Instantaneous Allocation of DG and DSTATCOM for Loss Reduction and Voltage Profile Enhancement in Radial Distribution Network

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Abstract— In the entire power system maximum power losses are occurring on the distribution system side. In a Radial Distribution System (RDS), maintaining the required voltage profile is a difficult task due to its rugged and irregular structure. Moreover, the power demand is increasing day-by-day with reducing fossil fuel availability, and also huge environmental pollution occurs while generating electrical energy by conventional methods. Usage of tiny Distributed Energy Resources such as wind, solar PV, and biomass at the load side reduces power losses and pollution to a minimum value. To improve the voltage profile DSTATCOM can be used. Optimal placement of Distributed Generator and DSTATCOM is very essential for their effective functioning in reducing power losses and improving voltage profile. This paper proposes a code in C language for finding the best location of DG and DSTATCOM in an RDS by using the Direct Load Flow technique for load flows and Stability Index factor for finding an optimal location. This methodology is tested on IEEE-9, IEEE-15, and IEEE-33 bus RDS.

Index Terms**— Radial Distribution System, Distributed Generator, DSTATCOM, Direct Load Flow, Stability Index.**

I. INTRODUCTION

The major generation of power in India is through non-renewable energy resources. Nowadays renewable energy sources gaining high attention throughout the world to overcome several environmental issues such as pollution increase in global warming etc. As non-renewable energy reserves are being under extinction, renewable energy resources usage has to be increased to meet the ever-increasing power demand in daily life. The major available renewable resources, PV system, wind turbine system, biomass, etc., cannot be used as base loads as their efficiency is low and lack availability throughout the day. In addition, the drawback with these DG sets is their intermittent nature because of various factors such as stability and weather conditions. To use these resources efficiently the Micro-grid concept came into the scenario. DGs are connected at different PQ buses of a bus system. The loads receive power from centralized power stations as well as from these DGs. These DGs are directly connected with the energy storage devices such as capacitors, batteries, etc. to increase efficiency. Thus, DG reduces the power demand to the central power station. By replacing non-renewable energy resources this DG is not only meeting the load requirements but also reducing the pollution and active, reactive power losses. These DGs are also helpful in supplying power to remote areas where there is no provision of transmission of power.

The major problem in the radial distribution system is the reduction of voltage profile at the end consumer and the power loss at each bus. In the distribution system, the DG should be placed near the load such that it enhances the quality of the system. The economical operation and minimized overall loss of the Distribution Network (DN) can be achieved by allocation of DG sources at appropriate bus locations. Even though DG sources are important, the design and operation of DN involving DG are of critical concern for the system planners.

Fahad Iqbal et al have explained the loss reduction and $V_{improve}$ by considering the factors loss LSF and VPI for appropriate allocation of DG and DSTATCOM [1]. A. Parizad et al have proposed the voltage stability and losses indices for the best location of Distribution Generation for reduction of losses in the distribution system [2]. C. Divya et al have illustrated the optimum location of multiple Distribution Generations using a sensitivity analysis approach for loss reduction and enhancement of voltage profile [3]. F. Peng et al have derived an operational methodology for micro-grid cooperated with DN based on Demand Response (DR) when a Distribution Generation is placed in the distribution system [4]. G.Kalidas et al [2015] have explained the mathematical modeling and load flow analysis of 9 bus RDS by using the BFSLF algorithm [5]. Marcelo Cortes Carmona et al have proposed the algorithm for the power flow analysis of Distribution Networks including Distribution Generation [6]. M. Natarajan et al [2015] have illustrated the best possible apportionment and sizing of DG's using the CABC algorithm in DN for the minimization of losses and improving the voltage stability in the distribution system [7]. Riteik Majumder et al have explained the stability enhancement and power-sharing of an independent micro-grid with non-inertial and inertial DGs with DSTATCOM [8]. Taiseer Tuffaha et al have derived the security evaluation of an MG distribution system with a solar photovoltaic and storage system [9]. T. Ramana et al have illustrated the direct and easiest power flow solution for electrical power DN [10]. The investigation on a new approach for optimal sitting and sizing of DSTATCOM for reducing the power losses in the Distribution

