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An Evaluation of Distributed Generation Constrained Connection Managers

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ABSTRACT: This paper presents the technical considerations and economics of a number of solutions that would allow a greater installed capacity of distributed generation to be connected to, and managed within, the distribution network. The paper describes the various solutions and compares their relative energy yield and economics. It was found that a distributed generation constrained connection manager informed by dynamic thermal ratings is the most attractive solution for developers wishing to connect wind generation to this case study network when compared to alternative solutions.

Keywords: Distributed Generation, Dynamic Thermal Rating, Control, Constrained Connection, Economics.

I. INTRODUCTION

In order to meet the United Kingdom (UK) government's environmental targets for 2010, approximately 10GW of additional distributed generation (DG) will have to be connected to UK distribution networks [1]. As this growth in DG is realised, power flows within distribution networks are expected to become increasingly congested. This may act as a barrier, inhibiting the amount of DG that can connect to the network and may impact on the energy yield (and hence profitability) of existing schemes as network capacity becomes saturated. Thus methods to manage the connection of DG schemes, in light of power flow constraints, could be beneficial both in the UK and internationally. The current practices regarding DG connections may:

- 1) Constrain the size of schemes at the planning stage to the existing capacity of the network based on static component thermal ratings.
- 2) Entail relatively high network reinforcement costs to connect schemes in excess of the network's current capacity.
- 3) Involve basic 'tripping' schemes to manage the DG output at times of constraint.

For the case study considered, comprising DG with an intermittent power output, this paper demonstrates that the energy yield from the unconstrained reinforcement solution is only slightly more than that delivered by an alternative operational solution utilising dynamic circuit ratings. DG constrained connection managers (CCMs) are one approach that facilitates a greater energy yield from DG schemes based on the available network capacity. It is acknowledged that asset ratings are not a static phenomenon but vary as a result of the prevailing meteorological conditions throughout the year. Thus increased amounts of electricity can be passed through distribution networks if the thermal limits of the network components are calculated from present conditions rather than from a fixed seasonal figure.

For the purpose of this research, dynamic thermal ratings (DTRs) are defined as a time-variant rating which can be practically exploited without damaging components or reducing their lifetime. Actual environmental parameter measurements are used as the input to steady state thermal models. In order to calculate and exploit the DTR, it is assumed that local environmental parameters are available and that there are no outages (planned or unplanned) present within the electrical power system. Short term transients, taking into account the thermal capacitance of power system assets are not included within the DTR assessment. It is felt that this would not affect the MWh/annum throughput of energy within the electrical power system.

The 132kV section of the network presented in this paper is a subsection of a wider trial network forming the research basis for the 'Active Control of Distributed Generators based on Component Thermal Properties' [2]. The collaborative project (involving AREVA T&D, Durham University, Imass, PB Power and ScottishPower EnergyNetworks) aims to develop, install and test a CCM for DG informed by DTRs.

This paper makes a comparison between a network reinforcement solution, two DG tripping solutions and two CCM solutions. Each solution would allow a greater installed capacity of DG to be connected to a single point within the distribution network. The CCM solutions increase in sophistication both in the manner in which the DG power output is controlled (demand-following as opposed to tripping) and by utilising different component rating regimes. By incorporating a backup trip protection system into the more sophisticated solutions, the risk of CCM system failure is minimised and thus the security of the network is maintained. An energy yield, electrical loss and economic evaluation show that, in this case, a CCM informed by DTRs is the most attractive solution for facilitating DG developer revenue gains when compared to the alternative solutions.

II. BACKGROUND

Conductor temperature rise is influenced by the ability of the component to dissipate to the environment the heat produced by the Joule effect governed by external conditions such as ambient temperature and wind speed.

Due to the extreme variability and unpredictability of meteorological conditions, fixed seasonal conditions are used at present to determine the most appropriate component rating. A DTR approach to network management consists of estimating or measuring component temperatures and real current carrying capacities, in order to allow the utilisation of power system components to be safely increased but maintained within continuous design specifications.

