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Strategy for Sizing and Placement of Distributed Generation in a Radial Distribution Network

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Abstract: Globally the usage of electric power is increasing day by day, which increases both real and reactive power loss in Transmission and Distribution lines especially for the centralized generation. Integration of non-depletable energy sources i.e., wind energy, solar energy, geothermal energy, hydropower, and biomass energy with distribution grid reduce losses of distribution network, consumption of fuel used for centralized fossil fuel-based power plants, environmental impacts, and cost of long-distance high voltage transmission and distribution lines. The above-mentioned benefits of renewable energy resources can be accessible when the optimal location for integrating renewable energy resources is properly planned or designed. Otherwise, this integration will cause negative impacts on the electric power system, such as the increase in the distribution line losses and voltage rise at various buses of the distribution network. If this integration of renewable energy resources is appropriately designed, it will improve the distribution network's voltage profile and reliability. Research highlights the impacts of sizing and location of DG on network loss and voltage profile. The technique proposed in this paper using MATLAB and Open DSS to validate sizing and placement of DGs optimally. Furthermore, simulation results show that integrating DG at optimal location line losses decreases, improves voltage profile and the grid will be reliable and optimized.

Keywords: Particle Swarm Optimization (PSO), Distributed Generation (DG), Open DSS, Renewable, Distribution Network (DN**)**

I. INTRODUCTION

Depletion of the ozone layer due to greenhouse gasses (GHG) emissions produced by fossil fuel-based power generating stations is dangerous to environmental conditions. This alarming situation forces the regulatory authorities to utilize distributed renewable energy resources to generate electric power. These distributed energy resources (DERs) reduce the environmental impact as this electricity generation by these resources follows the increasing trend worldwide[1]. According to the international renewable energy agency (IRENA), Pakistan expands its renewable generation capacity from 7012 MW to 12896 MW in the last decade[2]. Net metering policy issued by National Electric Power Regulatory Authority (NEPRA) also boosts the Distributed renewable generation capacity in Pakistan [3]. Electric Supply with the least cost and carbon emission comprising of Renewable Energy Sources (RES) for Pakistan National Grid 2017 are modelled in [4]. Deployment of DG with Power system minimizes problems such as energy crisis, new transmission lines expansion, and line congestion relief. Regardless of benefits, it has caused various difficulties for the distribution system's stability. Traditional distribution networks were passive; they have no control mechanisms to mitigate the adverse effects with installation of DGs. The distribution network should be active to ensure better power quality, reliability, and operation. Deployment of Active Distribution Network enables smart grid control, protection, and dynamic monitoring [5]. Impacts of a large amount of rooftop and utility-scale PVs on transient & voltage stability for large power system areas due to reactive power imbalance are discussed in [6]. IEEE standard 1547 states that the rooftop-based PVs do not provide reactive power control for voltage regulation but supply only active power [7]. Mixing DGs with DN causes higher fault current magnitude, which in-turn causes mal-operation of protection devices [8]. In [9], Protection Scheme uses a differential evolution algorithm to optimize the location & sizing of fault current limiter to lessen the fault current due to DGs integration. Protection strategies (i.e., fuse saving techniques, microgrid protection) for DN when DG is connected [10]. Effects of harmonic injection due to inverter-based DGs on the power quality are presented [11]. [12] discusses improvement of system reliability with evaluating reliability indexes such as System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), System Average Interruption Frequency Index (SAIFI). Impact on load forecasting results due to uncontrollable DGs, including wind power, small hydro, PV generation, CCHP, etc. are provided in [13]. Economic dispatch strategy is presented in [14] for distributed renewable energy sources (RESs) including both dispatchable (Fuel Cell, Microturbine, etc.) and non-dispatchable (Wind & Solar) energy sources. Effect of DER combinations on DN over the voltage regulations [15], Fuzzy logic combined with Particle Swarm Optimization (PSO) utilized for real-time voltage control considering smart grid scenario [16], and challenges to the application of DGs is discussed in [17]. Load Frequency Control (LFC) improvements to mitigate frequency deviation when microgrids are integrated into the traditional distribution network are given in [18]. The study presented in this paper is limited to discussing the impacts of technologies, sizing, and location of Distributed Energy Resources (DERs) on the distribution network's losses and voltage profile. Three types of generators are used in this study:

- Type-I: Supply only Active Power, e.g., Photovoltaic, fuel cells, etc.
- Type-II: Supply both Active and Reactive power, e.g., biofuel based Synchronous generator et. c.
- Type-III: Supply only reactive for voltage profile improvement, e.g., Capacitor banks, synchronous compensator.

The paper's main objective is to compare line losses due to DGs' integration at the optimal site by adding a constraint to DGs' size. Four cases are made for the size of DGs. DG size equal to 1) Load, 2) Half of load, 3) Quarter of the load and 4) Optimal size. The optimum location for DGs for above mentioned cases is found by Particle Swarm Optimization (PSO).

Organization of the paper is as follows; Section I presents the literature on the Impacts of DG. Section II covers a brief description of the Open DSS power simulator along with the distribution network model explanation. Problem formulation, objective function, and constraints are presented in Section III. Section IV describes the Methodology and flow of simulations. Explanation of Results in Section V and VII. Finally, conclusion taken from the results are presented in Section VII.

II. DISTRIBUTION NETWORK MODELLING

A. Power Simulator (Open DSS)

Open Distribution System Simulator (OpenDSS) is an open-source simulation tool created by EPRI (Electric Power Research Institute) in 2008. DSS Software can do fault studies, dynamics, power flow, load parametric variation, geometrically induced current, and harmonics flow analysis simulations. Open DSS can analyze DGs integration, multiphase (un-balanced) AC circuit analysis for the DN. Models for renewable base DGs including photovoltaics, biofuel, and wind, are available in Open DSS. The COM interface allows Open DSS to integrate with MATLAB, Python & C++ programming languages to control or change the algorithm's network parameters. Input and output flow in Open DSS is shown in Figure 1.

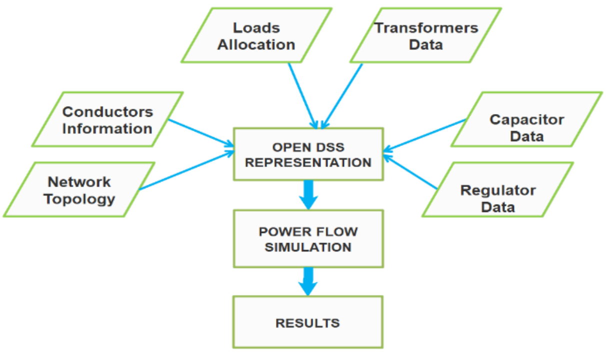

Fig. 1. Flow Chart of Open DSS Executions

B. Line Modelling

Geometric Mean Radius and self-resistance of conductor are obtained from a conductor specification sheet. Lines of DN are usually transposed. Modified Carson's equations are used to model the lines. Equations 1 and 2 are utilized for the modeling series impedance elements of the line. Shunt admittances have a negligible effect on the DN as compared to very high voltage transmission lines. Due to less effect, shunt elements are neglected in this study.

$$Zii = Rii + 0.095 + j0.12\left(\ln\frac{1}{Dii} + 7.93\right)\ \Omega/\text{mile} \quad (1)$$

$$Zij = 0.095 + j0.12\left(\ln\frac{1}{Dij} + 7.93\right)\ \Omega/\text{mile} \quad (2)$$

Where

Zii and Zij are the self and mutual impedances

Rii is self-resistance of conductor

Dii is the geometric mean radius

Dij is the geometric mean distance

C. Generator Modelling

Modeling of Type I-III of generators is done by changing the generator object in the Open DSS generator model. Specify negative values of active Power and reactive power to model generators.

