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Integrated Simulation Environment for Analysing Smartening Scenarios of Distribution Grids

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ABSTRACT

Due to the proliferation of the distributed energy resources (DERs) including renewable and non-renewable types, (re-)thinking on the way of planning and operation in electricity systems necessitated. Therefore, to decide on the best strategies for future growth in this evolution and to be able to host new DERs and to smarten operation and planning strategies a simulation environment is an essential tool. This paper presents the main characteristics of an integrated simulation environment (ISE) that can provide a multi-level analysis of the distribution level for scenario-based analysis of different distribution networks to support the smartening goals. It can help the decision-makers to decide on the best possible planning and operation strategies and in parallel help them to analyse future development scenarios. Indeed, the ISE can be applied in the design, optimization and re-adaptation of the energy networks using grid models of different smart grid pilots and different systems for various kind of studies to improve the energy potential and optimize the distribution and storage of the network at all levels.

1. Introduction

Due to the changing industry landscape, utilities all around the world are currently (re-) thinking the way of planning and operation to decide on the best strategies for future growth and to be able to host new distributed energy resources (DERs) and smartening strategies. So, they need to enhance their operations and planning and should become proactive enablers of integrating the new technologies.

Designing an integrated simulation environment (ISE) as a platform and decision tool for analysing different scenarios and implementing different protocols forms the basis for this paper. The ISE is a necessary tool for providing a multi-level analysis on the distribution level for scenario-based analysis of different networks to support the smartening goals [INT20-2]. It can help the decision-makers to decide on the best possible planning and operation strategies and in parallel help them to analyse future development scenarios. The ISE is able to be used to analyse both short-term and long-term effects of smartening scenarios in the distribution grids, using the forecasting tools along with the experimentally tested and validated models, behaviour profiling as well as data from the characterization of responses from the grid.

2. The ISE Concept

The conceptual design of the integrated simulation environment is illustrated in **Figure 1**. As it can be seen, there is a power system simulation tool as a core tool (here, it can be the integration test environment (ITE) of the Newcastle

