IMPACTS OF DIFFERENT TYPES OF DISTRIBUTED GENERATION PENETRATION ON DISTRIBUTION NETWORK VOLTAGE PROFILE

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Abstract: *Different types of distributed generation (DG) power plant have different impacts on distribution networks. This paper investigates the impact of optimal placement and sizing of different types of DG units in distribution networks with respect to power system losses and voltage profile. Three different types of DGs; solar photovoltaic, diesel generator and wind turbine are installed on a 30-bus 33kV radial distribution network. The analysis is conducted in power system software for Engineering (PSS/E) environment. The research used a two-step consolidated optimization novel technique with full Newton Raphson load flow algorithm combined with loss sensitivity factor to optimize the size and location of DG in the 33kV feeder distribution network. This optimization technique is evaluated using different types of distributed generators on the 30-bus, 33kV feeder distribution network. The obtained results show that different types of DG influence differently the distribution network and that their precise location and size are vital in reducing power losses and improving the voltage profile. The type 3 DG (wind) has the least potential for improving voltage profile as well as system power reduction of the distribution network. Hence this serves as a vital tool for system Engineers on the type of renewable energy source technology to be employed in integrating it to distribution power system.*

Keywords *distributed generation, impacts, voltage profile, feeder distribution network*

I. INTRODUCTION

Distributed Generation (DG) refers to generators that are connected to the distribution network. They are connected closer to the load and have the ability to reduce or postpone the need for investment in the transmission and distribution infrastructure when optimally sized and located [1]. It has the ability to reduce technical losses within the transmission and distribution networks as well as general improvement in power quality and system reliability. The penetration of distributed generation (DG) into distribution systems can enhance the operation of power systems by improving the voltage profile, reducing the energy losses of distribution feeders, reducing maintenance costs as well as loading of transformer tap changers during peak hours [2]. The major challenging issue of identifying the optimal size and location as well as the impact of different types DGs in the distribution network has generated a lot research interest especially to power system Engineers. The authors [3] studied that inappropriate positioning and sizing the distributed generators may lead to higher power losses on the existing entire distribution system. The paper attributed the ever increasing voltage drop to exponential electricity demand and thereby need for upgrading of the distribution system infrastructure. An overview of artificial intelligent-techniques for sizing PV systems in stand-alone, grid-connected and PV-wind hybrid systems was presented [4] but fails to optimize the location. In distribution system network, voltage variation and harmonic distortion is one of the major problems but several mitigation strategies such as the use of custom power controller, passive and active power filters were applied. However, these mitigation strategies require investment. Therefore, to improve voltage profile and eliminate harmonic distortion in a distribution system with DG, a non-invasive method is proposed, which involves appropriate planning of DG units and determining optimal placement and sizing of DG units [5]. Naresh *et al* [6] evaluated the optimal size and location of the DG to minimize active power loss based on exact loss formula. This method is applicable for single DG unit placement when only active power is supplied by DG.. Loss sensitivity factor (LSF) based method was employed to select the candidate locations for single DG placement. Results indicate that loss sensitivity factor based approach may not lead to the best placement for loss reduction. Analytical method [7] based on phasor current to identify optimal location of DG in both mesh and a radial system for power loss minimization was presented. However, the proposed approach is a non-iterative and there is no convergence problems associated with it. The drawback of this method is that it finds location for a fixed DG size only.

Duong Quoc *et al* [8] proposed an analytical method for determining optimal size and location of four different DG types viz: DG capable of delivering both real and reactive power, DG capable of delivering only active power, DG capable of delivering real power and absorbing reactive power and DG capable of delivering reactive power only. It was shown that operating power factor of DGs for minimizing power losses found to be nearer to the power factor of combined load in the respective system. However, the voltage profile impacts of the type of DGs were not verified. Also, a Genetic Algorithm (GA) based optimal size and placement of DG in distribution network has been proposed [9]. The GA methods are used to find optimal size and bus location for placing DG using power loss and energy loss minimization in a network system based on bus admittance, generation information and load distribution of the system. The effectiveness of the proposed method is tested through simulation results on 16, 37 and 75-bus test systems and minimum system loss is obtained under voltage and line loading constraint with uniform loading conditions.

