Enhanced Ancillary Services from Wind Power Plants

EASE WIND

Final Report
8th March 2015

Final report

1.1 Project details

Project title	EASEwind Enhanced Ancillary Services from Wind Power Plants
Project identification (program abbrev. and file)	PSO 2011-1-10653
Name of the programme which has funded the project	ForskEL
Project managing company/institution (name and address)	Vestas Wind Systems A/S Hedeager 44, DK-8200 Aarhus
Project partners	DTU/Wind Energy, DTU/Electrical Energy, DTU/Compute AaU/Energy Technology
CVR (central business register)	DK 10403782
Date for submission	08/03/2015

1.2 Short description of project objective and results

In addition to contributing to the energy balance, wind power plants of the future should offer provision of ancillary services. Not just substitute the MWh's from thermal plants, but provide as many "electrical benefits" as possible to the transmission system
EASEwind addresses particularly features requiring fast (sub-second or cycles) modulation of the wind power plant active power output: inertial response, power oscillation damping, and synchronising power. Features that had been lowly prioritised, as it normally needs previous reduction of output power which then results in a reduction of the plant's energy yield.

The project has targeted development and demonstration of the ancillary service control features in a wind power plant control architecture. The technical progress has been substantial, while the commercial progress only moderate. The scientific advancement and the industrial relevance are satisfactory. The technical results have been widely communicated, while limited lobbying for market participation has taken place.

1.3 Executive summary

Modern wind power plants can provide the transmission network with useful ancillary services, such as inertial response, power oscillation damping, and synchronising power. The EASEwind project (Enhanced Ancillary Services from Wind Power Plants) has defined plant level control algorithms, modelled and simulated their technical performance, and tested in a Danish wind farm. Associated necessary forecasting and trading strategies were developed and evaluated.

The commercial success remains uncertain. The time-to-market is questionable, as markets for wind as provider of ancillary services remain to be developed.

The technical ability is clear. The scientific contribution and industrial relevance is satisfactory. The continuation is straightforward, if commercial prospects prove their incentive.

1.4 Project objectives

1.4.1 Motivation & background

The EASEwind project concept arose in Vestas in 2010. It had long been on the technology roadmap to pursue development of wind power plant features that would resemble those offered to the transmission network by thermal/nuclear/hydro plants. In addition to contributing to the energy balance, wind power plants of the future should offer provision of ancillary services. Not just substitute the MWh's from thermal plants, but provide as many "electrical benefits" as possible: reactive power, voltage control, fault ride-through, up-/down-regulation of active power, primary reserve, power system stabilisation etc. Several of these (for example voltage control, FRT, frequency support) have been available from wind power plants for years and made their way into *de facto* requirements in the transmission system operators' connection codes. Yet, any feature requiring fast (sub-second or cycles) modulation of the plant active power output had been lowly prioritised, as it normally needs previous reduction of output power which then results in a reduction of the plant's energy yield.

Still, a suite of ancillary services (AS) from wind power plants (WPP) should ideally result in advantages as: (i) fewer hours where thermal plants would be forced on-line merely for network stabilisation or reserve power provision; (ii) less fuel burnt; (iii) higher allowable integration level of renewable generation: the benefit to society being lower system operating cost - the benefit to wind plant investors being higher revenues per installed plant capacity (€/MW).

The latter is founded on an important **hypothesis**: that an ancillary services market can reward wind plant owners with added **revenues that outweigh the lost energy sales**. Based on the knowledge that wind turbines designed with today's economic optimum really do not allow any overload, a wind power plant providing an active power reserve temporarily would need to be operated curtailed, with a resulting loss of generated energy.

The value of a commandable active power reserve provision from WPPs depends on if it is truly available when needed by the power system - how much & how fast & for how long - and whether it can be efficiently traded.

The above considerations are well described in the project application [ease01], where the following WPP ancillary services were identified as focus:
Inertial response: equivalent to synchronous generator inherent df/dt reaction
Power oscillation damping: equivalent to synchronous generator power system stabilisor
Synchronising power: equivalent to synchronous generator inherent power-angle reaction

At the time of writing the project application, there was **no formal requirement in any connection code** to provide the three types of ancillary services listed above. But they were discussed in working groups and with several transmission system operators (TSO), for example HydroQuebec [r5].

Still, the project application business plan stated: "*The control system functionality is likely to be developed and offered commercially even in the absence of an immediate market. The transition from technology push to market pull will happen as soon as the business case is positive and technical soundness is demonstrated. Proof is achieved through succesful operational experience, one plant at the time, until widespread acceptance is gained."*
The actual evolution experienced is discussed in a later section.

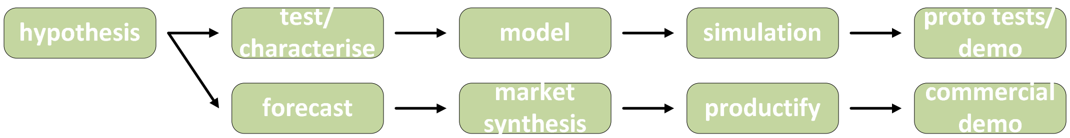
1.4.2 Problem formulation

The project application states: "*It is the **purpose** of this project to develop, assess and demonstrate technical solutions for providing a wide range of ancillary services and consolidating the control room operability that will enable a future large scale integration of wind power into the power system*".

The project application further states its **development targets**:

- Ancillary service control features: inertial response, synchronising power, power oscillation damping.
- WPP models embedding the AS control features above.
- Power system network model suited for simulation of AS control features.
- Probabilistic wind power forecasting methodology.
- Initial considerations for future AS markets.
- Demonstration by tests in a wind power plant including interaction with (energy and) power trading and the balance responsible, thereby identifying the real economics.

Though not explicitly formulated in the project application, the following are representative for the project's **problem statement and scientific method**:



1. Identify an adequate ancillary service response from the wind power plant to power system disturbances. Define the functionality in terms of controller architecture and transfer functions.
2. Identify a test case power system network, suitable for simulation & evaluation of the usefulness of wind power plant provided ancillary services.
3. Identify simulation models representative of wind turbine, of wind power plant and its controls, and of power system. Assess validity of multi-turbine model aggregation.
4. Assess power system behaviour with various degrees of wind power and ancillary services present in system. Establish technical capability of WPP AS adequacy in test case power system.
5. Implement and demonstrate plant-level ancillary service controllers in fair-sized wind power plant. Characterise plant level technical capability of AS control actuation.
6. Identify and quantify best-in-class capability of forecasting methods suitable for wind power prediction and bidding on a time-horizon of 12h-36h.
7. Identify a bidding strategy based on a decision-making algorithm for allocation of wind plant power between day-ahead markets for energy and for reserve power. Synthesize performance of bidding strategy.
8. Techno-commercial demonstration.

1.4.3 Project organisation

The project's objectives clearly required connecting research disciplines spanning power system dynamics, wind turbine & plant models, control theory, eletro-mechanical simulation, statistical processing of weather forecast information, modelling and synthesis of energy and reserve power markets. And of course connecting these to a route to industrial commercialisation. Thus, the project partners were selected on the basis of past collaboration experience and research track record.
It resulted in the project organisation, **work package** structure and budget shown below.

The project budget consisted mainly of man-hours, of which 50% were due from Vestas.
The budgeted total project cost was approximately 13667 kDKK, split into:

man-hours:	kDKK 11994	
travel:	kDKK 454	
machinery:	kDKK 1091	of which kDKK 1000 cover lost energy sales during tests*
other:	kDKK 179	

*: never charged

WP	Title	Budget [man-months]						Duration	
		Total	VWS	DTU/Wind	DTU/Elektro	DTU/Compute	AaU/ET	Start	End
WP0	Management	16	12	1	1	1	1	2012.01	2014.12
WP1	Control features for ancillary services	22	18	4	0	0	0	2012.01	2013.03
WP2	Modeling of wind power plant services	7	3	4	0	0	0	2012.01	2013.12
WP3	Power system model for new ancillary services	12	4	4	0	0	4	2012.01	2014.12
WP4	Forecasting	8	3	0	0	5	0	2012.07	2014.06
WP5	Power system dynamic studies	19	6	12	0	1	0	2013.01	2014.12
WP6	Initial market considerations	5	0	0	4	1	0	2013.10	2014.12
WP7	Demonstrator	12	8	3	0	1	0	2012.01	2013.03
WP8	Dissemination	5	1	1	1	1	1	2012.01	2014.12
	sum	*106*	*55*	*29*	*6*	*10*	*6*		

Table 1.4.1: Work packages, with budgeted hours, durations and wp leaders.

1.4.4 Project limitation

Throughout, the project has made conscious choices of what to include and what to leave out. To complement the problem statement, a series of items were excluded or assumed valid from previous work:

- *Choice of turbine type:* The availability of test specimens weighed heavily, and the turbine type on the Lem Kær demonstrator site was the Vestas V112-3.0MW turbine, employing full-scale converter.
- *Choice of turbine simulation model:* DTU/Wind Energy had a solid starting point in their wind turbine simulation model validated for a 2MW turbine (IEC 61400-27-1 type 4B), hence it was decided that WP2 and WP5 stuck to a 2MW turbine rating, extending the model to include the new features. This is deemed further advantageous as the model features for ancillary services should ideally be portable to the IEC working group's plans for model updates, and therefore should be adopted by TSOs.
- *Verification of turbine simulation model:* Whilst the control architecture and settings were made for the 3MW experimental turbine and wind plant, and adapted for the 2MW turbine and plant simulation, no validation between the two was included.
- *Redesign of turbine for ancillary services dynamics:* New dynamic operation regimes imply new loads on turbine, but the EASEwind project has not considered how to redesign a turbine to make it more suited for the particular ancillary services considered in the project.
- *Overloadability:* Whilst the simulation model includes the option to overload the turbine (operate above rated active power). However, the model does not include the limits to operation imposed by one particular turbine's design. In the demonstration, and most simulations, the turbine is operated in curtailed mode prior to provision of active power modulation called upon for ancillary services.
- *Power system network for application studies:* Although it would have provided additional proof to apply EASEwind's suggested solutions into a study of the transmission system of West Denmark, it was concluded early in the project to be too ambitious, as it would require excessive work to create use cases with the relevant properties. Instead, the project continued with the **IEEE 12-bus model** used in previous research ([r2,r3]). This model, originally developed for the purpose of testing FACTS devices, has been conditioned to suit the AS test purposes.
- *Power system simulation tool:* In WP3, the model was implemented in the **simulation tool PowerFactory**. This is a state-of-the-art tool adopted by several TSOs leading the wind power integration [r6-r8].
- *Tuning of ancillary service control algorithms:* AS controller tuning must be derived from the properties of the particular power system network (eigenfrequencies, combined inertia constant), success criteria (damping ratio, frequency nadir, margin to protection settings) and properties of the plant(s) providing AS. In previous work with the 12-bus system and ancillary services, the plant was assumed an ideal commandable active & reactive power source. This reduced tuning to be merely a function of the **power system**

properties. As EASEwind focuses on the wind power plant specific aspects, developing generic AS tuning rules has been excluded from the project, rather recommendations from [r2, r3] were used as a starting point for trial and error tuning, where specific WPP AS properties were included (for example limitations to active power ramp-rates).

- *Simultaneous engagement of multiple ancillary service control algorithms:* It was deemed an optional ambition to analyse if/how more than one AS controller could be enabled at any one time, and how to combine AS with established WPP control functionalities as fault ride-through and voltage control.
- *Local vs remote measurements:* Power system robustness is challenged by network disturbances. When events occur, such as short-circuits or loss of generators / loads, they are manifested through rapid changes to power system states (voltage amplitude, frequency, voltage angle, line current flow etc). Some of the power system states of relevance can be measured locally at the power plant point of connection, but in general there is a benefit from and a need to observe (measure or estimate) quantities at remote locations in the network. The usefulness of remote measurements, state estimation, signal processing are much researched globally non-specific to wind power. As an example the application of Phasor Measurement Units (PMU) has facilitated wide area measurements (WAMS). Hence, EASEwind has excluded solving issues specific to remote measurements, but merely assumed certain signals to be available to the plant ancillary service controller. This still allows comparing AS controller performance with local vs rem-measurements.
- *Instantaneous available wind power :* The topic of predicting instantaneous available wind power on a short time horizon of 0 to say 10 seconds has not been included. The turbine's own prediction (in EASEwind's case proprietary to Vestas) has been deemed sufficient, and modelled in WP1 by a first-order delay to the actual power [ease14].
- *Market analysis:* With the available time and resources in WP6, remuneration of reserve power is modelled as payment for balancing energy, but further abstraction is not made to payment for availability (of reserve power). It should be noted that still no market regulators accept wind power as an ancillary services provider.

1.4.5 Project evolution

The project has delivered succesfully on most, but not all, planned deliverables. The list of internal reports matches the list set out in the project application, and has answered the project problem statement.

The dominant deviations to project plan and expenditure are:

- Very dynamic staffing from all parties during the course of the project: Vestas has replaced two project managers, and two principal scientists. The university partners have replaced three lead researchers and moved one professor internally. The consequence has been delays in the procurement, but no sacrifice of agreed deliverables.
- Scope reduced due to delayed product development plans: Vestas decided to delay its productification and implementation of the ancillary service control algorithms into its wind power plant controller, beyond the prototype procured for tests. This is predominantly due to lower market pull for the solutions than originally anticipated. The consequence is that a second phase of commercial demonstration is abondened.
- Vestas' hours below target: In particular the 2nd half of the project has suffered from too few Vestas' internal hours, even taking the reduced scope into account.

