Proceedings of 10th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2021 Month: October Volume: 10

Simultaneous Reconfiguration with Optimal Placement and Sizing of D-STATCOM in a Radial Distribution System Using Genetic Algorithm

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Abstract

In this work, a multi-objective approach is changed to a single objective minimization function as the weighted sum of power loss, voltage profile index and load balancing index. Each single objective minimization function is tested on various weighted methods and analyzed giving equal importance to each objective function. In this work optimal switches of the considered network is obtained using Genetic Algorithm (GA) with help of the MATLAB script environment. Backward Forward Sweep technique is selected for load flow of the distribution network taking power as flow variable and reconfiguration of the radial distribution network is done on the basis of branch exchange technique. Both reconfiguration and optimal sitting and sizing of DSTATCOM of the considered network is carried out simultaneously in view of minimizing the objective function. Reduction of power loss, improvement in load balancing and improvement of voltage profile are the major intent of this work. The intended approach is validated on the IEEE-33 bus test system. The obtained result verified that simultaneous reconfiguration with optimal sizing and sitting of DSTATCOM reduces the power loss, improves the voltage profile index and increase load balancing of the feeder. The obtained outcomes has been correlated with the base value and found that simultaneous reconfiguration along with DSTATCOM is more beneficial than the separate reconfiguration and separate DSTATCOM placement in the radial distribution system and based on different weightage value all findings is analyzed.

Keywords

Simultaneous Reconfiguration, Distribution system power loss, Voltage Profile Index, Load Balancing Index, GA

1. Introduction

With the increased complexity of wind generation, electrical phenomenon generation,PV cell, hydro cell energy, distribution generation has flourished a lot comparatively other energy resources. The structure, functioning, and administration manner of DG alter when it is connected to a distribution network. It's a challenge to figure out how many DG capacity will be needed to link to distribution systems. Ties and sectionalizing are the two types of switches found in distribution systems. Reconfiguration means changing the state of switches present between nodes of the network in order to change the distribution network's structure. [1]. Network reconfiguration is a technique that includes altering the topology by interchanging the state of a set of switches normally opened (NO) and normally closed (NC) and until the minimum value of summation of all the feeder power losses, without isolating any load from the system is obtained[2]. For all scenarios of variable loads, the power loss in a dispersed network will not be minimal for a fixed network topology. As a result, network reconfiguration is necessary on a regular basis. Reconfiguration of a distribution network is carried out to reduce real power loss and relieve the feeder or a section from overloading along with overall improvement in voltage profile of the network. The main goal of reconfiguration is to cut back real power losses, will increases stability and dependability, improving the voltage profile(VP)[3], and relieve overloading in the distribution network.

FACTS devices[4] were designed originally for transmission systems, but they are now being used in distribution systems as well. DSTATCOM (Distribution STATCOM) is a shunt-connected voltage source converter that is used to adjust for power quality concerns such unbalanced loads, voltage sag, and voltage volatility. DSTATCOM is also used for long-term voltage correction, which is another component of power quality. Multi objective economic/emission dispatch algorithms[5] were investigated. Various methods, such as the simulated annealing technique, were used to optimize the multi-objective approach to DG planning in research on optimization methods[6], Tabu search method integrated with the genetic algorithm[7] (GA, and Fuzzy optimization method.

[8] A review of recent research on the DG planning paradigm and related algorithms follows. The optimization problem is solved using several intelligent optimization algorithms, including GA, particle swarm optimization (PSO), differential evolution (DE), and artificial bee colony (ABC), assuming minimum costs for network upgradation, operation, and maintenance, as well as losses for load growth and maximum DG penetration level. [9]. In addition, many approaches to DG allocation sensitivity analysis were expected. When there are numerous conflicting objectives, there may not be a solution that is the best alternative for all of them. Multi objective optimization, on the other hand, necessitates a “tradeoff” resolution rather than a single one. Based on GA, Farhoodnea et al projected a method to optimal sizing of DSTATCOM using firefly algorithm [10]. Jin et al. established a multi criteria planning model for reducing the cost and broaden the dependability of generating units[11]. Despite the fact that prior studies concentrated on power loss and network upgrade costs, voltage deviation and voltage stability enhancement received far less attention. Arash et al. proposed a method for the simultaneous placement of DSTATCOM and parallel capacitors employing multi objective PSO for the reduction in the power losses, voltage stability and voltage profile of the distribution system[12]. Although earlier work on power loss and network upgrade costs was taken into consideration, relatively little effort was put into improving voltage deviation and voltage stability. As a result, it is necessary to investigate the simultaneous reconfiguration and appropriate placement of D-STATCOM in the radial distribution system based on GA.

