Chapter 5

OPTIMAL DG ALLOCATION AND RECONFIGURATION CONSIDERING TIME-VARYING VOLTAGE DEPENDENT LOAD

5.1 INTRODUCTION

This chapter presents a methodology of network reconfiguration (NR) and optimal distribution generation (DG) allocation under time-varying voltage dependent loads in a distribution network. DG is placed optimally at the location determined by calculating the sensitivity index based on power loss. The technique of modified Grey Wolf Optimization is performed for calculating the optimal size of DG as well as switches to be opened and closed. In this work, two different types of time-varying voltage dependent loads are considered, one is residential summer night loads (RL) and the other is electric vehicle (EV) type loads. There are two prominent objectives of the proposed methodology, first, real power loss reduction and, second, to improve the voltage profile of the system within the permissible voltage limits. Present work has considered placement of Type-3 DG that injects both real as well as reactive power. Two cases have been investigated –(i) system with optimally placed DG but no reconfiguration and (ii) reconfigured network under optimally placed DG. Investigations have been carried out on IEEE 33-bus and 69-bus systems.

5.2 LOAD MODEL

In this work voltage dependent hourly time-varying loads [196] have been considered. Voltage dependent real power demand at bus-i ($P_{load,i}$) and reactive power demand at bus-i ($Q_{load,i}$) have been expressed as:

$$P_{load,i} = P^0_{load,i} V_i^{pr} \quad (5.1)$$

$$Q_{load,i} = Q^0_{load,i} V_i^{qr} \quad (5.2)$$

where,

$P^0_{load,i}$ and $Q^0_{load,i}$ denote the values of real power load and reactive power load at nominal voltage, respectively.

V_i denotes the voltage magnitude at bus-i.

pr and qr denote exponent of voltage magnitude V_i for real and reactive power load, respectively. Present work has considered exponent pr and qr as 2.59 and 4.06, respectively for Electrical Vehicle loads [197], [198] and 0.92 and 4.04, respectively, for residential summer night loads [196].

A typical normalized load profile for its variations during 24 hours period is shown in Figure 5.1 [199]. This pattern has been considered for variations of loads $P_{load,i}$ and $Q_{load,i}$ for both residential summer night load and electric vehicle type load in this work. Static voltage dependent loads obtained as per (5.1) and (5.2) have been multiplied with a factor corresponding to pu load shown in Figure 5.1 to represent time-varying residential summer night as well as EV loads for 24 hours duration.

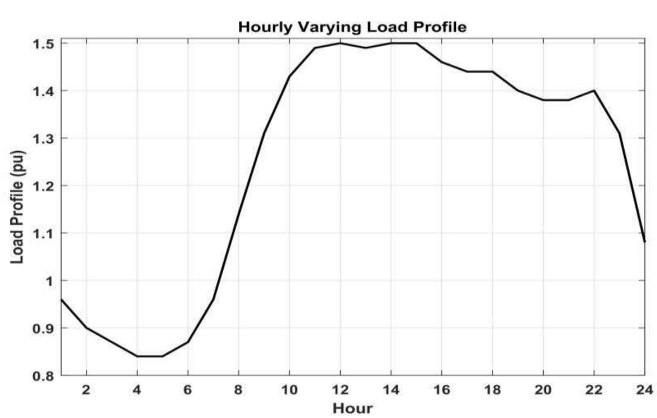

Figure 5.1: Load profile of hourly varying load [199].

5.3 COLLECTIVE POWER LOSS SENSITIVITY

In this work, a collective sensitivity (CS) index [200], [201] is obtained to determine the potential bus for DG unit placement. The sensitivity index helps in finding the most suitable bus and reduces the search space and computational burden of optimizer for DG location determination. The loss sensitivity of each system bus is obtained by differentiating the system's complex power loss ($\bar{S}_L$) with respect to active power injection and reactive power injection at that bus. Differentiating ($\bar{S}_L$) with respect to real power injection, P_j at bus-j and reactive power injection, Q_j at bus-j, real and reactive power loss sensitivity for a radial distribution network are obtained as [200], [201]:

$$\frac{\partial P_L}{\partial P_j} = \frac{2P_j R_j}{V_j^2} \tag{5.3}$$

$$\frac{\partial Q_L}{\partial P_j} = \frac{2P_j X_j}{V_j^2} \tag{5.4}$$

$$\frac{\partial P_L}{\partial Q_j} = \frac{2Q_j R_j}{V_j^2} \tag{5.5}$$

$$\frac{\partial Q_L}{\partial Q_j} = \frac{2Q_j X_j}{V_j^2} \tag{5.6}$$

where, $\frac{\partial P_L}{\partial P_j}$ = Sensitivity of real power loss w.r.t. real power injection at bus-j

$\frac{\partial Q_L}{\partial P_j}$ = Sensitivity of reactive power loss w.r.t. real power injection at bus-j

$\frac{\partial P_L}{\partial Q_j}$ = Sensitivity of real power loss w.r.t. reactive power injection at bus-j

$\frac{\partial Q_L}{\partial Q_j}$ = Sensitivity of reactive power loss w.r.t. reactive power injection at bus-j

R_j = Resistance of branch incident at bus-j

X_j = Reactance of branch incident at bus-j

V_j = Voltage magnitude at bus-j

Collective power loss sensitivity CS_j is given by,

$$CS_j = \left|\frac{\partial P_L}{\partial P_j}\right| + \left|\frac{\partial Q_L}{\partial P_j}\right| + \left|\frac{\partial P_L}{\partial Q_j}\right| + \left|\frac{\partial Q_L}{\partial Q_j}\right| \quad (5.7)$$

The collective power loss sensitivity is calculated for each bus. The bus with highest collective sensitivity is selected as the most suitable location for DG unit placement. Present work has considered placement of Type-3 DG at power factor of 0.82 considering it as optimal power factor [202].

5.4 PROBLEM FORMULATION: OBJECTIVE FUNCTION AND CONSTRAINTS

Present work has considered minimization of a new multi-objective function for the reconfigured distribution network under DG placement. The DG location has been obtained by collective sensitivity based analytical approach given by (5.7), and then optimal DG size is calculated by modified GWO optimization using the new multi-objective function formulated in this section. Once the DG location and size is obtained it has been installed in the system at their optimal location with their appropriate size obtained. Further, network reconfiguration is performed to achieve the additional improvement in multi-objective function in the presence of optimal DG solution obtained. The optimization has been performed using modified grey wolf optimization approach. The new multi-objective function is formulated below.

5.4.1 Proposed new multi-objective function

Proposed new multi-objective function considers minimization of real power loss and minimization of voltage deviations from minimum and maximum voltage limits as given below.

$$\text{minimize}\, h = \sum_{i=1}^{b} sw_i[I_i^2 R_i] + \sum_{i=1}^{nb} |(V_i - V_{min})| + \sum_{i=1}^{nb} |(V_i - V_{max})| \qquad (5.8)$$

where,

sw_i denotes the switch status of the branch.

I_i is the magnitude of current through branch-i.

R_i denotes the resistance of branch-i.

V_i denotes the voltage magnitude of the bus-i.

V_{min} and V_{max} represent minimum and maximum voltage limit, respectively. Present work has considered V_{min} and V_{max} as 0.95 pu and 1.05 pu, respectively, considering ±5% as permissible voltage variations.

h is normalized with respect to their base value at corresponding load multiplier as per Figure 5.1.

