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DIVERSITY MODELLING FOR ELECTRICAL POWER SYSTEM SIMULATION

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Abstract

This paper is consider diversity of generation and demand profiles against the different future energy scenarios and evaluate these on a technical basis. Compared to previous studies, this research applied a forecasting concept based on possible growth rates from publically electrical distribution scenarios concerning the UK. These scenarios were created by different bodies considering aspects such as environment, policy, regulation, economic and technical. In line with these scenarios, forecasting is on a long term timescale (up to every ten years from 2020 until 2050) in order to create a possible output of generation mix and demand profiles to be used as an appropriate boundary condition for the network simulation. The network considered is a segment of rural LV populated with a mixture of different housing types. The profiles for the 'future' energy and demand have been successfully modelled by applying a forecasting method. The network results under these profiles shows for the cases studied that even though the value of the power produced from each Micro-generation is often in line with the demand requirements of an individual dwelling there will be no problems arising from high penetration of Micro-generation and demand side management for each dwellings considered. The results obtained highlight the technical issues/changes for energy delivery and management to rural customers under the future energy scenarios.

Keywords: Demand side management (DSM); Low voltage (LV) network; Microgeneration (MG); Scenarios writing.

INTRODUCTION

Recently, the world has been facing severe climate change problems (Timothy J. Foxon et al., October 2010). One of the areas identified where savings could be met to reduce the impact on the environment is the mix of electricity generation and the level of use of energy. Thus, the electricity supply industry in the UK, and internationally, is seeing significant changes in order to tackle the climate change problem as well as to ensure a reliable, secure, affordable energy supply and a more efficient use of generation through the adoption of micro renewable and low carbon generation technologies (Willet Kempton et al., 1997, Kamalanath Samarakoon et al., 2009). The UK government's Micro-generation Strategy in acknowledged the potential of these technologies in contributing to achieve the above objectives. The combined production of heat and power (e.g. micro CHP) and renewable micro-generators (MG) (e.g. PV)

panels and micro-wind turbines) are believed to be able to increase the efficiency of local energy production and thusly help reduce carbon emissions (Peter Richardson et al., 2009, Ian Richardson, 2009). Also with the help of widespread demand side management (DSM) such as smart metering and direct load control, storage devices (e.g. electric vehicles (EVs)) and changes in consumer behaviour further impacts can be made on the electricity sector's targets.

This position requires changes to both the operation and management of the electrical system, several options identified will see a gradual shift from large centralised power plants to smaller and more distributed generators (Arturo. D. , April 2009). Such a change would have many implications for the existing distribution networks in terms of management and control. It is therefore important to examine how the networks in the UK today would respond to a move towards large-scale deployments of MG and adoption of DSM. Figure 1 shows an example of a future rural network with large penetrations of MG and energy storage. The analysis of the behaviour of such a system requires the modelling of both the electrical distribution system and the coupled MG devices in a realistic context. The remainder of the paper provides a review of relevant literature outlines the modelling approach adopted and applies this to a UK rural Zero Carbon Community network example. Finally simulation results are presented and conclusions and further work are given.

LITERATURE REVIEW

There are a number of previous studies that have investigated the impacts of a large penetration of MG (Peter Richardson and Andrew Keane, 2009) and DSM (Ian Richardson, 2009) on the distribution network system. Those and other studies generally addressed the network concerns in the problem; those of voltage imbalance (M Thomson and D Infield, 2008, Ian Richardson, 2009), quality of power (M Thomson and D Infield, 2008), voltage regulation, potential increases in network fault level and the breach of thermal constraints. However, the generation and demand data and how this data has been modelled for all these studies were different. Hence this study provides details about an integrated simulation approach to modelling the network and pays particular attention to how the diversity in the generation and demand profiles of these aspects will affect future system behaviour.

In addition, most studies performed to date have been rather simplistic in their approach and considered only the maximum and minimum limit of generation and demand profile as the boundaries conditions for their studies (Ian Richardson, 2009, Peter Richardson and Andrew Keane, 2009). These limits have been widely studied due to their importance in a conventional deterministic approach to network design. However, such a traditional approach could lead to large capital investment costs across the network that may not be tolerable and the power flow studies may not give an accurate result of the impact of a high level penetration of MG. It is evident from the published material that a range of profiles for both the demand and generation are crucial for understanding the nature of network performance with high penetrations of MG and DSM; hence the paper (G M Burt et al., 2008) was used as a foundation for this research but with the key differentiation being improved profiling especially in the stochastic load and generation modelling method as shown in figure 2.



