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Optimal placement and sizing of DG in Radial Distribution System using PSO Technique

M. H. RIND[++], M. K. RATHI*, A. A. HASHMANI*, A. A. LASHARI[++]

Department of Institute of Information and Communication Technology, Mehran UET, Jamshoro, Pakistan

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Abstract: Power distribution system having various buses, branches and loads that ultimately rises the power losses and from few decades, integration of solar and wind distributed generations has ever increased attention in radial distribution network (RDN). The main reason for DG integration in radial distribution system is increased load growth, transmission line loading, deregulated power system, power losses, increased greenhouse gas emissions, voltage drop and increased reliability issues in RDN. The main focus of this paper is to find optimal size and site of solar PV to improve voltage at all the nodes with in permissible limits and to reduce power losses in RDN using particle swarm optimization (PSO) algorithm. Here two scenarios were considered. Scenario one was the integration of 1DG and second scenario was the integration of 2DGs. Furthermore, Results obtained shows that greater number of DG integration increases the system reliability, reduces losses and improves voltage at all the nodes of the RDN.

Keywords: Distributed generations, Radial distribution network, IEEE 33 bus system, PSO algorithm

1.

In recent years DG integration in power system has increased as the load of electrical power network is rising exponentially. Small DGs of rating 5 kW to 5 MW are usually placed in power system distribution networks (Ackermann *et. al.* 2001). Solar, wind and fuel cells are integrated in distribution network having many benefits over centralized power generation network. DG optimal site and sizing is important at planning stage so that voltage at all the nodes are improved and overall power loss of RDN is improved. (AlRashidi and AlHajri, 2011). However, non-optimal siting and sizing of DG have negative impact on distribution network. Therefore, selection of optimal DG size and its site in RDN is a complex problem.

The optimal DG siting and sizing have lot of benefits has been studied by many researchers with the purpose of reduction of branch power losses, voltage improvement at different nodes and reliability indices of RDN.(Borges and Falcão, 2003) reduced 64.62% losses by suitable allocation and sizing of DG, also improved reliability and voltage profile of the system.(Mahesh *et. al.* 2017) used accelerated PSO algorithm for optimal siting and allocation of distributed generation units for losses minimization and voltage behavior enhancement at different nodes in distribution network. (Borges and Falcao, 2006) suggested genetic algorithm (GA) for improvement of reliability, voltage at each bus and reduction of active power losses in RDN. (Guan *et. al.* 2017) has improved power losses and voltage stability index of RDN using PSO technique.(Mohamed, 2018) compared the results of single and multi-objective optimal DG sitting and sizing for reduction of line losses (active and reactive losses), improvement of voltage stability index by taking constraints power equilibrium, DG capacity, total DG size and voltage at different number of DGs by using Particle Swarm Optimization (PSO), Firefly Algorithm (FA) and Novel Bat Algorithm (NBA). (Suyono *et. al.* 2017) suggested that DG units' integration has improved SAIFI up to 30.71% and SAIDI up to 32.27% as compare to base system. Khaled *et. al.* 2017) presented PSO algorithm for transmission losses reduction, cost minimization for RDN. (Elsayed *et al.* 2018) has taken Egyptian real system in consideration and has improved real system losses and improved voltage at all the nodes using PSO algorithm for optimal size and allocation in distribution network. (Sreevidya *et. al.* 2019) has considered IEEE 33 system using ETAP for interruption cost reduction and other reliability indices using PSO technique. (Gana *et. al.* 2019) used PSO algorithm for suitable allocation and sizing of solar DG for evaluation of only reliability of IEEE 33 network and Ran feeder.

This paper presents method to evaluate the influence of DG installation on reliability, line losses and voltage at different nodes of RDN. Proposed methodology is used to compare the performance characteristics of RDN without and with suitable installation and sizing of solar DG units.

