FUTURE NETWORK ARCHITECTURE – POWER NETWORK, PROTECTION, CONTROL AND MARKET REQUIREMENTS FOR 2020

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ABSTRACT

As distribution networks have traditionally been passive networks facilitating power flows in one direction from the grid intake point to demand customers, the architecture of future networks incorporating high levels of distributed generation needs to address not only the requirements of the power network but also the necessary changes to meet the corresponding protection, control, market and regulatory requirements. The report described in the paper considered the network architectures for three scenarios to 2020 in Great Britain with increasing levels of distributed generation, particularly micro-generation connected at low voltage (LV).

INTRODUCTION

The paper describes a report entitled "Future Network Architectures" published in 2007 by the British Government's Department for Business Enterprise and Regulatory Reform (BERR) [1] under the Energy Network Strategy Group's Horizon Planning Work Programme. Network architectures were identified to deliver solutions to accommodate a proposed portfolio of electricity demand and generation scenarios based on those identified in the preceding SuperGen 2020 study for the power system in Great Britain [2]. The network architectures identified innovative solutions combining heavy and light current solutions that could be justified in a business case framework.

ADAPTATION OF SUPERGEN 2020 DEMAND AND GENERATION SCENARIOS

An initial review of the four SuperGen scenarios for 2020 concluded that the Continuing Prosperity and Environmental Awakening scenarios would be the most challenging and more likely to influence future network architecture. These two particular scenarios also aligned more closely than the other Supergen scenarios with contemporary European Commission and British Government announcements on carbon emission and renewables targets. A third scenario, Power to the People, was developed to focus on the impact of high penetration levels of micro generation connected onto the low voltage network. The scenarios are presented in Table 1.

Table 1 - Capacity installed at each voltage level (GW) on the Great Britain Power System

Description	At end 2004	Scenario 1: Continuing Prosperity 2020	Scenario 2: Environ-mental Awakening 2020	Scenario 3: Power to the People 2020
Economic Growth		Increased	Current level	Current level
Environmental Focus		Slightly stronger	Stronger	Strong; energy efficient buildings
Technological Growth		Strong	Strong with environ-mental focus	Strong with high LV micro-generation
Regulatory Structure		Liberalised	Largely liberalized with some environ-mental intervention	Largely liberalized with some environ-mental intervention
EHV: Uncontrolled Generation		8.7	11.8	11.0
EHV: Synchronous Generation	73.8	63.0	49.0	45.0
HV: Uncontrolled Generation	3.9	4.0	5.1	4.0
HV: Asynchronous & Inverter Fed Generation	1.0	3.5	4.6	3.0
MV: Uncontrolled Generation	1.8	2.0	2.7	2.0
MV: Asynchronous & Inverter Fed Generation	0.7	1.5	2.2	1.0
LV: Inverter Fed Uncontrolled Generation	0.4	3.0	6.0	12.0
Totals	81.6	85.7	81.4	78.0
Peak Demand	59.4	66.0	60.0	57.0

"Uncontrolled generation" connected directly to the transmission system at EHV was considered to be mainly wind turbines (onshore and offshore).

Synchronous generation reflected conventional generation (fossil fuelled thermal and nuclear). At the HV and MV levels a further distinction was made where "uncontrolled generation" was considered to comprise biomass, non-storage hydro and heat-following combined heat and power (CHP). Furthermore at the HV and MV levels "asynchronous and inverter fed generation" was considered to comprise mainly wind turbines with some marine generation (wave and tidal flow). At the LV level all (micro) generation (domestic CHP, photo-voltaic and wind turbine) was considered to be connected through inverters and owned by domestic customers.

CHALLENGE OF INCREASING LEVELS OF DISTRIBUTED GENERATION

Variable generation

A principal driver for providing a future architecture for network control is the volume of distributed generation to be connected to the distribution network, particularly as the output of much of this generation would be variable, as it would comprise a large quantity of very small generating units connected at LV. Furthermore the variable output would be driven to a large extent by heat requirements (domestic CHP) and weather (solar, wind) and not by demand as with conventional generation. We would assume that micro generation, for example, would be self dispatched unless subject to constraints.

System operation

A Distribution Network Operator (DNO) would have to actively manage its distribution network with increasing levels of (variable) distributed generation, the tasks of Active Network Management (ANM) comprising:

- power flow management
- voltage control
- fault level management and
- demand side management (DSM).

With increasing levels of (variable) distributed generation a Transmission System Operator (TSO) would similarly have to

- balance the generation and demand within its control area/block
- manage the primary/secondary/tertiary control of system frequency within the synchronous area and
- manage unscheduled power flows.

