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Optimal Siting and Sizing of Single SPV System in Radial Distribution Network for Loss Reduction Based on Maximum Power Saving Technique

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ABSTRACT: *This paper presents the optimal placement of aSPV (Solar Photovoltaic) system in the distribution system using the backward and forward sweep method based on the analytical maximum power saving technique for the maximum power loss reduction and voltage profile improvement.The integration of the DG in the distribution network has several advantages such as the power line losses reduction and the improvement of the voltage profile thus the reliability of the system and the reduction of the environment's pollution due the greenhouse gases. On the other hand, the non-strategic location of DG can lead to a serious disturbance in the power network; therefore the research for the optimal siting and sizing of the DG in the radial network becomes crucial. The validity and performance the proposed method was tested on the IEEE 33 and 69 bus test systems and the results were satisfactory.*
Keywords:-*radial distribution network, power loss reduction, Solar Photovoltaic (SPV), Backward*

I. INTRODUCTION

The injection of the distributed or embedded generation defined as small non renewables resources or renewable resources such as wind turbines, solar photovoltaic, in the Radial Distribution Network (RDN) has considerable impact on the performance of the power system and they provide also the alternative power sources because the conventional power sources are finite and they have also participated in the pollution of the environment. The advantages of the penetration of the DG in RDN are numerous such as environmental friendliness, voltage improvement, the power line loss reduction, the postponement of the upgrading of the existing system, increasing the system security and the reduction of the global greenhouse gas pollution produced by the conventional power sources of generation. The high power losses and poor voltage profiles are real problem in the developing countries thus further losses are not tolerated. In order to achieve the above mentioned advantages, the optimal siting of the DG in the system is required and many approacheshave been proposed [1], yet the integration of the DGs in the power system remains a big challenge for the distribution systems operating and planning engineers [2].

Many researchers have investigated on the penetration of the DG in the radial distribution system with different tools such as analytical methods, the heuristic and metaheuristic iterative methods [3-6]. The main techniques used in the power loss minimization are the network reconfiguration [7], the coordination of the DGs in the power systems or the combination of the two [8] and the reactive power compensation.In [3], analytical method based on the exact loss formula was applied for the optimal siting of DG, the load flow was carried out twice with and without DG injected. In [10], the authors used the loss sensitivity and GA for the placement of DG and the results from the voltage sensitive index are different from the loss sensitive index.Several optimization algorithms were used for the placement of DG, Artificial Bee ColonyAlgorithm (ABC) [4], Direct Search Method [5], and Particle Swarm Optimization (PSO) [6]. All the optimization algorithms are based on the load flow analysis either using the Newton Raphson, Fast Decoupled method, Backward and Forward sweep or others proposed by the authors.The BFSM has proved to be efficient in the RDN load flow analysis, was therefore used to solve the optimization problem in this study.

In this paper, the analytical method based on the maximum power saving is proposed for the optimal single DG placement. The approach, was tested on standard IEEE 33 bus test RDN and the results yielded to a maximum power loss reduction and better voltage profile.

II. PROBLEM FORMULATION

The researches have shown that the non-optimal placement of DG in the RDN wouldincrease the power losses in the system [1], thus the mathematical formulation of the power losses is then critical in the siting of the DG. This section deals with the mathematical expression of the power loss and the constraints.

a) *Objective function*

The objective function of this study is to reduce the line losses considering the current flowing in the line.

$$PTL = \sum_{j=1}^{N} I_j^2 \times R_j \quad \textbf{(1)}$$

Where PTL is the total power loss in the system, Ij is the branch current and Rj the branch resistance.
The current flowing has a real and imaginary components, thus the equation 1 can be rewritten with Ij = Iaj + Irj as:

$$\text{PTL} = \sum_{j=1}^{N} I_{aj}^2 \times R_j + \sum_{j=1}^{N} I_{rj}^2 \times R_j \quad \textbf{(2)}$$

b) *Constraints*

The objective function is subjected to the inequality and equality constraints described below:

1. Bus Voltage limits constraints

The bus voltage should be within the tolerable value of the nominal operating constraint of ±5%.