2. PROBLEM FORMULATION:

The aim of this study is to find optimal site and size of solar in radial distribution system. Three objectives are considered first one reliability evaluation of the test network second one overall losses reduction and third one improving voltage at different nodes in RDN. Constraints taken in this study are power balance, voltage limits, current flow limit, DG size and location and thermal limit of line. The conventional load flow technique having slow convergence issues. Therefore, backward- forward power flow algorithm is considered

++Corresponding Author: M. H. RIND

*Department of Electrical Engineering, Mehran UET, Jamshoro

2.1 Power loss reduction

It is fact that distribution system consists of about thirteen percent (13%) power losses from the total power generation as reported in (Kumar *et. al.* 2017). Hence, the important aim of this study is to reduce the actual power losses of the network. In order to reduce the losses a backward forward power flow method is employed to calculate the diffident electrical parameters of RDN (Tefera *et.al.* 2017). Let us consider a radial distribution system having two nodes M and N connected through branch k is shown in (**Fig. 1)**

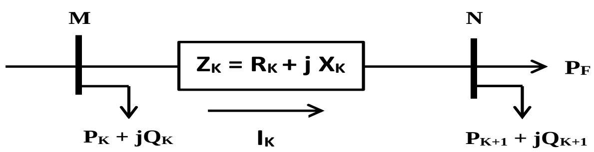

Fig. 1: Two bus RDN

Voltage at node N is calculated by Eq. (1)

$V_N = V_M - I_M \times (R_M + j\,X_M)$(1)

Line current is calculated by using Eq. (2)

$I_K = \left(\frac{P_K + Q_K}{V_K}\right)$(2)

Actual and re-active power loss is determined with Eqs. (3) and (4)

$$P_{kloss} = \left(\frac{P_{K+1}^2 + Q_{K+1}^2}{|V_{K+1}^2|}\right) \times R_K \qquad (3)$$

$$Q_{kloss} = \left(\frac{P_{K+1}^2 + Q_{K+1}^2}{|V_K^2|}\right) \times X_K \qquad (4)$$

Total power loss can be calculated by adding the actual and re-active losses across each branch and can be expressed by Eq. (5)

$$T_{loss} = \sum_{K=1}^{nb} P_{kloss} + j\sum_{K=1}^{nb} Q_{kloss} \quad (5)$$

Active power loss minimization is considered as an objective function and it is expressed by Eq. (6)

$$T_{loss} = min\left(\sum_{K=1}^{nb} P_{kloss}\right) \qquad (6)$$

2.2 Voltage profile improvement:

In distribution system load is inductive in nature. Due to inductive nature of load there is always under voltage issues are in radial distribution system. In order to avoid under voltage issues DG units are installed to improve the voltage profile of distribution system. Voltage at bus N is found by Eq. (1)

$$V_N = V_M - I_M \times (R_M + j\,X_M) \qquad (1)$$

Subjected to constraints**:**

- Power balance:

The sum of power supplied by substation and number of DGs is equal to the sum of power loss and total load connected in distribution network.

$$P_{substation} + \sum P_{DG} = \sum P_{loss} + \sum P_{load} \qquad (7)$$

$$Q_{substation} + \sum Q_{DG} = \sum Q_{loss} + \sum Q_{load} \quad (8)$$

Where $P_{substation}$ is the actual power supplied by the substation and $Q_{substation}$ the reactive power supplied by the substation. The actual and reactive power supplied by DGs are defined as P_{DG} and Q_{DG}. $\sum P_{loss}$ represents total active power loss, $\sum Q_{loss}$ represents total reactive power loss. The total active and reactive power load are defined as $\sum P_{load}$ and $\sum Q_{load}$ respectively.