WP	Title	Issuer	Date		Length	Risø Sharepoint
WP1	Report: "Control features for ancillary services - wind power plant"	Vestas	2013	Mar	23pp	yes
WP2	Report: "Type IV wind turbine model"	DTU/Wind	2013	Mar	50pp	yes
WP2	Report: "Verification procedure of WPP model"	DTU/Wind	2013	May	13pp	yes
WP2	Report: "Modelling of wind power plant controller, wind speed time series, aggregation and sample results".	DTU/Wind	2013	Dec	40pp	yes
WP3	Report: "Power System Model for New Ancillary Services"	AaU	2013	Mar	19pp	yes
WP4	Report: "Methodology and forecast products for the optimal offering of ancillary services from wind in a market environment"	DTU/Compute	2014	Apr	74pp	yes
WP5	Report: "Definition of simulation test cases for WP5"	DTU/Wind	2014	Apr	16pp	yes
WP5	Report: "Impact of advance wind power ancillary services on power system"	DTU/Wind	2014	Oct	65pp	yes
WP6	Paper: "Analysis of the impact of wind power participating in both energy and ancillary services markets - the Danish case"	DTU/Elektro	2014	Sep	6pp	yes
WP7	Report: "Demonstration of ancillary services. Part I"	Vestas	2013	Mar	27pp	yes
WP0	NoteA: "Power plant controller. Coordination & allocation of ancillary services"	Vestas	2013	Mar	4pp	yes
WP0	NoteB: "Modelling of turbine available power estimate"	Vestas	2013	Mar	6pp	yes
WP0	NoteC: "Test cases in WP5 Power system dynamic studies"	DTU/Wind	2013	Mar	5pp	yes
WP0	NoteD: "Comparison of the aggregated WPP model with the detailed WPP model (WP2) "	DTU/Wind	2013	Mar	4pp	yes
WP2	Simulation model in PowerFactory of turbine, issued by project partner DTU Wind Energy	DTU/Wind	2013	Mar		
WP3	Simulation model of generic power system (IEEE 12-bus) in PowerFactory	AaU	2012	Dec		

Table 1.4.2: Project internal reports / deliverables.

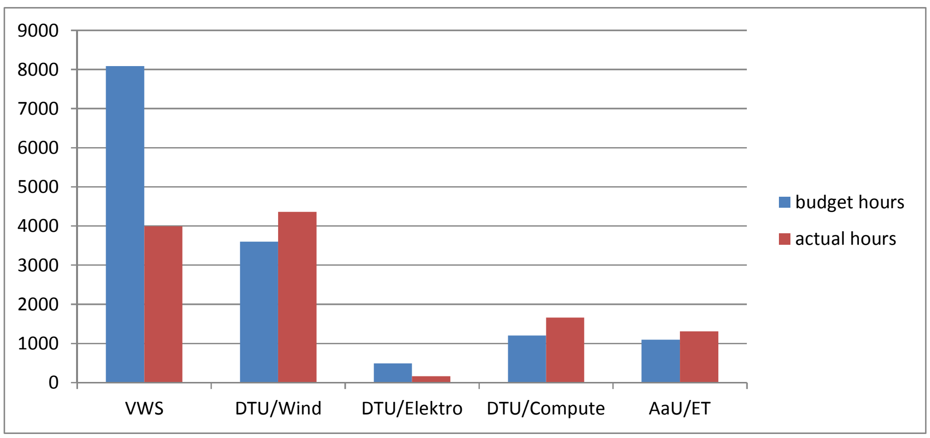


Figure 1.4.3: Project man-hours, budget and actual spend, per partner.

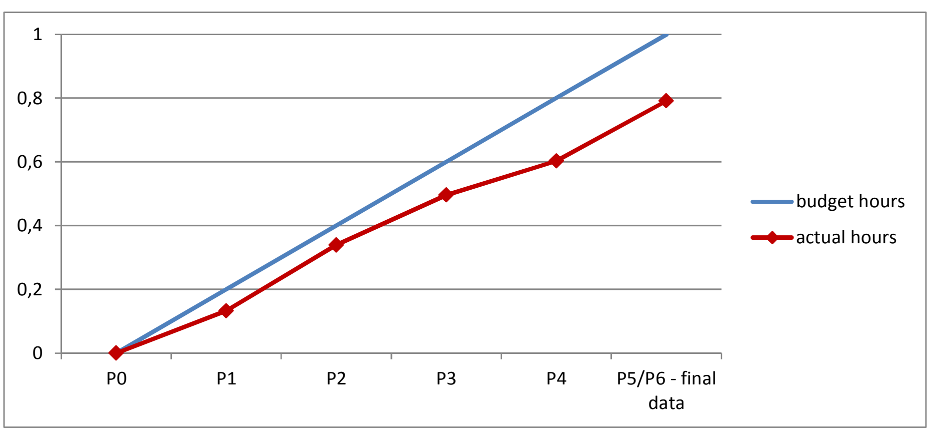


Figure 1.4.4: Project man-hours, budget and actual spend, sum of all partners.

Project totals	Total cost	Internal cost	PSO funding	Total hours
Budget, kDKK	13667 (100%)	7670 (56%)	5997 (44%)	14471 h
Actual, kDKK	6235 (100%)	1735 (27%)	4500 (73%)	11486 h
Actual vs budget, %	46%	23%	75%	79%
Residual, kDKK	7433 (100%)	5935 (80%)	1498 (20%)	2985 h

Table 1.4.3: Project budget and actual cost.

Figures 1.4.3 and 1.4.4 show the budgeted and actual man-hours, per partner and per project reporting period, respectively. Table 1.4.1 shows the budgeted and actual cost for the entire project period.

The following comments are relevant at this stage:

- DTU/Elektro & DTU/Compute: As DTU and Risø merged during the project, certain responsibilities were redistributed. The sum of hours for DTU/Elektro and DTU/Compute in total came to 107% of their budgeted hours. The two partners' accrued costs and PSO share of funding were slightly below budget.
- DTU/Wind: Actual hours came to 120% of budget, but PSO share of funding was kept on target, as hourly rates and overheads were lower than budgeted.
- AaU/ET: A slight overspend on hours, but with some hours distributed to staff of lower hourly rates than budgeted, the total budgeted cost and PSO share of funding were kept.
- Vestas: The 1000 kDKK budgeted to cover lost energy sales during plant tests & demonstration were not claimed. Mainly because the duration of tests & demonstrations was much shorter than foreseen.
- Vestas: Though 50% of the budgeted hours were delivered, only 1/3 of the budgeted PSO share of funding was claimed. Explanations follow below.

Vestas in the EASEwind project:

The EASEwind project organisation in Vestas has undergone significant changes and has challenged the continuity through 2013 and 2014.

The global financial crisis also impacted Vestas. Vestas' strategy "Triple 15" was officially abandoned ultimo 2011, followed by a sequence of managerial and organisational changes during 2012 and 2013, including significant layoffs [r14], [r15], close to 1/3 of all staff.

The turnaround, from a progressive growth and investment scenario to focus and caution, was embraced gradually. Vestas' Global Research division was closed in the end of 2012, but some research projects were allowed to continue, including a few jointly funded ones. EASEwind was one of these, as the project's objectives were still of strategic importance to Vestas, yet the time-to-market was questioned, as no ancillary service market had emerged in the first years of the project. The re-acceleration of a grander R&D programme was intended for 2014, but was delayed. Consequently, planned Vestas developments on upgrades to turbine and plant control products were delayed, too. This has substantially impacted the amount of Vestas hours spent, in particular in WP7 (demonstration).

In 2013, Vestas reported from Lem Kær site measurements. The developed control algorithms were tested, for feasiblity and to characterise the plant equipment. As highlighted in §1.5.4, the performance tested was somewhat lower than that assumed in the simulations of §1.5.3. The 2013 measurements revealed areas for improvement, first and foremost in the control loop cycle time. Upgrades to wind turbine and wind power plant controls were thus planned, but did not materialise in time. Consequently, the 2nd phase of WP7 testing (with upgraded performance) was not conducted.

The wind power plant demonstration site Lem Kær is in Western Denmark, where Energinet.dk is transmission system operator, but connects to the distribution network. A number of facts at the time, and today, challenged the business model of ancillary services from the plant:

- No balance-responsible trades WPP-AS with the TSO today, hence one would have to reach a direct agreement with the TSO. There is no context for bidding.
- The recorded payment for up-regulation primary reserve in Western Denmark's would not warrant the lost energy sales. It was deemed unlikely that payment for EASEwind's ancillary services would be better paid, should a trading context have emerged.
- There are no technical requirements to WPPs providing primary response, inertial response, power oscillation damping, synchronising power.

It was also deemed unlikely that technical demonstration could have been meaningful to the TSO:

- The demonstration site power level (12MW) is rather low, and probably too low to make provision of inertial response or synchronising power meaningful for the TSO.
- The plant's point of infeed is rather deep (distribution level), challenging power oscillation damping, even if based on remote measurements (local measurements not meaningful).
- The TSO had not sought further demonstration to accelerate AS from wind power.

On the other hand, further tests could have provided some benefits:

- Upgrades to communication and control loop cycle time, control algorithms and settings should undergo repeats of tests conducted in WP7.
- As it relies fully on local measurements, the IR functionality could have been enabled for a period of continuous operation, to record longer-term behaviour, probability of delivery and resulting loss of energy (from curtailment).
- Verification of simulation models from WP2 and WP1.
- If an overseas installation had been developed for provision of AS, further verification in Denmark would have been beneficial.
- If it was believed that further test results could have accelerated establishment of AS markets outside Denmark.
- The particular forecast and bidding processes of WP4 and WP6 could have been demonstrated.

Hence, with the lack of financial incentive and no market in immediate sight, Vestas delayed implementation of improvements to its product performance. The second phase of WP7 tests were stalled, and the hours not saved. Meanwhile, all work packages of the academic partners were completed, as they all provided value, unaffected by the shortening of WP7.

1.5 Project results and dissemination of results

The following pages summarise the results obtained in the project. The illustrations are all from the project internal reports listed in Table 1.4.2.

Viewed from the wind power plant, Figure 1.5.1 depicts the principal context of EASEwind in a compact manner: a large wind power plant connects somewhere to the bulk transmission network, akin to thermal/hydro/nuclear generation. The plant's output and performance is relevant at the **point of common coupling**, rather than at each individual wind turbine.

A local **power plant controller** measures the wind power plant output power, and the voltage and frequency at the point of common coupling. This PPC is responsible for control & monitoring of the ensemble of turbines in the plant. It receives feedback from each turbine's operating condition and available wind power, and it **dispatches** setpoints for active and reactive power. The PPC can be in autonomous or remote control mode, for example configured to receive setpoints or other commands or remote measurements from the network operator.

EASEwind's catalogue of **ancillary services** are intended to improve power system robustness to network disturbances. The ancillary service control algorithm must change the wind power plant active power (P) and/or reactive power (Q) in response and oppostion to observed changes in power system states (the manifestation of the disturbance). Observations can be local or remote to the connected wind power plant.

The ancillary service control **algorithms** reside in the power plant controller, together with the algorithms for the long-established wind power plant control functionalities as voltage control, frequency response and other (see Figures 1.5.1 and 1.5.1.3).

As wind turbines by default are controlled to harvest as much of the available wind power as possible, any provision of an additional **active power reserve** would require **previous curtailment** (as discussed in §1.4.1, this means a loss of energy). The same requirement already applies to wind power plant primary reserve support during network under-frequency events (up-regulation). Hence, to avoid previous curtailment and loss of energy, wind power plants' participation in primary reserve is most commonly restricted to down-regulation during network over-frequency events.

The **financial implication** of temporary loss of energy - due to reserve power provision via previous curtailment – is the topic of WP6's analysis, in modest depth according to the project scope.

All work in EASEwind on plant control features has assumed perfect knowledge of instantaneous available wind power. Essentially, this implies that curtailment can be scheduled to provide a **deterministic power reserve**, which then may be used up by any control feature. Still, there is a need to **allocate** this power reserve between the control algorithms that demand changes to plant output power.
Regarding any reactive power reserve, the default operating condition depends on the configuration.

