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OPTIMAL PLACEMENT OF DISTRIBUTED GENERATION WITH SVC FOR POWER LOSS REDUCTION IN DISTRIBUTED SYSTEM

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ABSTRACT

In recent years there has been a considerable growth on the integration of various renewable sources and multi types of flexible ac transmission systems (FACTS) in many practical power systems in the world. Hence the Distributed Generation is implemented in terms of using renewable source. The major problem faced in distribution network is power loss reduction and finding the proper location of distributed generation (DG). The main aim of the project deals with optimal placement of Distributed Generation with considering the Flexible AC Transmission Systems (FACTS) devices in order to minimize the total real power loss. This paper aims at improving the voltage profile in the Distribution network by optimally placing the DG with and without FACTS devices (SVC). The optimal placement of DG is done based on Voltage Stability Index. The simulation studies of proposed test systems are performed in MATLAB coding. The outcome of the coding shows that there is an improvement in the voltage profile and also there is minimization in power loss of the distribution system.

Keywords: flexible AC transmission system (FACTS), distributed generation (DG), forward sweep, backward sweep, voltage stability index, power loss.

1. INTRODUCTION

Distributed Generation is an important concept in improving the efficiency of the system by providing required power that can be produced by various sources such as solar, wind, fuel cells, micro turbines and so on near the place of power requirement. The power produced by these ways should be regulated by improving its voltage and also by minimizing the losses associated with the system. For this purpose the FACTS devices such as SVC is placed in the system and its effects arte studied in this paper. According to [1], the impact assessment of optimally placed different distributed generations (DGs) with different load models (DLMs) such as Distributed Generation and flexible alternating current transmission system (FACTS) controller like static VAR compensator (SVC) by employing genetic algorithm (GA) in a distribution power systems (DPSs) from minimum total real power loss of the system are studied. According to [2], a new planning strategy for modern power distribution system using a flexible variant based differential search (DS) algorithm named adaptive DS is seen and the algorithm investigated for solving the optimal location and sizing of multi distributed generation (DG) is explained. In this the total power losses have been optimized considering the cost component of DG for real power, and the cost of energy losses. In Reference [3], presents a genetic algorithm to seek the optimal location of multi-type FACTS devices in a power system. The optimizations are performed on three parameters: the location of the devices, their types and their values. The system loadability is applied as measure of power system performance. According to [4], a systematic simple approach to allocate multiple DG units in radial/meshed distribution network. The concept of equivalent load is introduced and extended to identify the load centroid precisely with two methods and the performance index that combines the power system real power loss and average node voltage is defined. In reference [5], Analytical expressions have been developed for finding the appropriate size of different types of distributed generations. Methodologies are presented for locating the DG in primary distribution network, assuming primary energy resources are evenly distributed along the network. The analytical expressions and placement methodologies have been tested on IEEE 33 bus system. According to [6], the importance of Proper location of DGs in power systems for obtaining their maximum potential benefits is studied. This paper presents analytical methods to determine the optimal location to place a DG in radial as well as networked systems to minimize the power loss of the system.

Distributed generation is an emerging approach in the electric power generation where power can be produced near the place of use generally these resources can either be grid connected or independent of the grid the generating plant is connected directly to grid at distribution level voltage or on the meter in the customer side it includes engine small and micro turbines, fuel cells and concentrating solar and photo voltaic cells the range of power produced from distributed generation varies from less than a kilowatt(Kw) to Megawatt(Mw) based on the size of distributed generation unit.

The DG can be classified into different types based on the application for which they are used some of the applications are standby, standalone, peak load shaving, remote applications and base load the DG size are not restricted and depends on the user type and it varies from one unit to large number of units

In this paper the optimal placement of distributed generation in the distribution system is done with the presence of the FACTS device and here the main aim is to minimize the power loss that occurs in the system and hence the performance of the distribution system is improved. The FACTS devices are employed in order to

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have control over the reactive power that makes the power loss to reduce. FACTS device is being employed in any distribution system in order to control the voltage associated with that system, compensation of the VAR and also muffling of oscillations.