A differential evolution optimization approach has been proposed [10]. In this study, DG resources were embedded to the network objectively for reduction of power losses and improvement of the voltage profile of the network at optimal location and size of DG units. The optimization technique used a single DG sizing and placement for real power loss minimization and did not take into consideration multiple DG injection. Artificial Neural Network (ANN) optimization was applied for DG size and placement [11]. It is a simple and fast approach for allocation and size evaluation of DG in distribution network. They developed a voltage stability index (VSI) from conventional power flow equation to determine the stability of buses. Then a priority list is set up using VSI to allocate DG units. Artificial neural network technique was used to determine proper size of the DG units to ensure the permissible static voltage for each bus. The result showed an improvement on the static voltage profile of the network but the impacts of different types of of DG units were not considered.

Different types of distribution generation (DG) power plant have different impacts on distribution networks. An instance, a type 1 DG (photovoltaic) that injects active power only into the distribution network system might have a different impact to that of a wind turbine. Therefore, the aim of this paper is to investigate the impact of optimal placement and sizing of different types of DG units in distribution networks with respect to power system losses and voltage profile. Three different types of DGs; solar photovoltaic, diesel generator and wind turbine are installed on a radial distribution network and analysis is conducted through a power system software for Engineering (PSS/E) environment. A two-step consolidated optimization novel technique with full Newton Raphson load flow is used. In the first step, the optimal size of DG is determined by partial derivative of exact loss formula with respect to active power injected by the DG. Whereas in the second step, the optimal location is found by loss sensitivity factor (LSF) aimed at reducing active power losses as well as improving the voltage profile of the network and the load flow algorithm is applied to evaluate the losses. This optimization technique is evaluated using different types of distributed generators on the feeder distribution network. The applied full Newton Raphson load flow algorithm combined with loss sensitivity factor to optimize location of the DGs in the 30-bus, 33kV feeder distribution system network is identified at the least system power loss This position impacts an improved voltage profile in the network.

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II. DG MODELING FORMULATION

This section presents the modelling of the different DGs, constraints to the objectives with respect to network problem formulation.

A. Modelling of DG Units

The placement, type and size of the DG should be optimal in order to maximize the benefits of it [7]. The impact of DG on power system not only affected by DG location but also depends on the network topology as well as on DG size and type [14]. Each and every type of DGs requires separate mathematical modelling. Distribution Generation (DG) from energy view point can be classified into three (3) types namely:

DG Type **1:** This is the type of DG capable of injecting real power only. This type of DG includes Photovoltaic (PV), Fuel Cell (FC), and Micro Turbine (MT). This will generate only real power when integrated to the main grid with the help of converters/inverters. However, to obtain optimum DG size at ith bus under the conditions of minimum loss:

$$P_i = (P_{DG} - P_D) \cdot \quad (1)$$

$$\frac{1}{\alpha_{ij}}[\beta_{ij} Q_i + \sum_{j=1\, j \neq i}^{N} (\alpha_i P_j - \beta_i Q_j)] = (P_{DG} - P_D) \quad (2)$$

From equations (1) and (2) the optimal DG size for ith bus in the network is given as:

$$P_{DGi} = P_D + \frac{1}{\alpha_{ij}}[\beta_{ij} Q_i - \sum_{j=1\, j\neq i}^{N} (\alpha_i P_j - \beta_i Q_j)] \quad (3)$$

Equation (3) describes the optimal sizing of DG for each bus so as to minimize the total active power loss after DG placement

DG Type 2: DG capable of injecting reactive power (Q) only. It provides only reactive power to improve voltage profile. Typical examples are diesel generators and synchronous compensators in power system. To determine optimal DG placement; the loss equation is differentiated on both sides with respect to Q. The optimal DG size for every bus in the system is given as:

$$Q_{DGi} = Q_{Di} - \frac{1}{\alpha_{ij}}[\beta_{ij} Q_i + \sum_{j=1\, j\neq i}^{N} (\alpha_i Q_j - \beta_{ij} P_j)] \quad (4)$$