- Location of DG

In test system bus 1 is defined as reference bus due to which integral of DG in this bus is not allowed.

$$2 \le \boldsymbol{DG_{location}} \le \boldsymbol{N_{buses}} \qquad (9)$$

- Voltage profile limitation

The limitation in voltage at each node is represented by equation (1) In this paper allowable voltage variation limit is ±5%. Therefore, voltage variation ranges from 0.95 to 1.05 pu.

$$V_{min} \le V \le V_{max} \qquad (10)$$

- DG sizing

The size of DG is never be greater than the sum of all the loads connected in distribution network

$$\sum P_{DG} \le P_{load} \qquad (11)$$

- Thermal limit

The thermal limit of distribution network is represented by the Eq. (12). The thermal limit of line must be less than the rated thermal limit.

$$S_{line} \le S_{rated} \qquad (12)$$

2.3 Distribution system reliability indices:

The term reliability means the capability of the network to meet its intended function, where the past analysis serves to estimate future performance of the system. Reliability is the possibility of network to behave well under certain constraints for required period. Under standard operating conditions. System reliability can be computed from the failure probability of the composite power system due to outage of lines, transformers and generators. There may be more than one failure condition for transformer, line or generator. Results from a reliability study can be expressed using different reliability indices. There are many possible reliability indices, which often are interdependent like CAIDI is the fraction of SAIDI to SAFI and IEAR is the fraction of ECOST to EENS. Depending on the application, a suitable set of indices has to be chosen, to perform the reliability evaluation. In order to benchmark the performance of any industry SAIFI, CAIDI, SAIDI reliability indices are commonly used (Sreevidya *et. al.*, 2019). Most commonly

measure the utility reliability are:

System Average Interruption Duration Index (SAIDI) is measured in hour/customer. year and it is the fraction of total sustained interruptions to number of consumers served per year as given in Eq. (13)

$$SAIDI = \frac{Ui.Ni}{Ni.}(hr./c.yr) \tag{13}$$

System Average Interruption Frequency Index (SAIFI) is measured in failures/customer. year and it is the fraction of total number of disturbances to total number of consumers served per yearas given in Eq. (14).

$$SAIFI = \frac{\sum Ni\times\lambda i}{Ni}(f./c.yr) \tag{14}$$

Average Interruption Frequency Index (CAIDI) is measured in hour/customer. interruption and it is the fraction of total duration of sustained disturbances to total number of disturbances served by consumers in a year as given in Eq. (15).

$$CAIDI = \frac{\sum Ui\times Ni}{\sum Ni\times\lambda i}\ (hr/c.yr) \tag{15}$$

Average service Availability (Unavailability)Index (ASAI)is measured in per unit (P.U) and it is the fraction of total duration of hours availability in year to total demanded hours by as given in Eq. (16).

$$ASAI = \frac{\sum Ni\times 8760 - \sum UiNi}{\sum Ni\times 8760}\ (p.u) \tag{16}$$

$$ASUI = 1 - ASAI\ (p.u) \tag{17}$$

Expected Energy Not Supplied (EENS) of the network is measured in MWh/year and it equal to sum of all the consumers EENS as given in Eq. (18)

$$EENS\ =\ \sum EENS\ (MWh/yr) \tag{18}$$

System expected interruption cost index (ECOST) of the network is measured in k$/MWh and it is equal to the sum of interruption cost of all the individual consumers as given in Eq. (19)

$$ECOST\ =\ \sum ECOST \qquad 19)$$

Average Energy Not Supplied Index (AENS) by the network is measured in MWhr/ year and it is ratio of total energy not supplied to total number of consumers as given in Eq. (20)

$$AENS = \frac{\sum Lai\times Ui}{\sum Ni} \tag{20}$$

Where λi is failure rate, Ui is outage duration per year, Lai is average load connected to load point i and Ni is the number of consumers connected to load point i.