Figure 1. Example of simplified low voltage network with large penetrations of microgeneration and demand side management



Figure 2. Changes of modelling approach from foundation paper (G M Burt et al., 2008)

MODELLING APPROACH

The method considered in this research utilises a forecasting technique to account for diversity in future generation and load profiles. The new scenarios for 2050 that are applied in this research are gained through considering a range of publicly funded UK future energy scenarios; LENS (OFGEM, OFGEM, December 2007), HDPS (G M Burt et al., 2008, C N Jardine and G W Ault), HiDEF (Consortium, [EPSRC], Brenda Boardman) and DECC (DECC [Department of energy and climate change], National strategy for climate and energy, 20 July 2009) scenarios which are all developed by considering several aspects such as the environment, policy, regulation and economic and technical factors.

A. Micro-generation and Demand profiles; UKGDS

In order to provide a more realistic appraisal of likely system performance, the halfhourly interval data of United Kingdom Generic Distribution Systems (UKGDS) network case study data set (United kingdom generic distribution system (UKGDS)) was applied as the basis for the profiles used in this research in order to give an accurate result for the load flow simulation studies and form accurate diversity profiles. The demand and generation profiles of UKGDS are then forecasted based on the growth rate(s) which are developed in line with the future distribution scenarios in the UK so as to create a large population of diverse devices and provide appropriate boundary conditions suitable for network studies. The practicality of the approach is demonstrated through its application to the analysis of the Zero Carbon Community network in this paper.

B. Publicly available electrical distribution scenarios in the UK

As part of this research work the authors' own future scenarios for 2050 have been considered based on the possible growth rates from publically available electrical distribution scenarios in the UK. Here are the summary of these different future scenarios:

1) HDPS (Highly Distributed Power Systems) scenarios

These scenarios were created by the consortium of UK Universities and industrial partners funded by the EPSRC which considered the control and design for future power systems(Consortium) with many distributed generation connections. It illustrate the scale of change required to reduce carbon emissions by 60% by 2050 (C N Jardine and G W Ault) in line with UK targets at the time.

2) LENS (Long- term Electricity Network Scenarios)

The project was undertaken by OFGEM under its commitment to look at a range of future scenarios for electricity networks that could arise as a consequence of market and policy developments (OFGEM). Together with OFGEM the LENS project team consisted of University of Strathclyde, Policy Studies Institute (PSI), University of Westminster and SPRU (Science and Technology Policy Research), University of Sussex (OFGEM, December 2007).

3) DECC scenarios (UK Low Carbon Transition Plan)

These scenarios were developed by the Department of Energy and Climate Change (DECC) (DECC [Department of energy and climate change]) and contain a comprehensive low carbon transition plan to 2020 which sets out how to deliver emission cuts of 18% on 2008 levels by 2020 and over a one third reduction on 1990 levels.

4) HiDEF (Highly Distributed Energy Futures) scenarios

This project is made up of UK universities and industrial partners and funded by the EPSRC and is an extension to the SUPERGEN: HDPS Power Systems project. It aims to "develop analytical sustainability and economic evaluation tools, interface technologies and coordination strategies that are required to demonstrate the credibility, test the feasibility and engineer the integrative solutions of a future power system that delivers sustainability and security through the widespread penetration of distributed

energy resources (DERs) and thus contributes to global ambition towards a low carbon future" (Consortium).

C. Forecasting scenarios for 2050

This research is conducted to improve the stochastic load and generation modelling method used by Galloway (2008), in which sample power generation time series profiles were processed and replicated in order to create a large population of diverse devices and provide appropriate boundary conditions suitable for network simulation as shown in figure 2. Contrastingly in this research, the method considered utilises a forecasting technique to account for diversity in future generation and load that becomes boundary conditions in network simulation study.

