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Optimal Location of Fuel Cell Based Distributed Generation In Distribution System

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ABSTRACT:

Power system deregulation and shortage of transmission capacities have led to an increase interest in distributed Generation (DG) sources. The optimal location of DGs in power systems is very important for obtaining their maximum potential benefits. This paper presents an algorithm to obtain the optimum size and optimum location of the DGs at any bus in the distribution network using Loss Sensitivity factor. The proposed algorithm is based on power loss minimization in the distribution network. The new algorithm is studied in MATLAB for 33 bus test distribution systems. Results indicate that, if the DGs are located at their optimal locations and have optimal sizes, the total losses in the distribution network are reduced by 27%. The results can be used as a look-up table, which can help design engineers when inserting DGs into the distribution networks

Keywords: Fuel cell, Distributed Generation (DG), Optimum Location, Loss sensitivity factor, power loss minimization

I. INTRODUCTION

A power system is an interconnected system composed of generation stations, which convert fuel energy into electrical energy, sub-station that distribute electrical power to loads or consumers and transmission lines that tie the generating station and distribution substation together. According to the voltage levels, an electrical power system can be viewed as consisting of a generating station, a transmission system and a distribution system.

The concept of a distributed utility is installation of smaller modular resources in a distributed manner closer to the point of end use. Dispersed generations could be photovoltaic cells, wind generation, battery storage, fuel cell, micro hydro, etc. Such locally distributed generation has several merits from the view point of environmental restriction and location limitations, as well as transient and voltage stability in the power systems. The objective of this paper is to obtain the solution for minimizing network power loss by optimally locating the dispersed generation under the constraint of the total injection of installed dispersed generation. Distributed Generation (DG) includes the application of small generators, scattered throughout a power system, to provide the electric power needed by electrical customers. It often offers a valuable alternative to traditional sources of electric power for industrial, commercial and residential applications so it appears as an alternative that utility planners should explore in their search for the best solution to electric supply problems

DG offers great values as it provides a flexible way to choose a wide range of combinations of cost and reliability. In term of size, DG may range from few kilowatts to over 100 MW. The share of DGs in power system worldwide is increasing and their contribution in the future power system is expected to be even more. Energy policies worldwide are encouraging installation of DGs in both transmission and distribution networks along with large scale power generating plants. But the fact is that the distribution systems were not planned to support the installation of active power generating units in them. DGs come with opportunities as well as challenges. They, in one hand, are expected to be the solution of most of the power system problems while, on the other hand, they are adding new problems.

Their grid connection, pricing, change in protection scheme are the name of the few. Still we can reap maximum benefit from this new power generation technology if it is handled properly. Hence, utilities and distribution companies need tools to place small generating units in their distribution systems. The need is even more essential when the DG tends to consume reactive power for every unit of real power produced.

In this paper, a load flow technique for radial distribution system is proposed along with the methodology to find the optimal size and location for connecting distributed generator.

II. LOAD FLOW ANALYSIS FOR RADIAL DISTRIBUTION SYSTEM

Load flow calculation is an important and basic tool in the field of power system engineering. It is used in the planning and design stages as well as during the operation stages of the power system. Conventional Newton Raphson and Gauss Seidel methods may become inefficient in the analysis of distribution systems, due to the special features of distribution networks, that is, radial structure, high R/X Ratio and unbalanced loads, etc. These characteristic features make the distribution systems power flow computation different and somewhat difficult to analyze as compared to the transmission systems when the conventional power flow algorithms are employed. Various methods are available in the literature to carry out the analysis of balanced and unbalanced radial distribution systems. Methods developed for the solution of ill-conditioned radial distribution systems may be divided into two categories. The first type of methods is utilized by proper modification of existing methods such as, Newton Raphson and Gauss Seidel. On the other hand, the second group of methods is based on forward and/or backward sweep processes using Kirchhoff's Laws or making use of the well known biquadratic equation. Due to its low memory requirements, computational efficiency and robust convergence characteristic, forward/backward sweep based algorithms have gained the most popularity for distribution systems load flow analysis. In the present study, network topology based forward/backward sweep algorithms have been used for load flow analysis.

A. MATHEMATICAL FORMULATION

To ensure a high-quality product, diagrams and lettering MUST be either computer-drafted or drawn using India ink.