3. METHODLOGY

3.1 PSO technique:

Kennedy and Eberhart presented PSO algorithm also known as population based stochastic algorithm in 1995(Kennedy, 2010). PSO simulates the behavior of fish schooling, bird flocking. In this algorithm a group of swarms is randomly generated and each particle moves in N dimensional search space with randomly generated velocity. In every iteration of PSO each particle is updated by two best values. First one is known as fitness (best) solution, it has achieved so far and is stored. This value is also known as p best. The second one best value is known as global best or g best and it is found by particle swarm optimizer by tracking from p best values. After finding the p best and q best values, particle (solution) velocity is updated using Eq. (21)

$$V_{M,N}^{new} = V_{M,N}^{old} + \alpha \times \text{randn k} + \beta \times \left(P_{M,N}^{global\ best} - P_{M,N}^{old}\right) \tag{21}$$

Where α and β are acceleration constants and randn is a random variable having value 0 to 1.

If solution is not found then position is updated by Eq. (22)

$$P_{M,N}^{new} = P_{M,N}^{old} + V_{M,N}^{new} \tag{22}$$

Where M = 1,2, 3…, y and N = 1, 2, 3…, z

To reduce the error a greater number of iterations are required so position should be in single step as

$$P_{M,N}^{new} = (1 - \beta) \times P_{M,N}^{old} + \beta \times P_{M,N}^{global\ best} + \alpha \times \text{randn k} \tag{23}$$

αranges from 0.1 to 0.5 and βranges 0.1 to 0.7.

3.2 PSO implementation:

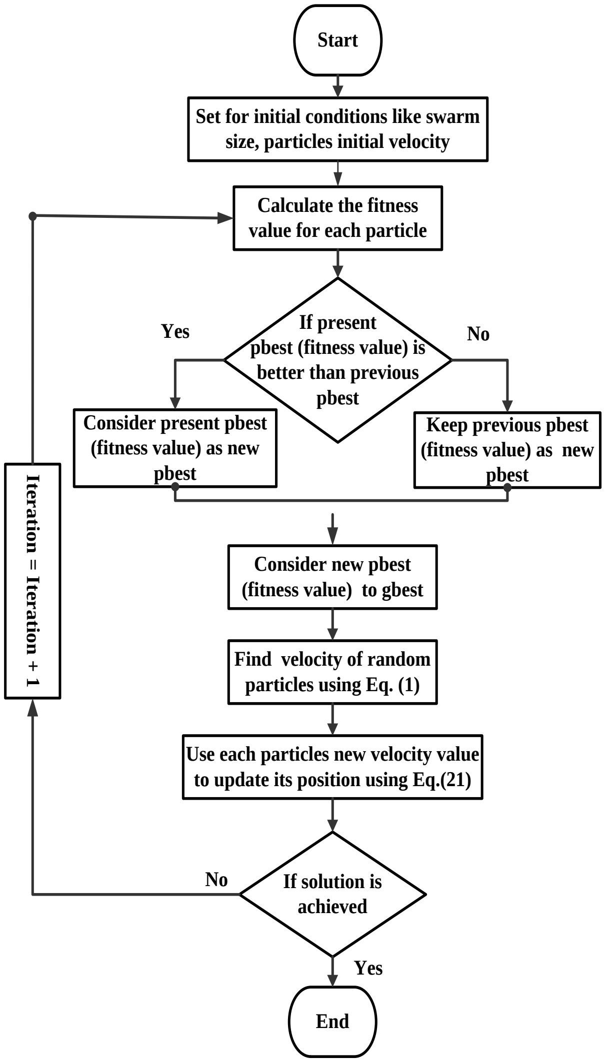

Fig. 2: PSO algorithm flow chart

3.3 Optimal site and location of solar DG

Table.1 Optimal sizes and locations of solar DG

S. No	Configuration	Location(s)	Size (s) MW
1	IEEE 33 bus system with1DG	Bus 6	2.51
2	IEEE 33 bus system with 2DG	Bus 7 and 16	2.14 and 0.654

