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Minimization of Power Loss in Distribution Networks by Different Techniques

L.Ramesh, S.P.Chowdhury, S.Chowdhury, A.A.Natarajan, C.T.Gaunt

Abstract**—**Accurate loss minimization is the critical component for efficient electrical distribution power flow .The contribution of this work presents loss minimization in power distribution system through feeder restructuring, incorporating DG and placement of capacitor. The study of this work was conducted on IEEE distribution network and India Electricity Board benchmark distribution system. The executed experimental result of Indian system is recommended to board and implement practically for regulated stable output.

Keywords—Distribution system, Distributed Generation Loss Minimization, Network Restructuring

I. INTRODUCTION

THE distribution system is the most visible part of the supply chain, and as such the most exposed to the critical observation of its users. It is, in many cases, the largest investment, maintenance and operation expense, and the object of interest to government, financial agencies, and associations of concerned citizens. About 30 to 40 % of total investments in the electrical sector go to distribution systems, but nevertheless, they have not received the technological impact in the same manner as the generation and transmission systems. Many of the distribution networks work with minimum monitoring systems, mainly with local and manual control of capacitors, sectionalizing switches and voltage regulators; and without adequate computation support for the system's operators. Nevertheless, there is an increasing trend to automate distribution systems to improve their reliability, efficiency and service quality. Ideally, losses in an electric system should be around 3 to 6%. In developed countries, it is not greater than 10%.However, in developing countries, the percentage of active power losses is around 20%; therefore, utilities in the electric sector are currently interested in reducing it in order to be more competitive, since the electricity prices in deregulated markets are related to the system losses. In India, collective of all states, in 2008 the technical and non technical losses are accounted as 23% of the total input energy. To manage a loss reduction program in a distribution system it is necessary to use effective and efficient computational tools that allow quantifying the loss in each different network element for system losses reduction. Various authors have discussed loss minimization in different aspects.

In order to increase the efficiency of the distribution electrical networks, a reconfiguration process was applied to improve the reliability indices. Considering Feeder reconfiguration for loss minimization was first proposed by Merlin et al. [1] using a discrete branch and bound technique. In this method all the network switches are closed to form a meshed system, and then the switches are opened successively to restore to the radial configuration. However, this method involves approximations. Shirmohammadi et al. [2] proposed an algorithm to overcome these approximations. In this method, the switches are opened one by one, based on an optimal flow pattern. Peponis *et al.* [3] have developed a methodology for the optimal operation of distribution network. In this method loss minimization is obtained by installation of shunt capacitors and reconfiguration of the network. Schmidt *et al.* [4] have formulated the problem as a mixed integer nonlinear optimization problem. The integer variables represent the status of the switches, and continuous variables represent the current flowing through the branches. Broadwater *et al.* [5] have considered the time varying load demand, obtained through load estimation, to reduce the loss. Morton *et al.* [6] have proposed a method based on an exhaustive search algorithm for obtaining a minimum loss radial configuration of a distribution system. The algorithm uses the graph-theoretic techniques involving semi-sparse transformations of a current sensitivity matrix. M.W. Siti et al. [7] contribute such a technique at the low-voltage and medium-voltage levels of a distribution network simultaneously with reconfiguration at both levels. While the neural network is adopted for the network reconfiguration problem, this paper introduces a heuristic method for the phase balancing/loss minimization problem. A comparison of the heuristic algorithm with that of the neural network shows the former to be more robust. K. Viswanadha Raju et al. [8] describes a new, two stages, and heuristic method, for determining a minimum loss configuration of a distribution network, based on real power loss sensitivities with respect to the impedances of the candidate branches.

