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Innovative controls for renewable source integration into smart energy systems

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D4.1

Annual scientific report

WP4 –Monitoring tools and secure operation of smart grids

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Authors (Partner)	Nicolas Retière (UGA)					
Responsible Author	Nicolas Retière	**Email**	Nicolas.retiere@univ-grenoble-alpes.fr			
	Partner	UGA	**Phone**	+33 4 76 82 63 60		
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DEFINITIONS

- Beneficiary partners of the INCITE Consortium are referred to herein according to the following codes:
- **IREC**. Fundacio Institut de Recerca de l'Energia de Catalunya (Spain)
- **UPC**. Universitat Politècnica de Catalunya (Spain)
- **TU Delft**. Technische Universiteit Delft (Netherlands)
- **VITO**. Vlaamse Instelling Voor Technologisch Onderzoek (Belgium)
- **UniBo**. Universita di Bologna (Italy)
- **UGA**. Université Grenoble Alpes (France)
- **GE Global Research**. General Electric Deutschland Holding GmbH (Germany)
- **Efacec Energia**. Efacec Energia - Maquinas e Equipamientos Electricos SA (Portugal)
- **Beneficiary**. The legal entity, which are signatories of the EC Grant Agreement No. 675318, in particular: IREC, UPC, TU Delft, VITO, UniBo, UGA, GE and Efacec Energia.
- **Consortium**. The INCITE Consortium, comprising the above-mentioned legal entities.
- **Consortium Agreement**. Agreement concluded amongst INCITE Parties for the implementation of the Grant Agreement.
- **Grant Agreement**. The agreement signed between the beneficiaries and the EC for the undertaking of the INCITE project (Grant Agreement n° 675318).
- **Partner Organisation**. Legal Entity that is not signatory to the Grant Agreement and does not employ any Researcher within the Project and namely, 3E NV (Belgium).

ABBREVIATIONS

- **CA**. Consortium Agreement
- **CMO**. Central Management Office
- **EC**. European Commission
- **ESR**. Early Stage Researcher
- **GA**. Grant Agreement
- **INCITE**. Innovative controls for renewable source integration into smart energy systems
- **IRP**. Individual Research Project
- **WPs**. Work Packages

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EXECUTIVE SUMMARY

WP4 deals with the design and the test of new advanced functionalities for monitoring and controlling smart grids. Three of the four research projects began between M8 and M10 of the action and have been ongoing for slightly over a year. The first models, mathematical frameworks, and tools required to design these new functionalities have been proposed and tested. Some further improvements have already been identified.

At the WP level, the PhD fellows involved in the research projects have collaborated to define a short list of possible common test cases. The objective is to use a unique test case to integrate all the methods and models developed individually in each project and, therefore, to facilitate the dissemination of the final results.

1. STATUS OF WP4

1.1 WP objectives

The increasing integration of renewable energy sources, active devices (e.g. electric devices or storage units), and the rising need for efficient, flexible, robust delivery of electrical energy requires to "smartify" even more the electrical distribution grid. Based on the aforementioned needs, WP4 aims to accomplish the following objectives:

- The development and implementation of communications and other features required for innovative control of future smart grids.
- The development of new monitoring schemes for electrical networks.
- The development of self-healing capabilities.

To address them and tackle the related scientific and technological issues, WP4 is split into 4 IRPs, involving collaborations between INCITE's partners:

- IRP 4.1: Study of requirements and issues in communications used in control of smart grids (UniBo, with secondments at UPC and Efacec).
- IRP 4.2: Development of fault detection and isolation algorithms for smart grids (UGA, with secondments at UPC and Efacec).
- IRP 4.3: Definition of monitoring and state estimation methodologies for electrical distribution grids (GE-GR, with secondments at IREC and TU Delft).
- IRP 4.4: Development of functionalities needed to implement new control schemes for smart grids (Efacec, with secondments at IREC and UGA).

1.2 WP general progress

The general progress of WP4 is fully satisfactory. For the recruited ESRs, their first year was dedicated to discover the INCITE project objectives and workplan, start working in their own Individual Research Projects, and develop mutually beneficial interactions inside the WP.

Unfortunately, research within IRP4.1 has not started yet because the two successively recruited fellows resigned just after starting their work at University of Bologna.

In IRP4.2, a first model for fault detection and isolation of PV arrays was designed and tested. A preliminary fault signature has been proposed to detect the faults from the grid.

The real-time control and monitoring of electrical distribution grids will greatly benefit from the original works performed in IRP4.3 on state estimation and optimal location of measurements.

New advanced functionalities are being designed in IRP4.4 too. They are more focused on the optimal day-ahead management of flexibility resources at LV level. A modelling framework required for the definition of these new functionalities has already been developed.