Here SVC (Static VAR Compensator) is used and the main aim of using SVC is to improve the voltage which in turn reduces the power loss and increase the overall efficiency of the system the factors that are need to be considered for the placement of FACTS devices are shown below:

- Type of device
- The capacity of the device
- Location that optimize the functioning of the system

2. RADIAL POWER FLOW ANALYSIS

Load flow studies are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. The increasing presence of distributed alternative energy sources, often in geographically remote locations, complicates load flow studies and has triggered a resurgence of interest in the topic. In a three phase ac power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is then to be called power flow or load flow. Power flow studies provide as systematic mathematical approach for determination of various bus voltages, there phase angle active and reactive power flows through different branches, generators and loads under steady state condition. In order to obtain a reliable power system operation under normal balanced three phase steady state conditions, it is required to have the followings:

- Generation supplies the load demand and losses.
- Bus voltage magnitudes remain close to rated values.
- Generator operates within specific real and reactive power limits.
- Transmission lines and transformers are not overloaded.

Power flow analysis is used to determine the steady state operating condition of a power system. Power flow analysis is widely used by power distribution professional during the planning and operation of power distribution system. In RDNs, the large *R*/*X* ratio causes problems in convergence of conventional load flow algorithms. For a balanced RDN, the network can be represented by an equivalent single-line diagram. The line shunt capacitances at distribution voltage level are very small and thus can be neglected.

3. BACKWARD/ FORWARD SWEEP METHOD

Load flow studies are performed on Power Systems to understand the nature of the installed network. Load flow is used to determine the static performance of the system. A power-flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various forms of AC power (i.e.: voltages, voltage angles, real and reactive power). It analyses the power systems innormal steady-state operation. The distribution networks because of the some of the following special features fall in the category of ill-condition.

- Radial or weakly meshed networks
- High R/X ratios
- Multi phase, unbalanced operation
- Unbalanced distributed load
- Distributed generation

Due to the above factors the Newton Raphson and other transmission system algorithms are failed with distribution network. So the backward forward sweeping method is introduced to analyse the distribution network. This method do not need Jacobian matrix unlike NR methods. However, conventional backward forward sweep method is not useful for modern active distribution networks. The method showed voltage convergence but could not be efficiently used for optimal power flow calculations.

The conventional Newton Raphson (NR) and fast decoupled load flow (FDLF) methods are inefficient in solving such systems. Even though with some advancements in Newton-Raphson Methods the robustness of the program is obtained but still the computational time is large enough.

The distribution power flow involves, first of all, finding all the node voltages. From these voltages, it is possible to compute current directly, power flows, system losses and other steady state quantities. Some applications, especially in the fields of optimization of distribution system, and distribution automation.

A radial network leaves the station and passes through the network area with no normal connection to any other supply. The Forward-Backward Sweep Method (FBSM) in is easy to program and runs quickly. The method is designed to solve the differential algebraic system generated by the Maximum Principle that characterizes the solution.

The power flow equations for a radial distribution system is defined as the relationship between the specified complex bus powers and the bus voltages. Let is the complex power flowing from bus 'i' to bus'j'

$$S_{ij} = P_{ij} + iQ_j = V_i \ (V_i * - V_j *) \ \mathrm{Y_{ij}} \quad \text{------- (1)}$$

The 'i'th bus powers are expressed as

$$P_i + Q_i = \sum_{iek(i)} P_{ij} + Q_{ij} = \sum_{iek(i)} V_i \left(V_i * - V_j *\right) Y_{ij} * \text{---- (2)}$$