3.4 Network Modelling:

Total load (active and reactive) connected with test system is 3.72 MW and 2.3 MW. The bus voltage is taken as 12.66 kV. IEEE 33 test model is made in ETAP software in edit mode with normal configuration. Main components of test system are buses, branches, utility grid, and load. It consists of 33 buses, 32 branches, 32 loads. Power is supplied to the load by inductive load. The designed solar DG of optimal size and location is connected with test model as found by PSO algorithm as shown in (**Fig. 3)**. In order to find the reliability, following indices like SAIDI, SAIFI, CAIDI, ASUI, ASAI, EENS and ECOST of radial distribution test system were evaluated using ETAP software. Reliability data for each component is taken from ETAP reliability library. The line and load data of IEEE 33 bus network is given below in (**Table 2).**

3.5 Solar Photovoltaic Design:

In this design 240 Wp solar panels of suniva ART 245-60 module were used. ART245-60 module manufactured by suniva in USA is robust and well-designed monocrystalline high efficiency solar cellstype that is used in standalone systems and grid connected solar power projects. (T**able 3)** shows the basic features of photovoltaic (PV) solar module and (**Table 4)**shows the basic features of ABB inverter. The standard test conditions (STC) considered forART245-60 solar module is 100mW/cm2, 1.5 air mass (AM) global spectrum at 25^0C temperature. (Gana *et. al.* 2019)

$$V(T) = V@25C(1 + \beta \times \Delta T) \quad (24)$$

Where β is temperature de-rating factor

Table 3. Basic features of photovoltaic (PV) modules

S#	Parameter	Rating
1	PV module output power @ P_{MP}	240W
2	Rated voltage (V_{MP}) @ P_{MP}	30.9V
3	Rated current (I_{MP}) @ P_{MP}	7.95A
4	Open circuit voltage (V_{OC})	37.4V
5	Short circuit current of module (I_{SC})	8.44A
6	Number of series cells in single module	60
7	Voltage de-rating factor, β (Voc % / °C)	-0.332
8	Current de-rating factor, α (Isc % / °C)	0.035
9	Power de-rating factor,γ (Pmax % / °C)	-0.465

