

Ancillary Services from Renewable Power Plants – RePlan Project

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The recent plans for the deployment of renewable energy in Denmark require new integrated regulation strategies, making renewable energy to be a key technology in the development of future power systems towards fossil and nuclear free energy generation. Accordingly, the bulk addition of large scale renewable generations to a power system should not be detrimental to the overall stability of the power system. In order to analyze the impact of the renewable generation on power systems, and also to explore the capability of these renewable generation plants, several projects have been conducted recently in Denmark. This paper describes a new ongoing Danish research project RePlan, which has as main objective to investigate the provision of ancillary services, like frequency/active power, voltage/reactive power support from wind power plants (WPP) and photovoltaic (PV) plants, incorporating communication properties in the control loops and using existing forecast techniques. It is intended to analyze the possibility to exploit and coordinate the ancillary services from these plants, identifying and analyzing their capabilities and limitations in respect to their coordination.

Keywords-power system operation and control, wind power plants, PV plants, ancillary services, coordinated control

I. INTRODUCTION

The increased penetration of renewable generation (ReGen) to attain the goal of the Danish government to convert the present power system into an entire renewable energy integrated system by the end of 2050 [1], will be accomplished by large scale of wind power (WP) and solar photovoltaic (PV) plants. For instance, the WP generation capacity in Denmark today of 4792 MW, supplying 26.7% of total electricity consumption [2], will be increased to 50% of Danish electricity consumption in 2025 [3]. Accordingly, the PV generation capacity in Denmark is around 553 MW today [4], and will be increased at 1000 MW in 2020 [5].

The foreseen high penetration of wind and PV into the Danish electricity supply imposes a transition from traditional operation and control of power systems to a new paradigm which consists of non-synchronous intermittent power generation, distributed energy resources, and pro-consumers. Additionally, all these new elements are employed with an information and communication technology (ICT) interface and network. In order to sustain ReGen installations without causing instability in power system operation, the requirements and grid codes were

published and are being updated by power system operators. In Denmark, the technical regulations for grid connection of WP and PV plants are introduced by Energinet.dk [6], [7]. These regulations represent the minimum technical and functional requirements of ReGen plants to be able to ensure stable, secure and economic operation of transmission and distribution grids with the existing conventional power plants. The ancillary services, which are the part of these regulations, are also provided by ReGen plants to support power systems if there is a request from the power system operator. In order to explore the capacity of ReGen plants and comprehend the power system needs, several projects have been carried out in Denmark.

Cell Controller Pilot Project (CCPP) [8] aimed to develop and demonstrate the capability of wind turbines and combined heat and power plants (DHCP) which are connected to MV distribution grids. The controller was employed in a HV/MV substation having the ability to control the wind turbines, switchable loads, DHCPs and distribution feeders. The services which are provided using this controller are voltage/reactive power control, active power control, islanding, frequency control, and load shedding. The controller could be used to provide ancillary services to both the transmission system operator and the distribution system operator at the same time or according to the specified priorities. For instance the cell controller acts as a virtual power plant controller for the transmission system operator to coordinate the active and reactive power in the distribution area. Accordingly, the distribution system operator could ask an automated voltage control to reduce the reactive power flows from the transmission grid. Some of the functions defined in the project framework were tested on site and results were compared with simulations.

Another project which is called iPower (Strategic Platform for Innovation and Research in Intelligent Power) [9] was conducted in Denmark focusing on the technical and economic design of flexible consumption/generation services for distribution grids. These flexible services were defined in terms of active power control (e.g. load shaping, aggregated response, reserve allocation) and voltage/reactive power support control. Besides these technical features aggregated response, market design, pricing, and risk issues were also considered and documented at the end of the project.

The last background project was the REserviceS (Economic grid support from variable renewables) which had the objective to investigate ReGen based grid support services at EU level [10]. It provided technical and economic guidelines to policy makers, market designers, and system operators. The ancillary services, which are controlling frequency and voltage with reserve management, were analyzed considering the capability and economic benefits of ReGen with market concepts.

Taking into account above projects as a background, the RePlan project (Ancillary services from renewable power plants) has been started in Denmark to investigate further the ancillary services provision from ReGen units. The previous projects studied to describe the ancillary services from ReGen units (i.e. wind and PV) individually, and the coordination between wind and PV plants and the grid needs are not addressed together. Therefore, the RePlan project are planned to exploit and coordinate the ancillary services from WP and PV plants with identifying and analyzing their strengths and limitations both in transmission and distribution grids.

