Integration of Solar Photovoltaic Generation in a Practical Distribution System for Loss Minimization and Voltage Stability Improvement

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1 Introduction

The power system includes generation, transmission and distribution stations. The power is supplied to consumers by distribution system, and this control and operation of distribution system are becoming more complicated due to drastic variation of load on the system. In general, distribution system is connected in radial configuration. The R/X ratio is more in radial system which leads to more voltage drop and significant power loss. Due to continuous increase in load in the system, the source has to supply this load current which leads to more drops in voltage and increase in losses. This increase in voltage drop and system losses reduces distribution system performance [1].

Currently, distributed generation (DG) technologies are attracting the researchers as an alternative solution for the conventional power supply from the central grid in order to reduce voltage drop and minimize the losses. Distribution generation (DG) is also called as dispersed generation which is small-scale generation and mainly connected at the consumer end in the distribution system [2]. This DG technology can supply electricity from sources which includes renewable and non-renewable energy sources. The renewable energy sources are small hydro, geothermal, wind, biomass, solar and cogeneration. The non-renewable energy sources are gas turbines, fuel cell,

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reciprocating engines and micro-turbines. The emission from most of these sources is less so it is good for environment and reduces the voltage drop and minimize losses [3]. The more benefits from these DGs can be obtained by finding the optimal placement and sizing of DG in the distribution network which includes increase in voltage stability and reduction in losses, power quality improvement, reduced transmission and distribution congestion which intern reduces the overall cost. Different factors have to be considered for finding the optimal size and location of the DG such as DG penetration level, its position ambiguity and changing output from DGs [4]. Out of all the renewable sources, the use of solar photovoltaic generation (PV) is increasing day by day due to many advantages such as its environmental friendly, available in abundant, its operating and maintenance costs are low and cost of solar panels are decreasing day by day compared to costs of other renewable energy sources. The government is promoting this use of solar energy by providing financial support, and installation of residential solar panels is simple on rooftops or on the ground without any intervention to human lifestyle [5, 6].

The one of the realistic distribution feeder is Shivamogga, Karnataka, India. The DGs are grouped into four types depending on its delivering capacity of real and reactive power into system.

"Type1: DG capable of delivering both active and reactive power (e.g. synchronous machine).

Type2: This type of DG is capable of delivering only active power (e.g. module, micro-turbines and fuel cells).

Type3: DG capable of delivering only reactive power (e.g. capacitor banks).

Type4: DG capable of delivering active power but consuming reactive power (e.g. induction generators, which are used in wind farms)" [7].

Numerous methods have been found in order to determine optimal DG position by means of either analytical or heuristic optimization techniques. In [8], optimal DG positions are found by determining critical buses using power stability index. In [9], modified voltage index is used to find and increase voltage stability margin in the system, and optimization difficulty is solved by mixed-integer nonlinear programming technique. In [10], the particle swarm optimization (PSO) which is heuristic optimization techniques is used to find the size and position of multi DGs by taking into account multi-objective index. In [11] the cuckoo search algorithm and in [12] GA algorithm are used as heuristic optimization techniques in order to solve the optimal DG placement difficulty.

Many researchers have done work for determining best possible placement and sizing of PV generation by considering power loss reduction and voltage stability improvement. In [13], in order to determine optimum placement of PV and wind turbine, PSO technique was used. In [14], VSI method is used to find optimal location of DG, and artificial bee colony optimization method is proposed to find optimal sizing of hybrid PV/wind turbine/fuel cell.

The main purpose of this work is to study this distribution feeder is having low-voltage profile, high energy losses, and more power interruptions and congestion in the feeder. The best possible position and sizing of DG decrease the system losses

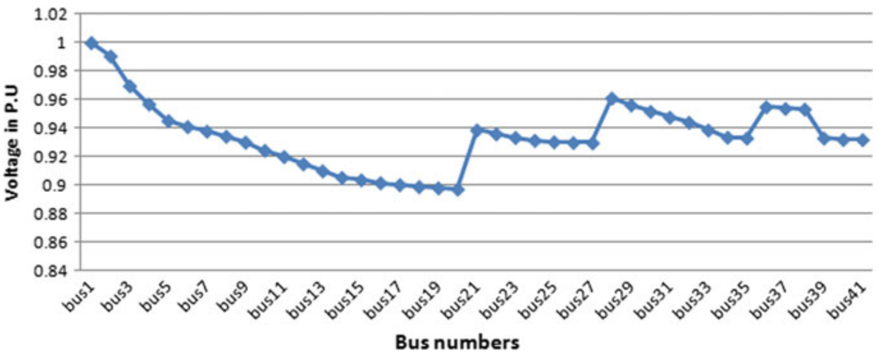

Fig. 1 Voltage profile of practical Devikathikoppa 41-bus distribution feeder

and pick up the voltage profile to stay within the suitable limits and thereby maintain voltage stability in the system.

