

UK Scenario of Islanded Operation of Active Distribution Networks – A Survey

S.P.Chowdhury, *Member IEEE*, S.Chowdhury, *Member IEEE*, P.A.Crossley, *Member IEEE* and Chui Fen Ten, *Non-Member*

Abstract- This paper reports on the current UK scenario of islanded operation of active distribution networks with distributed generators (DGs). Different surveys indicate that the present scenario does not economically justify islanding operation of active distribution networks with DGs. With rising DG penetration, much benefit would be lost if the DGs are not allowed to island only due to conventional operational requirement of utilities. Technical studies clearly indicate the need to review parts of the Electricity Safety, Quality and Continuity Regulations (ESQCR) for successful islanded operations. Commercial viability of islanding operation must be assessed in relation to enhancement of power quality, system reliability and supply of potential ancillary services through network support. Demonstration projects under Registered Power Zone and Technical Architecture Projects should be initiated to investigate the utility of DG islanding. However these efforts should be compounded with a realistic judgement of the associated technical and economic issues for the development of future power networks beyond 2010.

Keywords - Islanding Operation, Protection Coordination, Renewable Distributed Generation, Loss of Grid, Digital Protection, Global Warming

I. INTRODUCTION

With growing concern about global warming and the use of fossil-fuels for power generation, the new paradigm of renewable distributed generation is gaining popularity across the world. This paper reports on the current UK scenario of islanded operation of active distribution networks with distributed generators (DGs). Different surveys indicate that the present UK scenario does not economically justify islanding operation of active distribution networks with DGs. Several studies are undertaken by Department of Trade and Industry (DTI), Technical Steering Group (TSG), Distributed Generation Co-ordinating Group (DGCG) and others for the investigation into the technical, commercial and regulatory benefits and risks from the power islanded operation of DGs.

S.P.Chowdhury is with Electrical Engineering Department, Jadavpur University, Kolkata, India (e-mail: spchowdhury63@yahoo.com).

S.Chowdhury is with Women's Polytechnic, Kolkata, India (e-mail: sunetra69@yahoo.com).

P.A.Crossley is with University of Manchester, UK (e-mail: p.crosseley@manchester.ac.uk)

Consultation has been done with selected Distribution Network Operators (DNOs), Gas and Electricity Market regulatory body of UK (Ofgem) and others to obtain their views on islanding. The literature review confirms that islanding can be implemented from a technical standpoint. With rising DG penetration, much benefit would be lost if the DGs are not allowed to island only due to conventional operational requirement of utilities. Technical studies clearly indicate the need to review parts of the Electricity Safety, Quality and Continuity Regulations (ESQCR) for successful islanded operations. Very few current islanding operations are found mostly being geographic islands where islanded operation of diesel generators is the normal supply arrangement. When sub sea cables had been laid to join these islands to the mainland distribution network, the ability of the remote island network to operate in islanded mode are maintained. The benefits of islanding on these islands are clearly seen on examining the relative vulnerability of sub sea cables coupled with anticipated repair times. It is seen that islands can be operated in a safe and satisfactory manner provided the identified criteria are met. There are capital and revenue cost implications to meet the necessary criteria for both the DGs and the DNOs. These costs vary significantly between possible sites of application and the size and type of DGs. There must be suitable financial benefits to the DNOs and DGs for acceptable return on their investment.

Several benefits of DG islanded operation are identified for customers and all the other stakeholders, including society in general, suppliers, DNOs, developers and DG manufacturers. One future driver is identified for further consideration namely the impact of fuel shortages, terrorism etc. Two specific examples of wide variety of islanding options are studied [12] [17], using Simulink, as islanding principles namely:- a) The common mode failure of sole twin 33KV feeders, which would cause islanding of a primary substation 11kV busbars having no 11kV interconnection and b) The loss of a single transformer feeder primary resulting in the islanding of an 11kV network. The results are analysed on post island situations with large load swings. The result indicates that the DG and the induction motor loads within the two systems remains stable following the islanding event. But voltage and frequency variations exceed the acceptable limits laid down in the Electricity Safety Quality and Continuity Regulations, Engineering Recommendation G59, and the BS EN 50160 standard. The use of frequency sensitive load

controllers within the island in adding and shedding loads, as per necessity of the situation, can damp the voltage and frequency excursions within acceptable limits. Analysis of the pre and post islanding fault levels show that despite the short term boost provided by the generator AVRs, the fault levels in the islanded network are approximately half those of the grid connected network. These reduced fault levels require an adjustment to protection settings on the islanded network to ensure correct protection coordination in the island.