Compensation based algorithm which has both back ward sweep and forward sweep, is used to develop the distribution load flow analysis program using the designed objects. During back ward sweep the branch currents are calculated and during forward sweep bus voltages are calculated. Algorithm for radial configuration

1. Calculate the net nodal current injections using equation (1)

$$I_j^k = I_{s,j} - (I^k_{L,j} + I^k_{sh,j}) \quad (1)$$

Where

K Iteration number

I_j^k Net current injection at bus 'j'

$I_{s,j}$ Injected current by any source 's' at bus 'j'

$I^k_{L,j}$ Load current at bus 'j'

$$I^k_{L,j}=(S_{L,j}/V_j^{k-1})^* \quad (2)$$

$S_{L,j}$ Complex load power

$I^k_{sh,j}$ Current of the shunt device connected

$$I^k_{sh,j} = Y_{sh,j} V_j^{k-1} \quad (3)$$

$Y_{sh,j}$ Admittance of the shunt element

2. Calculate the branch current in all feeders using (4)

$$I^k_{br,j} = I^k_{br,j+1} - I_j^k \quad (4)$$

$I^k_{br,j+1}$ Current in the j+1th branch or current leaving the jth bus

$I^k_{br,j+1} = 0$ if the bus 'j' is the terminal node of a feeder

$=\sum I^k_{br,e}$ if the bus 'j' is the fork node,

E -emanating feeder sections from the fork node

First do the above calculations for the feeders terminating at the terminal node. Then do for the remaining feeders that are terminating at the fork node. This branch current calculation begins at the last branch and terminates at the first branch of each feeder.

B. Forward sweep

3. Calculate the nodal voltages using (5)

$$V^k_j = V^k_{j-1} - Z_j I^k_{br,j} \qquad (5)$$

Where

Z_j -- Impedance of the j^{th} branch

Z_j = Impedance of the j^{th} branch

Forward sweep starts from the feeder connected to the root node and continues to the feeders emerging from this feeder and so on.

4. Check for convergence .find the mismatch between the calculated load power and the specified load power at all buses. If the absolute of the mismatch at all buses are less than certain tolerance value, then stop the iteration, otherwise continue the back ward and forward sweeping

The active and reactive power losses in branch i are given by

$$P\ (i) = |I(i)|^2 \times R(i) \qquad (6)$$

$$Q\ (i) = |I(i)|^2 \times X(i) \qquad (7)$$

Where
R = Resistance of branch i
X = Reactance of branch i

III. DISTRIBUTED GENERATION

Distributed generation is an electric power source connected directly to the distribution network or customer side of the meter. It may be understood in simple term as small-scale electricity generation. The definition of distributed generation takes different forms in different markets and countries and is defined differently by different agencies. International Energy Agency (IEA) defines Distributed generation as generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltages. CIGRE defines DG as the generation, which has the following characteristics. It is not centrally planned; it is not centrally dispatched at present; it is usually connected to the distribution network; it is smaller than 50-100 MW. Other organization like Electric Power Research Institute defines distributed generation as generation from a few kilowatts up to 50 MW. In general, DG means small scale generation.

There are a number of DG technologies available in the market today and few are still in research and development stage. Some currently available technologies are reciprocating engines, micro turbines, combustion gas turbines, fuel cells, photovoltaic, and wind turbines. Each one of these technologies has its own benefits and characteristics. Among all the DG, diesel or gas reciprocating engines and gas turbines make up most of the capacity installed so far. Simultaneously, new DG technology like micro turbine is being introduced and an older technology like reciprocating engine is being improved. Fuel cells are technology of the future. The costs of photovoltaic systems are expected to falling continuously over the next decade. This all underlines the statement that the future of power generation is DG.

Supplying peaking power to reduce the cost of electricity, reduce environmental emissions through clean and renewable technologies (Green Power), combined heat and power (CHP), high level of reliability and quality of supplied power and deferral of the transmission and distribution line investment through improved loadability are the major applications of the DG . Other than these applications, the major application of DG in the deregulated environment lies in the form of ancillary services. These ancillary services include spinning and non-spinning reserves, reactive power supply and voltage control etc. DG Also has several benefits like reducing energy cost through combined heat and power generation, avoiding electricity transmission costs and less exposure to price volatility. Though the DG is considered as a viable solution to most of the problems that today's utility are facing, there are many problems (e.g. DG integration into grid, pricing, change in protection scheme, nuisance tripping etc.) that need to be addressed. Furthermore, the type of DG technology adopted will have significant bearing on the solution approach. In this paper, Fuel cell DGs capable of supplying real power only are considered. Real power injection at optimum location using fuel cell DG is the calculated optimum sizing from the proposed method.