II. ANCILLARY SERVICES

The definition of ancillary services differs significantly based on who is using the terms. While some definitions emphasize the importance of ancillary services for system security and reliability, others mention the use of ancillary services to support electricity transfers from generation to load and to maintain power quality [11], [12]. The accepted definition in RePlan is that ancillary services are all grid support services required by the transmission or distribution system operators to maintain the integrity and stability of the transmission or distribution grids as well as the power quality. These needs can be fulfilled by connected generators, controllable loads and/or network elements [10].

In Denmark, Energinet.dk has published an ancillary services strategy for 2011–2015 [13]. This strategy classifies the ancillary services into frequency-controlled reserves, secondary reserves, manual reserves and regulating power and properties required maintaining power system stability. Those properties include short-circuit power, continuous voltage control, voltage support during faults, and inertia. In this paper, in order to make it more specific the ancillary services, which are going to be analyzed in the RePlan project, are divided into three groups.

A. Frequency Support Ancillary Services

- *Fast Frequency Reserve* [10]: An additional increase in active power output from a generator (and/or reduction in demand) following a frequency event that is available within 2 seconds of the start of the event and is sustained for at least 15 seconds.
- *Frequency Containment Reserve* (FCR or primary response) [12]: The automatic response to frequency changes released increasingly with time over a period of some seconds. As a generation resource it is a fast-action, automatic and decentralized function.
- *Frequency Restoration Reserve* (FRR, secondary response) [12]: Activation of Frequency Restoration Reserve (FRR) modifies the active power set points of reserve providing units in the time-frame of seconds up to typically 15 minutes after an incident.

The provision of these ancillary services from ReGen units is going to be analyzed mainly in the transmission grid in the Replan project. Accordingly, for overfrequency situations the ReGen units in the distribution grid are also going to be included in the studies.

B. Voltage Support Ancillary Services

- *Steady-state Reactive Power/Voltage Control*: Controlling voltage node profile to a target value or within a target range. This control is commonly achieved by injecting or absorbing reactive power at a voltage controlled node by means of synchronous sources, static compensation, tap changing transformers in the substations, transmission lines' switching, virtual power plants including demand facilities and if necessary load shedding.
- *Fast Reactive Current Injection* [10]: Oriented towards system dynamic security and voltage quality, it can be provided by spinning generators and synchronous compensators, reactors and capacitors, Static VAR Compensators (SVCs), HVDC (implemented with technology VSC) substations and other FACTS devices, or other equipment capable of fast regulation.

Similar to the frequency control related services, these voltage support services mainly focus on the transmission grid. Since the distribution grid has different characteristics such as radial operation, distributed generation and load interaction, the ancillary services requirements should be modified for the ReGen units connected to the distribution grid. In the Replan project, the distribution level steady-state voltage control service will be analyzed considering the capability of ReGen units, coordination between ReGen units, voltage limits, and transmission system operator's VAR limits.

C. Other Ancillary Services

In addition to the above ancillary services, rotor angular stability support from ReGen units is going to be investigated in the RePlan project. The identification of rotor angular stability challenges related to the accommodation of future large penetration of ReGen will be studied in terms of small signal and mid-term stability, and afterwards the ancillary service provision will be developed to support the rotor angular stability with a possible coordinated control strategy from WP and PV plants.

The flexible active power control in distribution feeders is also going to be considered in the RePlan project. This control will be studied by adopting some of the flexible services which are presented in the iPower project [9] such as power urgent, power reserve, and power cap. The ancillary services which are going to be analyzed in the RePlan project are summarized in Table I.

TABLE I. ANCILLARY SERVICES IN THE REPLAN PROJECT

Ancillary Services	Application Area	
	Transmission Grid	Distribution Grid
Fast Frequency Reserve	✓	-
Frequency Containment Reserve (FCR)	✓	✓
Frequency Restoration Reserve (FR)	✓	-
Steady-state Reactive Power/Voltage Control	✓	✓

Ancillary Services	Application Area	
	Transmission Grid	Distribution Grid
Fast Reactive Current Injection	✓	-
Rotor Angular Stability Support	✓	-
Flexible Active Power Control	-	✓

III. REPLAN PROJECT

The main objective of the RePlan project is to contribute to the integration of large share of renewable energy in the Danish power system and thus to enable a resilient power system in the future by developing technical solutions for the provision of ancillary services by renewable power plants. RePlan focuses on WP and PV plants since they are expected to jointly produce the lion's share of renewable energy generation capacity needed to reach the Danish government 2050 targets.