The commercial and regulatory drivers and incentives that can make islanded operation an attractive proposition for both DGs, DNOs, suppliers and customers are infrastructure, services, and market. The infrastructure drivers revolve around the DG providing network support, whilst the services drivers look at boosting the financial penalties the DNO face for Customer Interruptions (CI) and network unavailability. The market driver highlights the fact that there is a sales opportunity for seamless islanding, though the DNOs, DGs, and suppliers are unable to compete in it at present. It appears feasible to implement schemes that will allow DG operation of islanded networks with apparent seamless transfer. Commercial viability of islanding operation must be assessed in relation to enhancement of power quality, system reliability and supply of potential ancillary services through network support. Demonstration projects under Registered Power Zone and Technical Architecture Projects should be initiated to investigate the utility of DG islanding. However these efforts should be compounded with a realistic judgement of the associated technical and economic issues for the development of future power networks beyond 2010.

It is probable that the engineering recommendation documents G59/1 and G75, together with Engineering Technical Report 113/1 will be updated soon in the light of the new Grid Codes that are being developed to ensure grid stability during, and following, a major fault on the transmission network. This will ensure a common approach for the benefit of overall network stability and resilience. It is recommended that such an update should consider Technical Architecture issues, including the deliberate provision for DG operated islands. It is clear that the limits for frequency and voltage excursions laid down in ESQCR are too stringent to allow seamless islanding to occur and that a more probabilistic approach, similar to that used for EN 50160 would need to be developed to accommodate such events, although not necessarily with the same limits. The commercial case for islanding can be pursued only with high penetrations of DGs providing ancillary services through network support. Although at present there is no commercial reason to take islanding forward, but technical architecture of future distribution networks need to be formulated for further experience of the requirements for successful islanding operation on active distribution networks. It is recommended that a demonstration project should be set up on a section of DNO network under the auspices of the Registered Power Zone arrangements. The issue of DG operated islanded operation needs to be included in the brief of the Technical Architecture think-tank for developing the route map in the

near future to consider the long-term technical requirements for DNO networks for 2024 and beyond.

II. PRESENT POSITION ON ISLANDING

It is reported that under current design practice and culture of distribution network operation, the DGs would be shut down by either the "G59/1" technical recommendations or by an intertripping signal originating at the circuit breaker (CB) tripping on fault. With G59/1 protection, the DNO may include additional backup protection in its CB. It prevents continued supply to customers in an islanded section of network, and responsibilities for maintaining the protection scheme, would be included in the connection agreement. The G59/1 protection typically includes under/over voltage and under/over frequency. Loss of Grid (LOG) protection in common usage are i) rate of change of frequency (ROCOF or df/dt), ii) vector shift (detecting the step change in generator power angle on the change in load impedance at the instant of islanding). There are several active lines of research and development into alternative, more reliable means of detecting the LOG situation including the application of Artificial Neural Network (ANN) architectures.

DGs are required to be shut down during islanded operation due to the risks associated with the following issues:-

- 1) DNOs may not be able to maintain the frequency, voltage balance and magnitude in the islanded network within the required statutory limits or industry standards. In addition, there may be voltage fluctuations to an extent where they cause flickers.
- 2) The neutral of the islanded network may not be earthed, thus allowing uncleared earth faults to persist. Phase to phase voltages can therefore arise between phase and earth conductors, causing insulation overstress, resulting in breakdown or flashover
- 3) The fault level contribution from the DG may be insufficient to allow protection to operate satisfactorily, resulting in sustained fault currents
- 4) Synchronizing equipment may not be installed in the islanded network, so that it cannot be resynchronised with the main network following clearance of the fault which led to islanding.

Unless measures are in place to prevent out of phase reclosures, there remains the risk of an out of phase closure causing high current flows and large voltage transients, with potential consequential damage to rotating equipment (especially the DG) through excessive mechanical torque transients.

