VOLTAGE PROFILE IMPROVEMENT OF A DISTRIBUTION FEEDER BY OPTIMAL PLACEMENT OF SOLAR PHOTOVOLTAIC USING GENETIC ALGORITHM

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Abstract— With consideration to importance of power quality in power system especially in distribution systems and with increasing load demand in lengthy radial distribution feeder which have lower voltage at the farthest end node, in this paper voltage profile distribution feeder has been surveyed. Genetic Algorithm (GA) based method has been used for optimal siting and sizing of active power source, solar Photovoltaic (PV), as distributed generation (DG) for improvement of voltage profile of the distribution feeder. The proposed method minimizes the summation of difference of voltage at each bus from unity for improvement of voltage profile. The search method of GA is limited to 50 generation with 50 number of population, 0.8 crossover fraction and 0.01 mutation fraction. The proposed method is used for placement of three, four and five number of solar PV on 11 kV Tandi Feeder of Ratnanagar Tandi Distribution Centre, Chitwan, Nepal. The analysis has been performed by means of coding in MATLAB for optimal placement of solar PV and static load-flow simulation in Digsilent PowerFactory and the application results are found to be promising.

Key words— *Distribution feeder, Voltage profile, Photovoltaics, Distributed Generation, Optimal placement and Genetic Algorithm.*

I. INTRODUCTION

Electrical energy is very essential form of energy to the human life. Between the year 2000 and 2016 the annual average rate of increase in electricity demand in Southeast Asia is 6.1%, which is twice the world's demand and in Nepal it has increased by an average annual rate of 10% for the last few decades [4, 8]. As per the reports in [2], majority population of Nepal lives in rural area and electricity supply feeder in these area are lengthy and radial type. Because of long length, voltage at the far end of rural distribution feeder becomes considerably low and low voltage issue becomes more severe during summer season when load increases. Because of low voltage in the feeder the loss of the feeder increases so maintaining the voltage profile is a major concern of distribution system. To maintain voltage profile in distribution networks, active power injection at different nodes of the feeder as distributed generation (DG) can be used as useful approach. Injection process includes optimal locating and sizing of DG for voltage profile improvement. Solar Photovoltaic (PV), with its clean and free availability, is one of the technologies used as DG for improvement of voltage profile of radial distribution network which has significant load during day time.

The authors of [9] have defined 4 sets of indices to quantify the benefits of DG and concluded that the introduction of DG in a distribution system offers several benefits to utility, customers and society such as reduced line losses, reduced central generating station's reserve requirements, improved voltage profile, increased system reliability and enhanced power quality. Studies presented in [6] and [10] attempted to establish the impacts of PV on voltage and determines the maximum distributed photovotltaic's generation to the distribution grids in Sweden. Three grids were considered in the studies and showed increase in voltage rise at the buses. The authors have discovered that with penetration of PV more than 1 MW, the voltage increases from 6:00 am to 6:00 pm without violation of grid code of Malaysia [7]. The authors of [5] has minimized the loss and improved the voltage profile of IEEE 37 node test-bus system by optimal reactive power planning using genetic algorithm. In this paper active power (solar PV) planning in present of loads of Tandi Feeder of Ratnanagar Tandi Distribution Centre, Chitwan, Nepal are described initially then problem formulation with fitness function introducing and optimal size and location of solar PV are found using Genetic Algorithm. Finally results have been shown on Tandi Feeder with 121 node.

II. OPTIMAL SOLAR PV PLANNING

Consumption growth leads to the increases in loss and drop in voltage of the distribution feeder. So finding methods that can keep system voltage in permissible limits and decrease losses synchronously is essential. This affair is performed by network active and reactive power control usually. Because low voltage can be very harmful for consumers, so solar PV placement as active power source for DG can also be one of best method for good power quality achievement. Improper selection of location and value of solar PV lead to increase in loss and voltage profile deviation.

III. METHODOLOGY APPROACH

In this paper the size and the location of the solar PV to be integrated into the feeder is to be optimized. Distribution systems have lines/cables with high R/X ratio and need load flow. The optimization methodology is Genetic Algorithm (GA) which maximizes or minimizes the given objective function and gives specified number of the output variables. The optimum size of solar PV to be integrated for voltage profile improvement to near about 1 per unit (p.u.) is found by using GA. The optimization is done for up to 8 locations. The optimum sizes are simulated in Dig-silent PowerFactory for various results.