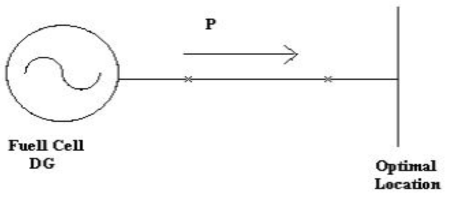


Figure 1. Placing of Fuell Cell based DG at Optimal Location

IV. PROPOSED METHOD FOR OPTIMAL LOCATION AND SIZE OF DG

This paper presents the problem formulation and the solution related to the fuel cell based optimal DG location and sizing using Loss Sensitivity Factor.

A. OPTIMAL LOCATION

Loss sensitivity factor method is based on the principle of linearization of original nonlinear equation around the initial operating point, which helps to reduce the number of solution space. Loss sensitivity factor method has been widely used to solve the capacitor allocation problem. Its application in DG allocation is new in the field and has been reported in

The real power loss in a system is given by (8). This is popularly referred to as ''exact loss'' formula. (8)

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} [\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)] \quad (8)$$

Where

$\alpha_{ij} = r_{ij} / v_i v_j \cos(\delta_i - \delta_j)$

$\beta_{ij} = r_{ij} / v_i v_j \sin(\delta_i - \delta_j)$

The sensitivity factor of real power loss with respect to real power injection from DG is given by

$$\alpha_i = \frac{\partial P_L}{\partial P_i} = 2\sum_{i=1}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) \quad (9)$$

Sensitivity factors are evaluated at each bus, firstly using the values obtained from the base case power flow. The buses are ranked in descending order of the values of their sensitivity factors to form a priority list. The top ranked buses in the priority list are the first to be studied alternatives location. This is generally done to take into account of the effect of nonlinearities in the system. The first order sensitivity factor are based on linearization of the original nonlinear equation around the initial operating condition and is biased towards function which has higher slope at the initial condition, that might not identify the global optimum solution. Therefore, priority list of candidate location is prerequisite to get the optimum solution.

B. OPTIMAL SIZE

The total power loss against injected power is a parabolic function and, at minimum losses, the rate of change of loss with respect to the injected power becomes zero.

$$\frac{\partial P_L}{\partial P_i} = 2\sum_{j=1}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) = 0 \quad (10)$$

It follows that

$$\alpha_{ii}P_i - \beta_{ii}Q_i + \sum_{j=1, j\neq i}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) = 0$$

$$P_i = \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i + \sum_{j=1, j\neq i}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j)\right] \quad (11)$$

$$\left.\begin{aligned} \alpha_{ij} &= \frac{R_{ij}Cos(\delta_i - \delta_j)}{V_iV_j} \\ \beta_{ij} &= \frac{R_{ij}Sin(\delta_i - \delta_j)}{V_iV_j} \end{aligned}\right\} \quad (12)$$

Where P_i is real power injection at node 'i' is the difference between real power generation and real power demand at that node.

$$P_i = (P_{DGi} - P_{Di}) \quad (13)$$

Where P_{DGi} is the real power injection from DG placed at node i, and P_{Di} is the load demand at node 'i'. By combining equations 11 and 13, one can get equation 14.

$$P_{DGi} = P_{Di} + \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i - \sum_{j=1, j\neq i}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j)\right] \quad (14)$$

Equation (14) gives the optimum size of DG for each bus i, for the losses to be minimum. Any size of DG other than P_{DGi} placed at bus i, will lead to higher loss. This loss however is a function of loss coefficient and when DG is installed in the system the values of the loss coefficients will change, as it depends on the state variable voltage and angle; this is the disadvantage of this method. After DG is installed, the values of the voltages and angles at all buses have significant changes and this may lead to high error in the optimal size obtained by equation.

V. RESULTS AND ANALYSIS

The computer programs have been developed in MATLAB software to examine the efficiency of the proposed approach. The proposed work is tested on one radial distribution system; it is 33-bus radial distribution system with a load of 3.72 MW and 2.3 MVAR. Based on the proposed methodology, the optimal DG sizes for all the buses are found in terms of their optimal real power production.