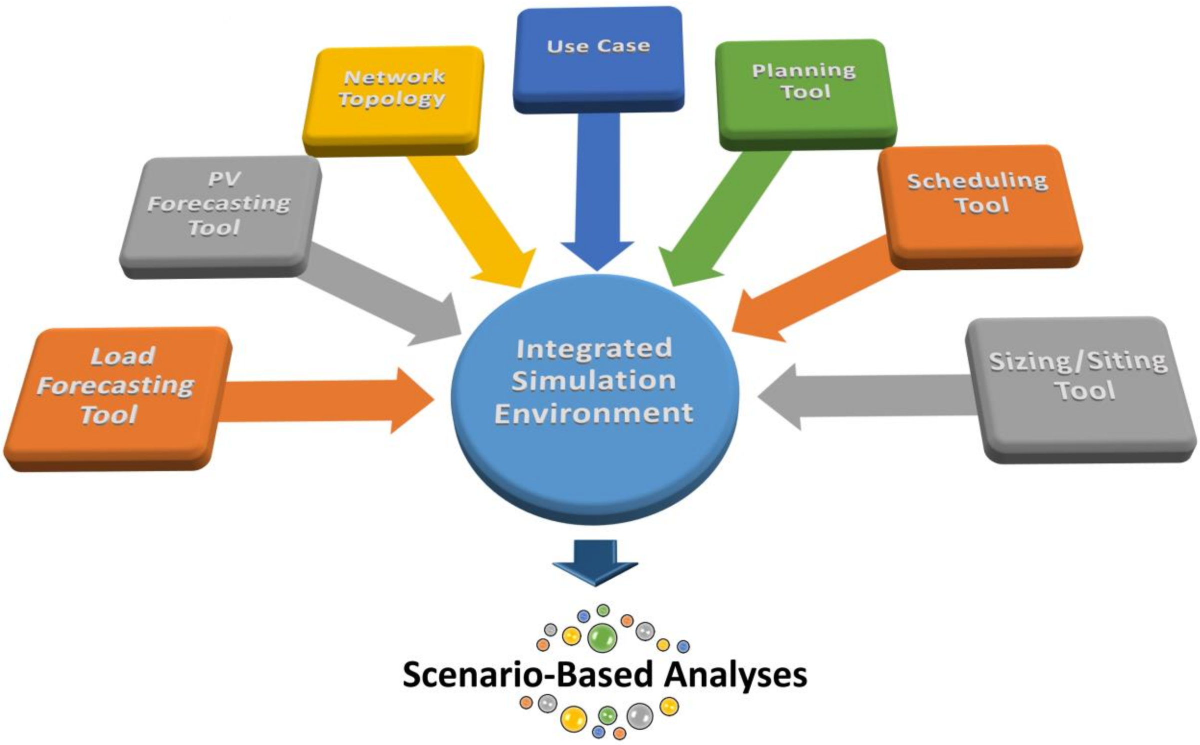

Figure 1. Conceptual Design of an Integrated Simulation Environment

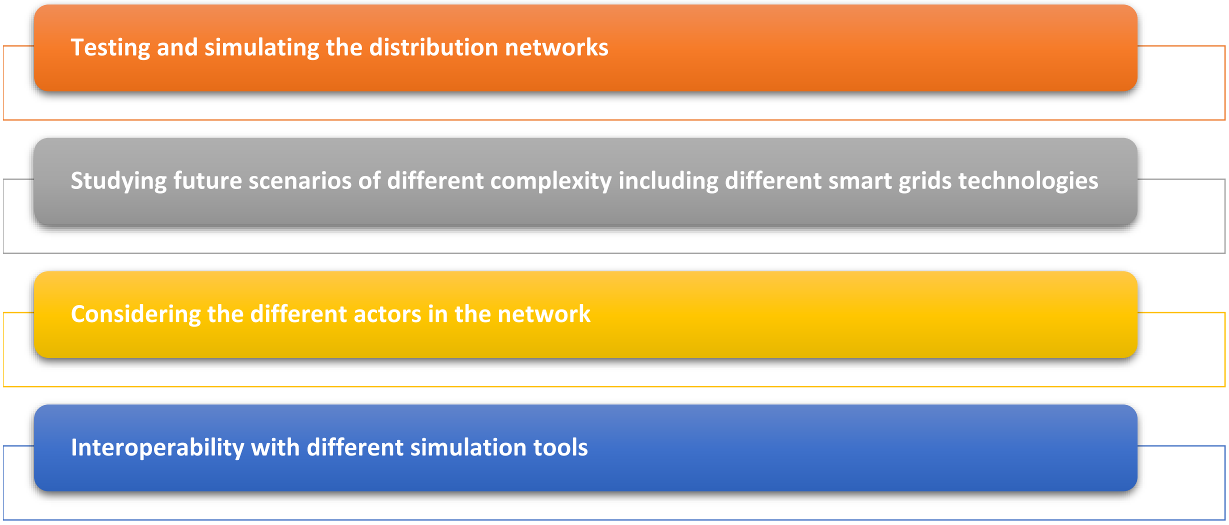

Figure 2. The main aims of the Integrated Simulation Environment development

University [JIA20-2] or in the simplest form the MATPOWER [MAT19]) that integrates different simulation tools according to the designed scenarios.

The integration of intermittent DERs including demand side responses (DSRs) energy storage systems (ESSs), renewable energy resources (RESs), and energy management is a challenge that calls for smarter modelling and simulation analysis of the electrical networks.

The ISE is a solution to provide an interface among the model of the grid in a power systems simulation tool and different modelling, forecasting, planning and operation tools. The ISE is able to model different types of power grids in steady-state and perform the control and optimisation tasks using different algorithms. The main aims for the development of an ISE are depicted in **Figure 2**.

3. The ISE Design

The ISE is able to be applied in the design, optimization and re-adaptation of the energy networks using grid models of different pilots and different systems for various kind of studies to improve the energy potential and optimize the distribution and storage of the network at all levels. Here, it includes three analytical layers as revealed in **Figure 3**, and these layers are described in the following.

