A TESTBED FOR THE ASSESSMENT OF ACTIVE NETWORK MANAGEMENT APPLICATIONS USING SIMULATION AND COMMUNICATIONS EMULATION

Craig BREADEN
University of Strathclyde – UK
craig.breaden@smartergridsolutions.com

Adam DYŚKO
University of Strathclyde – UK
a.dyso@strath.ac.uk

Graeme BURT
University of Strathclyde - UK
graeme.burt@strath.ac.uk

Euan DAVIDSON
Smarter Grid Solutions – UK
e.davidson@smartergridsolutions.com

Neil MCNEILL
Smarter Grid Solutions – UK
neil.mcneill@smartergridsolutions.com

ABSTRACT

Active Network Management (ANM) has emerged in recent years as a solution to removing a number of the barriers to connection for Distributed Generation (DG). Understanding the performance of a control system prior to deployment is essential for developers and operators as they decide how to strategically invest in a long-term solution to facilitate a DG connection on areas of the network not initially designed for it. To help make the transition between a trial product and one which network operators will use in a business as usual scenario, simulation-based testing is proposed as a method of assessing the merits of ANM. Thus it is the aim of this paper to present a flexible testbed for ANM solutions which makes use of commercially available power systems modelling software in a real-time environment. This gives utilities a representation of the dynamic effects of using ANM on their network and an opportunity to visualise the end-to-end implementation of the solution prior to its use on live networks.

INTRODUCTION

In recent years there has been growth in renewable energy generation in the UK as efforts are made to de-carbonise the economy. Distributed generation (DG) has however brought with it an array of issues. DG is typically located on areas of the network not previously designed to support bi-directional power flows and with limited transfer capacity. Thus network operators require novel solutions to alleviate problems caused by voltage rise, voltage step and power flow constraints. As the cost of network reinforcements is passed to the developer, connection offers on constrained areas of the network can be uneconomical. Actively managing the network has been proposed as a solution to better facilitate DG connections to the network.

The adoption of alternative solutions by customers in a business as usual scenario depends on addressing a number of technical and commercial requirements. Primarily evidence should be shown to demonstrate network behaviour is not adversely affected. The introduction of a control scheme to the network must not adversely affect quality and reliability of supply or an increase in customer minutes lost. Furthermore wide area control schemes such as ANM typically make use of modern communications infrastructure which, if incorrectly specified, is often considered a high risk topic to projects. Control systems must display graceful degradation in the result of communications deterioration.

To address these outlined requirements, Active Network Management (ANM) has been proposed and trialled in recent years. ANM covers a number of control techniques as described in [1]:

- Power Flow Management;
- Voltage Management;
- Automatic Restoration
- System Balancing and;
- Increased Visibility of Network Conditions

Power flow management, as implemented by Smarter Grid Solutions, monitors real time conditions of the network to control generation in a deterministic manner allowing latent capacity on the network to be fully utilised, and therefore, deferring or avoiding the necessity for line upgrades. Voltage management techniques have similar characteristics in that they actively issue set points to controllable devices in a predetermined manner to actively control voltage issues. Well-designed simulations and demonstrations can instil confidence in systems operators before its deployment. Utilities and generators will need to balance the cost of implementing an ANM solution and its associated expenditure against the performance benefits of said scheme. In addition to simulating the power network, communications emulation can add a further element of realism to a simulation based testbed.

Ultimately, the direction of smart grid developments will be driven by DNOs who require evidence on the suitability of ANM on their network. To give DNOs confidence in the use of ANM on their networks, simulation based testing is proposed. Demonstrating the use of control schemes in a realistically simulated environment can go a long way to assuring a DNO on the use of ANM, whilst giving a visual representation of the scheme. Simulation can provide a dynamic and interactive platform to evaluate the merits of varying levels of control prior to implementing a costly solution on a live network. DNOs historically have experience in real time simulation to test fast acting protection functions, therefore, many of the tools and methods are familiar to them.

A simulated environment by nature provides a configurable and repeatable environment for testing ANM applications. The aim of this paper is to demonstrate the development of a flexible testbed that will allow for the assessment of an ANM solution. The paper will give an overview of ANM and its drivers before giving a generic overview of the testbed architecture. In relation to power systems simulation the merits and drawbacks of commercially available modelling software will be compared. This paper will also highlight how communications emulation can add a further element of realism to a simulated environment.

