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Probabilistic Load Flow Analysis using Point Estimation Method in Tandi Distribution Feeder

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Abstract

On Increasing Distributed Generation(DG) at various location, the uncertainty factor in the Distribution system has increases rapidly. The use of Deterministic load flow(DLF) is unable to show the uncertainty operation of the grid so Probabilistic load flow(PLF) analysis is used to reflect the uncertainty of DG and load. Deterministic load flow is done using the square root method of load flow. The Result obtained from the Point-estimation method(PEM) and Monte-carlo simulation(MCS) is compared in IEEE-33 Bus Radial Distribution system. Integrated Nepalese Power System(INPS) of Tandi Feeder is used for PLF using PEM. Active Power of the DG and Active and Reactive Power use by the load are taken random variable for PEM. Gram charlier expansion with Chebyshev Hermite polynomial equation of random variable is consider to calculate the Probability Density function(PDF) and Cumulative Distribution Function(CDF). Hourly variation of solar irradiance from 9am to 5pm is model using the beta probability density function. Solar as a DG is connected at the different Buses and Probability of over voltage and under voltage at different bus before and after DG penetration is analysed. The result show the effect of DG penetration on Voltage and power loss of the system.

Keywords

Probabilistic Load flow, Distributed Generation, Gram charlier expansion, Point Estimation Method

1. Introduction

Rapid development of renewable energy resources play a vital role to control carbon emission. The increasing use of energy creates a challenges for energy saving as a result use of renewable energy resources has increases in the power system rapidly. With the development of new technology and innovation, the use of solar energy has increases, but due to the fluctuating nature of solar output operation and penetration problem arises [1]. The stochastic nature of solar output is generally due to maximum generation at the day time and no generation of power during the night. Solar output also vary seasonally, more at spring than the winter. The climatic condition and meteorological feature of different location also causes uncertainty generation of the solar in the distribution system [2].

There are normally three method for PLF calculation as analytical method, simulation method and approximation method. Analytical method include cumulant method and convolution method. Simulation method mainly include Monte-Carlo simulation(MCS) [1] and approximation method include the Point Estimation Method(PEM). MCS can be consider as the most accurate PLF method among various other method so it is commonly used for analysing the accuracy of various other probabilistic method [3]. The accuracy of MCS is achieve by the use of large number of random sampling and iteration calculation which makes this method computationally inefficient and time consuming hence for the large system with many buses MCS is not used [4]. so to overcome this drawback, PEM can be used.

PEM is superior than MCS method in the sense that PEM require less data, less computational burden, good balance of accuracy and it takes less computational time [5]. The accuracy of PEM is improved by increasing the number of estimation point 'm' so it can be said that three Point estimation Method(3PEM) is more accuracy than Two Point estimation Method (2PEM) but 3PEM only require one more iteration than 2PEM.

To analyse the impact of uncertainties of PV generation in transmission system, cumulant method is used and the obtained result are compared with the MCS method [5]. PLF analysis using PEM is applied on IEEE 6 bus system [6], output obtained from the proposed (2PEM) method shows that all the line parameter and power flow can be efficiently calculated if the stochastic nature of DG output is estimated. PLF is done in MATLAB Software in 30 bus radial network using 2PEM and 3PEM scheme and obtained result are compared using MCS method to show that 3PEM is better than 2PEM [7]. The comparison result of transmission system (30-Bus) and radial distribution system (33-Bus) with probabilistic power flow (PPF) is done, result shows that the PEM has better performance for radial networks as compared to MCS method [8].

In this paper, radial tandi distribution feeder of 122 buses which is one of the feeder of INPS is taken for the PLF analysis using 3PEM. DG penetration is based on considering the minimum voltage and end of the lateral branch. 25% of DG is penetrated based on ontario's standard [9] at different Buses considering only two factors, power loss and pu voltage.

2. Methodology

2.1 Load flow analysis

IEEE-33 bus radial distribution system and Tandi Distribution Feeder is used to implement Point Estimation Method. The Load flow of such a network is carried out using square root method [10].