S.K.Salam et al. discussed [9], the effects of distributed

L.Ramesh is with the Electrical Engineering Department, Jadavpur University, Kolkata, India (e-mail: raameshl@rediffmail.com).
S. P. Chowdhury is with the Electrical Engineering Department, University of Cape Town, South Africa (e-mail: sp.chowdhury@uct.ac.za)
S. Chowdhury is with the Electrical Engineering Department, University of Cape Town, South Africa (e-mail: sunetra69@yahoo.com).
A.A.Natarajan is with the Electrical Engineering Department, M.V.J Engg. College,Bangalore,India{e-mail: draanatarajan710@yahoo.co.in)
C.T.Gaunt is with the Electrical Department ,University of Cape Town,SA

generation on voltage regulation and power losses in distribution systems.C.L.T. Borges et al. [10] have presented a technique to evaluate the impact of DG size and placement on losses, reliability and voltage profile of distribution networks. Davidson et al. [11] have presented an optimization model for loss minimization in a distribution network with DG. An algorithm has been proposed by T.Griffin et al. [12] to determine the near optimal placement of distributed generation with respect to system losses. Mutale et al. [13] have presented a methodology to evaluate the impact of DG on power loss minimization by examining loss allocation coefficients. M.A. Kashem et al. [14] represent techniques to minimize power losses in a distribution feeder by optimizing DG model in terms of size, location and operating point of DG. Sensitivity analysis for power losses in terms of DG size and DG operating point has been performed. X. P. Zhang et al. [15] paper discusses the issue of energy loss minimization of electricity networks with large renewable wind generation. The impact of the special operating arrangements of large wind generation on energy loss of electricity networks is investigated. An optimal power flow (OPF) approach is proposed to minimize the energy loss of electricity network with reactive power and FACTS control, while satisfying the network operating voltage and thermal limits.W.M.Lin et al. [16] propose to reduce power loss by means of load reconnection of the prime phase sequence of the open wye open delta transformers. The Genetic Algorithms (GAs) has been implemented for solving the optimal problem. Practical examples of Taiwan Power Company demonstrate that the proposed method is effective and available.

M.S.Tsai et al. [17] compares several Genetic Algorithm reproduction methods for distribution system loss reduction and load balancing problems. Asexual reproduction method is proposed in this paper, which requires less generation to reach the optimal solution than gamogenesis. A.Augugliaro et al. [18] discussed the problem of voltage regulation and power losses minimization for automated distribution systems. The classical formulation of the problem of optimal control of shunt capacitor banks and Under Load Tap Changers located at HV/MV substations has been coupled with the optimal control of tie-switches and capacitor banks on the feeders of a large radially operated meshed distribution system with the aim of attaining minimum power losses and the flattening of the voltage profile. The considered formulation requires the optimization of two different objectives; therefore the use of adequate multiobjective heuristic optimization methods is needed. The heuristic strategy used for the optimization is based on fuzzy sets theory. K.Amaresh et al. [19] introduced HVDS with small capacity distribution transformers. A simple load flow technique has been used for solving radial distribution networks before and after implementation of HVDS. An advantage of implementing HVDS over LVDS system for loss minimization is discussed .T.M.Khalil et al. [20] presented a solution by using series capacitors connected to the nodes of distribution feeders. A proposed technique is introduced to calculate the desired size of series capacitors keeping the voltage at proper nominal operating limits and reducing the power losses. This technique is the Particle Swarm Optimization (PSO). A real case study is presented as an illustrative example showing the advantages of the proposed technique over other methods.

In their previous paper [21] [22] [23], the authors addressed on loss minimization in power distribution power flow. This paper proposes a loss minimization for power distribution system by various techniques. Different approach like restructuring, DG implementation and capacitor placement are discussed in this paper for loss minimization. The algorithm is tested with IEEE and Indian distribution systems. The superiority of proposed system is validated by comparing the tested result with existing system.

II. Distribution System Power Losses

Electrical power losses in distribution systems vary with numerous factors depending on system configuration, such as level of losses through transmission and distribution lines, transformers, capacitors, insulators, etc. [24].Power losses can be divided into two categories, real power loss and reactive power loss. The resistance of lines causes the real power loss, while reactive power loss is produced due to the reactive elements. Normally, the real power loss draws more attention for the utilities, as it reduces the efficiency of transmitting energy to customers. Nevertheless, reactive power loss is obviously not less important. This is due to the fact that reactive power flow in the system needs to be maintained at a certain amount for sufficient voltage level. Consequently, reactive power makes it possible to transfer real power through transmission and distribution lines to customers. The total real and reactive power losses in a distribution system can be calculated using equation 1 and 2.

$$P_{Loss} = \sum_{i=1}^{n_{br}} |I_i|^2 r_i \tag{1}$$

$$Q_{Loss} = \sum_{i=1}^{n_{br}} |I_i|^2 x_i \tag{2}$$

Where n_{br} is total number of branches in the system, $|I_i|$ is the magnitude of current flow in branch I, r_i and x_i are the Resistance and reactance of branch i, respectively. Different types of loads connected to distribution feeders also affect the level of power losses.