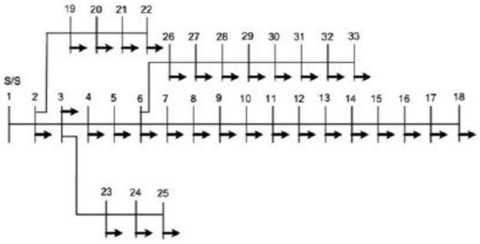


Figure 2. Single line diagram of 33 bus distribution test system

FUEL CELL DISTRIBUTED GENERATION SIMULINK MODEL

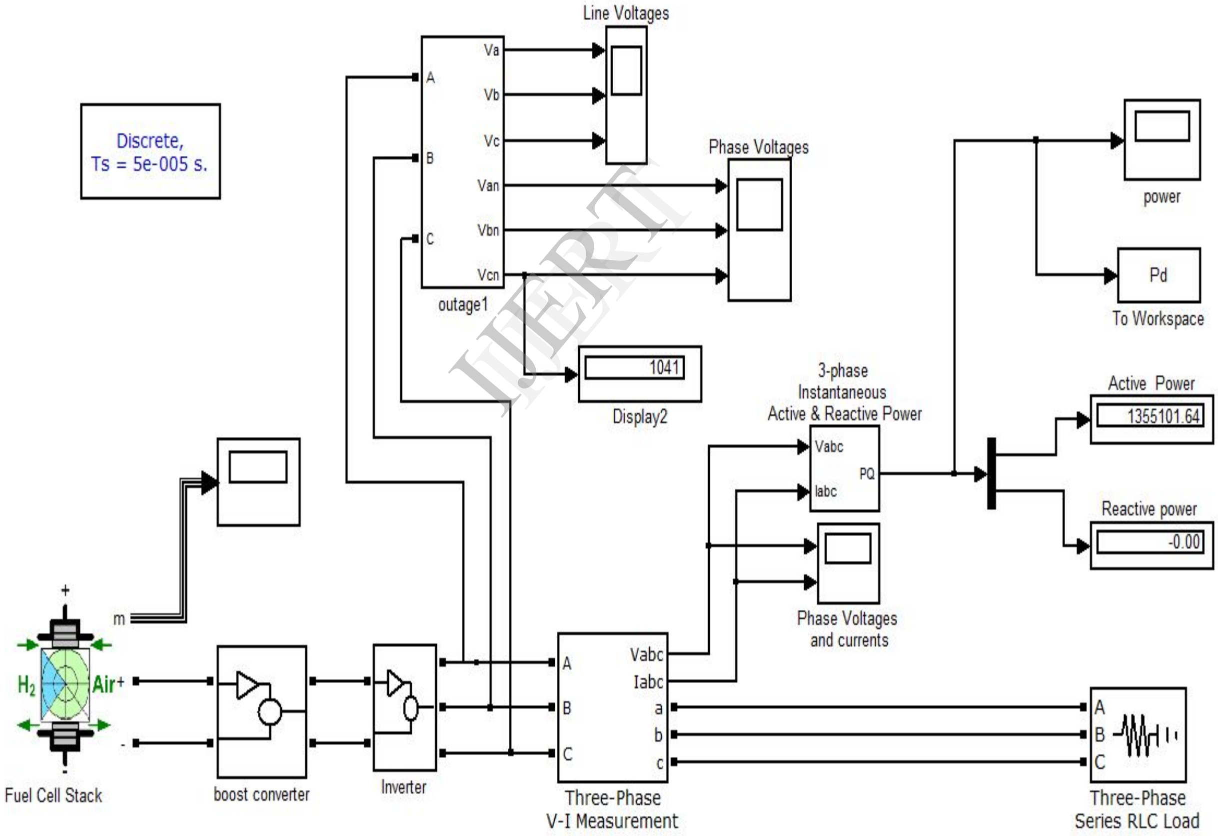


Fig 3. The Simulink model of Fuel Cell DG to generate the required optimal real power