$|V_{jmin}| \leq |V_j| \leq |V_{jmax}|$

2. Feeder capacity limits constraints
   Power flow in each branch must be less than or equal to its maximum capacity rating in order to respect the thermal capacity limit of the feeder lines.
   $|I_j| \leq I_{jmax}$, j=1, 2, 3…….N
3. Power flow equation constraints
   The total active power generated (P_{jGen}) must be equal to the sum of the total active power line losses (P_{loss}) and the total loads (P_{jloads}).

$$\sum P_{jGen} = P_{Loss} + \sum P_{jloads}$$

III. BACKWARD AND FORWARD SWEEP METHOD (BFSM)

The load flow problems are the heart of planning studies, operating conditions, and the starting point of transient and dynamic stability studies of the power systems; they establish the relationship between bus powers generated, the loads, power flow, bus voltage magnitude and phase angle. The radial distribution system is characterized by high R/X ratios, the low voltage operation and the unbalanced loads, thus the conventional Newton Raphson and Fast Decouple methods fail to effectively evaluate the load flow analysis [9], thus the load flow analysis in the radial network can be done by using the BFSM which has proved to be very effective [4], [5], [9]. It mainly constitutes of two paths, the forward walk and the backward walk [13].

During the backward path, the initial bus voltage was set flat at 1.0 p.u. and held constant while the branch currents are computed from the end far node toward the source node.The main purpose of the backward walk is to calculate the current flowing through each branch of the system.

In the forward path, the voltages at each node will be calculated from the source node which is set at 1.0 p.u toward the last node. The values of the currents calculated in the previous iterations are used for the evaluation of the node voltages. This process continues till the stopping criteria are met and the nodal voltages and branch currents can be used for further studies.

IV. PROPOSED METHOD

Many techniques have been used for the optimal placement and sizing of the SPVin the radial distribution system. In this study, the maximum power saving based on the branch current loss formula is analyzed and the result compared with the existing methods [12].The flowchart of the proposed method is shown in figure 1.

From the equation 2, if the DG current is injected at bus k, the current flow from the source to the bus k is affected by the SPV injected but beyond the node k, the flow remains the same, and the mathematical expression is given below:

$$\boldsymbol{PLDGk} = \sum_{j=1}^{k} (\boldsymbol{I_{aj}} + \boldsymbol{I_{DGk}})^2 \times \boldsymbol{R_j} + \sum_{j=k+1}^{N} \boldsymbol{I_{aj}^2} \times \boldsymbol{R_j} + \sum_{j=1}^{k} (\boldsymbol{I_{rj}} + \boldsymbol{a_k I_{DGk}})^2 \times \boldsymbol{R_j} + \sum_{j=k+1}^{N} \boldsymbol{I_{rj}^2} \times \boldsymbol{R_j} \quad \textbf{(3)}$$

Where PLDGk is the total active power loss with the DG injected at node k, Iaj and Irj is the real and imaginary components of the current from the base load flow, Idgk is the SPV current injected at node k and Rj is the line resistance.

a_k= (sign) tan (cos^{-1}(PFdg)), sign =+1 if DG injecting the reactive power and sign=-1 if DG is consuming the reactive power from the network.