2. Problem Formulation

This section provides the brief details of the methodology used in this paper.Different case analysis related to different weight age of this method using simultaneous reconfiguration with DSTATCOM and advantages and impacts on the radial distribution system and improvement in the power quality indices and improvement in the voltage profile of the system.

2.1 A . Power Flow Equations

Power flows in a radial distribution system are calculated by the following set of equations[13].In order to meet the objectives of the Network reconfiguration to minimize the power loss, the total power loss for each configuration is evaluated using a backward forward sweep method considering power as a flow variable. The feeder power loss and the node voltages are two parameters that are calculated during load flow. In order to illustrate the calculation of node voltages and total power loss, lets consider a simple two bus system as shown in figure 1.

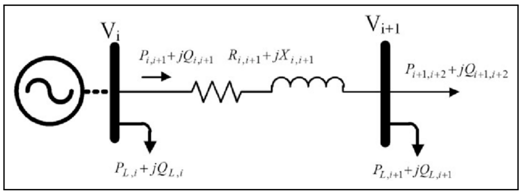

Figure 1: Simple Radial Distribution System

The Voltage magnitude $|V(m_2)|$ at the receiving end can be evaluated as,

$$|V(m_2)| = |B(j) - A(j)|^{1/2}$$

where,

$$A(j) = P(m_2) \times R(j) + Q(m_2) \times X(j) - 0.5|V(m_1)|^2$$

$$B(j) = \{A(j) - [R^2(j) + X^2(j)] \times [P^2(m_2) + Q^2(m_2)]\}^{1/2}$$

j is the branch number, m_1 and m_2 are sending end and receiving end node respectively. Similarly, the real and reactive power losses of a respective branch are calculated as,

$$LP[j] = \frac{R(j)[P^2(m_2)+Q^2(m_2)]}{|V(m_2)|^2}$$

$$LQ[j] = \frac{X(j)[P^2(m_2)+Q^2(m_2)]}{|V(m_2)|^2}$$

The system total power loss is the sum of branch power losses. The voltage and the power loss formulae as mentioned above is subject to the contraints

Bus voltage constraints :$V_{min} \leq V_i \leq V_{max}$

Feeder current limitations : $I_j \leq I_{max}$

2.2 Distribution Static Compensator

DSTATCOM is voltage source converter device connected in parallel and it's application helps in mitigation of power quality issues such load imbalance, and voltage sag and swell. It injects active power as well reactive power at the connected bus to sort out sensitive loads. In order to supply active power DSTATCOM requires storage of energy. DSTATCOM may generate regularly changing reactive power at a level higher than its maximum MVAR rating. It can give the exact amount of leading or lagging reactive current compensation [14]. It includes a dc capacitor, one or more inverter modules, an ac filter, and a transformer that matches the inverter output to the line voltage. DSTATCOM application as voltage-source converter changes dc voltage to three phase ac voltage which is synced with and linked to the connected line via a small tie reactor and capacitor (ac filter). The realistic principle of a DSTATCOM is quite similar to that of a synchronous machine. When a synchronous machine is under-excited, lagging current is produced, and when it is over-excited, leading current is produced. DSTATCOM has the ability to generate and absorb reactive power in a manner similar to synchronous machines[15].