- Generated Real power

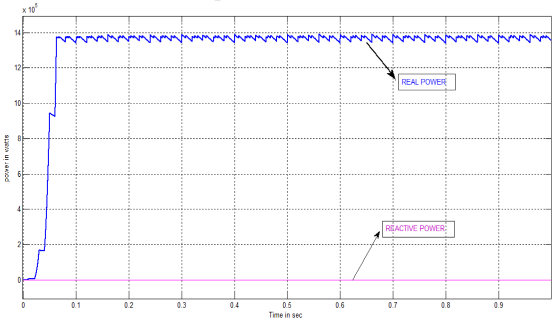
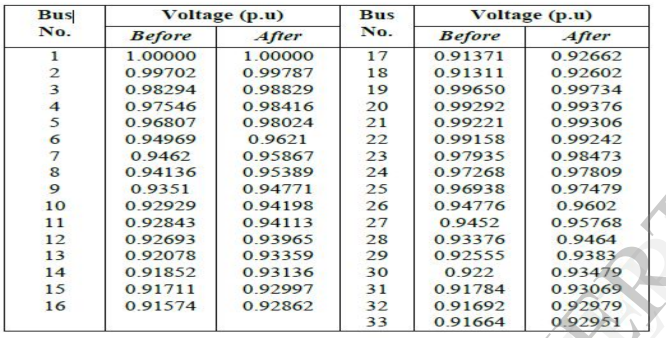


Fig4. Shown below indicates the real power generated by Fuel cell DG

Table I. Voltages obtained for 33-Bus system



Bus| No.	Voltage (p.u)		Bus No.	Voltage (p.u)	
	Before	*After*		*Before*	*After*
1	1.00000	1.00000	17	0.91371	0.92662
2	0.99702	0.99787	18	0.91311	0.92602
3	0.98294	0.98829	19	0.99650	0.99734
4	0.97546	0.98416	20	0.99292	0.99376
5	0.96807	0.98024	21	0.99221	0.99306
6	0.94969	0.9621	22	0.99158	0.99242
7	0.9462	0.95867	23	0.97935	0.98473
8	0.94136	0.95389	24	0.97268	0.97809
9	0.9351	0.94771	25	0.96938	0.97479
10	0.92929	0.94198	26	0.94776	0.9602
11	0.92843	0.94113	27	0.9452	0.95768
12	0.92693	0.93965	28	0.93376	0.9464
13	0.92078	0.93359	29	0.92555	0.9383
14	0.91852	0.93136	30	0.922	0.93479
15	0.91711	0.92997	31	0.91784	0.93069
16	0.91574	0.92862	32	0.91692	0.92979
			33	0.91664	0.92951

The graphical representation of voltages obtained for 33-bus radial distribution

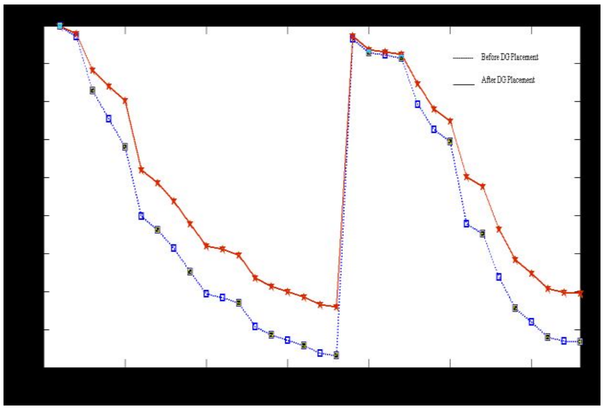


Fig5. Voltage profile before and after placing DG

The real power loss before and after DG placement is shown in Fig 6.