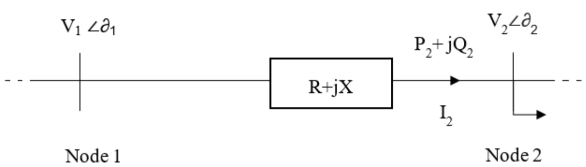

Figure 1: A branch of Radial distribution feeder

A figure 1 show the branch having node 1 and node 2 with resistance R and inductive reactance X. $V1\angle\delta 1$ & $V2\angle\delta 2$ are the voltage magnitudes with phase angles at node 1 and node 2 respectively. P2 = Real power load. Q2 = Reactive power load.

2.2 Probabilistic model of Photovoltaic DG

Due to stochastic nature of solar irradiance(I_b) the power output obtained from the solar vary at different time. The variation of solar irradiance and generated power by solar is consider to follow the beta distribution [11]. The probability density function of beta distribution of PV can be written as;

$$f(P_G) = \frac{\gamma(\alpha+\beta)}{\gamma(\alpha)\star\gamma(\beta)}(I_b)^{\alpha-1}\star(1-I_b)^{\beta-1}$$

$$for P_G \in [0, P_G(I_b)], 0 \leq I_b \leq 1,$$

$$\alpha > 0 \;\; and \;\; \beta > 0 \;\; otherwise \;\; 0.$$

$f(P_G)$ denote the probability density function of solar power. α and β denote the shape of the beta curve and γ notate gamma function.

2.3 Probabilistic model of Load

Active and reactive power of the load with certain value of mean and standard deviation follow the normal distribution [7]. The probability density function of P_L for the normally distributed load is;

$$f(P_L) = \frac{1}{\sigma_{PL}\star\sqrt{2\pi}}\star e^{\frac{-(P_L-\mu_{PL})^2}{2\star(\sigma_{PL})^2}} \tag{1}$$

Where; P_L is the load power[kW] of random variable, $f(P_L)$ is the PDF of power absorbed by load, μ_{PL} is the mean and σ_{PL} is the standard deviation. The normally distributed active power of the load is given by the equation 1. The PDF for the reactive power also follow normal distribution which is similar to the active power of equation 1 [7].

2.4 Point Estimation Method

Point estimation is an approximate method which is used to approximate the moment of the random variable. It consider the first four moment. The concentration of the random variable is define as a pair of location and weight. By using these moment and concentration of random variable, output information is obtained [12].

The various uncertain parameter are the power generated by the solar and normally distributed load active and reactive power, these uncertain parameter are consider random variable. For three point estimation method, the concentration of random variable can be calculated as [4];

$$\rho_{l,k} = \mu_{\rho l} + \xi_{l,k}\star\sigma_{\rho l} \tag{2}$$

Where; $\rho_{l,k}$ is the kth concentration of ρ_l random variable, $\mu_{\rho l}$ is the mean, $\sigma_{\rho l}$ is the standard deviation and $\xi_{l,k}$ is the kth standard location of respective random variable.

In case of 3PEM one concentration points out of three is taken at mean by considering one standard location $\xi_{l,k}$ as zero. Hence K = 3 is taken for 3PEM. The standard location $\xi_{l,k}$ and weight $W_{l,k}$ is obtained from [4];

$$\xi_{l,k} = \frac{\lambda_{l,k}}{2} \pm \sqrt{\lambda_{l,4} - \frac{3}{4}\lambda_{l,3}^2}$$

for k=1,2

$$\xi_{l,3} = 0$$

$$W_{l,k} = \frac{(-1)^{3-k}}{\xi_{l,k}(\xi_{1,l} - \xi_{2,l})} \quad for\, k = 1,2$$

$$W_{l,3} = (\frac{1}{m} - \frac{1}{\lambda_{l,4} - \lambda_{l,3}^2})$$

where, input random variable is denoted by m. for 3PEM standard location not depend on total number of input random variable as 2PEM. so 3PEM is consider more accurate than 2PEM.

