Optimal Placement of DG Based On Voltage Stability Index and Voltage Deviation Index

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Abstract

Objectives: In Modern world power production and its efficient usage defines the development of the country. In distribution system of an electrical network due to the influence of loads, voltage profile and losses are to be focussed a lot. In order to avoid the maximum losses and to maintain the voltage profile usage of Distribution Generator (DG) plays a major role in the network. Statistical Analysis: Since we have to use an appropriate place and size of DG, a measuring technique based with index through which optimal size and place can be identified and is implemented in the work. Findings: This Paper focuses on reducing power losses by accurately giving the location and size of DG based on two indices (a) Voltage Deviation Index (VDI) (b) Voltage Stability Index (VSI). Results such as power losses, location, size and cost of DG are obtained for both initial configuration and Feeder reconfigured state for IEEE 33 and 69 bus systems were listed. Applications: These analysis help us in installation of Different types of DG to present network where demand side management has to be followed.

Keywords: Distributed Generation, Voltage Deviation Index, Voltage Stability Index

1. Introduction

With the ever increasing demand for power and the continuous depletion of fossil fuels made the power industries to look for smarter way of meeting load demand with the existing power generation rather than increasing the generation every time whenever load is increasing. One such smart way is to change the topology of distribution network in such a way the same load can be met with reduced power losses and if an external source such as DG is employed in this the power losses can be further reduced. Some past attempts in this smart way are Reconfiguring feeder using algorithms to reduce power losses. In presented a modified technique for achieving reduced distribution system losses by the fast determination of switching configurations. Later a new 0-1 integer programming has been proposed for feeder reconfiguration to reduce losses. Methods which include artificial neural networks are also proposed to reduce power losses in feeders. Furthermore, a linear Programming method for reconfiguring feeders for reducing power losses has been proposed. An optimal switching scheme to achieve a maximum reduction of losses in a distribution network using systematic feeder reconfiguration technique has been proposed in. Further studies presented an effective approach to feeder reconfiguration and capacitor settings for power-loss reduction and voltage profile enhancement in distribution systems. Researchers turned their focus on reducing power losses by effectively planning transformer rearrangement. Modern works presented a new voltage stability index using local phasors for identifying weakest bus. A comparison of novel, loss sensitivity, voltage sensitivity, index vector methods is done for optimal location and sizing of DG. Astonishing methods
compares the effectiveness of voltage stability indices in providing valuable suggestions about the extent of volt-
age instability of a power system\textsuperscript{12}. Different type of DG sources have also been employed to specify a particular DG to be installed to reduce power losses\textsuperscript{13-16}. Recent trends concentrated on minimizing power losses without violating voltage constraints by optimal location of DG with respect to load growth.

In this paper a concept for DG location is proposed and is organized as follows:
   - Section-1. Introduction
   - Section-2. Problem formulation
   - Section-3. System under study
   - Section-4. Results

2. Problem Formulation

Optimal location of DG is determined from the following two concepts:
   - Case (i) Voltage deviation index
   - Case (ii) Voltage stability index

2.1 Voltage Deviation Index

Maintenance of bus voltage within the limits is the most important criteria. A slight variation in the voltage affects the whole system and may result in block out condition.

The amount of voltage that deviates from the voltage rated is given by the Voltage deviation index

\[
VDI = \sum_{i}^{NB} \left| \frac{V_{i} - V_{\text{rated}}}{V_{\text{rated}}} \right|
\]

Where $V_{\text{rated}}$ = nominal voltage of the system=1.0pu

$V_{i}$ is the Voltage at the $i_{th}$ bus in (Pu)

NB is the no. of buses.