Unless mitigating measures are implemented, the risks arising from these conditions will almost certainly result in complaints, and present unacceptable risks of danger to personnel and/ or damage to equipment (from e.g. over-speed, overload, stalling, overheating, mal-operation).

As a result, all of the above conditions represent a breach of one or more statutes such as the Electricity Safety, Quality and Continuity Regulations and the Electricity at Work Regulations as well as various national and international standards for network plant operation.

III. TRADING IMPACTS OF ISLANDING OPERATION

The following trading impacts of islanded operation are reported in these studies:-

- a) For suppliers of NHH-metered customers there is currently no significant trading impact of outages as these effects are lost in the averaging process of profiling meters to provide pseudo half hour data sets. Therefore there is absolutely no incentive on the supplier to support islanded operation, although there is also no incentive to resist islanded operation.
- b) For suppliers of HH-metered customers there is an impact of outages on their settlement position. However this impact is insignificantly small considering the overall forecast error. Therefore there is not sufficient incentive on suppliers to encourage islanding, although it would be in their interests if islanding took place.
- c) For suppliers contracting with normally operating DG (e.g. most renewables and CHP), islanding would reduce their exposure to SBP compared to the non-islanding alternative where the generator must shut down.
- d) For suppliers contracting with standby generation (e.g. standby diesel generators) commencing operation in islanded mode could reduce their exposure to SBP or increase their exposure to SSP. However this action can also be taken during normal network operation. If this activity is beneficial suppliers will put arrangements in place during normal operation first. It should then be possible, and in supplier's interests, to extend this operation to islanded situations.
- e) For suppliers operating DSM in islanded operation the picture is even more complex depending on the scenarios and assumptions made.

Hence, none of these benefits would appear to be sufficient to drive suppliers to promote islanded operation of DG.

IV. COSTS AND BENEFITS OF DG ISLANDING OPERATION

An assessment was undertaken by PB Power [25] to identify the technical, legal and commercial issues of operating distributed generators (DG) in islanded mode as well as to quantify the costs and benefits associated with this mode of operation. This assessment was achieved by undertaking the following tasks:

- 1) Identifying technical, legal and commercial risks of operating the DG in islanded mode.
- 2) Identifying ways to mitigate the risks identified in item 1.
- 3) Quantifying the costs and benefits of islanded operation to Distribution Network Operators (DNOs), generators, and customers.
- 4) Testing and seeking the consensus of the DNO and small generators on recommendations resulting from the above tasks.

All the tasks undertaken by PB Power are based on the context of existing distribution security standard Engineering Recommendation P2/5 [26]. ER P2/5 which was created in

1978 and has not undergone any modifications since then despite considerable changes in the technology and market structure in the electricity sector in Britain. P2/5 is currently undergoing a review by the Distribution Generation Working Group set up by the DTI and Ofgem in order to recognise the benefits that DG can provide in terms of improved reliability of power supply. The main benefit that islanded operation can bring to generators is the additional revenues from selling their energy during islanded operation. At the present time without the possibility of islanding generators, the additional revenue that a generator can receive from islanded operation will be small due to the fact that the DNOs are only allowed to keep a section of network separated from the main supply for a specified time, known as the network restoration time. This network restoration time varies depending on the number of electricity users on an islanded network as specified in Electricity Recommendation P2/5. The additional revenue may be so small that it may not be attractive after considering the cost of the additional equipment and facilities required to allow this mode of operation. Islanded operation is expected to be economically feasible in some specific cases that need to be assessed individually, taking into account the characteristics of the network, demand and the size of the distributed generators.

Operating the DG in islanded mode improves the overall reliability of power supply to electricity users. The DNO may gain additional revenue from Ofgem due to the improvement in the quality of power supply. Also the contribution of the DG to the reliability of power supply can reduce or delay the need to reinforce the network to comply with the statutory reliability standards, hence reducing the capital expenditure requirements. However, this contribution does not necessarily have to be associated only with islanded operation. It is generally associated with the overall availability of the distributed generation when needed by the DNO at specific locations. The main benefit that the islanded operation of the distributed generation can provide is reducing the duration of power interruption caused by the disconnection of a section of electrical network from the main supply. An assessment needs to be carried out to quantify this benefit because the customers will be responsible directly or indirectly for any expenditure required to allow the islanded operation of the distributed generation. Under the existing NETA, the main beneficiaries (the customers and DNOs) of the islanded operation will not have to bear any unbalance penalties caused by the islanding as these penalties are transferred to the generators in the main interconnected system, which would have otherwise been supplying the islanded customers.