System using optimization techniques was illustrated [11]. The minimization of power loss, total voltage deviation, and voltage stability index was considered as the objective using Lightning Search Algorithm. In this, the variation of feeder load was considered as a 1% change from light load to full load [12]. The factor considers for installing the DSTATCOM in the respective place of the bus, the voltage stability index was considered. IEEE 33 and IEEE 69 bus Radial Distribution Network was considered for analysis and the test results were compared with Immune Algorithm [13].B. Singh and D. Kumar have illustrated the detailed survey for enhancing the power transfer capability in Distribution Network by placing DG optimally. The four different types of DG were considered which also work with various power factors. In this, the reliability and security of the system, loadability CAIDI, SAIDI, short circuit current capacity, voltage profile improvement, etc were considered [14].

The mathematical model for flexible variant-based Differential Search (DS) algorithm to determine the optimal location and sizing of multiple DG optimally. In addition to this, the cost component for real power and energy losses were considered [15]. A brief overview of the optimal sitting and sizing of multi-type FACTS devices using metaheuristic techniques in power system were discussed. The location and types of FACTS device utilized was selected optimally [16]. The reconfiguration of DN by changing the status of sectionalizing switches to reduce the power loss and improve the voltage profile in steady-state conditions [17]. The solar PV, wind, and biomass were optimally placed in DN to reduce the losses but here the fulfillment of reactive power for the network was not considered which leads to the under-voltage problem [18]. Indian rural electrification (28 bus) was considered as the test case and the location of DSTATCOM based on voltage stability index and sizing was identified using the Whale Optimization Algorithm (WAO)[19]. The reactive power compensation was done on various buses on IEEE 33 bus RDN to improve the voltage profile using effective techniques and results were verified with the PSO algorithm [20]. In this paper different objective functions P_{loss}, Voltage Deviation (VD), and stability are majorly considered for the DG placement. In DG the major proportion of the load is inductive in nature which causes increased P_{loss} and enhanced VD. Hence mention issues can be achieved by appropriate allocation of DSTATCOM.

In this paper, the installation of DG and DSTATCOM is based on P_{loss} and Voltage profile Improvement ($V_{improve}$) by utilizing the various factors like Loss Sensitivity Factor (LSF), Fast Voltage Stability Index (FVSI), Voltage profile index (VPI), Line Utilization Factor (LUF), Stability Index (SI).

II. DIRECT LOAD FLOW METHOD

As mentioned earlier the major losses are in the distribution system. There are different configurations in distribution systems like the radial, ring, doubly-fed distribution systems. Among these RDS is mostly used because of its rugged structure and low economic nature. Due to the low X/R ratio and irregular structure Distribution Load Flow techniques are used like Ladder Network Method, Adaptive Newton-Raphson method, Direct Load Flow method. Therefore, the DLF method is considered in this paper due to its simple and adaptive nature for complex bus systems including DG, DSTATCOM considerations. Let's view this method in terms of IEEE 33 bus RDS.

At bus 'i' the complex load S_i can be written as following,

$$S_i = P_i + Q_i \quad (1)$$

Where i = 1, 2, 3 ...n.

Where n denotes the total number of buses P_i denotes i^{th} bus active power, Q_i denotes i^{th} bus reactive power.

The current at the i^{th} bus is given as follows,

$$i_i = \left(S_i / V_i \right)^C \quad (2)$$

Where V_i denotes voltage at the i^{th} bus.