D. Load Modelling

Open DSS has built-in all load models. The constant impedance (ZIP) model is used for this study.

III. PROBLEM FORMULATING AND OBJECTIVE FUNCTION

A. Problem Formulation

The distribution system has two types of losses active & reactive power loss. The relation for the total power loss in Radial Distribution Network (RDN) consisting of n branches is written as:

$$P_{loss} = \sum_{k=1}^{n} I_k^2\,(\text{location}) * R_k \quad (3)$$

DG integrations alter the losses in a network, which is a function of location. The apparent power supplied into a bus is given by

$$S_k = P_k + jQ_k = V_k I_k^* \quad (4)$$

Computation of load current at any bus is given by

$$I_{Lk} = \left(\frac{P_k + Q_k}{V_k}\right)^* = \frac{P_k - jQ_k}{V_k^*} \quad (5)$$

Where

$k =$ total number of buses

$I_{Lk} =$ line currents b/w two end-end buses

$R_k =$ resistance b/w two end-end buses

$P_k =$ active power demand

$Q_k =$ reactive power demand

$V_k =$ voltage at bus k

B. Objective Function

$$\mathrm{Min}(P_{loss}) = \sum_{m=1}^{K}\sum_{n=1}^{K}[\alpha_{mn}\,(P_mP_n + Q_mQ_n) + (Q_mP_n - Q_mP_n)] \quad (6)$$

$$\alpha_{mn} = \frac{R_{mn}}{V_mV_n}\cos(\delta_m - \delta_n) \quad (7)$$

$$\beta_{mn} = \frac{X_{mn}}{mV_n}\sin(\delta_m - \delta_n) \quad (8)$$

P_m and Q_m are the real and reactive power injections at bus m, respectively

P_n and Q_n are the real and reactive power injections at bus n are respectively

R_{mn} and X_{mn} are the resistance and reactance between end-end buses

V_m and V_n are the voltages at bus m and bus n, respectively

δ_m and δ_n are the voltage angles at bus m and bus n, respectively

Constraints

The algorithm must satisfy both equality and inequality constraints to ensure reliable operation of the power system.

$$V_{min} \leq V_k \leq V_{max} \quad (9)$$

$$I_k \leq I_{max} \quad (10)$$

$$P_{DG_{min}} \leq P_{DG} \leq P_{DG_{max}} \quad (11)$$

$$Q_{DG_{min}} \leq Q_{DG} \leq Q_{DG_{max}} \quad (12)$$

Where

I_{max} is the current carrying capacity of the line

V_{min} and V_{max} are the maximum and minimum ranges voltages

$P_{DG_{min}}$ is the minimum limit to the active Power of DG, which is almost considered zero

$P_{DG_{max}}$ is the maximum limit to the active Power of the DG, which is the total real power load

$Q_{DG_{min}}$ is the minimum limit to reactive Power of DG, which is almost considered zero

$Q_{DG_{max}}$ is the maximum limit to reactive Power of the DG, which is the total real power load

IV. METHODOLOGY

MATLAB and open DSS by (EPRI) software tools are used in this study. PSO algorithm is coded in MATLAB and studied network is modeled in Open DSS. Open DSS is interfaced with MATLAB through COM interface for applying PSO on a distribution network. PSO function calls the objective function, then the value of objective is calculated by Open DSS function and returned to the primary function of PSO in MATLAB.

Particle Swarm Optimization (PSO)

Nature-inspired metaheuristic technique proposed in 1995 by James Kennedy and Russ Eberhart named Particle Swarm Optimization. This optimization procedure mimics the natural behavior of swarms such as birds and fish. PSO is a robust stochastic algorithm that relies on the movement and intelligence characteristics of each swarm. Every particle in the swarm communicates directly or indirectly using search directions and moves in a multidimensional search space to find a global optimum. PSO comprises of three vectors. Current location of the particle is stored in x-vector (x_t), among all positions best location is assigned to p-vector decided by fitness value of the objective function. v-vector (v_t) gives the direction or velocity of the particle. The value of velocities is updated using equation (13) in each iteration of the algorithm. Updated velocities added to the previous location to get new updated locations of a swarm.