3.1 Load flow

Let us consider a branch of a radial distribution system as shown in the figure 1 below,

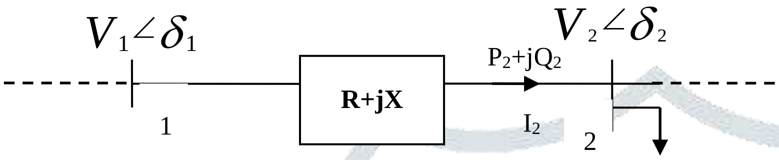


Figure 1: A branch of radial distribution network.

In the figure, 1 and 2 are sending and receiving end node of branch, P_2 and Q_2 are through power at bus 2 and R and X are resistance and the reactance of the branch.

Voltage magnitude and phase angle at receiving end node can be written in generalized form:

$$\mathrm{V(m2)} = \left|B(j) - A(j)\right|^{1/2}$$

Where; $A(j) = P(m2) * R(j) + Q(m2) X(j) - 0.5\left|V(m1)\right|^2$ and $B(j) = \left\{A(j) - \left[R^2(j) + X^2(j)\right] \times \left[P^2(m2) + Q^2(m2)\right]\right\}^{1/2}$

And

$$\delta(m2) = \delta(m1) - \tan^{-1}\left[\frac{P(m2) \times X(j) - Q(m2) \times R(j)}{P(m2) \times R(j) + Q(m2) \times X(j) + V^2(m2)}\right]$$

In above equations, J: the branch number, m1 and m2: are sending end and receiving end node respectively. If the deviation appeared in the voltage profile is less than the tolerance value then the load flow is said to be converged.

3.2 Problem formulation

The major concern in the optimal size and the location of solar PV system to be integrated to the feeder is the voltage profile improvement of the feeder. Hence, the location and the size of the solar PV are found subjected to minimal deviation of voltage at each bus from unity. Thus the objective function i.e. the fitness function of this study is to maximize voltage profile or minimize the voltage deviation as follows:

$$\text{Minimize, } V_{dev} = \sum_{y=1}^{N} (1 - V_y)^2$$

Where, V_{dev} is the deviation of the voltage of each bus from 1 p.u. V_y is the p.u. voltage at y^{th} bus of N-bus distribution network.

3.3 Genetic Algorithm

The Genetic Algorithm (GA) is a search algorithms based on the mechanism of natural selection and natural genetics which works with a population of individuals (chromosomes) and each individual stands for a solution. New generation is produced with considering individuals fitness function and genetic operators (selection, crossover and mutation) and individual's fitness improve through the algorithm iterations [3]. In this paper genetic algorithm is used for voltage profile improvement with consideration of optimal placement of the solar PV in distribution network. Stopping criteria determine the causes of the algorithm stopping and include two parts. The search method of GA is limited to 50 generation with 50 number of population, 0.8 crossover fraction and 0.01 mutation fraction. The GA methodology discussed above is implemented using following steps.

Step 1: Input the distribution system branch impedances and complex bus powers.

Step 2: Perform Base case Load Flow (without PV). Save the feeder voltage deviation (fitness value).

Step 3: Input maximum number of PV location i.e. three, four, five.

Step 4: Input genetic algorithm control data.

Step 5: Initialize population with random strings.

Step 6: Do while generation number is less than maximum number of generation taken (50).

- Do while population number is less than population size
- Pick up the string corresponding to population number and decode it into test configuration.
- Apply load demand and call distribution load flow solver.
- Compute fitness function.
- Increment population number by one.
- Use mating pool to create new population for next generation.
- Carry out reproduction, cross over and mutation in mating pool.
- Increment generation number by one.

Step 7**:** Find the best fitness value (minimum voltage deviation) and corresponding location (bus number) and size of PV in MW as global optima.

Step 8: end.