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The Power flows in a distribution system are computed by the following set of simplified recursive equations derived from the single-line diagram shown. The power flow analysis can be used to obtain the voltage magnitude, power losses of the 33 bus system. The objective function is to find the power flow

$$P_{k+1} = P_k - P_{loss,k} - P_{Lk+1} \quad \text{------------ (3)}$$

$$Q_{k+1} = Q_k - Q_{loss,k} - Q_{Lk+1} \quad \text{------------ (4)}$$

where Real power flowing out of bus; Reactive power flowing out of bus;
Real load power at bus k+1;
Reactive load power at bus k+1
The power loss in the line section connecting buses k and k+1 may be computed
as,

$$P_{loss}(k, k+1) = R_k \frac{P_k^2 + Q_k^2}{V_k^2} \quad \text{---------- -- (5)}$$

$$Q_{loss}(k, k+1) = X_k \frac{P_k^2 + Q_k^2}{V_k^2} \quad \text{------------ (6)}$$

The total power loss of the feeder may then be determined by summing up the losses of all line sections of the feeder, which is given as,

$$P_{T,loss}(k, k+1) = \sum_{k+1}^{n} P_{loss(k,k+!)} \quad \text{----------- (7)}$$

$$Q_{T,loss}(k, k+1) = \sum_{k+!}^{n} Q_{loss(k,k+1)} \quad \text{--------- (8)}$$

The backward sweep is basically a current or power flow solution with possible voltage updates. It starting from the branches in the last layer and moving towards the branches connected to the root node. The updated effective power flow computation by considering the node voltages of previous iteration.

It means the voltage values obtained in the forward path are held constant during the backward propagation and updated power flows in each branch are transmitted backward along the feeder using backward path. This indicates that the backward propagation starts at the extreme end node and proceeds towards source node. It is well known that there exist three main variants of the forward/backward sweep method that differ from each other based on the type of electric quantities that at each iteration, starting from the terminal nodes and going up to the source node (backward sweep), are calculated

$$P_{k+1}^{`} = P_{k+1} + P_{Lk+1} \quad \text{-------- (9)}$$

$$Q_{k+1}^{`} = Q_{k+1} + Q_{Lk+1} \quad \text{------- (10)}$$

The diagrammatic representation of the IEEE 33 bus system is shown in the Figure-1.

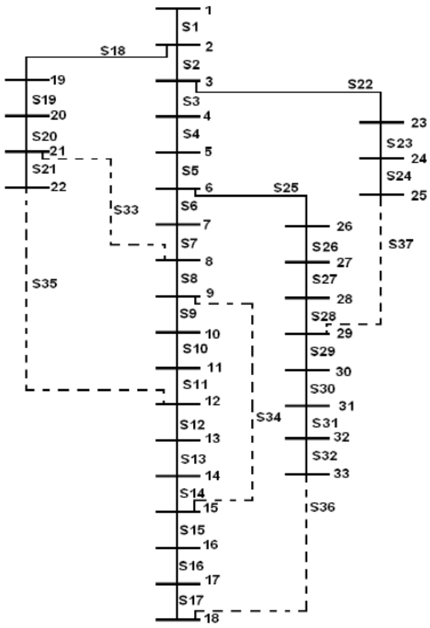

Figure-1. IEEE 33 bus system.

4. VOLTAGE STABILITY INDEX

Voltage stability concerns stable load operation, and acceptable voltage levels all over the system buses. Its instability has been classified into steady state and transient voltage instability, according to the time spectrum of the occurrence of the phenomena. A power system is said to have entered a state of voltage instability when a disturbance causes a progressive and uncontrollable decline in voltage. Voltage stability analysis often requires examination of lots of system states and many contingency scenarios. For this reason the approach based on steady state analysis is more feasible, and it can also provide global insight of the voltage reactive power problems. The voltage stability phenomenon has been well recognized in distribution systems. Radial distribution systems having a high resistance to reactance ratio causes a high power loss so that the radial distribution system is one of the power systems, which may suffer from voltage instability.

