PSO BASED DG SIZING FOR IMPROVEMENT OF VOLTAGE STABILITY INDEX IN RADIAL DISTRIBUTION SYSTEMS

Haruna Musa, Sanusi Sani Adamu
Department of Electrical Engineering Bayero University, Kano. Nigeria

e-mail: harunamusa2@yahoo.co.uk, adamus1664@buk.edu.ng

ABSTRACT
Many power system operators and planners are facing serious challenges as DG penetration increases into the distribution networks. The situation is even more critical if the DG is not properly sited as such can lead to an increased power losses and instability of the network. Most objectives have centered on minimization of only real power loss for the system. In this paper optimal sizing of DG considers not only the losses but also voltage stability index value (VSI) so that voltage stability of the network is improved as well. The study also takes into account all the necessary constraints. The objective functions are handled as single multi-objective function, and was subsequently optimized using the proposed Particle swarm optimization (PSO) algorithm. The effectiveness of the algorithm was tested on IEEE 33-Bus test system and result obtained shows that the proposed method gives better DGs outputs and use of VSI values in the optimization has greatly improved the minimum VSI values of the network when compared to situation without it and the power losses did not increase appreciably. The study has also indicated that optimal DG placement has greatly improved voltage profile and voltage stability of the network as well.

KEY WORDS:
Distributed Generation, Power losses, Voltage Stability Index, Particle swarm optimization, DG Placement.

1. INTRODUCTION
The rate at which Distributed generation penetration level is increasing in our network is always growing beyond the imagination of power distribution companies and this has serious impact on the system in terms of power flow, voltage profile, stability of the network both during normal operation and under fault condition. For this reason special attention will highly be required to address the consequences that are going to come up as a result of DG the presence. Under such case use of optimization methods for the purpose of best allocation and sizing of the DG has become important in order to improve the quality power supply to customers and further improve the efficiency of the network by reducing losses and increasing sensitivity of the system to voltage collapse.

Power sector is now undergoing some major reforms that have made the sector to completely changed from it passive nature into an active network with the flexibility of operating as a bidirectional network instead of it former form of unidirectional transportation of electricity. Presence of DG in the network have changed the system from passive into active since power is not only supplied by the grid alone but also DG that are embedded in the distribution network close to the cluster of customers with aim of enhancing the efficiency, reliability and operational benefits of the system[1].

The benefits associated with the DG are a lot and the most crucial are the reduction of line losses and improvement on voltage stability. These factors are only improved if proper sizing and siting is done. A lot of research work has already been done that have shown that poor selection of size and location would always lead to increase in losses when compared to situation without DG [2]. Recent research by [3] have shown that many utilities will experience problem of higher power losses and voltage instability as DGs penetration continue to increase if not properly sited and sized. Optimum allocation can give utility companies the advantage of system losses reduction and improvement in reliability of supply [4-6].

The positive consequences are that the transmission and distribution systems will have relief in terms of capacity and hence deferral of investment becomes possible.

Many authors in [7-11] have successfully introduced allocation and sizing of DG as one optimization problem. The factors considered were basically cost of investment, operational cost as well as cost of active and reactive power, power loss and voltage profile improvement. Other conventional methods were also employed apart from other intelligent optimizations techniques. Authors in [12] have introduced GA based optimization algorithm to optimized size and allocate multiple DG units for purpose of minimizing power losses and main grid supply to the network by taking into account the voltage limits of all the nodes in the system. Traditionally graphical methods that use P-V curves are the tools for study of voltage stability in systems. In [13] it has been established that the impact of DG in network is positive as it improves voltage profile and decreases reactive power losses by placing the DG units at the bus with highest sensitivity to voltage collapse.
Most researches have placed DG using PSO with non unity power factor but the objective was to minimize only real power loss of the system, in this paper optimal sizing of DG is going to consider not only the losses but also voltage stability index value (VSI) so as to improve voltage stability of the network. Comparison for VSI values with DG and without DG when the size is not optimized and when optimization is employed will be considered. All necessary constraints are going to be considered for the multiple objectives problem.

2. METHODOLOGY

This method is going to locate the DG based on the maximization of DG current so as to improve power losses by reducing the current sourced from the mains. The authors intended to introduce an approximation method that will identify the size of DG and the optimal location based on maximization of what is called loss saving value. Generally losses associated with active current in single-source radial networks cannot be minimized as the source has to supply all the active power. However, if DGs are placed in the network, the active branch current sourced from the single source is reduced due to the active current from the DG that compensates. The consequences are losses reduction due to current reduction sourced from the single source. The loss saving is therefore the difference between loss saving value by maximizing Losses reduction due to current reduction sourced from the single source. The authors determine the lowest power losses with highest VSI value.

\[
J(PL)_i = \text{Fitness Function for Power Losses , } i \text{ particle}
\]

\[
J(VSI)_i = \text{Fitness Function for Voltage Stability Index}
\]

The alpha value is set to 0.5 so that equal chances are given to both fitness functions towards reaching the optimal value. The optimum size of the DG for all the nodes is first obtain for base case and choice of location is based on the two objectives.

