Optimal Sizing and Placement of Distributed Generation to Power Distribution Network Using Analytical Approach

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Abstract: Energy is the mainstay of growth and development in Nigeria due to population outburst, industrialization, agricultural production and improving living standards. Nigeria is blessed with abundant primary energy resources enough to meet its present and future development requirement. With the recent initiatives on renewable energy coupled with the profound public assessment of the environmental impacts of using fossil fuels to generate electricity, penetration of renewable distributed generation into the distribution network has become increasing important in recent years. The aim of optimal sizing and placement of DG to the distribution network using analytical approach is to provide best location and size of DG to optimize electrical distribution network operation and planning taking into account DG capacity constraints. This method requires less computation and optimal solution.

Keywords: *Distributed generation Analytical expressions, loss reduction, optimal size*

1.0 INTRODUCTION

High rise of DG penetration into the distribution system is the current trend around the world, this may be due to constraints on building new transmission and distribution lines and environmental concerns (Ackermann, et al, 2001). However, with proper placement and sizing of DG to the distribution network, losses could be reduced, voltage profile improved and system reliability increased (Pavlos, et al, 2013) Presently, there are several DG technologies: the nonrenewable technologies, such as internal combustion engines, combined cycles, combustion turbines and micro-turbines, and the renewable DG technologies such as fuel cells, storage devices, biomass, wind, geothermal and photovoltaic (Hung, et al, 2010). The performance of distributed system becomes inefficient due to the reduction in voltage magnitude and increase in distribution losses. This has necessitated the need to consider active distribution network by incorporating DG unit (Zhu, 2002). Distributed generator could be grid-connected or standalone electric generation unit located within the electric distribution system at or near the end user. Optimization is a mathematical tool which can be used to locate and size the DG units in the system, so as to utilize these units optimally within certain limits and constraints (Pandey & Bhadoriya, 2014). Solar photovoltaic (PV) system as an energy source from the sun is one of the renewables that promote safe and clean energy exploration technology. It enhances the operation of power systems by improving the voltage profile, reducing energy losses of distribution feeders, reducing maintenance costs as well as loading of transformer tap changers during peak hours (Omran, et al, 2009, pp 1-6). The sizing and placement of DG to distribution network can either be done using heuristic approaches (Genetic Algorithm) or analytical approaches such as Lambda iteration method, gradient method, Newton-Raphson method, linear programming and interior point method. This paper is based on improved Newton Raphson approach for sizing and placement of DG because it requires less computation, and leads to optimal solution. The proposed approach is tested on IEEE 33 bus radial distribution system. The distribution system is classified into two types: the primary and secondary distribution systems, while it has [1]two main types of configurations: the radial and ring main configurations system (Anil, et al, 2019)

1.1 Problem Statement

Consumers in distribution system are suffering from low voltage profiles at load end. Wrong placement of DG in the distribution network can lead to active power loss and low voltage profile (Gozel, et al, 2009, pp 912-918). To overcome this problem, the placement of distributed generator to the distribution system should be done optimally. This can lead to voltage improvement, reduction in distribution losses; improve power quality and reliability of supply. Optimal sizing and placement of DG in power system distribution network using analytical approach deals with the determination of the optimal location and size of the DG unit to be installed into standard IEEE 33 bus radial distribution networks, subject to some constraints.

2.0 HEURISTIC APPROACH OF DG SIZING AND PLACEMENT

There have been many studies on the reconfiguration of distribution systems for loss reduction such as genetic algorithm (Nara, et al, 1992), simulated annealing (SA) (Jeon, et al, 2002), improved Tabu search (TS) (Zhang, 2007) and ant colony search (ACS) algorithm. Though these methods are suitable for multi-objective problems and lead to a near optimal solution, they however demand computational time. Newly developed heuristic genetic algorithm known as particle swarm optimization algorithm (PSO) has also been used for the determination of optimal size and placement of DG (Su, et al, 2005).

This method combines social psychology principles and evolutionary computation to motivate the behavior of organisms such as fish, birds etc. It was originally put forward by Doctor Kennedy and E Berhart in 1995 (Kennedy & Eberhart,1995). Other forms of genetic algorithm are artificial bee colony (ABC), whale optimization algorithm (WOA) (Ang & Leeton,2019)

These techniques may not be effective in distribution with non-uniformly distributed loads and with a DG that supplies both real and reactive power.