Deployment of PSO for solving the optimal site and size is done in the following steps:

Step 1: Initialization of parameters of PSO such as acceleration swarm size, acceleration coefficients (c_1 & c_2), inertia weight (w).

Step 2: Generate random locations and size of DGs for particles and check the constraints to size and location.

Step 3: Call the Open DSS function for power flow and evaluate each particle's objective function's fitness value (power loss).

Step 4: Compare the fitness value of each particle with *pbest* in each previous iteration to update the new pbest. If the objective function gives minimum value with the new position, then the new position will be pbest; otherwise, the previous position will consider pbest for this particle. The best position in the group of swarms is gbest.

Step 5: Compute new velocities of particles by substituting values of *pbest* & *gbest* in the equation.

$$v_t^{k+1} = w * V_t^k + c_1\mathrm{rand}\left(\mathrm{pbest}_t^k - x_t^k\right) + c_2\mathrm{rand}\left(\mathrm{gbest}_t^k - x_t^k\right) \quad (13)$$

Step 6: Update the positions of particles by adding new velocity to the previous location.

$$x_t^{k+1} = x_t^k + v_t^{k+1} \quad (14)$$

Step 7: After this, go to step 3 until the desired convergence is achieved.

In equation (13), w is inertia weight, while c_1 and c_2 are the Acceleration constants. The larger value of w and $c_1 > c_2$ facilitates global searchability, while the smaller value of w and $c_1 < c_2$ facilitates local searchability.

V. RESULTS

A real 50 bus 11.5kV radial distribution network of MEPCO (Electric distribution company) is taken for impact study (with an aggregate load of 4.43 MW and 2.74 Mvar) is shown in Figure 2.

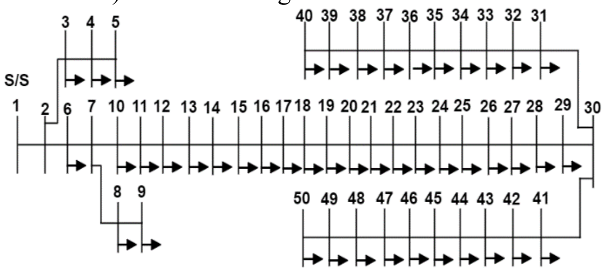

Fig. 2. 50 Bus Distribution Network

The impact of various types of DG technologies on system losses and voltage profile of the 50 bus Radial Distribution Network (RDN) is examined in this section. PSO technique is used to get optimum kVA size and nodes for Type-I, Type-II & Type III.