DG Type 3**:** These set type of DG supplies real power and in turn absorb reactive power. In case of wind turbine, induction generator is used to produce real power and the reactive power will be consumed in the process [15]. The amount of reactive power they require is an ever increasing function of the active power output. The reactive power consumed by this type of DG (wind turbine) is expressed in equation (5).

$$Q_{DGi} = -(0.5 + 0.004 P_{DG}^2) \quad (5)$$

B. Problem Formulation

The objective function is to minimize the active power loss using equation (2.6) and formulated as to minimize: $P_{Loss} = \sum_{K=1}^{LN} Loss$ (6)

Subject to: **Inequality constraints:**

$$\sum_{i=1}^{n} P_{Gi} \leq \sum_{i=1}^{n} (P_i + P_{Loss}) \quad (7)$$

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (.8)$$

$$|I_{ij}| \leq |I_{ij}|^{\max} \quad (9)$$

Equality constraints:

This expresses the load flow equation

$$Q_{Gi} - Q_{Di} - V_i \sum_{K=1}^{Ln} [G_{ij} Sin (\delta_i - \delta_j) + B_{ij} Cos (\delta_i - \delta_j)] = 0 \quad (10)$$

$$P_{Gi} - P_{Di} V_i \sum_{K=1}^{Ln} [G_{ij} \cos (\delta_i - \delta_j) + B_{ij} \sin (\delta_i - \delta_j)] = 0 \quad (11)$$

Where I = 1 , 2, ……Ln is the number of buses,

P_G and Q_G are generator real and reactive power respectively, P_D and Q_D a real and reactive loads respectively, G_{ij} and B_{ij} are transfer conductance and susceptance between bus i and bus j respectively.

III. PROPOESD METHODOLOGY

In this research, a 30 - bus distorted IEEE distribution feeder network with a base voltage of 33kV is used for the study. The single line diagram of the system is shown in figure 1 below modelled in PSS/E environment. The network details of loads and line data are obtained in [12]. The radial feeder test system network is connected with a transmission substation 132kV/33kV, 500KVA transformer. The network branches' maximum current is 520A and the allowable range for bus voltage magnitude is considered from 0.9 p. u to 1.01 p u.

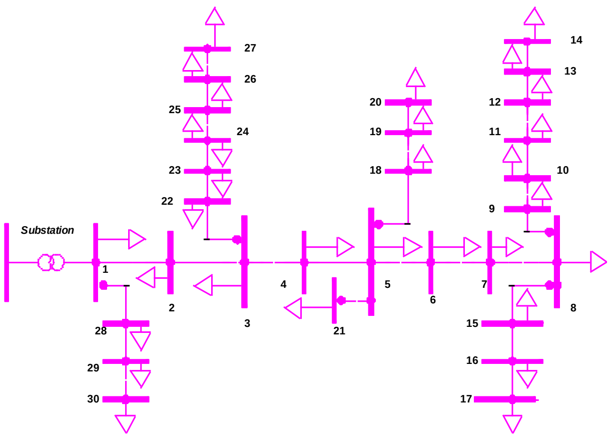


Fig: 1 30-bus IEEE distorted feeder distribution system network.

Four different case studies have been considered on this IEEE 30- bus radial feeder as follows: Radial distribution test feeder without DG (base case), Radial distribution test feeder with 3-tpes of DG (at optimal size and position), Radial distribution test feeder with DG evaluation of the system power losses and Radial distribution test feeder with DG evaluation of the network voltage profile.

A. Algorithm for DG Location and Sizing

The algorithm for DG location and sizing can be summarized in figure 2 using a flowchart with following steps:

Step 1: Input the network data and run the base case load flow.

Step 2: Form the voltage sensitivity indices of each bus and rank them in a priority list to form the candidate buses for DG placement

Step 3: Evaluate the optimal size of each DG using for each of the candidate buses.

Step 4: select a bus right from the highest priorities.

Step 5::Input the optimized size of the DG into first select candidate bus.

Step 6: check the objective constraint with respect to the selected candidate bus.