2.5 Standard central moment

The standard central moment is denoted by $\lambda_{l,j}$. It is useful in comparing the shape of different probability distribution. The moment of the probability distribution about the mean is the central moment. central moment show the variation of data from the first raw moment [4]. The various central moment are;

- $\lambda_{l,1}$ = Mean of random variable;
- $\lambda_{l,2}$ =Standard Deviation of random variable;
- $\lambda_{l,3}$ = Skewness of random variable.
- $\lambda_{l,4}$ = Kurtosis of random variable.

where, Skewness measure the symmetry of the distribution and study the shape of the curve. Kurtosis show the differences between the tail of the distribution with the Normal Distribution.

2.6 Gram−Charlier expansion

The density of Gram−Charlier distribution is the polynomial times the normal density. Gram−charlier expansion find the probability distribution of random variable in term of its cumulant. If a random variable x has mean value μ and standard deviation σ, the standardized variable x has the form $x = \frac{(x-\mu)}{\sigma}$ From the Gram−Charlier expansion, the cumulative density function F (x) and probability density function f(x) can be written as [7];

$$F(x) = \phi(x) + \frac{c_1}{1!}\phi'(x) + \frac{c_2}{2!}\phi''(x) + \frac{c_3}{3!}\phi'''(x)$$

$$f(x) = \varphi(x) + \frac{c_1}{1!}\varphi'(x) + \frac{c_2}{2!}\varphi''(x) + \frac{c_3}{3!}\varphi'''(x)$$

$\phi(x)$ and $\varphi(x)$ represent the CDF and PDF of the standard normal distribution with μ = 0 and σ = 1, respectively [11], c_v is constant coefficients which is solved using chebyshev hermite polynomial equation.

2.7 Procedure of Probabilistic load flow analysis

The probabilistic load flow of radial distribution network using PEM is computed in MATLAB 2020a software with following steps;

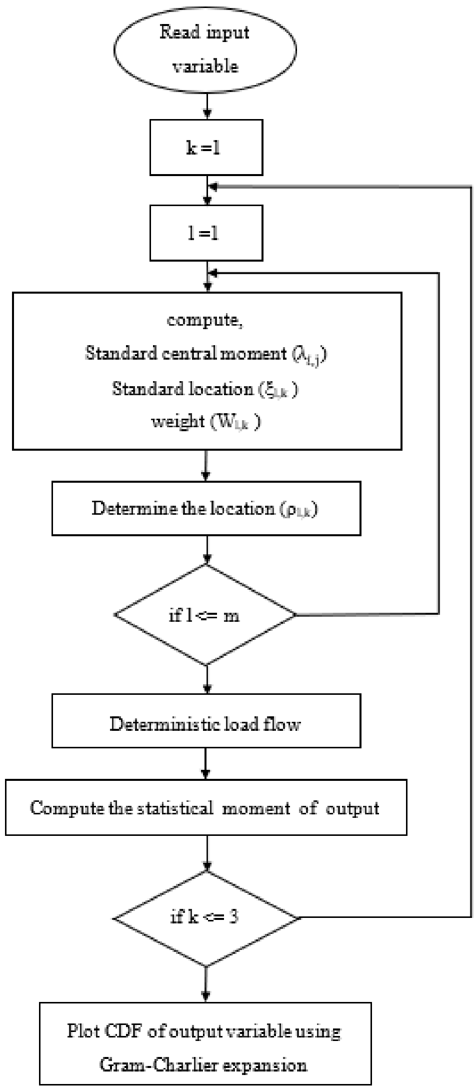

Figure 2: flowchart for Point estimation method

- Step 1: Read the input data.
- step 2: Set concentration or point K =1 to 3(for 3PEM)
- step 3: Set L =1 to m (m= Random variable)
- step 4: for all random variable calculate standard central moment,standard location and weight for the point.
- Step 5: Estimate the main location for the random variable.
- Step 6: Carry out load flow analysis for all ’k’ point.
- Step 7: Calculate the statistical moment of output variable.
- Step 8: For all output random variable calculate the cumulant and plot the CDF curve using Gram-Charlier expression.

