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Multiple Distributed Generation System Penetration in a Radial Distribution Network

Amandeep Gill, Surendra Kumar Yadav, Pushpendra Singh

Abstract*: Introduction of the distributed generation system is the boon to the existing distribution network. Distributed generations are placed near the load centers and hence reduce the transmission losses. Distributed generation systems are also beneficial for voltage profile improvement, minimizing the real and reactive power losses of the existing network. Renewable distributed generation systems has various ecological benefits. In this paper, we are working on multiple distributed generation penetration for the real and reactive power loss minimization and voltage profile improvement. There are four kinds of distributed generation systems exist based on their power supplying capability. Optimal penetration of multiple distributed generation system will be done at the buses having the lowest voltage sensitivity index. Optimal sizing of the multiple distributed generation system will be considered for the sizes showing maximum power loss reduction. This multiple penetrations will be tested at the IEEE 33 bus radial distribution network. For load flow analysis forward-backward sweep method will be applied at the IEEE 33 bus radial distribution network.

Index Terms*: Distributed Generation system (DGs), Radial distribution network (RDN), distribution network (DN) Powerfactor (PF), perunit (pu), Voltage sensitivity index (VSi).

I. INTRODUCTION

The existing power system structure has undergone the deregulation, due to which generation, transmission and distribution are disintegrated into different firms. GENCO is for generating and selling the power at a wholesale rate. TRANSCO is for transmitting the bulk power to the load centers. DISCO is for distributing the power in a particular region at retail rates. Transmission and distribution systems transfer the power at different voltage levels from one end to another end. Yet their network geographies and also features are fairly different. Distribution systems are popular for their low X/R proportion as well as significant power losses occur together with the feeders as a result of considerable voltage decline. Roughly 70% of the total electrical power system real power losses occurred in the distribution network (DN)[1]. The existing power system needs enormous financial investments and huge areas for generating stations which further causes environmental concerns. The substitute of this is to install small generation utility in the distribution network which will not just need a modular and versatile financial investment yet will certainly also provide various other technical, economic and ecological advantages. In order to attain the optimum benefits by integrating Distributed Generation systems (DGs) within the distribution network, the focus has to be provided to their siting and sizing. The power losses in the distribution systems are due to the factors like the density of load, distribution of the loads in the urban and rural areas, inappropriate structure of distribution system, the standard of construction and material, poor maintenance, harmonics etc. DGs are in trend from the last decade due to the environmental concerns by the traditional power generating stations which uses the non-renewable fuels. DGs operate on both renewable and non-renewable fuels. DGs refer to little power generation facilities varying from few kW to several MW. DGs are allocated close to the load centers, therefore reduces the line losses. The allocation of DGs in the distribution network has been triggered some favorable along with negative effects on power distributions and voltage problems in the distribution network. These effects depend upon not only on the characteristics and problems of distribution network's procedure but also the qualities of DG linked to the grid, particularly its siting, size as well as kind. DGs operate on different technologies from standard to modern power generation [2]. The standard technology is dependent on non-renewable sources like consolidated heat and power plant, diesel engines, reciprocating engines, consolidated cycle gas turbines, combustion turbines and micro-turbines. The modern technologies are like Fuel cells, PV cells and renewable-based generation. The disputes and advantages for utilizing DGs in the distribution network are divided into three parts, technological, economic and ecological. The technical problems are synchronization of protection devices, the occurrence of harmonics, reverse power flows, dynamic stability, system islanding, reclose problems, false tripping of relays. The economic problems are the costing of DGs, its maintaining expense and its working expense. The ecological problems are like the sound and shadow flicker brought on by large wind blades. The technical advantages of DGs are a decline in the total system losses, improvement of the network voltage account, decrease thermal anxieties on transformers and feeders, DGs can be constructed and developed in lesser time, decrease in consumer dependency on the main grid during peak load, decrease in transmission and distribution networks congestion. The economic benefits of DGs are reduced transmission and distribution relevant costs, lesser project investments, lesser fuel prizes, lesser maintenance costs, and lesser operation costs [3].

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***** Correspondence Author (s)
Amandeep Gill*, B.E. from University of Rajasthan, Jaipur Thapar University of Patiala, Punjab.
Dr. Surendra Kumar Yadav, Professor of Computer Science and Engineering in JECRC.
Dr. Pushpendra Singh, M.Tech. in Power System and Ph.D. in Electrical Engineering from Malviya National Institute of Technology (MNIT) Jaipur, Rajasthan, India.