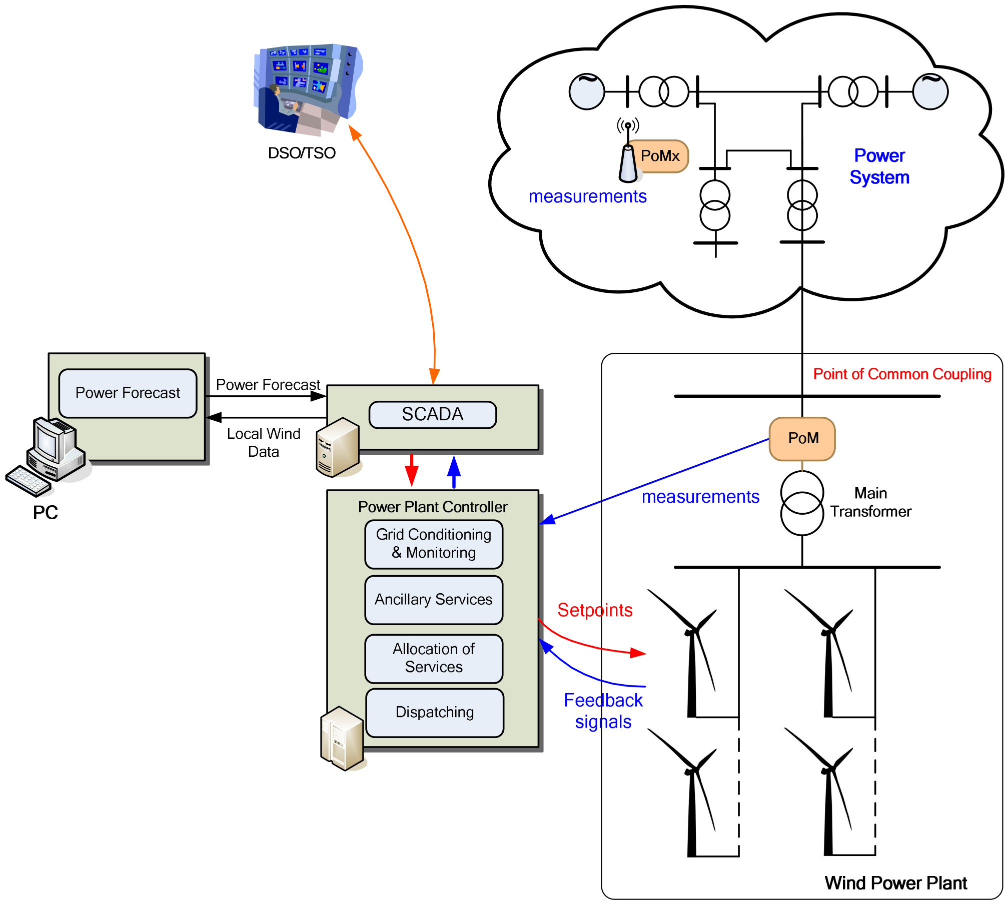


Figure 1.5.1: Principle diagram of power system connected wind power plant and controller.

1.5.1 AS functionality, controllers, architecture (WP1)

The three ancillary services of interest are, as detailed in [ease03]:
Inertial response: equivalent to synchronous generator inherent df/dt reaction
Power oscillation damping: equivalent to synchronous generator power system stabilisor
Synchronising power: equivalent to synchronous generator inherent power-angle reaction

The research foundation that led to formulating controller transfer functions for these three ancillary services is reported in several PhD theses started prior to EASEwind ([r1-r3]).

Figure 1.5.1.1.(a) shows the principle of inertial response (IR): a transient power increase, followed in this case by a static power addition (primary reserve). In its strictest interpretation, inertial response should result in a change to power proportional to the time derivative of frequency, df/dt. However, pure derivative action is too sensitive, and the wind turbine operating regime (torque-speed and wind speed vs rotational speed ratio) limit the duration of power increase and resulting speed excursion. Various variants of IR have been compared, and EASEwind settled on the effective IR controller block diagram in Figure 1.5.1.2(a). The inputs are measured frequency and its derivative, output the setpoint for the wind power plant active power. This has been used in the case studies in WP5, with settings from WP1.

Figure 1.5.1.1(b) shows the principle of power oscillation damping (POD), and Figure 1.5.1.2(b) the block diagram of the POD controller. A signal representative of a measured or estimated network state (line current, power flow, voltage amplitude or other) is the input to POD the controller. The output is either active power (P) or reactive power (Q) setpoint for the wind power plant. The effectiveness of which input and output to use depends on where the plant is connected to the network and of the network properties. The controller settings were tuned for the particular power system.

Figure 1.5.1.1(c) shows the principle of synchronising power, and Figure 1.5.1.2(c) the block diagram of the SP controller. The input to the controller is a signal representative of the measured or estimated difference in bus voltage angles, or generator rotor angles. The controller output is either active power (P) setpoint for the wind power plant.

For all three ancillary service functionalities, their setpoints to plant active power (and reactive power) should be within the plant's capabilities. The power plant controller is responsible for housing all control functionalities and selecting which controllers to enable, as well as measuring relevant quantifies at point of connection, and performing closed-loop control on plant P and Q.

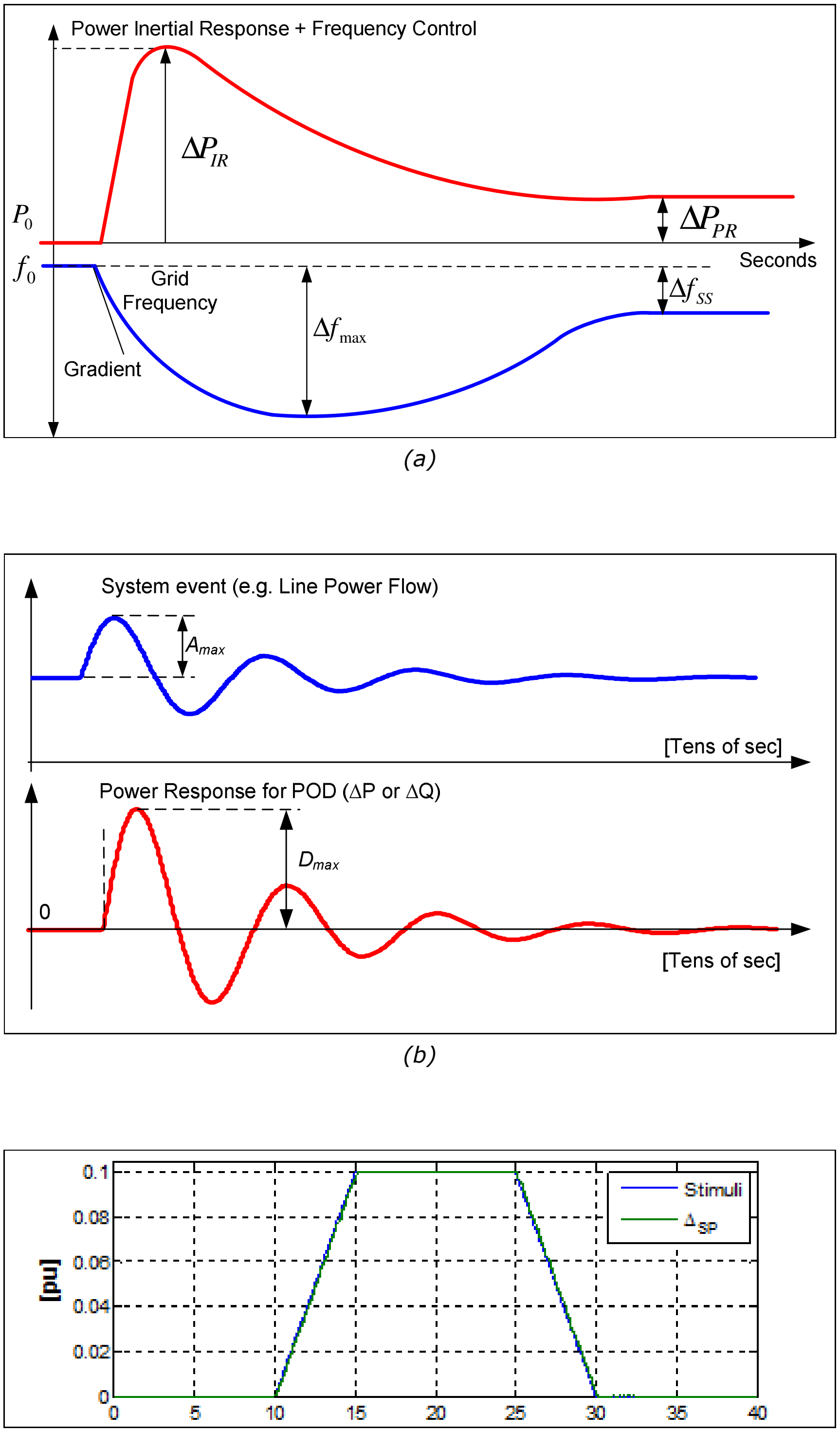


Figure 1.5.1.1: Three ancillary services characteristic signal time traces: inertia response (IR), power oscillation damping (POD), synchronising power (SP).

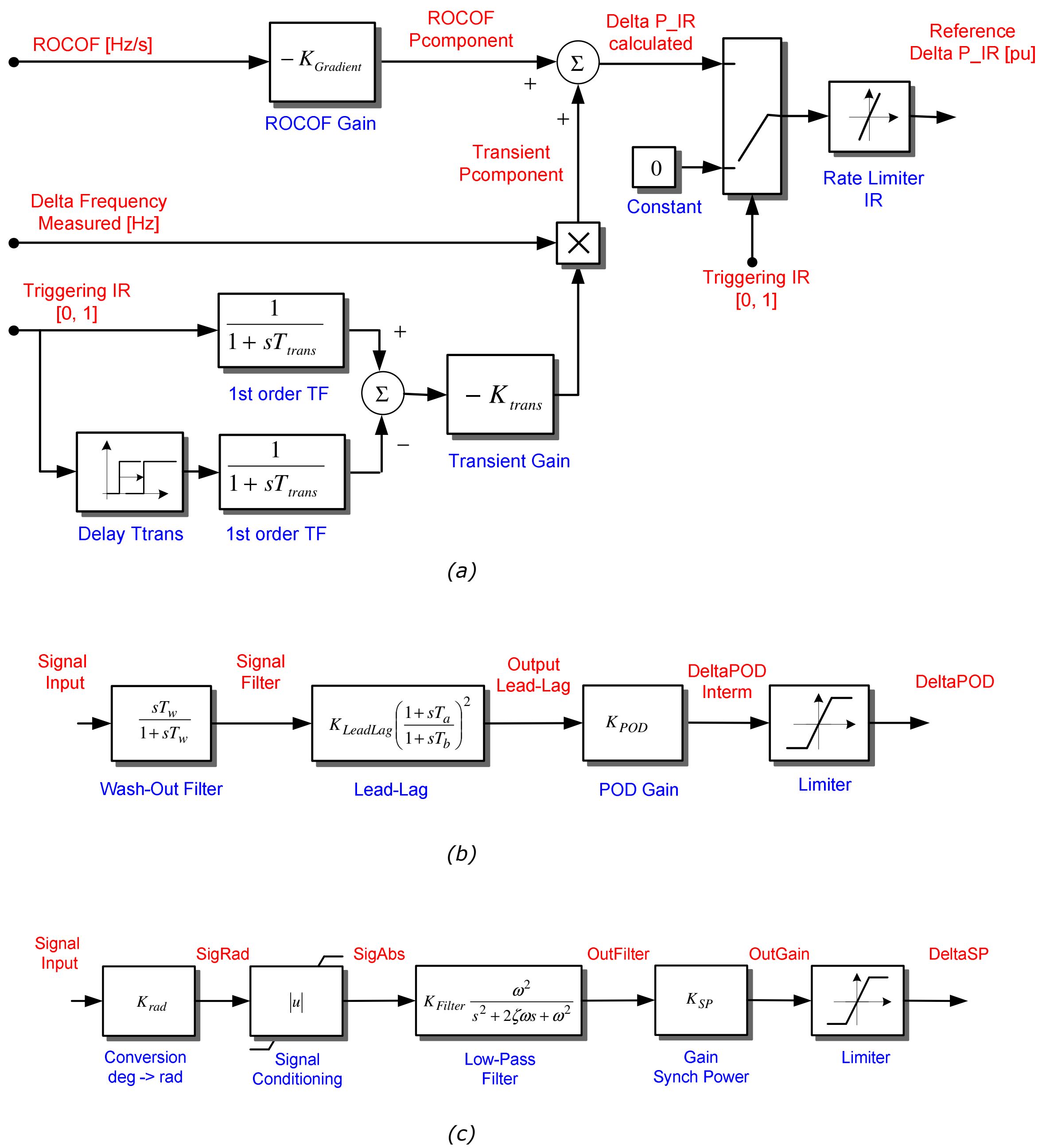


Figure 1.5.1.2: Ancillary services candidate controller transfer functions:
(a) inertia response (IR), (b) power oscillation damping (POD), (c) synchronising power (SP)

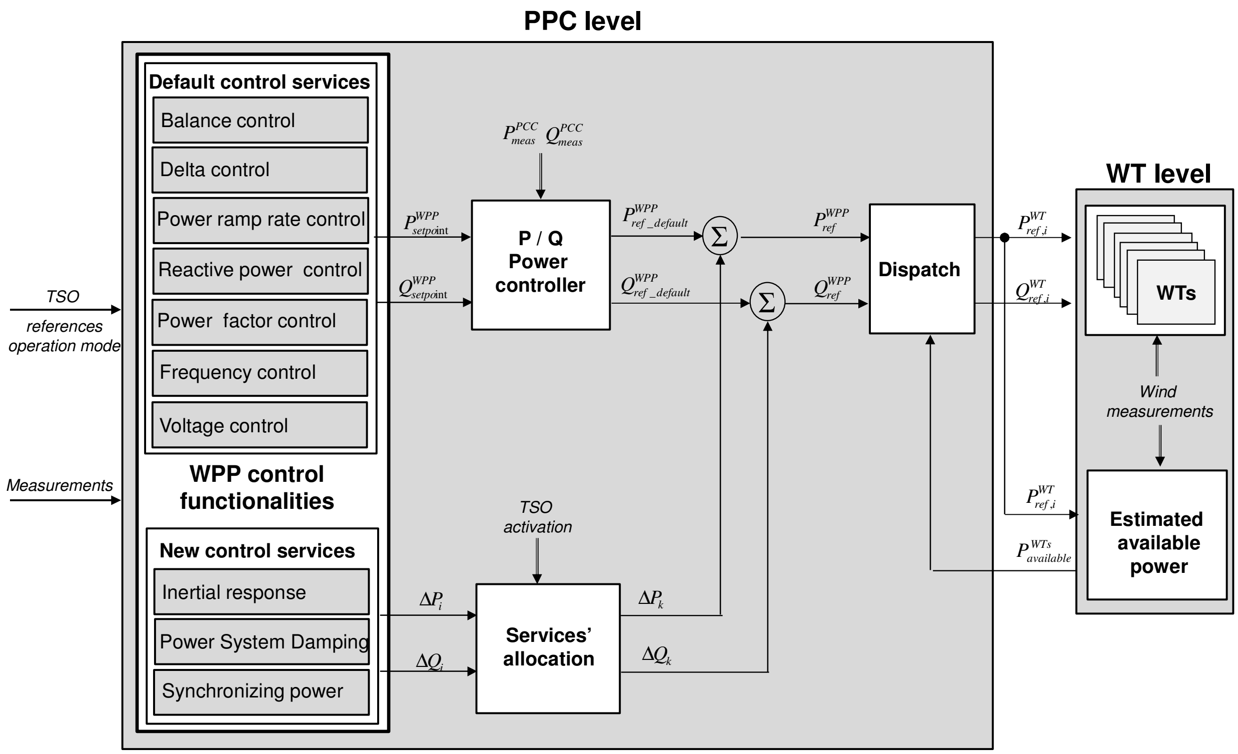


Figure 1.5.1.3: Wind power plant controller allocation of ancillary services controllers.