2.2.1 DSTATCOM Modeling

This part describe the mathematical modeling of DSTATCOM[16]. In a traditional radial system, voltages at the buses are often less than 1 pu. Because the voltage on bus $'m+1'$ is expected to be less than 1 pu, DSTATCOM is installed on this bus to optimize the voltage profile. $[v'_{m+1}\angle\theta'_{m+1}]$: Voltage of bus $m+1$ after taking DSTATCOM into account.
$v_m\angle\theta_m$: Voltage of bus m.
$i_m\angle\alpha$: Current flow in line after taking DSTATCOM into account.
$i_{DSTATCOM}\angle(\theta'_{m+1}+\Pi/2)$: Injected current by DSTATCOM . Now,

$$\begin{aligned} v'_{m+1}\angle\theta'_{m+1} &= v_m\angle\theta_m - (r_m + jx_m)i_m\angle\alpha \\ &-(r_m + jx_m)i_{DSTATCOM}\angle(\theta'_{m+1} + \alpha/2) \end{aligned} \tag{1}$$

At bus $m+1$, injected voltage , current and reactive power will be the following.

$$v'_{m+1} = v'_{m+1}\angle\theta'_{m+1} \tag{2}$$

$$i_{DSTATCOM} = i_{DSTATCOM}\angle(\theta'_{m+1} + \Pi/2) \tag{3}$$

$$jq_{DSTATCOM} = v'_{m+1} i^*_{DSTATCOM} \tag{4}$$

where$*$ denotes conjugate of complex variable.

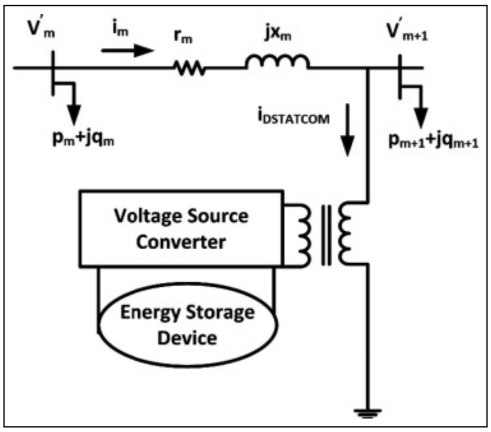

Figure 2: Single Line Diagram of two buses with DSTATCOM consideration

3. Network Reconfiguration

The act of changing the open/closed status of sectionalizing and tie switches to change the topological structure of distribution feeders is known as network reconfiguration in a distribution system. Network reconfiguration, a very complex and non-linear optimization for time-varying loads, can be calculated using the evolutionary method (GA). By moving loads from strongly loaded feeders to lightly loaded feeders, network reconfiguration can balance feeder loads and lighten overload conditions[17]. They are basically classified in two approaches:

3.1 Sequential Switch Opening Method

All tie switches were closed during the loop cutting or sequential switch opening approach. In this state, the usual distribution system, similar to the transmission system, would be "weakly meshed." A minimum-loss solution will be obtained from the meshed system's load flow (in the absence of any control action). Despite this, the system must be radialized. This is accomplished by opening switches that carry the least amount of current, in the hopes of causing the least amount of disruption to the mesh load flow solution. Before selecting the next switch to open, the meshed load flow must be recalculated after each switch opening. If the system is radial, the algorithm stops.

3.2 Branch Exchange Method

In order to configure a distribution network maintaining its radiality, a viable technique branch exchange is adopted here. One of the tie switches is eventually closed, and another switch is opened to complete the loop, restoring the radial layout. Heuristics and approximation formulas for the change in losses are used to choose the switched pairs. When no more loss reductions are possible, the branch exchange strategy is abandoned. The branch exchange approach is the network reconfiguration concept used in this paper. Due to the islanding of inner and exterior nodes, the radial topologies obtained at each step by opening a sectionalizing switch may not be practical due to the major operating constraint of maintaining the radial nature serving all the loads. To limit the possibility of creating infeasible individuals, loop vectors, common branch vectors, and prohibited group vectors are utilized [17] are discussed below.

1. Obtain all the loop formed in a meshed network. The *loop vector, L* consist of the set of elements that come in the loop path.
2. Determine *common branch vectors* having set of elements common between two loops.
3. Determine *prohibited group vectors*, which is the set of common branch vectors incident at the principal nodes of the distribution network.