The ecological benefits of the DGs are a reduction of greenhouse gases as compared to the conventional power plants. The conventional radial distribution networks (RDN) are unidirectional for power distributions. With the introduction of DGs in the RDN, it has bidirectional power streams. In the last decade, the swiftly boosting allocation of DGs in the network is causing some functional troubles and impacts in existing setups. The influences of the infiltration level of DGs units depend upon its areas, sizing, kind, power factors and a load factor of the power system. In this paper, multiple DGs sizing and penetration in the existing radial distribution network for minimization of real and reactive power losses is suggested, which further improves the voltage profile. DGs are utilized for real and reactive power compensation in the DN. Allocation of DGs is for the planning of real and reactive power of DN. Reason for the maximum power losses in the DN is the maximum presence of inductive loads. The proper setups of DGs in the RDN is necessary for numerous reasons like minimization of power losses, price decrease, voltage account renovation, voltage stability renovation, ecological benefits. This effect can be boosted by means of optimum DG positioning and sizing. Three DGs that ran at various power factors (PF) are set up into the network. Two circumstances of each DGs are checked. The initial take into consideration the DGs with unity PF, while the other DGs has the 0.9 leading PF. This multiple DGs penetration will be checked at IEEE 33 bus RDN and the outcomes will be compared to the outcomes of the RDN without DGs [4].

II. Modeling of RDN for Multiple Penetrations of Optimal DGs

There should be some assumptions for the modeling of the IEEE 33 bus RDN, which are as follows:

- Load flow analysis should be done by considering base apparent power (S_b = 100MVA) and base voltage (V_b =12.66 kV).
- Three DGs that operated at various power factors i.e. infuse just pure actual power (unit PF) or infuse actual power and reactive power (0.9 leading PF) are placed in the RDN.
- The buses connected with the load will be considered for DGs penetration and the source buses will not be considered for DGs penetration.
- Assume the voltage at the initial bus as 1.0 per unit (pu).
- The upper and lower limitations of bus voltages are between ± 0.05 pu.
- There should be one DGs placed on each bus.
- The loads utilized in the modeling should be uniform with continuous power.

A. Load flow analysis

A backwards-forward sweep method is utilized for a load flow analysis of the 33 bus balanced three-phase RDN. This method utilizes the KVL for calculating the voltage at each node and KCL for calculating current at each branch. Initially, the voltage at each bus will be assumed as 1.0 pu. Consistent power loads of design are utilized in the evaluation. The voltages of the last iterations are utilized for calculating the current. The voltage dip at each branch will be computed. The voltages and currents in each iteration until the final iteration is reached. The iterations will end when the difference in last iteration voltage and the current iteration voltage will be less than 0.0001. In DGs synchronous generators are utilized for geothermal power, tiny hydropower, combustion turbines and integrated cycles. The induction generators are utilized for wind and micro-hydro power. The power electronic inverter generators are utilized for micro gas turbines, solar power, PV cells and fuel cells. DGs can be designed as PQ type (Apparent power supply) e.g. induction generator for the RDN. DGs can be designed as PV type (Voltage controlled bus) e.g. synchronous generator controls the network voltage by managing excitation voltage in the RDN. The PV design controls the incurable bus voltage by adjusting its reactive power result. Nevertheless, it is liked to not to make use of a PV version, given that injecting an excellent amount of reactive power in order to increase the bus voltage may overheat the generator and causes high field currents, activating the excitation restriction and detaching the generator from the RDN. The PQ design is commonly utilized DG version. In this version, DGs load is considered a negative load supplying real and reactive power to the RDN. Mainly DGs are of four kinds based on their power supplying capacity.

- DG A: DGs supplying real power, e.g. PV cell, fuel cell and so on (PF = 1).
- DG B: DGs supplying real and reactive power, e.g. synchronous generators (0<PF <1, lead).
- DG C: DGs supplying real power and consuming reactive power, e.g. induction generators for wind ranches. (0< PF<1, lag).
- DG D: DGs supplying reactive power just to enhance the voltage profile, e.g. kVAR compensator, capacitor banks and so on (PF = 0) [5].