A common test case is being defined by the WP4 participants. The methods and results provided by every IRPs will be integrated into the test case to demonstrate their positive impact on the smart grid's operation.

1.3 WP impact

The progress made in WP4 has already contributed to enhance the research and networking skills of the PhD fellows. Consolidation of the obtained skills and further enhancement is expected during the up-coming year with the continuation of the scientific research and the first months spent in the premises of the other partners.

While very few publications have been done during this first year, the results obtained are very encouraging and should produce some conference or journal publications very soon.

2. PROGRESS OF THE IRPS

2.1 IRP 4.1 – Integrated simulation and design optimisation tools

After the resignation of the candidates selected for the 2016 call, a new call has been organized in 2017. The vacancy has been opened in the INCITE web (http://www.incite-itn.eu/vacancies/) and posted in our social media with deadline 1 October 2017. 12 applications have been received and evaluated. The selection procedure has been finished in November and the selected candidate is expected to join UniBo during December 2017.

2.2 IRP 4.2 – Fault detection and isolation for renewable sources

The main goal of this project is to develop fault detection and isolation methods for renewable energy sources (mostly wind and solar plants) connected to grids (through AC or DC links) and to ensure high level of availability of renewable power plants in order to reduce the impact of outages. After the 2nd INCITE workshop at UPC in Barcelona, it was decided that two additional cases will be studied during the secondments: a) the case of grid faults at Efacec and b) the case of fuel cells as a renewable source at UPC.

After a literature review on fault detection and isolation in power systems, the photovoltaic (PV) system was selected as the first test case.

In order to design the model of a PV array, 3 steps were necessary: 1) extraction of the basic parameters from the equations describing the equivalent circuit of a PV cell, using only the available data from the manufacturer's datasheet, 2) usage of the known parameters to solve the transcendental current-voltage characteristic equation (using Newton-Raphson method or Lambert-W functions) and obtain the current-voltage characteristic curve, and 3) synthesis of several elements in series and in parallel to construct the PV array. The Bishop's model for PV cells was selected as the most appropriate model for fault detection and isolation on PVs.

Among the various available topologies of connecting PV arrays to the grid, the two-stage conversion through a DC-DC boost converter connected in series with an inverter was selected. Furthermore, the most popular maximum power point tracking technique (MPPT), perturb and observe (P&O) was implemented. As a first step in designing and testing the model of the system, the averaged model was used for both the boost converter and the inverter. A preliminary attempt to introduce faults in the system, e.g. shading, was successful. After verifying that the averaged model responded accurately to simple faults, the exact models of the converter and the inverter were developed and tested separately. Their successful implementation into a complete system followed.

At the moment, the various effects that different faults (e.g. shade, IGBT open circuit, etc.) have on the system are being studied. The AC variables (V, I, P, Q) are being monitored in order to determine which faults can be detected from the AC side and which from the DC side. The symptoms of the grid are assigned to the corresponding faults, thus creating the fault signature.

The following steps include: a) further analysis of how different faults affect the plant, b) extension of the fault signature table with more symptoms and faults, and c) development of a fault detection and isolation algorithm for the PV test case. After this process is completed, the test case of wind farms will be examined.

2.3 IRP 4.3 – Advanced Monitoring and Controls of the Electrical Distribution Grid

In distribution networks, only a very limited number of measurements are available and installing the required quantity of sensors to make the system fully observable would be economically prohibitive. However, to include distributed generation such as solar panels or electrical vehicles and to implement demand response programs, it is required to monitor the network to determine the needs at every moment.

For that purpose, a Distribution System State Estimator (DSSE) that considers the few measurements deployed and the previous knowledge and assumptions about the network structure and loads, to determine an accurate estimation of the network state has been developed. This method can include all sorts of measurements: voltage, current, load, synchronous or asynchronous. Additionally, it is computationally highly efficient, which allows for fast computations every few seconds and, thus, monitoring the network continuously. It could be therefore used for a continuous security analysis and for control purposes such as curtailing generations, voltage control, connecting and disconnecting loads, etc.

At the same time, different approximation algorithms for the optimal placement of new measurements together with guarantees of their accuracy have been developed. This problem is intractable for large networks, since all combinations of sensors need to be tested in order to determine the optimal placement. However, with our methodology, it is possible to decide where to allocate the measurements to maximize the information gained about the network and minimize the uncertainty caused by fast-changing loads.

Both methodologies have been tested on standard distribution feeders provided by the IEEE Power & Energy Systems Society. First, it has been shown that the method developed for State Estimation performs as well as standard methods but significantly reduces the computation time, thus enabling its use for real-time monitoring of these networks. Secondly, it has been observed that the algorithms developed for optimal measurements placement are approximately as good as the possible optimal solution, while having a reasonable computing time.