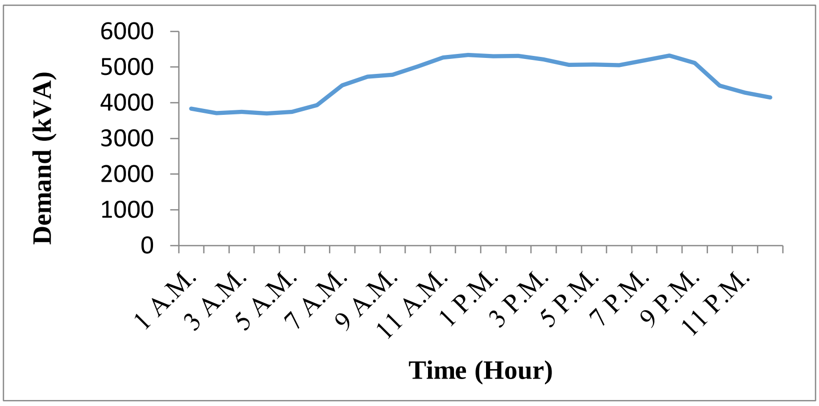
The algorithm discussed above is implemented as MATLAB toolbox, i.e. a group of related functions for finding optimum size and the location (bus number) of active power source (solar PV) for voltage profile improvement of the distribution feeder.

3.4 Simulation of the system in Digsilent PowerFactory

PowerFactory is a leading power system analysis software application for use in analyzing generation, transmission, distribution and industrial systems. Detail line diagram of Tandi Feeder is modeled and simulated in the Digsilent PowerFactory to obtain voltage profile, line loading and losses of the feeder before and after placement of solar PV.

IV. STUDY CASE

The selected network in this paper is 'Tandi Feeder' of Ratnanagar Tandi Distribution Centre,Chitwan, Nepal. This is 11 kV distribution feeder with 122 number of buses, which receives power from 16 MVA 33/11 kV transformer at Parsa sub-station. As this feeder passes through main city area (Tandi Bazzar) to rural area (Padampur), there is diversified end-user and load demand is almost equal during mid-day time and night time (7-8 PM). The end users on this feeder are industrial, commercial and domestic. As Tandi is in Chitwan district of Terai region with no significant altitude difference, microhydro isn't feasible for real power source. As per the report [1], the wind power density of Chitwan district is only 7 watt/square meter, so the wind turbine is also not feasible but annual tilt solar radiation of the Chitwan is 5.461 kwh/sq. m/day. So solar PV can be one of best renewable active power source for placement in Tandi feeder for voltage profile improvement.



Among 12 month, 3 months (Baishakh, Jestha and Ashad) has been selected for load profile analysis because it is the month at which voltage drop problem is more severe in this feeder. Average daily load demand of 3 selected months is shown in figure 2. The maximum loading on feeder at sub-station i.e. 5339.33 kVA (with 0.85 power factor) at 12 PM is chosen for base load for active power source (solar PV) placement. The bus node and line arrangement of the Tandi Feeder is as shown in figure 3 and transformer and line data is as shown in Table 1 below.

Figure 2: Average hourly load curve of Tandi feeder in the Baishak, Jestha and Ashad of 2075 B.S. (Source: Ratnanagar Tandi Distribution Centre, 2074 BS)