2.1 Analytical approach of DG sizing and placement.

Analytical approach is better used to determine the size and location of DG in both radial and loop systems to reduce losses (Wang &Nehrir, 2004). Most approaches model DG as a machine that is capable of supplying real power, but there are other types of DG that can be integrated into the distribution systems.

3.0. METHODOLOGY

For a balanced distribution network, the network can be represented by an equivalent single line circuit. The line shunt capacitances at distribution voltage level are very small and thus can be neglected.

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3.1: Mathematical Modeling of Standard IEEE 33 Bus Radial Distribution Network

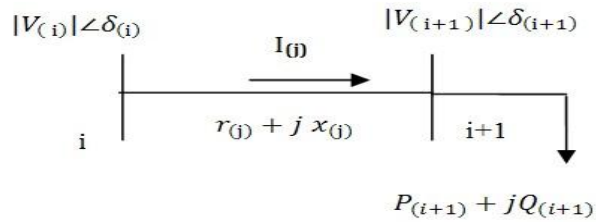

Fig 3.1: Equivalent Single Line Circuit of a Radial Distribution Network (RDN)

The complex power fed to node i is represented by

$S_i = V_i I_i^* = P_i + jQ_i$ (1)

$I_i = \left(\frac{S_i}{V_i}\right)^* = \frac{P_i - jQ_i}{V_i^*}$ (2)

$I_i = I_i cos\theta_i + jI_i sin\theta_i$ (3)

$\theta_i = tan^{-1}\left(\frac{Q_i}{P_i}\right)$ (4)

Branch current calculation:

$I_{bi} = \sum_{i=1}^{n} \quad |I_i|cos\theta_i + j\sum_{i=1}^{n} \quad |I_i|sin\theta_i$ (5)

$\angle I_{bi} = tan^{-1}\frac{im(I_b)}{Re(I_b)}$ (6)

Voltage calculation

$V_r = V_s - I_b Z_b$ (7)

$|V_r|\angle\theta_r = |V_s|\angle\theta_s - |I_b||Z_b|\angle\phi$ (8)

Equating real and imaginary part, equation (8) split as

$|V_r|cos\theta_r = |V_s|cos\theta_s - |I_b||Z_b|cos\phi$ (9)

$|V_r|sin\theta_r = |V_s|sin\theta_s - |I_b||Z_b|sin\phi$ (10)

Real and reactive power losses

$P_{loss} = |I_b|^2 R_b$ (11)

$Q_{loss} = |I_b|^2 X_b$ (12)

Where

S_i: *Complex power fed at node i*
P_i: *Real power fed at node i*
Q_i: *Reactive power fed at node i*
$|V_i|$: *Voltage magnitude at node i*
θ_{vi}: *Voltage angle of node i*
$|I_i|$: *Load current magnitude at node i*
θ_i: *Load current angle at node i*
$|I_b|$: *Current magnitude in branch node i*
$\angle I_b$: *Current angle in branch node i*
V_s: *Sending node voltage*
V_r: *Receiving node voltage*
I_s: *Sending end node of branch j*
I_r: *Receiving end node of branch j*
P_{loss}: *Real power loss of branch j*
Q_{loss}: *Reactive power loss of branch j*

3.2 Optimal location and sizing of PVG in 33 bus Radial Network by Analytical Approach

Integration of solar PV energy into the distribution grid has the primary goal of minimizing losses. The total loss in the network is derived from exact loss equation [18].

$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} \left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right]$(13)

$P_i = (P_{solar} - P_{load})$ (14)

The optimal size of the DG at each bus I for minimizing losses is given as:

$P_{solar} = P_{Di} + \frac{1}{\alpha_{ij}}\left[\beta_{ij}Q_{Di} + \sum_{j=1}^{N} \alpha_{ij}P_j - \beta_{ij}Q_j\right]$ (16)

The optimal placement of the PV DG is determined using loss sensitivity factor (LSF). Differentiating the power loss with respect to a power injection from solar generator at ith bus to obtain the loss sensitivity factor

$\alpha_i = \frac{\delta P_L}{\delta P_i} = 2\sum_{j=i}^{N} \sum_{j=i}^{N} \left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)$(17)

Through this loss sensitivity factor, the buses are ranked into priority list to find the most sensitive location.