Similarly the Market Operator (MO) would have to manage the trading of variable generation and the impact of real-time process to the customer.

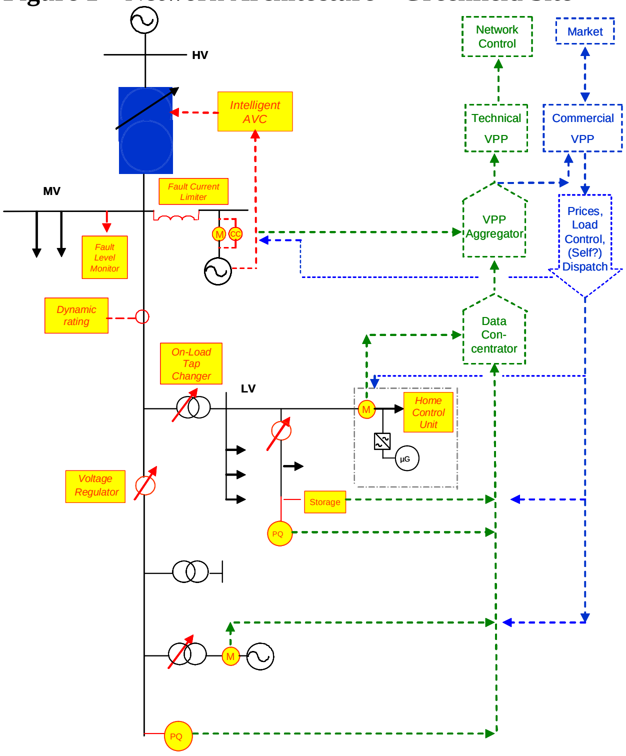
VIRTUAL POWER PLANT (VPP) CONCEPT

The VPP concept is aimed at making distributed generation manageable from the viewpoint of the system operator. The VPP is being developed to aggregate the on-line signals from multiple distributed generation and controllable loads and to present these signals as if they were from large scale power plants and the VPP acted accordingly. In the architecture proposed by the FENIX project, a VPP would perform two activities, a Commercial VPP (CVPP) and a Technical VPP (TVPP) [3]. The meter data, from smart meters, would be shared between the two activities. The Technical VPP function would be locational, covering voltage and power flow control and hence would be performed by the DNO. It is envisaged that the balancing mechanism and frequency control function would continue to be performed by the TSO.

Network Architecture for a "Greenfield" site

Figure 1 presents the new devices applied to the primary network and the provision of the corresponding control and market systems.

Figure 1 – Network Architecture – Greenfield Site



The new devices to be integrated with the power network would address the control of voltage, management of fault level, dynamic rating of circuits (Active Network Management) and measurement of power quality (PQ), including voltage unbalance due to single phase generation. Protection systems would be arranged to accommodate bi-directional power flows and to avoid the potential problems of protection blinding and false tripping.

The smart meter with two-way communications is expected to play a crucial role, particularly for domestic microgeneration, providing real time metered information to a virtual power plant (VPP) aggregator and thence to network control, overall system (frequency/balancing mechanism) control and to the market operator. In return dynamic information on prices and load control would be fed back to the users, including the many expected domestic customer with microgenerators.

REGULATION

The report analysed the commercial and regulatory implications associated with the adopted 2020 scenarios and concluded that:

- the energy regulator, Ofgem, should consider reviewing the functional and licensed roles of supply, distribution and transmission under a low carbon, high distributed generation future
- this should ideally extend to examine the licence restriction on DNOs owning and operating generation and storage, and the respective roles of the distributor and supplier in relation to commercial treatment of demand side management and storage.
- such a review should also examine the ability of distributed generation to offer, deliver and trade ancillary services on a local and regional basis to DNO, as an alternative to the TSO providing these via transmission connected generation
- in future Distribution Price Controls flexibility should be introduced to allow for rapid unseen expenditure caused by distributed generation and
- regional balancing markets should be considered where the volume of connected micro generation is large.

ANALYSIS OF NETWORK ARCHITECTURES TO MEET REQUIREMENTS OF SCENARIOS

The analysis of network architectures to meet the requirements of the three scenarios reviewed the corresponding indicative capital costs of:

- control of voltage
- management of fault level
- demand side management (DSM) and
- electricity market and trading facilities.

Control of voltage

The measures considered for control of voltage comprised:

- replacement of automatic voltage control (AVC) schemes (transformer tap changer control)
- replacement of on-load tap changers (OLTC) on (typically HV/MV) power transformers where the tap changers are of an obsolete type without a reverse power capability and
- equipping MV/LV distribution transformers with on-load tap changers.