Each tie switch combination consists of number of switches equal to the number of loops in the system. For reducing the search space of the reconfiguration technique, the following rules must be fulfilled:

Rule 1: Each element of the switching combination must be part of the loop vector that corresponds to it.

Rule 2: To establish a tie switching combination, only one member from a common branch vector can be chosen.

Rule 3: To establish a tie switching combination, all the common branch vectors of each prohibited group vector must participate at the same time.

Rule-1 prevents the network's perimeter nodes from becoming islands, whereas Rule-2 and Rule-3 prevents the islanding of the nodes located at the interior of the network [17]. The tie switching combination generated using the above rules helps to reduce the search space for reconfiguration problem during optimization.

Illustrative Example

To grasp this , let us take an example of an IEEE-33 bus system as shown in fig 5. For this system after closing five tie switches, the network topology recognizes five *Loop vectors* and seven *Common branch vectors* as shown in the table 1.

Table 1: Loop Vectors and the Common Branch Vectors

Loop vectors	Common Branch Vectors
$L_1 = [2\ 3\ 4\ 5\ 6\ 7\ 33\ 20\ 19\ 18]$ $L_2 = [9\ 10\ 11\ 12\ 13\ 14\ 34]$ $L_3 = [8\ 9\ 10\ 11\ 35\ 21\ 23]$ $L_4 = [25\ 26\ 27\ 28\ 29\ 30\ 31\ 32\ 36\ 17\ 16\ 15\ 34\ 8\ 7\ 6]$ $L_5 = [22\ 23\ 24\ 37\ 28\ 27\ 26\ 25\ 5\ 4\ 3]$	$C_{13} = [33]$ $C_{14} = [6\ 7]$ $C_{15} = [3\ 4\ 5]$ $C_{23} = [9\ 10\ 11]$ $C_{24} = [34]$ $C_{34} = [8]$ $C_{45} = [25\ 26\ 27\ 28]$

The prohibited group vectors and the corresponding islanded nodes for the system are shown in table 2.

Table 2: Prohibited Group Vectors and the Principal Islanded Nodes

Prohibited Group Vector	Islanded Node
$R_8 = [C_{13}\ C_{34}\ \ C_{14}]$	8
$R_9 = [C_{24}\ C_{34}\ \ C_{23}]$	9
$R_6 = [C_{14}\ C_{15}\ \ C_{45}]$	6
$R_{89} = [C_{13}\ C_{14}\ \ C_{24}\ \ C_{23}]$	8, 9
$R_{86} = [C_{13}\ C_{34}\ \ C_{15}\ \ C_{45}]$	8, 6
$R_{896} = [C_{13}\ C_{24}\ \ C_{15}\ \ C_{45}\ \ C_{45}]$	8, 9, 6

4. Simultaneous Reconfiguration problem formulation

The objective of reconfiguring existing distribution network is the reduction in power loss, and improvement of voltage profile index & load balancing index. To obtain this objective, the GA algorithm searches for the optimum switch status, DSTATCOM placement and sizing in the radial distribution system. In the GA, at every step, it chose individuals at random from the current population to be parents and used them to produce the children for the next generation. Over successive generations, the population evolves toward an optimal solution represent the switch state for the problem of reconfiguration the distribution system and sizing and sitting of DSTATCOM. For the feasibility of the switch configuration generated, the constraint imposed on each parents is that the electrical