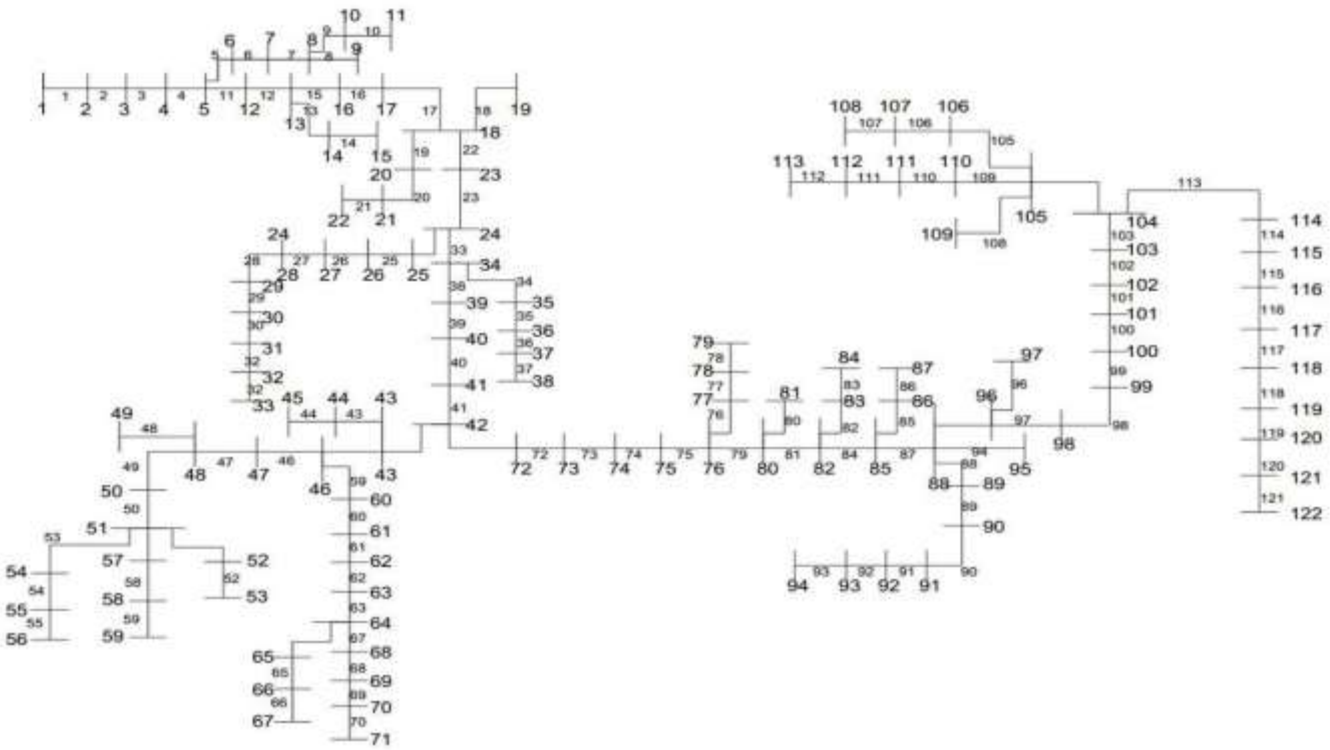


Figure 3: Bus node and line arrangement of the Tandi Feeder.

Table 1: Line and load data of Tandi feeder. (Source: Ratnanagar Tandi Distribution Centre, 2074 BS)

SN	RN	Condr Type	L (km)	Tr. Size (kVA)	SN	RN	Condr Type	L (km)	Tr. Size (kVA)	SN	RN	Condr Type	L (km)	Tr. Size (kVA)
1	2	Dog	0.8	50	42	43	Dog	0.2	100	83	84	Rabbit	0.5	50
2	3	Dog	0.5	50	43	44	Weasel	0.7	50	82	85	Dog	0.4	200
3	4	Dog	0.4	50	44	45	Weasel	0.5	50	85	86	Rabbit	0.5	50
4	5	Dog	0.5	50	43	46	Dog	0.4	50	86	87	weasel	0.5	50
5	6	Rabbit	0.6	100	46	47	Dog	0.3	150	85	88	Dog	1	50
6	7	Rabbit	1	50	47	48	Dog	0.4	150	88	89	Dog	0.4	100
7	8	Rabbit	0.5	50	48	49	Weasel	0.6	100	89	90	Dog	0.4	25
8	9	Rabbit	0.5	100	48	50	Dog	0.5	50	90	91	Dog	0.8	100
8	10	Rabbit	0.8	100	50	51	Dog	0.35	100	91	92	Dog	1	50
SN	RN	Condr Type	L (km)	Tr. Size (kVA)	SN	RN	Condr Type	L (km)	Tr. Size (kVA)	SN	RN	Condr Type	L (km)	Tr. Size (kVA)
10	11	Rabbit	0.7	50	51	52	Weasel	0.6	100	92	93	Dog	1	50
5	12	Dog	0.5	50	52	53	Weasel	0.5	100	93	94	Dog	1	25
12	13	Dog	0.3	50	51	54	Weasel	0.5	50	88	95	Rabbit	1	50
13	14	Rabbit	1	150	54	55	Weasel	0.5	25	88	96	Dog	0.6	50
14	15	Rabbit	1.5	100	55	56	Weasel	0.6	25	96	97	Weasel	0.5	100