ACTIVE NETWORK MANAGEMENT

The regulatory framework in the United Kingdom (UK) has provided the ideal platform for the development and trials of innovative solutions on the grid. As part of OFGEM's price control period 2010-2015, £500million [2] was made available to DNOs to stimulate innovative trials. Moreover UK and European government targets [3] for the reduction in carbon emissions have accelerated the use of 'clean energy' solutions, primarily wind generation and to a lesser extent (in the UK), photovoltaic and tidal energy.

As DG penetration increases, network planners are faced with a number of issues. The introduction of DG can give rise to bi-directional power flow on areas of the distribution network previously designed for unidirectional flow [4]. Moreover when all DG is fully exporting, the power flow of a line may exceed that of its rated capacity. Recognising that this is a relatively rare occurrence, instead of an upgrade that would be capital intensive, making use of real time control and distributed computing can actively manage conditions on the network, offsetting the requirement for a costly outlay. Efficient use of existing infrastructure can free latent capacity on the network. As in the UK the cost of network reinforcements are charged to the generator, this solution helps a DNO offer a cheaper and faster solution in comparison to a traditional upgrade. Herein lies the fundamental business case for ANM.

The field of ANM has been explored by a number of researchers in recent years. The AuRA-NMS project made some effort to understanding the technical challenges of implementing variety of control techniques. The authors of [5-6] explored the use of methods such as Constraint Programming and Multi Agent Systems to address multiple objectives such as power flow management, voltage management and automatic restoration. Furthermore the use of open standards and their relevance to ANM was addressed.

Power flow management has been trialled in a live environment on the Orkney Islands off the north coast of Scotland. The 33kV islanded network with an interconnector provided the ideal opportunity to trial ANM, as the network was considered as operating at full capacity due to high wind generation penetration. Measuring the power flows at strategic locations and actively controlling generation has allowed for the further connection of over 20MW of generation without the requirement of a traditional upgrade. Commercially the grid operates on a Last-In-First-Off (LIFO) agreement whereby the latest generator to be connected is the first to be curtailed [7].

SIMULATION

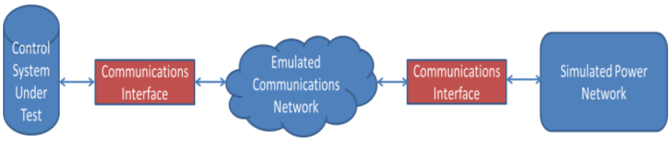

Figure 1: Generic Architecture of test bed

To provide a demonstrative testbed of an ANM scheme the architecture in Figure 1 is proposed. This proposal provides a flexible environment to test a multitude of ANM algorithms. The selection of communications interface will depend on what level of modelling is required and what interface the simulated power systems network can support. There are a number of tools which can be used to model power systems. For the purposes of comparing different simulation features including time resolution each simulation can run, three widely used platforms were chosen, namely Quasi Steady State Simulator, DiGSILENT PowerFactory and RSCAD. A summary of selected software is given in Table I.

Table I: Summary of Power System Simulation Software

	Simulation Time Step(ms)	Number of buses	Dynamic Simulation	Interface
Quasi Steady State Simulator	1000	Unlimited	No	Python/ OPC
DiGSILENT PowerFactory	10	Unlimited	Yes	OPC
RSCAD	0.05	Limited	Yes	DNP3/ IEC 61850 GOOSE

Quasi Steady State Simulator

Using its Python scripting interface as a bridge between IPSA and an OPC Server, data can be exchanged periodically. Network data can used to resolve voltage constraints on the simulated network. Actions designed to alleviate constraints are issued by **sgs voltage** via an OPC Client. As IPSA is a steady state load flow engine, intermediate controllers have to be created manually in Python to simulate ramp rate response and tap changing delays, updating the IPSA model appropriately as the simulation progresses. The modelling process in IPSA is such that models can be created and modified in a relatively simply manner. The simulator displays only the steady state values of a system and thus does not allow the user to observe the dynamic response of a network.

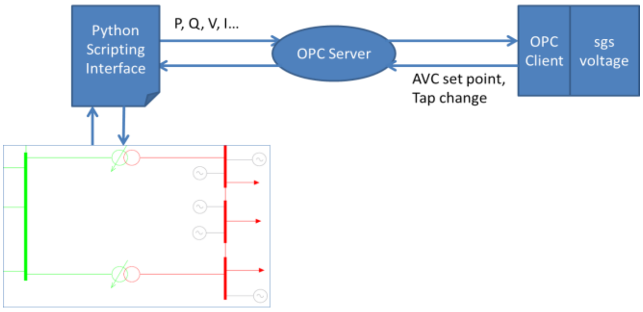

Figure 2. Architecture of Quasi Steady State Simulator

DiGSILENT PowerFatory

The use of DiGSILENT for testing control algorithms has been explored by the authors of [8]. Running PowerFactory in Engine mode allows set points to be changed in 'real-time' and observe the transient response caused by these changes. The architecture of the testing environment is similar to that proposed in the previous subsection, however, controllers are modelled within the PowerFactory environment and the simulator has a direct OPC link. The maximum number of buses within the simulation is dependent on the computational capacity of the host machine.