V. FUTURE SCENARIOS OF ISLANDING BENEFITS

For significant enhancement of islanding benefits it is needed to increase the value of continuity of supply. The duration and frequency of incidents of islanding will also play a role into it. If the "business as usual scenario" is followed, future networks will focus on increasing network reliability and reduce the opportunities for islanding to take place. However, with the increased penetration of DG, this

investment could be better directed at islanded operation, which would require appropriate incentives. But it is necessary to consider divergent scenarios where these trends would reverse and where islanding could play a more major role. These scenarios may include i) severe weather changes where severe weather conditions cause increasing breakdown of the distribution (or transmission) networks including extremely high temperatures, storms, icing, snowing etc., ii) power cuts due to fuel supply shortages, iii) power cuts due to demand changes – e.g. high summer urban demand in the south-east from air conditioning loads driven by climate change, iv) terrorist attacks on grid infrastructure, v) planned islanding for system outages

VI. ASSESSMENT OF ISLANDED OPERATION AND PROTECTION ISSUES: UK PERSPECTIVE

The review of existing UK practices and guidelines related to islanded operation of distribution network and LOG protection has been reported by EConnect [12][17]. It's a thorough review on islanding issues and the hazards as a result of DG operation in power island mode. The DNO has the responsibility to ensure the safety of its distribution network and customers from all possible hazards. It has been identified that DGs can bring different benefits to customers while operating in power island mode and hence guidelines are being established for their intentional islanding operation. It is shown that a seamless transfer of load from the main utility grid to the islanded DG is the most preferred islanding scenario. If a DNO cannot ensure this seamless transfer, it needs to incorporate a black-start capability to ramp up DG power output from zero to the rated capacity with a voltage and frequency control. It will involve substantial modification of standard DGs resulting in significant cost impacts [12][17].

Existing technical standards and guidelines related to interconnection of DGs are not delivering consistent policy about islanding protection of DGs amongst DNOs and DG owners or consensus with their customers. The DGs are compelled to bear the costs of their own anti-islanding protection as well as that for the anti-islanding back-up protection installed by DNOs for extra safety and security of the utility distribution network. This is heavily discouraging the investment in DGs and renewable DGs for minimising green house gas emissions. Besides, the cost of connection of small DG units are escalating on networks where there is a need for intertripping as the primary means of anti-islanding protection. In UK, engineering recommendation G59 and its guidance note ETR113 are written and revised on the basis of the understanding that DGs are not a significant factor in the distribution system supply security. But this scenario is no longer valid with high penetration of DGs across the country. Hence, the recommendations should be revised to provide sufficient foundation for consistent and risk-based decision making on developing appropriate islanding protection schemes. The assessment of islanding probability highlights increasing risk of power islanding of distribution networks and importance of cumulative effects of multiple DGs on the

utility operation and protection, which is not properly addressed in the current standards and guidelines [12][17].

Although, it is technically feasible to harness the growing generation from DGs to deliver network benefits by intentional power islanding, it is concluded in the standards that this will be a marginal activity and should not detract from the need to develop appropriate recommendation on anti-islanding protection techniques. It has been verified that various LOG techniques are subject to possible common mode tripping with the potential of significant impact on the utility transmission and distribution system. Trying to avoid the tendency towards common mode tripping usually leads to reduced sensitivity of the primary LOG protection functions of the DGs and this calls for a compromise setting to provide acceptable, low risk of islanding and system disturbance. The intertripping techniques are quite dependable but involve potential complexity and unjustified cost, especially when the DGs are capable to support several islanded zones.