Previous studies that have employed forecasting of the load and demand profile in the power system area but most of these studies run on short and medium timescales (G.A. Adepoju, 2007). The work in this paper will focus on long term forecasting, typically 40 years, which means there is a need to implement a suitable forecasting method for this long term horizon. Based on (Chris Chatfield) forecasting methods are broadly classified into two groups i) Quantitative, also known as Univariate and Multivariate and ii) Qualitative, which is known as 'expert judgement 'or subjective.

The qualitative forecasting method, or scenarios writing, was the best choice for this research as this method is suitable for a long term forecasting period of up to 40 years. Moreover this scenarios writing method has been successfully applied in the power system area (R. Ghanadan and J.G. Koomey, 2005; C. E. T. Foote et al., 2005; I.M. Elders et al., 2005). Based on (R. Ghanadan and J.G. Koomey, 2005) scenarios writing provides a set of alternative contexts for exploring different ways that a future may unfold. Moreover, it is a unique technique as it can explore a range of possible outcomes resulting from uncertainty; in contrast with the quantitative forecasting method which aims to identify the most likely pathway and estimate uncertainties. Nevertheless, quantitative forecasting models are most efficient when under conditions such that extensive information is available and the understanding of governing is high.





However, when the interrelationships between factors are less stable and the predictability of the systems are lower, the quantitative forecasting method has shown to be inadequately equipped to characterise the processes of change (R. Ghanadan and

J.G. Koomey, 2005). This statement was supported in (Craig, 2002) which asserted that in a recent review of energy forecasting of the US in the last 50 years illustrated that the historical forecasts have regularly failed to represent actual conditions by systematically overestimating consumption and underestimating uncertainty. As stated in modelling approach section, the forecast scenarios were created by considering several aspects such as environment, policy, regulation, economic and technical issues across the published scenarios (LENS, HDPS, DECC and HiDEF). As such, there are four main points for future 2050 scenarios have been successfully created by the author; as shown in figure 3.

D. Rate forecast for 2020

1) Micro-generation profiles

Paper (C. E. T. Foote et al., 2005) designed a questionnaire to collect opinions on the suitability of different DG technologies to different LV grid condition and from this method the authors have identified the top three ranked technologies in each of the LV grid scenarios for 2010 and 2020. Since this paper more focuses in the future scenarios (2020 until 2050) the result for 2020 only will be considered in this research; based on this paper, photovoltaics emerged as the dominant technologies in 2020 and followed by reciprocating engines and wind turbines. Moreover, as one of the main points for 'future energy scenarios for 2050' in figure 3 above; the 'clean energy cash-back' scheme which also called FITs tariffs will be adopt in the UK and the eligible small-scale low carbon electricity technologies for this FITs tariff are Wind turbine, Solar photovoltaics (PV), Hydro, Anaerobic digestion and Domestic scale micro-CHP. Thus, based on these statements the Photovoltaics, Wind turbine and Micro-CHP have been chosen as the top three ranked technologies that suit the best for this research.

The 'prioritized but arbitrary assignment' method from paper (C. E. T. Foote et al., 2005) have been applied and altered to be suit with the case of this research in order to produce the growth rate(s) value. From the four mains points for future 2050 scenarios as shown in figure 3, the total percentages of energy value that need to come from the renewable source and low carbon sources by 2020 is 42%. Thus, the total growth rate(s) of each micro-generation that have been considered in this research could be split between them. The split could be based on an arbitrary division, with the top-ranked technology taking, say, half. Then the second ranked taking a third and the third ranked taking a sixth (C. E. T. Foote et al., 2005). This arbitrary value of growth rate(s) between technologies would produce realistic and useable scenarios for micro-generation profiles as summaries in more detail in table 1. From these scenarios and the methodologies laid out in (C. E. T. Foote et al., 2005) and (G M Burt et al., 2008), the growth rate(s) of micro-generation profiles for Photovoltaics, Micro-Wind Turbines and Micro-CHP as well as demand profiles for Smart Meters and Electric Vehicles were forecast and created as shown in figure 4.