3.1. Data Layer

The accuracy of every study depends not only on the efficiency of the employed model and algorithms but also on both the quality and quantity of available data. For simulation purposes, according to the cases, a variant range of data is needed. Fortunately, with the deployment of the smart grid, an avalanche of metered data

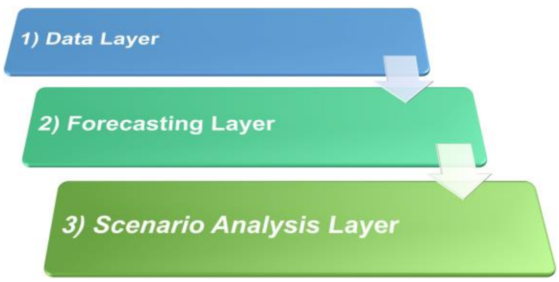

Figure 3. Analytical Layer of the Simulation Environment

has become accessible that would be able to introduce a fresh perspective on the analysis of the systems. In the inteGRIDy pilots [INT17-1], we have extensive use of AMI and metering infrastructure that play a vital role in enriching simulation studies through the provision of a wide range of data.

3.2. Forecasting Layer

Forecasting is an essential and vital function in almost any industry. In the power and energy industry, forecasting enables the effective planning operation of the systems. It is the foundation for operation and planning studies, and it is a fundamental business problem in the industry. Particularly with the significant change in the energy resources basket and an increasing amount of renewable energy resources which brings unusual risks to the electric power industry, it is crucial to have accurate load and renewable generation forecasts for optimal operation and planning.

In the inteGRIDy project, there are various forecasting tools developed in different pilots [INT20-1] that can make a building block of the data-enriched analysis layer of the proposed simulation environment. The forecasting tools can be used to predict short-term, mid-term, and long-term time series of load and PV generation and other influential data.

In the forecasting layer, we would be able to use different available tools to forecast the profile of load, PV, etc. to have the first step to analyse future scenarios.

3.3. Scenario Analysis Layer

The objective of this layer includes the determination of the siting of new distribution generations, taking into account the flow limits of the distribution lines, voltage constraints, and meeting the required demands in different parts of the network.

In this layer, a power system simulation environment such as ITE [JIA20-2] or MATPOWER [MAT19] are able to act as the core tool. Other developed simulation tools in the inteGRIDy project, including Integrated Decision Support & Supervisory EMS (IDS&SEMS) and Supervisory Model Predictive Control for Energy Systems (SMPC) [INT20-1], can integrate with the core tool and can be used to perform a specific study or analyse an alternative scenario.

4. The ISE Capabilities

Alternatives simulation scenarios that can be examined by decision-makers using the ISE include, but are not limited to, the followings:

- Analysis of the impacts of adding new distributed generating capacity (different non-renewable DGs, renewable generations, customer-owned generations) in different locations of the IoW (i.e. electric busbars at 11kV and 33kV level) on the technical parameters of the network (voltage, line flows and power losses);
- Analysis of the impacts of the change of the loads in different locations of the IoW (i.e. electric busbars at 11kV and 33kV level) on the technical parameters of the network (voltage, line flows and power losses);
- Analysis of technical parameters due to the change in distribution topology (but limited) by adding new distribution lines or switches;