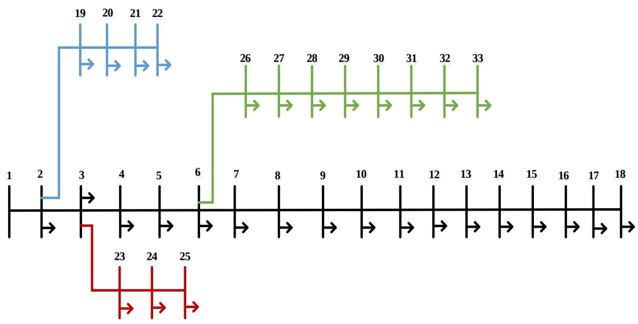

Figure 1. IEEE 33 bus RDS

The current injection matrix can be obtained by computing the currents at all buses using (2). The Branch Current to Bus Injection (BIBC) matrix can be obtained by applying KCL in the given system and the bus injected currents for IEEE 33 bus RDS are as follows as per Figure 1.

$$B_1 = i_1 + i_2 + \ldots\ldots\ldots + i_{15} + i_{16} + i_{17} + i_{18} + \quad + i_{30} + i_{31} + i_{32}$$

$$B_{10} = i_{10} + i_{11} + \quad + i_{17}$$

B22 = i22 + i23 + i24 $B_{25} = i_{25} + i_{26} +$ $+ i_{32}$

$B_{18} = i_{18} + i_{19} + i_{20} + i_{21}$ (3)

The relationship between I_{branch} currents and I_{bus} current injections is expressed in the following equation,

$$[B] = [BIBC]\,[i] \quad (4)$$

Where BIBC = Bus Injections to Branch Currents matrix.

The Bus Injection to Bus Voltage matrix (BCBV) is given by,

$$[BCBV] = [BIBC]^T Z \quad (5)$$

Where Z = diag (Z_b) and Z_b = Branch impedance matrix.

The iterative change in voltages for each bus is given by matrix as,

$$[\Delta V] = [BCBV]\,[BIBC]\,[i] \quad (6)$$

The DLF can be calculated as,

$$[DLF] = [BCBV]\,[BCBI] \quad (7)$$

From the equation 6,

$$[\Delta V] = [DLF]\,[i] \quad (8)$$

The voltage for next iteration is given by,

$$[V^{c+1}] = [V_0]-[\Delta V^{c+1}] \quad (9)$$

Where c is iteration count and V0 is initial voltage.

The tolerance criterion is checked by the following equation,

$$\Delta i_i = i_i^c - i_i^{c-1} < \varepsilon \quad (10)$$

Where ε is the tolerance value, when equation 10 satisfies at every bus then the values can be finalized without further iterations. The active and reactive power losses are given by,

$$P_{j,loss} = \left(\frac{\left(P_j^2 + Q_j^2\right) R_{ij}}{V_j^2} \right) \quad (11)$$

$$Q_{j,loss} = \left(\frac{\left(P_j^2 + Q_j^2\right) X_{ij}}{V_j^2} \right) \quad (12)$$

Where

P_i = Total real power delivered at node 'j'

Q_i = Total reactive power delivered node 'j'

R_{ij} = ij^th bus resistance.

X_{ij} = ij^th bus reactance.

P_i = (BIBC) x (P_{RLPM})

Q_i = (BIBC) X (Q_{RLPM})

P_{RLPM} = Active power matrix of the system.

Q_{RLPM} = reactive power matrix of the system.

III. PROBLEM FORMULATION

3.1 DG Sizing

The DG size is calculated iteratively. Considering DG size to a minimum value real and reactive power losses of the system are determined. Increasing DG size step-wise the losses of the system are determined at each size of DG. The final size of DG is considered such that the system has maximum reduced active and reactive power losses.

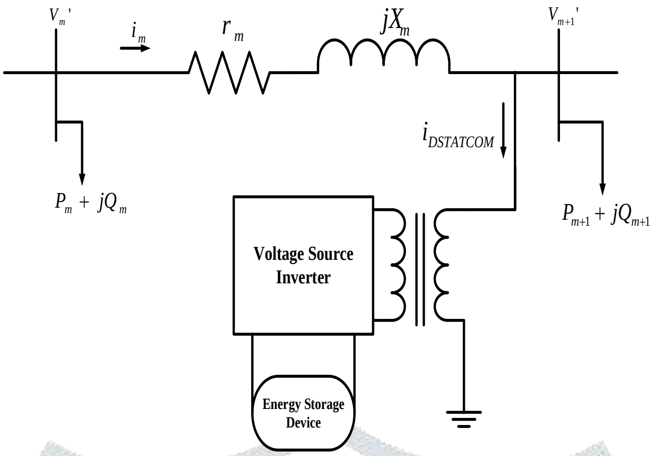

Figure 2. Two bus representation with DSTATCOM [1]