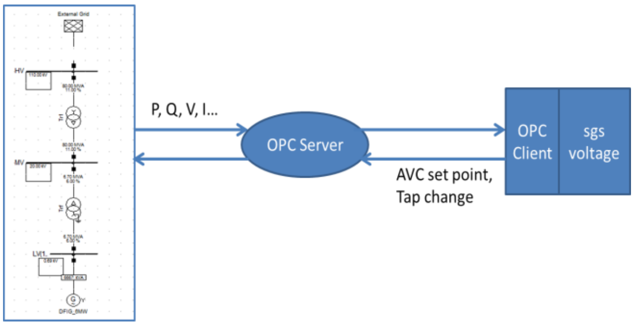

Figure 3. Testbed setup using DiGSILENT PowerFactory

Like the previous set up pertinent data can be interfaced with a voltage management controller to actively manage network conditions. Figures 4 & 5 show the step change response of a voltage set point being issued to an AVC, the resultant voltage output by a generator and the power generation profiles respectively. The transient response of active and reactive power can also be observed to demonstrate there are no issues relating to thermal or mechanical constraints being breached as a result of a change in set point.

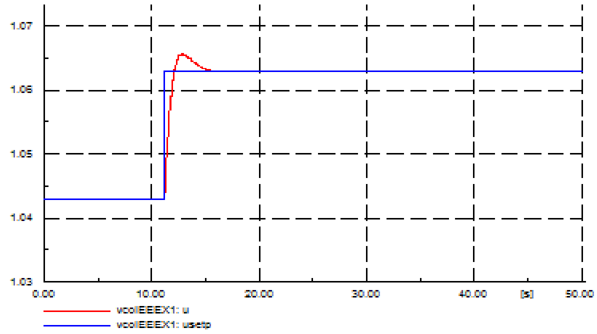

Figure 4. Voltage Profile

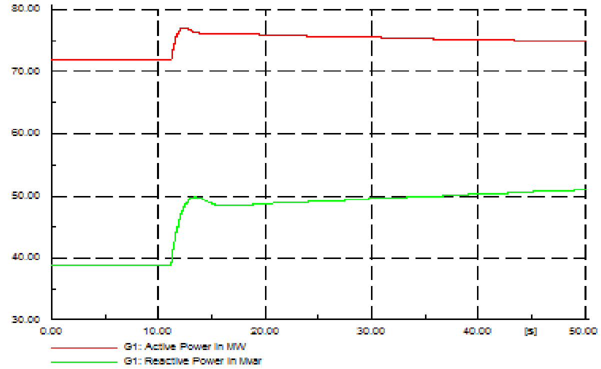

Figure 5. Active & Reactive Generation Profile

RSCAD

RSCAD is the modelling environment used to run simulations on the Real Time Digital Simulator©(RTDS). The modelling environment provides similar capability to that of PowerFactory, although the time step is much smaller. Scalability is an issue as there are a limited number of nodes per processing rack. To interface with control algorithms the GTNET card of the RTDS has DNP3 and IEC 61850 GOOSE capabilities. The time resolution of this modelling set up is redundant as the behaviour of the network at this time step is beyond the scope for ANM. However, as solutions evolve simulations in this vein may be of interest.

For testing purposes DiGSILENT's PowerFactory is our current solution as it meets required characteristics, in that it demonstrates the dynamic response to a change in set point. The time resolution of PowerFactory is sufficient for testing ANM algorithms. Moreover, PowerFactory is a tool many of our clients already use.

COMMUNICATIONS EMULATION

Communications platform and protocol selection will be chosen by considering the following criteria: existing infrastructure, location, cost, availability and criticality of operation. For a DNO, being able to quantify the technical attributes of a given solutions when balanced with its practical uses allows for a more cohesive assessment and enhanced cost benefit analysis. ANM solutions normally exhibit 'fail safe' behaviour whereby in the event of a communications failure the system will locally detect the disrupted link and back off to a stable operation. For power flow management this results in a full curtailment of 'non-firm' generation. It is therefore desirable for generators to have a reliable communications link to maximise its capacity factor. It is however not always critical and a less expensive option may be more apt if the platform is marginally less reliable. For example, a leased line may be more reliable than a VHF Radio link, however at much larger cost it may be more beneficial to accept the lesser reliability.

