A DEMONSTRATOR FOR ACTIVE NETWORK MANAGEMENT DEVICES AND TECHNIQUES

R.M. TUMILTY
University of Strathclyde – UK
ryan.tumilty@eee.strath.ac.uk

D.A. ROBERTS
ScottishPower EnergyNetworks plc – UK
dave.roberts@sppowersystems.com

A.S. KINSON
Rolls-Royce plc – UK
alan.s.kinson@rolls-royce.com

G.M. BURT
University of Strathclyde – UK
g.burt@eee.strath.ac.uk

J.R. McDONALD
University of Strathclyde – UK
j.mcdonald@eee.strath.ac.uk

ABSTRACT

The traditionally passive nature of electrical distribution networks is changing as generation is connected within the context of a supportive regulatory framework and greater awareness of environmental issues. As the penetration of distributed generation becomes widespread, a myriad of issues with an increasingly network-wide scope arise, and have led to proposals for numerous techniques and devices to improve the management and operation of the network. Examples include: voltage regulation schemes, fault current limiters and active generation curtailment to mitigate thermal and security constraints. However, some major barriers still remain to be overcome before these are adopted by distribution network operators, and many remain as predominately laboratory-scale demonstrations. This paper will introduce, justify and describe the actual-scale network demonstrator being developed jointly by ScottishPower EnergyNetworks, Rolls-Royce and the University of Strathclyde, that will offer an environment within which the gap between research and field deployment can be bridged.

INTRODUCTION

The use and requirements of electrical distribution networks are changing. Generation is being connected across all voltage levels, disturbing the traditional uni-directional power flow from the transmission system through distribution networks towards customers. At the same time, customers are expecting increased reliability and quality of supply, performance criteria that are being strongly backed by regulatory incentives and penalties. In themselves these would be sufficient drivers for innovation; however, when combined with a backdrop of ageing assets and the largest levels of asset replacement in the UK since the late 1960s, ensuring that investment is conducted wisely and in accordance with future energy policy is evidently essential.

It is becoming more apparent that a continuation of the design principles developed and adopted throughout the 20th Century – either through like-for-like asset replacement or new connections – may not be the most suitable for the next 30-50 years. Whilst the outline statutory requirements for the customer's service connection, be they domestic or industrial, load or generator, for a reliable, safe and economic supply may not have altered, the manner in which the network is expected to adapt to meet changing load or generation patterns is significantly more challenging.

This environment gives rise to a range of potential problems and, indeed, opportunities for all stakeholders within the electricity supply industry. The requirement for new or novel technologies will increase greatly as distribution networks evolve to meet the exacting demands of the future.

Demonstration of these technologies, systems or practices is vital in ensuring that they are accepted within an industry that is heavily controlled through statutory obligations and regulation, operates networks with extremely long operational lifetimes and is, consequently, risk averse.

This paper will introduce, justify and describe the network demonstrator being developed jointly by ScottishPower EnergyNetworks, Rolls-Royce and the University of Strathclyde. The paper provides the following:

- The results of extensive scenario development and analysis will be used as the basis for justifying the network demonstrator.
- A discussion of the network demonstrator within the context of the research and development, demonstration & commercial deployment (RDD&D) process. This will be supplemented by an application example using the microgrid concept.
- An overview of the planned physical demonstrator system.

SCENARIOS FOR THE UK ELECTRICITY SUPPLY INDUSTRY IN 2020

Scenario development is a useful tool for investigating the potential future impacts of varying economic, environmental, technological and regulatory trends on the industry. The objective of this work is not to create specific predictions of the future, but rather attempts to provide a set of plausible contexts in which the UK electricity supply system could evolve over the coming decades.

From the scenarios developed, a good appreciation can be obtained for the range and penetration of novel or emerging technologies. Moreover, by considering the wider context of the network, the requirements for reinforcement or modifications to network control and management can likewise be scoped.