DSTATCOM is a shunt-type FACTS device that absorbs or injects the reactive power from the mainline or to the mainline respectively in the Distribution System. It is a very quick process, precise, and has a wide controlling area as the DSTATCOM is made up of the energy storage device and power electronic devices which have fast response.

Generally, the furthermost of the distribution systems are represented in RDS and the power is supplied from one end to the other end. Figure 2 illustrates the connection of DSTATCOM in the position of $m+1$. Where R_m symbolizes the resistance of the line and X_m symbolizes the reactance of the line between 'm' and $m+1$ buses respectively. Similarly, P_m+jQ_m and $P_{m+1}+jQ_{m+1}$ are the confined loads related to buses m and $m+1$. Likewise, the voltages at buses 'm' and 'm+1' are represented as V_m and V_{m+1}. Normally in the conventional RDS, voltages at the buses are defined at the values of less than 1 p.u. Let us assume that the bus 'm+1' is under voltage and the DSTATCOM is placed to make its voltage equal to 1 p.u. The expressions for modeling DSTATCOM are given in [1].

Here two objective functions are created considering different factors for the best location of DG and DSTATCOM.

$$F_{1i}=W_1 (PLSF+QLSF) + W_2 (VPI_i) + W_3 (FVSI_i) \quad (13)$$

Where

PLSF = Active Power Loss Sensitivity Factor

QLSF = Reactive Power Loss sensitivity Factor

VPI = Voltage Profile Index

FVSI = Fast Voltage Stability Index

F_{2i} represents the 2nd objective function includes the stability index alone.

$$F_{2i}=SI_i \quad (14)$$

Where

SI = Stability Index

1. Loss Sensitive Factor

$$P_{LOSS,i} = (P_i^2 + Q_i^2)\frac{R_{ij}}{V_i^2} \quad (15)$$

$$Q_{LOSS,i} = (P_i^2 + Q_i^2)\frac{X_{ij}}{V_i^2} \quad (16)$$

Where

P_i = Real power delivered to the jth node

Q_i = Reactive power delivered to the jth node

R_{ij} = Resistance of ijth bus

X_{ij} = Reactance of ijth bus

2. Voltage Stability Index

$$VSI_{ij} = \frac{4Z_{ij}^2 Q_j}{V_i^2 X_{ij}} \quad (17)$$

3. Voltage Profile Index

$$VPI = \frac{V_i}{V_{ref}} \quad (18)$$

Where

V_i = ith bus voltage

V_{ref} = reference bus voltage

4. Stability Index

$$SI = 4R_i \frac{(P_i^2 + Q_i^2)}{V_i^2 P_i} \quad (19)$$

IV. Results and Discussion

4.1 IEEE 9 Bus RDS

The base voltage considered for this system is 23kV. The total active and reactive power losses before placing DG are 703.608 kW and 909.577 kvar respectively. After running the code in C language using IDE compiler the optimal placement of DG results at 9th Bus with a size of 3700 kW. After placing DG at 9th Bus the total active and reactive power losses are reduced to 210.396 kW and 336.075 kvar respectively as shown in Figure 3. The voltage profile of the system without and with DG is as follows. As the voltage profile is as per the requirement after placing DG and due to heavy load ratings, DSTATCOM is not placed in IEEE 9 bus RDS.