As part of the testbed for ANM solutions, it is proposed that communications emulation is integrated to add a further element of realism and aide DNOs select communication platforms. An open source research tool for communication simulation and emulation is the discrete event simulator Network Simulator 3 (NS3)[9]. NS3 makes use of a real time scheduler to transmit packets with time delays, out of sequence and drop packets. NS3 was selected as a cost effective solution due to its attention to realism and the ability to test solutions in a repeatable and configurable environment prior to full deployment. There is a wealth of technical literature that makes full use of the simulation capabilities of NS-3 [10], however due to the novel set-up papers relating to emulation for power systems applications are sparse. Similar software such as OPNET has been explored for 'Software-in-the-loop' uses in power systems similar to the testbed being proposed in this paper [11].

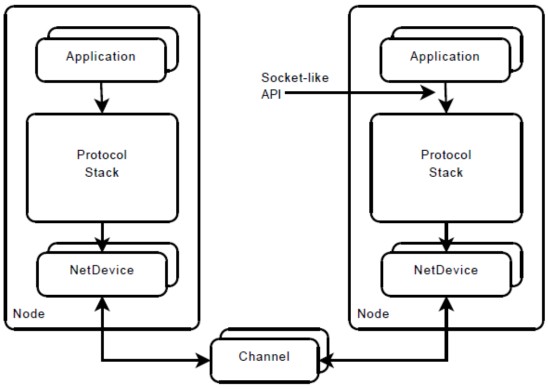

Figure 6. Caption

NS-3 aims to emulate the behaviour of a network stack by modelling as per the architecture shown in Figure 4. Nodes are intended to be representative of a host system (i.e. a computer) which will have a network interface (*NetDevice*), use a specified protocol stack and have traffic generated by an application. Using an emulated communications network will go some way to addressing the communications needs of a solution and understanding what may be problematic at an earlier stage of the design process.

CONCLUSION

This paper has discussed the development of a testbed for ANM solutions. Three commercially available software packages have integrated into the test environment and their applicability assessed. To add realism to the test bed communications emulation is proposed as a method of assessing various methods of transporting data. Future work includes validating the testbed against an existing case study, perhaps the aforementioned Orkney platform.

REFERENCE

[1] E.M. Davidson, M.J. Dolan, G.W. Ault, S.D.J. McArthur, 2010, "AuRA-NMS: An Autonomous Regional Active Network Management System for EDF Energy and SP Energy Networks" *IEEE Power and Energy Society General Meeting*.

[2] Low Carbon Network Fund, www.ofgem.gov.uk

[3] Government Targets

[4] N.G.A Hemdan, M. Kurrat, 2008, "Distributed Generation Location & Capacity Effects on Voltage Stability of Distribution Networks" *IEEE Annual Conference*

[5] E.M. Davidson, S.D.J. McArthur, C. Yuen, M. Larsson, 2008, "AuRA-NMS: Towards the Delivery of Smarter Distribution Networks through the Application of Multi-agent Systems Technology", *IEEE Power and Energy Society General Meeting.*

[6] E.M. Davidson, M.J. Dolan, S.D.J. McArthur, G.W. Ault, 2009, "The Use of Constraint Programing for the Autonomous Management of Power Flows", *International Conference on Intelligent System Applications to Power Systems.*

[7] R.A.F. Currie, G.W Ault, C.E.T. Foote, N.M. McNeill, A.K.Gooding, 2010, "Smarter ways to Provide Grid Connections for Renewable Generators", *IEEE Power and Energy Society General Meeting*.

[8] F. Andren, M. Stifter, T. Strasser, D. Burnier de Castro, 2011, "Framework for Co-Ordinated Simulation of Power Networks and Components in Smart Grids Using Common Communication Protocols", *IECON 2011 – 37th Annual Conference on IEEE Industrial Electronics Society*.

[9] Network Simulator 3, www.nsnam.org

[10] J.-S. Jung, K.-W. Lim, J.-B. Kim, Y.-B. Ko, Y. Kim, S.-Y. Lee, 2011, "Improving IEEE 802.11s Wireless Mesh Networks for Reliable Routing in the Smart Grid Infrastructure," *International Conference on Communications Workshop*.

[11] M. Haffar, J.M. Thiriet, M. El-Nachar, "Software and hardware in the loop component for an IEC 61850 Co-Simulation platform," in *Proc. of the International Multiconference on Computer Science and Information Technology*, pp. 817-823. 2010.