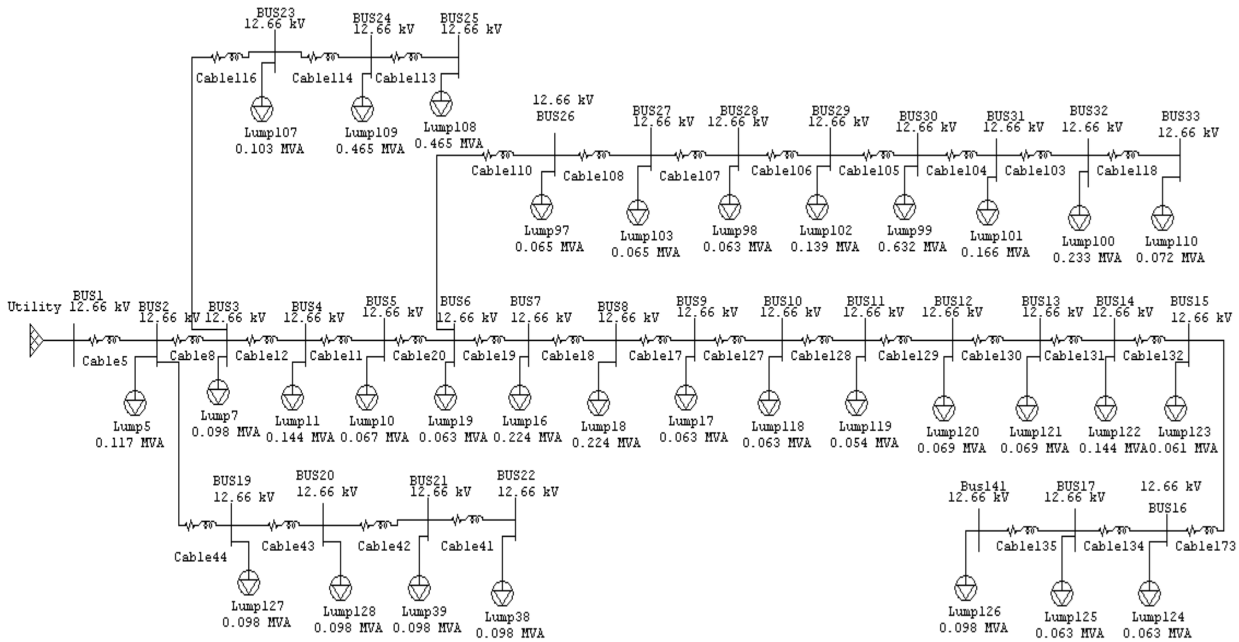

Fig.3: IEEE 33 bus system ETAP model without DG

Table2.Branch and load data of IEEE 33 bus network (Ramachandran *et. al.* 2019)

From Bus	To Bus	R(Ω)	X(Ω)	Load at To Bus		From Bus	To Bus	R(Ω)	X(Ω)	Load at To Bus	
				P(Kw)	Q(Kvar)					P(Kw)	Q(Kvar)
1	2	0.0922	0.047	100	60	17	18	0.732	0.574	90	40
2	3	0.493	0.2511	90	40	2	19	0.164	0.1565	90	40
3	4	0.366	0.1864	120	80	19	20	1.5042	1.3554	90	40
4	5	0.3811	0.1941	60	30	20	21	0.4095	0.4784	90	40
5	6	0.819	0.707	60	20	21	22	0.7089	0.9373	90	40
6	7	0.1872	0.6188	200	100	3	23	0.4512	0.3083	90	50
7	8	0.7114	0.2351	200	100	23	24	0.898	0.7091	420	200
8	9	1.03	0.74	60	20	24	25	0.896	0.7011	420	200
9	10	1.044	0.74	60	20	6	26	0.203	0.1034	60	25
10	11	0.1966	0.065	45	30	26	27	0.2842	0.1447	60	25
11	12	0.3744	0.1298	60	35	27	28	1.059	0.9337	60	20
12	13	1.468	1.155	60	35	28	29	0.8042	0.7006	120	70
13	14	0.5416	0.7129	120	80	29	30	0.5075	0.2585	200	600
14	15	0.591	0.526	60	10	30	31	0.9744	0.963	150	70
15	16	0.7463	0.545	60	20	31	32	0.3105	0.3619	210	100
16	17	1.289	1.721	60	20	32	33	0.341	0.5302	60	40

Table. 4 Basic features of ABB 1MW central inverter

S#	Parameter	Rating
1	Rated power	1000 Kw
2	Maximum power	1200 kW
3	Output DC voltage range	600-850 V
4	DC voltage (V_{max})	1100 V
5	DC current (I_{max})	1710 A
6	6. DC (Direct current) inputs	8-20 A
7	Rated AC voltage	400 V
8	Rated AC current	1445 A

4. Results For Evaluation of Impact of Distributed Generation

Three cases are simulated for observation of reliability indices, voltage drop and power loss improvement as mentioned in (**Table.5)**

Table. 5 Case studies

Case No:	Description
1	Base case (without DG integration)
2	Integration of 1 DG
3	Integration of 2 DG

4.1 Reliability indices simulation results

Reliability indices of IEEE 33 bus system with and without solar DG integration are shown in **(Fig. 4)**. The value of SAIDI before DG were 8.0494 hr/consumer. year and after solar DG integration improved by 65.71%. The value of SAIFI before DG integration found to be 1.891 f/consumer. year and after solar DG integration improved 78.15%. The value of CAIDI before DG were 4.266 hour/customer. interruption and after solar DG integration improved 38.66%. The value of ASAI before DG were 0.9812 p.u and after solar DG integration it is improved by 1.62%. The value of ASUI before DG were 0.01876 p.u and after solar DG integration it is improved 84.28%. The value of AENS before DG were 0.187MWh/consumer. Year and after solar DG integration improved 85.19%. The value of EENS before DG were 28.2 MWh/year and after solar DG integration it is improved 61.03%. The value of ECOST before DG were 112970.4 $/MWh and after solar DG integration its cost is reduced by 64.71%. reliability indices values are mentioned in **(Table 6).**