1.5.2 Simulation model of wind turbine, plant controller and aggregated plant (WP2)

As stated in the scientific method in §1.4.2, simulations of the wind power plant rely on adequate models. For power system transient stability studies involving representation of larger networks, the demand is to use power plant models without too high complexity. This has so far been addressed with the advent of IEC standardised models of a single wind turbine [r4]. Wind plants with N turbines are then represented by a single turbine model, where the electrical output power is multiplied by N. However, for studies of the dynamic operation of wind turbines imposed by ancillary service provision the aggregated representation using the standardised turbine model was deemed potentially insufficient.

It was recognised that AS active power modulation may imply curtailment and/or temporary overload, rapidly changing setpoint and output power from individual turbines with different instantaneous wind speeds. The implications were serious: how could a complete wind power plant be modelled in a compact and not-too-complex manner for studies of ancillary services? For TSOs to include WPP ancillary services in their network dynamic studies, a WPP should be represented by a relatively simple model. And preferably a standardised model architecture, configurable to match specific vendors and operators.

To answer this, EASEwind investigated to which extent active power control dynamics coincide with the frequency content of wind turbulence, and with time constants of turbine aerodynamics and electromechanics - phenomena that could render the simpler, aggregated model invalid.

To start with, in [ease04], the standard wind turbine model of [r4] was **augmented** to include representation of instantaneous wind speed input, aerodynamics and pitch actuation, drive-train kinetics, and turbine controller estimation of available power. This work produced a simulation model of the single wind turbine with representation of dynamic actuation, such as that commanded by plant ancillary service controllers.

Next, the augmented model was used to simulate various dynamic cases and verify its functionality. The same cases were used to investigate behaviour when operating the turbine either curtailed or overloaded while subjected to active power dynamics relevant to AS. [ease04] confirmed that temporary overload (**overproduction**) of turbines in partial load (at wind speeds below rated power) comes with the price of a subsequent power drop (the **recovery** period). This intrinsic behaviour has been much discussed elsewhere, and manufacturers' designs allow different degrees of overload, if any. The simulations in WP5 include some cases with overload, while all experiments are without overload.

Finally, an investigation was made into the effect of temporal and spatial distribution of wind speed across N turbines in a wind power plant (see Figure 1.5.2.1). Using previously developed models to generate time series of wind speed, and the augmented model of N turbines, each individual turbine wind speed and electrical output power were simulated, together with the total plant output power. From the individual turbine wind speeds, an **equivalent common wind speed** was calculated. The latter was fed into a single wind turbine model to calculate an equivalent **aggregated output power** for the plant. Figure 1.5.2.2 shows this calculation principle. Figure 1.5.2.1 shows a common wind speed signal effectively low-pass filtering the individual turbines' wind speed signals. Figure 1.5.2.3 shows an example from a simulation case where the error signal is the difference between the power summed from individual turbines and the power output by the aggregated model fed by the equivalent common wind speed.

Although not an exhaustive investigation, the work led to important conclusions: The observed differences in simulated powers between detailed and aggregated models was low. In particular, there was good agreement during dynamics of ancillary service control. Therefore, it was deemed sufficient in general for studies of WPP AS impact on power system dynamics to use **an aggregated, augmented turbine model fed by an equivalent common wind speed time signal**.

The common wind speed signal can be time-varying or constant. It has been kept constant in all the EASEwind WP5 studies, which continues state-of-the-art behind the application of the IEC standard model. However, the augmentation of the IEC standard model will remain necessary if the AS active power modulation becomes limited by any turbine control and protection, based on observed signals such as rotor speed and available power estimate. As turbine manufacturers develop their AS controllers, and transmission system operators familiarise themselves with WPP provided ancillary services, convergence towards a standardised model must be expected. WP2 has provided an excellent starting point.

To complement the model for aggregated representation of N turbines in a wind power plant a fitting model of the wind power plant controller (PPC) was developed. It contains the features shown in Figure 1.5.1.3, including ancillary services and other control functions, their power reserve allocation, measurements (and power dispatch, if aggregation is not used in turbine representation). The PPC model should be suitable for use in IEC model standardisation.

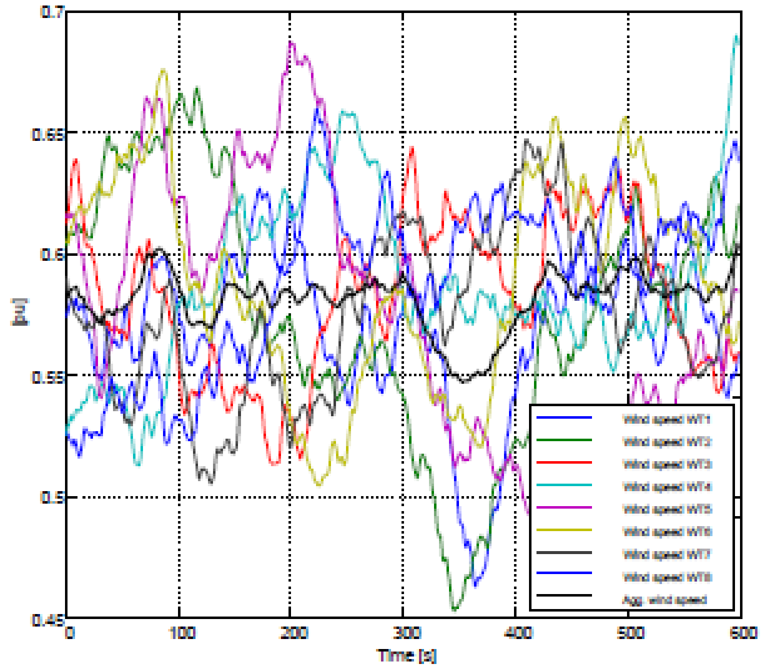


Figure 1.5.2.1: Wind speed time series from individual turbines and average.

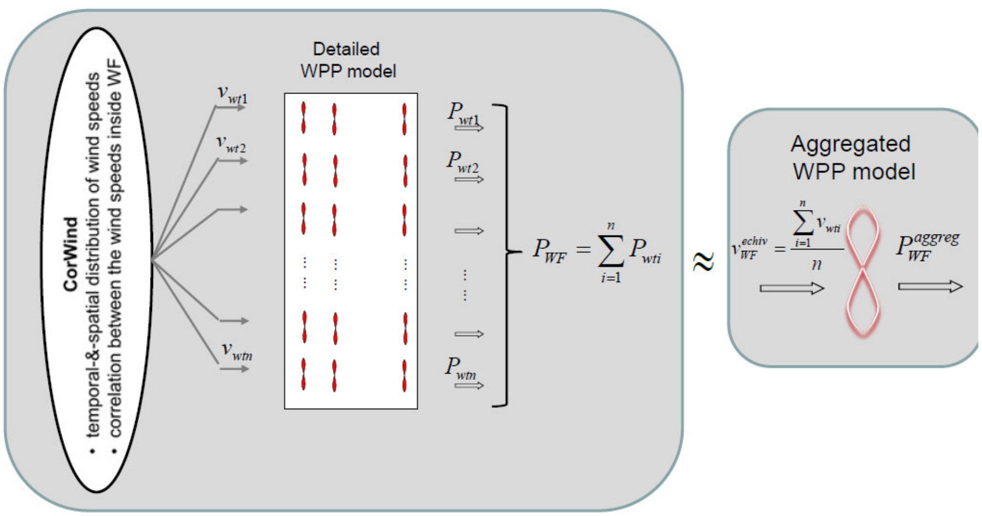


Figure 1.5.2.2: Principle in averaging wind speed.

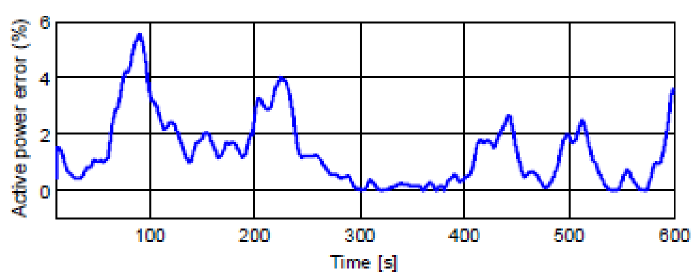


Figure 1.5.2.3: Error in power between detailed and aggregated representation.

1.5.3 Power system simulations (WP3, WP5)

With adequate simulation models of the wind power plant and its candidate ancillary service control functions, the proof of concept needed a **model of a power system** with properties that would benefit from WPP AS. In other words, the candidate solution needed a problem to be tested against.

The 12-bus model, originally developed for the purpose of testing FACTS devices, has been conditioned to suit the AS test purposes. In WP3, the model was implemented in the **simulation tool PowerFactory**. A series of power system configurations were prepared, for between **0% and 50% wind power** generation in the system. Within these configurations, use cases were tried and demonstrated the following "problems":

i. excessive frequency excursions following loss of generation leading to load shedding
ii. large oscillations in line power flow and voltage levels following short-circuit faults and clearing
iii. loss of synchronism from excessive rotor angle differences following significant changes to loads

The network is shown in Figure 1.5.3.1, and all details are given in [ease07]. The test cases of priority are listed in Table 1.5.3.1, showing amount of wind generation, load and conventional generation. Figures 1.5.3.2-1.5.3.4 show sample results from the studies [ease10] where the AS controllers of WP1 were applied. **Tuning of the AS controllers** was done by trial and error, starting from recommendations in ([r2, r3]). Comparisons were made of the effectiveness of AS provision from only one, or multiple, wind power plants in the system of Figure 1.5.3.1.
Note that only one ancillary service functionality is enabled at a time. The combined activation of multiple functionalities, both AS and established ones as fault ride-through and voltage control, is a subject for further work.

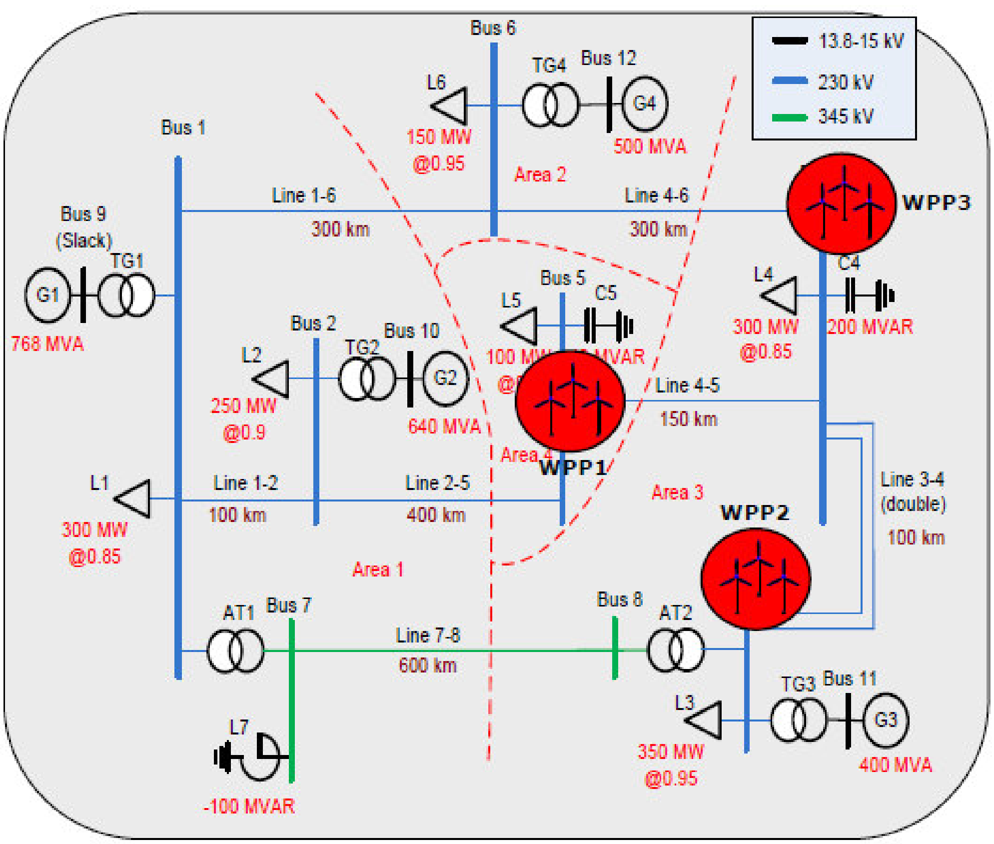


Figure 1.5.3.1: IEEE 12-bus power system network adapted for case studies, showing location of wind power plants.