13	16	Dog	0.4	50	51	57	Dog	0.5	200	96	98	Dog	0.8	100
16	17	Dog	0.5	100	57	58	Dog	1	50	98	99	Dog	0.6	50
17	18	Dog	0.4	100	58	59	Weasel	0.8	25	99	100	Dog	0.6	50
18	19	Rabbit	0.7	50	46	60	Dog	0.5	50	100	101	Dog	0.6	50
18	20	Rabbit	1	25	60	61	Dog	0.5	100	101	102	Dog	0.7	100
20	21	Rabbit	0.5	150	61	62	Dog	0.6	100	102	103	Dog	0.8	50
21	22	Rabbit	1	100	62	63	Dog	0.4	50	103	104	Dog	1	50
18	23	Dog	0.5	100	63	64	Rabbit	0.65	100	104	105	Dog	0.8	50
23	24	Dog	0.3	100	64	65	Rabbit	0.5	50	105	106	Rabbit	0.5	25
24	25	Dog	0.7	100	65	66	Rabbit	0.75	100	106	107	Weasel	0.5	50
25	26	Dog	0.6	100	66	67	Rabbit	0.7	200	107	108	Weasel	0.5	25
26	27	Dog	0.8	200	64	68	Rabbit	0.5	25	105	109	Weasel	0.4	25
27	28	Dog	0.1	50	68	69	Rabbit	1	50	105	110	Dog	0.1	50
28	29	Dog	0.2	200	69	70	Rabbit	0.9	100	110	111	Rabbit	0.8	50
29	30	Rabbit	1	50	70	71	Weasel	1	50	111	112	Dog	0.7	100
30	31	Rabbit	0.7	50	42	72	Dog	0.3	50	112	113	Dog	0.5	25
31	32	Rabbit	0.5	25	72	73	Dog	0.2	100	104	114	Dog	0.5	100
32	33	Rabbit	0.8	25	73	74	Dog	0.4	50	114	115	Dog	0.7	50
24	34	Dog	0.5	50	74	75	Dog	0.2	50	115	116	Dog	0.5	50
34	35	Dog	0.7	50	75	76	Dog	0.5	100	116	117	Dog	0.5	50
35	36	Dog	0.6	100	76	77	Rabbit	1	100	117	118	Dog	0.5	25
36	37	Dog	0.5	50	77	78	Rabbit	0.5	100	118	119	Dog	0.4	25
37	38	Dog	0.6	200	78	79	Rabbit	0.6	100	119	120	Dog	0.6	100
34	39	Dog	0.5	100	76	80	Dog	1	100	120	121	Dog	0.3	25
39	40	Dog	0.2	50	80	81	Weasel	0.9	50	121	122	Dog	2	300
40	41	Dog	0.4	50	80	82	Dog	0.5	50					
41	42	Dog	0.2	100	82	83	Rabbit	0.7	100					

SN: Sending Node, RN: Receiving Node, L: Length,
Transformer number and line number is as per RN.

V. RESULTS AND DISCUSSION

The proposed method was tested on 11 kV Tandi distribution feeder of Ratnanagar Tandi Distribution Centre, Chitwan, Nepal having 122 number of buses and 121 line section. Three options, case 1: three optimal location, case 2: four optimal location, case 3: five optimal location, for active power (solar PV) placement have been investigated. The total load on the feeder is 5339.33 kVA with 0.85 power factor and rated substation voltage is 11 kV and is considered as 1.0 p.u. The feeder network was modeled on Digsilent Power Factory using feeder parameter. The optimal size and location of active power source was obtained using GA for all three cases. The feeder network was simulated with and without solar PV on the feeder and voltage profile, line loss and line loading were obtained. The summary of line loss and minimum voltage before placement of active power source in the feeder is shown in Table 2 below.

Table 2: Minimum voltage level and power loss before PV placement.

Total Load	Minimum voltage (p.u.)	Minimum voltage bus number	Power loss (kW)
5339.33 kVA @ 0.85 pf	0.83352	122	484.638

It is seen that there has been up to 16.648% voltage drop in the farthest end bus of the feeder. Active power loss in the feeder is found to be 484.638 kW.

The result of proposed GA are summarized in Table 3. The minimum voltage after PV placement were also found in node number 122 for each cases.