The new index considers both the real power loss reduction and voltage profile to be well within the permissible maximum and minimum voltage limits. The new multi-objective function given by (5.8) have been minimized sequentially first by DG unit placement and then by performing network reconfiguration under set of equality and inequality constraints defined in Section 2.5.2 (chapter 2) and Section 2.5.3 (chapter 2), respectively, and satisfying radiality constraint given by (3.4) and (3.5) in chapter 3.

Generally, the distribution network consists of a mix of residential, industrial and commercial types of loads. These may have variable load patterns with respect to time. So, the system may be heavily loaded at one point in time but lightly loaded at some other time. In such a situation, load scheduling by network reconfiguration may ensure the optimal performance of the system thereby minimizing the system real power loss and improving the voltage profile. Network reconfiguration may be helpful in smoothening peak demand which in turn improves the voltage profile and thereby increases the overall reliability of the system.

Once the DG location using sensitivity approach (5.7) is obtained, the optimization is performed to evaluate the optimal size of Type-3 DG to minimize the objective function given by (5.8). Further reduction in power loss and improvement in voltage profile have been done through network reconfiguration in the presence of optimally placed Type-3 DG.

Figure 5.2 shows the flowchart that lists out the steps to be followed to achieve the proposed objectives.

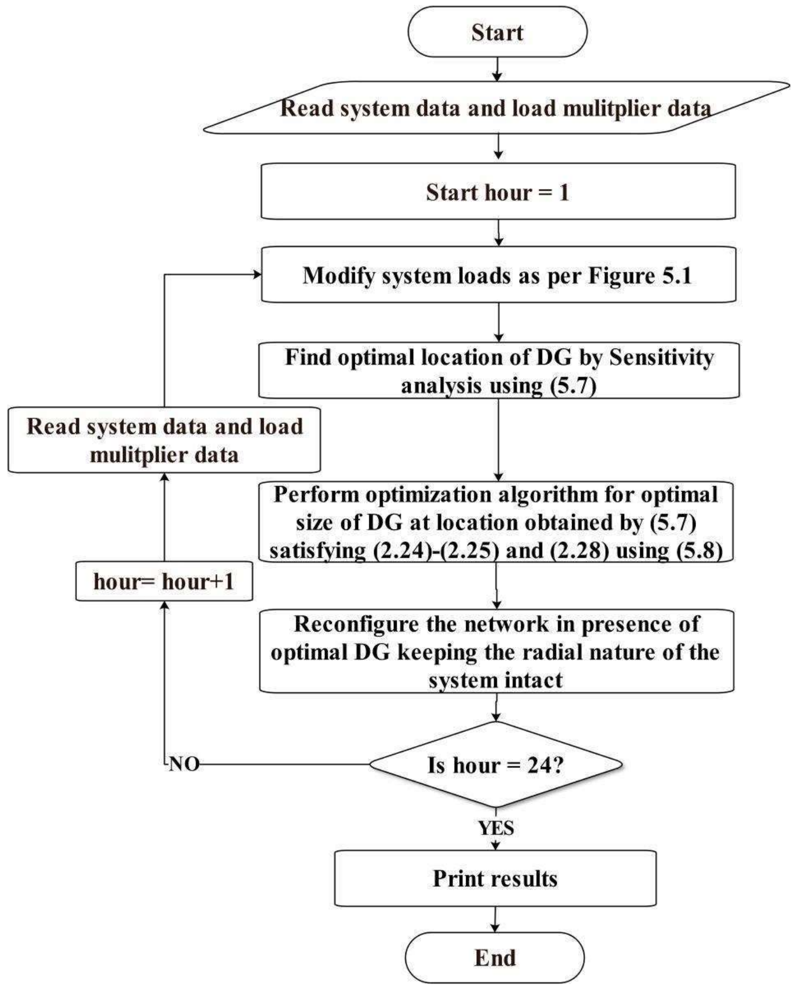

Figure 5.2: Flowchart for DG placement and network reconfiguration

5.5 RESULTS AND DISCUSSION

To validate the effectiveness of the proposed algorithm, numerical simulation is accomplished on IEEE 33-bus [126] and 69-bus [58] reconfigurable distribution systems. The details of the two systems under consideration are presented in Appendix A and B, respectively. It was observed that network reconfiguration after optimal placement of DG resulted in encouraging results. This work has been carried out for two different types of loads. One is residential summer night load (RL) and the other is electric vehicle (EV) type of loads. The results obtained for the two test systems with both the types time varying voltage dependent loads are discussed below.

5.5.1 Test system 1 (33-bus RDS)

Simulations were carried out for two types of load considered in this chapter viz. residential summer night load and electric vehicle load. It is quite interesting to note that for 33-bus RDS the collective sensitivity analysis results bus-6 as an optimal location of DG to be placed for both types of load model considered. Moreover, DG location found remains same for hourly load pattern of entire 24 hours duration.

5.5.1.1 *For Residential Summer Night Loads*

Table 5.1 presents the hourly results of varying residential summer night loads for 33-bus RDS. This Table consists of base case real and reactive power loss, and minimum system voltage for every hour before DG allocation and network reconfiguration. The optimal DG size is obtained and presented performing optimization using modified GWO at each hour considering DG placed at bus-6. Thereafter, optimal reconfiguration of the network is obtained through rule based fundamental loop analysis that resulted in opening of switches associated with lines 11, 13, 32, 33, and 37. Table 5.1 also presents the real and reactive power losses and minimum system voltage under optimal DG placement followed by network reconfiguration. Percentage reduction in real and reactive power losses under DG placement followed by network reconfiguration has also been shown in Table 5.1 for each hour of 24 hours period considered. It is observed from Table 5.1 that DG placement followed by network reconfiguration through proposed approach results in quite a large reduction in real and reactive power losses and significant enhancement in system minimum voltage for the whole duration of 24 hours period considered in this work.

Table 5.1: Results of system with hourly varying residential summer night load for 33-bus RDS

Hourly results for RL load of 33-bus RDS with opened switches (11, 13, 32, 33, 37)									
Hour	**Type-3 DG size (MVA) at 0.82 pf**	**Real power loss (kW)**			**Reactive power loss (kVAr)**			**Minimum voltage**	
		BC*	**RDG***	**%Red***	**BC***	**RDG***	**%Red***	**BC***	**RDG***
1	2.7465	147.34	46.57	68.39	97.89	37.97	61.21	0.9263	0.9755
2	2.5799	130.17	41.03	68.48	86.49	33.45	61.32	0.9307	0.9771
3	2.4965	121.96	38.38	68.53	81.03	31.30	61.38	0.9329	0.9778
4	2.4129	114.00	35.82	68.58	75.75	29.21	61.44	0.9352	0.9786
5	2.4129	114.00	35.82	68.58	75.75	29.21	61.44	0.9352	0.9786
6	2.4965	121.96	38.38	68.53	81.03	31.30	61.38	0.9329	0.9778
7	2.7465	147.34	46.57	68.39	97.89	37.97	61.21	0.9263	0.9755
8	3.2422	204.71	65.24	68.13	135.98	53.19	60.88	0.9132	0.9709
9	3.7058	266.78	85.63	67.90	177.17	69.80	60.60	0.9009	0.9666
10	4.0302	315.10	101.61	67.75	209.25	82.82	60.42	0.8924	0.9635
11	4.1917	340.64	110.09	67.68	226.20	89.72	60.33	0.8881	0.9620
12	**4.2185**	**344.99**	**111.53**	**67.67**	**229.08**	**90.90**	**60.32**	**0.8874**	**0.9617**
13	4.1917	340.64	110.09	67.68	226.20	89.72	60.33	0.8881	0.9620
14	**4.2185**	**344.99**	**111.53**	**67.67**	**229.08**	**90.90**	**60.32**	**0.8874**	**0.9617**
15	**4.2185**	**344.99**	**111.53**	**67.67**	**229.08**	**90.90**	**60.32**	**0.8874**	**0.9617**
16	4.1111	327.76	105.81	67.72	217.64	86.24	60.38	0.8902	0.9628
17	4.0572	319.29	103.00	67.74	212.03	83.95	60.41	0.8917	0.9633
18	4.0572	319.29	103.00	67.74	212.03	83.95	60.41	0.8917	0.9633
19	3.9493	302.67	97.49	67.79	201.00	79.46	60.47	0.8945	0.9643
20	3.8953	294.52	94.79	67.81	195.59	77.26	60.50	0.8959	0.9648
21	3.8953	294.52	94.79	67.81	195.59	77.26	60.50	0.8959	0.9648
22	3.9493	302.67	97.49	67.79	201.00	79.46	60.47	0.8945	0.9643
23	3.7058	266.78	85.63	67.90	177.17	69.80	60.60	0.9009	0.9666
24	3.0776	184.62	58.68	68.21	122.64	47.84	60.99	0.9175	0.9725