2) Demand profiles

Demand profiles that studied in this research includes Smart meters and Electric vehicles were forecast and created based on the four main points for future 2050; as shown in figure 3. As mention above these forecast scenarios were created by considering several aspects such as environment, policy, regulation, economic and technical issues across the published scenarios in the UK. Based on future energy scenarios 2050 created in figure 3, every home have applied Smart meter by the end of 2020; this statement gave an idea that by 2020 the demand profiles for every home in

the UK will be reduced to 50% and this reduction rate(s) were predicted to be consistent until 2050. Electric vehicle's percentage for 2020 was also created by considered one of the main points as created in 'future energy scenarios 2050'; as shown in figure 3. By targeting 10% of transport demand need to come from the renewable source and low carbon sources by 2020, this research applied 10% as a growth rate(s) value for demand profiles as represent the adoption of Electric vehicle in the network studies.

Micro- generation Technologies	Division	Percentage of growth rates for MG from 42%
Solar Photovoltaic	50%	21%
Micro Wind Turbine	33%	14%
Micro CHP	17%	7%

Table 1. Defining growth rate(s) for micro-generation penetration in 2020

Since objective of this research is to model and forecast the future profile; 2020 until 2050. Thus, the growth rate(s) in table 1 were used as a base growth rate(s) which it is expected that every 10years the value of growth rate(s) for the profile will be double the rate(s) of the base growth rate(s) as shown in table 2 aligned with the forecast scenarios for 'future' energy systems in figure 3.

 Table 2. Micro-generation and demand side management penetration forecast rates for future energy through to 2050

Rate forecast for energy 2020	Rate forecast for energy 2030				
Energy produced profile from Microgeneration	Energy produces profiles from Microgeneration				
> Solar Photovotaic; increase to 21%	> Solar Photovotaic; increase to 42%				
>Micro Wind turbine; increase to 14%	>Micro Wind turbine; increase to 28%				
>Micro CHP; increase to 7%	>Micro CHP; increase to 14%				
Energy demand profiles	Energy demand profiles				
>Electric vehicle; increase to 10%	>Electric vehicle; increase to 20%				
>Smart meter (100% installed); reduce to 50%	>Smart meter (100% installed); reduce to 50%				
Rate forecast for energy 2040	Rate forecast for energy 2050				
Energy produced profile from Microgeneration	Energy produced profile from Microgeneration				
> Solar Photovotaic; increase to 63%	> Solar Photovotaic; increase to 84%				
>Micro Wind turbine; increase to 42%	>Micro Wind turbine; increase to 56%				
>Micro CHP; increase to 21%	>Micro CHP; increase to 28%				
Energy demand profiles	Energy demand profiles				
>Electric vehicle; increase to 30%	>Electric vehicle; increase to 40%				
>Smart meter (100% installed); reduce to 50%	>Smart meter (100% installed); reduce to 50%				

SIMULATIONS

A. Micro-generation and demand profile

Figures 4 and 5 show the original 10 year UKGDS forecast profiles based on growth rate(s) created previously (United kingdom generic distribution system (UKGDS)). The

final profiles have been produced by forecasting the original profile data from UKGDS for every 10 years based on the growth rate of the publically available scenarios of electrical distribution system in the UK research which used as a boundary conditions in the network simulation studies.

B. Overview of the network modelled

Power flow studies were run in order to investigate the effects of high penetrations of MG and DSM on the future 'smart network'. The network was implemented using DIgSILENT Powerfactory V14.0 software and was used as a test-bed study for this research. By modelling individual dwellings network security issues such as under and over voltage, power quality and reverse power flow for each dwelling could be explored in more detail. Here, the example of a Zero Carbon Community network (Figure 1) was designed with the main terminal connected to the three-phase network and each load was connected to single phase network with an underground cable. The load and generation profiles were developed and forecast by the process described above and were installed in each dwelling of the network. The high-level characteristics of this model are its long circuit length, low customer density, radial topology and large overall size.



Figure 4. Forecasting growth rates for half-hourly interval of power production data of a day after the adoption of (a) solar photovoltaic (b) Micro-Wind turbine and (c) Combined Heat and Power for 2050



Figure 5. Forecasting rates for half-hourly interval of demand unrestricted data of a day after the adoption of (a) Electric vehicle and (b) Smart meter demand data for 2050

RESULTS AND DISCUSSION

Studies have been conducted for the network and details of the results are shown in figure 6 until 9 and the summaries of the result shown in Table 3. The results from table 3 identify that the demand across each of the time periods cannot totally be met by the configuration of onsite generation. Electrically the network is balanced in terms of power quality measures (see figure 6) although loads and generation were installed in a different phase of each bus. This balance is largely achieved because the network still has support from the main grid enabling shortfalls in generation to be covered.



