A PSEUDO-REAL TIME DISTRIBUTION NETWORK SIMULATOR FOR ANALYSIS OF COORDINATED ANM CONTROL STRATEGIES

James ROBERTSON
University of Edinburgh – UK
J.Robertson@ed.ac.uk

Gareth P. HARRISON
University of Edinburgh – UK
Gareth.Harrison@ed.ac.uk

A. Robin WALLACE
University of Edinburgh - UK
Robin.Wallace@ed.ac.uk

ABSTRACT

This paper describes a pseudo-real time distribution network simulator developed to investigate the use of real time distribution system control presets to better integrate high levels of distributed energy resources into active distribution networks. A combination of historical and modelled generation profiles, along with varying demand patterns, are used to demonstrate the real time application and improved system response from active network management control strategies.

INTRODUCTION

The integration of significant levels of renewable and distributed generation (DG) into existing electricity networks would, without evolution of existing planning and operating philosophies, stretch the capabilities of the current network system beyond its limits of operation and constrain the volume and benefit of DG that can connect. Existing research has investigated new ways to plan, operate and control distribution networks. Common characteristics often feature autonomous or Active Network Management (ANM), micro and macro network optimisation, and advanced metering infrastructures (AMI). Studies have shown that expensive network upgrades and refurbishments can be deferred or avoided if promising ANM strategies are implemented. However such schemes have seen slow uptake due to a lack of pre-validation and demonstration. Distribution Network Operators (DNOs) have been reluctant to accept new operating and control philosophies on their networks because of the limited real time visibility of distribution network state and switching actions. Similarly investments in Advanced Metering Infrastructures (AMI) for distribution networks that will underpin the new control capabilities has been limited due to the uncertain benefits relative to high costs.
This work reports initial research investigating a method for DNOs to test and quantify improved network operation with the potential to continually optimise yield, asset and system response of distribution networks. The work suggests and demonstrates an ability to assess the pseudo-real time implications and predict system consequences of varying power flow with active control strategies. The ability to maximise connectable capacity, minimise voltage excursion, manage asset loading and minimise tap changes against varying levels of data collection and network visibility will ultimately aid the deployment of ANM and increase the network integration of DG.

SIMULATION ARCHITECTURE

The core of the work is the development of a suite of interconnected model elements to simulate 'real time' network operation and its interaction with network controls operating autonomously or via commands from one or more distribution management systems (DMS). While these model elements are in software form, the intention is that they would be interchangeable with hardware-in-the-loop or the real network.
The two interfaced elements are: (i) a distribution management element within which a range of management approaches can be articulated and (ii) a distribution network simulator that translates commands within specific infrastructure. Both will be fed by detailed information on load and production. Figure 1 illustrates the simulator architecture.

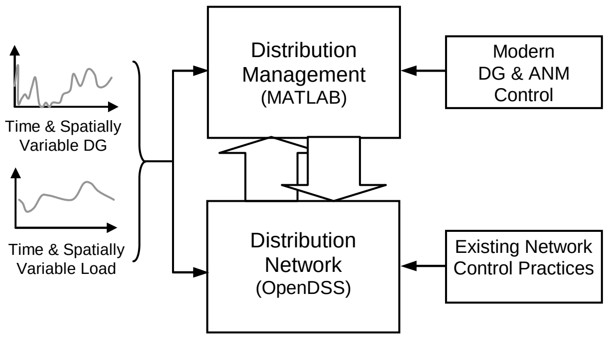

Figure 1: Distribution Network Simulator system model

Some of the key functionalities of the full simulation environment include:

- Flexibility over distribution network cases to implement active DG and network control.
- Flexibility of the DMS to accept new means of supervisory control decision engines.
- Ability of the DMS to mask, or neglect information on current network state to any means of supervisory control decision engines, replicating a loss of communication from AMIs.
- Ability to supply erroneous (forecast) data to the supervisory control decision engine and view the implications from the discrepant and actual data.
- Ability to view and analyse interactions and conflicts between the existing network autonomous control functionality and retrospective ANM techniques.
- The ability to perform and investigate, like for like, reactive and proactive ANM control techniques.