For ReGen plants, investigation of ancillary services, coordinated control, communication properties and forecast of available power are key factors on the route toward a future resilient power system. In this respect, the RePlan project will develop controllers for the delivery of ancillary services, incorporating communication properties in the control loops of the ReGen plant model and using state-of-the-art methods for simulation of renewable generation patterns and wind power forecast methods. Based on both simulation models and verification in laboratory facilities, this project intends to address this challenge: *What is the impact of communication and forecast error in providing coordinated ancillary services from ReGen plants?*

The novelty of RePlan consists in the investigation and verification of: 1) the ancillary services provision from WP and PV plants and 2) the suitability to coordinate their services provision to power system operator. Furthermore, RePlan strives to identify and analyze the strengths and limitations of WP and PV plants, anticipating new challenges and exploring some of the more complex issues and uncertainties related to the coordination of their ancillary services.

In the RePlan project, the state-of-the-art methods for simulation of renewable generation patterns will be considered. For this purpose, the RePlan will use DTU Wind Energy's software CorWind [14] for simulation of wind power, supplemented with available models for PV power in CEE DTU Elektro [15]. Furthermore, the RePlan project has the verification work of the proposed controllers for the ancillary services in two different scale power system facilities.

The first power system test facility is a Real-Time Hardware-in-the-Loop (RT-HIL) environment based on multi-domain physical systems in Aalborg University Energy Technology Department. The RT-HIL environment comprises of a hierarchical control structure starting from transmission grid down to ReGen plant controller based on industrial solutions including also communication network infrastructure. This test facility is presented in Figure 1.

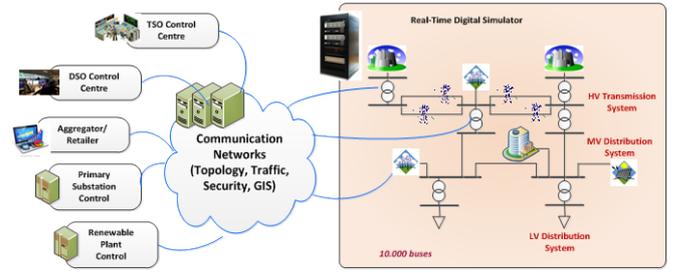


Figure 1. Smart Energy Systems Laboratory, Aalborg University

The second test system which is going to be used in the RePlan project is a real small scale power system, namely the SYSLAB facility existing in the DTU Risø Campus integrating a number of decentralized production and consumption components including wind turbines and PV-plants in a system context, will be used for testing some of the ancillary services from WP and PV plants in a distribution power system. The feasibility and the performance of some ancillary services from real physical entities spatially distributed will be analyzed. Due to the existing hardware limitations in small scale power system laboratory as it is SYSLAB, it will not be able to demonstrate all the ancillary services proposed and developed in the project. The SYSLAB is presented in Figure 2.

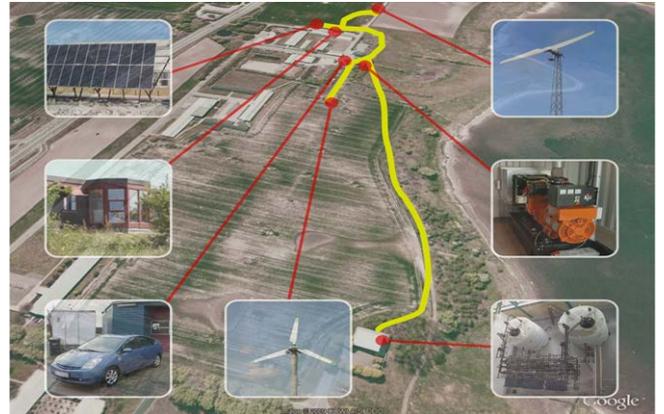


Figure 2. SYSLAB in Risø, DTU

The RePlan project is organized in seven work packages as it is illustrated in Figure 3. In work package 1 (WP1) the technical feasibilities of ReGen technologies will be investigated and an hierarchical control framework including ICT infrastructure for coordinated participation of ReGen will be defined in the provision of the ancillary services (Table I) to support the stability of a future entire renewable energy integrated power system.