Now the saving at each node is calculated by subtracting the total power loss with DG from the total based loss without the DG as shown below:

Saving (SS) = PTL – PLDGk

$$SS = -2I_{DGk}\sum_{j=1}^{k} I_{aj} \times R_j - I_{DGk}^2 \sum_{j=1}^{k} R_j - 2a_k I_{DGk}\sum_{j=1}^{k} I_{rj} \times R_j - a_k^2 I_{DGk}^2 \sum_{j=1}^{k} R_j \quad (4)$$

The maximum value of power saving is found by equating to zero the derivative of the power saving with respect to its equivalent DG current injectedat node k and assuming ak =0 for active power injection.

$$\frac{\partial SS}{\partial I_{DGk}} = 0 \cong -2\sum_{j=1}^{k} I_{aj} \times R_j - 2I_{DGk}\sum_{j=1}^{k} R_j \quad (5)$$

From equation 5, the value of the current injected at each node can be evaluated respectively and these computedcurrent values are replaced in equation 4 for all the nodes, then the node with higher power saving is identified and selected as candidate for SPV placement. The expression for the SPV current at each node is given below:

$$I_{DGk} = -\frac{\sum_{j=1}^{k} I_{aj} \times R_j}{\sum_{j=1}^{k} R_j} \quad (6)$$

The optimal SPV size at selected node k is calculated using the DG current injected at optimal branch and its corresponding voltage magnitude.

$$P_{DGk} = I_{DGk} \times |V_k| = -|V_k| \frac{\sum_{j=1}^{k} I_{aj} \times R_j}{\sum_{j=1}^{k} R_j} \quad (7)$$

This method is suitable for the optimal siting and sizing of a SPV in the RDN, moreover for the multiple DG placement, it faces the local optima challenges.

V. RESULTS AND DISCUSSION

The proposed method validity and performance was tested with the IEEE 33-bus and 69 bus test RDN [12], [13]; the study was done under Matlab R2013a and the based load flow losses and the voltage using the BFSM load flow analysis method is shown in table 1 below

Table 1. Based case result of the test systems

	33 bus	69 bus
Total load (MVA)	3.715+j2.30	3.8021+j0.4869
Total active loss (KW)	201.9057	224.5935
Total reactive loss (Kvar)	134.6618	101.9903
Min voltage (p.u)	0.9134 (18)	0.9102 (65)
Max voltage (p.u)	1	1

Applying the maximum power saving formula in the based load flow results above, the nodes 6 and 61 were identified for the optimal placement of the Solar Photovoltaic with the saving of 91.16 KW and 58.55 KW for 33 and 69 nodes respectively. They were then selected for the maximum active power loss reduction and the optimal size of the SPV injected at unity power factor is calculated before another load flow is carried out with the SPV injected to get the new system line loss and the new voltage profile. The results are presented in the table 2 below.

Table 2. Simulation results for 33 and 69 bus systems

	33 bus	69 bus
optimal siting	6	61
optimal size (MW)	2.48752	0.614
Total active loss (KW)	102.9785	143.3473
Min voltage (p.u)	0.9507 (18)	0.9352 (65)

