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Monitoring and Management of Power Transmission Dynamics in an Industrial Smart Grid

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***Abstract*— This article is a position paper whose purpose is to give the context for presentations in a special session at PowerTech 2013. The special session is being proposed by the EU FP7 Real-Smart Consortium, a Marie Curie Industry-Academic Pathways and Partnerships project. The paper gives an overview of topics on modeling, monitoring and management of power transmission dynamics with participation from large industrial loads.**

***Index Terms*—Industrial smart grid; Phasor measurement unit (PMU); Power grids; Wide area oscillation; Wind energy generation.**

I. Introduction

The issue to be addressed is the integrated operation of power grids with variable generation from renewable sources and flexible use of power by heavy electrical loads in the oil and gas and other electricity-intensive industries. It is a topical subject because new real-time measurements such as Phasor Measurement Units (PMUs) and transmission control systems give the future potential to incorporate wind generation and industrial users into grid operations in a responsive way for enhanced reliability, stability and security. The paper will present an overview, and then a selection of underpinning work towards the following goals:

- Developing systems for enhancing power transmission system security by:
  - converting wide-area measurements into information about real time performance and operation of the transmission system;
  - detecting emerging problems at an early stage and quickly localizing the root cause;
  - initiating control action for operation in a confident and robust manner;
  - supporting advanced planning and operations to relieve bottlenecks and increase throughput.
- Investigating, understanding and quantifying the dynamic impact of heavy industrial loads on the grid, and the effect of grid dynamics on the industrial loads;
- Modifying grid planning methods in such a way that they take better into account the installed large scale wind power.

The next section discusses the background and highlights the new technologies which are influencing the way transmission grids are being operated and used. The willingness of industrial end-users and automation companies to participate in supporting grid operations is a significant new development. Research in this area is being driven by process automation vendors and university process automation groups. Section III mentions some of the exploratory work to be presented in the proposed Special Session which provides some underpinning elements of a future industrial smart grid.

II. Background

Electrical transmission and distribution in Europe has been experiencing a period of significant renewal and technological change. Transmission grids including the Nordic system, the National Grid in the UK and the continental European system are accepting power injections from new and variable energy sources, especially from large scale wind power generators, and will therefore face major future challenges to operate and control. Policy documents from the US DOE and EU [1],[2] and the National Grid [3] have highlighted (i) the need for improved grid infrastructure and advanced control technologies and (ii) the importance of emerging measurement-based technology in enhancing the stability and security of AC transmission.

Changes happening in the process industries also have an impact on electrical supply. Sustainability, efficiency and maintenance considerations are leading to electric motors taking over from traditional gas turbine drivers for rotating machinery such as compressors. Understanding and managing the interface between these large and variable electrical loads and the transmission grid is of great interest for smooth operation of the transmission system.

The European Commission established the SmartGrids European Technology Platform in 2006 [4], while in the long term a Super Grid is envisaged linking sources of renewable generation in North Africa to Europe where there will also increasingly be variable and decentralized production of

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electricity. The Smart Grid concept has also taken a high profile in the USA following the Energy Independence and Security Act, 2007 [5] and in Europe with an ambitious agenda for operation of the European electricity supply networks in the future [6]. The term *smart* refers to the use of information technology and real-time communication in grid operation.

With these in place it becomes possible to consider commercial and technical ways to adjust industrial loads to meet variable generation from renewable sources. The concept of an *Industrial Smart Grid* has recently emerged from the process automation sector. For instance, senior technical authorities from Honeywell Labs have commented on advances in automated demand response, dynamic markets, and the need for standards [7]. Industrial loads will participate in grid management in a future industrial smart grid and there are significant opportunities for automation vendors.

The Real-Smart IAPP is a consortium of ten partners including TSOs, automation and electro-technology companies and universities. It is addressing the technical issues outlined in this paper by means of secondments between partners. The researchers involved have contributed several papers to PowerTech 2013 [8]-[15]. The authors include experts in electrical power systems, modeling, signal analysis, and automation of oil and gas and chemical processes. Figure 1 shows the topics covered by these papers, as outlined in section III.

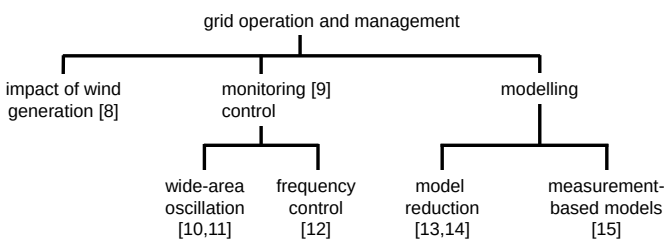

Figure 1. Overview of the papers submitted for PowerTech 2013 discussed in this article

III. Technical Issues

A. *The impact of wind generation*

Large-scale wind generation is leading to the need for significant grid renewal. Examples include proposals for an HVDC grid in the North Sea [16] and incorporation of significant wind generation both on- and off-shore in the Scandinavian grid. The system planners of the TSOs require simulations and tools to assess the impact of new wind generation on grid operation.

A paper submitted for PowerTech 2013 by Kunjumuhammed et al. [8] reports the effect of variable wind power output on the stability of future power systems. It provides a strong motivation for developing systems for enhanced power transmission system security to accommodate future wind generation The test system is based on the UK transmission system network described in [17] and is used to provide insights into the way in which system operation will be affected by increased use of wind generation and new HVDC lines.

B. *Grid monitoring and control*

A network control center of a transmission system operator uses a supervisory control and data acquisition (SCADA) system to collect data from remote terminal units and substations. These are local measurement points, however transmission system operators are also increasingly using information from wide area monitoring system (WAMS) using PMUs to give readings of grid conditions at selected strategic points across a very large area. Because the PMU readings are time-stamped using GPS they can capture global information about oscillations, load dynamics and stability indicators based on power flows, magnitudes and phase angles of voltages and currents between two geographical locations. These developments in measurement and communications are the emerging technologies that [1] has identified and are the driving force for research using measurements as the basis for the future management of electrical transmission systems.