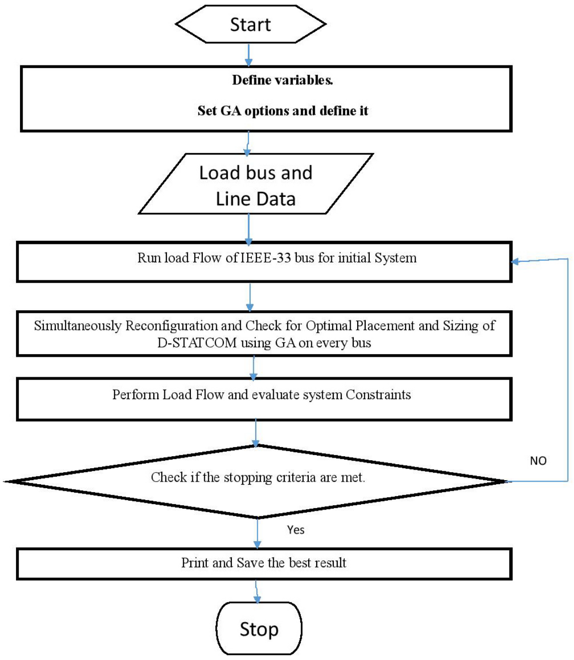

Figure 3: Flowchart showing Overall Procedure for Simultaneous Reconfiguration with DSTATCOM

connection from source to the load should be preserved. The overall working process is shown in the flowchart 6. An objective function needs to be defined at each stage of the iteration to determine the suitability of the solution sought by the parents. It checks for the feasibility of the switch configuration, at first for each offspring and if feasible, it evaluates the system Power loss indices, Voltage profile indices and load balancing indices and checking the current supplied by the DSTATCOM and correspondingly its size and placement of DSTATCOM.

The multi-objective function that is formulated for minimization with the proposed technique is formulated as:

$$Minimize:\ W_1 P_{Loss} + W_2 V.P + W_3 L.B$$

where,
P_{LOSS} is the total real power loss in the distribution system with respect to Simultaneous Reconfiguration with DSTATCOM. V.P is the voltage Profile Index with respect to Simultaneous Reconfiguration with DSTATCOM. L.B is the Load Balancing Index with respect to Simultaneous Reconfiguration with DSTATCOM w_1 , w_2 w_3 are the weights assigned to the parts of the objective function. A large value K is assigned to the value of the objective function if the configuration is not feasible. This function mainly has three objectives namely [3] 1) reducing the loss 2) increasing the L.B 3) improving the V.P The constraints of the problem can be presented by: 1) $V_{kmin} \leq V'_k \leq V_{kmax}$
2) $\mid I'_{k,k+1} \mid \leq \mid I_{k,K+1max} \mid$ The first element of the objective function gives real power loss that is defined using [3]

$$P_{Loss} = \sum_{j=1}^{n_f} \sum_{k=1}^{n_s} R_k \mid I_k^2 \mid$$

Where I_k is the current passing through line m and n_f is the total number of feeders.
The second element of the objective function gives the improvement in the voltage Profile which can be shown as VP Index as [3]

$$VP = \sum_{j=1}^{n_f} \sum_{k \varepsilon lb} \mid V_K - V_{ref,k} \mid$$

where lb is the collection of load buses and $V_{ref,k}$ is the nominal voltage at load bus k. The third element of the objective function gives LB Index of the lines of the feeders which can be represented by

$$LB = \sum_{j=1}^{n_f} \sum_{k=1}^{n_s} \left(\frac{I_k}{1/n_f \times \sum_{k=1}^{n_f} I_k} \right)^2$$

where n_s is the total number of section in the feeders. Different weight value considered for single objective function but by analysis, the weighting factors are considered as w_1 = w_2= w_3=0.33 in which the three objectives are supposed to have equal importance,

4.1 Genetic Algorithm

The genetic algorithm exhibited many advantages over other algorithm. It has random solutions started with initial solutions with evaluation checking the fitness function and selected the fittest individual and then it exchanged the data with the fitness value and if there is the mutation then it produced the best optimal solution and vice versa with the mechanism. The Genetic algorithm for this paper started with the random selection of the data with the input range given as input which defined for the output in this case is the new switch position after radial configuration and optimum location of the bus and its sizing which is based on the maximum demand of the reactive load of the system. Then its primary objective is to selection of the best solution and then its crossover among the best data and then its mutation. If it's the best optimum solution, then its stopping