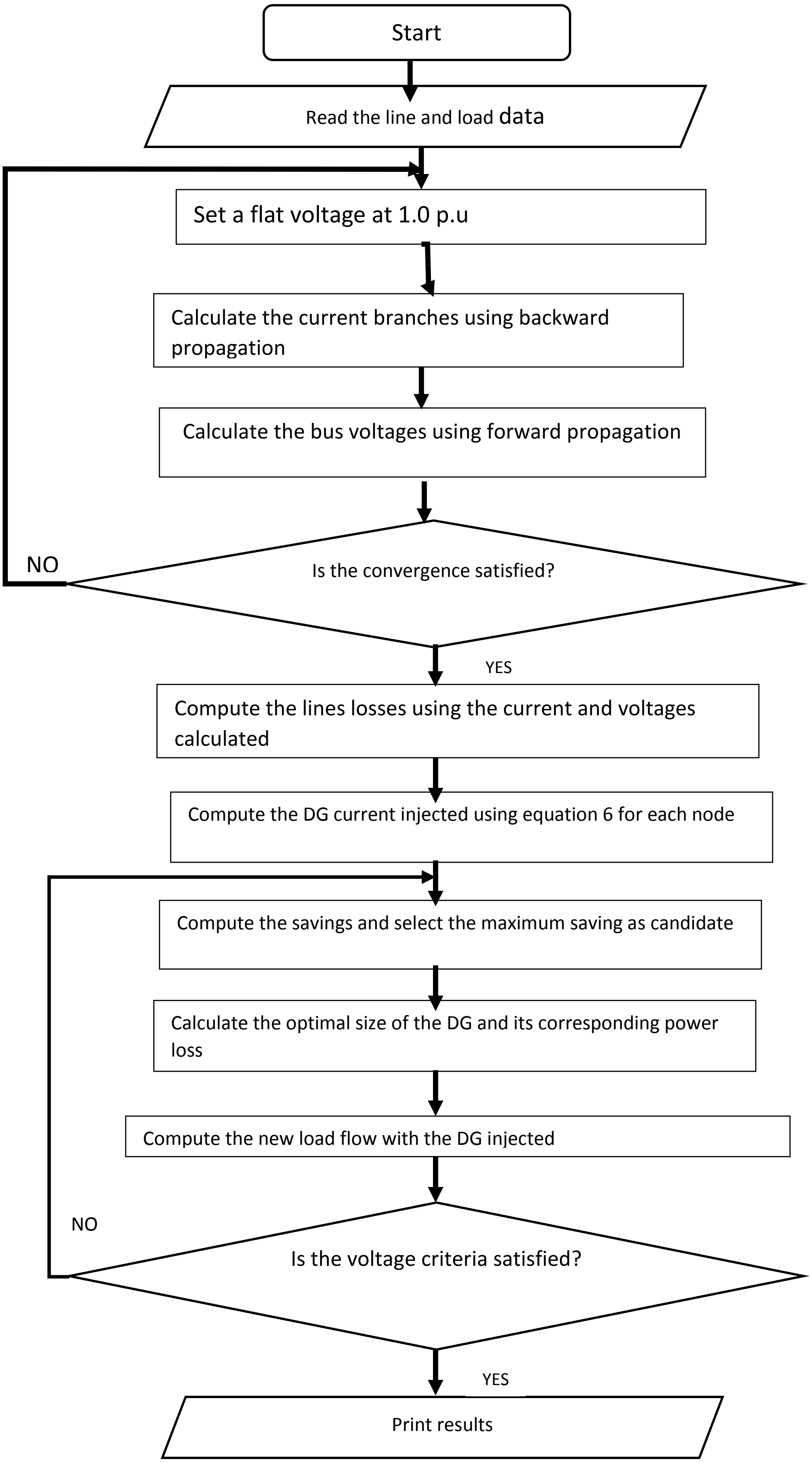

Fig1. Flowchart of BFSM for optimal DG placement

The line losses without and with DG are shown in figure 2 and 3 below, it is noticed that the power line losses have drastically reduced with the presence of the SPV in the radial system.