Several problems were identified in this report with regard to avoidance of islanded operation as summarised below:

a) Inadequate assessment of network risk:

Engineering and technical recommendations G59/1 and ETR113/1 do not clearly assess distribution network and generator risk in case of failure of operation of LOG system. It is really difficult to justify whether its worth to improve LOG technologies without such an assessment.

b) Restriction imposed on available DG generation:

Existing LOG systems operate on the basis of the measurement of network parameters like ROCOF, phasor displacement etc. The error in measurement of these parameters often cause the LOG system to trip the DGs spuriously even though there is no such occurrence. Such unwanted tripping of DGs may drastically reduce the quality of supply to the local DNO network, if such DGs have any network support role.

c) Significant cost of unnecessary tripping of DGs:

The unnecessary tripping of DGs leads to significant cost of generation over a period of time and thus the DG owners suffer a significant reduction in their revenues in addition to an increased maintenance requirement due to undesirable crash stop.

d) Unclear ownership of LOG systems

Normally the DG owners and the DNOs should operate their own sets of LOG protection systems in order to protect their DGs and distribution networks. However, under the current UK practices, DG owners are forced to bear the costs of installing LOG protection systems both for themselves as well as for the DNOs, leading to their dissatisfaction.

The following proposals have been made to initiate effective change for the required islanding protection :-

- a) It is necessary to establish clear and common understanding of the risks both of operation and spurious operation of anti-islanding schemes in order to develop risk based methodologies for appropriate selection of protection solutions.
- b) The requirements for the protection of the distribution networks and DGs must be clearly segregated and defined for the responsibility and ownership of the selected protections.
- c) Alternative approaches to preventing islanding must be investigated which will have the potential to provide effective protection at reasonable costs.
- d) The engineering recommendations G59, G75 and ETR113 should be revised for properly addressing islanding protection issues on the basis of clarity, rigour and innovation established in its preparation.

VII. CONCLUSION

It is probable that the Engineering Recommendation documents G59/1 and G75, together with Engineering Technical Report 113/1 will be updated soon in the light of the new Grid Codes that are being developed to ensure grid stability during, and following, a major fault on the transmission network. This will ensure a common approach is applied which will benefit overall network stability and resilience. It is recommended that such an update should consider Technical Architecture issues, including the deliberate provision for DG operated islands. It is clear that the limits for frequency and voltage excursion laid down in Electricity Safety Quality & Continuity Regulations (ESQCR) are too stringent to allow seamless islanding to occur and that a more probabilistic approach, similar to that used for British Standard EN50160 would need to be developed to accommodate such events, although not necessarily with the same limits. The commercial case for islanding is not pursued until more DG becomes connected and plays a more active role in the operation of both Distribution and Transmission networks, first through the provision of Ancillary Services, and then through network support. Although at present there is no commercial reason to take islanding forward, to enable a long term strategy for the technical architecture of future distribution networks to be formulated there is value in gaining further experience of the requirements for successful islanding on actual distribution networks. To enable this it is recommended that a demonstration project should be set up on a section of DNO network under the auspices of the Registered Power Zone arrangements, by providing incentives to the DNO to designate an area of network in which high quality innovation projects facilitate the added value connection of distributed generation (DG). The issue of DG operated islanded operation should be included in the brief of

the Technical Architecture think-tank so that the route map that may be developed in the near future adequately considers the long-term technical requirements for DNO networks for 2024 and beyond.

VIII. DEFINITION OF ACRONYMS

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| ANN | Artificial Neural Network |
| AVR | Automatic Voltage Regulator |
| BETTA | British Electricity Transmission & Trading Arrangements |
| BSC | Balancing Settlement Code |
| CB | Circuit Breaker |
| CCTV | Closed Circuit Television |
| CHP | Combined Heat and Power |
| CI | Customer Interruptions |
| CML | Customer Minutes Lost |
| CO2 | Carbon Dioxide |
| CVA | Central Volume Allocation |
| DCHP | Domestic Combined Heat and Power |
| DEG | Diesel Generator |
| DG | Distributed Generation |
| DNO | Distribution Network Operator |
| DPCR | Distribution Price Control Review |
| DSM | Demand Side Management |
| DTI | Department of Trade and Industry |
| EDF | Electricite de France |
| EPN | Eastern Power Network (subsidiary of EdF Energy) |
| ESQCR | Electricity Safety, Quality and Continuity Regulations |
| GSP | Grid Supply Point |
| HH | Half-Hourly |
| HV | High Voltage |
| IDMT | Inverse Definite Minimum Time |
| IFI | Innovative Finance Initiative |
| IIP | Information and Incentives Project |
| LOG | Loss of Grid |
| LV | Low Voltage |
| NETA | New Electricity Trading Arrangements |
| NGT | National Grid Transco |
| NHH | Non-Half-Hourly |
| NVD | Neutral Voltage Displacement |
| PLC | Programmable Logic Control |
| ROCOF | Rate of change of frequency |
| RPZ | Registered Power Zone |
| SBP | System Buy Price |
| SCADA | Supervisory Control & Data Acquisition |
| SLD | Single Line Diagram |
| SSE | Scottish and Southern Electricity Ltd |
| SSP | System Sell Price |
| SVA | Supplier Volume Allocation |
| SVC | Static VAR Compensator |
| TMS | Time Multiplier Setting |
| TSG | Technical Steering Group |
| TSO | Transmission System Operator |
| UPS | Uninterrupted Power Supply |
| UU | United Utilities |
| WPD | Western Power Distribution |

