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Diagnostics and Long Term Prognostics for Investment Decision Support in Smart Grids

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Abstract: Proliferation of distributed renewable generation and other low carbon technologies create new challenges for the electricity distribution networks. In particular, distribution network operators are increasingly exploring alternatives to conventional reinforcement in order to reduce network operation costs, increase security of supply and allow more renewable generation to be connected to the network. Selecting the most optimal combinations of interventions in regards to long-term cost and performance of the network is something that the current tools and approaches used by the industry cannot adequately do.

This paper describes a novel techno-economic planning and investment modelling tool for electricity distribution networks termed as Scenario Investment Model (SIM). The SIM is able to find optimal network evolution scenarios in the presence of changing demand conditions by applying multiple electricity and storage technologies to resolve network issues.

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1. INTRODUCTION

Sustainable energy production is a topic of overwhelming importance for the European Union and its member states. The EU produces only half of the energy it consumes Eurostat (2015). Sustainable energy production from renewable sources not only will increase energy security, but also deliver the 80-95% reductions of greenhouse gas emissions expected by the Energy Roadmap 2050 European Commission (2011). To meet such ambitious targets, the networks is going to change significantly by 2050. Increased adoption of heat pumps, electric vehicles, deployment of renewable solar and wind generation and CHP will place new demands on the distribution network. To cope with these demands and achieve cost reduction in comparison with conventional network reinforcement, the grid needs to adopt advanced electricity networks and storage (EN&S) technologies. In fact, some of the low carbon technologies, e.g., wind and solar generation are critically dependant on EN&S technologies to leverage their full potential Low Carbon Innovation Coordination Group (2012).

At the moment, the innovation in EN&S technologies is riddled with uncertainty regarding which technologies to choose, which investment to support and how the choices would evolve in the long term Moselle, Padilla and Schmalensee (2010). With many alternatives to conventional network reinforcement available and being developed, e.g., distributed generation, various forms of energy storage Kondoh et al. (2000), demand response Poudineh and Jamasb (2014), mesh networks Behnke, Erdman, W. and Horgan, S. (2005), dynamic asset rating Yang et al. (2015), etc., it becomes difficult for the distribution network operators (DNOs), regulators and policy makers to find an optimal network investment roadmap, pick the right mix of EN&S technologies to create local network development plans and forecasts the costs of optimal electricity distribution.

There are a number of previous notable projects that address the uncertainty around integration of low carbon and EN&S technologies into the distribution grid. The Smart Distribution Network Operation for Maximising the Integration of Renewable Generation (SuSTAINABLE) performs optimisation of network operation modes and reinforcement planning in the presence of renewable generation SuSTAINABLE (2015). Smart Grid Forum Work Stream 3, which later become EA Technology Transform model EA Technology (2016), is a parametric representation of the electricity distribution network that is aimed to create long-term strategic investment plans. It is important to note that there are certain limitations in Transform that are characteristic to all parametric models, in that the operating characteristics of devices and their relationship to other technologies require extensive calibration to produce a qualified answer. To some extent the limitations of Transform were addressed by Smart Grid Forum Work Stream 7 Smart Grid Forum (2015), which took four of Transform's parametric representations of typical distribution networks and converted them into nodal network models in order to understand how the Transform solutions function. Other examples include ETI EnergyPath model, which is targeted at local energy systems ETI (2016), and Comillas

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University Reference Network Model (RNM) Gómez et al. (2013), which is a large scale distribution network planning tools that can create optimal networks. The RNM can be used by regulators and policy makers to estimate network development and operation costs.

Despite the differences in their respective approaches, the aforementioned models and software tools share some common limitations. They have limited ability to capture emerging behaviour arising from simultaneous application of multiple EN&S technologies to the electricity distribution network. Likewise, it is difficult to add new EN&S technologies into the mix, either due to lack of automatic application of smart techniques or, as is the case with Transform, the parametric approach needs information about the way different technologies compete with each other, which is difficult to obtain. And finally, no decision support for a particular piece of distribution network can be provided either because of lack of automation or the parametric nature of the model. The following sections introduce and describe a novel techno-economic modelling tool for the distribution network that performs dynamic network modelling and analysis in the presence of multiple EN&S technologies. It uses nodal network modelling to capture the emerging behaviour and create localised network development plans.