2 Statement of the Problem

This manuscript analyses a practical distribution feeder called "Devikathikoppa feeder" emanating from 110/11 kV Alkola substation, situated in Shivamogga, Karnataka, India. The feeder has the peak load of 1.977 MW and 0.617 MVAR with 41 distribution transformers (DTC). The load on the distribution system increases with time due to rise in population. As load demand increases, there is an increase in the system losses and decrease in the voltage profile of the system. The consumer at the last bus will face the voltage stability problem, i.e. voltage profile is not within the acceptable limits; therefore, there is a decrease in performance of distribution system. Distribution generation (DG) placed at the consumer end will improve the voltage profile at the buses and decrease the total loss in the system. This paper analyses the main problems faced by the practical distribution consumers, i.e. reduced supply voltage and high system losses. The voltage profile of the existing "Devikathikoppa feeder" is shown in Fig. 1. During analysis, as per the standard we considered 6% variable voltage as acceptable stable voltage limit, i.e. $V_{\min} = 0.94$ p.u and $V_{\max} = 1.06$ p.u. In the subsequent part, we will show how optimum size and position of DG impact on voltage level of interconnecting buses.

3 Proposed Analysis Method

In our analysis, sensitivity factor method is used to calculate best possible size and position of DG using Power World Simulator software in order to decrease the losses and progress the voltages at the various buses which maintain the voltage stability in the system. For a given system, when size of DG is varied from P_{DG1} to P_{DG2} and the consequent change in power loss is correspondingly P_{L1} to P_{L2}, then formula to find the sensitivity factor is

$$\frac{dP_L}{dP_i} = \frac{P_{L1} - P_{L2}}{P_{DG1} - P_{DG2}}.$$

In this analysis, in order to reduce the search space in the system, the sensitivity factors are calculated for every bus using above equation. Out of which the bus with maximum sensitivity is recognized and all other buses which have sensitivity factors very near to the maximum value are selected for analysis. Then at all these selected buses, the DG size varies in large step value to find power loss. The bus which gives minimum loss for various DG size is best position, and corresponding generation is the optimum DG size [15].

4 Steps Used in PWS Software to Carry Out Simulation

The main aim of this sensitivity factor method is to discover best place and size of a DG unit to decrease the power losses and get better the voltage profile in the system. In a system, there might be several best possible locations and sizes for a DG unit, out of which any one solution is the best one.

“The following steps are carried out to model the test system in the Power World Simulator

1. Draw the buses and enter the data.
2. Draw the transmission lines, generators, load and enter the data as given in the test system.
3. Now run the model and study the voltage at all the buses and total losses in the system without DG.
4. Determine the sensitivity of each bus with small penetration of DG and list the most sensitive buses.
5. Select a bus from the list and calculate power loss for large variation of DG size.
6. Make sure whether all sensitive buses have been analysed.
7. Find the bus which has minimum power loss and its corresponding DG size.
8. Find the voltages at all the buses with optimum DG size and location.
9. Analyse the voltage stability of the system.
10. If the voltage stability is not maintained at all the buses. then increase the DG size at a optimum location until the voltage stability is maintained” [15].

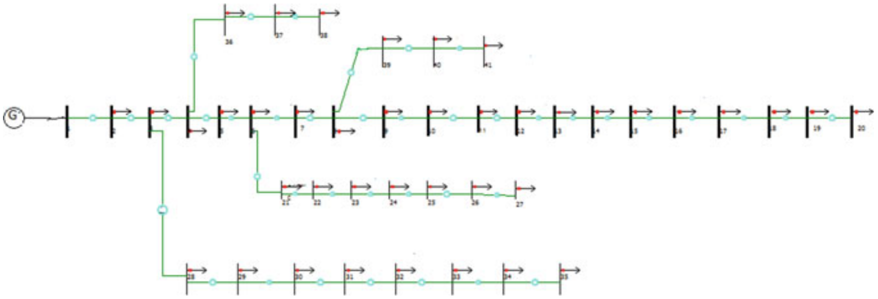

Fig. 2 41-bus practical Devikathikoppa distribution feeder

5 Simulation Results

5.1 *Devikathikoppa 41-Bus Practical Distribution System, Shivamogga*

The practical "Devikathikoppa feeder" is shown in Fig. 2 which is a 11 kV distribution feeder having total 41-bus with bus-1 is the slack bus and is modelled and simulated in Power World Simulator software, and voltage stability and system losses are analysed with and without placement of DG. Without DG real power loss of the system is 0.1334 MW, reactive power loss is 0.096 MVAR and minimum bus voltage is 0.8967 p.u at peak load.