Computational approach or flow chart for the proposed methodology

Step1: run load flow for the base case

Step2: find the base case loss

Step3: find the optimal size of the DG for each bus

Step4: place the DG with the optimal size obtained at each bus one at a time and calculate the appropriate loss for each case

Step5: Locate the optimal bus at which the loss is minimum corresponding with the optimal size at that bus.

Step6: run load flow with the optimal size at the optimal location and calculate the exact loss and the values of α and β after DG placement. MATLAB Simulink tool was used to model the equations and in the determination of optimal location and size of photovoltaic generator for the standard IEEE 33 radial bus system using it base values

3.3 Control Circuit

The control circuit is designed to ensure maximum extraction of energy from the PV system by tracking the solar array's maximum power point (MPP) that varies with the solar radiation values and temperature. The controller parameters are chosen to maintain constant PV voltage and to minimize the current ripple. Control is done in inverter mode and grid connected mode. The reference current and voltage due to compensation of PV current and voltage are:

$I_1^* = PI\left(V_{pv}^* - V_{pv}\right) + I_{pv}$ (18)

$V_{pv}^* = PI(I_1^* - I_1) + V_{pv}$ (19)

Where PI is the proportional integral controller

4.0 RESULT

Table 4.1: System load flow result without integration of DG.

*****The values in red indicate weak buses in the distribution network that should be compensated by optimal placement of the DG

Bus Number	Voltage (pu)	Angle (deg)	V max (pu)	Vmin(pu)

1	1.0000	60.00	1.1000	0.9000
2	0.9953	60.03	1.1000	0.9000
3	0.9717	60.16	1.1000	0.9000
4	0.9590	60.28	1.1000	0.9000
5	0.9465	60.39	1.1000	0.9000
6	0.9153	60.23	1.1000	0.9000
7	0.9094	59.83	1.1000	0.9000
8	0.9012	59.90	1.1000	0.9000
9	0.8905	59.77	1.1000	0.9000
10	0.8805	59.66	1.1000	0.9000
11	0.8791	59.67	1.1000	0.9000
12	0.8765	59.69	1.1000	0.9000
13	0.8660	59.52	1.1000	0.9000
14	0.8622	59.38	1.1000	0.9000
15	0.8597	59.31	1.1000	0.9000
16	0.8574	59.27	1.1000	0.9000
17	0.8539	59.13	1.1000	0.9000
18	0.8529	59.11	1.1000	0.9000
19	0.9948	60.02	1.1000	0.9000
20	0.9929	59.98	1.1000	0.9000
21	1.0000	0.00	1.1000	0.9000
22	1.0000	0.00	1.1000	0.9000
23	0.9658	60.11	1.1000	0.9000
24	0.9549	59.97	1.1000	0.9000
25	0.9495	59.90	1.1000	0.9000
26	0.9137	60.27	1.1000	0.9000
27	0.9093	60.37	1.1000	0.9000
28	0.8898	60.51	1.1000	0.9000
29	0.8758	60.65	1.1000	0.9000
30	0.8698	60.84	1.1000	0.9000
31	0.8627	60.69	1.1000	0.9000
32	0.8611	60.64	1.1000	0.9000
33	0.8606	60.63	1.1000	0.9000