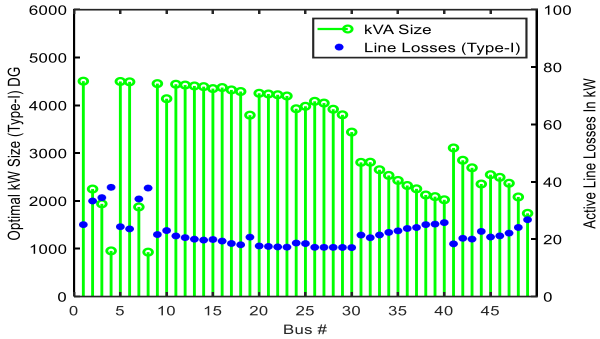

Fig. 3. Optimal DG size & line losses of (Type-I) for 50 Bus Network

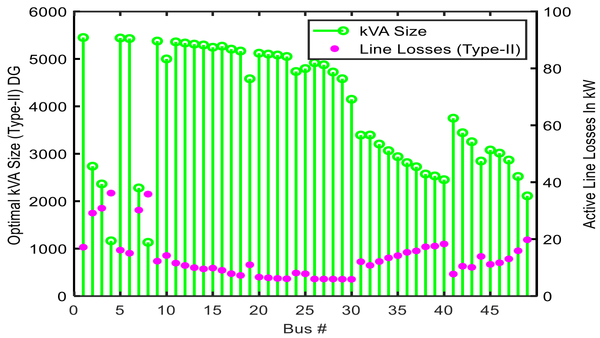

Fig. 4. Optimal DG size & line losses of (Type-II) for 50 Bus Network

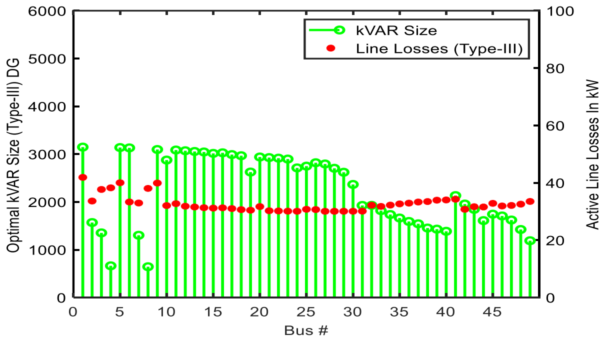

Fig. 5. Optimal DG size & line losses of (Type-III) for 50 Bus Network

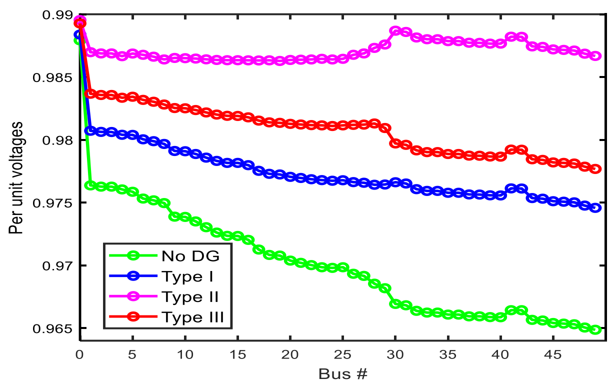

Fig. 6. Voltage profile of the network with and without various technologies of optimal DG

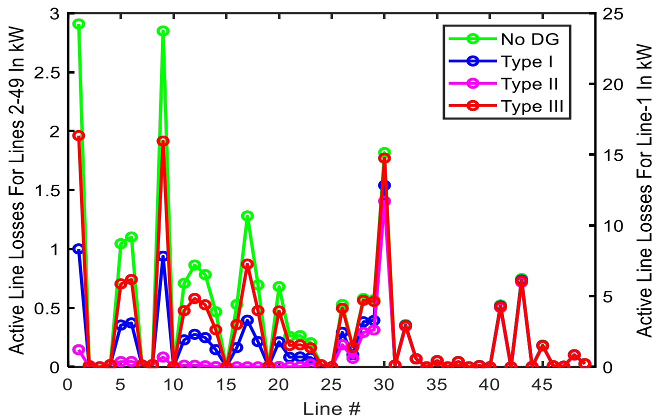

Fig. 7. Change in active losses of lines with and without the integration of DGs

Figure 3,4 & 5 illustrates optimal size & line losses variations at each node of RDN for Type-I, Type-II & Type-III. After integrating different DGs of optimal size and location, per unit voltages are shown in Figure 6. A further improvement of the network's voltage profile is possible with type-II DG compared to other types. Line losses for each line are given in Figure 7. Line No.1 has a major loss of network and its value is higher in magnitude as compared to remaining lines is shown right Y-axis of Figure-6 for better visualization.