3. Results and Discussion

In this Paper, a PLF algorithm is developed and implemented in Integrated Nepalese Power System (INPS) network of tandi feeder. Tandi feeder is one of the feeder of NEA, Ratnanagar Tandi Distribution center among 4 Feeder having feeder length 115km located at Chitwan District of Nepal. Before implementing in INPS system of Tandi Distribution feeder the developed algorithm is checked in the standard Radial Distribution system of IEEE-33 bus system for comparison. All the working is done under MATLAB R2020a script environment. The various specification of laptop used for the computation is shown in table 1.

Table 1: Specification of Laptop

Parameter	features
Processor	2.4GHz, core i5-6200U
RAM	8GB
Hard drive	512 HDD,240 sata SSD
Operating system	Window 10 pro 64 bit

3.1 Comparison between PEM and MCS

Probabilistic load flow of IEEE-33 bus system is carried out by MCS technique for 500 iteration and in each iteration 40 samples are taken. Similarly PLF of IEEE-33 bus system is also carried out using 3PEM and comparative result obtained from both the method on assuming perfectly normally distributed load for both cases are:

Table 2: Comparative table between PEM and MCS

Parameter	PEM	MCS
Total Active Power loss	211.503	211.14
Total Reactive Power loss(Kvar)	143.392	143.135
Mean of Minimum voltage	0.9408	0.9408
Mean of Maximum voltage	0.9467	0.9466
Minimum voltage	0.90376	0.90375
Execution Time(IEEE-33)	2.956 sec	42.36 sec

It is obtained that the Pu voltage output from Both the method coincide each other and have the error less than 0.001%. The power loss are almost similar from both the method and error is less than 3%. Hence it can be concluded from the comparison result of PEM and MCS method that the accuracy of MCS method is also maintain by PEM and PEM is Prefer here for further work because,

- Execution time of PEM is around 20 times less than MCS method.
- PEM takes less memory and space than MCS method.
- only 2m+1 times iteration in PEM than 1000 of iteration in MCS method.
- For large and vague system MCS need powerful processor with extra RAM and memory, but not by PEM.

Tandi feeder is a radial distribution system with 122 buses. The single line diagram of Tandi feeder with Parsa substation as a source at Bus 1 is shown in figure 3.

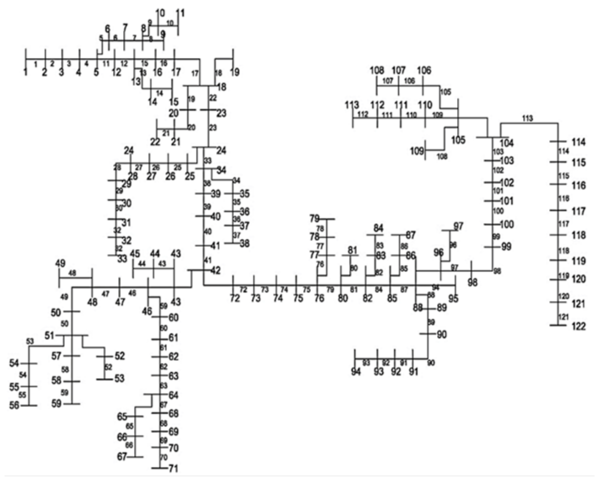

Figure 3: Single line diagram of Tandi Feeder

The key parameter of Tandi Feeder are as shown in the Table 3

Table 3: Key parameter of Tandi feeder

S.N	Parameter	Data
1	Number of Buses	122
2	Number of Branches	121
3	System voltage (KV)	11
4	Base MVA	100
5	Total Active Power(KW)	4674.19
6	Total Reactive Power (KVar)	2773.49

The total Transformer size of 122 transformer of tandi feeder is 9150 KVA. The maximum KVA is 5439.52 KVA with 0.86 average power factor obtained from the TOD load data of Tandi feeder. Hence 59.4% Transformer loading is obtained. The mean of the load parameter of tandi feeder is taken with reference to 59.4% transformer loading and 0.86 pf and standard deviation is taken with references to standard deviation obtained from 22 TOD load data. The daily load curve of Tandi Feeder is shown in the figure 4. It is the hourly variation of average of 8 month data of Tandi feeder for the whole day of 24 hours.The maximum load of 2800KW is obtained from the daily load curve of the Tandi feeder. The Tandi Feeder is the domestic dominated with maximum load occurring during the morning 8am and afternoon 6 to 7 pm as shown in the figure 4.