The formula for calculating the voltage stability index is shown below:

$$SI(i+1) = \{|V(i)|\text{^}4\} - 4.0\{p(i+1)x(j) - Q(i+1)r(j)\}\text{^}2 - 4.0\{p(i+1)r(j) + Q(i+1)x(j)\}\,|V(i)|\text{^}2 \quad \text{------ (11)}$$

Where SI- Stability Index.

These are the various factors that are being considered while placing one or more Distributed Generation in a system and also during calculating the stability index and other factors related to the system.Using the Stability Index values obtained, the ranking is done.

5. RESULTS AND DISCUSSIONS

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A. Radial power flow analysis

The radial power flow analysis is performed for IEEE 33 bus system using the backward and forward sweep method from the values of the voltage magnitude that is obtained during the backward sweep load flow analysis and based on that ranking the placement of Distribution Generation is being done in this Radial distribution system.

Table-1. Voltage magnitude in radial power flow analysis.

Bus number	bus magnitude
1	1
2	0.996
3	0.997
4	0.9669
5	0.9568
6	0.9318
7	0.9271
8	0.9205
9	0.9120
10	0.9040
11	0.9029
12	0.9008
13	0.8925
14	0.8894
15	0.8875
16	0.8856
17	0.8829
18	0.8821
19	0.9954
20	0.9942
21	0.9932
22	0.9924
23	0.9722
24	0.9633
25	0.9588
26	0.9292
27	0.9257
28	0.9102
29	0.899
30	0.8942
31	0.8884
32	0.8872
33	0.8868

Based on the Voltage Stability Index Ranking the node 19 is identified as the node with weakest voltage profile followed by node 18 with second weakest voltage profile. The voltage with maximum voltage profile is node 33 which will receive the maximum value of voltage.

B. Voltage stability index

To find the ranking of the voltage magnitude and the change in the voltage in the system the voltage stability is found based on that the ranking is made and the node with weakest voltage profile is found and the DG is being placed in that respective node.

Table-2. Voltage Stability Index (VSI) and its ranking.

Node	Voltage stability index	Vsi Ranking
1	1.0000	33
2	0.9998	32
3	0.9872	31
4	0.9331	26
5	0.9052	24
6	0.8771	21
7	0.8117	20
8	0.7999	18
9	0.7840	16
10	0.7634	15
11	0.7461	13
12	0.7432	12
13	0.7372	10
14	0.7182	8
15	0.7112	7
16	0.7069	4
17	0.7011	3
18	0.6963	2
19	0.6956	1
20	0.9826	30
21	0.9709	29
22	0.9672	28
23	0.9660	27
24	0.9115	25
25	0.8868	23
26	0.8828	22
27	0.8069	19
28	0.7967	17
29	0.7590	14
30	0.7419	11
31	0.7197	9
32	0.7085	6
33	0.7070	5

C. placement of DG and facts

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The placement of DG and FACTS in the 33 bus system is being done by analyzing three cases and based on these three cases the change in power loss as well as the change in the bus voltage are being calculated

Case 1:
Comparison of voltages at three conditions:

(i) Without DG
(ii) With DG and Without Q
(iii) With 2 DG and Without Q

Table-3. Comparison of Power loss in Case (1).

Real power loss without using distribution generation	Real power loss with one DG in 19th bus	Real power loss with DG in 19th bus and 18th bus
280.43	279.98	276.14