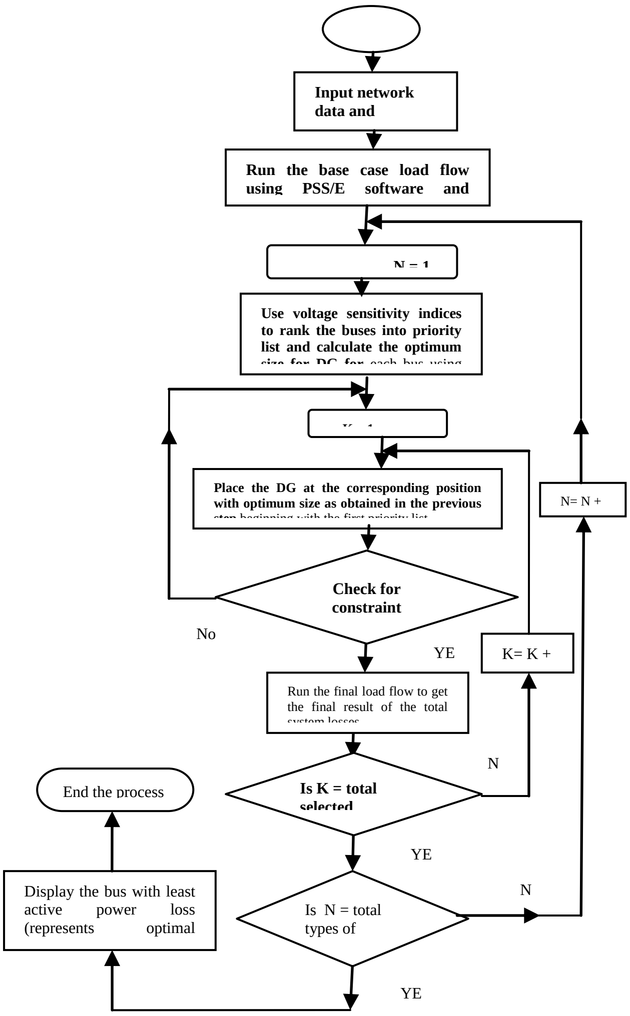
Step 7: Run the full Newton Raphson load flow and evaluate the total system power loss.

Step 8: Compare the results,, the least power loss marks the optimum position for the DG placement

Step9: Repeat step 5 to step 8 for all the three types DGs to be evaluated

Step 10: Compare the different results obtained in all the evaluations

Step 11: End the process.



Fig/ 2: Flow Chart of the Proposed Method

IV. RESULT AND DISCUSSIONS

A. Analysis of Distribution Network with Type 1 DG.

A PV system of optimal sizes according to priority list has been connected at each bus. This is executed through a single DG placement in order to examine its impact on the distribution network. A load flow analysis has performed for each case. The obtained voltage profiles for all the buses is then compared with the base case as shown in figure 3 below. The shows that there are improvements on the general system profile especially those vulnerable buses (30, 26, 29 and 24).

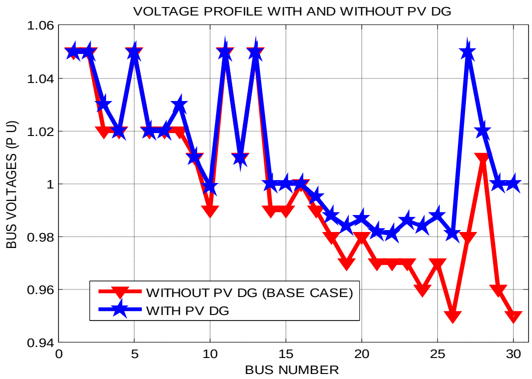


Fig. 3: Voltage profile of the system network with and without PV DG

Also, figure 4 displayed the result of the total active power loss for each of the candidate buses. The least active power loss amongst them corresponds to optimal position as indicated on the graph. This optimal position at bus 30 was obtained at optimal of 15.9 MW.