2.2 Voltage Stability Index

TBus stability has to be maintained for proper function-
ing and to avoid the block out condition of the system. This stability of the bus is given by Voltage stability index

Bus with VSI near to zero is more stable and bus with VSI closer to 1 should be taken care of.

\[
VSI = \frac{4X}{V_{i}^{2}} \left( \frac{P_{i}^{2}}{Q_{i}} + Q_{i} \right) \leq 1
\]

Figure 1. Equivalent circuit of RDS.
2.3 Load Flow Solution

In this paper Bus Injection to Branch Current (BIBC) and branch current to bus voltage (BCBV) methods have been used to solve a set of nonlinear load flow equation.

For any bus the complex load $S_i$ is given by following equation expressed by Figure 1.

$$S_i = P_i + jQ_i$$

Where $i$=no. of buses.

The current injection at the $i_{th}$ bus is given by

$$I_i^k = I_i^k(V_i^k) + jI_i^k(V_i^k) = \left(\frac{P_i + jQ_i}{V_i^k}\right)$$

Where $V_i^k$ is the bus voltage at $k_{th}$ iteration?

$I_i^k$ is the current injection at the bus at the $k_{th}$ iteration,

$I_i^r$ and $I_i^i$ are the real and imaginary parts of current injection at the bus at the $k_{th}$ iteration. The relationship between the bus injection branch current, bus voltages are obtained by Kirchoff’s Current Law (KCL).

2.4 Assumptions of DG Placement

1. DG is taken to be a negative load.
2. DG is used as an external source capable of injecting only active power at unity power factor.
3. Maximum DG size is up to 40% of the load.
4. DG is placed at a particular location whose VDI is maximum and VSI is minimum.
5. DG size is determined by the successive fall and sudden rise of corresponding indices.

2.5 Method to Determine Cost of DG and Cost of Energy Losses

Cost of DG is determined by the following formula:

$$C(P_{dg}) = a \times P_{dg}^2 + b \times P_{dg} + cS/i$$

Where $P_{dg}$ is the real power output of DG

$a$, $b$, $c$ are constants $a=0$; $b=20$; $c=0.25$

Cost of Energy losses is determined by the following formula:

$$CL = (Total\ Real\ Power\ Loss) \times (E_C \times T)$$

Where $E_C$ is Energy rate

$T$ is time duration

3. System under Study

33-bus and 69-bus radial distribution systems are chosen

![33 bus RDS.](image)
for study in this paper which mentioned in Figure 2 and 3.

For 33-bus RDS, Substation voltage=12.66KV, Active power load=3.71MW, Reactive power load=2.31Mvar and Voltage limit=1.00pu.

For 69-bus RDS, Substation voltage=, Active power load=3.8014MW, Reactive power load=2.6936, and Voltage limit=1.00pu.

4. Results and Discussion

Results are obtained for both standard IEEE and reconfigured 33 and 69 bus RDS.
Table 1. Standard IEEE 33 bus test results based on VDI

| Parameter                  | Base case | Reconfigured with DG | Random check |
|----------------------------|-----------|----------------------|--------------|
| Switch Configuration       | 33,34,35,36,37 | 7,34,35,32,37        | 7,34,35,32,37 |
| Total P loss (KW)          | 223.8788  | 129.9026             | 127.6343     |
| Total Q loss (KW)          | 149.0574  | 91.3819              | 89.7860      |
| Max. VDI                   | 0.0866    | 0.0552               | 0.0549       |
| Location of Max. VDI       | 18        | 32                   | 32           |
| DG location                | -         | 31                   | 32           |
| DG size (MW)               | -         | 1.5                  | 1.5          |
| DG cost ($/h)              | -         | 30.25                | 30.25        |
| Cost of energy losses ($)  | 235,341.3946 | 136,553.6131       | 134,170.2274 |
| Savings in cost of energy losses ($) | 98787.7815 | 101171.169          |