2.1 DG Sizing using PSO

Global optimal solution for the DG size can be obtained by using PSO for multiple DG placements simultaneously. The optimization method that uses PSO is developed based on evolutionary a computational technique which is essentially based on bird flocking or fish schooling's social behavior. It is a population based search method which involves change of position with time for individuals known as particles [14-15]. Change of position of the particle is based on its own experience which is called pbest and the experience of its neighboring particles called Gbest. New position is attained based on current position, current velocities and the distance between current position, and Pbest and Gbest as expressed by the equation.

\[
v_{i}^{k+1} = wv_{i}^{k} + c_{1} \text{rand } x(p_{\text{best}i}^{k}) + c_{2} \text{rand } x(g_{\text{best}}^{k}) \quad (5)
\]

where,

\(v_{i}^{k}\): velocity of agent \(i\) at iteration \(k\),
\(w\): weighting function,
\(c_{1}\): weighting factor,
\(\text{rand}\): random number between 0 and 1,
\(s_{i}^{k}\): current position of agent \(i\) at iteration \(k\),
\(p_{\text{best}i}\): pbest of agent \(i\),
\(g_{\text{best}}\): gbest of group

The current position based on (5) is given by;

\[
s_{i}^{k+1} = s_{i}^{k} + v_{i}^{k+1} \quad (6)
\]

For the weighting factor it can be express as weighting function that is based on maximum and minimum values as;

\[
w_{i} = w_{\text{max}} - \frac{w_{\text{max}} - w_{\text{min}}}{\text{iter}_{\text{max}}} \text{iter} \quad (7)
\]

The appropriate values of \(c_{1}\) and \(c_{2}\) are between 1 and 2 while the \(w_{\text{min}}\) and \(w_{\text{max}}\) are 0.4 and 0.9 respectively [15].

3. PROPOSED PSO ALGORITHM FOR DG SIZING

The approach is to minimize real power losses and determine the VSI value that can keep the system in stable state by randomly generating an initial population of particles with random positions and velocities in the solution space. Each of the particles is subjected to
constraints specified while running the power flow in order to calculate the power losses and VSI values which are required for assessment of the particle’s feasibility or otherwise. The individual best is compared with objective value and if the objective value is less than the $P_{best}$, the value is set as the current $P_{best}$ and the particle position is recorded. The particle with minimum $P_{best}$ of all particles is chosen as the current overall best $G_{best}$. Maximum fitness and average fitness values are compared and if the difference is less than specified tolerance the $G_{best}$ particles gives the optimal DG sizes at known location and results are presented otherwise velocity and position of particles are updated using equations (5) and (6). The iteration counter is incremented all steps are repeated as shown in the algorithm indicated in Fig. 1.

4. SIMULATION RESULTS AND ANALYSIS

The algorithm proposed was tested on 33 bus radial distribution systems as shown in Fig. 2. The system was simulated in MATLAB environment with sole aim of calculating loss saving, DG Size and location at which loss saving maximum and such location is considered as the candidate location for sitting of the DG.

Fig. 2 33 bus radial distribution network

Fig. 1 Proposed PSO algorithm
4.1 DG Bus Operating as PV and PQ Busses

By employing equation (2), the optimal placement of DG for maximum loss savings is determined to be at bus number 6, 25 and 16. It is assumed that the planner has the flexibility of chosen the DG operating mode as either PV or PQ modes. The operation modes are given attention here for the purpose of DG type applications. Typical example is Photovoltaic type that can be employed for its PV inverter reactive power capability in mitigating dynamic voltage variation. In this regards any analysis for PV operating mode refers to PV-DG type while PQ mode refers to conventional type. The target is to analyze the impact of these two operating modes on the entire network in terms of voltage profile and power losses.

Fig. 3 shows the voltage profile of the network after all the DGs are located at the appropriate buses for the two operating modes. The DG bus when operated as a PV bus, some of the buses from 2 to 17 have improved voltage profile when compared to situation when no DG connection. It can also be observed that the average voltage profile of all the busses is better for the PV operating mode when compared to PQ mode.

The effect of DG placement on power losses can be observed as shown in Fig. 4 where increased in the number of DG placement reduces the power losses by at least 20% for every addition of DG in the network for the both PV and PQ operating modes. It can however, be observed that the best operating mode that will give better reduction in power losses for both low and high penetration of DG is the PV mode. Therefore, the best operating mode in terms of voltage profile improvement and better reduction of power losses is PV mode.