In next steps or IRP4.3, the operation and control of these networks using the State Estimator, taking into account its uncertainty, will be considered. This estimation will be used to control the integration of renewable energies, the level of the tap voltage change in the transformers, the charge and discharge of batteries along the networks, etc.

2.4 IRP 4.4 – Advanced functionalities for the future smart secondary substation

The increasing integration of Renewable Energy Resources (RES) as well as several Distributed Energy Resources (DER) pose several challenges on the planning and operation of the networks. The conventional electricity sector presently transits to a major shift in its design; thus, planning and operation of distribution networks are foreseen to follow novel trends beyond the so far centralized and "fit-and-forget" approach.

The main goal of this research project is to develop control and management functionalities which will take advantage of the DER, such as Battery Storage Systems, controllable loads and Electric Vehicles, to optimize the operation of Low Voltage (LV) networks. Since a Distribution Transformer Controller (DTC) is envisaged to be placed at the Secondary Substation, these control functionalities will be accommodated within a top-level centralized architecture. The proposed control algorithms will manage the flexibilities of the integrated DER along the grid; thus, any technical challenges provoked by them, will be efficiently mitigated.

The overall control strategy will be organized in a multi-temporal scheme that follows a preventive and predictive nature, in the sense that any technical problem might be anticipated and resolved, allocating properly the DER resources. In the day-ahead scale, the available flexibility services will be communicated to the DTC, where the underdeveloped optimization problem will aim at scheduling (i.e. sequence and allocation) the coordination of these flexible assets, in such way that the LV operation is optimized from a technical and economic viewpoint. Therefore, the scheme relies on short-term demand and renewable generation forecasting, so as to define the control actions (i.e. set-points for the operating mode of DER) for the following day. Besides, the contingency of uncertainties of forecast net-load demand is meant to be addressed with corrective control actions closer to the time of the delivery.

The first year covered an extended literature exploration on control strategies related to different types of DER -controllable loads, Electric Vehicle and Battery Storage System-, integrated in the LV network so as to accomplish techno-economic objectives. The impact of extended DER integration was studied and simulated by using simulation tools as OpenDSS and Simulink. Additionally, the DER and LV grids were integrated in OpenDSS (which was selected to be the simulation tool for the developments). A unified simulation framework in MATLAB-OpenDSS together with a graphic user interface was created in order to ease the process of any ongoing simulations.

Improvements are made in the models of the DER components that are being used within MATLAB and OpenDSS framework. Concurrently, probabilistic analysis is being held so as to assess the potential flexibility capacity for different levels of DER penetration, at the level of the LV grid.

Following this analysis, the focal point will be the formulation of the day-ahead optimization scheme, which will be responsible to allocate the DER flexibility resources. Inputs for this tool will be, initially, the flexibility (in the sense of availability) curve-profiles by the end-users as well as the operating constraints for the DER units. In the frame of formulating the day-ahead operation tool, it is meant to further explore the methodology of optimization technique, depending on the technical details such as time resolution (e.g. intervals of subdividing the day-ahead optimization), as well as the feasibility of setting different techno-economic objectives for the LV network operation. In the 1st mobility-secondment, the proposed scheme will be verified and tested using the test bed of IREC microgrid and emulators.

Further and future steps will include corrective control actions, which will lead to prevent any deterioration on the grid operation in favour of uncertainties of forecasted analytics, as well as the coordination of the DER units with an OLTC asset. The overall goal will be to assess the impact of introducing that level of control at the Secondary Substation, in the operation of the LV grid.

3. INTERNAL AND EXTERNAL COLLABORATIONS

To develop internal collaborations, two conference calls were held on the 4th of April 2017 and 6th of June 2017. The main objective was to define some possible common test cases that could be shared among the researchers inside WP4. Two short lists were drawn up. A first one about the PV and wind turbine models that could be used to perform detailed simulation of distribution networks with embedded renewable energy sources. The second list compiles some test cases that could be used to carry out studies on MV or LV, radial or meshed, American or European distribution electrical networks.

The choice of the common reference architecture and use case has not been finalized yet. It should be done in the upcoming year to provide a comprehensive demonstration of the tools and methods developed in WP4 by all the partners.

To strengthen the collaborations inside WP4, some mobility periods are being planned for the PhD fellows. The first secondment should start in April 2018.

4. DISSEMINATION OF RESULTS: PUBLICATIONS & CONFERENCES

K. Kotsalos, N. Silva and H. Leite, “Advanced functionalities for the future Smart Secondary Substation,” *Book of Abstracts of the 2nd Symposium on Electrical and Computers Engineering*, 2017, 1-3, ISBN 978-972-752-222-4, URL https://paginas.fe.up.pt/~dce17/wp-content/uploads/2017/01/BoAECE.pdf