2. SCENARIO INVESTMENT MODEL

The Scenario Investment Model (SIM), which is a major deliverable of Low Carbon Network Fund Tier 2 FALCON project and the subject of this paper, was conceived as a new generation network planning tool to address the uncertainty around integration of low carbon and EN&S technologies into the distribution grid. Like the conventional network modelling tools, e.g., PSS SINCAL Siemens (2016) or IPSA Tnei (2016), the SIM uses nodal network models of actual networks. The nodal network model works in tandem with a state-of-the-art load prediction engine, which can produce substation load profiles showing annual changes in demand and distributed generation that comprise daily load curves for a number of characteristic days in a year. Pluggable models of novel EN&S technologies along with models of various modes of conventional reinforcement allow the SIM to perform automatic resolution of network issues and consequently create dynamic network evolution and investment plans.

The SIM initially supports six different EN&S technologies (dynamic cable and transformer rating, automatic load transfer, battery storage, mesh, distributed generation and demand side management) alongside six types of conventional reinforcement (transformer, cable, busbar and overhead line upgrade and replacement, creating new feeder, transferring load to adjacent feeder).

2.1 SIM Use Cases

Referring to Fig. 1, the SIM includes use cases for three primary actors, namely, strategic planner, local planner and policy user. The local planner has three primary uses of the system, to plan asset replacement or diversion, connect new load or new local generation or to explore the dynamic network model. The strategic planner has just a single use of the software to prepare a long term investment plan for a larger segment of the network. Meanwhile, the policy user has access to the same use cases as both planners, but for a different purpose to produce rules of thumb for planning manuals. All user-oriented use cases map to three system use cases that allow to a) set up experiment, run simulation and save results to results store, b) browse and compare individual results and c) browse and compare aggregated results.

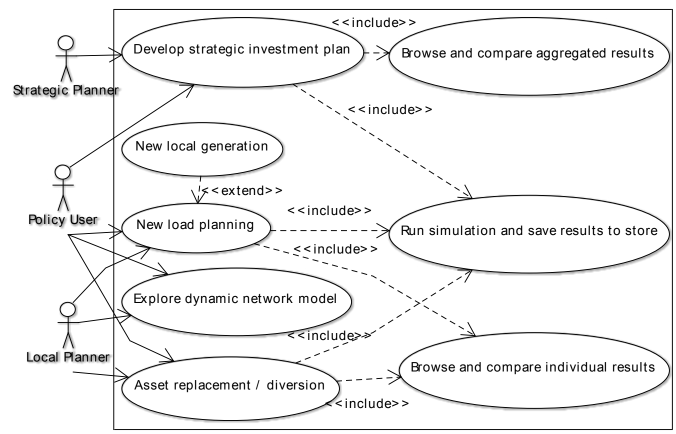

Fig. 1. SIM use cases.

2.2 SIM Architecture

To support the use cases, the system implements a multitier architecture with separate presentation, application processing and data management layers. Referring to Fig. 2, the SIM consists of 12 main component subsystems, among which components 1-4 are responsible for storage and management of load scenarios, network patches, which represent planned changes to the network, network model and costing models respectively. The experiment planner allows to set up an experiment by selecting an area of the network, demand scenario, cost model and other run parameters such as start and end years of the evaluation period. Components 6 and 7 perform the actual experiment processing by performing heuristic expansion of the initial network state. The experiment runner is an optimisation framework around a network modelling tool, which is a commercial off the shelf software that performs power flow and reliability studies. The network modelling tool also applies intervention technique models to resolve network issues, while the optimal combinations of techniques are selected by the experiment runner. Once the network development plans that keep the network compliant throughout the evaluation period are found, they are saved to the results store. The user can browse results either as individual solutions or aggregations using the result browser and view them using the result visualisation or result set visualisation tools, respectively. The result visualisation tool relies on the network model visualisation tool to render the dynamic network diagram either in single line or geographic layout.

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