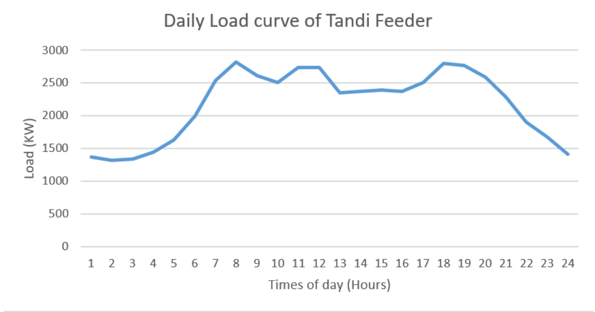

Figure 4: Daily load curve of Tandi feeder

The under voltage probability from bus 1 to bus 20 of Tandi feeder is shown in the figure 5. There is no under voltage probability from bus 1 to bus 6 and above bus 15 to bus 122 there is 100% probability of getting under voltage before DG penetration which is more clearly shown by the figure 5. There is no chance of over voltage probability in Tandi feeder.

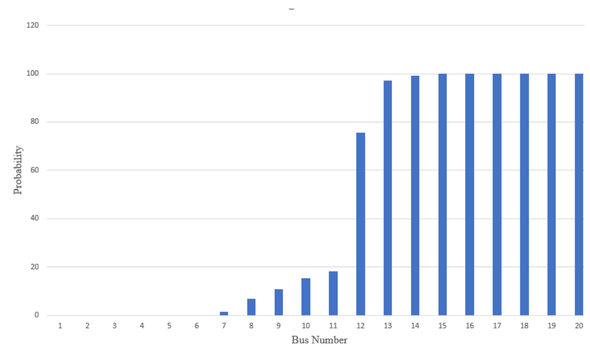

Figure 5: Under voltage Probability of Tandi feeder.

The Minimum and maximum voltage obtained from each buses of Tandi feeder is shown in figure 6. The pu voltage goes on decreases as we move toward the end buses and variation of pu voltage at end buses is 0.802 to 0.8347 pu.

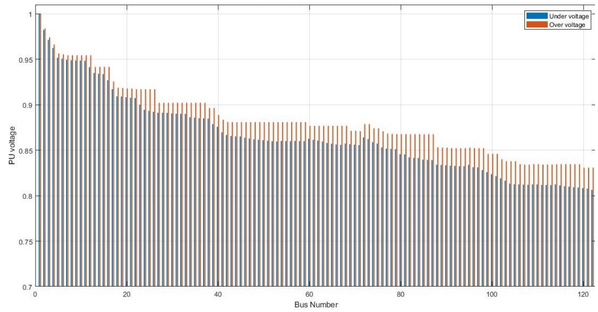

Figure 6: Minimum and Maximum voltage of Tandi feeder.

3.2 Point Estimation Method with DG penetration

To analyse the probabilistic model of the system,to improve the Pu voltage and also to decrease the losses 25% of the solar as per ontario's standard [9] and [13] is penetrated at different buses of the real system considering only two factors, power loss and voltage regulation and other factor such as economic and geographic are not considerations.

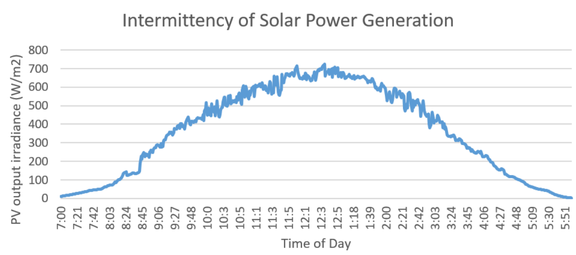

Figure 7: Intermittency of solar power generation.