Table 3: Optimal solar PV placement using proposed GA, losses, fitness value and minimum voltage.

Options	Fitness value after placement	Active power loss after placement (MW)	Minimum voltage after placement (p.u.)	Fitness value reduction (%)	Active power loss reduction (%)	Minimum voltage improvement (%)	Bus Number	PV plant Size (MW)	Total size (MW)
Case 1	0.0324	0.1614	0.9351	98.40	66.14	13.86	69	0.9367	3.13960
							101	1.6339	
							9.1	0.5690	
Case 2	0.0321	0.1510	0.9359	98.42	68.85	13.96	86	0.4113	3.13165
							96	1.0481	
							69	0.8535	
							114	0.8188	
Case 3	0.0310	0.1475	0.9380	98.47	69.57	14.22	88	0.6265	3.14346
							119	0.3344	
							89	0.6416	
							68	0.9404	
							104	0.6005	

Note: Fitness function value before placement of solar PV=2.032595
Active power loss before placement of solar PV=0.484638 MW
Minimum voltage before placement of solar PV=0.8333518 p.u.

Table 3 depicts the optimal nodes with their PV capacities and improvement in fitness value, line losses and minimum node voltages. The table shows there is up to 14.22% improvement in voltage of minimum node voltage and 69.57% reduction in active power for case 3. The table shows that the total installed PV is 3.13960 MW for case 1, 3.13165 MW for case 2 and 3.14346 MW for case 3. The rise in voltage at minimum voltage bus is 2.59% from case 1 to case 3 while the reduction in active power loss is 5.18%.

Figure 3 compares the voltage of the minimum node bus and loss of the line for different cases. It is clearly seen that for all cases power loss reduced and minimum node voltage improves remarkably when compared with base case of the network. Figure 4 and 5 shows the impact of solar PV placement on system voltage and feeder current profiles before and after placement of solar PV. Since the load demand is supplied by solar PV nearer to the load, the loading of the line nearer to the substation is reduced significantly as shown in figure 5.

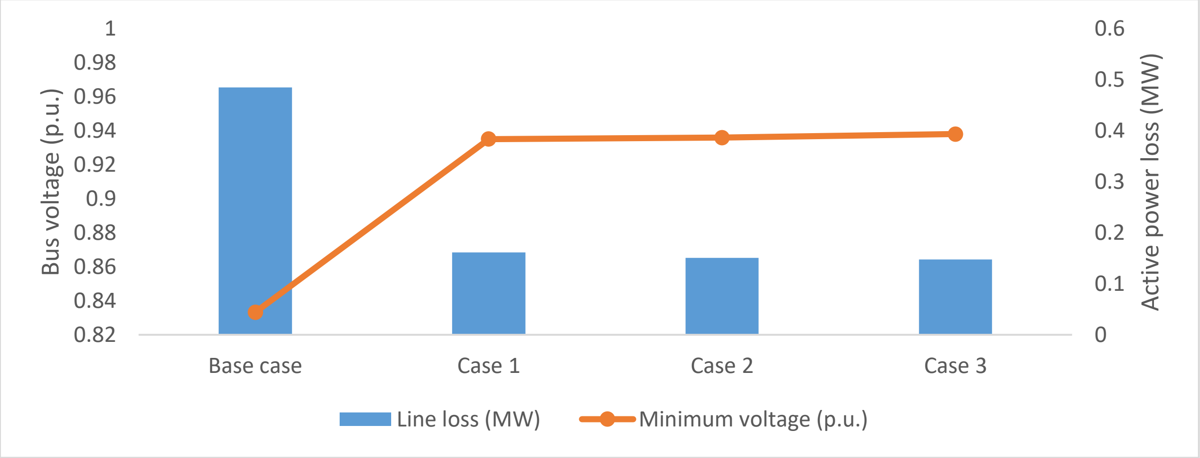


Figure 3: Comparison of power loss and minimum node voltage before and after placement of PV.