* BC: Base case, RDG: reconfiguration followed by DG, %Red: % Reduction

5.5.1.1.(i) Power injected by DG

Figure 5.3 presents the power injected at each hour by the DG unit for the residential summer night load. It is pertinent to note from Table 5.1 and Figure 5.3 that the maximum size of the DG unit obtained for this type of load is 4.2185 MVA at peak load hours (load hours 12th, 14th and 15th).

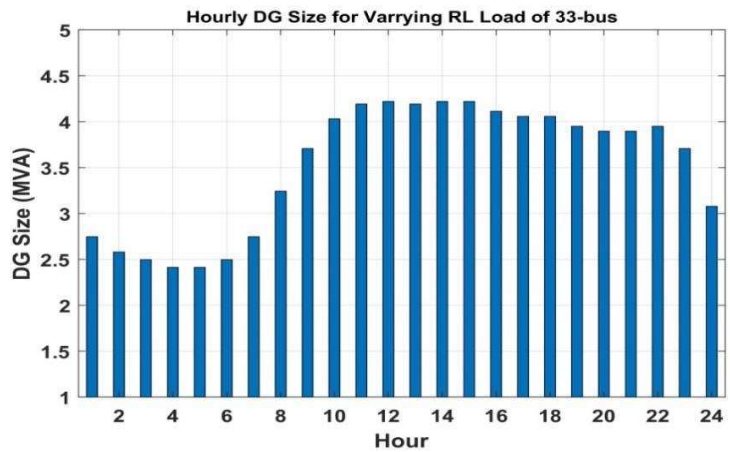

Figure 5.3: DG size for residential summer night load

5.5.1.1.(ii) Real power loss reduction

One of the most prominent objectives of this work is to minimize the real power loss in the network. Figure 5.4 shows hourly variation of real power loss associated with the system in the base case before DG placement and reconfiguration, and after the DG placement followed by network reconfiguration for the 24 hours period considered in this work. It is pertinent to note that the effect of proposed methodology is significant, as it has resulted in significant reduction of real power loss for the whole duration considered. For instance, at 15th hour the value of the real power loss at base case is 344.9875 kW, which drops to 111.53 kW after DG placement and network reconfiguration. This is approximately 67.67% reduction.

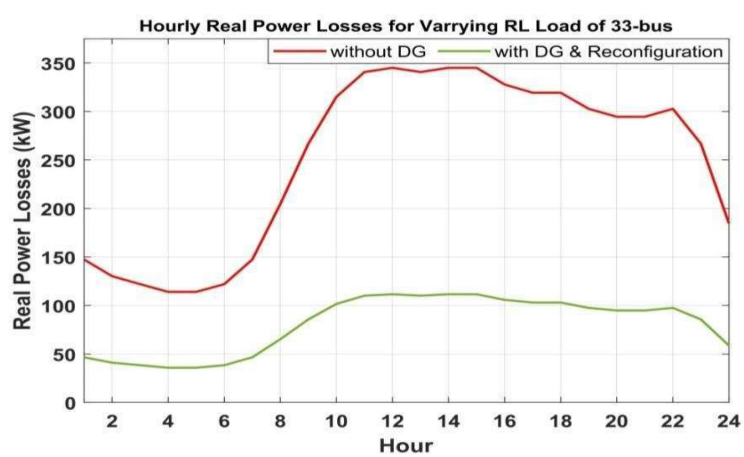

Figure 5.4: Real power loss of network for residential summer night load

5.5.1.1.(iii) Reactive power loss reduction

Not only real power loss is reduced by this methodology but also the reactive power loss is reduced significantly using the proposed objective functions. Plot of hourly variations of reactive power loss is shown in Figure 5.5 for without DG and reconfiguration, and with DG placement followed by network reconfiguration case. It is observed from Figure 5.5 that reactive power is considerably less upon deploying proposed methodology. From the value of 229.08 kVAr in the base case, it has reduced to 90.90 kVAr after DG placement and network reconfiguration. This represents approximately 60.32% reduction in reactive power loss.

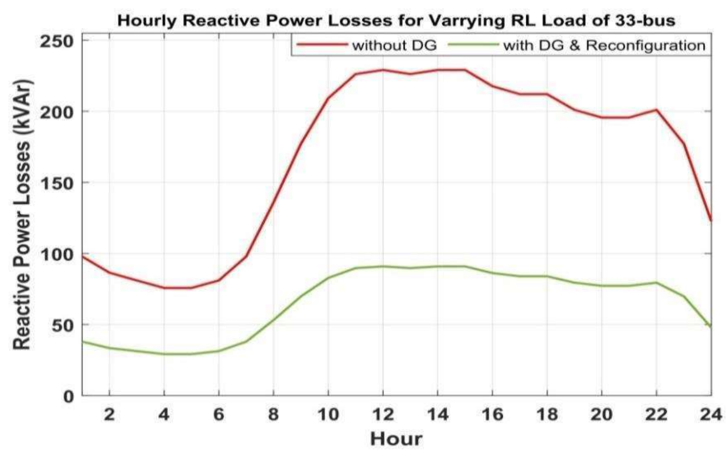

Figure 5.5: Reactive power loss of network for residential summer night load

5.5.1.1.(iv) Magnitude of minimum system voltage

The second important objective of this work apart from losses reduction is the improvement of the voltage profile of the distribution system. Hourly variation of system minimum voltage for the system having no DG and reconfiguration as well as for the system employed with optimally placed DG and reconfiguration have been shown in Figure 5.6. It is observed from Figure 5.6 that the magnitude of minimum voltage for residential summer night season has improved quite significantly for each hour on deploying proposed methodology. It can be observed that value of minimum voltage of 0.8874 pu occurring at peak load hours (12th, 14th and 15th) at base case (i.e. under no DG and reconfiguration) has improved significantly to 0.9617 pu after network reconfiguration and DG placement. It can also be observed that the minimum voltage is more than 0.95 pu at each hour.

