IMPACTS AND MANAGEMENT ARRANGEMENTS FOR HIGH PENETRATION DISTRIBUTED GENERATION

Payon PUNJAD*
Project Planning Division
Provincial Electricity Authority (PEA), Thailand
ppunjad@eee.strath.ac.uk

G W AULT, J R McDONALD
Advanced Electrical Systems Research Group*
University of Strathclyde, UK
g.ault@eee.strath.ac.uk

ABSTRACT

The UK government has set targets for clean, secure and adequate supplies of energy for the future. The contribution of combinations of large numbers of small and medium scale distributed generation (DG) technologies provides the potential to support government targets in terms of both energy and environmental concerns. The use of small and medium scale distributed generation technologies installed in medium and low voltage distribution networks are being widely investigated by Distribution Network Operators (DNOs). The key issues for installation of DG into distribution networks have been investigated separately on the effect of power flow, voltage regulation, fault level and security by connecting individual generator connections in DG networks. These studies investigate only a small number of generating unit connection points, but such approaches might not be appropriate to future networks that have very large numbers of small generating units. This paper presents the impact of different connections of multiple generation unit mixes in power networks with different penetration levels based on the generation technologies available in future scenarios. The results also provide valuable guidance on the impact of different combinations of key influences on future power systems.

INTRODUCTION

The evolution of power markets worldwide has been driving DNOs to improve their planning, operation and investment efficiency. This has caused DNOs to identify and develop more economical methods of supplying energy in order to deal with increased energy demand in the future. Connecting renewable and distributed generation to their networks is one flexible alternative when DNOs want to strengthen power distribution system in terms of maximising network capability without expensive network upgrading. Traditionally, distribution systems were designed on the basis of passive circuits or the so-called “fit-and-forget” approach, which means power flows from Grid Supply Point (GSP) at higher voltage to lower voltage levels and loads. The flow of power can become bi-directional when renewable and distributed generation is connected to the network. This can cause adverse impacts that existing distribution systems cannot deal with.

The UK electricity supply industry is investigating support for the development and deployment of new technologies in the future. The trend of DG technologies has been moving towards connection closer to end-users through the development of generation technologies and control and power electronic equipment. New connection standards for the electricity industry and new planning methods are required when the electricity industry has to take account of wide spread use of small scale generation without upgrading existing network.

This paper starts by introducing the problem posed by high penetrations of generation in distribution networks and presents future network scenarios. Then the development of the models for studies of DG in generic network models is introduced, followed by the results of power system simulations and conclusions.

DG PROBLEMS

The installation of renewable and distributed generation in distribution networks has a number of major technical implications. These technical implications are being widely investigated and can be divided into four main groups [1]:

- Load Flows
- Voltage Control
- Fault Levels
- Network Security

The key issues of installation of DG into power networks have been investigated separately on the effect of power flow, voltage regulation, fault level and security by connecting individual generator connections in DG networks [2]. These solution schemes might not be appropriate to the increased uncertainties in the future regarding the amount of energy demand, availability of generation technologies and location of generating units. Moreover, these problems can lead to difficulties or barriers in operation and planning of distribution networks with increasing distributed generation penetration level in the future. Thus, there is a requirement to study the impacts of high penetration levels as might be in place towards the year 2050 to identify and develop new planning methods or provide valuable guidance to support the development and deployment of DG in the future.

FUTURE NETWORK SCENARIOS

This section describes the scenarios used in this paper for the UK power system in 2050 as identified and developed in the Advanced Electrical Systems Research Group, University of Strathclyde [3,4,5]. The aim of creating scenarios is to represent possible different situations for power networks in the UK in the year 2050 by considering several aspects such as technical, economic, environment and regulations. This paper has created five case studies under three of those scenarios to investigate the impacts of high DG penetration levels to support potential new planning concepts to support the development and deployment of DG in the future. Each case study is created by considering the particular type of power network (e.g. urban, rural) to scenarios. The case studies consist of energy demand, generation capacity and load forecast and growth rate of load for 2050. Each case study has been populated with several distributed generation penetration level comprise of the following levels (and these are explicit in the results presented):