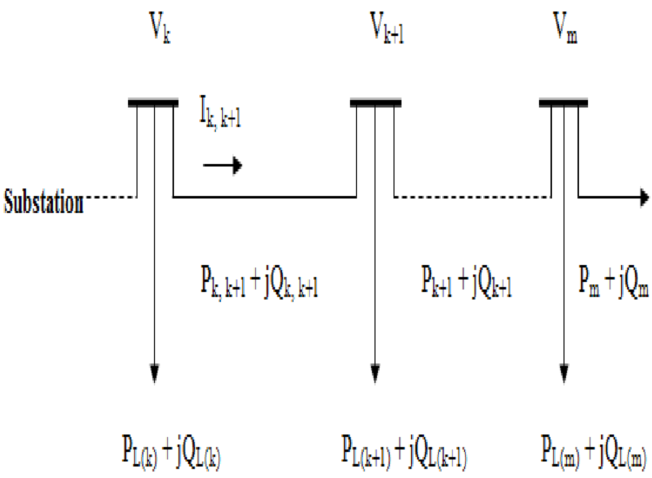

Figure 1. A Sample of RDN.

By taking into consideration the DGs properties and to model it as per our network requirement, the real and reactive power supply by the DGs to the k[th] bus of fig 1 are designed as follows:

$$P_{k,k+1} = P_{DGk} - P_{L(k)} \tag{1}$$

$$Q_{k,k+1} = Q_{DGk} - Q_{L(k)} = (\beta_k P_{DGk}) - Q_{L(k)} \tag{2}$$

$$Q_{DGk} = (\beta_k P_{DGk}) \tag{3}$$

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$$\beta_k = \pm\tan\left(cos^{-1}(PF_{DGk})\right) \quad (4)$$

Where $P_{k,\,k+1}$ is the real power in the feeder transferred from the bus k to k+1, P_{DGk} is the real power supplied by the DGs at the bus k, $P_{L(k)}$ is the real power consumed by the load at the bus k, $Q_{k,\,k+1}$ is the reactive power in the feeder transferred from the bus k to k+1, Q_{DGk} is the reactive power supplied by the DGs at the bus k, $Q_{L(k)}$ is the reactive power consumed by the load at the bus k. The PF and sign (±) depend upon the kind of DGs used. Here we are utilizing two DG A kind of DGs at unity PF and one DG B kind of DGs at 0.9 PF leading.

B. Model Formulation

This formulation is done for the optimal DGs penetration and sizing to minimize the real and reactive power losses, boost the voltage profile and stability of RDN while pleasing all restrictions for a set number of DGs and a certain complete ability of the DGs.

Objective feature

The objective features are taken into consideration independently as a single purpose for the DGs unit positioning as well as sizing problem in the radial distribution network [6].

Minimization of the real and reactive power losses

The real power loss of the branch between the bus k and k+1 is acquired by (5).

$$P_{Loss\,(k,k+1)} = r_{k,k+1}\left(\frac{P_{k,k+1}^2+Q_{k,k+1}^2}{|V_k|^2}\right) \quad (5)$$

Where $P_{Loss\,(k,\,k+1)}$ is the real power loss between the bus k and k+1, $r_{k,\,k+1}$ is the resistance of the feeder between the bus k and k+1, V_k is the voltage at the bus k.
The total real power loss in the RDN is acquired by (6).

$$F_1 = P_{Tloss} = \sum_{k=1}^{m-1} r_{k,k+1}\left(\frac{P_{k,k+1}^2+Q_{k,k+1}^2}{|V_k|^2}\right) \quad (6)$$

Where P_{Tloss} is the total real power losses of the network.
The reactive power loss of the branch between the bus k and k+1 is acquired by (7).

$$Q_{Loss\,(k,k+1)} = x_{k,k+1}\left(\frac{P_{k,k+1}^2+Q_{k,k+1}^2}{|V_k|^2}\right) \quad (7)$$

Where $Q_{Loss\,(k,\,k+1)}$ is the reactive power loss between the bus k and k+1, $x_{k,\,k+1}$ is the reactance of the feeder between the bus k and k+1.
The total reactive power loss in the RDN is acquired by (8).

$$F_2 = Q_{Tloss} = \sum_{k=1}^{m-1} x_{k,k+1}\left(\frac{P_{k,k+1}^2+Q_{k,k+1}^2}{|V_k|^2}\right) \quad (8)$$

Where Q_{Tloss} is the total reactive power losses of the network.