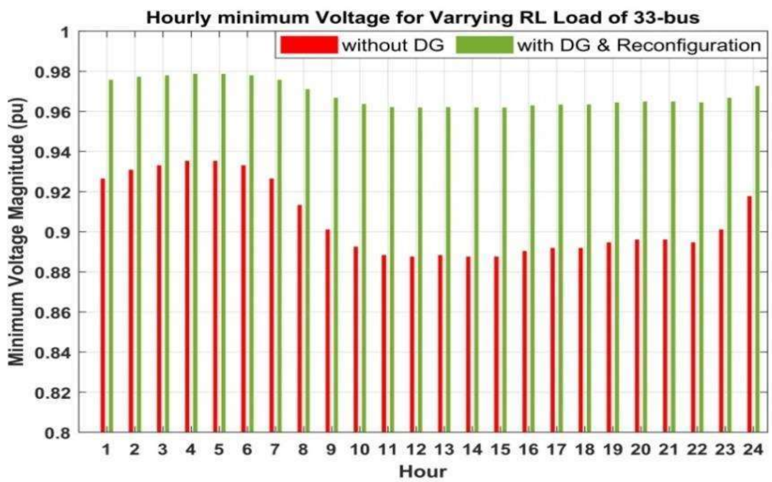

Figure 5.6: Hourly minimum voltage magnitude for residential summer night load

5.5.1.2 *For Electric Vehicle Loads*

Table 5.2 presents the hourly results of varying electric vehicle loads for 33-bus RDS. This Table consists of base case real and reactive power loss, and minimum system voltage, for every hour before DG allocation and network reconfiguration. The optimal DG size is obtained performing optimization using modified GWO at each hour considering DG placed at bus-6. Thereafter, optimal reconfiguration of the network is obtained through rule based fundamental loop analysis that resulted in opening of switches associated with lines 11, 13, 32, 33, and 37. The Table 5.2 also presents the real and reactive power losses and minimum system voltage under optimal DG placement followed by network reconfiguration. Percentage reduction in real and reactive power losses under DG placement followed by reconfiguration has also been shown in Table 5.2 for each hour of 24 hours period considered. It is observed from Table 5.2 that DG placement followed by network reconfiguration through proposed approach results in quite a large reduction in real and reactive power losses and significant enhancement in system minimum voltage for the whole duration of 24 hours period considered in this work.

Table 5.2: Results of system with hourly varying electric vehicle load for 33-bus RDS

Hourly results for EV load of 33-bus RDS (11, 13, 32, 33, 37)									
Hour	**Type-3 DG size (MVA) at 0.82 pf**	**Real power loss (kW)**			**Reactive power loss (kVAr)**			**Minimum voltage**	
		BC*	**RDG***	**%Red***	**BC***	**RDG***	**%Red***	**BC***	**RDG***
1	2.6462	130.41	44.68	65.74	86.47	36.36	57.95	0.9313	0.9752
2	2.4913	116.06	39.46	66.00	76.97	32.12	58.26	0.9351	0.9768
3	2.4134	109.14	36.96	66.13	72.38	30.09	58.42	0.9371	0.9776
4	2.3351	102.39	34.54	66.26	67.91	28.13	58.58	0.9390	0.9784
5	2.3351	102.39	34.54	66.26	67.91	28.13	58.58	0.9390	0.9784
6	2.4134	109.14	36.96	66.13	72.38	30.09	58.42	0.9371	0.9776
7	2.6462	130.41	44.68	65.74	86.47	36.36	57.95	0.9313	0.9752
8	3.1033	177.30	62.08	64.98	117.48	50.50	57.01	0.9200	0.9705
9	3.5257	226.43	80.86	64.29	149.96	65.74	56.16	0.9097	0.9661
10	3.8183	263.68	95.43	63.81	174.56	77.56	55.57	0.9026	0.9629
11	3.9629	283.06	103.11	63.57	187.36	83.78	55.28	0.8992	0.9614
12	**3.9870**	**286.33**	**104.42**	**63.53**	**189.52**	**84.84**	**55.23**	**0.8986**	**0.9611**
13	3.9629	283.06	103.11	63.57	187.36	83.78	55.28	0.8992	0.9614
14	**3.9870**	**286.33**	**104.42**	**63.53**	**189.52**	**84.84**	**55.23**	**0.8986**	**0.9611**
15	**3.9870**	**286.33**	**104.42**	**63.53**	**189.52**	**84.84**	**55.23**	**0.8986**	**0.9611**
16	3.8906	273.31	99.24	63.69	180.92	80.64	55.43	0.9009	0.9622
17	3.8424	266.88	96.69	63.77	176.67	78.58	55.52	0.9021	0.9627
18	3.8424	266.88	96.69	63.77	176.67	78.58	55.52	0.9021	0.9627
19	3.7456	254.18	91.69	63.93	168.29	74.52	55.72	0.9044	0.9637
20	3.6969	247.91	89.23	64.01	164.15	72.53	55.82	0.9056	0.9642
21	3.6969	247.91	89.23	64.01	164.15	72.53	55.82	0.9056	0.9642
22	3.7456	254.18	91.69	63.93	168.29	74.52	55.72	0.9044	0.9637
23	3.5257	226.43	80.86	64.29	149.96	65.74	56.16	0.9097	0.9661
24	2.9523	161.06	55.99	65.23	106.74	45.56	57.32	0.9237	0.9721

* BC: Base case, RDG: reconfiguration followed by DG, %Red: % Reduction

5.5.1.2.(i) Power injected by DG

Figure 5.7 presents the power injected at each hour by the DG unit for the electric vehicle load. It can be noted from Table 5.2 and Figure 5.7 that the maximum size of the DG unit for the hourly time varying loads case came out to be 3.9870 MVA during peak load hours (hours 12th, 14th and 15th).

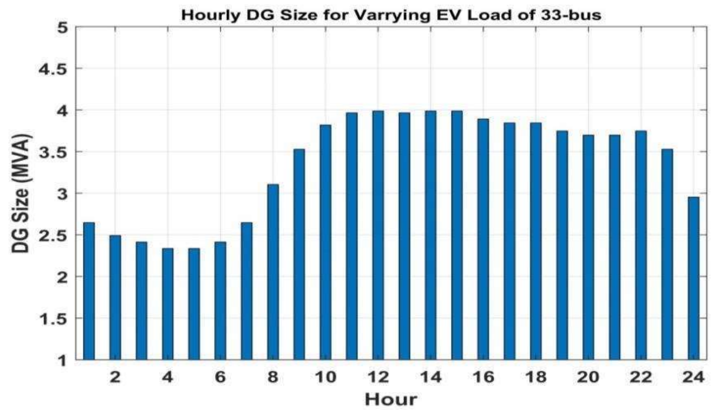

Figure 5.7: DG size for electric vehicle load

5.5.1.2.(ii) Real power loss reduction

Figure 5.8 shows hourly variation of real power loss associated with the system in the base case before DG placement and reconfiguration, and after DG placement followed by network reconfiguration for the 24 hours period considered in this work. It is pertinent to note that the effect of proposed methodology is significant, as it has resulted in significant reduction of real power loss for the whole duration considered. For instance, at 15th hour the value of real power loss at base case (i.e. without DG placement or network reconfiguration) is 286.33 kW, which drops to a significant value of 104.42 kW after DG placement and network reconfiguration. For EV loads too, a significant percentage drop in real power loss is (63.53% reduction) is achieved which establishes the consistency of the proposed methodology.