Research carried out at Durham University aiming to develop a DTR system shows, for typical UK climates, that there is an average exploitable headroom for overhead lines, underground cables and power transformers in the region of 80%, 12% and 15%, respectively, beyond the static component rating. This is in agreement with the findings described in [3] and [4].

The DTR system under development at Durham University comprises a number of different weather stations and temperature measurement devices, placed in different locations over a wide network area. These are connected to a centralised computer which is responsible for estimating the current carrying capacities of the network component based on the present meteorological conditions. This information may then be used as a decision support tool for the secure operation of the distribution network.

DG Constrained Connection Managers

Engineering Technical Recommendation (ETR) 124 [5] presents a number of different solutions that may be developed to actively manage the power flows associated with the connection of a single DG scheme. The most basic systems involve the disconnection of DG in the event that the power output from the DG scheme exceeds the capability of the network (assessed as static capacity of network assets plus the minimum load demand). This solution may be developed further by actively switching between seasonal fixed ratings and adjusting the number of disconnected generators accordingly. More sophisticated CCM solutions are developed from the principle of generation power output control, utilising technologies such as the pitch control of wind turbine blades to capture a desired amount of wind energy. In this approach the powers flowing in the critical feeders of the network are monitored, taking load demand into account, and the power exported from the DG scheme is controlled to ensure the capability of the network is not exceeded. This may be developed as a CCM utilising static asset ratings, with demand-following control of the DG output, or as a CCM utilising asset dynamic thermal ratings, with demand-following control of the DG output.

III. OVERHEAD LINE DYNAMIC RATING

This paper focuses on the application of a DTR system to overhead lines, but it has also been applied to cables and

power transformers. The fundamental concept behind the component rating is that the temperature limits of the power component must not be exceeded in order to avoid damaging the component. For overhead lines in particular, a temperature rise leads to a reduction in conductor tension and to an increase in the sag. Typical values for maximum conductor temperature are between 50°C and 90°C.

Component temperature is not a constant value but depends upon the energy balance between the heat produced inside the component and the heat exchange on its surface. The heat dissipated depends on the electrical current flowing in the conductor as well as the conductor's resistance to the current flow. However, the heat exchange is mainly influenced by the temperature difference between the conductor and ambient environmental conditions, and by other external factors such as wind speed or solar radiation.

Considering the heat dissipated by the Joule effect (I^2R), the heat exchanged by convection (Q_c) and radiation (Q_r), and the solar radiation (Q_s), the energy balance for an overhead line conductor is described in Equation (1).

$$RI^2 + Q_s = Q_c + Q_r, \quad [Wm^{-1}] \quad (1)$$

The heat gained by solar radiation can be calculated as in Equation (2) considering solar radiation (W_s), conductor diameter (D) and an absorption coefficient (α).

$$Q_s = \alpha W_s D \quad (2)$$

The radiative heat exchange depends on conductor temperature (T_c), ambient temperature (T_a), the Stefan-Boltzman constant (σ) and an emission coefficient (ϵ), as given in Equation (3).

$$Q_r = \epsilon \sigma (T_c^4 - T_a^4) \pi D \quad (3)$$

The convective heat exchange depends on air thermal conductivity (λ) and the Nusselt number (Nu) as given in Equation (4).

$$Q_c = \pi Nu \lambda (T_c - T_a) \quad (4)$$

The Nusselt number can be calculated using a wind direction correction factor (K_{dir}) and the Reynolds number (Re) as given in Equation (5).

$$Nu = K_{dir} \cdot (0.65 \cdot Re^{0.2} + 0.23 \cdot Re^{0.61}) \quad (5)$$

The wind direction correction factor and the Reynolds number can, in turn, be calculated as given in Equations (6) and (7), using wind direction (W_d), wind speed (W_s) and empirical parameters (A, B, C).

$$K_{dir} = A + B \sin^C(W_d) \quad (6)$$

$$Re = 1.644 \cdot 10^9 \cdot W_s \cdot D \left(\frac{T_c + T_a}{2} \right)^{-1.78} \quad (7)$$

More information about the overhead line thermal model may be found in [6] and [7]. The simulated daily dynamic thermal rating of a Lynx conductor is given in Figure 1 for the calendar year 2005. The simulation used the model described in Equations (1) to (7) and historical meteorological data for the ‘Valley’ area of Wales, UK. As a comparison, the seasonal ratings for the conductor are also plotted in Figure 1.