Voltage sensitivity index for finding the optimal location for DGs

To find the voltage sensitivity of the buses DGs at 30% loading was placed at each load bus at a time. Voltage sensitivity index (VSi) can be acquired by (9). DGs is placed at bus k, VSi for bus k is as follows [7]:

$$VSi_k = \sqrt{\frac{\sum_{k=1}^{m}(1-V_k)^2}{m}} \quad (9)$$

Where V_k is the voltage at the bus k and m is the number of buses. The bus with lowest VSI will be the optimal location for DGs penetration.

Optimal sizing for DGs

For finding the optimal sizing for DGs penetrate the DGs at the bus having lowest VSI. At constant PF vary the size of DGs from minimum range to the range equal to the branch load capacity in steps until minimum real and reactive power loss is attained. This is the optimal size for DGs.

C. Network restraints

The objective feature undergoes the adhering to restrictions like equality restraints and inequality restraints.

Equality restraints

Power equilibrium restrictions

The total real and reactive power supplied by DGs has to satisfy the power equilibrium restrictions.

$$P_S + \sum_{k=1}^{m} P_{DGk} = \sum_{k=1}^{m} P_{L(k)} + P_{Tloss} \quad (10)$$

$$Q_S + \sum_{k=1}^{m} Q_{DGk} = \sum_{k=1}^{m} Q_{L(k)} + Q_{Tloss} \quad (11)$$

Where P_s and Q_s are the real and reactive power supplied by the substation to the RDN.

Inequality restraints

Bus Voltage restrictions

The voltage at different buses ought to be preserved within the appropriate restrictions by (12).

$$V_{k,\,min} \leq V_k \leq V_{k,\,max} \quad (12)$$

Thermal restrictions

The current at numerous branches ought to be preserved within the appropriate restrictions by (13).

$$I_{k,\,k+1} \leq I_{max\,(k,\,k+1)} \quad (13)$$

Power limits of DG

The real and reactive power of DGs at the bus k, are managed between the appropriate restrictions by (14) and (15).

$$P_{DGK,\,min} \leq P_{DGK} \leq P_{DGK,\,max} \quad (14)$$

$$Q_{DGK,\,min} \leq Q_{DGK} \leq Q_{DGK,\,max} \quad (15)$$

A PQ design is taken under consideration for DGs. The DGs is placed on the test system of IEEE 33 bus RDN for evaluating its performance.

III. RESULTS

Two kinds of three DGs are considered for multiple DGs penetration in the RDN. Two DG A kind of DGs at unity PF and one DG B kind of DGs at 0.9 PF leading.

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The 12.66 kV, IEEE 33 bus RDN [8] containing 33 buses configured with one substation, is used for testing of three multiple DGs penetration at the buses having lowest voltage sensitivity index. Forward-backward sweep method has been applied for the load flow analysis of the network. The total real and reactive loads on this network are 3.8 MW as well as 2.4 MVAR. The single line diagram of IEEE 33 bus RDN is shown in fig 2.