Plot 1. Comparison of VDI of 33 bus RDS under base case, FR with DG and random check.
Table 3. Standard IEEE 69-bus test results based on VDI

| Parameter                  | Base case       | Reconfigured with DG | Random check |
|----------------------------|-----------------|----------------------|--------------|
| Switch Configuration       | 11,13,15,50,27  | 11,20,15,58,27       | 11,20,15,58,27 |
| Total P loss (KW)          | 216.6168        | 126.5560             | 124.8632     |
| Total Q loss (KW)          | 98.0373         | 121.0370             | 119.4836     |
| Max. VDI                   | 0.0866          | 0.0672               | 0.0366       |
| Location of Max. VDI       | 65              | 65                   | 65           |
| DG location                | -               | 65                   | 64           |
| DG size (MW)               | -               | 0.61                 | 0.61         |
| DG cost ($/h)              | -               | 12.45                | 12.45        |
| Cost of energy losses ($)  | 227707.5802     | 133035.6672          | 131256.1958  |
| Savings in cost of energy losses ($) | 94671.913 | 96451.3844 |
Plot 3. Comparison of VDI of 69 bus RDS under base case, FR with DG and random check.

Table 4. Standard IEEE 69-bus test results based on VSI

| Parameter                  | Base case       | Reconfigured with DG | Random check               |
|----------------------------|-----------------|----------------------|----------------------------|
| Switch Configuration       | 11,13,15,50,27  | 11,20,15,58,27       | 11,20,15,58,27             |
| Total P loss (KW)          | 216.6168        | 126.5560             | 124.8632                   |
| Total Q loss (KW)          | 98.0373         | 121.0370             | 119.4836                   |
| Min. VSI                   | 0.6951          | 0.7626               | 0.7622                     |
| Location of Min. VSI       | 65              | 64                   | 65                         |
| DG location                | -               | 65                   | 64                         |
| DG size (MW)               | -               | 0.61                 | 0.61                       |
| DG cost ($/h)              | -               | 12.45                | 12.45                      |
| Cost of energy losses ($)  | 227707.5802     | 133035.6672          | 131256.1958                |
| Savings in cost of energy  |                 |                      |                            |
| losses ($)                 |                 | 94671.913            | 96451.3844                 |
From Table 1 for 33-bus it can be observed that a change in two switches together with DG results in reduction of loss from 223.8788KW to 129.9026KW and the VDI has reduced from 0.0866 to 0.0552 which accounts to 41.9% reduction in loss and 36.25% reduction in VDI. The net amount of money that is saved is 98787.7815$ which can be put to some meaningful use. Further a random check is performed at all busses with the same DG size shows that installation of DG at 32nd bus gives further more reduction in power loss, VDI and increased money save and corresponding plots are shown to reach a deeper understanding. The plot 1 and 2 refer with the output of 33 bus with respect to VDI and VSI representing the base case, FR with DG and random check. The results are quite matching with random check as well as FR with DG output.

In the same manner results from Table 2 can be inferred for 33-bus based on VSI.

From Table 3 for 69-bus it can be observed that a change in two switches together with DG results in reduction of loss from 216.6168KW to 126.5560KW and the VDI has reduced from 0.0866 to 0.0672 which accounts to 41.5% reduction in loss and 22.4% reduction in VDI. The net amount of money that is saved is 94671.913$ which can be put to some meaningful use. Further a random check is performed at all busses with the same DG size shows that installation of DG at 64th bus gives further more reduction in power loss, VDI and increased money save and corresponding plots are shown to understand clearly. The plot 3 and 4 refers with the output of 69 bus with respect to VDI and VSI representing the base case, FR with DG and random check. The results are quite matching with random check as well as FR with DG output.

In the same manner results from table-4 can be inferred for 69-bus based on VSI.

5. Conclusion

This paper presents two indices for recommending location and size of DG. Size of DG is determined randomly by continuous fall and sudden rise of corresponding VDI or VSI. DG is installed randomly at all busses and a particular bus is chosen as a location where power losses are minimum. This method is tested on initial and reconfigured IEEE 33 and 69 bus radial distribution system.
Results attained show that power losses are reduced significantly and the cost of energy losses are reduced.

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