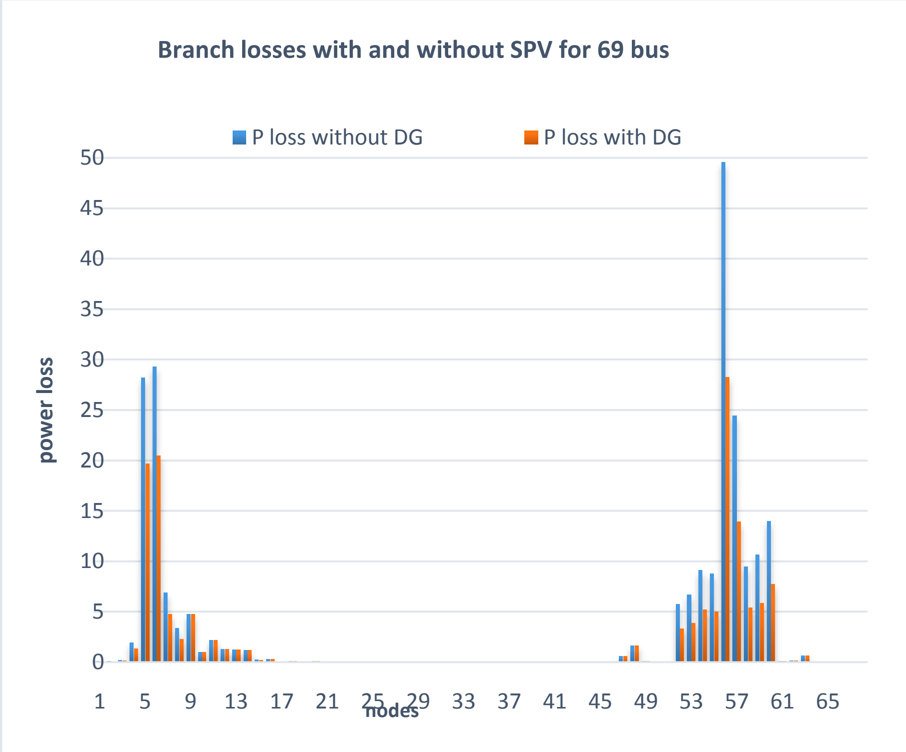

Fig 2. Branch active losses without and with SPV for 69-bus.

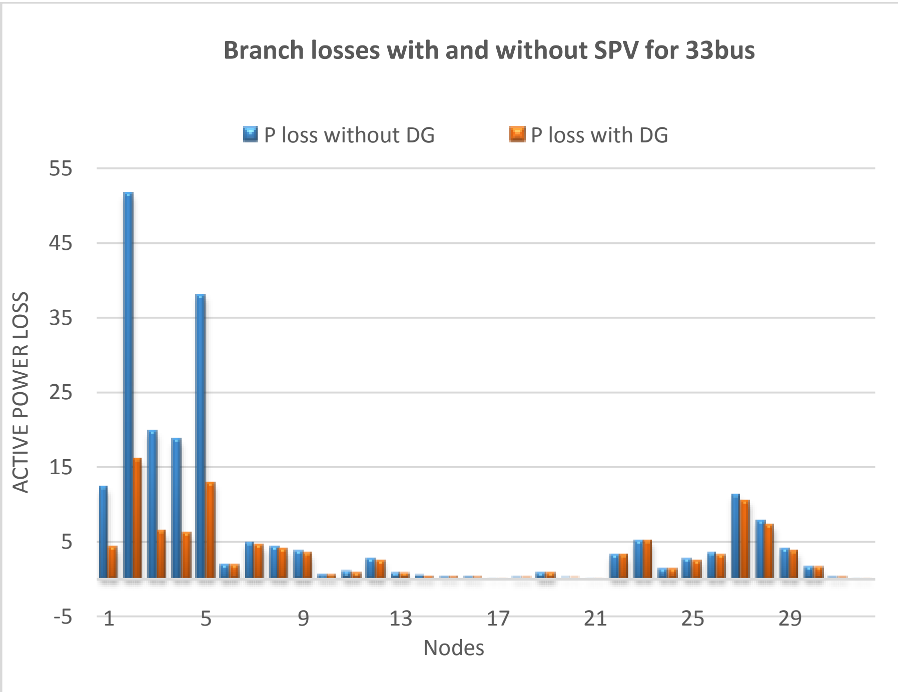

Fig 3. Branch active losses without and with SPV for 33-bus.

The voltage profile of the systems before and after integrating the solar PV system into the grid are shown in figure 4and 5 for 33 and 69 bus respectively.