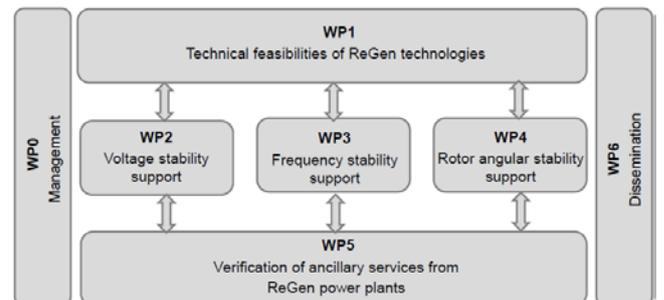


Figure 3. Overview of Work Packages in the RePlan Project

In the second, the third, and the fourth work packages, the voltage, frequency, rotor angular stability challenges will be identified respectively, related to the accommodation of large penetration of ReGen plants. Following this identification study, the controllers for the ancillary services will be developed with a specific aim of supporting voltage/frequency/rotor angular stability. Accordingly, the feasibility analysis will be performed for a coordinated voltage/frequency/rotor angular stability support from WPs and PVs. Finally, in work package 5, the capability of ReGen plants with the developed controllers will be verified to provide the ancillary services in the power system test facilities which are described above.

The RePlan project will also seek a close involvement of the main actors in the creation of future market for ancillary services (transmission and distribution system operator) inviting them to actively participate in workshops. By interacting with the power system communities and incorporating their feedbacks into the development of the coordinated ancillary services from WP and PV plants, the project results will be early recognized and then broader acceptance from relevant stakeholders would be possible. The visualization of the RePlan project is given in Figure 4. This figure is not representing exactly a central controller implementation to manage all the ancillary services, but it is describing the coordination between different plants and grid levels considering the communication infrastructure for the related ancillary service.

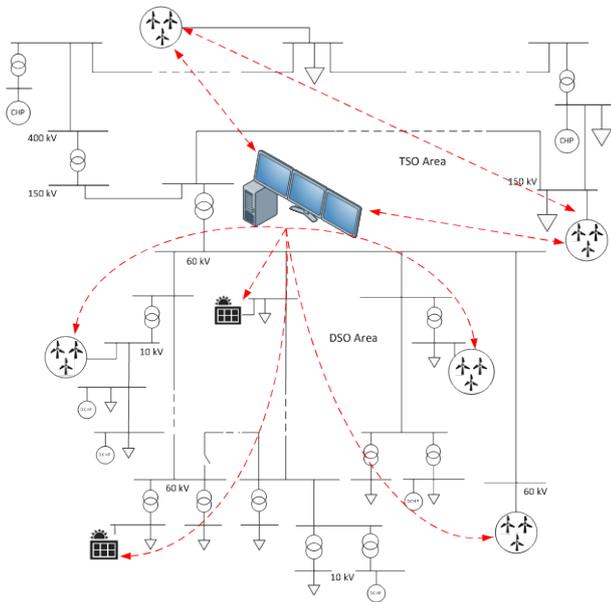


Figure 4. Possible Control Structure for Ancillary Services Provision from Wind and PV Plants in the RePlan Project

IV. SUMMARY

Besides the need for further research in the area of provision of ancillary services by ReGen plants, there is also an imperative need for verification and extensive studies for the quantification of the impact of the ancillary services from WP and PV plants on the power system stability. To the best of our knowledge, a thorough insight and understanding on the increasing complexity of the future

power system with large share of wind and solar plants is still missing at the present stage of the research with respect to large integration of ReGen plants into the system.

In this paper, the RePlan project is summarized briefly. The RePlan project will investigate the provision of ancillary services, like frequency/ active power, voltage/ reactive power support from WP and PV plants. Studies of the communication between ReGen plants and system operators' control rooms, and this communication structure impact on the provision of ancillary services are going to be carried out in this project. RePlan also strives to develop a coordination strategy between ReGen plants comparing with individual control strategy of ReGen plants.

ACKNOWLEDGMENT

This work was carried out by the DTU Wind Energy Department in cooperation with DTU Elektro (CEE), Aalborg University (Energy Technology and Electronic Systems Departments), and Vestas Wind Systems A/S. Energinet.dk is acknowledged for funding this work in contract number: PSO project 2015 no. 12347: "Ancillary services from renewable power plants (RePlan)" www.replanproject.dk.

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