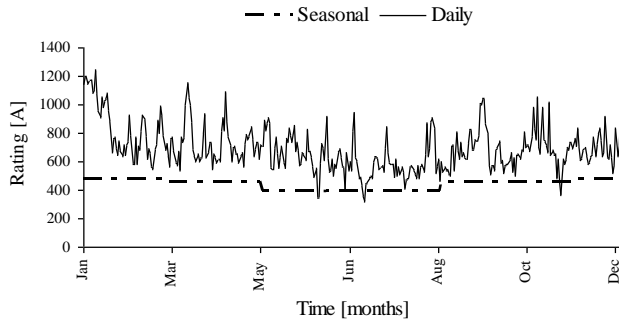


Figure 1- Rating variation of Lynx overhead line

IV. CASE STUDY NETWORK

The case study network shown in Figure 2 is derived from a section of ScottishPower’s distribution network. Although it is not displayed in Figure 2, Engineering Recommendation P2/6 [8] ‘security of supply’ requirements are met for the connected load through an underlying meshed 33kV infrastructure. An installed wind capacity of 150MW was selected to create a constrained connection.

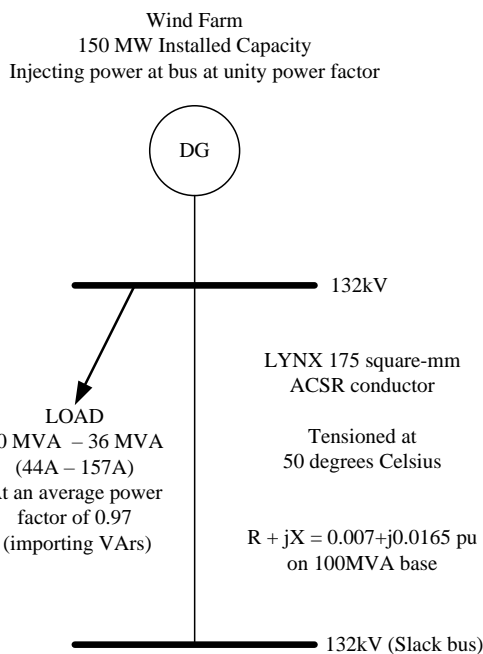


Figure 2 – The 132kV network

Analytical Considerations

The constrained connection configurations were simulated through an offline analysis of the typical half-hourly regional loading and wind farm output data for the calendar year 2005.

Table 1 displays the ratings used in the energy yield quantification analyses. The static and seasonal ratings were based on the SP Manweb Long Term Development Statement [9]. The average simulated daily minimum DTR is also given in Table 1. Offline analysis showed that a thermal constraint would be met in this section of the network before voltage or fault-level limitations.

Table 1 - Summary of Ratings Utilised

Conductor Type	Rating Condition	Rating (A)	Rating (MVA)
Lynx	Static	390	89
Lynx	Seasonal Summer Continuous	390	89
Lynx	Seasonal Spring / Autumn Continuous	450	103
Lynx	Seasonal Winter Continuous	485	111
Lynx	DTR (Average Daily Minimum)	695	159
Upas	Static	770	176

V. SOLUTION DESCRIPTIONS

Solution 1: DG tripping based on a static assessment of network availability

Solution 2: DG tripping based on component seasonal thermal ratings

Solution 3: DG output control through a CCM based on component static thermal ratings and load demand

Solution 4: DG output control through a CCM based on component dynamic thermal ratings and load demand

Solution 5: Network reinforcement to provide an unconstrained connection.

Each section below assesses the strengths and weaknesses of the particular solution, describes the algorithm used to manage the DG output and gives an approximate cost of the solution installation.