- Base case is the present situation in 2005
- 2050 is situation in the year 2050 by forecasting load from base case
- DG1 is situation in 2050 with distributed generation
- DG2 is situation in 2050 with DG plus 25% increasing in generation capacity
- DG3 is situation in 2050 with DG plus 50% increasing in generation capacity

APPLICATION OF DG TO NETWORK MODELS

The process of investigating the impact of DG on the network models can be summarised in five steps:

- ***Step 1:*** Selection of generation technologies for distribution networks. The sub-set generation technologies are selected from the generation scenario based on the generation technologies likely in distribution networks.
- ***Step 2:*** Transforming the national generation level to the local level. A scaling factor method is applied to convert the generation capacity of selected generation scenario for the year 2050 from national to local level after the generation technologies are selected.
- ***Step 3:*** Determining the generation output at the local level. The generation applicable to the network in the case study are associated with select connection points.
- ***Step 4:*** Converting prepared data. Since this work uses the PSS/E analysis package, all data in spreadsheet need to be converted into raw file before running a simulation.
- ***Step 5:*** Simulation of the model. The PSS/E package software to find the results of the case studies simulates all data from step 4.
- ***Step 6:*** Results processing. The results are from step 5 translated and collated for presentation.

DEVELOPMENT OF NETWORK MODELS

The United Kingdom Generic Distribution System (UKGDS) are used in this study. The UKGDS models were created to provide a standard test resource to support the study of distributed generation. The network models that will be applied to the design and analysis process are divided into two types: rural and urban [6,7,8]. These typical radial topology networks are widely used as examples of existing UK networks.

Rural Area Network Model

The example network topology used in this study is developed and designed from the original EHV1 model starting from Grid Supply Point (GSP) at 132 kV voltage level, down through 33 kV network and ending at 33/11 kV transformers. The 11kV/LV network is expanded from the 33/11 kV stations. The network is comprised of a 132 kV source (GSP), two 132 kV/33kV transformers, twenty 33/11 kV transformers and nine 11 kV outgoing feeders. Each of the 11 kV feeders is an overhead line, representing 15 km of 185 mm^2 conductors supplying nine 11/0.415 kV transformer fed branches, which are modelled as lumped load on low voltage side.

Urban Area Network Model

The network model used for urban area in this paper is developed and designed from the original UKGDS-EHV5. The network consisted of 400 kV source (GSP), three 400/132 kV transformers, two 132/33 kV transformers, twenty three 132/11 kV transformers, two 33/6.6 kV transformers and nine 11 kV outgoing feeders. Each 11 kV underground feeder is represented by a 4 km circuit 185 mm^2 cable supplying four 11/0.415 kV branches.

Demand and Generation Profiles

The demand profiles used in this study are divided into three types: Domestic, Commercial and Industrial. Demand profiles for the year 2050 have been projected from the UKGDS demand in 2005 by using a growth rate appropriate to each scenario.

Distributed Generation Technology

The application of generation technology in LV networks for this case study is based on the generation technologies available in the year 2050 scenarios and are summarised in Table 1.

Table 1. Typical Generation Technology

Type of DG	Generation Technology
Wind Turbines	Squirrel Cage Induction Generator
Micro Generation	PV with Interface & Control Unit
Biomass	Synchronous Generator
CHP	Synchronous Generator

Software Tools

The PSS/E power system analysis software tool is used to generate results for: power flow, fault levels, voltage level and system losses. The UKGDS software tools are also used for preparing model data.

RESULTS OF POWER SYSTEM SIMULATIONS

The results presented in this section describe the impact of distributed generation on the performance of the networks models studied using the approach described above.

Utilisation of network capacity

Figure 1 and Figure 2 present results showing circuit loading reduction at system peak periods of the rural network model for 33 kV and 11 kV circuits respectively.