Ancillary service	Network event	Network behaviour of interest
IR	Loss of largest generator unit	Frequency excursion
POD	Short circuit	Electromechanical oscillations
SP	Sudden load increase	Voltage angle / rotor angle excursion

Case	0%	20%	50%
CPP (GW)	2.00	2.00	1.65
Load (GW)	1.45	1.85	1.85
WPP (GW)	0.00	0.40	1.00

Table 1.5.3.1: Principal test cases.

Inertial response:
With 50% wind power in the system, a loss of the largest generator would result in a frequency excursion triggering the under-frequency detection and causing load shedding. To counteract, the wind power plants are to provide inertial response. In the example shown, the wind power plants are curtailed, ie they are commanded to deliver only 90% of the estimated available wind power, prior to the event. Upon detection, the inertial response controller increases the active power command until the estimated available power is used up. Note that in the simulation cases for wind speeds above nominal power, the IR controller has been allowed to command power above the nominal rating temporarily.

Power oscillation damping:
With the AS controllers, their tuning and the success criteria for obtained performance, all from WP1, WP5 tested power oscillation damping across several degrees of freedom:

- Remote or local measurement of power system signal
- POD algorithm actuation of wind power plant active or reactive power output
- 20% or 50% wind power in system, at high and low wind speeds
- Single plant contribution or multi-plant contribution of AS

The conclusions drawn from the POD simulations were:

- At 20% wind power presence, only a single plant contributed. Any combination of input (measured signal) and output (active/reactive power) contributed to improved damping of the oscillations, whether remote or local measurement.
- At 50% wind power presence, local or remote measurements, with the same single plant contributing, the conclusions were as for 20%. With other plants contributing alone, damping performance changed with specific inputs and outputs.
- At 50% wind power presence, with multiple plants contributing, the choice of inputs and outputs to the individual plants' AS algorithms impacts significantly on damping performance and the usefulness of individual plants contributions.
- Consequently, tailoring the amount of AS power contributed at different nodes is likely to offer better performance. More detailed investigations and tunings is likely to render better performance.

It should be noted that the dominant oscillation is of the order of 0.7Hz. The model of the wind power plant and its controller from WP2 shows that plant active and reactive power track their references nearly perfect at this frequency. The simulated performance are largely supported by experiments. WP7 reports on tests with active power modulation of 0.1Hz and reactive power modulation of 1Hz. The modulation frequency of active power was restricted to stay well clear of some turbine eigen-frequencies.

Synchronising power:
This feature impacts the WPP in similar ways to the inertia response, as it involves a temporary increase of plant active power output to compensate network excessive bus voltage (or generator rotor) angle differences that occur during sudden load changes.
Figure 1.5.3.4 shows a simulated example of a load change and associated bus voltage angle difference without/with one WPP provided synchronising power, assuming remote measure-

ments. In this particular case, the WPP SP controller has been allowed to command power above the available power temporarily. Regardless, the study results have demonstrated the feasibility of wind power plants providing synchronising power to a system, based on angle measurements being available.

The simulation results in [ease10] confirm that wind power plants can be controlled to provide ancillary services to improve the stability of the transmission network. The results are based on:

i. an established benchmark power system network model with motivated adaptations
ii. an established model of wind turbine with motivated augmentation
iii. a suggested representative model of the wind power plant controller with its ancillary service control algorithms
iv. a motivated aggregated wind power plant representation with assumptions on wind speed distribution and on estimated available wind power
v. assumptions regarding power system measurement latency
vi. assumptions regarding allowable operating regime of wind turbine

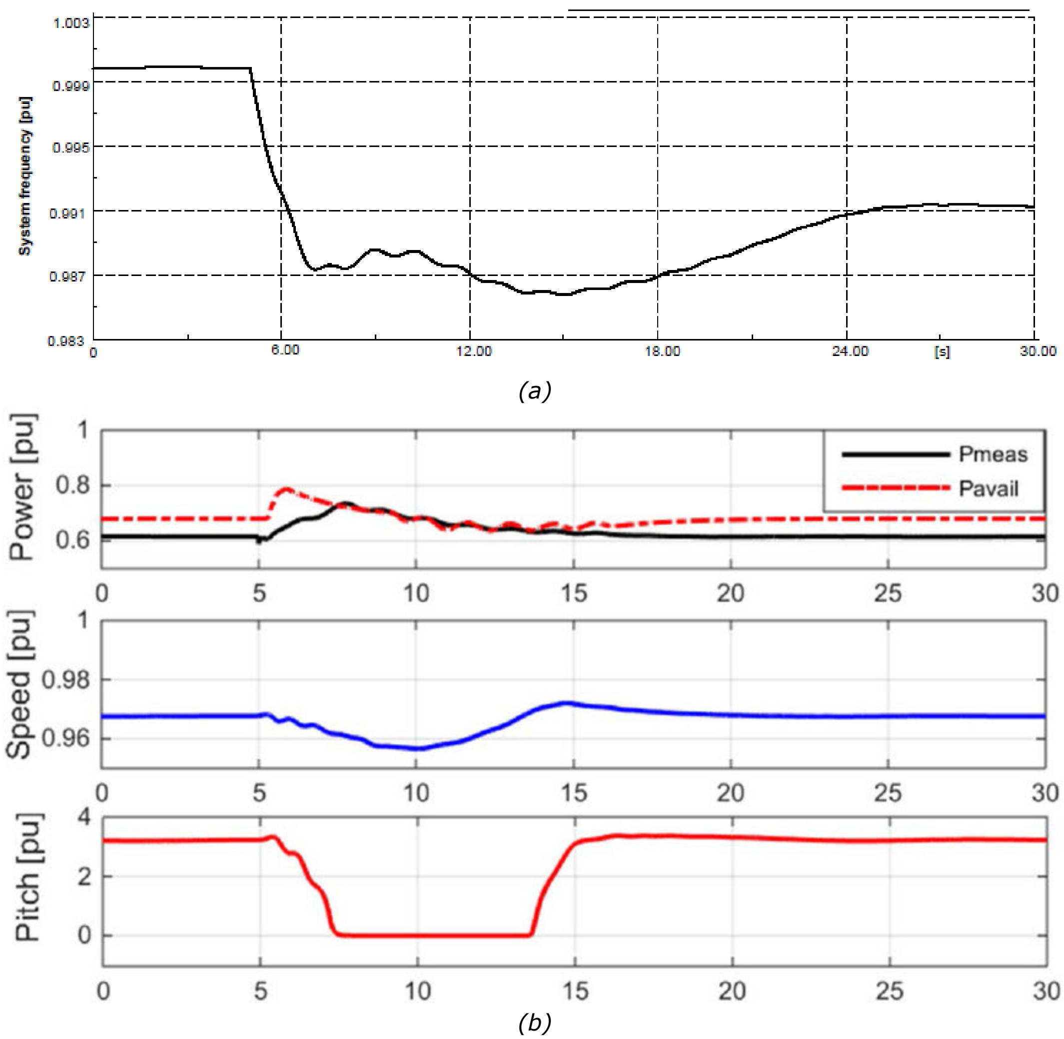


Table 1.5.3.2: Inertial response simulation example with 50% wind power in the system at wind speed below nominal (partial load): (a) frequency excursion; (b) WPP output power and estimated power, speed, pitch angle.

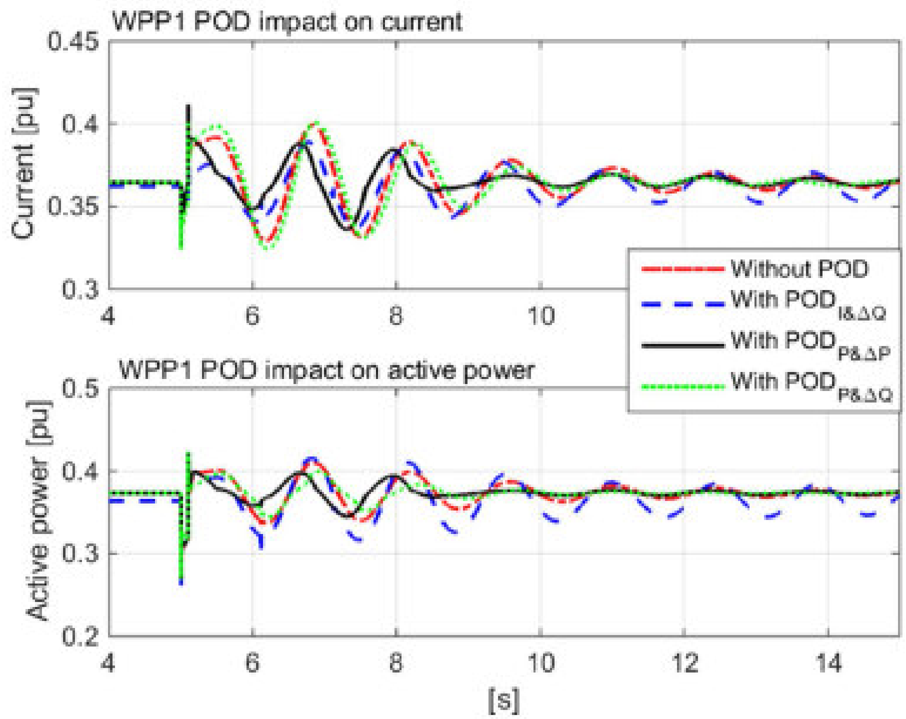


Figure 1.5.3.3: Power oscillation damping simulation example with 50% wind power in the system at wind speed above nominal (full load, local measurements and only one wind power plant providing POD. Comparison of observed oscillations in line current and power flow. In this case, the more effective combination of input & ouput is to measure active power flow (P) in the line and modulate the WPP active power (ΔP).

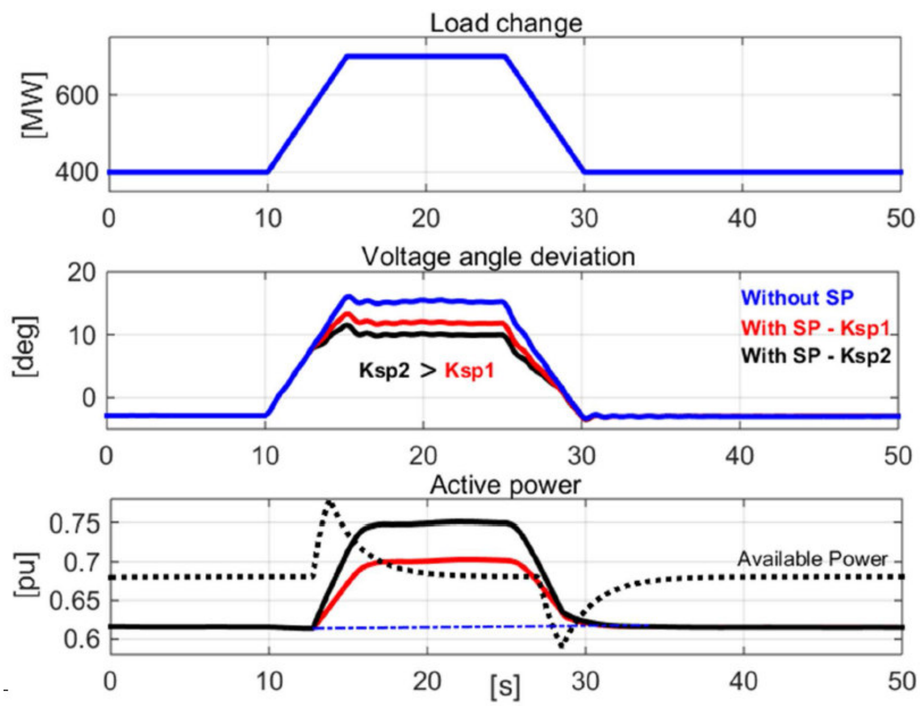


Figure 1.5.3.4: Synchronising power simulation example with 30% wind power in the system at wind speed below nominal (partial load) and remote measurements. Comparison of observed angle difference without/with one wind power plant providing SP (based on remote measurements).