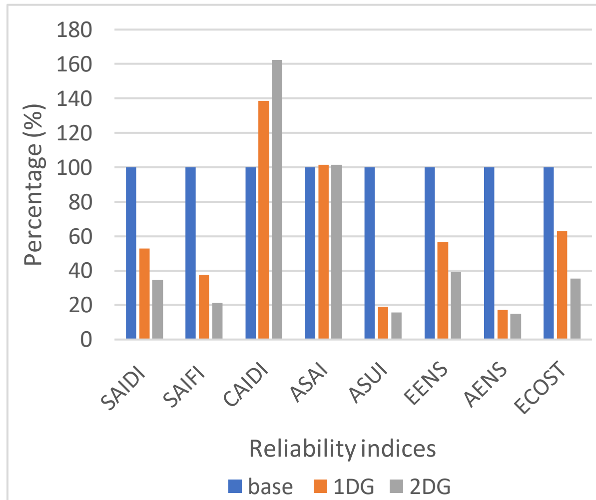

Fig. 4: Reliability indices plot of IEEE 33 bus system

Table 6. Reliability indices of IEEE 33 bus system

System configuration	SAIDI (hr/c.yr)	SAIFI (f/c.yr)	CAIDI (hr/c.int)	ASAI (p.u)	ASUI (p.u)	EENS (MWh/yr)	AENS (MWh/c.yr)	ECOST ($/MWh)
Base case	8.0494	1.891	4.266	0.9812	0.01876	28.2	0.187	112970.4
1DG	4.256	0.71	5.9153	0.00354	0.00354	15.9	0.0323	70976.6
2DG	2.7941	0.402	6.93	0.00295	0.00295	10.99	0.0277	39872.3

Table.7 Voltage of the test network before and after DG integration

Test system	Base case		After DG	
	Voltage (p.u)		Voltage (p.u)	
	Minimum	Maximum	Minimum	Maximum
Base case	0.9038 at bus 18	1.00 at bus 1		
1DG			0.96061 at bus 18	1.00 at bus 1
2DG			0.997786 at bus 18	1.00 at bus 1

Table. 8Power loss before and after DG integration

Test system	Base case		After DG		Power loss reduction (%)	
	Power loss		Power loss			
	Ploss (KW)	Qloss (KVar)	Ploss (KW)	Qloss (KVar)	Ploss (KW)	Qloss (KVar)
Base case	211	143				
1DG			94	65.2	55.45	54.4
2DG			71	54.8	66.35	61.67

4.2 Voltage profile improvement simulation results:

(Table 7) shows that in base case voltage drop across 18 bus is 0.9038 P.U which is less than the allowable voltage limit of distribution system. This under voltage is improved in this paper by integration of solar DG of optimal size and location. After solar 1DG integration has improved voltage profile by 6.28% and after integration of solar 2DG voltage profile is improved by 9.41%. Voltage profile improvement of IEEE 33 bus system with and without solar DG integration is shown in **(Fig. 5)**.