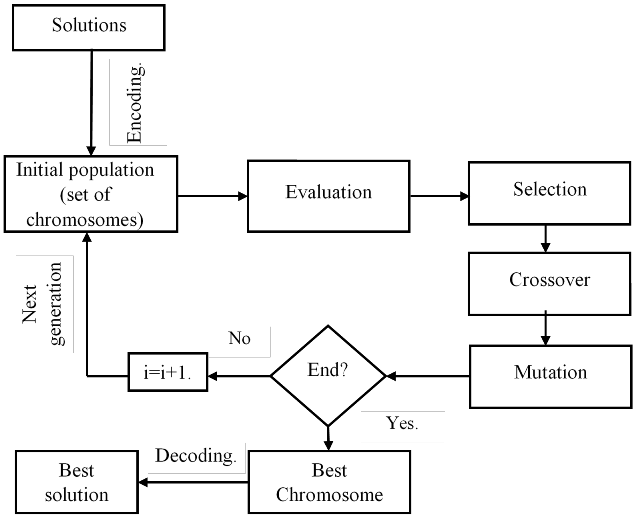

Figure 4: Genetic Algoritm Procedure

after certain conditions defined. The GA parameters used in this paper are population size:100, Generation: 200,mutation : 1,Stall gen limit:500 , time limit:300, Stall time limit:20 respectively.

5. Test Results and Discussion

The MATLAB based programming is elaborated in script environment that uses the described algorithm GA to generate the optimal switching configuration that minimizes the three single objective function. A standard IEEE-33 Bus radial distribution system is used as a test system to implement the described methodology. Different case scenario was analysed as the need for simultaneous reconfiguration advantages over other cases such as DSTATCOM only can be analysed and the need of DSTATCOM as it can be explained by the different five cases.

5.1 Case Scenario

The methodology is at first implemented to an IEEE-33 bus system as shown in figure 5. It is a 12.66kV 33 Bus system comprises of four different laterals, 32 line branches and 5 tie lines and one feeder. The total peak load of this test system is 3715 kW and 2300 kVAr. For the base configuration the open switches(tie lines) are $T_{33}, T_{34}, T_{35}, T_{36}, T_{37}$ which are represented by dotted lines.