IMPLEMENTATION

The key components first developed are briefly discussed. In order to fully investigate the requirements and benefits of real time active control techniques, it was necessary to develop a means of performing flexible time-sequential power flow simulations that can effectively handle the added functionality of ANM techniques. Many commercial power flow packages proved insufficiently flexible to accommodate innovative control response in distributed generators whilst performing time-sequential simulations. The MATLAB environment is currently utilised as the Distribution Management element that hosts and implements the distribution network control philosophies. It links to and controls (via a COM interface) the proxy distribution network simulated in OpenDSS, an open source distribution systems tool for developed by EPRI [1]. This is used for time-sequential network power flow modelling of the network, distributed resources and to perform the high resolution switching of active distribution network control actions.

Distribution Network Simulator

In many areas existing network control infrastructure possesses the ability to run responsively to alterations of the network as well as receiving commands. Therefore the use of OpenDSS controlled and driven by MATLAB provides a viable platform to represent the application to a real life system. The separation of the simulator and command/control algorithms reflects a realistic evolution of the network by mapping modern, more intelligent control techniques onto the conventional passive sections of the network.
Distribution Network case studies have been built explicitly in the OpenDSS environment. Each specific case is composed of the physical network topology, including existing control functionality, and all associated demand and generation profiles. The segregated OpenDSS power flow solver is used solely to replicate the time dependent response of the network assets and resultant power flows. In this manner the OpenDSS block is envisaged as the *operating* distribution network.
This novel application of OpenDSS models key functionalities of both conventional responsive, but passively operated, distribution networks assets and intelligent active distributed control practices. This has created a bespoke distribution network simulator that can fully assess the introduction of both decentralised and centralised modern control practices in distribution networks.

Real Time Management

Real time analysis will evaluate network power flow constraints based on the current network conditions, through wide area measurement and state estimation, such that overall power and energy participation of DG developments can be maximised. The prime criterion for real time analysis is the determination of DG output levels and network control presets from prevailing network conditions and is not the speed of operation as is commonly perceived.
Ultimately one or more Optimal Power Flow (OPF) engines will deliver the real time scheduling of network set-points and the maximisation of connectable capacity and energy yield from distributed resources. As yet this component of the work is still under development but with existing commercial packages limited in their ability to support some of the innovative control requirements; it is likely that a bespoke solution will be necessary. To illustrate the operation of the environment as it stands analyses are presented that operate from a decentralised basis and from substituted OPF values.

Re-Active and Pro-Active control

Methods to increase DG headroom levels in distribution networks include a range of centralised architectures as well as more decentralised methods such as adaptive power factor control of DG [2]. Control methods also fall into either re-active or pro-active techniques, the latter invokes control setting alterations based on upcoming events, as opposed to responding to an event. Re-active control techniques would perform the same functionalities as conventional OLTC or adaptive power factor control. Implementation of pro-active control techniques in the distribution network simulator is achieved by issuing commands from the DMS based on pre-scripted time wise set points.

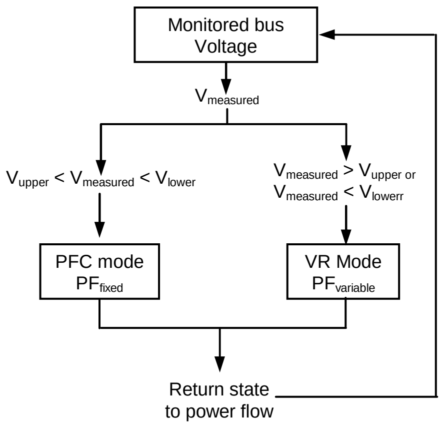

Figure 2: Functional diagram for hybrid power factor modification techniques [2]

An example of the simulation is provided based around decentralised control of DG power factor on a test case network. Figure 2 shows a functional diagram of the control technique described in [2]. In essence it applies the power factor control method to a DG plant at unity power factor until voltage rise or drop nears pre-specified limits. In a transition to voltage control, power factor is then modified to absorb or inject reactive power to restore voltage levels. In this simplified approximation, the power factor is altered incrementally in steps of ±0.01 in a power factor range of ±0.97. A dead band also exists between voltages to prevent hunting.

TEST CASE

To demonstrate the preliminary capabilities of the simulator a simple and convenient test case network is used. The network is a section of typical Irish 38kV distribution network utilised in previous work [3]. In the pre-DG network, voltage levels were regulated by the substation transformer at the head of the feeder. Voltage limits were taken to be +10/-6% of nominal with a target voltage of 1.078pu at the substation secondary, Bus Tx.