The distribution network is the terminal stage of power system and ended by consumers. The problems which may be found in the distribution network affect both consumers and utilities. One of these problems is the problem of voltage drop that must be reduced to keep the voltages at load points within standard limits. The voltage drop problem may arise when using lateral radial feeders with long distance or feeding large loads. Therefore, the solution of this problem becomes imperative, that is, the voltage at different nodes of the system must be controlled. The voltage control means actually reactive power control. Consequently, controlling the reactive

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power and regulating the node voltages result in a reduction of power loss which has a great concern by utilities. To enhance the voltage and to control the reactive Power, the distribution systems are equipped with a lot of voltage controlling devices such as network restructuring, DG implementation, tap-change Transformers, voltage regulators, shunt/series capacitors etc. Different approaches like restructuring, DG implementation and capacitor placement are discussed in this paper.

III. EXPERIMENTAL RESULTS

A. *Feeder Restructuring*

The problem of restructuring of the distribution network under normal operation to reduce active losses and to balance loads in the system will be considered. The concept of restructuring the topology of the distribution network to minimize losses can immediately be recognized as being cost efficient and consequently of interest to efficiency conscious electric utilities. Electric distribution networks are mostly figured as radial for proper protection coordination: distribution feeders may be frequently reconfigured by opening and closing switches while meeting all load requirements and maintaining a radial network. This requirement results in a proper planning of system to reduce loss and improve efficiency of the system. In this work Tamil Nadu Electricity Board [TNEB] 11KV Distribution substation is taken as example and analyzed using ETAP software for proper restructuring which cause loss minimization and good regulation. The existing and proposed substations with feeders were simulated for technical improvements. The restructured feeder implemented practically for quality result.

1) *Existing System*

Tamil Nadu Electricity Board which contains Vyasarpadi substation consists of two HV (33kV) feeders, one main and one as alternative or (backup) as input and three LV (11kV) feeders as output previously to serve the area. Existing vyasarpadi substation has two input 33kV feeders one of the feeders is the main feeder and the other is alternative. HV supply is drawn from main Vyasarpadi feeder and the sembium feeder is an alternative feeder which used only when the main feeder is down due to some reason, which the supply should be fed continuously to the customers. The three output feeders were (i) 11 KV Vyasar Nagar Feeder (ii) 11 KV M.K.B Nagar Feeder (iii) 11KV Industrial Estate feeder

From the figure 1, it was observed that due to increasing load demand and overload conditions the substation was facing major problem regarding regulation , voltage instability and more line loss.