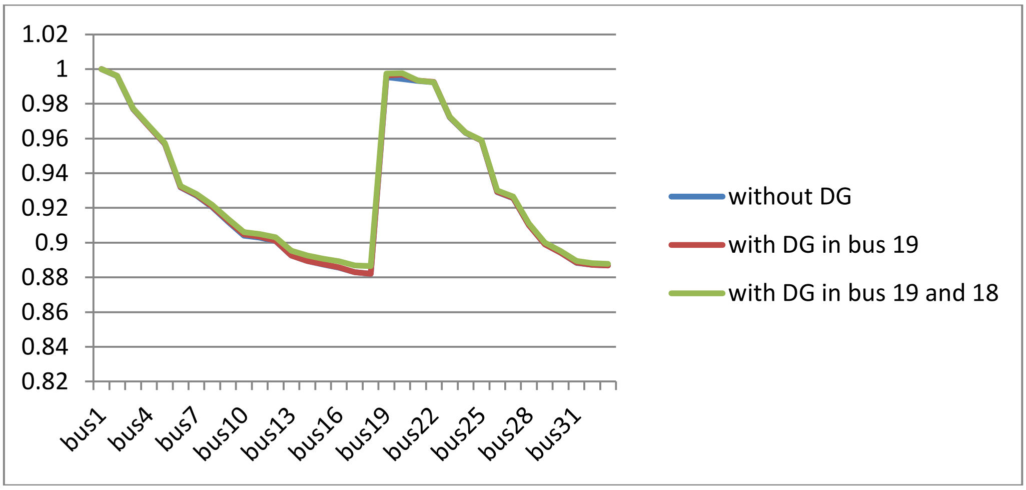

Figure-2. Change in voltage magnitude at different conditions of Case (1).

Case 2
Comparison of voltages at three conditions:

(i) Without DG
(ii) With DG and With Q
(iii) With 2 DG and With Q

Table-4. Comparison of power loss in Case (1).

Real power loss without using distribution generation	Bus voltage with 1 DG (Q=50 kvar)	Bus voltage with DG in bus 19 and 18 (Q=100 kvar)
280.43	269.671	263.248

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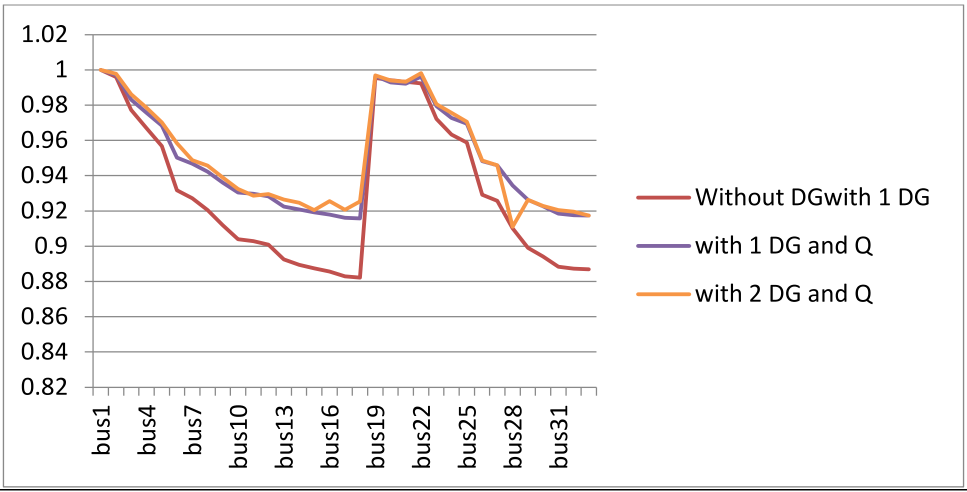

Figure-3. Change in voltage magnitude at different conditions of case (2).

Case 3

Comparison of voltages at three conditions:

(i) Without DG
(ii) With 1 DG, Without Q and without SVC
(iii) With 2 DG, With Q and with SVC

Table-5. Comparison of power loss in Case (3).