1.5.4 Demonstration, site measurements (WP7)

The project identified Lem Kær wind power plant as suitable for tests & demonstrations, see Figure 1.5.4.1 and the photograph on the title sheet of this report. Ten Vestas V112-3.0MW turbines make up the plant. They connect via three 10kV feeder cables to a 60/10kV + 150/60kV substation. Only four of the ten turbines were used in the tests. The four turbines making up the "test plant" are on the same, common 10kV feeder, allowing easy measurements at point of connection with a single meter. The four turbines were operated with a power plant controller, while the remaining turbines were left to operate as normally. Vestas V112-3.0MW turbine employs a geared generator with full-scale conversion. The turbine and plant controller are well-matched by the architecture of the simulation model [ease04-ease06].

Agreements were reached with the owner of the four wind turbines [r9], and with the distribution system operator ([r10],[r11]), governing the terms and conditions for the tests and involved assets. It is worth noting, that at the same substation, Vestas has installed an energy storage system, among others this has delivered primary reserve commercially since February 2013. The storage system and the four turbines were in 2012 used for tests of supplying primary, secondary and tertiary reserves using the power plant controller in a virtual power plant configuration via a balance responsible [r12].

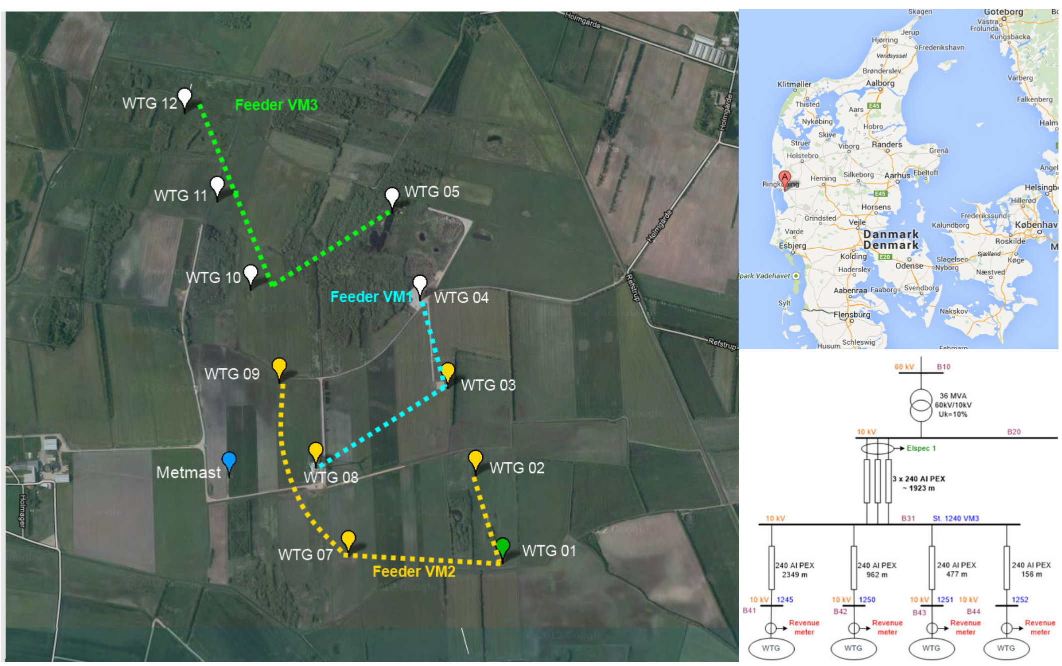


Figure 1.5.4.1: Aerial view of Lem Kær wind power plant (left), location (top right) and single line diagram of plant used for tests (bottom right).

Test results:

Early in the project, the suggested ancillary service control algorithms were simulated on a preliminary power system network model. From here, we could extract archetypal characteristics of the AS controller and the resulting time-series of active/reactive power setpoints and outputs. From simulations, a catalogue of AS setpoint data time-series were generated and taken to field tests.

The time-series were embedded in the power plant controller, and then **"played back"** as signals ΔP_i and ΔQ_i into the block "services allocation" in Figure 1.5.1.1. After the "dispatch" block setpoints were transmitted to individual turbines, returning their state feedback. The sum of powers at plant level were measured, controlled and recorded together with the total plant setpoint. Examples are given in Figures 1.5.4.2 and 1.5.4.3 for POD functionality using reactive power and active power, respectively.

These tests were, to the knowledge of the project participants, **the first time** ancillary service functionality such as power oscillation damping, had been tested and reported on a wind power plant. Albeit the test neglected the power system state observation and communication of relevant signal (from TSO) into the power plant controller, all other elements of measurement, communication, control, actuation were included. **This validated the WPP AS functionality**. The tests made use of the power plant controller and PPC-turbine communications protocol as they were at the time, in particular with a limited active power setpoint update rate.

Although not a scheduled part of the project, nor disclosed in the reports, the test campaign highlighted many **challenges**, specific to the turbine manufacturer's design:

- Accuracy and bandwidth of turbine estimated available wind power during curtailed operation, during active power setpoint changes.
- Latency from estimated power signal to update of active power setpoint.
- Update rate of active power setpoint.
- Dispatch in presence of erroneous available power estimate.
- Coordination of pitching speed vs active power modulation amplitude and frequency.
- Coordination w.r.t. turbine structural and torsional eigen-frequencies.
- Coordination of curtailment level with forecasted available power.

The **characteristic performance** that could be extracted from the early test campaign are listed in Table 1.5.4.1. Note that the simulations in WP5 [ease10] employ faster actuation than what was tested. The implications are discussed later.

Characteristic:	**Approx equal to or better than:**
Active power ramp-rate	0.1pu/sec
Active power response time	0.5sec initial delay + 0.5sec
Active power sampling time ctrl. loop	1 sec
Active power gain @f=0.1Hz	1.0 through range
Active power phase @f=0.1Hz	10% (36°)
Reactive power ramp-rate	10pu/sec
Reactive power response time	0.05sec
Reactive power gain @f=1.0Hz	1.0 through range
Reactive power phase @f=1.0Hz	10% (36°)

Table 1.5.4.1: Capability data sheet from early test results.

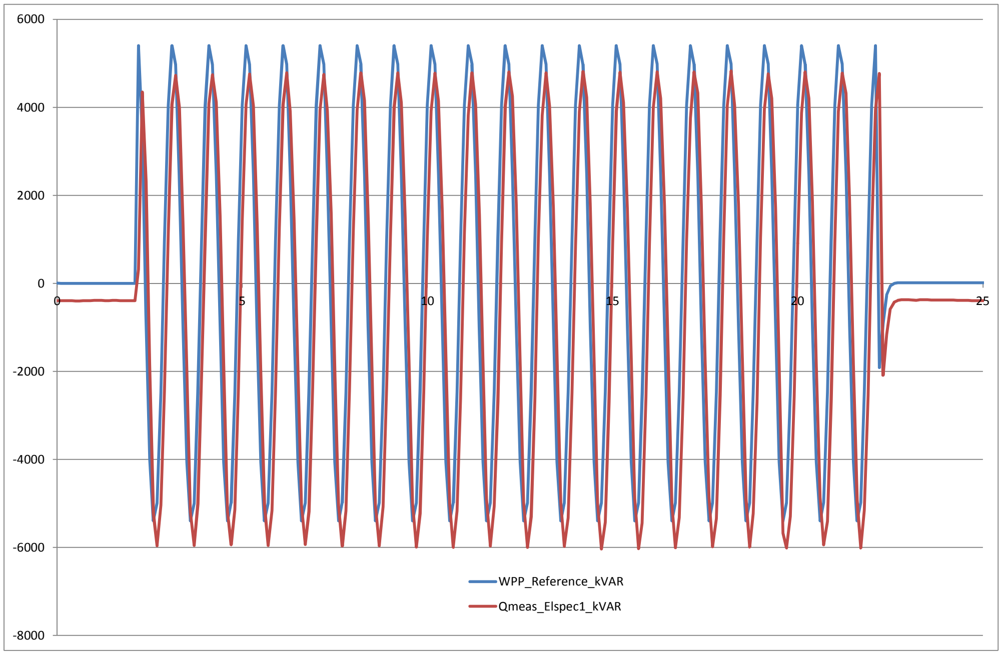


Figure 1.5.4.2: Example of test of power oscillation damping using reactive power, with 1Hz variation of plant reactive power setpoint. Blue curve is setpoint, red curve is measurement at point of connection.

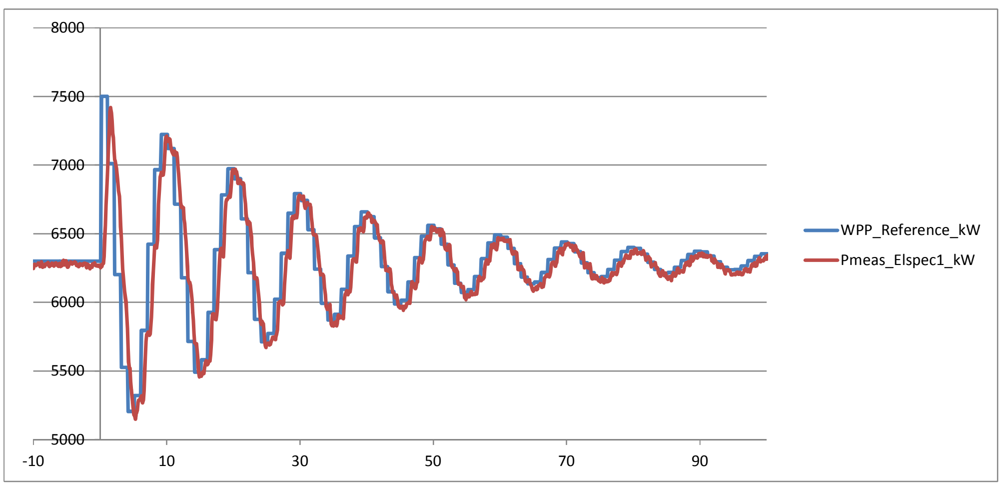


Figure 1.5.4.3: Example of test of power oscillation damping using active power, with 0.1Hz variation of plant active power setpoint. Blue curve is setpoint, red curve is measurement at point of connection.

1.5.5 Forecasting (WP4)

Forecasting of wind power is integral to electricity trading. Whether for the energy market (as today), or for current or future reserve power markets (including ancillary service markets). EASEwind's scope has not emphasised the creation of new rules for market participation, though in WP6 a bidding strategy was formulated. Regardless of the market rules and bidding strategy, there will be a need for forecasts with quantifiable fidelity of available wind power on a time-horizon shorter than the 36h used in current day-ahead energy market bidding. Hence, WP4 has focussed on methodology for how to forecast minimum wind power levels below which the actual wind power "never" drops: "never" in this context means a statistically founded recurrence interval selectable between 1 month and 10 years.

Existing data were available for an 18 month period for hourly measured wind power and forecasted wind power for forecast horizons of 1,2,3...42 hours, covering Western Denmark and Eastern Denmark, respectively. Statistical extreme value techniques were applied to model forecast errors, explained in detail in [ease08]:

Using a year's data, negative residuals ε are calculated, split into a number of blocks. For each block, the maximum ε is found for a given block length and forecast time horizon. From here, the max. forecast error is illustrated in relation to forecasted power level and horizon, see example in Figure 1.5.5.1.
Eventually, the selected "best fit" forecast models are applied to produce forecasted wind power levels over time for different forecast horizons and different recurrence intervals (ie. statistical duration between actual power dropping below forecasted value). The results are shown in Figure 1.5.5.2 and Figure 1.5.5.3. Clearly, as the forecast horizon increases, the "guaranteed level" decreases. Similarly, as the recurrence interval increases, the "guaranteed level" decreases. As expected, a short forecast horizon with a modest certainty results in the least conservative forecast.

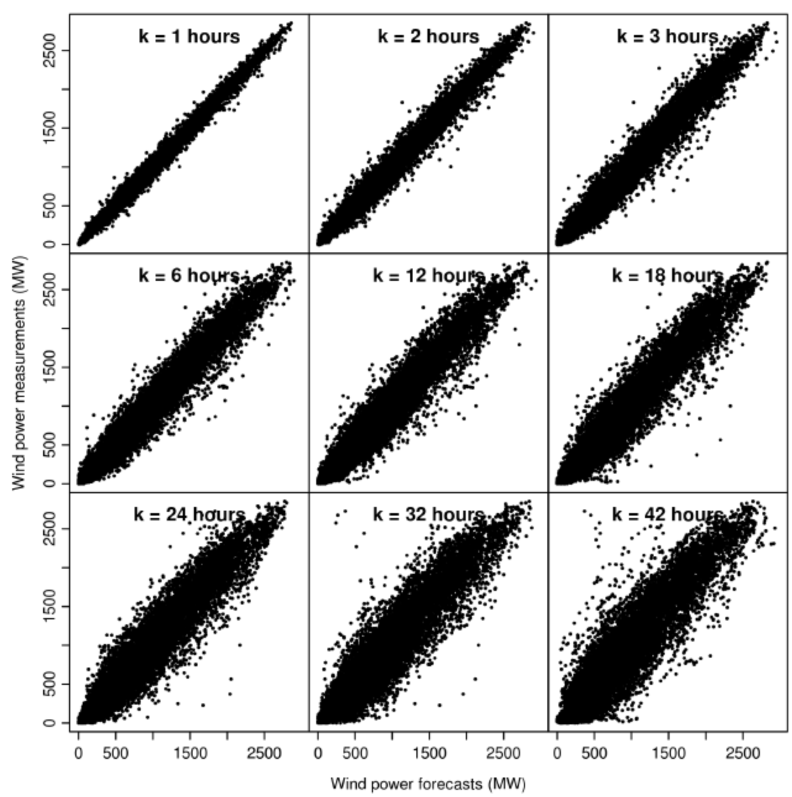


Figure 1.5.5.1: Wind power measurement vs forecast for nine forecast horizons.