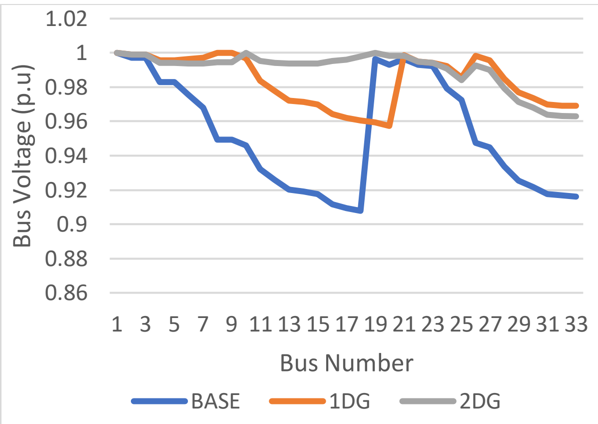

Fig.5: IEEE 33 bus system voltage profile improvement

4.3 Power loss reduction simulation results:

(Table 8) shows that in without DG total power (active) loss is 211kW and total (reactive) loss is 143kVar. This line loss (active and reactive) is reduced by integration of solar DG of suitable size at optimal locations. Solar 1DG integration has reduced overall line losses (active and reactive) by 55.45% and 54.4%. Integration of solar 2DG has reduced line loss (active and reactive) by 66.35% and 61.67%. the line losses with and without DG integration are shown in **(Fig. 6** and **Fig. 7).**

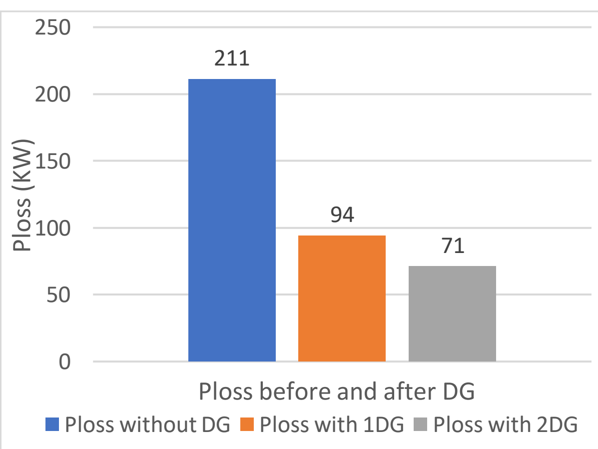

Fig. 6: Active power loss before and after DG

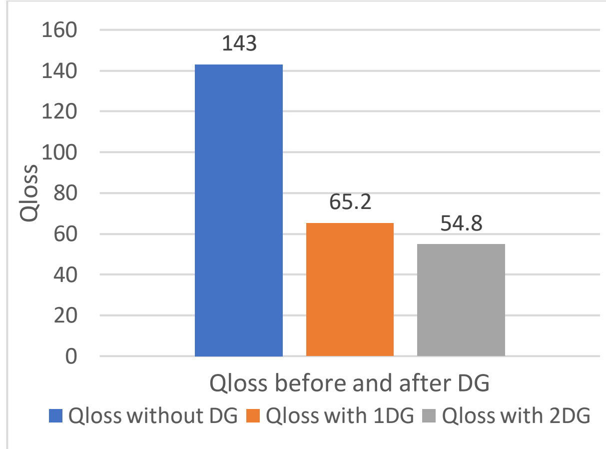

Fig.7: Active power loss before and after DG

5. CONCLUSIONS

There is reliability, 13% losses and voltage drop issues in distribution network due to consumers indicative load behavior. In this IEEE 33 bus network is modeled in ETAP software. Optimal locations and sizes are obtained by PSO algorithm using MATLAB code. (Mahesh *et. al.* 2015) using PSO algorithm reduces power loss by 56.73% but in this paper active power loss is reduced by 66.35%. Before DG allocation voltage at bus 18 was crossing allowable limits and after DG integration voltage at all the nodes is within permissible limits. Voltage of node 18 after solar DG allocation is improved by 9.41%. Reliability indices are improved like SAIDI (65.71%), SAIFI (78.15%), CAIDI (38.66%), ASAI (1.62%), ASUI(84.28%), AENS(85.19%), EENS (61.03%) and ECOST (64.71%). Furthermore, a greater number of DG unit's integration in RDN, improves the reliability, voltage and power losses performance of the network.

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