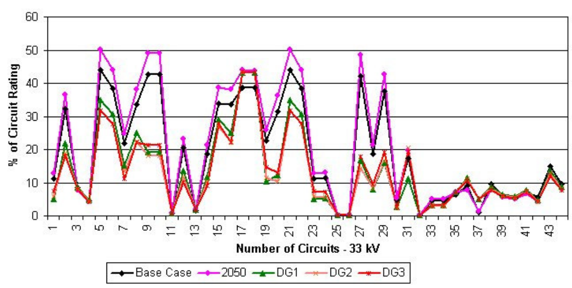

Figure 1. Circuit loading at peak load for 33 kV

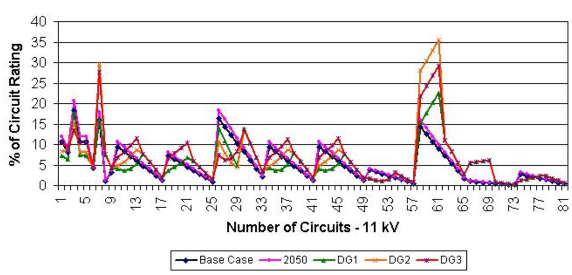

Figure 2. Circuit loading at peak load for 11 kV

Figure 1 shows that circuit loading drops by up to 30% in 33kV circuits for higher DG cases (e.g. DG1, DG2 and DG3). Loading reductions in 11 kV circuits are around 10%. As can be seen in Figure1 and Figure 2, reductions of circuit loading of both 33 kV and 11 kV networks occur at or near the locations where DG is connected to the networks. These reductions occur on various locations because of DG installed across the network but not on every circuit. This means that the trend of circuit loading reduction will occur more on circuits if DG is connected. Note that, in some locations circuit loading reduction is increased rather than decreased when DG is connected to the network due to increased generation capacity. Furthermore, the reduction in circuit loading and peak loading level is a key contribution from DG enabling DNOs to consider deferring circuit upgrading.

Fault Level

Balanced three-phase fault method is used to simplify the fault study. The fault level excedence is calculated based on the percentage of fault current compared with maximum short-circuit rating at each voltage level.

Table 2. Nodes with excessive fault levels

Generation Capacity Scenarios	Nodes Exceeding Fault Rating		
	33 kV	11 kV	0.4 kV
Base Case	0	0	0
2050	0	0	0
DG1	0	0	1
DG2	0	0	4
DG3	0	0	7

As shown in table 2, the increase in distributed generation capacity in the system leads to increasing the number of nodes with excessive fault levels. In this case, the fault level in nodes at 33 kV and 11 kV does not exceed the limits of equipment, but the fault level in LV networks exceeds the switchgear ratings because of the effect from DG. Thus, upgrading of switchgear would ordinarily be required. Note that, this study used synchronous reactance values in the range 0.15-0.2 p.u.. This might overestimate the fault contribution from some generating technologies.

Energy Losses in the System

Figure 3 shows the electrical losses in the system under several generation capacity scenarios for analysis over one week at one hour resolution.

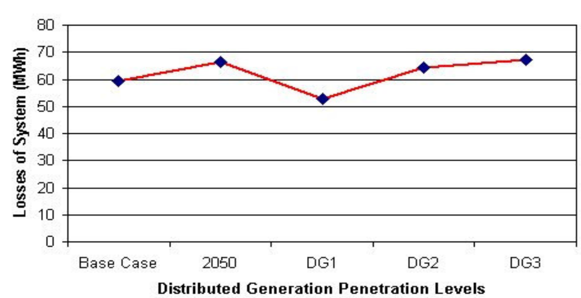

Figure 3. Electrical losses in system

As revealed by the Figure 3, the system losses have increased from base case to the year 2050 base due to increased power flows. With a moderate level of DG connected in 2050 the losses are reduced substantially (DG1) but the curve trend shows that system losses increase with increasing distributed generation capacity (DG2 and DG3). The relationship of increasing DG capacity to decreased system losses is dependent on several factors such as location of DG, network topology, load profile and generation operation and output profile.

Voltage Regulation

The results of voltage regulation studies are presented in Figure 4. These studies count the number of instances of voltage levels across one week.