Tripping Solutions

The tripping solution schematic is shown in Figure 3 and implements the algorithm given in Equation (8).

$$\begin{aligned} \text{If:} & \quad \text{Current} > \text{Rating} \\ \text{Then:} & \quad \text{'Trip' DG to Rating} + \text{Base Load} \end{aligned} \quad (8)$$

When this algorithm is implemented with the static rating of 390A, the DG output will be tripped to 434A at unity power factor (390A rating + 44A base load) if the current flow in the line exceeds 390A. This corresponds to the implementation of Solution 1.

Similarly, in a seasonal rating implementation [10], such as Solution 2, the DG output will be tripped to the seasonal rating plus the base load if line flow exceeds the seasonal rating. These solutions are conservative as they do not account for the dynamic nature of the load and thus they trip generators off rather than constraining them back. Furthermore, the seasonal rating approach bears the latent risk of an anomalous ‘hot day’ where the prevailing

meteorological conditions mean that assets may be rated higher than they should be.

Estimated Basic Tripping Relay Cost:
Local tripping relay £10k

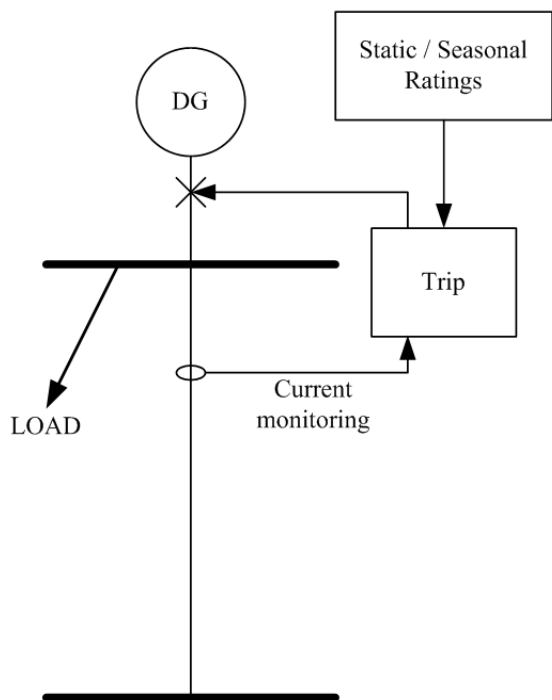


Figure 3 – The DG trip solution with static or seasonal thermal ratings

Constrained Connection Management Solutions

Figure 4 shows the schematic that allows the algorithm in Equation (9) to be implemented to control the DG output based on static or dynamic network availabilities and load demand.

If: $Current > Rating$ (9)
Then: Control DG output to $Rating + Load Demand$

Control algorithm (9), implemented with a static rating of 390A, corresponds to Solution 3. The CCM solutions are more sophisticated than the DG trip options and have the potential to offer energy yield gains by taking into account the dynamic nature of the load demand. Additional power flow monitoring equipment is required to facilitate a demand-following DG output control regime.

In the case of the DTR-informed system (Solution 4), additional thermal and meteorological monitoring is also required. To ensure the safe and secure operation of the network assets, each CCM solution requires an auxiliary trip system, which calculates the same ratings as the control system, to act as a backup in the case of CCM system operation failure.

Estimated cost of demand-following DG output control based on static/seasonal ratings:

Monitoring and Regulation Equipment: £50k

Estimated Cost of demand-following DG output control based on DTRs:

Monitoring and Regulation Equipment: £100k

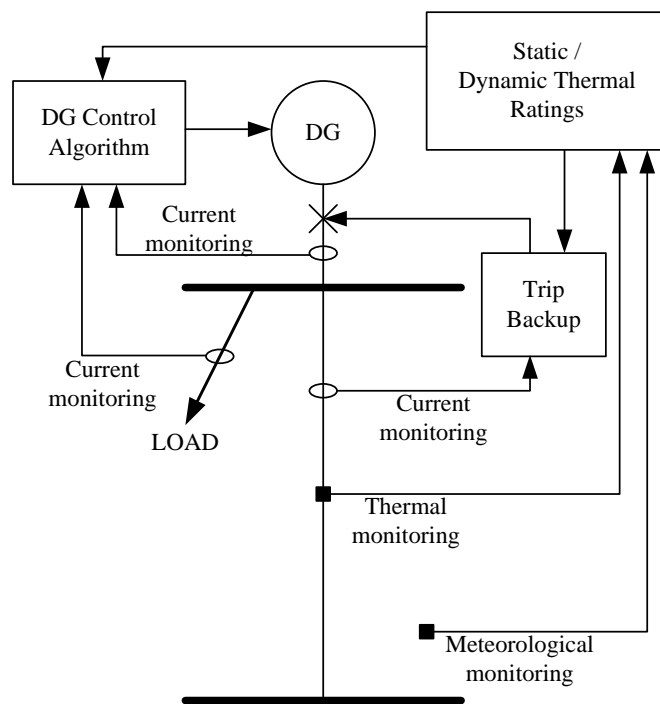


Figure 4 – The demand-following DG output control solution with static or dynamic thermal ratings

Network Reinforcement Solution

The network reinforcement option (Solution 5) would require a replacement 132kV overhead line to be constructed and the existing overhead line to be decommissioned. It is assumed that the replacement line conductor is ‘Upas’ 300mm² AAAC. If this conductor is tensioned to maintain statutory ground clearances [11] at an operational temperature of 75°C, the rating would be sufficient to provide an unconstrained annual energy yield from the DG scheme. However, it requires the largest capital investment [12] and could take several years to be installed due to the lengthy environmental assessments, planning permission, commissioning and building processes.

Estimated Reinforcement Cost:

Installation of up-rated 132kV line (7km) £2M

VI. QUANTIFICATION METHODOLOGY

Weather data from Valley (Wales, UK) was used to estimate weather parameter values along the length of the overhead line. These, in conjunction with the model described previously, were used to calculate a series of daily thermal ratings for the studied line. The method detailed in [6] was used for the overhead line modelling, with the correction for wind direction, as given in [7].

Control algorithms (8) and (9) were applied to the case study network (with the relevant rating operating regime)

and the necessary constraints were implemented offline. The annual energy yield at the DG connection busbar was calculated for each solution, by integrating the real power output of the DG scheme across the year in 30 minute intervals. The per unit electrical losses (I^2R) resulting from each solution implementation were calculated using the current flowing in the overhead line with per unit resistances of 0.0070 and 0.0041 for the ‘Lynx’ and ‘Upas’ conductors respectively. These were then summated across the year on a half-hourly basis to produce annual energy loss figures. For each solution the net annual revenue was calculated by multiplying the annual energy yield at the DG connection bus by £101.43/MWh (£52.15/MWh wholesale electricity price [13] + £49.28/MWh ‘Renewables Obligation Certificate’ sale price [14]) and making an adjustment for the cost of the losses incurred by transferring this energy to the slack busbar (calculated as the annual energy losses multiplied by the wholesale electricity price).

The basic tripping scheme based on summer static ratings (Solution 1) was taken as the datum solution with a capital cost of £10k and net annual revenue of £42.35M (based an energy yield at the DG connection busbar of 418.1GWh and 1.3 MWh lost through power transfer to the slack bus). The estimated marginal costs (due to additional network costs), predicted marginal revenues (due to additional energy yield) and marginal losses (resulting from electrical power transfer to the slack busbar and changes in electrical resistance of the line) were compared to this solution. This allowed a basic Net Present Value (NPV) comparison of the alternative solutions, based on their relative marginal costs and marginal revenues. A 10% discount rate and 20 year economic life was assumed [15]. The capital cost of the wind farm itself was neglected as this would be constant across each solution. Furthermore, because the wind farm is connected at via a single overhead line, any faults or scheduled maintenance on this line will cause it to shut down. Since such events have an equal constraint on the energy yield of each solution this effect was neglected. All the costs within the financial evaluations are estimates of equipment costs, based on the most appropriate data available at the time of consideration.

VII. RESULTS

The results from the quantification methodology are summarised in Table 2.