Scenario Formulation

Four scenarios were created for the time horizon of 2020, and were derived by extrapolating back from an existing set of six 2050 scenarios developed by Elders *et al* [1]. The motivation for initially considering an end point of 2050 is based on the need to account for the long lifetime of assets within the electricity supply industry, and to ensure that the scenarios developed are independent of the influence of current trends within the industry. The initial lower number of 2020 scenarios results from the inherent evolutionary nature of the electricity supply industry: thus, in the shorter term, it will take longer for distinct trends or divergence to appear in design or operational practices.

The scenarios are summarised in Table 1 in terms of the four trends noted previously. As an example, a brief review of the "Environmental Awakening" scenario is provided in the following section.

"Environmental Awakening"

Heightened public awareness and popular support of environmental issues has created the impetus for strong growth and adoption of 'green' technologies within the electricity supply industry.

Demand within this scenario has peaked and is at the start of a period of decline as direct consequence of energy efficiency measures (365TW/year in 2020).

The UK generation mix experiences a significant level of renewables connecting and amounts to 25% of installed capacity. Use of coal and nuclear thermal plant is in decline and combined cycle gas turbines (CCGT) constitute the largest proportion of the installed centrally dispatched generation capacity. On- and off-shore wind resources have been widely exploited. However in the case of on-shore wind, public opinion now limits the scope for further large-scale transmission connected developments, and attention is now being directed back towards smaller community lead schemes connected to the distribution network. There has been a large increase in the volume of generation connected to distribution networks, particularly in the form of small-scale wind and biomass. Microgeneration connected at low voltages amounts to 6GW across the UK.

Flexible ac transmission system (FACTS) devices are used extensively to improve the utilisation of existing networks. The high penetration of generation at the lower levels of the distribution network offer the potential for considering novel operating methods, such as intentional islanding using microgrids to improve the security of supply.

Analysis of Network Performance

The contexts expressed within the 2020 scenarios have been applied to representative ScottishPower rural, suburban and urban (radial and meshed) networks. Generation has been added to these network models based on a two stage scaling process intended to localise the UK-wide mix. Firstly, the generation to be connected to the distribution network is scaled according to the relative size of the segment of network (based on peak local and national load). This gives a quasi-uniform UK-wide spread and, additionally, includes binary multipliers to remove generation that is not applicable based on geographical considerations. Secondly, penetration levels based on multiples of this initial scaling were applied to investigate local clustering effects such as customer types, targets or incentives. Example results of fault level and voltage regulation are discussed below as illustrations of the issues that could arise towards 2020.

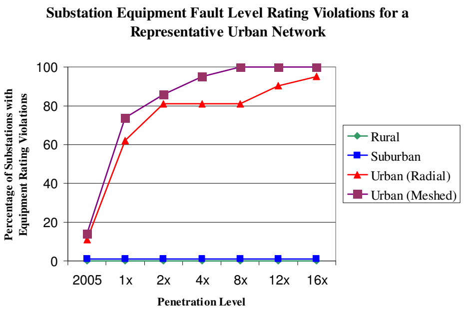

Figure 2: *Primary substation (33/11kV) equipment fault level violations ("Continuing Prosperity" scenario).*

Figure 2 shows an indication of the severity of the problem arising from excessive fault levels within the urban network considered. The initial percentage of rating violations in

Table 1: *Summary of 2020 Scenarios*

2020 Scenario	Economic Growth	Environmental Focus	Technological Growth	Regulatory Structure
Continuing Prosperity	Increased	Slightly stronger	Strong	Liberalised
Economic Concern	Reduced	Reducing	Weak	Liberalised
Environmental Awakening	Current level	Stronger	Strong with environmental focus	Largely liberalised with some environmental intervention
Supportive Regulation	Current level	As at present	Moderate with central support	Mildly interventionist

2005 is due to existing issues and is managed by operational switching restrictions – a solution that cannot be practically extended to cover the higher penetration levels investigated.