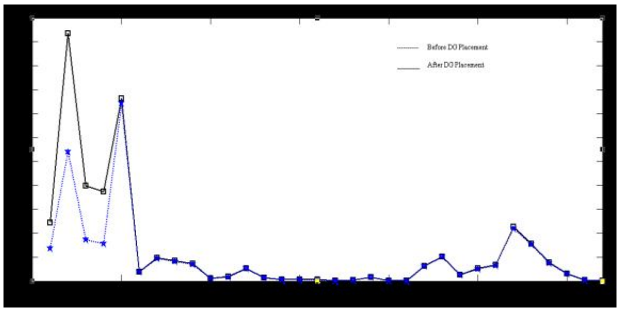


Figure 6. Real power loss befor and after

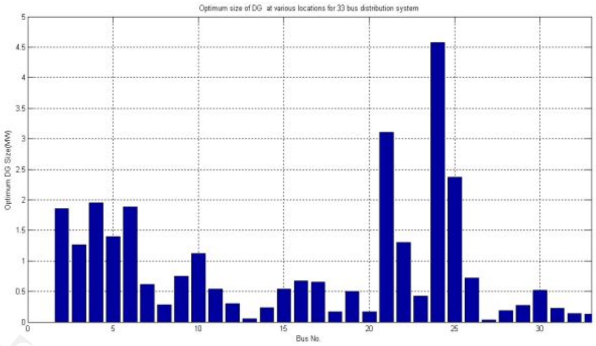
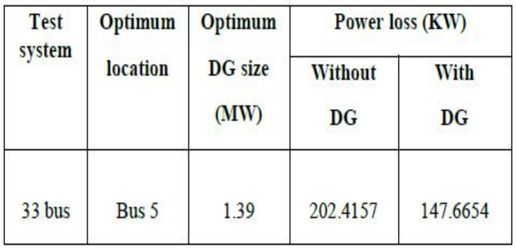


Figure7. Optimum size of DG at various locations for 33 bus distribution system.

Comparison of Active power losses in 33-Bus radial Distribution system is shown in Table II.



Test system	Optimum location	Optimum DG size (MW)	Power loss (KW)	
			Without DG	With DG
33 bus	Bus 5	1.39	202.4157	147.6654

From the results it can be observed that the voltages obtained from after placing DG is greater than before placing DG and the active power losses reduced from 202.4157 to 147.6654 KW which results in 27.048% real power loss reduction and the reactive power losses reduced from 135.0485 to 106.3172 KVAR which results in 21.274% reactive power loss reduction.

VI. CONCLUSIONS

This paper presents a new methodology to place Fuel cell based DG optimally in the radial distribution system with the view of minimizing the real power loss in the system while considering its characteristic. The methodology is fast and accurate in determining the size and location and furthermore, a look up table can be created with only one power flow calculation and the table can be used to restrict the size of DGs at different buses, with the view of minimizing total losses. In this paper, we assume that the DG is installed only at one location at a time, which is a valid assumption. The Performance analysis shows that the proposed algorithm is superior to other methods in the aspect of loss reduction.

REFERENCES

[1] Wang, C. and Nehrir, N.H. 2004. Analytical Approaches for Optimal Placement of Distributed Generation Source in Power System, IEEE Transaction on Power System, Vol. 19, No. 4, pp. 2068-2076

[2] Acharya, N. Mahat, P. and Mithulananthan, N. 2005. An analytical approach for DG allocation in primary distribution network, International Journal of Electrical Power & Energy Systems

[3] CIGRE. Impact of increasing contribution of dispersed generation on the power system. Working Group 37.23, 1999.

[4] IEA Publication. Distributed generation in liberalized electricity market, 2002.Availablefrom: http://www.iea.org/dbtwwpd/textbase/nppdf/free/2000/distributed2002.pdf.

[5] Thomas Ackermann, Goran Anderson, Lennart Soder. Distributed generation: a definition. Electric Power System Res 2001; 57: 195-204.

[6] Francesco Gulli. Distributed generation versus centralized supply: asocial cost-benefit analysis. Institute di Economia e Politica dell ’Energia e dell’ Ambiente (Iefe), Universita` Bocconi, Milano, July 2003.Available from: http://www.econ.cam.ac.uk/dae/repec/cam/pdf/cwpe0336.pdf.

[7] Resource Dynamics Corporation. Assessment of distributed generation technology applications. February 2001. Available from: http://www.distributed-generation.com/Library/Maine.pdf.

[8] R.M.Kamel and B.Kermanshahi; ”optimal size and location of distributed generation for minimizing power losses in a primary Distribution Network” Computer Science & Engineering and Electrical Engineering Vol.16, No.2, pp. 137 {144 c Sharif University of Technology, December 2009.

[9] M. P. Selvan and K.S.Swarup.”Distribution System Load flow using Object-Oriented Methodology”2004 international conference on power systems technology-POWERCON 2004 Singapore 21-24 November 2004.

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Praveen Kumar Boshetti was born in 1989. He received the B.Tech Degree in EEE from J.N.T.U-Hyderabad. Currently pursuing M.Tech in Vignana Bharathi Institue of Technology, INDIA.

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