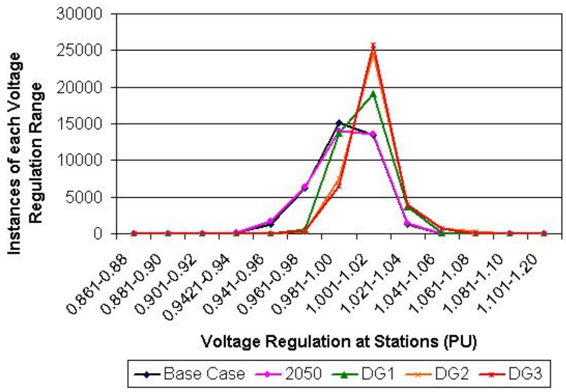

Figure 4. Voltage regulation in the system

As can be seen in Figure 4, voltage regulation of the system before adding DG to the system (i.e. for base case and 2050 scenarios) tend towards more voltage levels below 1.0 pu and even below statutory voltage thresholds. Problem nodes tend to be located far from the GSP. This voltage problem has been solved to an extent by connecting DG to the system, and in particular near the voltage problem areas.

ARRANGEMENTS TO MANAGE IMPACTS OF DG

From the results, a number of plausible arrangements for dealing with technical problems are as follows:

- Power systems should be planned by considering jointly network design and network operation to support increasing generation penetration level. This will increase the potential of networks to connect DG and harness the benefits without suffering the problems. For example, active network management schemes require a joint planning and operations consideration.
- Operating networks with active network management schemes will enhance the capability of networks to connect higher generation penetration levels, resulting in increasing network utilisation and optimal benefits.
- Using new technologies to improve network performance in terms of fault rating such as applying new electronic fault limiter in network will mitigate some of the negative points of DG connection but at a cost.

CONCLUSIONS

This paper presents the results of studies of the main impacts of DG on power distribution networks by using generation scenarios, generic network models and solution software tools. With the contributions of wide spread use of DG across network, power flows generally reduce and utilisation of network thermal capacity is reduced. As a result, more load demand can be added to networks without loss of demand security if appropriate measures and taken. Therefore, DNOs can defer investment or upgrading existing system capacity.

There is no fault level violation in HV and MV networks, but there tends to be more problems in LV network because of increasing generation level and location of DG. DNOs can exploit the benefits from losses reduction through increasing DG capacity, resulting in improved financial outcomes from losses reduction incentives or energy purchase reduction.

ACKNOWLEDGEMENTS

Support for this work was provided by Energy Policy and Planning Office (EPPO), Ministry of Energy and Provincial Electricity Authority (PEA), Thailand.

REFERENCES

[1] DTI/OFGEM Embedded Generation Working Group, December 2000, "Future Network Design, Management and Business Environment", UK

[2] Electricity Association, 2003, "Guidelines for Actively managing Power Flows Associated with the Connection of a Single Distribution Generation Plant" Engineering Technical Report (ETR) 124

[3] T. Jamasb, W. J. Nuttall, M. G. Pollitt, 2006, *Future Electricity Technologies and Systems*, Cambridge University Press, Cambridge, UK

[4] G. W. Ault, I Elders, J. R. McDonald, G. M. Burt, and R. Tumilty; SuperGen Future Network Technologies Consortium; "Electricity Network Scenarios for 2020", July 2006

[5] G. W. Ault, I. Elders, S. Galloway, J. R. McDonald, J. Kohler, M Leach, and E Lampaditou, "Electricity Network Scenarios for 2050," July 2005, SUPERGEN Future Network Technologies Consortium – WP5: Foresight

[6] N. Jenkins, et al., 2000, *Embedded Generation*, The Institution of Electrical Engineers, London, U K

[7] M. R. Patel, 2006, *Wind and Solar Power Systems: Design, Analysis, and Operation,* Taylor & Francis Group, Florida, USA

[8] DTI Distributed Generation Programme (Contractor: EA Technology); "Network Losses and Distributed Generation"; Contract Number: DG/CGI/00038/00/00, URN Number: 06/1238; 2006