projects to join the pilot.

The pilot works on removing technical and economic barriers for entering the ancillary service markets with an aggregated fleet of EVs.

The pilot group directly uses Nikola results to address such barriers. The work in the group will be taken over by the Parker project.

6.2 The Frederiksberg Forsyning commercial pilot

On the 29th of august 2016 a pilot was launched at the utility Frederiksberg Forsyning. The pilot represents the world's first commercial field aggregation of V2G EVs.

In the pilot participates Nissan, Enel and Nuvve as technology providers of cars, chargers and aggregation software. It is Frederiksberg forsyning that hosts the pilot using ten Nissan eNV200 vans driven daily by their employees.

This commercial activity builds directly on top of the cooperation with Enel and Nissan in the Nikola project and the work of the system-wide services WP.

Figure 16 - Frederiksberg Forsyning pilot

The pilot will be the last step in validating the technical and economic viability in ancillary service participation by commercial fleets.

The pilot will interface with, and support, the newly started Parker project.

6.3 The Parker project.

During 2015 DTU applied for funds to launch the Parker project.

The Parker project seeks to validate that series produced electric vehicles, as part of a vehicle fleet, can be made to participate in advanced, vertically integrated, smart grid services. Where Nikola represented applied research, Parker represents the next step on the technology readiness level focusing on pilot validations.

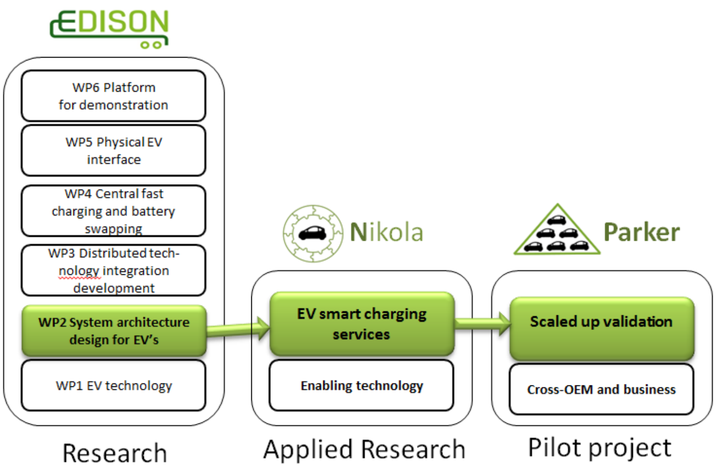


Figure 17 - The Parker project

The services identified in Nikola (Nikola service catalog), having the highest technical and economic potential, will be implemented by Parker. Besides from the service catalog, both the technologies and the accumulated experience gathered by Nikola partners will be carried into the Parker project.

6.4 The ACES project

Another project, ACES, starting in 2017, will also build on the results of Nikola.

ACES intends to holistically investigate technical and economic system benefits and impacts by large scale electric vehicles integration in Bornholm, augmented by real usage patterns, grid data and field testing for across continents replicability.

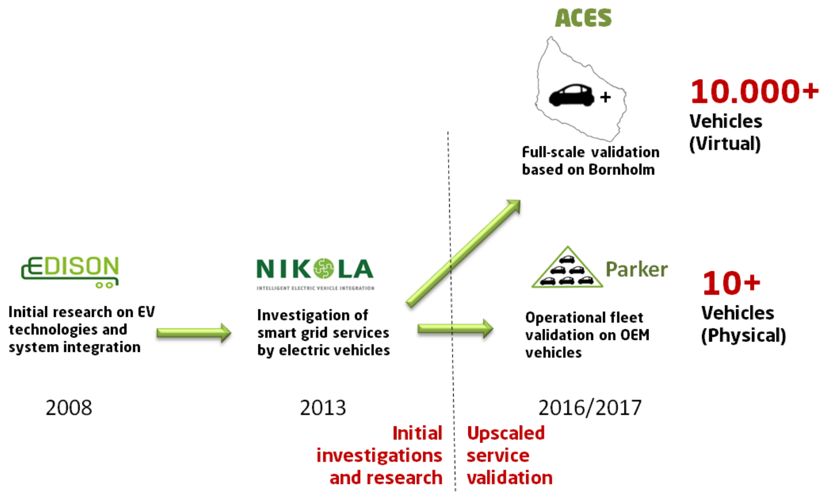


Figure 18 - The ACES project

A full scale penetration scenario of EVs in Bornholm will be simulated in order to assess how new aggregating functionality can support both technically and economically the successful integration of electric vehicles into the energy system.
It will also initiate a small scale pilot project involving up to 100 privately owned Nissan vehicles and V2G chargers for proving that EVs can be used for effectively balance the system.

7. Project conclusion and perspective

The Nikola project meet its objective by identifying, prioritizing and evaluating a structured group of services through a number of simulated and physical test and evaluation activities.