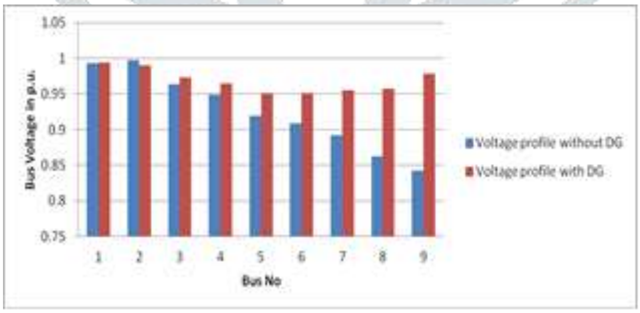

Figure 3. Voltage profile of IEEE 9 BUS RDS

4.2 IEEE 15 Bus RDS

The base voltage considered for this system is 11 kV. The total active and reactive power losses before placing DG are 56.103 kW and 51.344 kvar respectively. For this system, the optimal placement of DG is found to be at bus 6 with a size of 600 kW. The active and reactive power losses are reduced to 46.255 kW and 40.828 kvar respectively. The DSTATCOM size is found to be 139.641 kvar.

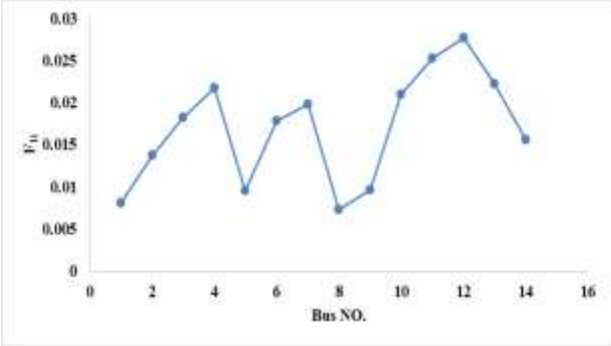

Figure 4. Optimal placement of DG from the 1st objective function is at bus '12'

After placing both DG and DSTATCOM the active and reactive power losses are 36.529 kW and 33.215 kvar respectively and the results of the objective functions are shown in Figure 4 and Figure 5.

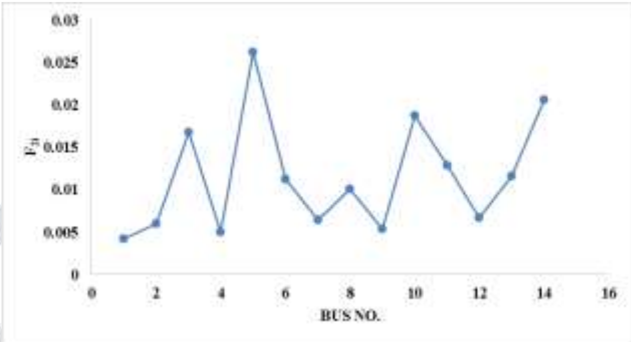

Figure 5. Optimal placement of DG from the 2nd objective function is at bus '5'