VI. DISCUSSIONS AND LOSSES COMPARISON OF PROPOSED CASES

The optimal size of different DG types at optimum nodes; also, Optimal nodes for DGs when size restricted to 100, 50 & 25 percent of load are recorded in Tables I, II, III & IV. When we add the constraint of size to the DG PSO algorithm changes the optimal node for DG in some scenarios depending upon the size. A node that results in a minimum value of objective function upon DG integration is optimal. Significant increase in losses when we decrease or increase the size of DG beyond optimal. Minimum losses are only possible with type-II integration compared to other types of DGs. Without DG, the line losses were 41.896 kW and dropped to 17.07, 5.904 & 30.074 with Type-I, Type-II & Type-III at optimal size and location can be shown in Figure 8.

TABLE I. Optimal Nodes, Sizing & Loss reduction (Case-I)

Type of DG	Size (Equal to Load)	Bus	Loss Reduction
Type-I (kW)	4435	23	58.70%
Type-II (kVA)	5217	23	85.22%
Type-III (kvar)	2748	27	28.21%

TABLE II. Optimal Nodes, Sizing & Loss reduction (Case-II)

Type of DG	Size (Half of Load)	Bus	Loss Reduction
Type-I (kW)	2218	30	51.85%
Type-II (kVA)	2609	30	74.29%
Type-III (kvar)	1374	41	23.25%

TABLE III. Optimal Nodes, Sizing & Loss reduction (Case-III)

Type of DG	Size (Quarter of Load)	Bus	Loss Reduction
Type-I (kW)	1109	45	34.48%
Type-II (kVA)	1305	45	49.35%
Type-III (kvar)	687	45	15.12%

TABLE IV. Optimal Nodes, Sizing & Loss reduction (Case-IV)

Type of DG	Size (Optimal)	Bus	Loss Reduction
Type-I (kW)	3340	30	59.25%
Type-II (kVA)	4150	30	85.91%
Type-III (kvar)	2795	27	28.21%

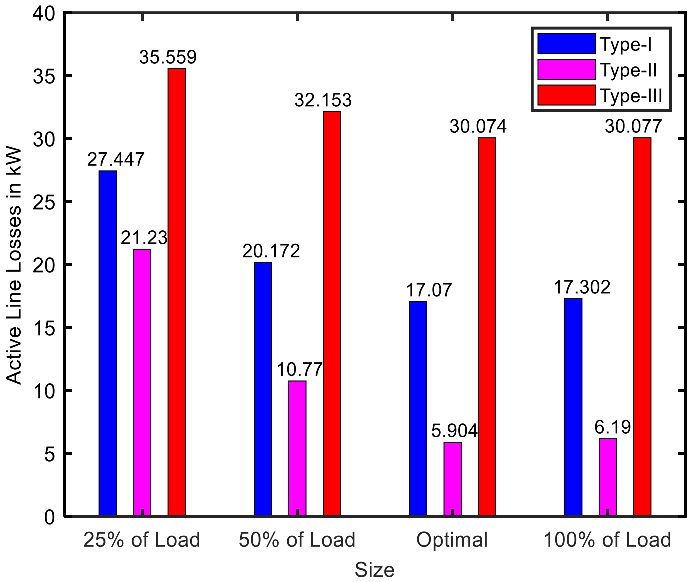

Fig. 8. Comparison of Line losses with size

VII. CONCLUSION

The technique proposed for sizing and placement of DGs to discuss their impacts on network losses and voltage profile is explained in this paper. The comparison study gives line losses of different DGs at the optimal location by changing their size and technology. Also, the optimal size for the integration of each type of DG at each bus is evaluated. The optimal location and size of DGs are calculated using PSO. Effectiveness proposed methodology is tested on 50 BUS radial distribution feeders. Research finds that Type-II (Supply both Active and Reactive power) gives better loss reduction and increment in voltage profiles as compared to Type-I and Type-III. In the future, this work results compare with the results of different optimization results, also consider 24 hours load levels.

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