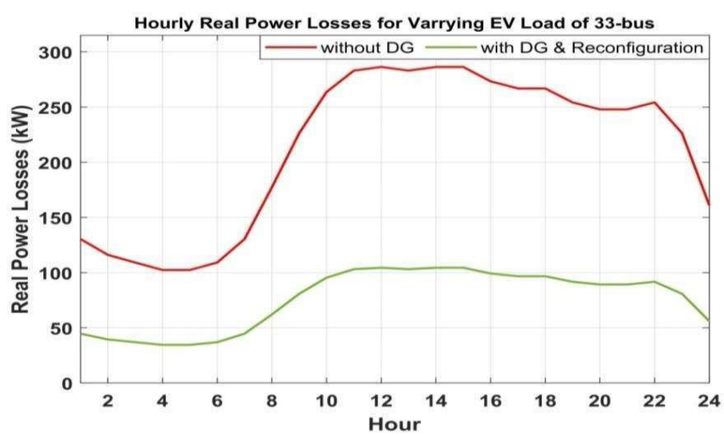

Figure 5.8: Real power loss of the network for electric vehicle load

5.5.1.2.(iii) Reactive power loss reduction

Not only real power loss is reduced by this methodology but also the reactive power loss is reduced significantly using the proposed objective functions. Plot of hourly variations of reactive power loss is shown in Figure 5.9 for system without DG and reconfiguration, and with DG placement followed by network reconfiguration case. It is observed from Figure 5.9 that reactive power loss is considerably less upon deploying proposed methodology. From the value of 189.52 kVAr in the base case, it has reduced to 84.84 kVAr after DG placement and network reconfiguration. This represents approximately 55.23% reduction in reactive power loss.

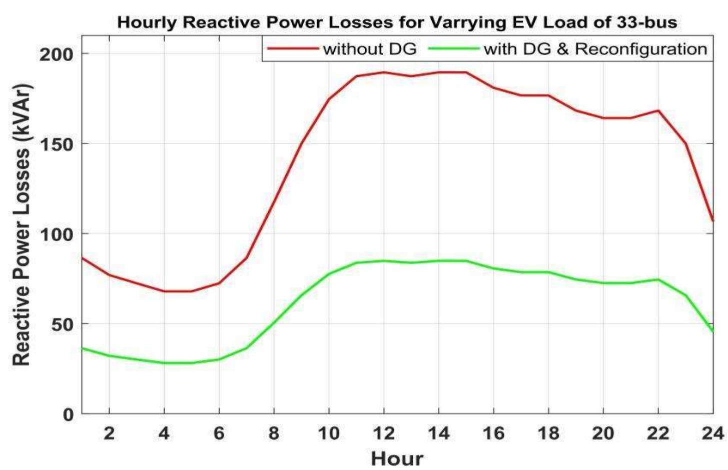

Figure 5.9: Reactive power loss of the network for electric vehicle load

5.5.1.2.(iv) Magnitude of minimum system voltage

Hourly variation of system minimum voltage for the system having no DG and reconfiguration as well as for the system employed with optimally placed DG and reconfiguration have been shown in Figure 5.10 for electric vehicle type loads. It is observed from Figure 5.10 that the magnitude of minimum system voltage for electric vehicle load has improved quite significantly for each hour on deploying proposed methodology. It can be observed that value of minimum voltage of 0.8986 pu occurring at peak load hours (hours 12th, 14th and 15th) at base case (i.e. under no DG and reconfiguration) has improved significantly to 0.9611 pu after DG placement and network reconfiguration. It can also be observed that the minimum voltage is more than 0.95 pu at each hour.

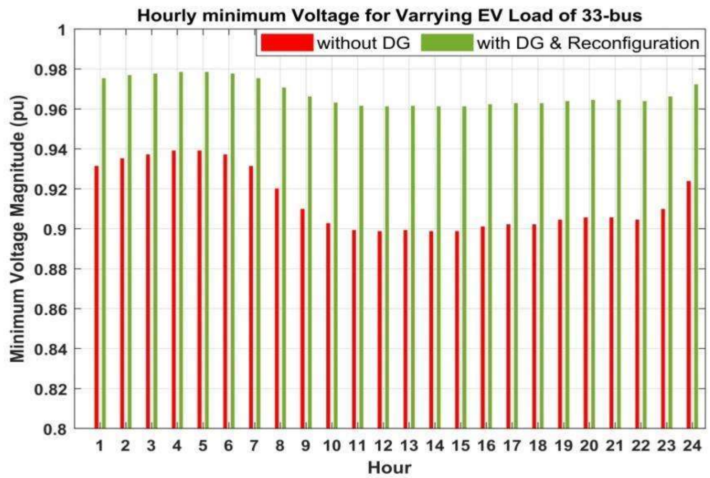

Figure 5.10: Hourly minimum voltage magnitude for electric vehicle load

5.5.1.3 *Operation table for network reconfiguration*

Table 5.3 presents the opened switches satisfying the proposed objective of this work. It is observed from Table 5.3 that opening of switches 11, 13, 32, 33, and 37 resulted in optimal reconfiguration for all the hours of 24 hours period for residential summer night as well as electric vehicle loads.

Table 5.3: Open switches for both types of loads for 33-bus RDS

Hours	**Opened switches**
1-24	11, 13, 32, 33, 37

5.5.1.4 *Comparative analysis of the present work with* [183]

Table 5.4 presents comparison of results with work done in reference [183] for the residential summer night load. As size of Type-3 DG has been expressed in MW in [183] through multiplication of its MVA rating by power factor, same has been done here so that DG size may be compared. It is observed from Table 5.4 that maximum real power loss occurring at peak load hours (hours 12th, 14th and 15th) gets reduced to 111.53 kW through DG placement and network reconfiguration obtained by proposed approach that is much less than real power loss of 159.1213 kW obtained in [183] through DG placement and network reconfiguration. DG size obtained by proposed approach is less than that obtained in [183].

Table 5.4: Comparative analysis of the results with residential loads at peak hour for 33-bus RDS

Comparative results of the residential loads for peak hour 15th for 33-bus RDS						
Case	**Maximum real power loss without DG and NR* (kW)**	**DG size (MW)**	**Maximum real power loss after DG and NR* (kW)**	**Opened switches**	**V_{min} (pu)**	**% Loss reduction**
Reference [183]	344.9864	5.5	159.1213	19, 14, 24, 32, 35	0.960	53.87
Results of the present work	344.9875	**3.95**	**111.5334**	**11, 13, 32, 33, 37**	**0.961**	**67.67**

*NR- Network reconfiguration

Moreover, the value of minimum value of voltage magnitude in the present work is 0.961 pu which is slightly higher compared to 0.960 pu (obtained in [183]). It shows that proposed approach is not only more effective in loss reduction but is more cost effective, too, compared to work carried out in [183] as DG size obtained by proposed approach is much less compared to size obtained in [183].

5.5.2 Test system 2 (69-bus RDS)

Simulations are performed and the results are analysed for two types of loads considered in this chapter (viz. residential summer night load and electric vehicle load) for 69-bus RDS, also. It is quite interesting to note that for 69-bus RDS the collective sensitivity analysis results bus-61 as an optimal location of DG to be placed for both types of load model studied. Moreover DG location found remains same for hourly load pattern of entire 24 hours duration.

5.5.2.1 *For Residential Summer Night Loads*

Table 5.5 presents the hourly results of varying residential summer night loads for 69-bus RDS. This Table consists of base case real and reactive power loss, and minimum system voltage for every hour before DG allocation and network reconfiguration. The optimal DG size is obtained performing optimization at each hour considering the DG placed at bus-61. Thereafter, optimal reconfiguration of the network is obtained through rule based fundamental loop analysis that resulted in opening of switches associated with lines 12, 21, 52, 69, and 70. Table 5.5 also presents the real and reactive power losses and minimum system voltage under optimal DG placement followed by network reconfiguration. Percentage reduction in real and reactive power losses under DG placement followed by network reconfiguration has also been shown in Table 5.5 for each hour of 24 hours period considered. It is observed from Table 5.5 that DG placement followed by network reconfiguration obtained through proposed approach results in quite a large reduction in real and reactive power losses and significant enhancement in system minimum voltage for the whole duration of 24 hours period considered in this work.