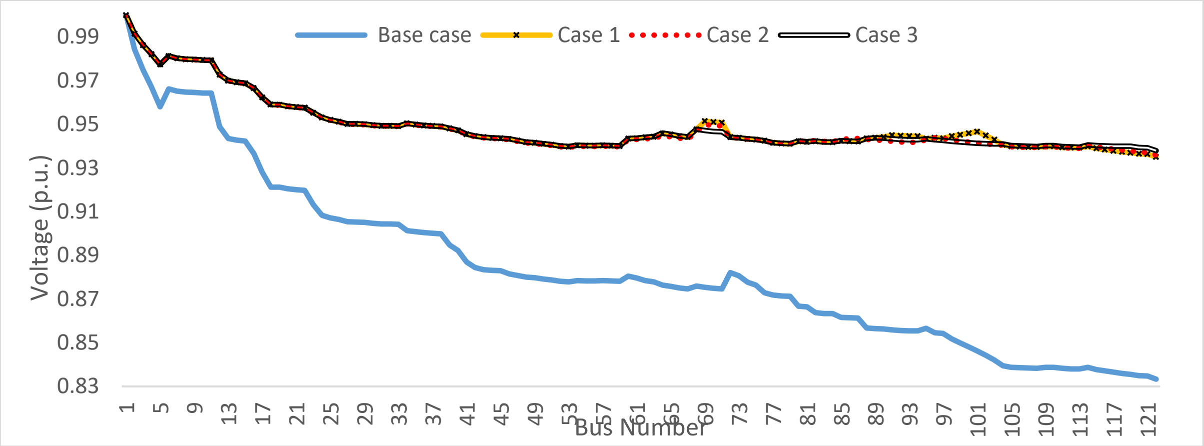


Figure 4: Comparison of voltage profile before and after placement of solar PV in the Tandi feeder.

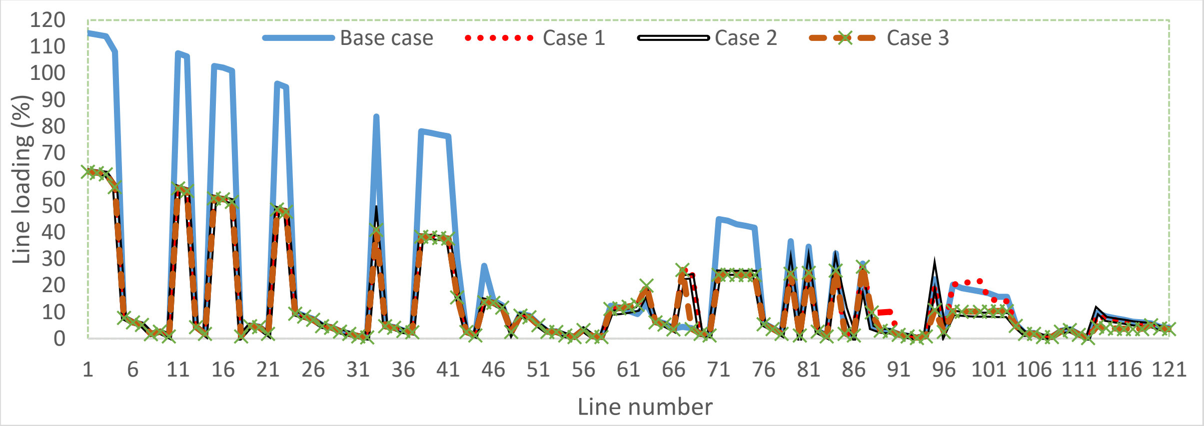


Figure 5: Comparison of line loading before and after placement of solar PV in the Tandi feeder.

It can be concluded from these figures that the performance of Tandi feeder can be partially improved by optimal placement of active power source i.e. solar PV in this case.

VI. CONCLUSION

This paper presents a GA based methods for optimal placement of active power source i.e. solar PV on three, four and five different location for voltage profile improvement of distribution feeder. The proposed GA minimizes the summation of difference of voltage at each bus from unity by improving the voltage and current profiles and reducing power losses with optimal placement of active power source in 11 kV Tandi feeder. The effectiveness of the proposed strategy is ensured by lower power loss, better system node voltage and feeder current profile. The results show that the improvement of voltage of minimum voltage node is 13.86%, 13.96% and 14.92% for three, four and five PV placement cases respectively and there is only 2.59% improvement in voltage of minimum voltage node from three to five PV placement case. Likewise the loss and line loading of the feeder has reduced by this method.

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