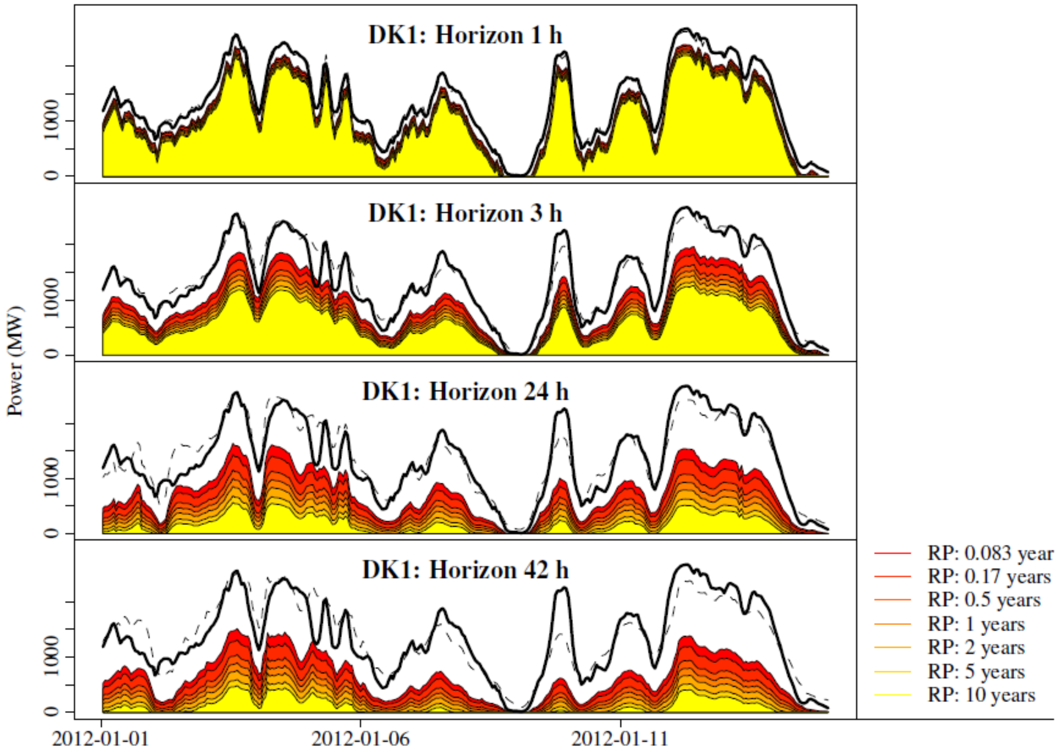


Figure 1.5.5.2: Wind power measurement, original forecast and modelled forecasts for four forecast horizons and seven recurrence intervals.

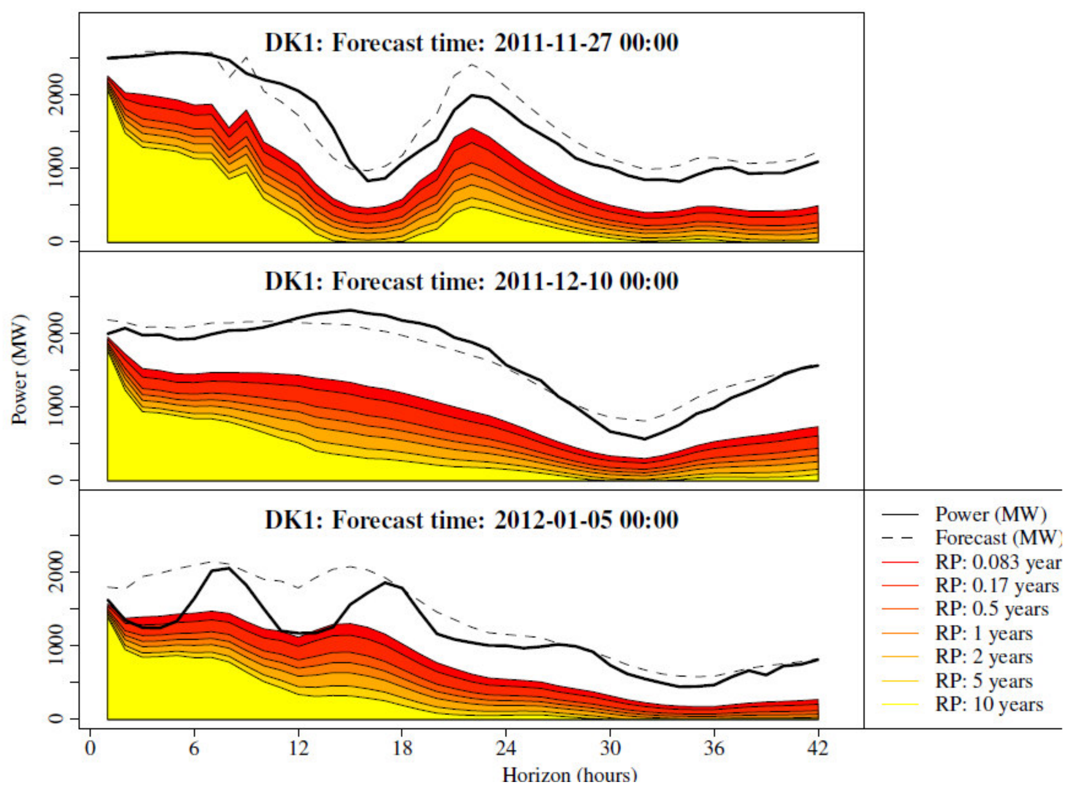


Figure 1.5.5.3: Three examples of forecasts for 1h-42h horizons for seven recurrence intervals.

The first big question reg. forecasting was: For a given forecast certainty (recurrence level), and a given forecast horizon (1h-42h), how much lower is the forecasted wind power level than the actual wind power? Ie. how much energy would have been lost, if the actual generation was limited to the forecasted level? This is the subject of much forecasting research, but in WP4 with focus on "never" forecasting too optimistically. Figures 1.5.5.2-3 illustrate the results of WP4's case study.

The second big question is: How is such a probabilistic forecast used to bid an amount of wind energy into the energy market (day-ahead) and an amount reserved for ancillary services? This was the topic of WP6.

1.5.6 Market (WP6)

The objectives of WP6 are to identify a bidding strategy based on a decision-making algorithm for allocation of wind plant power between day-ahead markets for energy and for reserve power and to synthesize performance of bidding strategy.
Ambitions for this investigation had to match the modest amount of resources allocated. Still, a methodology and a case study were developed.

Two distinct principal methods were identified to allocate available wind power to energy market (day-ahead) and to reserve power (unknown bidding horizon): the PWRS (proportional wind reserve strategy) and the CWRS (constant wind reserve strategy). As shown in Figure 1.5.6.1, PWRS uses a constant relative amount of the available wind power, while CWRS uses a constant absolute amount (once the available wind power is above that constant level).

A data set covering just over 1 year was used for the regions Western Denmark and Eastern Denmark:

- Wind power forecast and actual wind power generation
- Power consumption forecast and actual consumption
- Forecasted and actual power exchanged in/out of region on transmission corridors
- Region power imbalance (Area Control Error)
- Day-ahead energy market prices, up-/down regulation power market prices.

An algorithm was developed to synthesize the remuneration going to the wind power generators when participating in day-ahead energy market and a reserve power market, see Figure 1.5.6.2. Note, the algorithm does not dictate a particular use of the reserve power, merely an allocation (whether for balancing energy or for an available standby res such as EASEwind's ancillary services). The remuneration, however, must model whether payment is received for energy delivered or for availability of a power reserve, or a mixture. The algorithm can be configured for either.

The actual study in WP6 modelled revenues from reserve power as payment for actual (reserve) energy delivered. Correlation of system imbalance and wind forecast error data showed benefits from wind offering balancing power. Linear regression modelled a relation between day-ahead price and ratio of forecasted wind power to forecasted consumption. Hence, pulling wind power out of the energy market to put it into the reserve market does impact prices, as one would expect. With the particular data available, the algorithm in Figure 1.5.6.2 simulated the benefit from wind power selling a selectable amount of its forecasted power to the reserve market. It also simulated the accumulated time (over one year), where the available wind power would be insufficient to honour the reserve power sold, and a penalty cost to the generator was included in the algorithm. The proportional wind reserve strategy proved more attractive, and both its remuneration and insufficiency improved with an increased participation in the reserve market.

This is of course a very interesting conclusion, but it is specific to the assumptions in the study. It does not allow to conclude on the attractiveness on withholding wind power from the energy market to sell an available reserve for ancillary services. Significantly more work would be needed to synthesize this setup, in particular on modelling both the market, the participants' marginal costs and the power system network conditions. This has been known all along to be beyond the scope of EASEwind. However, WP6 has proposed a simplified methodology that may be continued with improved data and assumptions to yield a first indication of societal benefits of wind provided ancillary services.

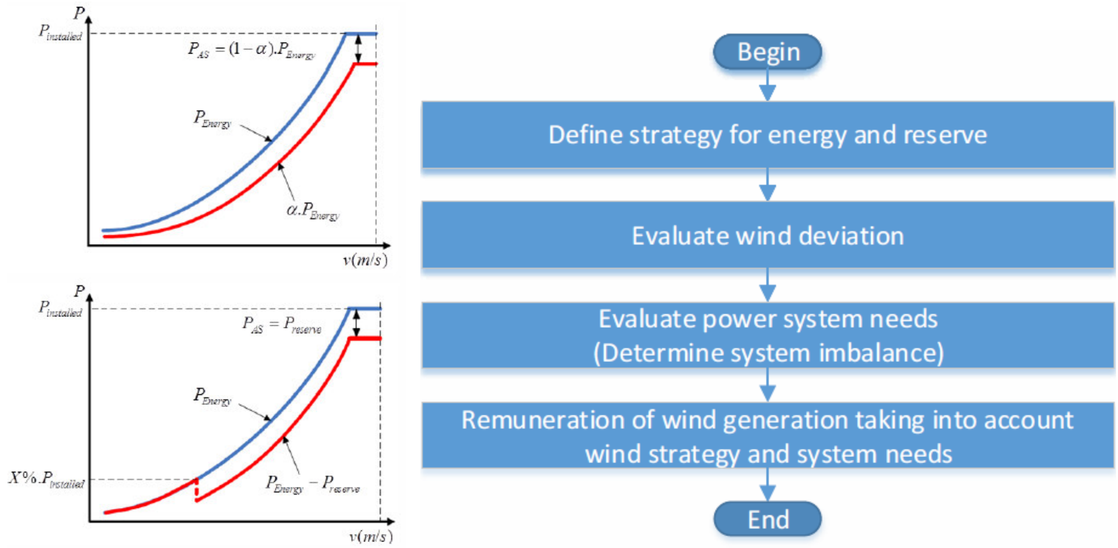


Figure 1.5.6.1: Left: "Proportional wind reserve strategy" (top) and "Constant wind reserve strategy" (bottom), showing split between wind power used in energy market, and wind power reserved for ancillary services. Right: process used in case study of remuneration of provided energy and withheld reserve power.

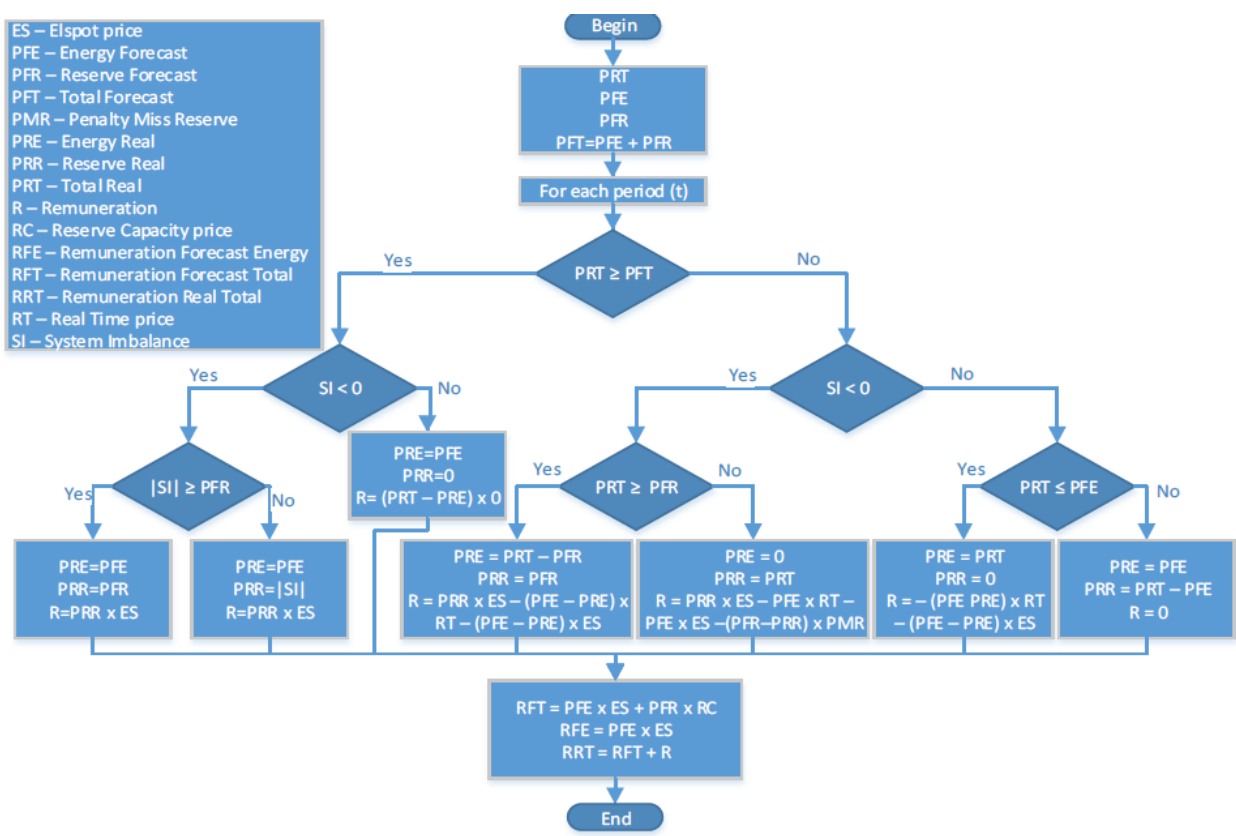


Figure 1.5.6.2: Detailed process for synthesis of remuneration of wind power plant provided energy and reserve power.