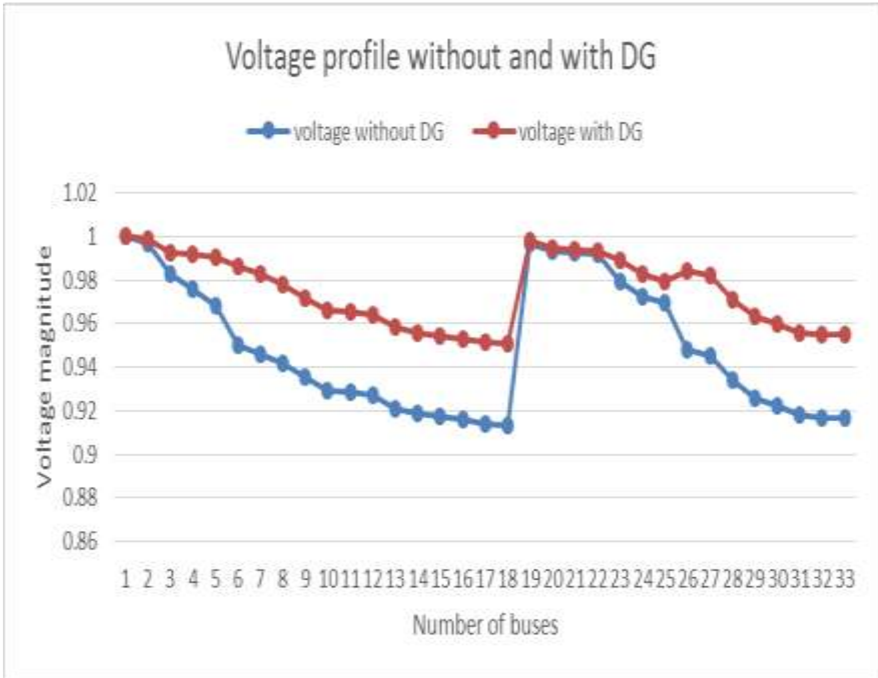

Figure 4. The voltage profile of 33-bus without and with DG integrated.

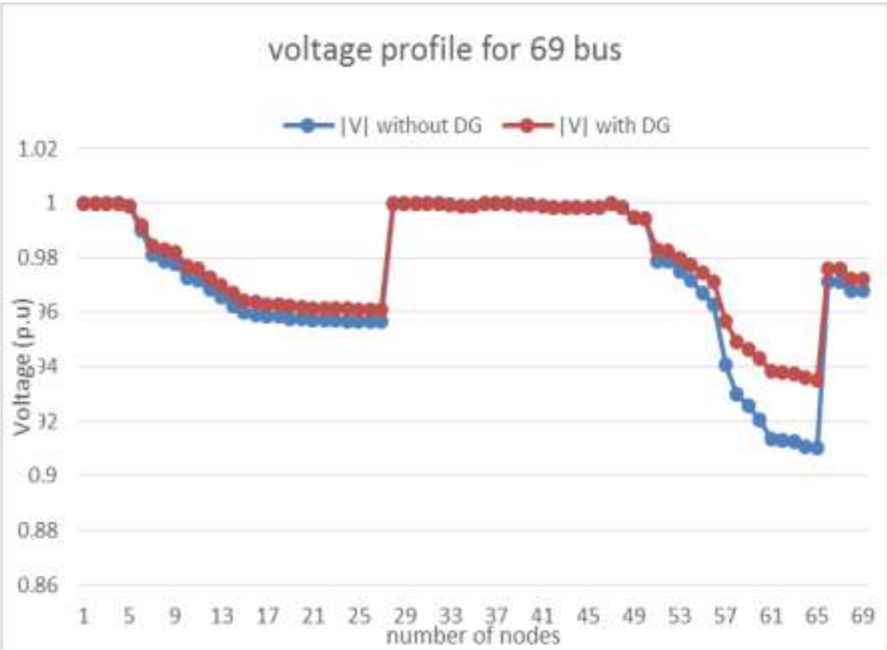

Figure 5. The voltage profile of 69 bus without and with DG integrated.