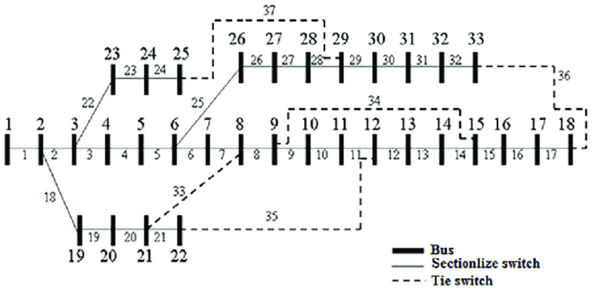

Figure 5: IEEE-33 Bus Radial Distribution System

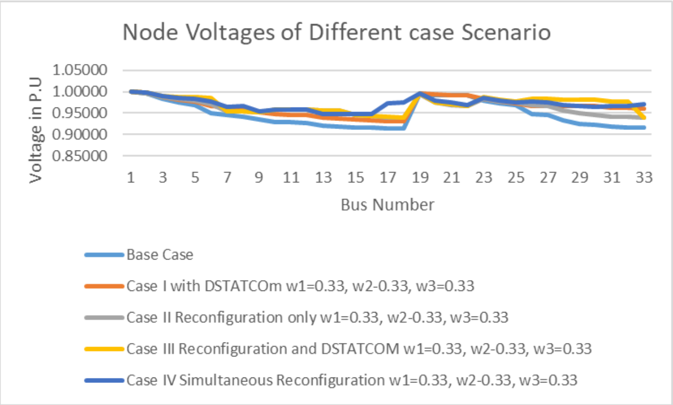

Figure 6: Node voltage of different case Scenario

Table 3 represents the Optimal Solution for IEEE-33 Bus system. It shows switches opened and other system parameters after different case scenarios considering power loss, Voltage Profile Index and Load Balancing Index as , as the objective function for different values of w_1, w_2 and w_3 . The weights w_1, w_2 and w_3 shows the relative importance and equal importance for the three objective function as it was tested on different weight age scale for different test results. The decrease in power loss , voltage profile index and Load Balancing Index considering Simultaneous reconfiguration with DSTATCOM as objective function is 37.51%, 43.97% and 22.14% respectively while considering reconfigured network with DSTATCOM Placement is 41.85%, 42.649% and 10.43% respectively in comparison to base case. Since, the objective is minimization the function and results show reduction in the considered parameters of the system hence, the selected process for Simultaneous reconfiguration with DSTATCOM is justified. Also,The decrease in power loss , voltage profile index and Load Balancing Index considering with DSTATCOM as objective function is 22.14%, 32.74% and 9.53% respectively while considering reconfigured network only is 29.53%, 28.50% and 5.91% respectively in comparison to base case. As from the results we can calculate the size and optimal Placement of DSTATCOM for different case scenario as for case I with only DSTATCOM Placement , it is at 30th bus and 1896.60 kVAR . So after different case analysis, it was noted that DSTATCOM Size gradually

Table 3: Output for Different Case

S.N.	Description	Weightage	At Bus No.	Minimum Voltage (pu)	Power Loss (kW)	Voltage Index	Load Balancing Index	Switches Opened
1	**Base Case**		**18**	**0.913092**	**202.6744**	**1.700922**	**65.698649**	**33,34,35, 36,37**
2	**CASE-I With DSTATCOM Only**	W1=1/3; W2=1/3; W3=1/3	18	0.931262	157.8062	1.143977	59.439973	
		% Change		1.99%	22.14%	32.74%	9.53%	
	DSTATCOM Sizing (kVAR)	**1896.608**						
	DSTATCOM Placement	**30th bus**						
3	**CASE-II Reconfiguration Only**	W1=1/3; W2=1/3; W3=1/3	33	0.938796	142.8274	1.216228	61.810906	6,14,9, 32 & 37
		% Change		2.82%	29.53%	28.50%	5.918%	
4	**CASE-III Reconfiguration with DSTATCOM**	W1=1/3; W2=1/3; W3=1/3	33	0.939293	117.8489	0.975489	58.846578	6,14,9, 32 & 37
		% Change		2.87%	41.853%	42.649%	10.43%	
	DSTATCOM Sizing (kVAR)	**1525.130**						
	DSTATCOM Placement	**30 th bus**						
5	**CASE-IV Simultaneous Reconfiguration with**	W1=1/3; W2=1/3; W3=1/3	13	0.946754	126.6537	0.953595	51.148459	**6,12,8, 16 & 37**
		% Change		**3.687%**	**37.51%**	**43.937%**	**22.147%**	
	DSTATCOM Sizing (kVAR)	**1216.656**						
	DSTATCOM Placement	**18th bus**						

decreasing with reconfigured network with DSTATCOM in comparison with base case.The Size and Optimal Placement of DSTATCOM for main objective function considering Simultaneous reconfiguration with DSTATCOM is at 18 th bus and 1216.565 kVAR respectively. From figure 6 it can be observed that after Simultaneous reconfiguration with DSTATCOM at few buses there will be increase in the minimum voltage and voltage profile improvement.

6. Conclusion

In this paper, different case scenario was analyzed considering reconfiguration and DSTATCOM Placement in the radial distribution system for the improvement of power quality indices such as power loss, voltage profile and load balancing Index . Reconfiguration of the network was done by branch exchange method and DSTATCOM placement was done based on the voltage constraint and sizing was calculated by the current supplied by the DSTATCOM for the improvement of the voltage and based on that different case was analyzed for the impacts of their objective functions and their relative importance on the main objective function The minimization of objective function problem is solved by using GA algorithm in script environment of MATLAB software. The equal weights assigned provided the best improvement in the system as different weight value was evaluated. The performance of proposed technique is tested in IEEE-33 bus network . The test results shows that after reconfiguration and DSTATCOM Placement only separately, there is slight improvement in total power loss, voltage profile and load balancing of the system. However, the best result is obtained with the Simultaneous reconfiguration with DSTATCOM, there is admirable improvement in total power loss, voltage profile and load balancing of the system with DSTATCOM sizing even less than standalone DSTATCOM placement.

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