IX. ACKNOWLEDGEMENT

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X. REFERENCES

- [1] N.Jenkins, R.Allan, P.A.Crossley, D.Kirschen and G.Strbac, "Embedded Generation", IEE Power and Energy Series 31, The IEE, 2000.
- [2] A.Bertani et.al, "Electrical Energy Distribution Networks: Actual Situation and Perspectives for Distributed Generation", *Proc. of CIRED, 17th International Conference on Electricity Distribution*, Barcelona, Spain, 12-15 May, 2003.
- [3] R.H.Lasseter and P.Paigi, "Microgrid: a conceptual solution", *Proc. of Power Electronics Specialists Conference(PESC)*, Aachen, Germany, 20-25 June, 2004, Vol.6, pp. 4285- 4290.
- [4] N. Hadsaid, J. F. Canard and F. Dumas: "Dispersed Generation Impact on Distribution Networks", IEEE Computer Applications in Power, 1999.
- [5] CIGRE: "Impact of increasing contribution of dispersed generation on the power system", Final Report, Study Committee no. 37, September 1998.
- [6] T. Moore: "Emerging Markets for Distributed Resources", EPRI Journal, March/April 1998.
- [7] L.Kumpulainen and K.Kauhaniemi, "Distributed Generation and Reclosing Coordination," *Proc. of Nordic Distribution and Asset Management Conference, NORDAC 2004*, Espoo, August 23-24 2004.
- [8] J.A. Pecas Lopes, N. Hatzigiorgiou, J. Mutale, P. Djapic and N. Jenkins, "Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities", *Electric Power System Research*, 77(2007), pp.1189-1203.
- [9] F. M. Gatta, F. Iliceto, S. Lauria and P. Masato, "Modelling and Computer Simulation of in Dispersed Generation in Distribution Networks. Measures to prevent disconnection during system disturbances", *Proc. of IEEE Power Tech Conference*, Bologna, Italy, June 23-26, 2003.
- [10] F.A.Viawan, D.Karlsson, A.Sannino and J.Daalder, "Protection Scheme for Meshed Distribution Systems with High Penetration of Distributed Generation", *Proc. of Power System Conference 2006: Advance Metering, Protection, Control, Communication and Distributed Resources*, 2006.
- [11] T.Thacker, "Control of Power Conversion Systems for the Intentional Islanding of Distributed Generation Units", Thesis for Master of Science in Electrical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA, September, 2005.
- [12] Econnect, "Assessment of Islanded Operation of Distribution Networks and Measures for Protection", ETSU K/EL/00235/REP, 2001.
- [13] M.A.Redfern, J.I.Barrett and O.Usta, "A New Microprocessor Based Islanding Protection Algorithm for Dispersed Storage and Generation Units", *IEEE Transactions on Power Delivery*, Vol. 10, No. 3, July 1995, pp.1249-1254.
- [14] M.Robitaille, K.Agbossou and M.L.Doumbia, "Modeling of an Islanding Protection Method for a Hybrid Renewable Distributed Generator", *Proc. of Electrical and Computer Engineering*, Canada, 1-4 May, 2005, pp.1477-1481.
- [15] M.A.Redfern, O.Usta and G.Fielding, "Protection Against Loss of Utility Grid Supply for a Dispersed Storage and Generation Unit", *IEEE Transactions on Power Delivery*, Vol. 8, No. 3, July 1993, pp.948-954.
- [16] C.G.Bright, "COROCOF: Comparison of Rate of Change of Frequency Protection : A Solution to the Detection of Loss of Mains", *Developments in Power System Protection, Conference Publication No. 479* © IEE 2001.
- [17] Econnect, "Islanded Operation of Distribution Networks", DG/CG/00026/00/00, 2005.
- [18] L.J.Powell, "An Industrial View of Utility Cogeneration Protection Requirements", *IEEE Transactions on Industry Applications*, Vol. 24, No. 1, Jan/Feb 1988, pp.75-81.
- [19] N.Perera and A.D.Rajapakse, "Agent-Based Protection Scheme for Distribution Networks with Distributed Generators", *Proc. of IEEE Power*