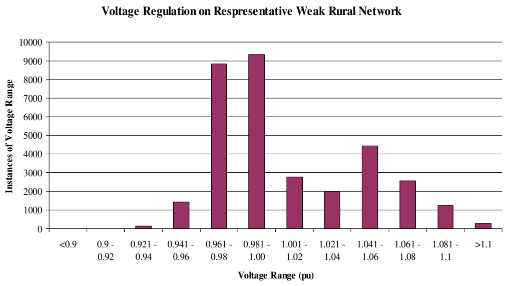

Figure 3: 11kV v*oltage regulation on representative weak rural network (“Environmental Awakening” scenario).*

Figure 3 above shows a frequency distribution of the instances of voltage bands on section of 11kV weak (long) rural network (10 minute intervals over 1 day) for a specific level of generation penetration. The plot is clearly skewed towards higher voltage bands and shows that the upper statutory voltage regulation limit of +6% has been breached. Additionally, the number of tap changer movements has been observed to increase as intermittent generation is connected that has a profile that is not coincide well with local demand.

KEY TECHNOLOGIES & THE ROLE OF NETWORK DEMONSTRATION

The 2020 scenarios and the analysis of network performance highlighted a range of devices that are either necessary or offer tangible benefits if applied. These include: voltage regulation schemes, fault current limiters, compensation devices and micrograms (intentional islanding) to name but a few. The technologies required to realise these are in various stages of development [2]. However, some major barriers – technical, economic and regulatory – still stand in the path towards adoption and acceptance from their current state as predominantly laboratory-scale demonstrations.

The penultimate part of the RDD&D process should, for credibility, be conducted in as realistic and flexible environment as possible. Identifying the integration issues with legacy systems and testing under as many different network conditions are difficult to achieve under controlled laboratory conditions. Furthermore, the increasingly wide scope of the problems which novel technologies and control methods are tasked with resolving require larger test facilities, and would subject consumers to unacceptable risks of supply interruption if the actual network is used.

The example of the microgrids concept is discussed in the following section as a vehicle for outlining some of the applications of a network demonstrator.

Microgrids

The term ‘microgrid’ refers to the coordinated integration of small-scale distributed or microgeneration within the lower voltage levels of the distribution network, facilitated through the formation of semi-autonomous zones covering a relatively small geographical area [3].

Background

A microgrid can be temporarily operated in an intentional islanded mode in response to significant disturbances within the upstream grid system (e.g. outage of circuits or power quality disturbances) to improve levels of supply security. The adoption of such a strategy effectively creates a cellular structure within the distribution network. This will break down the conventional hierarchical approach to control and raises issues surrounding the operation and management of a potentially fragmented active network.

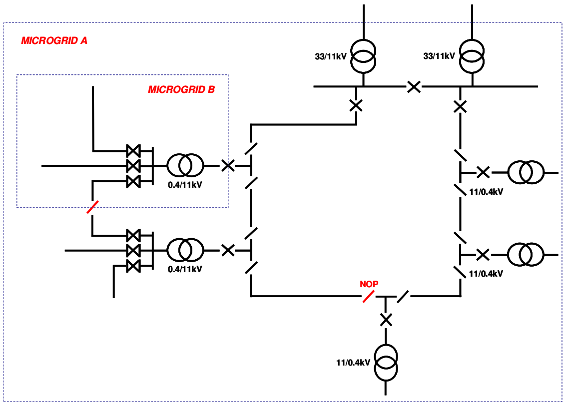

Figure 4: *Potential Microgrid Networks*

Some illustrative examples of micro-grids are shown in Figure 4 that highlight the potential for nested networks encompassing both high and low voltage distribution within the UK (only existing primary system assets are shown).

Network Demonstrator Application

Consider the demonstration of microgrid successfully islanding and, at some point in the future, reconnecting to the grid. Such a demonstration would include:

- The logics, signalling and switching required to complete the isolation from the grid.
- The control of generation and energy storage to ensure the stability of the islanded network.
- The adaptation of the network protection to meet the new electrical conditions (e.g. reduced fault level).
- The automation and synchronisation equipment required for reconnection to the grid, either at the initial point of isolation or at an alternative point of supply (through the closure of a normally open point).