These activities included field testing, user testing, lab testing and software modelling. The physical tests were conducted using series-produced vehicles and chargers as well as equipment developed by the project itself (vehicles, chargers and supporting equipment).

The services, along with evaluations of each, are summarized by a service catalog and in more detail in a number of WP reports.

The work with the electric vehicles has produced more than twenty academic publications of which six are high-impact journal papers. A total of 35 student projects have been organised during the project to have students both learn from, and contribute to, the project.

A PhD study has been completed adding valuable knowledge to the project and the research field in general.

About two years into the project, Nissan motor, Groupe PSA and Enel joined the project. The equipment provided by the OEMs represented a substantial self-financed investment into Nikola.

Cooperating with Nissan and Enel, Nikola managed to execute the world's first demonstration of series-produced V2G cars providing ancillary services.

The project has carried out heavy dissemination activities including two seminars, presentations at large Danish and international events and mentions in large news outlets. The project has directly contributed to the development of the IEC 61850-90-8 standard and provided input to an upcoming version of ISO/IEC 15118.

Nikola's results will directly carry into four follow-up activities and has helped pave the way for a commercial pilot in Denmark.

<u>The following general conclusions are made by the project:</u>

! While "adaptive charging" services (charging is delayed in time) are easy to implement, no real incentives exists in Denmark today. The initial focus is therefor put on frequency-based ancillary services where a better business case can be identified.

! The services with the most immediate economic incentive, frequency-based ancillary services, are also the ones that depend the most on advanced EV/EVSE capabilities such as fast response, V2G support and access to battery status information. E.g. the services that may be commercial viable short-term brings requirement that standards are not yet ready to support.

! For local grid services, the technical value to the grid has been shown and implementation approaches has been suggested and demonstrated. A lack of market and/or means to incentivize participation is still a challenge. As part of the PhD study in Nikola, a roadmap for DSO's use of EV services have been defined.

! The availability of the IEC 61851 and CHAdeMO standards are the only standards of present with real support of service functionalities – Standards such as IEC/ISO 15118 and 61850-90-7 has promise but is in need of development. Present-day V2G support by CHAdeMO 2.0 must currently be combined with custom (non-standardized) communication between EVSE and aggregator in order to work.

! Grid services are a foreign concept to users and technical services such as frequency balancing and voltage support will be difficult to convey in an easily understood manner. If the user, however, is sufficiently informed and the required involvement is kept to a minimum, he or she may still choose to allow a 3rd party system to manage the charging of her or his EV. A suit of economic and feel-good incentives are needed to make the owner interested.

! With sufficient follow-up R&D/pilot activities Denmark may maintain its good working relationship with international OEMs and its role in supporting the definition and development of grid integrated electric vehicles. This will give an early advantage in the utilization of renewables and the development of supporting technology.

8. Acknowledgements

The Project team would like to thank all the students who contributed to the project.

A special thanks is given to Ole Jan Olesen and Bent Mortensen for their valuable and voluntary contributions to the project.

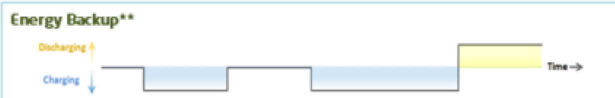
Also the project thanks PhD students Katarina Knezovic and Sergejus Martinenas for their contributions and devotion to the project.

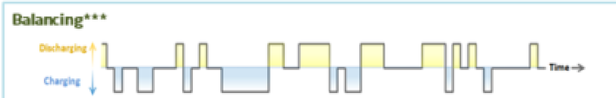
Figure 19 - The Nikola project team

Finally, the Nikola project team would like to thank the ForskEl programme for the funding and support that made the project possible.