4.2 Optimization of DG Size with the Proposed Algorithm

Even though allocation of multiple units of DG in the network has reduced the power losses, further improvement can still be achieved by optimizing the size or the capacity of DG so that optimal sizes can be obtained. The introduction has given an overview of optimization methods that have been implemented by many researchers on DG capacity sizing, but most of them did not consider VSI during their optimization process. The VSI is one of the static methods used for power system stability. It is generated from the basic power flow equation. This method uses an Index that shows the system’s stability condition and can be used to estimate the systems operating states. The mathematical expression of a VSI is often written as a polynomial containing the systems real-time measurements such as voltage magnitudes, phase angles, bus injected power and branch power flow values, etc. The index can be different by using different power system models [16] and target parameters. The changing process of the VSI values in the region from no loading condition to maximum permissible loading condition will also reflect the system’s stability trend from stable to unstable. Voltage magnitude is the most often used parameter in voltage stability index studies. A typical Voltage Stability Analysis considering voltage magnitude [17] is based on a simplified 2-bus system was applied on a practical Khoda Bande Loo distribution feeder in Tehran to demonstrate realistic situation of DG installation.

For the purpose analysis a critical study on VSI value with and without optimization was conducted for the following cases;

- Case 1- Base case without DG in the network
- Case 2- Allocation of DG without optimization
- Case 3- Optimization of DG size using proposed algorithm
- Case 4- Optimization of DG size using proposed algorithm considering VSI as one of the constraints
Case 5- Optimization of DG size using Multi-objective PSO for power losses and VSI

From Fig. 5 the VSI values for all busses for all the cases shows that case 1 has the lowest VSI value of 0.8 while the others have values higher than 0.8. The VSI value indicates proximity of a bus to voltage collapse as load increments. In order word, the lower the value of VSI the higher it is for the bus to accommodate more loads. Busses with high VSI values are likely to experience voltage collapse easily for any small increment in load. Those buses that have low values of VSI are the best busses for planners to consider for accommodation of future loads.

Fig. 5. Voltage Stability Index for all busses for all the cases

In Table 1 the total power losses and the minimum VSI values for all the cases is presented. Case 2 has the highest VSI value and power losses when compared to all the cases. Cases 3 & 4 which involves optimization has the lowest power losses and this can be attributed the optimization employed. Case 3 however, has low VSI value when compared to case 4 and this due to the fact that the VSI is not considered as one of the constraints when producing the particles during optimization. Case 5 however presented higher values of power losses and VSI value when compared to cases 3 & 4. Despite all these variations the voltage profile for case 2-5 still remains the same as shown in Fig. 6.

Table 1: DG sizes and Number of iterations

<table>
<thead>
<tr>
<th>Case</th>
<th>Size of DG 1 (bus 6)</th>
<th>Size of DG 2 (bus 25)</th>
<th>Size of DG 3 (bus 16)</th>
<th>No. of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>2.4878</td>
<td>0.4970</td>
<td>0.3556</td>
<td>97</td>
</tr>
<tr>
<td>Case 2</td>
<td>1.6998</td>
<td>0.7743</td>
<td>0.5303</td>
<td>115</td>
</tr>
<tr>
<td>Case 3</td>
<td>1.7005</td>
<td>0.7742</td>
<td>0.5298</td>
<td>122</td>
</tr>
<tr>
<td>Case 4</td>
<td>1.7224</td>
<td>0.7762</td>
<td>0.4842</td>
<td>143</td>
</tr>
<tr>
<td>Case 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It can also be observed the number of iterations all the case varies. Minimum iteration was achieved for case 2 and the iteration took longer when constraints were increased as shown in Table 1.

Table 2: Total power losses and Minimum VSI for the network

<table>
<thead>
<tr>
<th>Case</th>
<th>Total Power Losses</th>
<th>Min VSI in network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>135.9891</td>
<td>0.6869</td>
</tr>
<tr>
<td>Case 2</td>
<td>23.1049</td>
<td>0.8449</td>
</tr>
<tr>
<td>Case 3</td>
<td>17.1721</td>
<td>0.8059</td>
</tr>
<tr>
<td>Case 4</td>
<td>17.1721</td>
<td>0.8121</td>
</tr>
<tr>
<td>Case 5</td>
<td>17.2729</td>
<td>0.8261</td>
</tr>
</tbody>
</table>

In Fig. 7 and 8 the 3 DGs output power for case 3-5 are presented with case 5 having the highest output power for DG1. It can however be observed that the output power for all the 3 cases is the same for DG 2 while in the case of DG3 case 5 has the lowest output power. Fig 8 has clearly shown that DG sizing can have great impact on power losses and VSI value as well.

Fig. 6. Voltage profile for case 2-5

5. CONCLUSION

In this paper PSO based algorithm for DG placement and sizing in radial distribution networks is presented. The performance of the proposed algorithm was tested on a 33-buses radial distribution networks. The result shows
that the proposed method which takes into consideration the voltage stability index as one of the factors that system planners do not consider gives better DGs outputs. The implementation of VSI values in the optimization has greatly improved the minimum VSI values of the network when compared to situation without it and the power losses did not increase appreciably. The results showed that optimal DG placement is fast and great improvement in voltage profile and increase in voltage stability range is achieved. Placement of more than 3 DGs in the network is not recommended as it will violate the benefits power losses reduction. Hence the optimal numbers of DGs for this network are 3.

ACKNOWLEDGEMENTS

H. Musa acknowledges with gratitude the financial support, in form of research fellowship, offered by Bayero University, Kano. Nigeria.

REFERENCES