ADVANCED ELECTRICAL NETWORK TECHNOLOGIES DEMONSTRATOR

This is a facility that will provide network operators, equipment manufacturers and academia with the opportunity to demonstrate the next generation of operational strategies and technologies that will aid in the active management of electrical distribution networks. It is a collaborative project involving ScottishPower EnergyNetworks, Rolls-Royce and the Institute for Energy & Environment at the University of Strathclyde. The demonstrator will be built at the existing ScottishPower training centre near Cumbernauld.

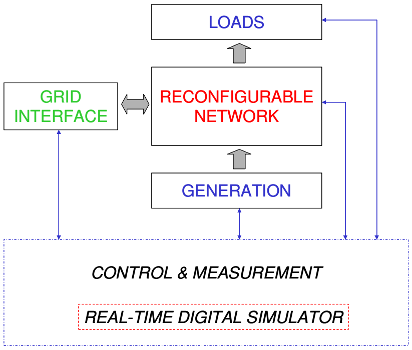

Figure 5: *Demonstrator network functional elements.*

At the core of the facility will be a reconfigurable collection of primary network assets that allow for the realistic representation of 11kV and 400V circuits within rural, suburban, urban and marine networks. This network will be configured according to the needs of the scenario or technology under study, and will have the appropriate controllable load, generation and energy storage connected. Out of necessity, both load and generation will be scaled; however, by careful control of switched circuit impedances realistic voltage gradients will still be present on the system. Cables and overhead line circuits will be represented using both short lengths of actual assets and lumped impedance equivalents.

The demonstrator will be provided with the capability to derive a supply from the grid network using two unity ratio transformers (with on load tap changers (OLTC)) intended to limit the propagation of disturbances from within the demonstrator network and to provide means to control network voltage. A further capability will be to supply the network using a motor-generator (M-G) set (under a reduced network loading), thus allowing for both voltage and frequency disturbances to be imposed onto the demonstrator. The references for the OLTCs and M-G set will be supplied from manual operator commands, recorded profiles or a real-time digital simulation of a wider upstream network.

A powerful feature of the demonstrator will be the ability to examine the wider upstream impacts of operational strategies and technologies outside the section of network physically constructed by making use of real-time simulation of an upstream network. This will allow for the control of the grid interface to expose the demonstrator network to a range of disturbances or, indeed, characteristic conditions reflecting the expected future nature of the wider network.

As an example of how the demonstrator will operate, consider the demonstration of a novel network voltage controller designed to control a range of assets across a section of network. The device will be physically installed within the reconfigurable network and includes several remotely communicated voltage measurements. By adjustment of load, generation and the grid interface, the network voltage controller will be subject to a wide range of disturbances and its performance verified.

CONCLUSIONS

This paper has summarised the results of scenarios produced for the UK electricity supply industry with the time horizon of 2020, and commented upon some elements of the performance of future distribution network.

The emergence of key technologies and the requirement for demonstration have been used in the justification of the demonstrator as an important part of the RDD&D process. A flexible and realistic facility such this offers the potential to meet the needs of a wide range of stakeholders and reduce the time to market for the products and services that are seen as vital in realising future aspirations for distribution networks.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of ITI Energy and the EPSRC Supergen 1 (Future Network Technologies) consortium in the creation of the scenarios presented in this paper.

REFERENCES

[1] Elders *et al.* (2006). “Electricity network scenarios for the United Kingdom in 2050”, in T. Jamasb, W.J. Nuttall and M.G. Pollitt (eds), *Future Electricity Technologies and Systems*, Cambridge University Press, UK

[2] R.A.F. Currie, G.W. Ault, 2006, “Register of Active Management Pilots, Trials, Research, Development and Demonstration Activities”; UK DTI Project Report. Available at http://www.dti.gov.uk/files/file33116.pdf

[3] Lasseter, R. H., “Microgrids”, *IEEE PES Summer Meeting 2002*, p305-308