The basis for the indicative capital costs was a Network Voltage Change report prepared for the British Government's Department of Trade and Industry (DTI) (now BERR) in which the costs per MW of additional distributed generation were derived from modelling of networks [4]. The model considered, at each discrete voltage level, increasing the level of distributed generation until a limitation (reverse power on transformer tap changers, voltage rise outside statutory limits) was identified, costed and the resulting allowed increase in distributed generation quantified. The impacts of additional distributed generation on rural and urban networks were evaluated separately. The costs per MW of additional distributed generation were then applied to the gross amounts of additional distributed generation at each voltage level to obtain overall costs. The costs so obtained were essentially the costs of reinforcing the existing network infrastructure.

The capital costs in the Network Voltage Change report were updated to take account of recent developments, including:

- intelligent AVC [5]
- MV/LV distribution transformers fitted with an on-load tap changer connected to existing off-circuit taps, so avoiding replacement of the transformer [6].

The derivation of indicative capital costs were subject to certain qualifications and exclusions, mainly on the grounds of complexity, and were noted in the report as issues for future investigation:

- networks as modelled were assumed to be homogeneous whereas in practice there would be a statistical spread of circuit utilizations
- islanded networks were not considered in the analysis
- only reverse power and voltage control remedial measures were identified – other measures such as dynamic rating or Active Network Management could similarly be considered
- no allowance was made for operating costs nor for incidence of capital expenditure in the years to the horizon of 2020
- costs of harmonic filters were not included although with inverter-connected generating equipment there may be an increasing requirement for filters
- limitations of capacity due to voltage unbalance caused by the single phase connection of domestic micro-generation were excluded (in Great Britain domestic connections are single phase)
- energy storage devices (power balancing) and

- costs of enhanced protection to overcome the problems of false tripping of feeders (distributed generation feeding an upstream fault) and blinding of protection (protection under-reach) were excluded [7].

Management of fault level

Both the Network Voltage Change report and a separate report [8] to the DTI have identified fault levels on urban MV networks as being at risk of being exceeded with increased MV distributed generation, although the fault level monitoring concept needs to be further developed to confirm perceived problems. One prospective mitigation measure is the installation of the superconducting short circuit fault current limiter presently under development.

Demand Side Management (DSM)

Smart meters were included to facilitate DSM with two-way communication and appropriate export/import metering on the basis of one meter per domestic micro-generator.

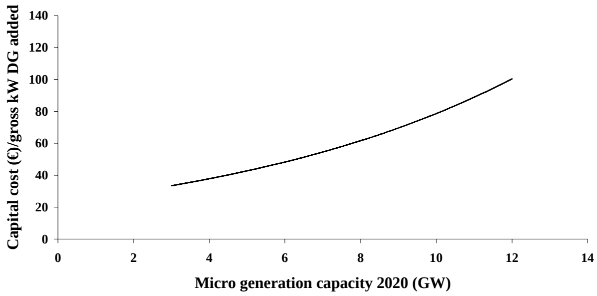
Electricity market and trading facilities

Estimated costs were included for a VPP/aggregator IT system and for modifications to the existing system of trading arrangements.

Estimates of indicative costs of modifying the architecture of an existing network

Figure 2 presents the trend in cost per 'gross kW of distributed generation added' - a function of the micro-generation capacity connected to the LV networks, the pre-dominant cost driver. The trend is that capital costs increase exponentially with micro generation capacity and, although dominated by smart meter costs, may themselves indicate a limit to that capacity being added to an existing network. The highest cost is associated with Scenario 3, Power to the People, and reflects the assumed quantity (about 12 million) of smart meters at about €150 each.

Figure 2- Increase in capital cost/kW with micro generation capacity



The above costs exclude costs of connection and of the distributed generation itself. In the last Distribution Price Control Review, the energy regulator Ofgem reported a typical overall level of average capital expenditure to connect distributed generation of about €120 per kW.

CONCLUSIONS

The principal conclusions of the report were:

- short circuit levels could be a problem on urban networks
- voltage rise problems tended to be an issue on rural networks
- voltage unbalance and voltage rise are potential issues on LV networks and unbalance might limit the connection of LV micro generation
- changes to the regulatory regime may be required including providing more flexibility to the DNO
- where micro generation is installed the key network architecture device is the smart meter with two way communications; data aggregation would be required and the VPP concept adopted
- indicative capital costs of network architecture measures are in the range €30 to €130 per kW of additional distributed generation, depending on the level of micro generation.

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