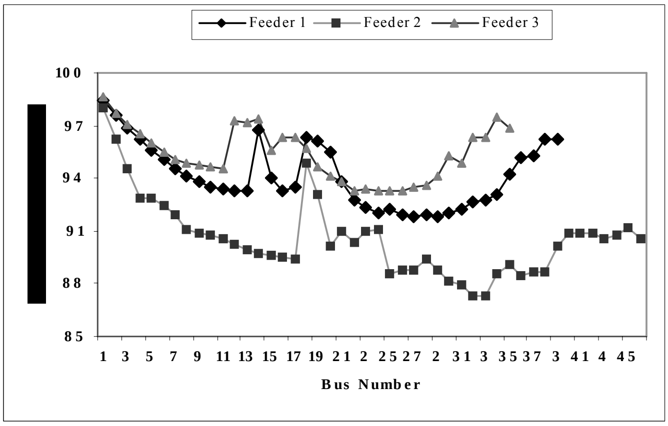

Fig. 1 Existing Feeder Voltage Magnitude respect to Bus

2) *Proposed System*

To rectify the problem faced by existing system during peak demand, length of cable, line loss and HT voltage regulation of the substation, the substation was restructured with the help of ETAP and the three output feeders were replaced by five feeders. The modified system was simulated in ETAP for performance analysis [10]. It was observed that the overall performance of the system was increased, all the problems regarding the loads were resolved; also the regulation and efficiency improved considerably. Existing vyasarpadi substation has two input 33kV feeders; one of the feeders is the main feeder and the other is alternative. HV supply is drawn from main Vyasarpadi UG feeder and the sembium feeder is an alternative feeder is used only when the main feeder is down due to some reason, that the supply should be fed continuously to the customers .The proposed new feeders are S.A Colony, Vyasar nagar, JJR Quarters, Industrial Estate-I and Industrial Estate-II.

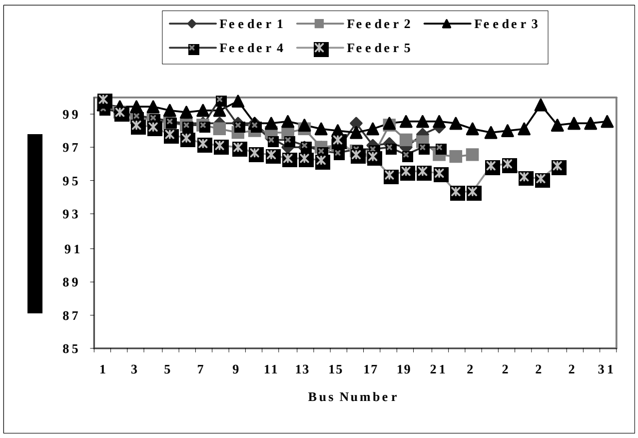

Fig. 2 Proposed Feeder Voltage Magnitude respect to Bus

Figure 2 represents the simulated output of new proposed feeders; it was observed that voltage magnitudes are maintained within the voltage limit with better regulation.

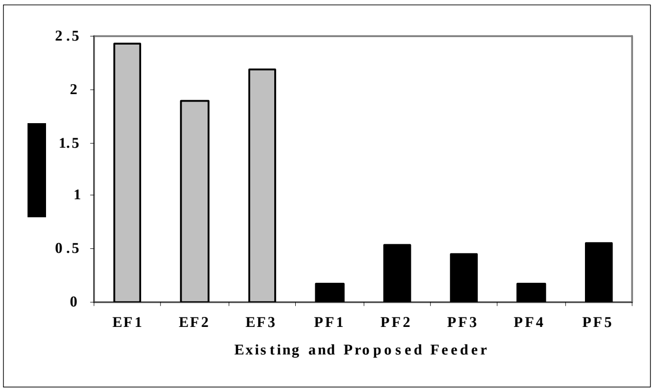

Fig. 3 Existing Feeder [EF] and Proposed Feeder [PF] line losses

Figure 3 represents the simulated output of existing and proposed feeders line losses; it was observed that line loss is reduced by 70% in proposed feeders.

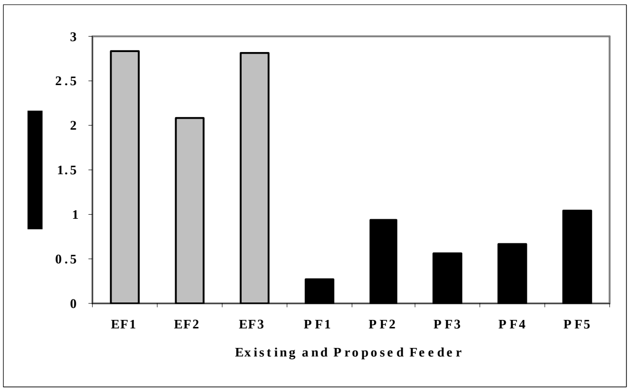

Fig. 4 Existing Feeder [EF] and Proposed Feeder [PF] line losses

The new proposed feeders are implemented practically .Figure 4 represents the practical output of line losses of the existing and proposed feeders; it was observed that the line loss is reduced by 60% in proposed feeders. The total expenditure for investment cost is 299lakhs, the Line loss savings is 64778 Units/Month, Power outage savings is 16606 Units/Month and the payback period is 10.67 years.