Figure 6. The result of unbalance power; the result was taken at the first substation in the network of Zero Carbon network



Figure 7. The results of voltages between different phase (A, B, C) and (b) power between load and micro-generators in the bus BH8 in the network



Figure 8. The results of (a) voltages between different phase (A, B, C) and (b) power between load and micro-generators in the bus MH1 in the network



Figure 9. The results of (a) voltages between different phase (A, B, C) and (b) power between load and micro-generators in the bus M7 in the network

Due	On site	00:00 04:20		05:00 00:20		10:00 14:20		15:00 10:20		20:00 22:20	
Bus	OII-Site	00:00 -04:30		05.00-09:50		10:00-14:50		15:00-19:50		20.00-25:50	
	generation										
BH8	On-site	Main	80%	Main	10%	Main	72%	Main	73%	Main	48%
	generation	Grid		Grid		Grid		Grid		Grid	
	could only			-							
	support 39% of	On-Site	20%	On-	90%	On-	22%	On-	27%	On-	52%
	demand	Gen.		Site		Site		Site		Site	
	needed			Gen.		Gen.		Gen.		Gen.	
MH1	On site	Main	0%	Main	37%	Main	50%	Main	68%	Main	56%
IVIIII	on-site	Crid	070	Crid	5770	arid	5770	Crid	0070	Crid	5070
generation	Grid		Gild		gna		Grid		Grid		
	could only	On-Site	Extra	On-	53%	On-	41%	On-	32%	On-	44%
	support 52% of	Gen	49% of	Site		Site		Site		Site	
	demand	oom	demand	Gen		Gen		Gen		Gen	
	needed.		needed	Gen.		Gen.		Gen.		Gen.	
M7	On-site	Main	50%	Main	0%	Main	5/1%	Main	18%	Main	12%
1417	on-site	Crid	5770	Crid	070	Crid	5470	Crid	4070	Crid	1270
generation	Onu		Onu		Onu		Onu		Onu		
	could only	On-Site	41%	On-	Extra	On-	45%	On-	52%	On-	88%
supp	support 74% of	Gen.		Site	69% of	Site		Site		Site	
	demand			Gen	demand	Gen		Gen		Gen	
	needed.				needed	2.5111		2.5111		2.511	

Table 3. Result of power flow analysis for selected of dwelling/bus in the network

CONCLUSIONS AND FURTHER WORK

In this paper, the energy and demand profiles have been created based on publically available energy scenarios for the UK. These profiles are realistic profiles for 2050 and were used as appropriate boundary conditions for the analysis of the future 'smart networks' Zero Carbon network. It is shown from result in table 3 that even though the value of the power produced from each Micro-generation is often in line with the demand requirements of an individual dwelling there is still a shortfall in supplying the full demand. However, the network results show that for studies considering power and voltage values, each phase of the network remains balanced. As the network still has the support from the main grid enabling shortfalls in generation to be balanced through imports. Thus, this paper shown that there will be no problems arising from high penetration of Micro-generation and Demand side management for each dwelling in the community network as long as the network has the support from the main grid.

The 'smart network' considered here might look advanced compared to the existing infrastructure and management but in line with the future scenarios such systems may appear bringing with them a challenge for the network operator and the future. This research has a special contribution to our country as the energy scenarios in Malaysia have been subject to tremendous change from the 8th Malaysia Plan (2001-2005) until the current plan, the 10th Malaysia Plan (2011-2015). Oil and gas have traditionally been the main energy sources in Malaysia, however, with its gas reserves estimated to last only another 33 years and oil for only 19 years, the Malaysian government has been strengthening the role of renewable energy (RE), as the fifth main energy source as noted in (UniMAP, wteconsult). Moreover, this research may help the Malaysian government in obtaining a clearer viewpoint regarding the implication of an increased penetration of generation coming from renewable sources to Malaysia's network system.

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