Publishable JRP Summary Report for ENG52 SmartGrid II
Measurement tools for Smart Grid stability and quality

Background

The increased use of renewable energy is vital to meet emission reduction targets and ensure security of supply in Europe. However renewables are intermittent and unless the energy flows are measured and controlled, the increased use of these distributed generation resources will cause costly power quality (PQ) degradation, ultimately leading to wide-spread blackouts. Smart Grids are the mechanism to reliably utilise large amounts of renewable energy and new measurement tools as proposed in this project are essential for their stable operation.

The emergence of GPS synchronised measurements has opened up many new measurement opportunities to determine grid parameters and behaviour over a wide geographical area. This is a common theme to the techniques that will be developed in this project which will ultimately lead to new grid management methods to help design, control and stabilise Smart Grids of the future.

Need for the project

Smart Grids are primarily required to dynamically balance variable renewable supply with variable demand to achieve grid stability and prevent a degradation of PQ that would otherwise lead to cascading failures and power blackouts.

Network operators need tools to measure the quality and stability of the electricity supply under the challenging dynamic conditions prevalent in networks with a high penetration of distributed renewable generation. Wide-area measurement systems using phasor measurement units (PMU) are increasingly seen as the “life-support monitors” for Smart Grids and they present many new opportunities to understand the complex dynamics of these networks. However, unless properly formulated and deployed, these new measurement techniques have many potential pitfalls that will give rise to misleading results that could ultimately undermine, rather than boost confidence in future-networks.

This project will engage with this rapidly developing technology and implement a complete metrology framework for PMUs. In particular, addressing the exacting calibration requirements for PMUs and associated transducers when used to monitor the stability of distribution networks where very small phase changes are critical. Furthermore, new synchronised grid measurement techniques are needed to determine the propagation of PQ in networks, locate significant sources of PQ disturbance and measure network impedance, all of which are essential to Smart Grid planning and management.

Scientific and technical objectives

The common theme to the measurements to be developed in this project is the use of multiple digitising instruments placed at geographically remote locations around an electricity grid. These instruments are time-synchronised to form a wide-area measurement system using GPS. Specifically the project has the following objectives:

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- ***PQ Propagation***. Determination of PQ propagation mechanisms associated with a selection of disturbance sources in a variety of distribution and transmission networks. The results will be reconciled against network topology, drawing conclusions to support future network planning and standardisation.
- ***PQ Disturbance and Fault Location***. Amplitude and phase measurements for multiple GPS synchronised instruments will be used to determine power flows associated with major PQ disturbance / faults and their locations will be estimated.
- ***Network impedance and system resonances.*** Wide-area measurements and the analysis of system impedance and resonances in HV/MV/LV networks. Results will be evaluated against network design data and models.
- ***PMUs in Distribution Networks***. Selection, comparison and validation of new PMU algorithms suitable for use in LV and MV distribution networks. These networks are characterised by smaller distances and hence require higher phase sensitivity whilst at the same time accounting for a higher level of PQ disturbances.
- ***Dynamic calibration of PMUs***. Develop extensions to a laboratory PMU calibrator to provide new calibration support for the dynamic performance of PMUs.
- ***On-Site Calibration of PMUs.*** Undertake on-site measurements using reference PMUs, suitably modified to calibrate/verify the operation under realistic conditions including PQ disturbances.
- ***PMU/PQ Transducer Characterisation***. Develop/apply wideband evaluation facilities for transducers and optimise non-invasive transducers specifically applied to the PMU/PQ measurement chain.
- ***Digitised Waveform Corrections***. Develop and evaluate signal processing methods to apply transducer frequency response corrections to sampled complex wave shapes typically present in PMU/PQ measurements. Reconcile the propagation of transducer uncertainties through complex PQ and PMU algorithms.
- ***Standardisation Input.*** Provide metrology input and pre-normative research to the evolution of International (CEN, CENELEC, IEC, IEEE) standards concerning PMUs for network controllability and PQ in a Smart Grid context

Expected results and potential impact

Utilising wide-area measurement technology, this project is achieving significant advances in Smart Grid measurements in the following areas:

- ***PQ Propagation***. Four different distribution networks of varying topology, generation mix and demographics have been selected for measurement campaigns. At each site, a group of time synchronised digitisers/PMUs and associated voltage and current transducers will be used to measure PQ propagation in these networks. These networks include:-

  i) Bornholm Island (DK) in the Baltic Sea; a model smart grid with more than 50% renewable energy resources and a sub-marine interconnector to the mainland (SE). The island is an example of the 2050 EU energy scenario and will provide a unique insight into the PQ issues that will occur in smart grids.