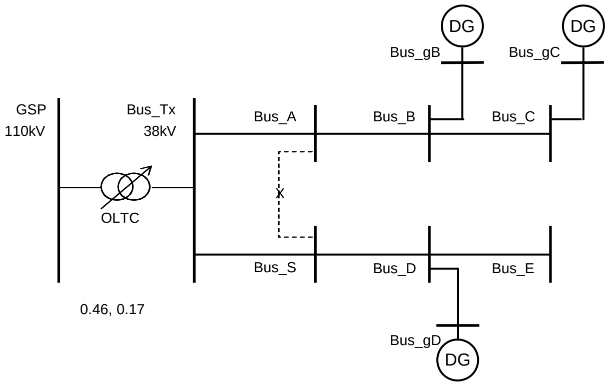

Figure 3: 110/38kV 5 bus Irish distribution network

Input data was sourced from a historic demand profile and modelled generated outputs from wind, wave and tidal resources. A section of high DG output and minimum demand was chosen to represent a worst case scenario.

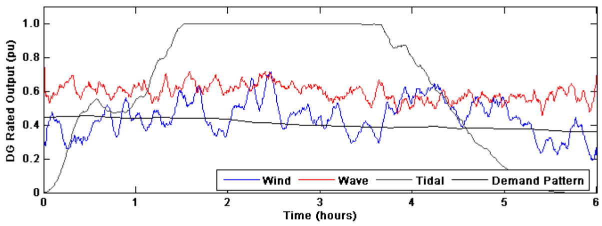

Figure 4: DG temporal variability generation profile and variable demand pattern

Simple Demonstration

An application of the re-active technique is demonstrated on a reduced section of the test case network comprising the lower feeder only, buses S, D and E, where peak demand is 4.7MW.

In the conventional un-managed assessment of DG, voltage rise tends to be the main constraint on DG capacity. For the worst case scenario of maximum generation/ minimum demand, analysis shows voltage rise to limit DG capacity to 4MW at Bus D. With the adaptive power factor control technique, headroom capacity can be raised but time sequential power flow simulations are required to fully determine the real time network response under variable DG and load patterns. The simple demonstration is of a tidal energy plant connected to Bus D ramping up while demand is held constant at the minimum value of 0.36pu. With time delays for existing network infrastructure in the region of 30-90secs, the simulator operates at 30sec intervals over a two hour period.

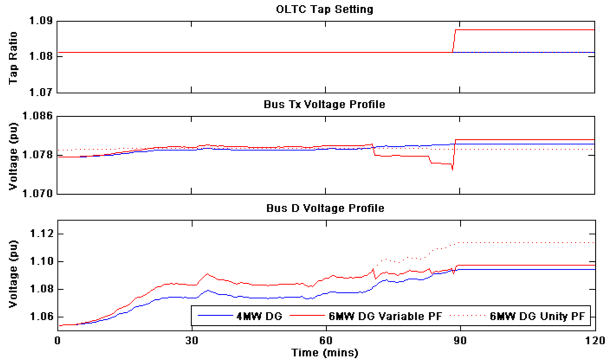

Figure 5: (Top, a) Substation OLTC Tap Setting; (middle, b) Substation regulatory voltage level; (bottom, c) DG location voltage level.

In theory the headroom can be increased using power factor control but there is scope for conflict with control targets at the existing OLTCs. Figure 5 demonstrates the interactions between the OLTC and the application of adaptive power factor control at the DG. The ability of the simulator to identify operational phenomena, like that shown in Figure 5, provides confidence in its potential to quantify real time control issues. The passive 4MW DG is modelled and shown alongside examples of a 6MW DG with fixed power factor and the adaptive control. OLTC tap ratio and voltages at the regulated bus (Tx) and DG location are shown. The voltage excursion with a 6MW DG plant with fixed power factor and the attenuated voltage level under adaptive control can be seen clearly in Figure 5(c). Figure 5(b) shows the effect that these have on the substation with the adaptive power factor control drawing additional reactive power sufficient enough to reduce the secondary voltage level and invoke correcting tap changes however, there is no evidence of 'racing'. The foregoing simple model validates the proposed approach to use real time OPF techniques to generate network set points in active management.