Appendix 1 – Service catalog

Definition						Evaluation *Danish case, now/near-term (<3 Years)*			
Type	Groups	Name	Short description	Behavior	Stakeholders & potential benefits	Value for system	Value for owner	Tech./ standard support	Market/ regulatory support
Power and energy services	System-wide services	Frequency regulation	Keeps the frequency in an interval around 50Hz	Balancing***	Aggregator/EV Owner: Market earnings TSO: Larger, more competitive market	High	High	Medium/High	High
		Frequency regulation - very fast	Frequency regulation with ramping times and precision that go beyond what traditional generators can provide	Balancing***	Aggregator/EV Owner: Market earnings TSO: New/improved service	High	High	Medium/High	Low
		Secondary regulation	Replaces frequency regulation and restores the frequency to 50 Hz	Balancing***	Aggregator/EV Owner: Market earnings TSO: Larger, more competitive market	Medium	Low	Medium/High	Low
		Tertiary regulation	Replaces secondary regulation and fulfills a higher requirement to energy capacity and delivery timescale	Balancing***	Aggregator/EV Owner: Market earnings TSO: Larger, more competitive market	Low	Low	Low	Low
		Synthetic inertia	Mimics rotational inertia by taking advantage of the fast chemical reaction of batteries	Balancing***	Aggregator/EV Owner: Market earnings TSO: New/improved service	Medium/High	Low	Low	Low
		Adaptive charging	Delays or advances charging in time based on e.g. energy costs or renewable contents	Adaptive*	Aggregator/EV Owner: Energy cost or CO2 savings	High	High	Medium/High	Low
		MORE - Mother of all regulation	Includes all the abovementioned traditional types of regulation in one - assuming a large fleet of EVs.	Balancing*** Energy backup** Adaptive*	Aggregator/EV Owner: Market earnings TSO: New/improved service + Larger, more competitive market	Low	Low	Low	Low
	Distribution grid services	Islanded micro grid and black start	Enables one or a set of EVs to sustain a small power system	Energy backup**	EV owner: Security of supply.	Low	High	Low	Low
		LV network balancing	Mitigates unbalances between phases of LV network	Balancing***	Aggregator/EV Owner: Unknown DSO: New service	Medium	Low	Low	Low
		LV overvoltage management	Mitigates overvoltage of LV feeders	Balancing*** Adaptive*	Aggregator/EV Owner: Unknown DSO: New service	High	Medium	Medium	Medium
		MV-LV transformer and lines overloading	Mitigates overloading of transformers and cables of LV network	Adaptive*	Aggregator/EV Owner: Unknown DSO: New service	High	Medium	Medium	Low
		LV congestion due to fast charging stations	Manages EV fast charging to keep within operational limits of LV network	Adaptive*	Aggregator/EV Owner: Unknown DSO: New service	High	Medium	Medium	Low
ICT Services	User added services	Charging management	Support EV service participation for the EV owner through interface.		Aggregator/EV Owner: Added simplicity for service participation		High	Low	
		Charging flexibility assessment	Estimates whether sufficient charging flexibility exists in order to participate in services.		Aggregator/EV Owner: Knowledge on charging flexibility		High	Low	
		Charging information	Presents the EV user with the information most relevant when controlling (dis)charging of the EV		Aggregator/EV Owner: Improved information service		Low	Medium	
		Vehicle-to-Load	Enables the EV to supply electric energy to the EV user in places where access to the general electric grid is impossible or impractical		EV Owner: New electric energy services		Medium	Medium	





Appendix 2 - Publications

Publications in the Nikola project by year of publication

2014 (7 publications, 7 Conference papers)

Conference papers

P. B. Andersen, M. Marinelli, O. J. Olesen, G. Poilasne, B. Christensen, C. Amstrup, and O. Alm, “The Nikola Project: Intelligent Electric Vehicle Integration”, Innovative Smart Grid Technologies (ISGT Europe), 2014 5th IEEE PES International Conference and Exhibition on, pp.1-5, Istanbul, 12–15 Oct. 2014.

K. Knezović, M. Marinelli, R. J. Møller, P. B. Andersen, C. Træholt, and F. Sossan, “Analysis of Voltage Support by Electric Vehicles and Photovoltaic in a Real Danish Low Voltage Network,” Proceedings of the 49th International Universities Power Engineering Conference (UPEC) IEEE. Cluj-Napoca, Romania, pp. 1–6, 2014.

K. Knezović, M. Marinelli, P. B. ; Andersen, C. Træholt, “Concurrent Provision of Frequency Regulation and Overvoltage Support by Electric Vehicles in a Real Danish Low Voltage Network,” Electric Vehicle Conference (IEVC), 2014 IEEE International, pp.1-7, Florence, Italy, 16-18 Dec. 2014

A. Zarogiannis, M. Marinelli, C. Træholt, K. Knezović, P.B. Andersen, “A Dynamic Behaviour Analysis on the Frequency Control Capability of Electric Vehicles,” Power Engineering Conference (UPEC), 2014 49th International Universities, pp.1-6, 2-5 Sept. 2014

S. Martinenas, M. Marinelli, P. B. Andersen, and C. Træholt, “Implementation and Demonstration of Grid Frequency Support by V2G Enabled Electric Vehicle,” Universities Power Engineering Conference (UPEC), 2014 Proceedings of the 49th International, pp.1-6, Cluj Napoca, 2–5 Sep. 2014.