Table 5.5: Results of system with hourly varying residential summer night load for 69-bus RDS

Hourly results for RL load of 69-bus RDS (12, 21, 52, 69, 70)									
Hour	Type-3 DG size (MVA) at 0.82 pf	Real power loss (kW)			Reactive power loss (kVAr)			Minimum voltage	
		BC*	RDG*	%Red*	BC*	RDG*	%Red*	BC*	RDG*
1	2.1377	157.99	10.83	93.15	72.94	10.31	85.87	0.9234	0.9899
2	2.0045	139.67	9.52	93.18	64.46	9.06	85.94	0.9280	0.9906
3	1.9378	130.90	8.90	93.20	60.40	8.47	85.98	0.9303	0.9909
4	1.8712	122.39	8.30	93.22	56.46	7.90	86.01	0.9327	0.9912
5	1.8712	122.39	8.30	93.22	56.46	7.90	86.01	0.9327	0.9912
6	1.9378	130.90	8.90	93.20	60.40	8.47	85.98	0.9303	0.9909
7	2.1377	157.99	10.83	93.15	72.94	10.31	85.87	0.9234	0.9899
8	2.5370	219.14	15.23	93.05	101.27	14.51	85.67	0.9097	0.9881
9	2.9137	285.17	20.07	92.96	131.91	19.14	85.49	0.8968	0.9863
10	3.1794	336.51	23.87	92.90	155.76	22.79	85.37	0.8879	0.9851
11	3.3122	363.64	25.90	92.88	168.36	24.73	85.31	0.8834	0.9845
12	**3.3343**	**368.25**	**26.25**	**92.87**	**170.50**	**25.06**	**85.30**	**0.8827**	**0.9844**
13	3.3122	363.64	25.90	92.88	168.36	24.73	85.31	0.8834	0.9845
14	**3.3343**	**368.25**	**26.25**	**92.87**	**170.50**	**25.06**	**85.30**	**0.8827**	**0.9844**
15	**3.3343**	**368.25**	**26.25**	**92.87**	**170.50**	**25.06**	**85.30**	**0.8827**	**0.9844**
16	3.2458	349.96	24.88	92.89	162.01	23.75	85.34	0.8856	0.9848
17	3.2016	340.97	24.21	92.90	157.83	23.11	85.36	0.8871	0.9850
18	3.2016	340.97	24.21	92.90	157.83	23.11	85.36	0.8871	0.9850
19	3.1130	323.32	22.89	92.92	149.63	21.85	85.40	0.8901	0.9854
20	3.0688	314.65	22.25	92.93	145.60	21.23	85.42	0.8916	0.9856
21	3.0688	314.65	22.25	92.93	145.60	21.23	85.42	0.8916	0.9856
22	3.1130	323.32	22.89	92.92	149.63	21.85	85.40	0.8901	0.9854
23	2.9137	285.17	20.07	92.96	131.91	19.14	85.49	0.8968	0.9863
24	2.4040	197.74	13.68	93.08	91.35	13.03	85.73	0.9142	0.9887

* BC: Base case, RDG: Reconfiguration followed by DG, %Red: %Reduction

5.5.2.1.(i) Power injected by DG

Figure 5.11 presents the power injected at each hour by the DG unit for the residential summer night load. It is pertinent to note from Table 5.5 and Figure 5.11 that the maximum size of the DG unit obtained for residential summer night load is 3.33427 MVA at peak load hours (load hours 12th, 14th and 15th).

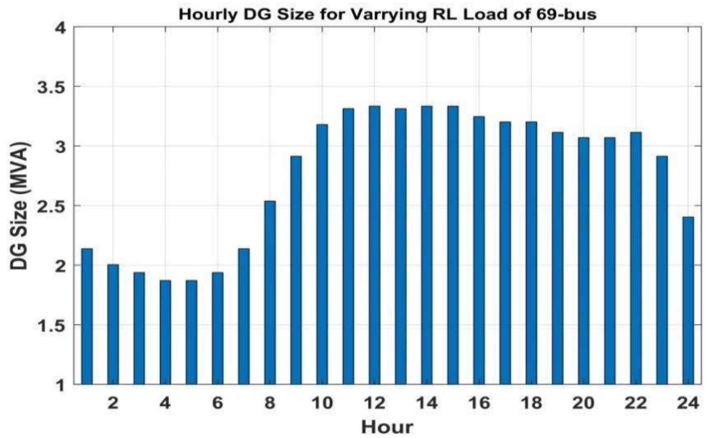

Figure 5.11: DG size for residential summer night load

5.5.2.1.(ii) Real power loss reduction

One of the most prominent objectives of this work is to minimize the real power loss in the network. Figure 5.12 shows hourly variation of real power loss associated with the system in the base case before DG placement and reconfiguration, and after DG placement followed by network reconfiguration for the 24 hours period considered in this work. It is pertinent to note that the effect of proposed methodology is significant, as it has resulted in significant reduction of real power loss for the whole duration considered. For instance, at 15th hour the value of the real power loss at base case is 368.25 kW, which drops to 26.25 kW after DG placement followed by network reconfiguration for residential summer night load. This is approximately 92.87% reduction.

Figure 5.12: Real power loss of network for residential summer night load

5.5.2.1.(iii) Reactive power loss reduction

Not only real power loss is reduced by this methodology but also the reactive power loss is reduced significantly using the proposed objective functions. Plot of hourly variations of reactive power loss is shown in Figure 5.13 for without DG and reconfiguration, and with DG placement followed by network reconfiguration case. It is observed from Figure 5.13 that reactive power is considerably less upon deploying proposed methodology. From the value of 170.50 kVAr in the base case, it has reduced to 25.06 kVAr after DG placement and network reconfiguration. This represents approximately 85.30% reduction.

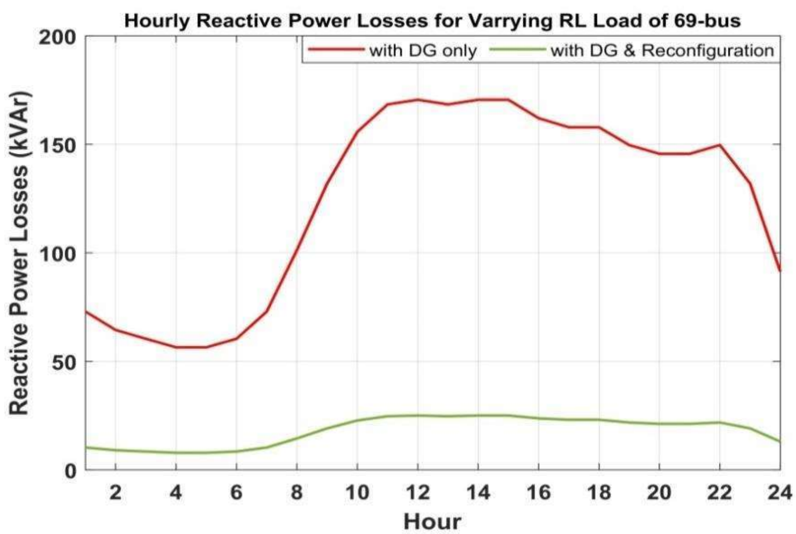

Figure 5.13: Reactive power loss of network for residential summer night load

5.5.2.1.(iv) Magnitude of minimum system voltage

The second important objective of this work apart from losses reduction is the improvement of the voltage profile of the distribution system. Hourly variation of system minimum voltage for the system having no DG and reconfiguration as well as for the system employed with optimally placed DG and reconfiguration have been shown in Figure 5.14. It is observed from Figure 5.14 that the magnitude of minimum voltage for residential summer night season has improved quite significantly for each hour on deploying proposed methodology. It can be observed that value of minimum voltage of 0.8827 pu occurring at peak load hours (12th, 14th and 15th) at base case (i.e. under no DG and reconfiguration) has improved significantly to 0.9844 pu after DG placement and network reconfiguration for residential summer night load. It can also be observed that the minimum voltage is more than 0.95 pu at each hour.