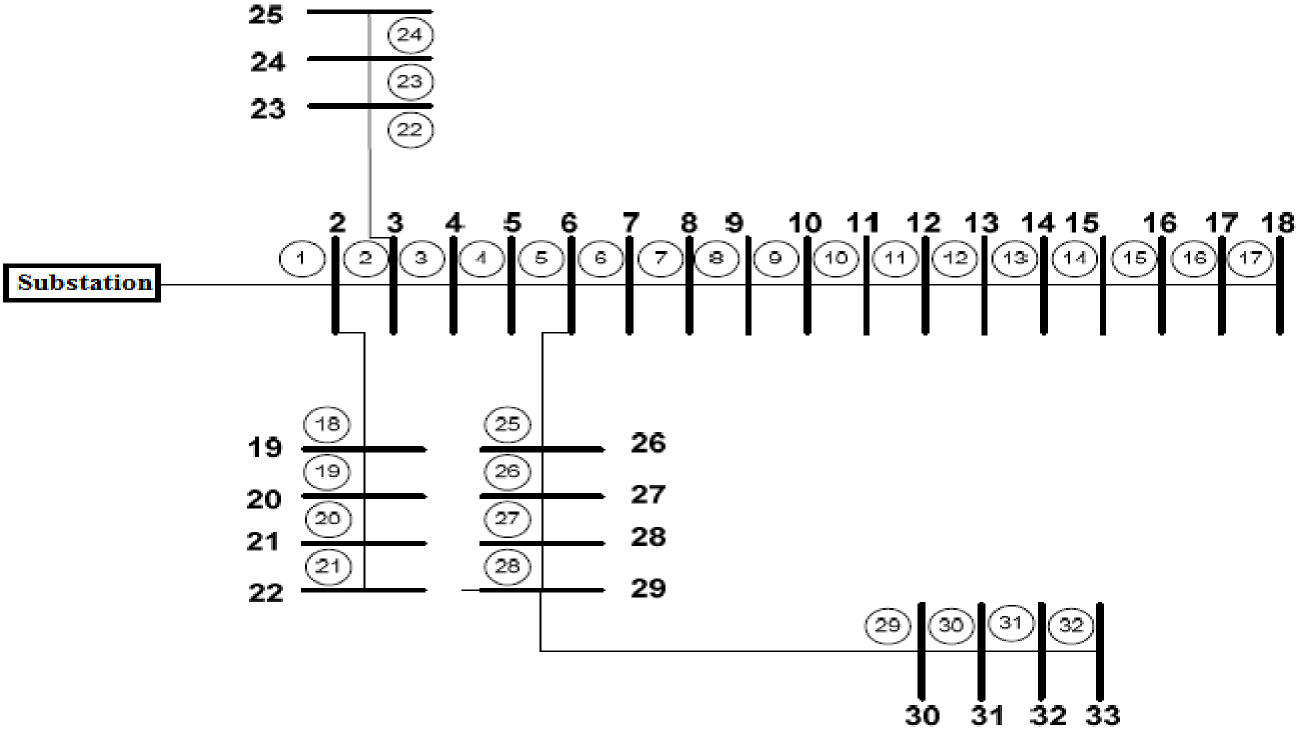

Figure 2. Single line diagram of IEEE 33 bus RDN.