S. Martinenas, A. B. Pedersen, M. Marinelli, P. B. Andersen, C. Træholt, “Electric Vehicle Smart Charging using Dynamic Price Signal,” Electric Vehicle Conference (IEVC), 201, IEEE International, pp.1-7, Florence, Italy, 16-18 Dec. 2014

M. Svendsen, M. Winther-Jensen, A. B. Pedersen, P. B. Andersen, T. M. Sørensen, “Electric vehicle data acquisition system,” Electric Vehicle Conference (IEVC), 201, IEEE International, pp.1-7, Florence, Italy, 16-18 Dec. 2014

2015 (5 publications, 4 conference papers, 1 journal papers)

Conference papers

K. Knezović, M. Marinelli, P. Codani, and Y. Perez, “Distribution Grid Services and Flexibility Provision by Electric Vehicles: a Review of Options,” Proceedings of the 50th International Universities Power Engineering Conference (UPEC) IEEE. Staffordshire, UK, pp. 1–6, 2015.

P. Lico, M. Marinelli, K. Knezović, and S. Grillo, “Phase Balancing by means of Electric Vehicles Single-Phase Connection Shifting in a Low Voltage Danish Grid,” Proceedings of the 50th International Universities Power Engineering Conference (UPEC) IEEE. Staffordshire, UK, pp. 1–6, 2015.

A. B. Pedersen, S. Martinenas, P. B. Andersen, T. M. Soerensen, H. S. Hoej, *“A method for remote control of EV charging by modifying IEC61851 compliant EVSE based PWM signal”*, 2015 IEEE International Conference on Smart Grid Communications (SmartGridComm).

P. B. Andersen; C. Clemmensen, “EV owner smart grid involvement,” Presented at: Electromobility Challenging Issues (ECI), 2015, Singapore.

Journal papers

S. Martinenas, K. Knezović, and M. Marinelli, “Management of Power Quality Issues in Low Voltage Networks using Electric Vehicles: Experimental Validation,” IEEE Transactions on Power Delivery, in press

2016 (11 publications, 5 journal, 5 conference)

Conference papers

S. Martinenas, M. Marinelli, P.B. Andersen, C. Træholt, *“Evaluation of electric vehicle charging controllability and response time for the provision of grid services,”* UPEC 2016, Power Engineering Conference (UPEC), 2016 51st International Universities, Porto, Portugal, pp. 1-6, Sept. 2016

S. Martinenas, S. Vandael, P. B. Andersen, Bjoern Christensen, *“Standards for EV charging and their usability for providing V2G services in the primary reserve market”*, EVS29 Symposium 2016

J. Lin, K. Knezović, “Key Attributes of Possible Designs for Flexible Distribution System Operation,” 13th International Conference on European Energy Market, Porto, Jun. 2016

J. N. Alvarez, K. Knezović, M. Marinelli, “Analysis and Comparison of Voltage Dependent Charging Strategies for Single-Phase Electric Vehicles in an Unbalanced Danish Distribution Grid,” UPEC 2016, Power Engineering Conference (UPEC), 2016 51st International Universities, Porto, Portugal, pp. 1-6, Sept. 2016

A. Thingvad, S. Martinenas, P. B. Andersen, B. E. Christensen, and O. J. Olesen,”Economic evaluation of electric vehicles performing unidirectional and bidirectional frequency control in Denmark with practical validation”, UPEC 2016, Power Engineering Conference (UPEC), 2016 51st International Universities, Porto, Portugal, pp. 1-6, Sept. 2016

Journal Papers

K. Knezović, M. Marinelli, “Phase-Wise Enhanced Voltage Support from Electric Vehicles in a Danish Low-Voltage Distribution Grid,” Electric Power System Research, vol. 140, pp. 274-283, Nov. 2016

K. Knezović, S. Martinenas, M. Marinelli, P. B. Andersen, A. Zecchino, “Electric Vehicle Smart Charging Controller: Field Validation of Multiple Flexibility Services in Low Voltage Distribution Grid,” IEEE Transaction on Transportation Electrification, in press

B. Morvaj, K. Knezović, R. Evins, M. Marinelli, “Integrating Multi-Domain Distributed Energy Systems with Electric Vehicle PQ Flexibility: Optimal Design and Operation Scheduling for Sustainable Low-Voltage Distribution Grids,” Sustainable Energy, Grids and Networks, vol. 8, pp. 51-61, Dec. 2016

M. Marinelli, S. Martinenas, K. Knezovic, and P. B. Andersen, “Validating a centralized approach to primary frequency control with series-produced electric vehicles,” Journal of Energy Storage, vol. 7, pp. 63-73, Aug. 2016

Knezović, K.; Marinelli, M.; Zecchino, A.; Andersen, P.B.; Træholt, C.; “Supporting involvement of electric vehicles in distribution grids: Lowering the barriers for a proactive integration”, Energy, under review

Knezović, K.; Soroudi, A.; Marinelli, M.; Keane, A.; “Multi-objective PQ scheduling for Electric Vehicles Flexible Unbalanced Distribution Grids”, IET Generation Transmission and Distribution, under review