Solution 1: DG tripping based on a static assessment of network availability

Solution 2: DG tripping based on component seasonal thermal ratings

Solution 3: DG output control through a CCM based on component static thermal ratings and load demand

Solution 4: DG output control through a CCM based on component dynamic thermal ratings and load demand

Solution 5: Network reinforcement to provide an unconstrained connection

Table 2 – Quantification Methodology Results

Solution	Marginal Cost (£k)	Marginal Annual Energy Yield at DG Connection Bus (%)	Marginal Annual Energy Losses (%)	Marginal Net Annual Revenue (£M)	Marginal 20 Year NPV @ 10% dcf (£M)
1	0	0.00	0.00	0.00	0.00
2	0	4.93	18.41	2.08	17.71
3	40	5.24	18.99	2.21	18.76
4	90	10.75	43.39	4.53	38.46
5	1990	10.76	-16.31	4.58	36.97

VIII. DISCUSSION

For this case study, it appears that controlling DG output to follow load demand based on a single summer static rating (Solution 3) yields greater revenue for the developer than switching ratings on a seasonal basis and tripping DG as a result (Solution 2). DG tripping based on seasonal thermal ratings (Solution 2) requires a lower initial investment, however, the risk on the part of the DNO is greater if seasonal ratings are utilised. This is due to the possibility of an anomalous hot day occurring when ratings have been relaxed. This risk may be mitigated by investment in a dynamic thermal ratings system to provide accurate knowledge of the current thermal status of the network.

Economically, the most attractive solution to the developer is the CCM based on component dynamic thermal ratings and load demand (Solution 4). The annual revenue of the project is increased by £4.53M and shows the highest marginal NPV at £38.46M. For this case study, this solution appears to be more attractive than the alternative reinforcement option (Solution 5). This provides an unconstrained energy yield (and hence maximum annual revenue) but would require an extra capital investment of £1.99M to upgrade the overhead line.

Network reinforcement (Solution 5) would reduce network losses relative to the other solutions since the larger cross-sectional area of the conductor would reduce the electrical resistance to power flow. However, despite increasing electrical losses through implementing a CCM solution, the cost of capital for the DG developer is likely to make the active management solutions, with lower upfront costs, a more attractive investment.

IX. CONCLUSION

This paper has presented the technical solutions that would allow a greater installed capacity of distributed generation to be connected to, and managed within, the distribution network. This could be of value in situations where power flows have become congested as a result of distributed generation proliferation. For each solution the annual energy yield was quantified and used as a basis to compare solutions using an estimate of their relative Net Present Value to the distributed generation developer. It was demonstrated that a constrained connection manager informed by dynamic thermal ratings was the most cost effective solution for facilitating wind generation access to the case study network when compared to alternative

solutions. Work is continuing in this area to realise the potential of constrained connection manager solutions.