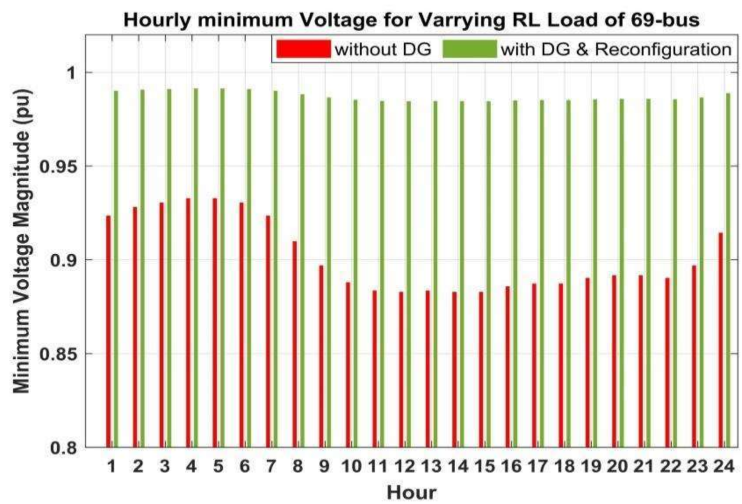

Figure 5.14: Hourly minimum voltage magnitude for residential summer night load

For Electric Vehicle Loads Table 5.6 presents the hourly results of varying electric vehicle loads for 69-bus RDS. This Table consists of base case real and reactive power loss, and minimum system voltage, for every hour before DG allocation and network reconfiguration. The optimal DG size is obtained performing optimization at each hour considering the DG placed at bus-61. Thereafter, optimal reconfiguration of the network is obtained through rule based fundamental loop analysis that resulted in opening of switches associated with lines 12, 21, 52, 69, and 70. The Table 5.6 also presents the real and reactive power losses and minimum system voltage under optimal DG placement followed by network reconfiguration. Percentage reduction in real and reactive power losses under DG placement followed by network reconfiguration has also been shown in Table 5.6 for each hour of 24 hours period considered. It is observed from Table 5.6 that DG placement followed by network reconfiguration through proposed approach results in quite a large reduction in real and reactive power losses and significant enhancement in system minimum voltage for the whole duration of 24 hours period considered in this work.

Table 5.6: Results of system with hourly varying Electrical Vehicle load for 69-bus RDS

Hourly Results for EV Load of 69-bus RDS with open switches (12, 21, 52, 69, 70)									
Hour	**Type-3 DG size (MVA) at 0.82 pf**	**Real power loss (kW)**			**Reactive power loss (kVAr)**			**Minimum voltage**	
		BC*	**RDG***	**%Red***	**BC***	**RDG***	**%Red***	**BC***	**RDG***
1	2.1289	137.10	10.66	92.22	63.95	10.23	84.01	0.9296	0.9901
2	1.9967	122.23	9.39	92.32	56.95	9.00	84.20	0.9335	0.9907
3	1.9305	115.04	8.78	92.37	53.57	8.41	84.30	0.9355	0.9910
4	1.8644	108.02	8.19	92.42	50.28	7.84	84.40	0.9375	0.9913
5	1.8644	108.02	8.19	92.42	50.28	7.84	84.40	0.9375	0.9913
6	1.9305	115.04	8.78	92.37	53.57	8.41	84.30	0.9355	0.9910
7	2.1289	137.10	10.66	92.22	63.95	10.23	84.01	0.9296	0.9901
8	2.5247	185.43	14.96	91.93	86.76	14.38	83.43	0.9182	0.9882
9	2.8977	235.71	19.65	91.66	110.60	18.94	82.88	0.9078	0.9865
10	3.1605	273.62	23.34	91.47	128.66	22.52	82.50	0.9006	0.9853
11	3.2918	293.26	25.29	91.37	138.04	24.42	82.31	0.8972	0.9847
12	**3.3136**	**296.58**	**25.63**	**91.36**	**139.62**	**24.75**	**82.27**	**0.8966**	**0.9846**
13	3.2918	293.26	25.29	91.37	138.04	24.42	82.31	0.8972	0.9847
14	**3.3136**	**296.58**	**25.63**	**91.36**	**139.62**	**24.75**	**82.27**	**0.8966**	**0.9846**
15	**3.3136**	**296.58**	**25.63**	**91.36**	**139.62**	**24.75**	**82.27**	**0.8966**	**0.9846**
16	3.2262	283.39	24.31	91.42	133.32	23.46	82.40	0.8989	0.9850
17	3.1824	276.86	23.66	91.45	130.20	22.83	82.47	0.9001	0.9852
18	3.1824	276.86	23.66	91.45	130.20	22.83	82.47	0.9001	0.9852
19	3.0948	263.96	22.39	91.52	124.05	21.59	82.59	0.9024	0.9856
20	3.0511	257.59	21.77	91.55	121.02	20.99	82.66	0.9036	0.9858
21	3.0511	257.59	21.77	91.55	121.02	20.99	82.66	0.9036	0.9858
22	3.0948	263.96	22.39	91.52	124.05	21.59	82.59	0.9024	0.9856
23	2.8977	235.71	19.65	91.66	110.60	18.94	82.88	0.9078	0.9865
24	2.3929	168.73	13.45	92.03	78.86	12.92	83.62	0.9219	0.9888

* BC: Base case, RDG: Reconfiguration followed by DG, %Red: %Reduction

5.5.2.1.(v) Power injected by DG

Figure 5.15 presents the power injected at each hour by the DG unit for the electric vehicle load. It can be noted from Table 5.6 and Figure 5.15 that the maximum size of the DG unit for the hourly time varying electric vehicle loads case came out to be 3.31362 MVA during peak load hours (hours 12th, 14th and 15th).

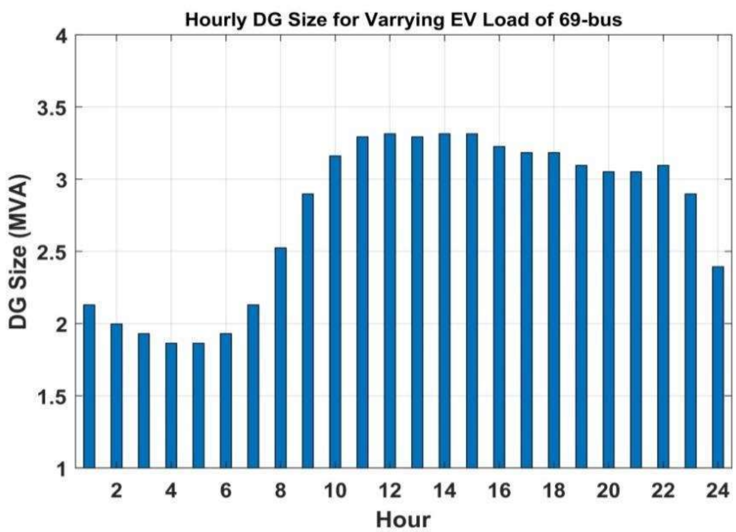

Figure 5.15: DG size for residential summer night load

5.5.2.1.(vi) Real power loss reduction

Figure 5.16 shows hourly variation of real power loss associated with the system in the base case before DG placement and reconfiguration, and after DG placement followed by network reconfiguration for the 24 hours period considered in this work. It is pertinent to note that the effect of proposed methodology is significant, as it has resulted in significant reduction of real power loss for the whole duration considered. For instance at 15th hour the value of real power loss at base case (i.e. without DG placement or network reconfiguration) is 296.58 kW, which drops to a significant value of 25.63 kW after DG placement and network reconfiguration. For EV loads too, a significant percentage drop in real power loss of 91.36% is achieved which establishes the consistency of the proposed methodology.