The paper submitted for PowerTech 2013 by Marinakis and Larsson [9] provides a survey showing the impact that measurements from PMUs have had in measurement-based power system operation. They present the state-of-the art and compare a range of methods and applications that have been applied in practice or proposed in the literature for converting wide-area measurements into information about real time performance, especially for real-time security assessment and situational awareness. Topics covered include state estimation and real-time detection of wide-area oscillations.

1) *Wide-area oscillations – monitoring and conrol*

Low frequency electromechanical oscillations with frequencies broadly between 0.1 and 0.8 Hz are inherent in large interconnected power systems [18]. These inter-area oscillations are typical for power systems with long transmission lines and they are visible in a poorly damped electric power system after system events (e.g. short circuits, transmission line trips, changes in loads). The observable symptom is that synchronous generators in a geographical region swing against generators in another region. This leads to power oscillations on the interconnecting lines.

Accurate quantification of the frequencies and damping of these electromechanical oscillation modes is critical to controlling and operating a stable power system [19], to enable disturbances caused by system events to die away faster and to raise the overall energy transfer closer to the thermal capacity. Policy 3, “Operational Security” of the ENTSO-E Operation Handbook specifies measures for assurance of angle stability. The policy implies a need for detection of oscillatory modes, determination of their damping, for diagnosis of their root cause and for methods of bringing them under control. An open question concerns the extent to which wind generation and the new grid topology will interact to influence the damping of wide-area modes. The simulations in [8] showed that operating conditions resulting from variable wind generation can cause large variation in damping levels, hence the need for monitoring and control will become more urgent.

Inter-area modes can also be excited during ambient operation by random changes in load. It is beneficial for transmission system operators to detect and diagnose the modes during ambient operation. However, the detection of the modes may be challenging due to problems such as the weak excitation of the modes and low signal to noise ratio. Several new methods have recently become available and their performance was compared in [20]. The PowerTech 2013 paper by Seppänen et al. [10] has extended the methods further. It uses WAMS data to build an empirical multivariate autoregressive model which captures correlations between measurements from PMUs at various locations in the power grid as well as the temporal correlations between them. The methods in [10] and [20] will form a starting point for new commercial tools.

As mentioned, the reason for detection of inter-area oscillations is that they can threaten system stability. Weixelbraun et al. [11] have reviewed the need for control and offer an approach to control of the damping of low frequency inter area oscillations. They show that when the oscillation frequency is low, the application of single input PSS to the actuators of hydro governor systems (PSS-G) can be effective. The study was conducted in Norway, and showed the capability of digital hydro governor systems to provide damping for oscillation frequencies below 0.5 Hz.

2) Frequency control using industrial loads

There is a two-way interaction between large and variable industrial loads (e.g. arc furnaces, liquefied natural gas (LNG) plant and gas handling plants) and the AC transmission grid dynamics. The topic is of interest because, increasingly, rotating machinery (such as gas refrigeration and gas export compressors) is being powered by electric motors and variable frequency drives [21]. The Industrial Smart Grid envisaged by process automation vendors [7] has the potential to allow industrial loads to participate in grid services in response to a regulation signal. Previous work [22] has demonstrated the participation of energy-intensive industry in frequency control by adjustment of the energy drawn from the grid in response to commands from the grid operator.

The paper of Fabozzi et al. [12] shows it is feasible and desirable to use flexible loads as fast and automatic secondary Frequency Restoration Reserves (FRR) to accommodate the unpredictable and variable power output of renewable generators. However, measuring and specifying the capability of industrial loads to provide such a service is not straightforward because of constraints imposed by their main business of making products. The paper examines methods to evaluate process capability and windows of operation of industrial loads as providers of FRR in such a way that the process constraints can be honored.

C. Power system modelling

1) Model reduction

Zhang et al. [13] have given a comprehensive review of the current requirements for power system model reduction in applications such as state estimation and steady-state voltage control. They have revisited REI (Radial, Equivalent, Independent) network reduction and show how the proposed method can be used to produce and update the reduced network model. Their motivation for revisiting system reduction techniques is increasing needs for on-line assessment and optimized operation on large scale networks. A further development being explored by Real-Smart members is dynamic REI, as originally proposed in [23], for purposes such as on-line dynamic security assessment which accommodate equivalence modeling of parts of the external system. This work will be reported elsewhere. The work by Kishor and coauthors [14] aims to reduce a coherent area of a power network to a reduced-order state-space equivalent model where the dynamic behavior of the dominant poles is retained. Their principal interest is in inter-area oscillations and the simplified representation of wide-area modes.

2) Measurement-based models

Models might have a structure based on system topology, as described above, however another approach is to generate a model based on time series analysis of the measurements from the system. Real-time methods that generate models from operating data have potential for enhanced control because they capture the current state of the grid. This approach has become attractive in recent years because of the deployment of PMUs. The second paper from Kishor et al. [15] successfully uses a method based on mutual information to determine the coherent generators in each area of a network followed by identification of the dynamics of rotor angle and rotor angular speed deviations for the generators based on measurement data, available through WAMS. The authors suggest how such models might be used for design of robust multivariable controllers for damping of wide-area power oscillations.

IV. SUMMARY

This article has given an overview of a proposed special session taking account of the papers which have been submitted, [8]-[15]. The list of topics outlined above is by no means exhaustive, however all are key elements of the monitoring and management of power transmission dynamics of a future industrial smart grid involving participation from large industrial loads.

V. ACKNOWLEDGEMENTS

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