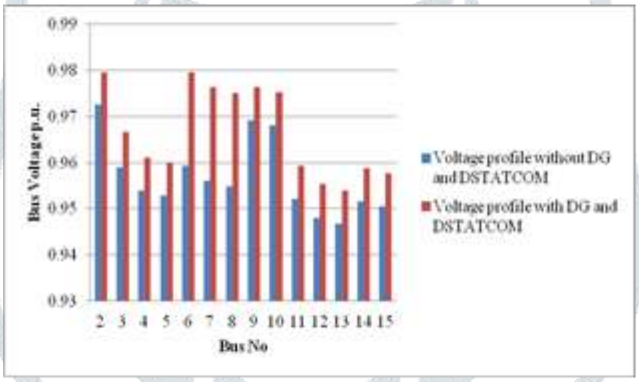

Figure 6 (a). Voltage profile of IEEE 15 bus System

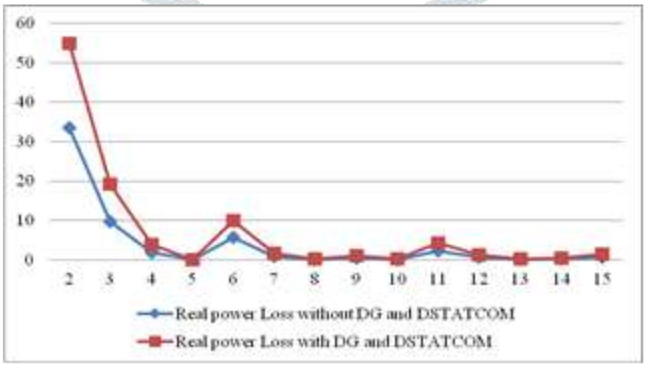

Figure 6 (b). Active power losses of IEEE 15 bus RDS

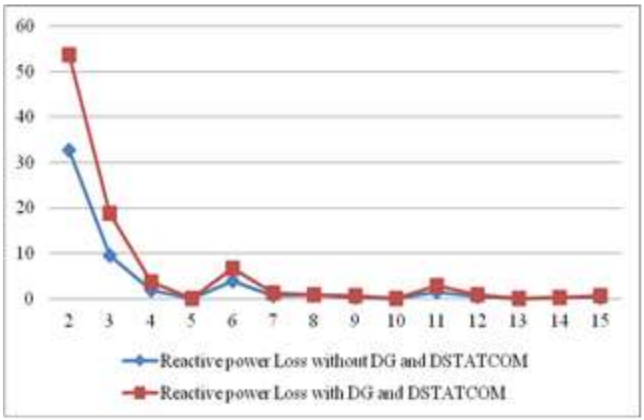

Figure 6 (c). Reactive power losses of IEEE 15 bus RDS

The voltage profile, active power (P) loss, and reactive power (Q) losses of IEEE 15 bus network with and without DG based combined objective function as shown in Figure 6 (a), (b), and (c) corresponding to Series 1-without DG and Series 2-with DG.

4.3 IEEE 33 Bus RDS

For the 33 bus system, the base voltage is considered as 12.6 kV. Earlier placement of DG and DSTATCOM, the total active and reactive power losses are 199.04 kW and 134.53 kvar respectively. The best location of DG is found to be bus 30 with a size of 1500 kW. Once the DG is placed, the reduced P and Q losses are 119.954 kW and 84.597 kvar respectively. The size of DSTATCOM is found to be the value of 1858.56 kvar. With the effect of both DG and DSTATCOM placement, the reduced active and reactive power losses are 80.935 kW and 60.512 kvar respectively.

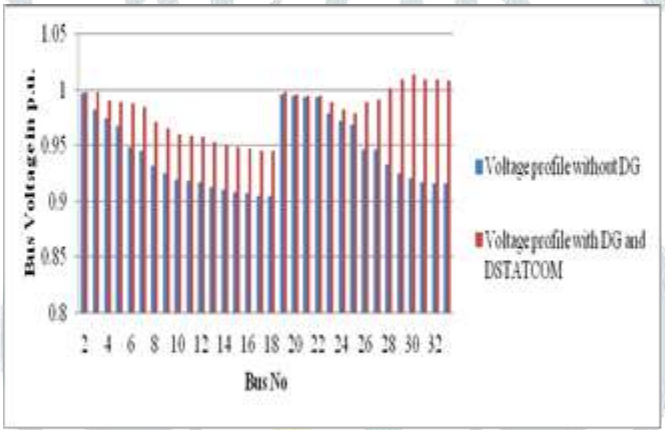

Figure 7. Voltage Profile of IEEE 33 Bus RDS

The voltage profile of the system without DSTATCOM and DG, with DG and both DSTATCOM and DG, is as shown in Figure 7. The P and Q power losses of the IEEE 33 bus system are shown in Figure 8.