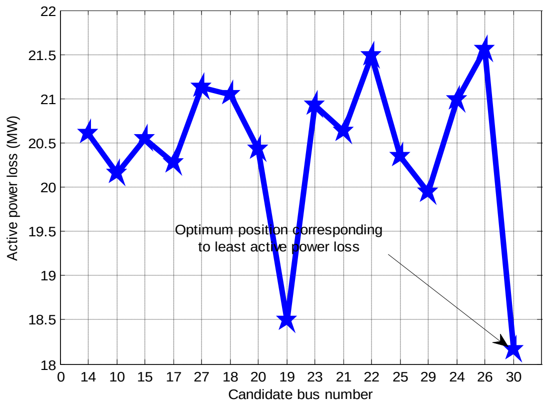


Fig .4 Total active power losses at various buses with type 1 DG.

B. Analysis of Distribution Network with Type 2 DG.

The chosen candidate bus location from the priority list are install with type 2 DG (diesel generators). Each diesel generator was installed at a time and load flow analysis was performed. The obtained result of the comparative voltage profiles for all the buses is shown in figure 5 below. The overall voltage improvements of the system profile especially on the vulnerable buses (30, 26, 29 and 24) were not as strong as that of type 1 DG impact. The total active power losses after the installation of type 2 DG at optimal position were 17.81MW at optimal size of (17.5 MW + j16.8 MVar) as illustrated in figure 6.

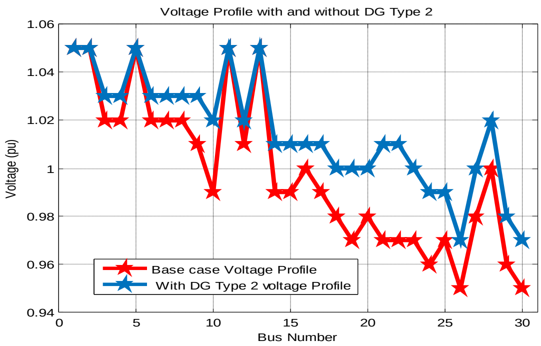


Fig. 5: Voltage profile of the system network with and without type 2 DG

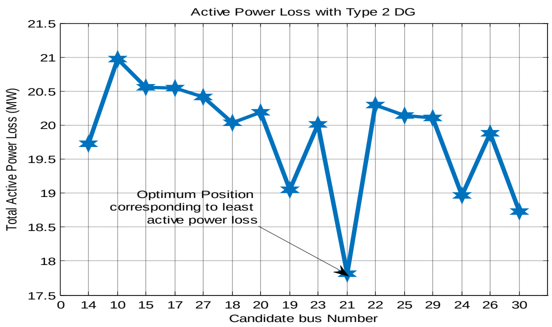


Fig. 6: Total active power losses at various buses with type 2

C. *Analysis of Distribution Network with Type 3 DG.*

The impact of type 3 DG (wind turbine) was observed in the distribution network. Each of the DG is connected with each of the selected candidate buses at optimal size and position. Load flow analysis was performed for each case. The obtained comparative result the voltage profiles at optimal position (bus 21) and size (17MW/1.23MVar) of the examined distribution network after the installation of DG 3-wind is represented in Figure 7 below. The impact of this type of on the network shows general improvement especially on the vulnerable buses (30, 26, 29 and 24). However, the strength of its impartations is relatively lower compared to other types of distributed generation

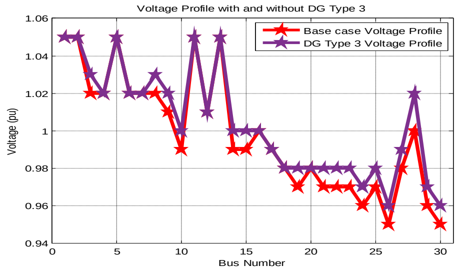


Figure 7: Voltage profile of the system network with and without type 3 DG

Figure 8 shows the result of the total active power loss for each of the candidate buses. Each of the candidate bus is placed with the optimal size DG and analysis of load flow was carried out for each case. The least active power loss (18.11MW) amongst them corresponds to optimal position (bus 21) as indicated on the graph below.