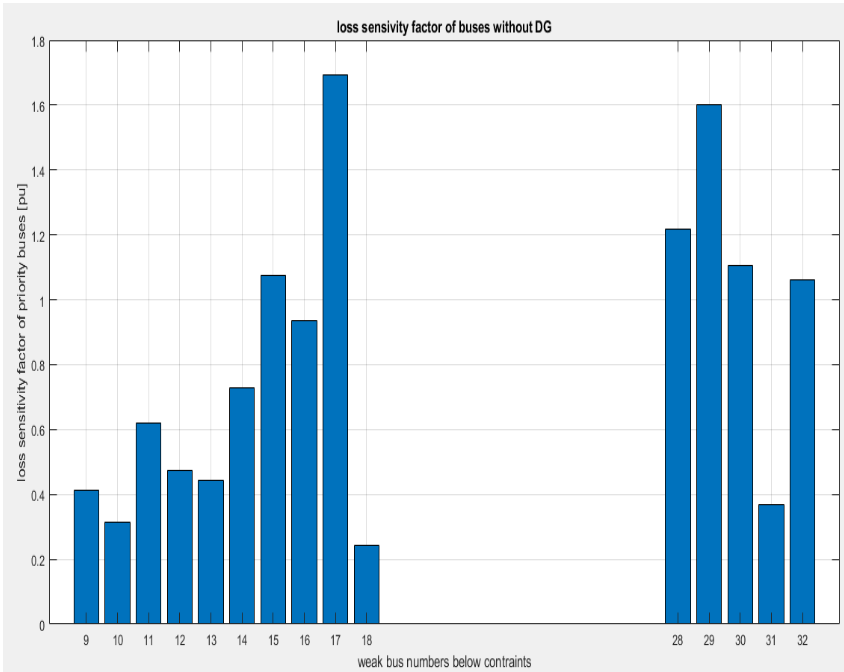

Fig 4.1: Graph of loss sensitivity factor without DG

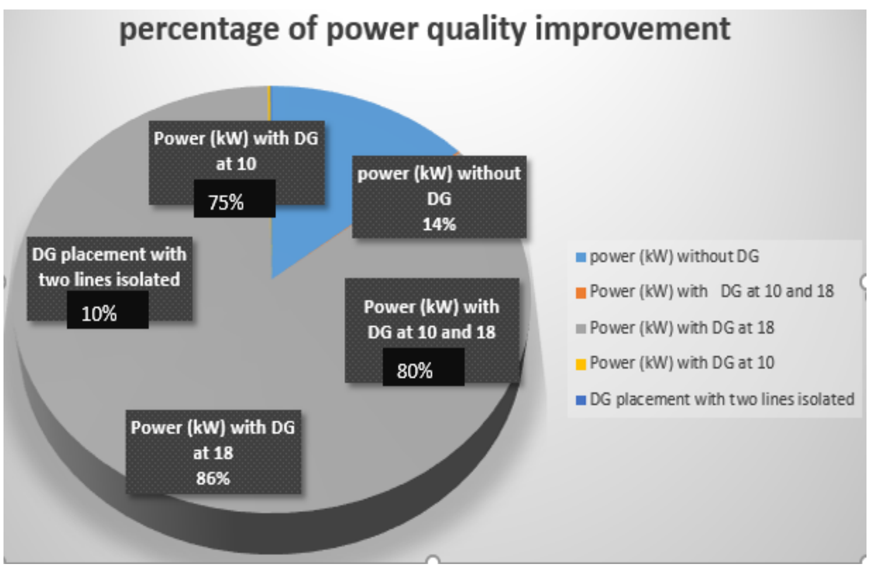

Fig 4.2: Percentage of power quality improvement

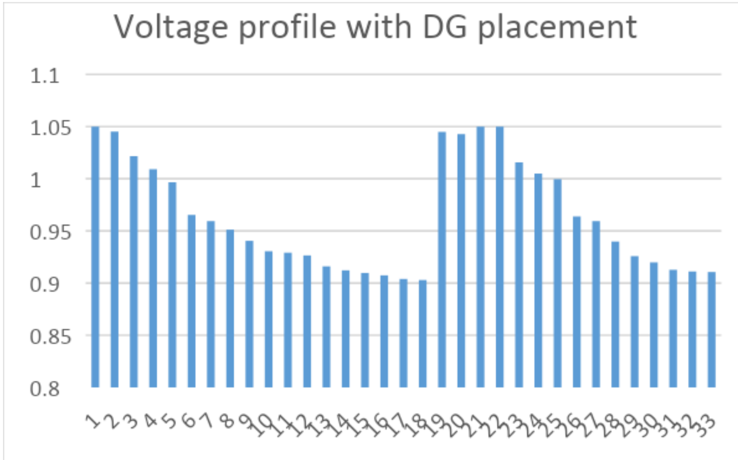

Fig 4.3: Voltage profile of the network with DG placement

5.0 CONCLUSION

This work used standard IEEE 33 bus radial distribution system as a case study on optimal sizing and placement of photovoltaic generator carried out through the use of PSS/E software. A validated analytical approach with full Newton Raphson load flow through developed algorithm is used to determine the optimal location and sizing of the DG. The installation of PVG unit at non-optimal places can result in an increase in system losses, which adds to costs, and poor power quality in the network, which is quite contrary to the desired objective. However, by proper siting and sizing of DG at optimal place (bus 18), real power loss is reduced by 19% with PV DG size of 188.2kW and weak bus voltages were improved to nominal statutory limits.

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