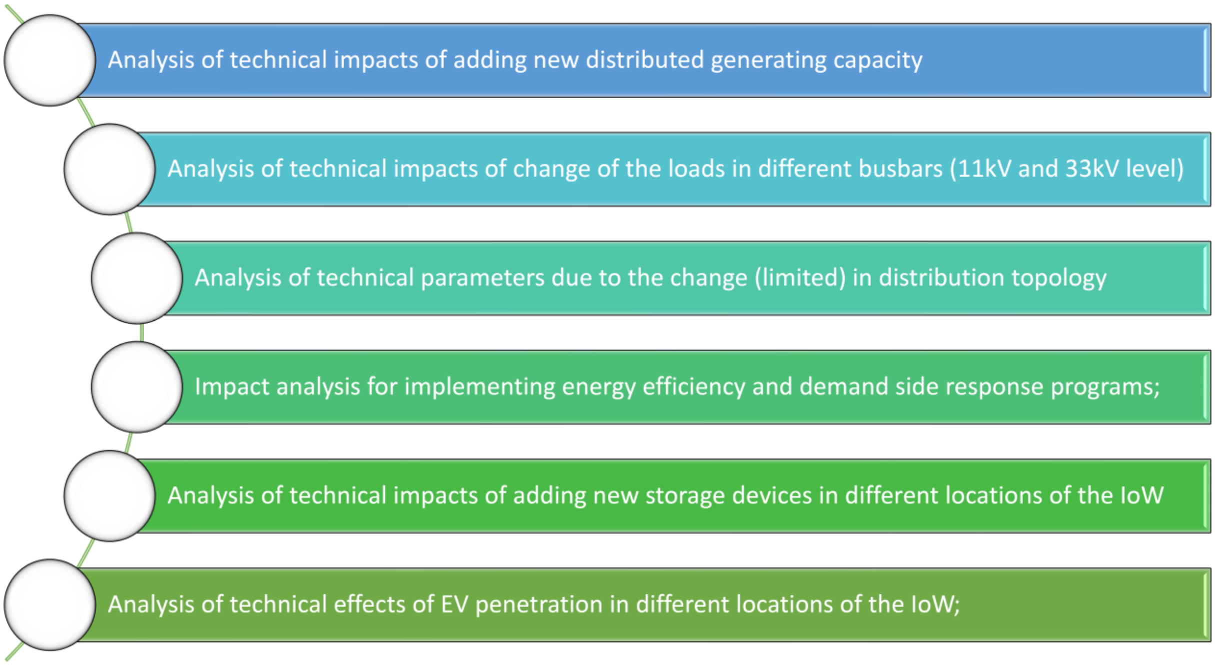

Figure 4. Different possible studies using the proposed simulation environment

- Impact analysis for implementing energy efficiency and DSR programs;
- Analysis of the impacts of adding new electricity storage devices in different locations of the IoW (i.e. electric busbars) (at 11kV and 33kV level) on the technical parameters of the network (voltage, line flows and power losses);
- Analysis of the effects of EV penetration in different locations of the IoW (i.e. electric busbars at 11kV and 33kV level) on the technical parameters of the network (voltage, line flows and power losses);
- Analysis of the effects of DSR programs in different locations of the IoW (i.e. electric busbars at 11kV and 33kV level) on the technical parameters of the network (voltage, line flows and power losses).

A summary of the aforementioned possible studies using the ISE is illustrated in **Figure 4**.

5. Scenario Assessment

Three main steps needed to perform a scenario assessment using an ISE which are depicted in **Figure 5** and explained in the following:

- Data gathering and system identification;
- Forecasting the future values of loads, PV generations, and so forth;
- Identification of the model of the system to study alternative scenarios (e.g. potential energy resources for meeting the future loads considering the predicted future generation potentials of PVs) [IPS20], [JIA20], [VAH19];
- Executing the simulation tools for analysing alternative scenarios;
- Creation and implementation of the future operational plans.