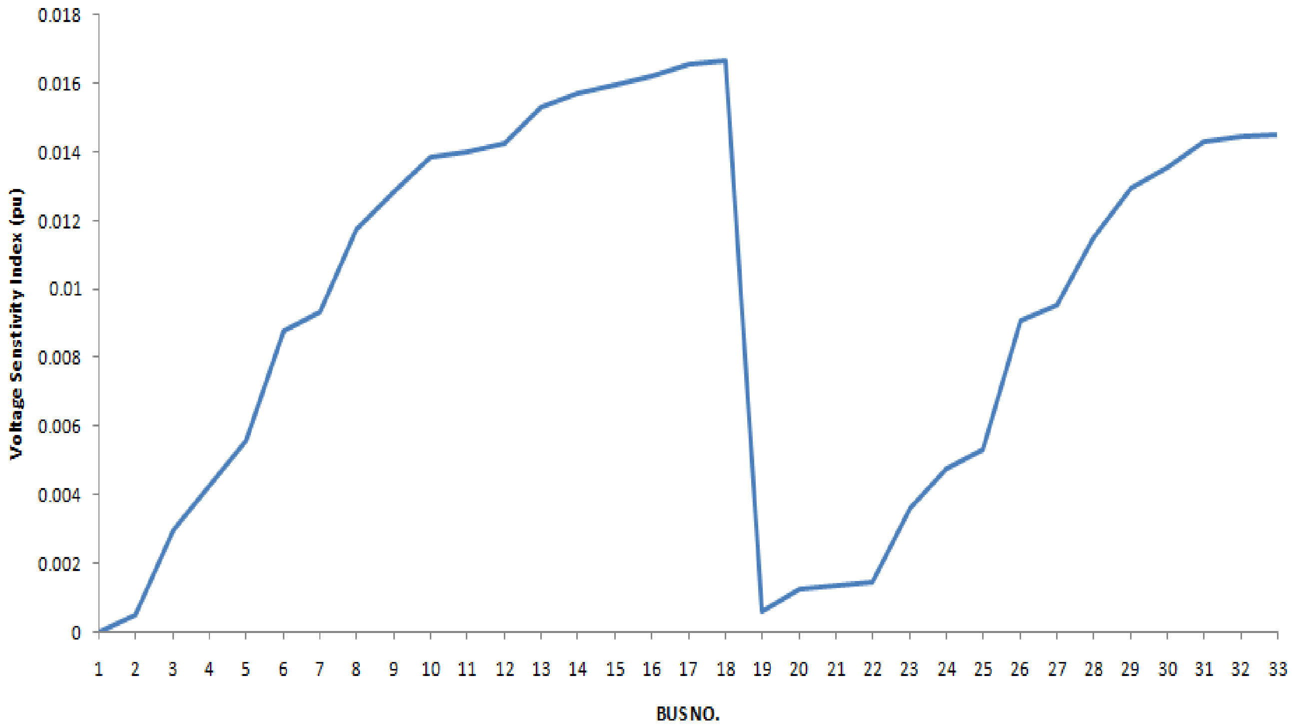

Figure 3. Voltage Sensitivity index of RDN.

As shown in fig 3 the VSI of the bus 19 is lowest i.e. 0.0006 pu, the VSI for bus 20 is 0.0012 pu, the VSI for the bus 22 is 0.0013 pu. The Buses 19, 20 and 22 are the optimal nodes for DGs penetration as they have the lowest VSI of the RDN. The optimal size for the multiple penetrations of three DGs is shown in table 1.

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Table 1. Details of Multiple DGs placed in the RDN

S.No.	DG Type	Power factor	Size (MVA)	Bus Location
1	DG A	Unity	1.35	19
2	DG A	Unity	1.63	20
3	DG B	0.9 leading	1.82	22

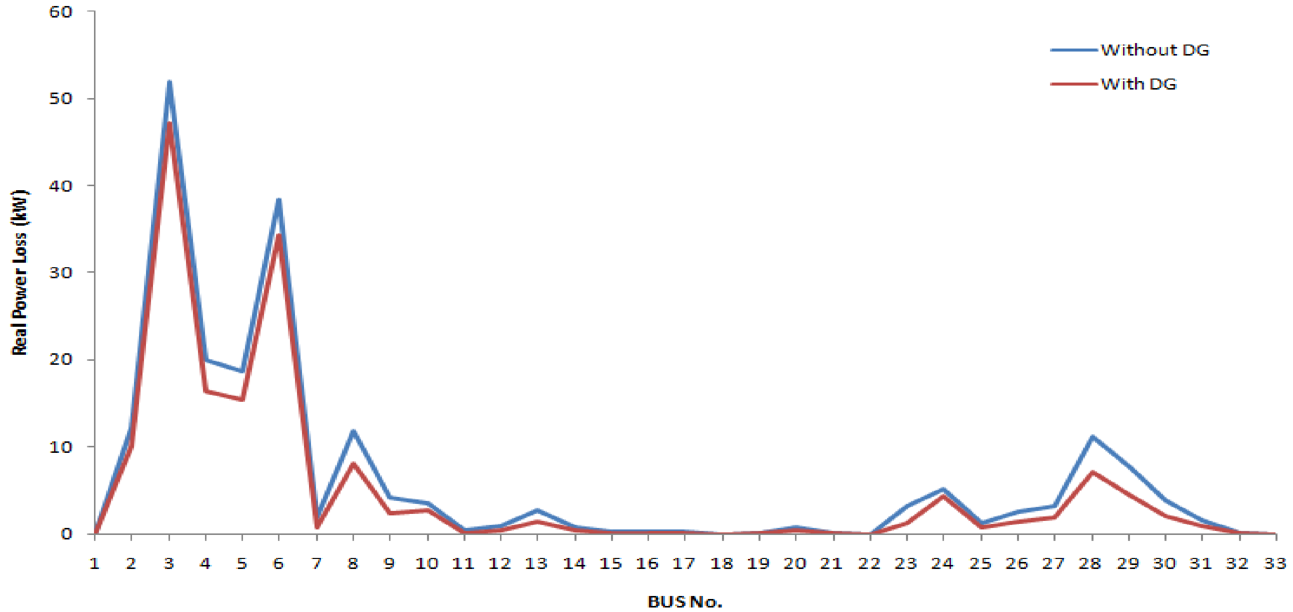

Figure 4. Real power losses of the RDN.