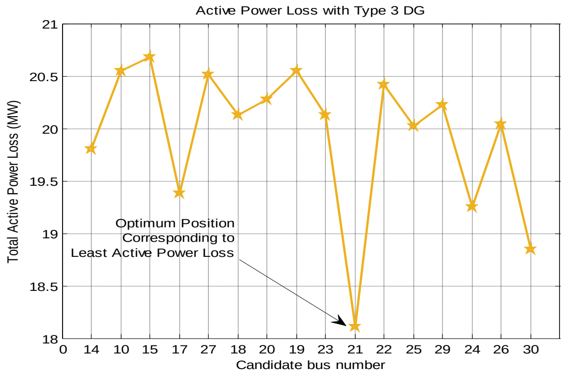


Fig 8: Total active power losses at various buses with type 3 DG

D. Comparative Analysis of the Simulation Result

The comparative analysis of the impacts of different types of on the voltage profile of a distribution network implies that different level of voltage improvements are obtained with respect to the type of DG. As shown in figure 9, the three different types of DG produced different voltage profile on this distribution network at different optimal size and position. From the figure, it shows that type 2 DG (diesel) has the highest level of voltage improvement. The lowest is the type 3 DG (wind).

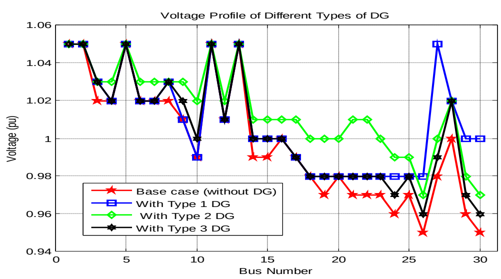


Fig. 9: voltage profile impacts of the 3-types DG.

As shown in figure 10 there are different levels of active power loss reduction in the network. Whereas the type 2 DG (diesel) produced the highest percentage (18.5%) of active power loss reduction, type 1 DG (photovoltaic) 16.8% is the least in the power network.

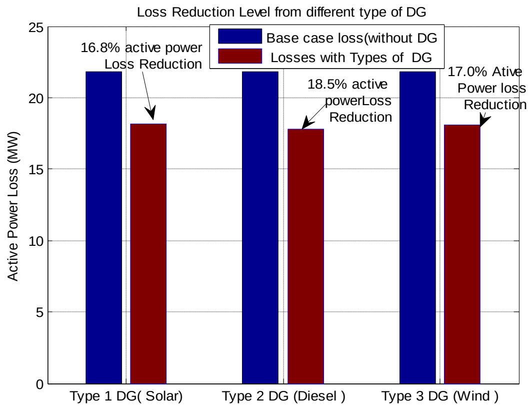


Fig. 10: Level of active power loss reduction for each type of DG

The active power losses with each of the selected candidate buses as shown in figure 11 depicts the impacts of different types of DG on distribution network. Each of the candidate bus has its own level of active power loss with respect to different DGs. The type 2 and type 3 DGs have greater level of active power reduction in the whole power system.

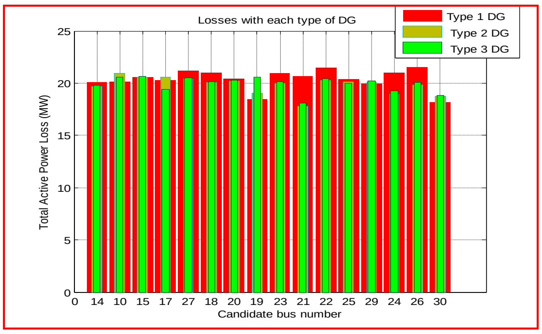


Fig. 11: Active power loss impacts on each of the candidate buses

E. Conclusions

This research paper investigated the impacts of different types of distribution generators on the distribution system. The authors used a two-step consolidated optimization novel technique with full Newton Raphson load flow in a power system software for Engineering (PSS/E) environment. Three different types of DG were investigated via; photovoltaic (PV), diesel generator and wind turbine. Each type of DG at optimal location and size were placed in the distribution network with regards to voltage profile and system power losses. The obtained results show that different types of DG influence differently the distribution network and that their precise location and size are vital in reducing power losses and improving the voltage stability. The type 3 DG (wind) has the least potential for improving voltage profile as well as system power reduction of the distribution network. Hence this serves as a vital tool for system Engineers on the type of renewable energy source technology to be employed in integrating with distribution power system for optimum benefits.

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