The integration of the solar in the system has reduced the active power loss by 49% for 33 bus and 36% for 69 bus RDN. The voltage profile has increased by 0.0375 p.u and 0.025 p.u for 33 and 69 bus respectively. The integration of solar system in the distribution system has a positive impact by significantly reducing the losses and improving the voltage profile at the same time reducing the pollution of the environment.

VI. CONCLUSION

An analytical method based on the maximum power saving method was used for the single solar PV system placement and sizing optimization problem. The test was successfully carried on the IEEE 33 and 69 nodes systems with significant active power loss reduction and improvement of the voltage profile.

In further studies, the network reconfiguration with the solar PV integrated for the maximum loss reduction can be considered and cost of the SPV penetration.

References

[1]. Borges, Carmen LT, and Djalma M. Falcão. "Impact of distributed generation allocation and sizing on reliability, losses and voltage profile." Power Tech Conference Proceedings, 2003 IEEE Bologna. Vol. 2. IEEE, 2003.

[2]. Kamaruzzaman, Z. A., Mohamed, A. &Shareef, H. "Effect of grid-connected photovoltaic systems on static and dynamic voltage stability with analysis techniques – a review", University Kebangsaan Malaysia, July 2015.

[3]. Acharya, N., P. Mahat, and N. Mithulananthan, "An analytical approach for DG allocation in primary distribution network." International Journal of Electrical Power & Energy Systems, 2006. 28(10): p. 669-678.

[4]. Abu-Mouti, F.S. and M.E. El-Hawary, "Optimal Distributed GenerationAllocation and Sizing in Distribution Systems via Artificial Bee ColonyAlgorithm." Power Delivery, IEEE Transactions on, 2011. **26**(4): p. 2090- 2101.

[5]. Nagaraju, B., K. Sri Padmini, and J. Viswanatha Rao. "Optimal Placement of SPV based DG for Loss Reduction in Radial Distribution System Using Direct Search Algorithm.", Vol. 3, Issue. 1, ISSN: 2345 – 9603, April, 2015

[6]. M.PadmaLalitha, V.V.V.R., V. Usha, Optimal DG placement for minimumreal power loss in radial distribution systems using PSO. Journal of Theoretical and Applied Information Technology, 2010. **13**(2): p. 107-116

[7]. Wu, Y. K., Lee, C. Y., Liu, L. C., & Tsai, S. H. "Study of reconfiguration for the distribution system with distributed generators." Power Delivery, IEEE Transactions on, (2010). 25(3), pp. 1678-1685.

[8]. M.N. Muhtazaruddin, J.J. Jamian, G. Fujita, M.A. Baharudin, M.W. Wazir and H. Mokhlis "Distribution Network Loss Minimization via Simultaneous Distributed Generation Coordination with Network Reconfiguration", Arabian Journal for Science and Engineering, Springer, Vol. 39, No. 6, pp. 4923-4933, June 2014.

[9]. S. Kumar Injeti and N. Prema Kumar, "A novel approach to identify optimal access point and capacity of multiple DGs in a small, medium and large scale radial distribution systems", Electrical Power and Energy Systems, vol. 45, **(2013)**, pp. 142–151.

[10]. Singh, Nitin. Optimal Sizing and Placement of DG in a Radial Distribution Network using Sensitivity based methods. Diss. THAPAR UNIVERSITY, PATIALA, 2014.

[11]. Hung, Duong Quoc, NadarajahMithulananthan, and R. C. Bansal. "Analytical expressions for DG allocation in primary distribution networks." Energy Conversion, IEEE Transactions on 25.3 (2010): 814-820.

[12]. Hung, Duong Quoc. "Smart Integration of Distributed Renewable Generation and Battery Energy Storage." (2014).

[13]. Rupa, JA Michline, and S.Ganesh. "Power Flow Analysis for Radial Distribution System Using Backward/Forward Sweep Method." World Academy of Science, Engineering and Technology, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering 8.10 (2014):1559-1563.