Real power loss without using distribution generation, reactive power and SVC	Bus voltage with 1 DG (Q=50 kvar) (SVC=1550 kvar)	Bus voltage with DG in bus 19 and 18 (Q=100 kvar) (SVC=1940 kvar)
280.43	246.671	238.248

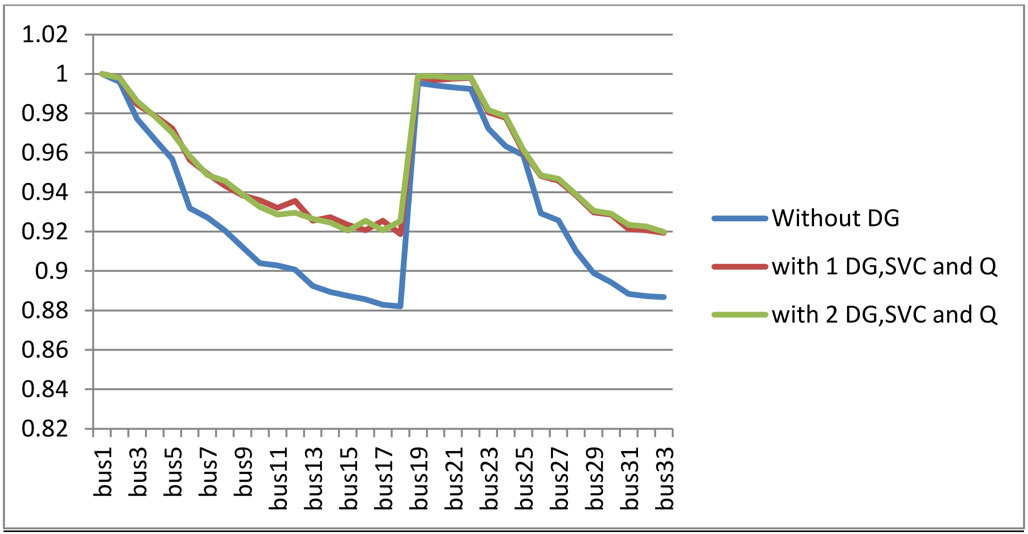

Figure-4. Change in voltage magnitude at different conditions of case (3).

The three cases are being considered in order to notice the changes in the voltage and also to show the improvement in the overall performance of the system mainly the power loss associated with this 33 bus system. From the above considerations it is clearly seen that the voltage associated the system have been increased and also the power loss is minimized when compared to the case without DG. Thusit is clearly seen that placement of Dg and SVC improves the system performance and minimize power loss.

D. Overall change in power loss

The changes that occur in the power loss are being shown below, as the difference between the three cases that are considered and the variations are shown. From Figure-5 it is clearly shown that the losses are minimized in the case (3) more when compared to the other two cases thus the changes are clearly seen. When compared to system without DG and SVC the system with two DG and SVC gives out less power loss.

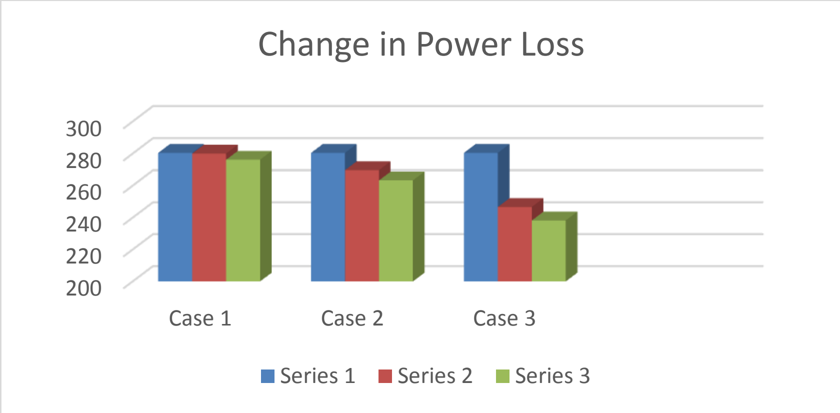

Figure-5. Overall change in power loss.

6. CONCLUSIONS

The radial power flow analysis for the distribution system is performed using the backward/forward sweep method and the change in voltage and its real power losses are calculated and the value of total power losses are considered with and without placing the distributed generation and FACTS devices. The optimal placement of Distributed Generation done by finding the voltage stability index values. The system performance is checked after placing distributed generation and SVC and the improvement is seen in the voltage profile and also the power losses are minimized in the distribution system.

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