The following different cases are considered as below:

Case-1: Integration of only DG units.
Case-2: Integration of only capacitor.
Case-3: Incorporation of DG and capacitor simultaneously.

Case 1: Integration of only DG (solar PV module) unit

The simulation diagram of Devikathikoppa feeder in PWS is as shown in Fig. 3. The proposed loss sensitivity factor technique is used to find the optimal placement and sizing of DG. The optimal placement obtained using this method is at bus 18 and size of DG is 30% of the total generation obtained without DG from central grid. The optimal DG location obtained from this method is at bus-18 with DG size of 0.633 MW.

The results, before and after DG placement, are shown in Table 1. After DG placement, the real power loss is reduced to 0.0783 MW from 0.1334 MW, reactive power loss is reduced to 0.0589MVAR from 0.096 MVAR, and lowest bus voltage is also improved to 0.9401 p u from 0.8967 p u.

By placing DG, the system real and reactive power losses are reduced to 41.30% and 38.54, respectively, and voltage profiles at all the buses are within the acceptable limits (0.94 < Vi < 1.06) which in turn improves the voltage stability of the system.

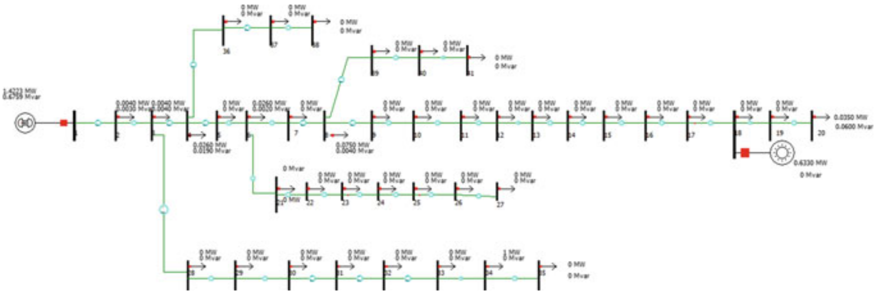

Fig. 3 Devikathikoppa feeder is modelled in PWSS with optimal placement and size of DG

Table 1 Loss reduction analysis

Cases	With out DG	DG only	Capacitor only	DG and capacitor
DG location at bus	–	18	18	18 and 16
Active power supplied by DG in MW	–	0.633	0	0.633
Reactive power supplied by DG in MVAr	–	0	0.214	0.214
Active power loss in MW	0.1334	0.0783	0.1188	0.0709
Reactive power loss in MVAr	0.096	0.0589	0.088	0.0498
P loss reduction in %	–	41.30	10.94	46.85
Q loss reduction in %	–	38.64	8.33	48.12

Case 2: Integration of only capacitor

The optimal size and location of shunt capacitor unit for 41-bus system are calculated by proposed technique, and it is 0.214 MVAR at bus-18. After capacitor placement, the real power loss is reduced to 0.1188 MW from 0.1334 MW, reactive power loss is reduced to 0.088 MVAR from 0.096 MVAR, and minimum bus voltage is also improved to 0.9166 p u from 0.8967 p u. The results are shown in Table 1.

Case 3: Integration of DG and capacitor simultaneously.

In this case, both DG and capacitor are located simultaneously, the optimal size of DG is 0.633 MW at bus-18, and optimal size of capacitor is 0.214 MVAR at bus-16. From Table 1, it can be seen that after DG and capacitor placement, the percentage real and reactive power loss drop of the practical system are 46.85% and 48.12%, respectively. The least bus voltage is also improved to 0.9431 pu from 0.8657 pu.

Comparison of voltage profile for 41-bus practical distribution system for various cases is shown in Fig. 4. It can be seen from Fig. 4 that after simultaneous position of DG and capacitor the voltage profile of each bus is within the allowable limit.