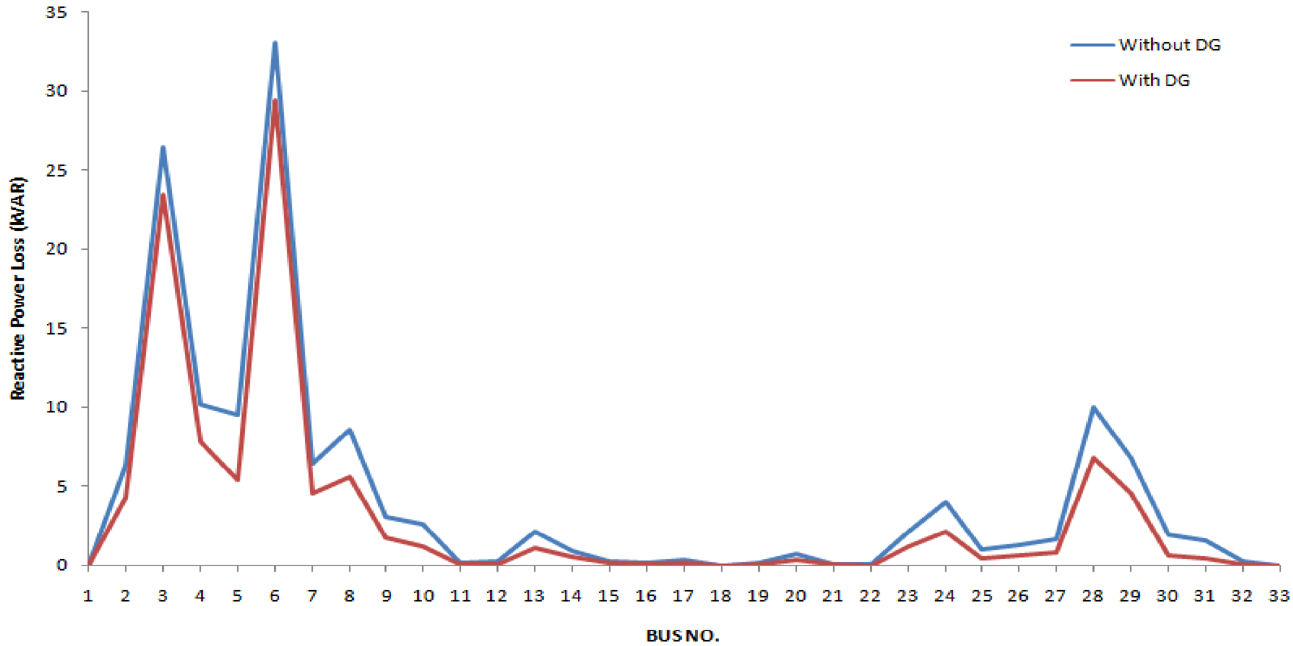

Figure 5. Reactive power losses of the RDN.

Multiple DGs penetration in the RDN has reduced the total real and reactive power losses of the RDN as shown in fig 4 and fig 5. Multiple DGs penetration has also enhanced the voltage profile of the RDN as shown in fig 6. Table 2 shows the results of the multiple DGs penetration compared with the results of RDN without DGs penetration. The real power losses are reduced by 20.18% and the reactive losses are reduced by 25.72% with the multiple DGs penetration.

Table 2. Results of the multiple DGs penetration.

S.no.	IEEE 33 BUS RDN	Real power loss (kW)	Reactive Power loss (kVAR)	Voltage Profile (pu)
1	Without DGs	208.58	140.36	0.943
2	With DGs	166.47	104.25	0.986