B. DG Implementation

Distributed Generation [DG] [24] is any small-scale electrical power generation technology that provides electric power at or near the load site; it is either interconnected to the distribution system, directly to the customer's facilities, or both. According to the Distributed Power Coalition of America (DPCA), research indicates that distributed power has the potential to capture up to 20% of all new generating capacity, or 35 Gigawatts (GW), over the next two decades. Recent development in small generation technologies has drawn an attention for the utilities to change in the electric infrastructure for adapting Distributed Generation (DG) in distribution systems. Employment of DG technologies makes it more likely that electricity supply system will depend on DG systems and will be operated in deregulated environment to achieve a variety of benefits. As DG systems generate power locally to fulfill customer demands, appropriate size and placement of DG can drastically reduce power losses in the system. DG inclusion also defers transmission and distribution upgrades, improves supply quality and reliability and reduces green house effects

In this work, sensitivity analysis has been performed to determine the appropriate size and operating point of DG for minimization of power losses in distribution systems. The analysis is carried out in IEEE 37 Bus and Indian Electricity Board TNEB 11KV Distribution System feeder using ETAP 5.1 licensed Power system Software package. The IEEE 37 Bus is taken for implementation of proposed approach. The line impedance of the system is assumed as Z_l =0.038018+0.146173 Ω/1000 ft per conductor. Nominal voltage at substation is 11KV .It is assumed that loads are uniformly distributed along the feeder at load buses. The base MVA used in the computation is 100MVA and the base KV used is the same as the nominal voltage of 11KV.The feeder is supplying a total of 600MVA.In order to obtain the maximum potential benefits from DG, the sensitivity analysis for the losses of the system is performed.

As per sensitivity indices DG is placed at bus 735,738,720,724 and 729 that injects only real power into the system. Figure 4 shows the real power losses with respect to the system without DG and with DG.From figure 5 it is clearly proved that, by injecting DG in to the Distribution System, we can reduce the distribution line losses.

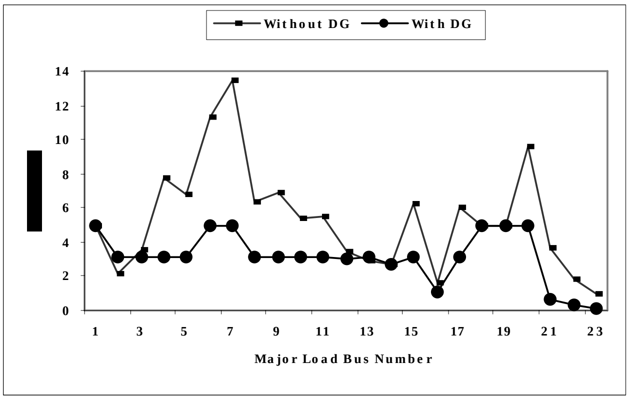

Fig. 5 Distribution Real Power Losses in KW with and without DG

The voltage profile of the system with and without DG is illustrated in the figure 6.It is proved from the figure that voltage profile is improved better when DG is connected with appropriate size and location.

C. Capacitor Placement

This work presents the system studies of boiler manufacturing plant and suggested for new proposed system with the help of simulation studies in ETAP (Electrical Transient Analyzer Program).