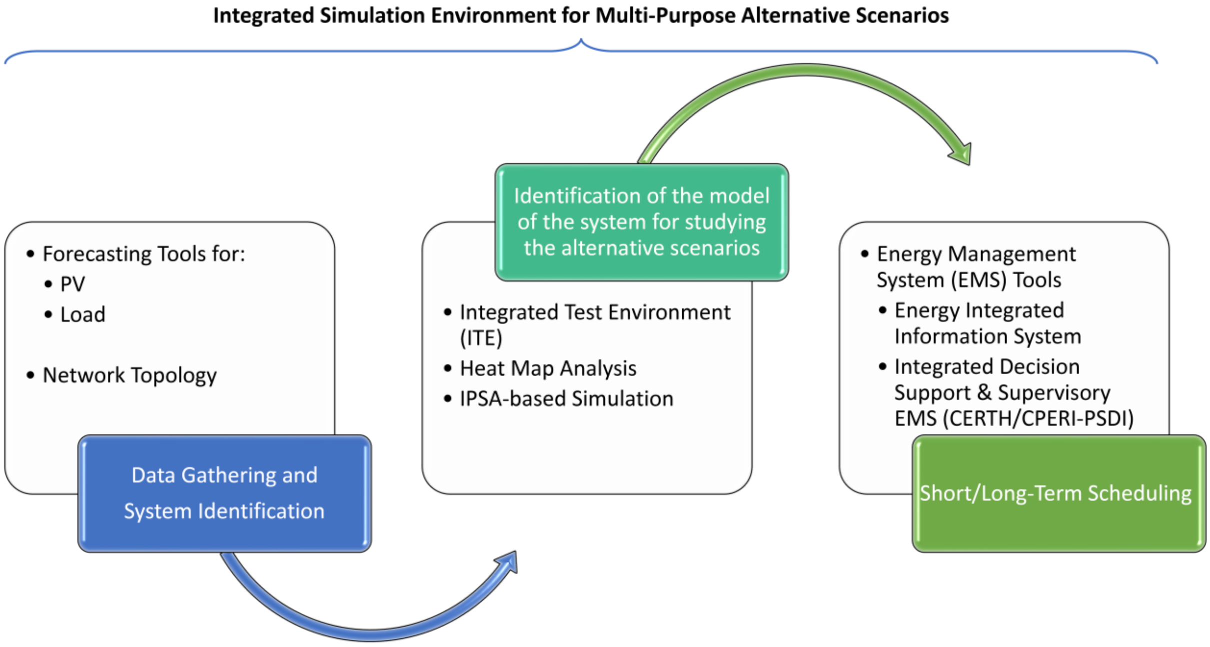

Figure 5. The main steps need to be taken in the creation of a scenario analysis

6. Conclusions

The ISE provides a comprehensive simulation environment for scenario-based analysis of different pilot distribution networks to support the smartening goals. It is based on a set of the state-of-the-art tools provided in different inteGRIDy pilot areas and can be applied as a useful means for analysing various scenarios in any distribution systems. It can help the decision-makers to decide on the best possible planning and operation strategies and in parallel help them to analyse future development scenarios. Indeed, the presented ISE can be applied in the design, optimization and re-adaptation of the energy networks using grid models of different pilots and different systems for various kind of studies to improve the energy potential and optimize the distribution and storage of the network at all levels. A demonstrator based on the ISE for the Isle of Wight [INT20-2], as one of the large pilots in the inteGRIDy project, showed the potential of the ISE for analysing a wide range of scenarios.

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About Newcastle University

Newcastle University is among the top 20 higher education institutions in the UK in terms of research power, according to the influential professional publication, Research Fortnight. The group of Electrical Power at Newcastle University is also one of the strongest research groups in the UK and it covers all areas of electrical power, ranging from power systems to electrical drives/machines and power electronics. More specifically in the area of electrical power, the group is considered to be one of the world's leading research teams with international collaboration, large research funding from EU/UK, multiple esteemed publications and a very strong collaboration with industry. The infrastructure regarding power systems has been recently further strengthened with 2 newly built research facilities (The Smart Grid Lab and Energy Storage Test Bed) funded with £2m from the Engineering and Physical Sciences Research Council (EPSRC), Newcastle University and industrial partners Northern Powergrid and Siemens. These key facilities part of Newcastle's £200 million flagship project Science Central bring together academia, the public sector, communities, business and industry to create a global centre for urban innovation and sustainability.

Information about the authors

Dr Vahid Vahidinasab is a senior researcher in the School of Engineering at Newcastle University. His research interests are threefold: (1) Integrated Energy Systems Operation and Planning; (2) Energy Markets and Transactive Energy, (3) Energy Systems Integration. Before joining Newcastle University, he has been a faculty member in the Department of Electrical Engineering, Shahid Beheshti University for 10 years. With 140+ technical reports and publications in top rank journals and conferences and 1000+ citations (h-index=17, i10-index=25), he is a research scientist with more than 15 years of experience and has worked with international researchers on various interdisciplinary problems in power and energy systems, economics, operation research, and control theory. He is the recipient of several International, National, and Institutional Prizes. He is a Senior Member of the IEEE and a Member of Editorial Board and Associate Editor of the IET Generation, Transmission & Distribution as well as the IET Smart Grid.

Dr Damian Giaouris has received his PhD & MSc in the area of Control of Electrical Systems from Newcastle University (UK), Postgraduate Certificate & BSc in Mathematics from Open University (UK), and BEng in Automation Engineering from Technological Educational Institute of Thessaloniki (Greece). He was a Lecturer in Control Systems at Newcastle University since 2004, before moving to the Centre for Research and Technology Hellas (Greece) in 2011. He is a Reader in Control of Energy Systems at Newcastle University. His research interests include power systems, smart grids, electric vehicles, and nonlinear dynamics of electrical systems. He has more than 110 publications (with more than 2700 citations). He was an associate editor of IET Power Electronics, and he has been a Guest Associate Editor of IEEE Journal on Emerging and Selected Topics in Circuits and Systems. He has been involved with many research projects (EU or EPSRC) and currently, he works in one of the leading UK Universities in the area of Energy Systems.

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