Full Test Case

These issues were further explored on the full network with wind, wave and tidal DG resources connected at Buses B, C and D respectively. Two techniques: (i) a fixed tap at the substation with all voltage regulation carried out by DG units; and (ii) operating the distribution network control settings in a pro-active manner were studied as a means of active network management.

The former represents the trivial solution but has the added advantage of being implementable without AMI infrastructures and could be considered as an interim or alternative solution. Reverting to a fixed tap position of 1.08125 on the LV side enhanced DG headroom capacity levels to 9MW wind, 6MW wave and 8MW tidal power for a limited power factor operating range of ±0.97. This

has a very limited effect on the pre-DG voltage regulation, and has enhanced the DG capacity by increasing the allowable level of adaptive DG power factor control.
The latter will require new levels of AMI and new system security measures but will be required to truly optimise network operation and maximise DG penetration levels. This second approach pro-actively conditions the OLTC and DG power factor set-points and allows for enhanced headroom capacity by exploiting the full extent of the voltage envelope. In the no DG case the network set-points can be scripted to replicate the pre-DG operation. Utilising active management of the network set points enhanced DG capacities of 17MW wind, 8MW wave and 19MW of tidal power are demonstrated as operational in Figure 6.
Improved network set points at each interval were determined based on generation and demand combinations using a robust multi-period OPF [4] originally developed to evaluate the hosting capacity of distribution networks with active network controls under variable demand and supply combinations. In this application the network control set points, namely the OLTC tap ratio and the DG power factor settings are determined from generation and demand scenario based analysis. Levels of demand and mean generation of type outputs, over 30 second intervals, were binned within 20% segments and combined to form a series of time interval scenarios depicting the time dependent power injections for the network. The OPF algorithm determines the 'optimal' control set points for each scenario. A look up table is used to translate these 'optimal' set points for each scenario into specific network settings for each time step ahead of time.
The results from the OPF are not used directly due to high levels of unnecessary network reconfiguration caused by differences in continuous and discrete tap changer ratios and discontinuity in the time series reformation from the scenario based optimisation. The results shown have gone through a smoothing process to reduce the effect of these issues. Optimum network set-points at independent time steps can also be modelled effectively in the simulator but have not been demonstrated here due to space restrictions. This arrangement can only be achieved in parallel with an AMI.

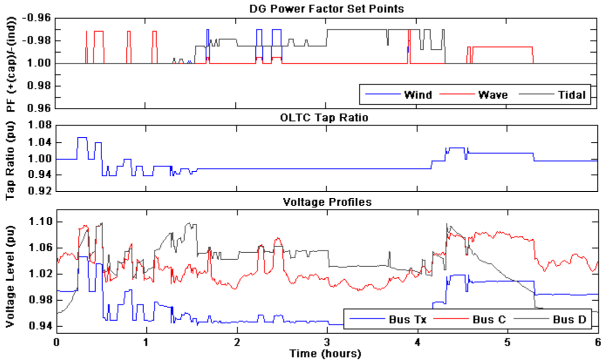

Figure 6: Improved pro-active network operation

DISCUSSION

Preliminary results demonstrate the suitability of OpenDSS to analyse and implement pseudo-real time more active means of network control. Firstly, reactive network operation was modelled through a variety of steady state network excursions where a means of fast-acting and more active network control have been initiated to restore systems settings. Extensive simulations have been performed to demonstrate the simulator's ability to perform proactive network control. In this test case, varying network set-points were pre-prescribed under multiple generator profiles and varying demand patterns to determine the simulator's suitability to model real-life distribution networks and more active means of network control. Early indications are that the pseudo-real time distribution system simulator is capable of successfully resolving time sequential power flow incorporating responsive network control. The results from these simulations provide a better understanding and a unique insight into the formulation of online OPF techniques

CONCLUSIONS

The environment created and subsequent analysis presented demonstrates the potential for coordinated and synergetic proactive network control strategies to improve and facilitate the evolution of distribution management practices. Simulations have shown that active control of DGs within a community shared network control scheme can improve the connectable capacity, system performance and energy yield from distributed resources.

ACKNOWLEDGEMENTS

This work is funded by the EPSRC UK-China Network of Clean Energy Research.

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