Engineering Society General Meeting 2006, Montreal, Canada, 18-22 June, 2006.

- [20] G. Celli, F. Pilo, G. Pisano, V. Allegranza, R. Cicoria and A. Iaria, "Meshed vs. Radial MV Distribution Network in Presence of Large Amount of DG", *Proc. of IEEE PES Power Systems Conference and Exposition, 2004*, 10-13 October, 2004, Vol.2, pp.709-714.
- [21] S.M.Brahma and A.A.Girgis, "Development of Adaptive Protection Scheme for Distribution Systems with High Penetration of Distributed Generation", *IEEE Transactions on Power Delivery*, Vol. 19, No. 1, January 2004, pp.56-63.
- [22] S.M.Brahma and A.A.Girgis, "Effect of Distributed Generation on Protective Device Coordination in Distribution System", *Proc. of Large Engineering Systems Conference on Power Engineering LESCOPE '01*, Halifax, Canada, 11-13 July, 2001, pp.115-119.
- [23] S.M.Brahma and A.A.Girgis, "Microprocessor-Based Reclosing to Coordinate Fuse and Recloser in a System with High Penetration of Distributed Generation", *Proc. of IEEE Power Engineering Society Winter Meeting, 2002*, Vol.1, pp.453-458.
- [24] Hui Wan, K.K.Li and K.P.Wong, "Multi-Agent Application of Substation Protection Coordination with Distributed Generators", *European Transactions on Electrical Power*, Vol.16, Issue 5, September, 2006, pp. 495-506.

BIOGRAPHIES

Dr. S.P.Chowdhury received his BEE, MEE and PhD in 1987, 1989 and 1992 respectively. In 1993, he joined E.E.Dept. of Jadavpur University, Kolkata, India as Lecturer. He was promoted to Senior Lecturer and then to Reader grades both in 1998. He visited Brunel University, UK several times on collaborative research programme. He has published two books and over 100 papers mainly in power systems. He is a fellow of the IET (UK) with C.Eng. IE (I) and the IETE (I) and Member of IEEE (USA). He is a member of Membership and Regions Board (MRB), MRB Finance Committee, Council and the Regional Representative Committee of the IET (UK).

Dr. S. Chowdhury received her BEE and PhD in 1991 and 1998 respectively. She joined M/S M.N.Dastur & Co. Ltd as Electrical Engineer and Women's Polytechnic, Kolkata, India as Lecturer in 1991 and 1998 respectively. She was promoted to Senior Lecturer in 2006. She visited Brunel University, UK several times on collaborative research programme. She has published two books and over 50 papers mainly in power systems. She is a Member of the IET (UK), IEEE (USA) and IE(I). She is acting as YM Coordinator in Indian Network of the IET (UK).

Prof. P.A.Crossley is Professor of Electrical Engineering at the University of Manchester. He graduated with a B.Sc degree from UMIST, United Kingdom in 1977 and a Ph.D. degree from the University of Cambridge, United Kingdom in 1983. He had been involved in the design and application of digital protection relays and systems for more than 25 years, first with GEC, then with ALSTOM and UMIST and the Queen's University of Belfast, United Kingdom and currently with the University of Manchester. Currently, he is the Director of Joule Centre for Energy Research, The University of Manchester, UK. He is an active member of various CIGRE, IEEE and IET committees on protection.

Chui Fen Ten received the BEng degree from Universiti Teknologi Malaysia, Skudai, Malaysia, in 2005 and the MSc degree from University of Manchester (formerly UMIST), Manchester, UK, in 2006. Currently, she is working towards her PhD degree in the School of Electrical and Electronic Engineering of the University of Manchester (formerly UMIST), Manchester, UK.