X. ACKNOWLEDGEMENTS

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XI. REFERENCES

- [1] Mott MacDonald, "The Carbon Trust & DTI Renewables Network Impact Study, Annex 1: Capacity mapping and market scenarios for 2010 and 2020", London, 2003.
- [2] A. Neumann, P.C. Taylor, S.C.E. Jupe, A. Michiorri, D. Curry, A Goode, D.A. Roberts, "Dynamic thermal rating and active control for improved distribution network utilisation", PowerGrid Europe, Milan, Italy, June 2008.
- [3] P.D. Belben, C.D. Ziesler, "Aeolian Uprating: How Wind Farms Can Solve Their Own Transmission Problems", World Wind Energy Conference and Exhibition, Berlin, Germany, July 2002.
- [4] D.A. Douglass, A.A. Edris, "Real-time monitoring and dynamic thermal rating of power transmission circuits", IEEE Transactions on Power Delivery, Vol.11, No.3, 1996, pp.1407-1418.
- [5] Energy Networks Association, "Engineering Technical Recommendation 124", ENA, London, 2003.
- [6] IEC, "IEC/TR 61597 - Overhead electrical conductors – calculation methods for stranded bare conductors", 1995.
- [7] CIGRE WG 22.12, "The Thermal Behaviour of Overhead Conductors – Section 1", Electra, Vol. 144-3, 1992.
- [8] Energy Networks Association, "Engineering Recommendation P2/6 – Security of Supply", ENA, London, 2006.
- [9] Scottish Power Transmission and Distribution, "Distribution Long Term Development Statement for SP Manweb plc for the years 2005/06 to 2009/10", Scottish Power Plc, Merseyside, 2005.
- [10] D.A. Roberts, "Network Management Systems for Active Distribution Networks – A Feasibility Study, Report Number: K/EL/00310/REP, URN 04/1361", DTI, London, 2004.
- [11] DTI, "The Electricity Safety, Quality and Continuity Regulations", The Stationery Office, London, 2002.
- [12] Mott McDonald, "The Carbon Trust and DTI Renewables Network Impact Study, Annex 3: Distribution Network Topography Analysis", London, 2003.
- [13] European Commission, "Quarterly Review of European Gas and Electricity Prices", Luxembourg, 2005.
- [14] Ofgem, "Renewables Obligation: Annual Report 2006-2007", Ofgem, London, 2008.
- [15] BERR, "Strategic Environmental Assessment, Wind Background – Cost of Wind Power Generation", online at <http://www.offshore-sea.org.uk>, 2004. (Last accessed 5th August 2008)

XII. BIOGRAPHIES

Dr Philip Taylor, BEng, EngD, CEng, MIEE, MIEEE, FHEA

Phil Taylor is a Senior Lecturer in the Energy Group in the School of Engineering, Durham University. He received an Engineering Doctorate in the integration and control of renewable energy in electrical networks from the University of Manchester Institute of Science and Technology (UMIST) in 2001.

He has significant industrial experience as an electrical engineer including a period working in the transmission and distribution projects

team at GEC Alstom. His most recent position was Research and Development Director at Econnect, a consultancy firm specialising in the grid integration of renewable energy.

He acts as an independent assessor of research proposals for the DTI relating to their New and Renewable Energy Programme and is a member of the EPSRC Peer Review College.

He is a member of the CIGRE working group C6.11, "Development and Operation of Active Distribution Networks".

He is a member of the editorial board for the newly formed International Journal of Renewable Energy Technology (IJRET) www.inderscience.com/ijret

Samuel Jupe, M.Eng (Hons) Dunelm

Samuel Jupe is a doctoral researcher in the Energy Group at the School of Engineering, Durham University.

He is currently researching the active control of distributed generators based on component thermal properties. He received a Master of Engineering degree in General Engineering from Durham University in 2006. His interests include the management of distributed generation constrained connections and fuzzy control systems.

Andrea Michiorri

Andrea Michiorri graduated in Mechanical Engineering at the University of Rome "La Sapienza" in 2005. He is a doctoral researcher in the Energy Group at the School of Engineering, Durham University. His research involves the influence of environmental parameters on distribution network components and state estimation techniques. His scientific interests include energy conversion and transmission systems and computer applications in energy.

Christopher Berry, BSc (Hons), CEng, MBA, MIET

Christopher Berry has over 25 years experience in the UK electricity industry. He started his career as a Craft Apprentice with British Nuclear Fuels and progressed with them to achieve Chartered Engineer status with responsibility for the design of instrumentation, control and electrical aspects of a number of new major facilities for the Sellafield site. He then joined ScottishPower/Manweb where he has held a variety of power distribution system design and project management positions. Currently he is responsible for design standards for the SP Manweb plc distribution system at all voltage levels and leads a team of professional engineers responsible for the design and development of the 132kV and 33kV networks.

Chris is also an active member of the design work stream of the Distribution Working Group (DWG) – the United Kingdom Electricity Supply Industry focus group charged with identifying and co-ordinating R&D work to address the issues that affect the transition of power systems to a low-carbon future. He received his BSc (Hons) in Electrical and Electronic Engineering from the University of Manchester Institute of Science and Technology (UMIST) in 1985 and his MBA (Distinction) from the Edinburgh Business School in 2002. He is a corporate member of the Institution of Engineering and Technology (MIET).