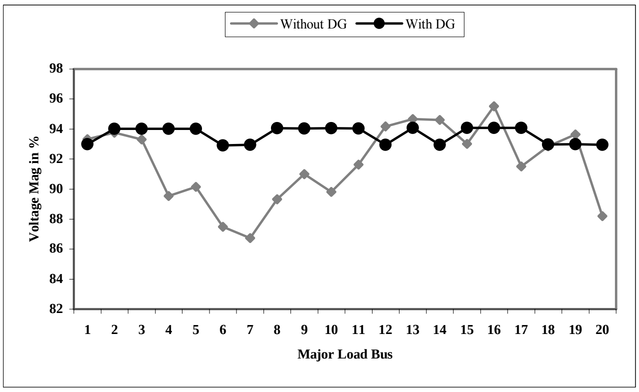

Fig. 6 Distribution Load Bus Voltages in % with and without DG

The author collected the practical data from AE &E (Australian Energy and Environment) Boiler Manufacturing plant in Chennai, India .It was modeled in ETAP by providing all collected data .Various analyses like load flow, short circuit, harmonic and motor starting analysis are performed experimentally for the existing plant. With respect to the experimental results the system restructuring, resizing of cables, replacement of unconditioned equipment and implementing static relays are done. Intelligent algorithm is developed to identify the size and location of capacitor bank to improve power factor .After redesigning experimental results is taken for proposed system. In general, capacitor banks are installed in power distribution system for voltage support, power factor correction, reactive power control, loss reduction, system capacity increase and billing charge reduction.

This process involves determining capacitor size location, control method and connection type. The main effort usually is to determine capacitor size and location for voltage support and power factor correction. Secondary considerations are harmonics and switching transients. The ETAP Optimal Power Flow (OPF) program is to optimize the capacitor sizes based on the candidate locations selected by user. This method requires pre-selected locations, since OPF can optimize the capacitor sizes but not the locations. The pre-selected location is identified by reinforcement learning approach [11]. The table: 1 below show the location and size of capacitor bank to place in a plant.

Figure 7 represents the comparatative analysis of existing and proposed system percentage power factor. The graph is plotted in between the various distribution board and percentage power factor. Figure 8 represents the comparative analysis of existing and proposed system line loss on KW. The graph is plotted in between the various cable and real line loss in KW.

TABLE: 1
SIZE AND LOCATION OF CAPACITOR PLACEMENT

S.NO	CapacitorBank Size inKvar	Location
1	150	MSB-1
2	150	SSB-6
3	15	SSB-3
4	10	SSB-4
5	10	PDB-10
6	25	PDB-7
7	25	SSB-2
8	20	PDB-9
9	50	PDB-6

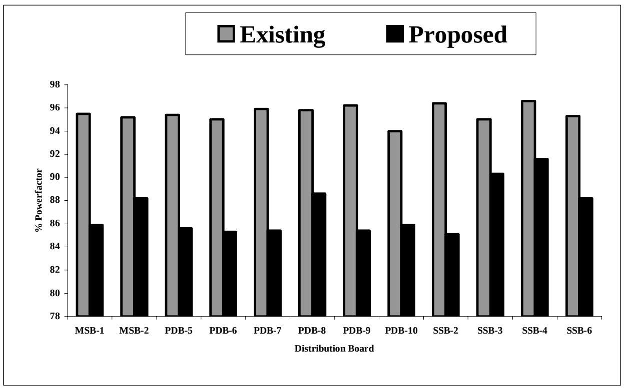

Fig. 7 Existing and Proposed % PF with various distribution boards

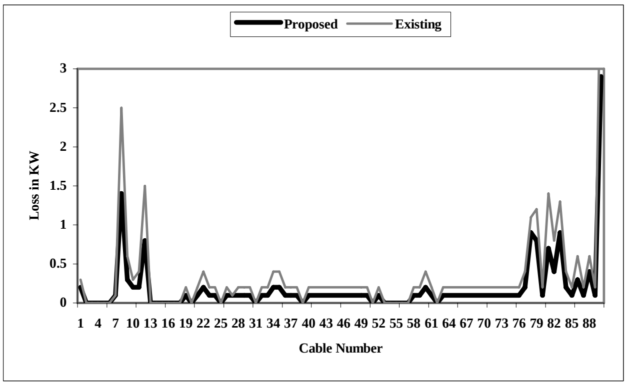

Fig. 8 Existing and Proposed line loss with cable

From the Distribution system studies performed, it is concluded that all Electrical equipments – Transformers, Switchgears, Distribution boards, and Cables are adequately sized. The following improvement such as reduction of transformer loading to 76.9% from 86.3%, the improvement power factor reduction by 8.14%, the reduction of voltage drop, the improvement in voltage regulation with minimum over voltage buses, minimization of Real losses by 7% and Short circuit current is known for each bus, which is to easy for selection of CB make the proposed reliable system. The authors suggested the boiler manufacturing plant to go for new proposed distribution system to achieve all benefits and not to pay any fine for electricity board for lagging PF.