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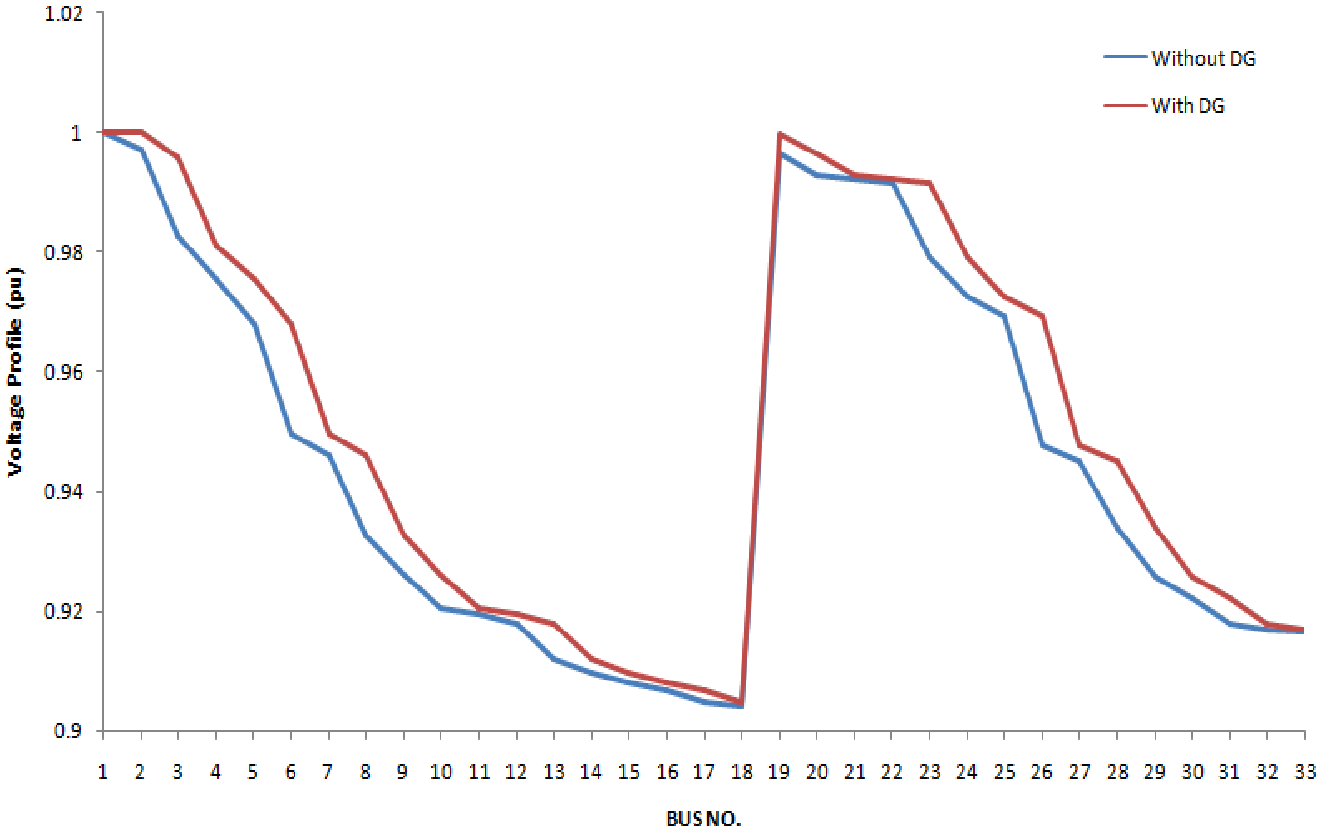

Figure 6. Voltage profile of RDN.

Voltage profile of the RDN has improved from 0.943 pu to 0.986 pu by the multiple DGs penetration.

IV. CONCLUSION

Three DGs are penetrated in the IEEE 33 bus RDN for the real and reactive power loss minimization and voltage profile improvement. Forward-backward sweep method has been applied for the load flow analysis of the network. This multiple DGs penetration is done on the buses having the lowest voltage sensitivity index, these buses are the optimal nodes for the penetration. The Optimal size of the DGs placed at the lowest VSi buses are selected by increasing the size of DGs from minimum to the branch loading capacity, the size at which maximum real and reactive power loss is obtained is the optimal size of DGs. Hence the real and reactive power losses reduced due to the multiple DGs penetration. The voltage profile of the RDN is improved.

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AUTHORS PROFILE

Amandeep Gill received his B.E. from University of Rajasthan, Jaipur and M.E from Thapar University of Patiala, Punjab. He is pursuing his Ph.D from JECRC University, Jaipur, Rajasthan. He is working as Assistant Professor at JECRC University, Jaipur, Rajasthan. His research fields are Distributed Generated systems, Power Systems, Artificial Intelligence etc.

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Dr. Surendra Kumar Yadav is presently working as Professor of Computer Science and Engineering in JECRC. He did M.Tech. in Computer Science, MBA in Human Resource management and Bachelors in law. He was awarded his Ph.D. in field of Search Techniques in Artificial Intelligence.

Dr. Pushpendra Singh received the M.Tech. in Power System and Ph.D. in Electrical Engineering from Malviya National Institute of Technology (MNIT) Jaipur, Rajasthan, India. He is currently working as Associate Professor, department of Electrical Engineering, JK Lakshmipat University, Jaipur, Rajasthan, India. He is the member of The Institute of Engineers, India (IEI).

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