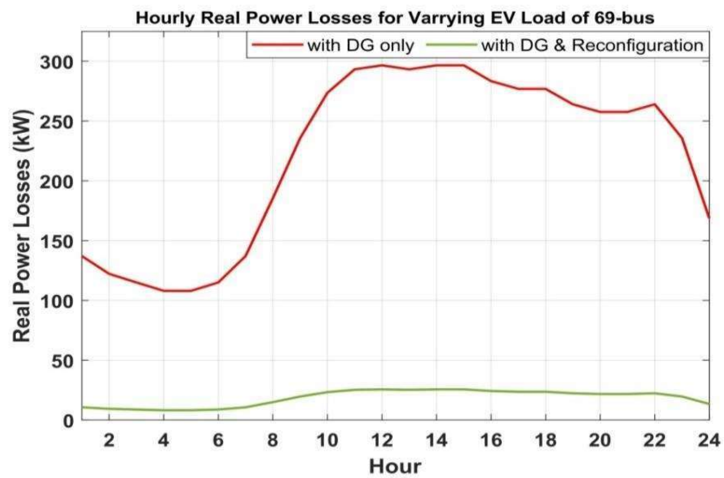

Figure 5.16: Real power loss of the network for electric vehicle load

5.5.2.1.(vii) Reactive power loss reduction

Not only real power loss is reduced by this methodology but also the reactive power loss is reduced significantly using the proposed objective functions. Plot of hourly variations of reactive power loss is shown in Figure 5.17 for system without DG and reconfiguration, and with DG placement followed by network reconfiguration case. It is observed from Figure 5.17 that reactive power loss is considerably less upon deploying the proposed methodology. From the value of 139.62 kVAr in the base case, the reactive power loss has reduced to 24.75 kVAr after DG placement and network reconfiguration. This represents approximately 82.27% reduction in reactive power loss.

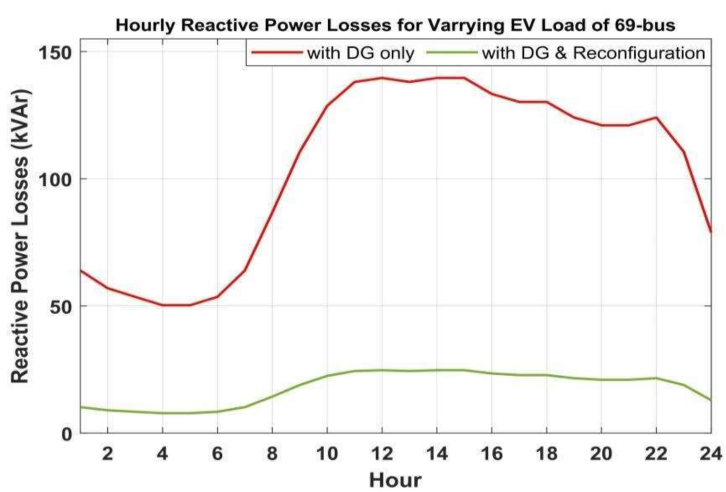

Figure 5.17: Reactive power loss of the network for electric vehicle load

5.5.2.1.(viii) Magnitude of minimum system voltage

Hourly variation of system minimum voltage for the system having no DG and reconfiguration as well as for the system employed with optimally placed DG and reconfiguration have been shown in Figure 5.18 for electric vehicle loads. It is observed from Figure 5.18 that the magnitude of minimum system voltage for electric vehicle load has improved quite significantly for each hour on deploying proposed methodology. It can be observed that value of minimum voltage of 0.8966 pu occurring at peak load hours (hours 12th, 14th and 15th) at base case (i.e. under no DG and reconfiguration) has improved significantly to 0.9846 pu after DG placement and network reconfiguration. It can also be observed that the minimum voltage is more than 0.95 pu at each hour.

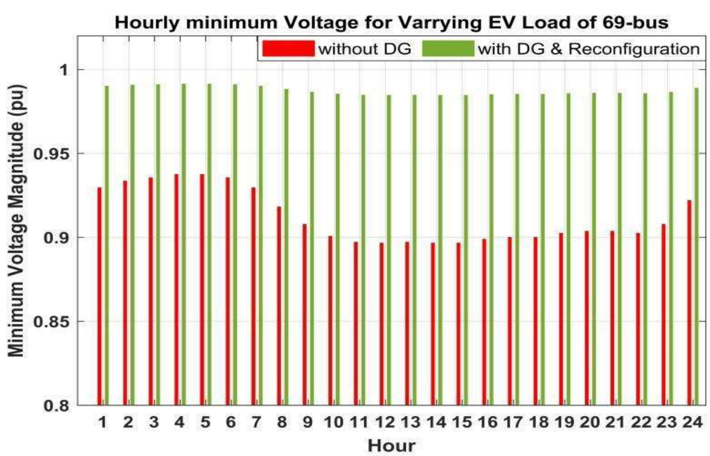

Figure 5.18: Hourly minimum voltage magnitude for electric vehicle load

5.5.2.2 *Operation table for network reconfiguration*

Table 5.7 presents the opened switches satisfying the proposed objective of this work. It is observed from

Table 5.7 that opening of switches 12, 21, 52, 69, and 70 resulted in optimal reconfiguration for all the hours of 24 hours period for residential summer night as well as electric vehicle loads.

Table 5.7: Open switches for both types of loads for 69-bus RDS

Hours	Opened switches
1-24	12, 21, 52, 69, 70

5.6 SUMMARY

This chapter presented an approach for power loss reduction and voltage profile improvement through DG placement and network reconfiguration for time varying voltage dependent loads. Residential summer night loads and electric vehicle loads were considered as voltage dependent time varying loads. Simulations were performed for a 24 hours period under a pre-defined load variation pattern. The optimal location of DG was found by collective sensitivity approach, which came out to be same for each hour for both types of load considered in this work. Two prime objectives for this work were, first, to minimize the real power loss incurred in the system and second, to improve the overall voltage profile of the system. For this, a multi-objective function was formulated that was optimized through modified GWO algorithm under DG placed at the location obtained by sensitivity approach. The system with optimally placed DG (size obtained through modified GWO while location obtained through sensitivity approach) was reconfigured using rule-based fundamental loop method. Case studies were performed on IEEE 33-bus and 69-bus test systems. Simulation results on two test systems validated the effectiveness of proposed approach of DG placement and reconfiguration for both types of voltage dependent time varying loads (viz. residential summer night loads and electric vehicle loads). Quite a large percentage reduction in power loss and considerable enhancement in voltage profile were obtained.