IV. CONCLUSION

The Various aspects of loss minimization in distribution system were discussed in this paper. From the experimental and practical implemented proposed system, clearly identified that the percentage reduction in line loss, and voltage regulation were achieved. These can further extended for more complicated system for system expansion planning.

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L.Ramesh, is presently an Assistant professor of Electrical and Electronics Engineering Department, Dr.M.G.R.University, Chennai, India and Research Scholar of Jadavpur University, Kolkota, India.He obtained B.E from M.S.University and M.Tech from Kerala University, India. He is a member of IET (UK) and chairman of IET-UK YMS Chennai Network, India. raameshl@rediffmail.com , lramesh@theiet.org .

Dr. S.P. Chowdhury received his BEE, MEE and PhD in 1987, 1989 and 1992 respectively. In 1993, he joined E.E.Deptt. of Jadavpur University, Kolkata, India as Lecturer and served till 2008 in the capacity of Professor. He is currently Associate Professor in Electrical Engineering Department in the University of Cape Town, South Africa. He became IEEE member in 2003. He visited Brunel University, UK and The University of Manchester, UK several times on collaborative research programme. He has published two books and over 110 papers mainly in power systems and renewable energy. 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 technical Professional Service Board of the IET (UK).e-mail: sp.chowdhury@uct.ac.za

Dr. Sunetra Chowdhury received her BEE and PhD in 1991 and 1998 respectively. She was connected to M/S M.N.Dastur & Co. Ltd as Electrical Engineer from 1991 to 1996. She served Women's Polytechnic, Kolkata, India as Senior Lecturer from 1998 to 2006. She is currently the Senior Research Officer in the Electrical Engineering Department of The University of Cape Town, South Africa. She became member of IEEE in 2003. She visited Brunel University, UK and The University of Manchester, UK several times on collaborative research programme. She has published two books and over 55 papers mainly in power systems. She is a Member of the IET (UK) and IE(I) and Member of IEEE(USA). She is acting as YM Coordinator in Indian Network of the IET (UK). e-mail: sunetra69@yahoo.com

Dr.A.A.Natarajan, born in 1943, is presently DEAN (Academics) And HOD(ECE) with M.V.Jeyaram Coll. Of Engg. Bangalore, India. He obtained B.E.E, M.E (High voltage Engg.) and Ph.D. (Engg.) Degree in IISC Bangalore .Initially he served as Faculty at IISC Bangalore from 1967-1971.Thereafter he served in Electrical Manufacturing plant (NGEF) for 28 years holding responsible position in Design, Testing,R&D and Manufacturing. He has published more than 100 research papers in different International and National Journals and Conference Proceedings. He is a member of MPSS, LMISTE, MISLE, and MCDA.He serves in number of prestigious committee and council. . (draanatarajan710@yahoo.co.in)

Dr. C.T.Gaunt received a BSc(Eng) from Natal University in 1971, an MBL (SA) with distinction in 1979 and a PhD (Cape Town) in 2003. He worked for 28 years with an electrical equipment manufacturer, electricity supply utility and consulting engineers, where he was a director. He is currently a Professor and Head of the Department of Electrical Engineering at UCT, but stands down from the HOD position at the end of 2008 to concentrate on teaching and research. He has received Best Paper awards from the Transactions SAIEE and the AMEU, a technology innovation award from Worldaware in UK, and a Cigré Technical Committee Award in 2004. He is the South African member of the Cigré Study Committee C6 (Distribution and Dispersed Generation). He has supervised several postgraduate students in DG research. He was the electrical engineer for the integration of and scheduling for several small hydro stations (6-72 MW) into grid operation in Southern Africa. e-mail: ct.gaunt@uct.ac.za