1.6 Utilization of project results

Commercial viability: Beginning with the conditions external to the project, the expected development in market has not occurred. No wind power installations are yet remunerated for provision of the ancillary services targeted in EASEwind. A few TSOs have requested functionality to be present or a future feature (Hydro-Quebec and ERCOT request inertia, ELIA and NGET discuss power oscillation damping), but without added payment. The grid connection codes do not formulate any sharp requirements, either.

Lobbying for a renewable ancillary services market is cautious. The only known example is [r13], where EASEwind's partners also take part. As discussed in §1.4.1, if AS payment should outweigh lost energy sales when withholding active power for AS provision, the effective cost-of-energy for wind would be increased. Further, the heterogoneous definitions of the AS features in the connection codes between TSOs deserves some harmonisation before a wider implementation.

The EASEwind project aimed to, by singular case implementation or by simulation of a regional implementation, demonstrate commercial viability. This has not happened. The simulated case is not conclusive enough to promote concrete AS market initiatives (nor was this expected, considering the budget of WP6). Implementation, with the demonstration site, of AS trading was not pursued (i) for reasons stated in §1.4.5 and (ii) as it would have amounted in a financial loss. EASEwind must acknowledge that the ambition stated in the last paragraph of §1.4.1 has not and could not be met.

Technical viability: EASEwind has thoroghly described, simulated, demonstrated the functionality of AS controls which are in a state that they can be adopted across manufacturers and TSOs. There is, though, still room for improvements.

WP1 and WP7 and their derived publications provided, to the best knowledge, the first ever reports of plant-controlled features like power oscillation damping and inertia. Wind power plant equipment is already amenable to the particular AS control properties. Continuous improvements take place to control loop cycle time, to quality of estimated instantaneous available wind power, and to turbine allowable rate-of-change-of-power.

WP2, WP3, WP5 reported on a turbine, power plant, power plant controller and power system network that together allowed studying the impact from wind plant provided AS on the network. This is believed to be the first ever reported method, models and simulations adequate for the study of wind provided AS. The models and simulation method are readily adoptable for other network studies.

The probabilistic forecast method of WP4 quantified the necessary forecast conservatism vs 'guaranteed minimum' and return rate for a particular data set. This method deserves application on longer data sets, and data sets from other regions, to conclude on its resulting impact on lost energy production, but can readily be adopted. Remuneration to wind plant owners for provision of AS was synthesized in WP6. The approach must be updated to reflect a payment for reserve power availability, but is prepared for this. Decision-making in the bidding algorithm algorithm can also integrate forecasting data of WP4.

Intellectual Property Rights: Vestas filed one patent application after acquisition of rights from AaU. PCT/DK2013/050032, filed on 2013.02.07.

Future work:
Whoever becomes first mover, any wind AS market inclusion requires a convincing financial case, routed via the authorities to a propoal for the actual rules for market participation. Together with synthesis of the technical conditions of network in question (energy flow, power balance, system stability), the associated financial value must be synthesised.

EASEwind employed a particular power sytem network model for its studies. Changing to another network, with other characteristics, the tuning of AS controllers must be repeated. Tailoring the amount of AS power contributed at different nodes is likely to offer improved performance. Similarly, the combined activation of multiple functionalities, both AS and established ones as fault ride-through and voltage control, is a subject for further work.
The detection of relevant network states, and communication of setpoints to wind power plant controllers is another subject for specific investigation.

On the wind power plant, and wind turbine, improvements must be continued on control loop cycle time, to quality of estimated instantaneous available wind power, and to turbine allowable rate-of-change-of-power.

The work in WP2 started from the wind turbine simulation model contained in IEC61400-27-1, and has suggested a wind power plant model and aggregation method suitable for both constant and variable wind speeds. The results from WP2 form a very useful input to further standardisation under IEC61400-27-2, where the project participants also form part of the working group.

Dissemination:
The EASwind project has been widely published and presented throughout the project period. The tables below list the scientific papers published and the contributions made at symposia and conferences. The exposure is almost exclusively on the technical findings of the project.

WP2	"Simplified Type 4 wind turbine modeling for future ancillary services", A. D. Hansen, I. D. Magaris, G. C. Tarnowski, F. Iov EWEA 2013, Vienna, February 2013.
WP7	“Power system stabilising features from wind power plants augmented with energy storage”, G. C. Tarnowski, P. C. Kjær, R. Lærke, F. Iov EWEA 2013, Vienna, February 2013.
WP7	“Ancillary services provided from wind power plant augmented with energy storage”, P. C. Kjær, R. Lærke, G. C. Tarnowski EPE 2013, Lille, September 2013.
WP2	"Methods for representations of wind power plants for active power studies", A.D. Hansen,, N. A. Cutululis, A. Müfit , 12th Wind Integration Workshop, London, Oct 2013.
WP2	“Wind turbine and wind power plant modeling aspects for power system stability studies”, M. Altin, A.D. Hansen, O. Göksu, N. A. Cutululis , P.E. Sørensen, Wind energy grid-adaptive technologies 2014, Korea, 20-22 Oct 2014.
WP6	"Analysis of the impact of wind power participating in both energy and ancillary services markets - the Danish case", T. Soares, H. Morais, P. Pinson 13th Wind Integration Workshop, Berlin, Nov 2014
WP2	"Analysis of the short-term overproduction capability of variable speed wind turbines", A.D.Hansen, A. Müfit Altin I. D. Margaris, F. Iov, G. C. Tarnowski , Renewable Energy Journal, 68 (2014) 326-336
WP5	“Wind farm aggregation method for dynamic active power studies”, G. Rossi, A.D. Hansen, N. Cutululis 13th Wind Integration Workshop, Berlin, Nov 2014

Table 1.6.1: Conference and journal publications.

Andrzej Adamczyk - Damping of Low Frequency Power System Oscillations with Wind Power Plants, PhD thesis Vestas Power Programme, Dec 2012
Mufit Altin - Dynamic Frequency Response of Wind Power Plants, PhD thesis Vestas Power Programme, Dec 2012
"Twenties" project Power Hub VPP demonstration day, DONG Energy, 2013-01-24 (http://www.twenties-project.eu/node/19)
EWEA 2013, Vienna, February 2013.
EPE 2013, Lille, Sep 2013
12th Wind Integration Workshop, London, Oct 2013.
13th Wind Integration Workshop, Berlin, Nov 2014.
Danish Research Consortium for Wind Energy annual conference, Herning, March 2014
Grid Support And Ancillary Services Forum June 2014. Wind Power Monthly. Hamburg,
Danish Smart Grid Research Network Event, Aarhus, 05 Sep 2014
5th Annual European Electricity Ancillary Services and Balancing Forum, Mainz, Germany 8-10 Sep 2014
IWEA Autumn Conference 2014, Kilkenny, Ireland
EERA-Workshop "Ancillary Services and System Stability", Kassel, 2014
Wind Energy Systems Workshop, Risø, Dec 2014

Table 1.6.2: Conference/symposium contributions, invited presentations.

1.7 Project conclusion and perspective

EASEwind has met most but not all of its objectives. Wind power plant provided ancillary services were identified, described, characterised and demonstrated. The technical ambitions were largely met. The commercial analysis was attempted, but commercial demonstration abandoned. The project has moved the technical status forward, while commercial reality awaits emergence of ancillary service markets.
The principal investigator has underspent. The remaining partners' contributions were unaffected.

Looking ahead, there is no imminent solution to avoid curtailment of wind power plants prior to upwards modulation of its active power output. AS thus implies some loss of energy. Before further technical development is undertaken, the market preparation should be analysed in much further detail, including taking concrete steps towards payment for AS from wind as one of the means to increase wind's role in the energy mix.

1.8 References

[ease01]	EASEwind project application 2011
[ease02]	EASE wind project application business plan 2011
[ease03]	WP1 Report: "Control features for ancillary services - wind power plant", Vestas, March 2013, 23pp.
[ease04]	WP2 Report: "Type IV wind turbine model", DTU Wind, March 2013, 50pp.
[ease05]	WP2 Report: "Verification procedure of WPP model", DTU Wind, May 2013, 13pp.
[ease06]	WP2 Report: "Modelling of wind power plant controller, wind speed time series, aggregation and sample results", DTU Wind, December 2013, 40pp.
[ease07]	WP3 Report: "Power System Model for New Ancillary Services", AAU, March 2013, 19pp.
[ease08]	WP4 Report: "Methodology and forecast products for the optimal offering of ancillary services from wind in a market environment", DTU Compute, April 2014, 74pp.
[ease09]	WP5 Report: "Definition of simulation test cases for WP5", DTU Wind, April 2014, 16pp.
[ease10]	WP5 Report: "Impact of advance wind power ancillary services on power system", DTU Wind, October 2014, 65pp.
[ease11]	WP6 paper: "Analysis of the impact of wind power participating in both energy and ancillary services markets - the Danish case", DTU Elektro, September 2014, 6pp.
[ease12]	WP7 Report: "Demonstration of ancillary services. Part I", Vestas, March 2013, 27pp.
[ease13]	WP0 NoteA: "Power plant controller. Coordination & allocation of ancillary services", Vestas, March 2013, 4pp.
[ease14]	WP0 NoteB: "Modelling of turbine available power estimate", Vestas, March 2013, 6pp.
[ease15]	WP0 NoteC: "Test cases in WP5 Power system dynamic studies", DTU Wind, March 2013, 5pp.
[ease16]	WP0 NoteD: "Comparison of the aggregated WPP model with the detailed WPP model (WP2) ", DTU Wind, March 2013, 4pp.
[r1]	German C. Tarnowski: "Coorinated frequency control of wind turbines in power systems with high wind power penetration", Industrial PhD thesis, Technical University of Denmark, 2012.
[r2]	Andrzej Adamczyk: "Damping of Low Frequency Power System Oscillations with Wind Power Plants", PhD thesis, Aalborg University/Vestas Power Programme, Dec 2012
[r3]	Mufit Altin: "Dynamic Frequency Response of Wind Power Plants", PhD thesis Aalborg University/Vestas Power Programme, Dec 2012
[r4]	IEC 61400-27-1 "Electrical simulation models for wind power generation".
[r5]	"Transmission provider technical requirements for the connection of power plants to the Hyro-Quebec transmission system" http://www.hydroquebec.com/transenergie/fr/commerce/pdf/exigence_raccordement_fev_09_en.pdf
[r6]	http://www.energinet.dk/DA/El/Udvikling-af-elsystemet/Analysemodeller/Sider/PowerFactory.aspx
[r7]	http://www.digsilent.de/index.php/company-news-detail/items/national-grid-uk-publishes-2011-seven-year-statement.html
[r8]	http://www.westernpower.com.au/documents/business_studies_computer_models.pdf
[r9]	Skovgaard Invest ApS, Kirkebyvej 1, 7620 Lemvig
[r10]	RAH Net, www.rahnet.dk
[r11]	Vestjyske Net 60 kV A/S, www.vestjyskenet.dk
[r12]	"Twenties" project Power Hub VPP demonstration day, (http://www.twenties-project.eu/node/19)
[r13]	"REserviceS". http://www.reservices-project.eu/
[r14]	October 2009, "Vestas Triple-15 strategy". [www.vestas.com/~/media/vestas/.../2009_q3_presentation.pdf]
[r15]	November 2011, "Vestas says it will no longer be able to hit the target of €15bn ($20.6bn) in revenue and a before-interest-and-tax (Ebit) margin of 15% in 2015, citing expected weak economic growth." [http://www.rechargenews.com/news/policy_market/article1294764.ece]

*[easeXX] available from SharePoint site for project: http://teamsites.risoe.dk/easewind