The real power loss for different cases is shown in Fig. 5, and reactive power loss for different cases is shown in Fig. 6. The figure shows that more reduction in real

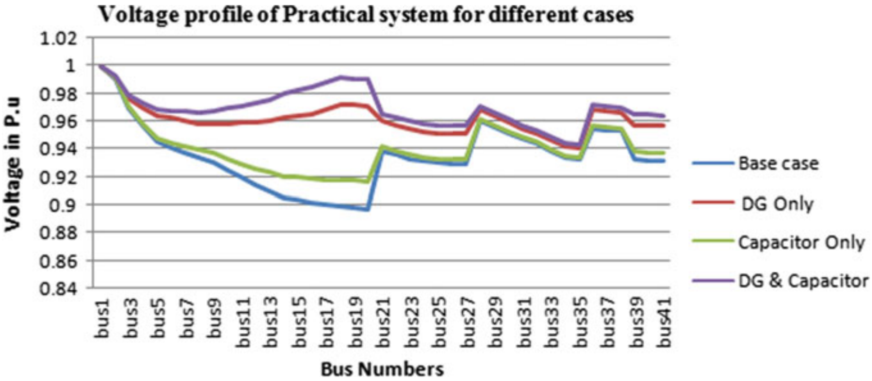

Fig. 4 Voltage profile of practical 41-bus distribution system for different cases

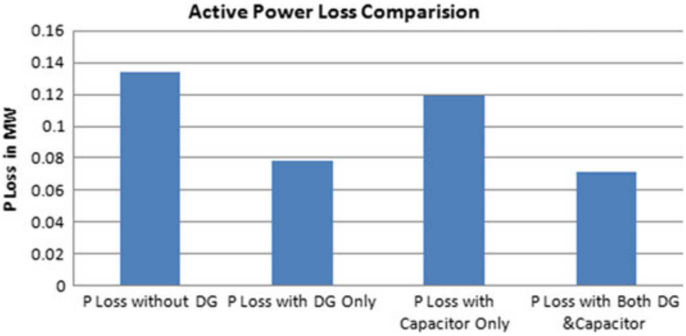

Fig. 5 Real power loss of practical 41-bus distribution system with different cases

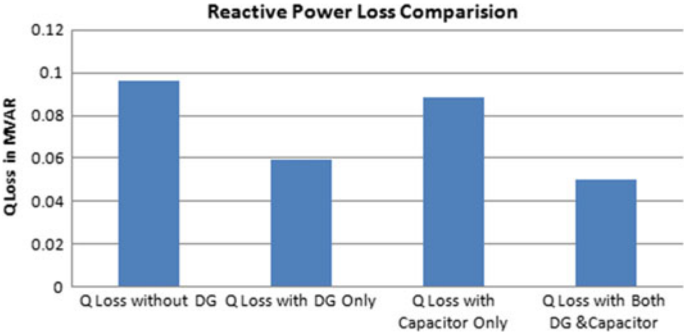

Fig. 6 Reactive power loss of practical 41-bus distribution system for different cases

and reactive power losses occurs when we place DG and combination of DG and capacitor in the distribution system.

6 Conclusion

This work analyses a practical distribution feeder called “Devikathikoppa feeder” emanating from 110/11 kV Alkola substation, positioned in Shivamogga, Karnataka, India. The feeder has 41-bus with peak load of 1.977 MW and 0.617 MVAR. New technique based on loss sensitivity factor is implemented to minimize total power loss and improve voltage profile of RDS by optimal position and sizing of DG and capacitor by considering various operating conditions. To test the effects of the proposed method, it is tested on 41-bus real distribution system of Devikathikoppa feeder in Shivamogga city. The result shows that once DG and shunt capacitor allotment is done, the percentage real and reactive power loss reduction of the practical system are 46.85% and 48.12%, respectively, and voltage profile at all the buses is within the acceptable limits. The consumers or utility companies are encouraged to set up a rooftop solar PV system at the load side after analysing the results of practical distribution system.

Appendix

Table 2 shows the geographical site condition of Shivamogga, and Fig. 7 shows the monthly solar radiation details of Shivamogga city.

Table 2 Geographical site condition of Shivamogga

S. No.	Geographical site	Technical value	Unit
1	Latitude	14	^{o}N
2	Longitude	75	^{o}E
3	Elevation	632	m
4	Ambient temperature	20–30	^{o}C
5	Relative humidity	55–75	%
6	Tilt angle	7–20	Degree

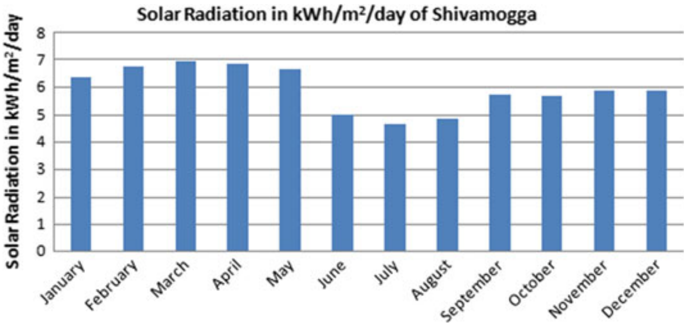

Fig. 7 Monthly solar radiation details of Shivamogga city

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