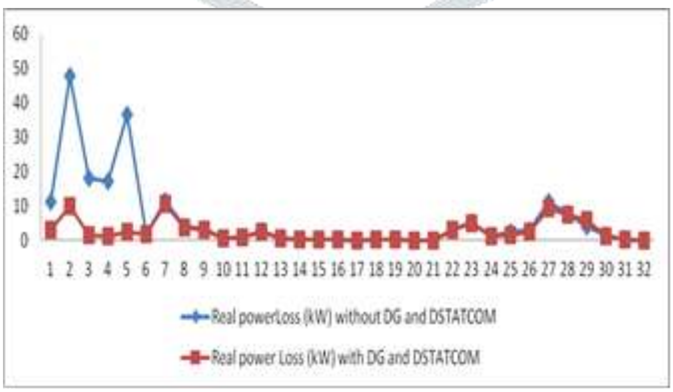

Figure 8 (a). Active power losses of IEEE 33 bus RDS

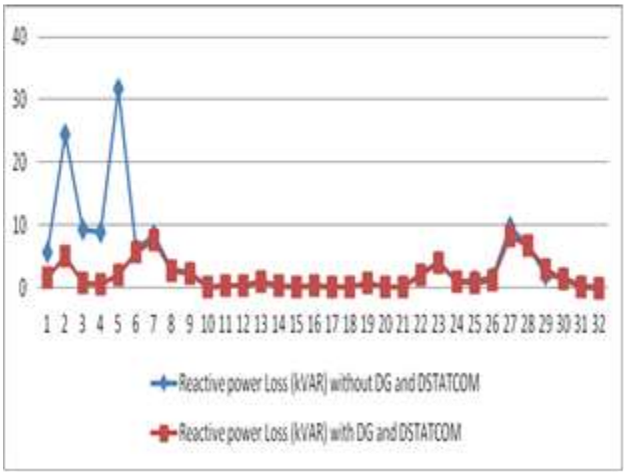

Figure 8 (b). Reactive power losses of IEEE 33 bus RDS

The active and reactive power losses for IEEE 9 Bus, IEEE 15 Bus, and IEEE 33 Bus RDS are compared without DSTATCOM and DG, with DG alone and with DG and DSTATCOM in Figure 7 and Figure 8 (a), (b) respectively. The comparison of losses in the above test cases before and after installation of DG and DSTATCOM is shown in Tables I, II, and III.

Table 1 IEEE 9 Bus RDS Losses

DG/DSTATCOM	IEEE 9 BUS		DG Size (KW) (Bus No.)	DSTATCOM (kvar) (Bus No.)
	P_{Loss} (KW)	Q_{Loss} (kvar)		
Without DG and DSTATCOM	703.608	909.57	-	-
With DG (F1)	210.396	336.075	3700 (9)	-

Table 2 IEEE 15 Bus RDS Losses

DG/DSTATCOM	IEEE 15 BUS		DG Size (KW) (Bus No.)	DSTATCOM (kvar) (Bus No.)
	P_{Loss} (KW)	Q_{Loss} (kvar)		
Without DG and DSTATCOM	56.1503	51.344	-	-
With DG (F1)	46.255	40.828	400 (12)	-
With DG (F2)	42.279	38.286	600 (5)	-
With DG and DSTATCOM	36.529	33.215	600 (5)	139.641 (5)

Table 3 IEEE 33 Bus RDS Losses

DG/DSTATCOM	IEEE 33 BUS		DG Size (KW) (Bus No.)	DSTATCOM (kvar) (Bus No.)
	P_{Loss} (KW)	Q_{Loss} (kvar)		
Without DG and DSTATCOM	199.04	134.53	-	-
With DG	119.954	84.597	1500	-
With DG and DSTATCOM	80.936	60.512	1500	1858.56

V. CONCLUSIONS

This paper proposes a code in C language with IDE compiler for finding the best location and sizing of DSTATCOM and DG in RDS. The direct Load Flow method was used for calculating load flows. Loss Sensitivity Factor, Fast Voltage Stability Index, and Voltage Profile Index are used to frame the first objective function of the placement of DG and DTATCOM. Stability Index is used for framing the second objective function of the placement of DG and DTATCOM. Out of these two objective functions, the second objective function provides better results. Therefore, Stability Index is considered for the best location of DSTATCOM and DG. The same Objective function is used for placing both DG and DATACOM as placement of DG and DSTATCOM at the same bus is more effective. The DG is size calculated by an iterative process. The DSTATCOM rating is calculated from DSTATCOM modeling. By the location of DG and DSTATCOM in the test cases as per the result, gives better results in reducing true and reactive power losses and also enhancing the voltage profile.

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