     Six measurement sites have been selected and transducers and instruments prepared and calibrated for each site. Installation is planned in two stages in early 2016. The network has been modelled to predict the PQ propagation. Data collection infrastructure, communications equipment and analysis software has been prepared/developed.

ii) Big Glen wind generation (SE). Measurements are complete on a transmission feeder from a wind-turbine site in Gothenburg Bay. Data is being analysed to determine the properties of the transmission line.

iii) Liander LiveLab in Zaltbommel (NL). This is a typical urban distribution network with very good circuit records. The PQ scenarios have been modelled and data is currently being collected using installed monitoring equipment. Analysis and reconciliation with the PQ model is to follow.

iv) A regional 50 kV ring-topology network (NL). Measurement sites have been selected and the measurement equipment has been installed and the first results are now starting to be analysed.

v) An urban network with high levels of PQ disturbance (SK). Three measurement sites planned.

These campaigns will develop an understanding of the effect of PQ on the wider-area network, allowing holistic management and mitigation strategies to be developed and implemented for a variety of grid topologies. This will improve grid planning, reducing the need for reinforcement and enabling the timely and efficient connection of new renewables.

- ***PQ Disturbance and Fault Location***. This work is not scheduled to start until 2016.
- ***Network impedance and system resonances.*** This is a difficult measurement as the impedances (hence signals) are low and must be measured in a hostile environment.

  A new algorithm for impedance estimation has been completed and tested in computer simulations for realistic conditions. Initial results show very good performance for both transposed and untransposed lines, even in presence of corrupted data, owing to proposed robust estimation. At the moment, the algorithm is being tested for real measurement data from a 50 kV grid.

  Network impedance is important for operators to better model the behaviour of their system such that it can be closely-controlled in order to maintain PQ and reduce potential blackouts. It is also important for system design and the mitigation of undesirable effects such as harmonics.
- ***PMUs in Distribution Networks***. Simulations are underway to test and compare a range of published and proposed PMU algorithms. To aid this process a workshop was held involving many of the workers in the field. A unique comparison of these algorithms to determine the best solution for future PMUs is now underway utilizing simulations and a library of typical power system waveforms which will be used to test the waveforms and eventually to test full PMU systems.

  Identifying the best algorithms for given network conditions will ensure that the PMUs of the future will give timely and accurate situational awareness information the network operators can trust to manage their systems and reduce the build-up of instabilities that lead to blackouts.
- ***Dynamic calibration of PMUs***. System level designs for the PMU calibrator have stared including identifying the accuracy and timing specifications of the various sub-systems required to achieve the exacting overall uncertainty requirements of the calibrator. Studies of commercial available PMUs have been made to ensure that the proposed instrument is capable of addressing the specific requirements of these common instruments.

  To-date there has been no facilities available to calibrate PMUs with dynamic waveforms, typical in real networks. The exacting phase requirements require the highest accuracy advanced calibrator to be designed and built. This system will use atomic clocks as timing sources and the highest quality Digital to Analogue and Analogue to Digital convertors which will need to be optimized for precise phase measurements. Comprehensive error budgets have been developed to understand the performance requirements of the components in the calibrators to ensure it is designed to meet the phase requirements. The calibration capabilities developed in this project will be critical to the confident operation of the new and complex instruments.
- ***On-Site Calibration of PMUs.*** This work is not scheduled to start until 2016.

- ***PMU/PQ Transducer Characterisation***. Transducers are an essential element of the PMU/PQ measurement chain and their errors, particularly at higher harmonic frequencies can be substantial, however these errors are often unknown and consequently ignored.

  The use of non-invasive current transducers has always been a major error source in field measurements and WP4 work into the optimised use of these devices will be of great benefit to PQ and PMU measurements and will add to the understanding of how these devices perform under various conditions. Transducers are an essential element of the PMU/PQ measurement chain and their errors, particularly at higher harmonic frequencies can be substantial, however these errors are often unknown and traditionally they have not been measured (due to lack of facilities/methods) and are ignored.

  The design of a voltage transducer (VT) characterization facility to investigate the complex frequency response up to 60 kV is in progress. This will be a unique facility (beyond the state-of-the art) used to investigate the performance of various designs of VT used in PMU/PQ measurements such potentially large frequency related errors can be suitably corrected. Errors due to stray capacitance are a significant error source in any such system and work is currently underway to optimize the reference transducer against these errors at 15 kHz.

  A new digital filter based algorithms capable of real-time implementation will use the frequency response corrections obtained for each transducer and correct raw measurement samples to account for the distortion caused by transducer amplitude and phase errors. Assuming stable transducers, this approach will largely eliminate the largest error contribution in the PMU measurement chain which can give serious errors particularly to waveforms with high frequency components.

- ***Digitised Waveform Corrections***. This work is not scheduled to start until late 2015.

- ***Standardisation Input.*** The project has had active discussions and inputs to the ongoing work of the IEC/IEEE committee on PMU standardization. These complex instruments are recent innovations and their design is still highly evolutionary. The experiences of this project will be highly valuable to the development of future standards.

Through these activities, this project will deliver verified and practical measurement tools for the planning and management of smart grids with the aim of ensuring **reliable, stable, high-quality energy-supply** from renewable-based generation. The outcomes will benefit stakeholder groups including designers of smart grids systems, electricity network operators, manufacturers of instrumentation and government policy-makers/regulators.

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