The intermittency of solar power generation of average of 8 days of irradiance data obtained from pyranometer of Gairapatan Pokhara is shown in figure 7. The solar irradiance for each hour of the day is modeled by the Beta probability density function based on collected data of solar irradiance from 9am to 5pm of 4 month is taken as a reference for PV penetration. The mean value of irradiance obtained is 0.451 KW/m^2 and 61.03% standard deviation with beta distribution shape parameter as;

Table 4: Shape parameter of PV

Parameter	Alpha	Beta
Solar	1.025	1.248

25% of total load of PV is connected at different location of Tandi feeder. The location for PV penetration is selected based on minimum per unit voltage and end of the lateral branches. Bus number 122, 94 and 71 is chosen for the PV interconnection of the tandi feeder.Three different scheme is consider for the study as 25% DG connected at Bus 122, 25% DG connected at Bus 122,94, 25% DG connected at Bus 122,94,71 of tandi distribution feeder.

After PV interconnected at different Buses the CDF plot of Pu voltage at different buses can be obtained. The maximum value of distribution function for CDF is 1 p.u. or 100%.From the CDF curve we can say that with the considered range of variation in input parameter what will be the probability of maintaining the voltage within the required range of the respective buses and hence other corrective measures can be followed to avoid the voltage collapse, thus improving the reliability of supply. The CDF curve of pu voltage for Bus 120 at different scheme is shown in the figure 8.

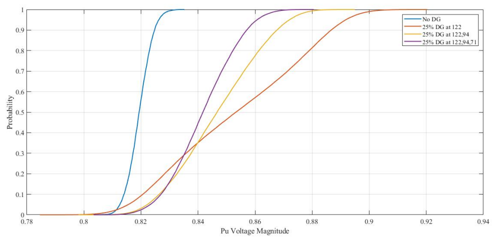

Figure 8: CDF plot of Pu voltage at Bus 120

It is seen from figure 8 that probability of Pu voltage at Bus 120 is increases after DG is connected at different scheme. Although the minimum voltage probability remain almost same, the maximum voltage probability is improved after DG connection. The maximum improvement in voltage at Bus 120 is seen at scheme 1. similarly minimum voltage and maximum voltage probability at each buses can be obtained. The CDF plot of Active power loss at branch 4 for different scheme of DG connection is shown in the figure 9.

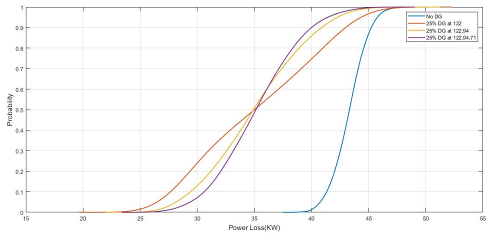

Figure 9: CDF plot of Active power loss at Branch 4

When DG is not connected, the branch active power loss at branch 4 is 43.122Kw, which is decreases to 35.109 KW at scheme 1, 34.968 kW at scheme 2 and 35.025kw at scheme 3. similarly for different buses, the probability of active power loss can be obtained. Hence the probability of branch power loss is decreases as DG is connected. The improvement in voltage after DG connection for each scheme is shown in figure 10.

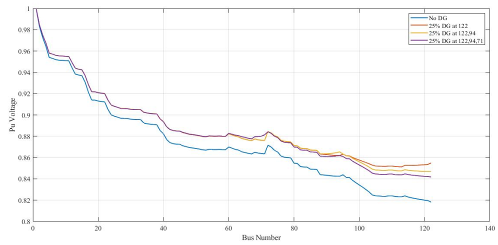

Figure 10: Comparison of Pu voltage for different penetration

The table 5 shows the comparison of various parameter before and after DG connection at different scheme. Bus 1 to Bus 20 is taken to calculate the mean under voltage probability because from bus 20 to end bus 122 there is 100% probability of under voltage and under voltage probability is not changed for each scheme of DG connection. 46.2% under voltage probability at normal condition is reduced to 42.9% at scheme 1 of DG connection which is more clearly seen by the table 5. Hence maximum reduction in under voltage is achieved when DG is connected at end bus. There is no chance of over voltage at each scheme although the DG is connected.

Table 5: Comparison of parameter for 25% DG connection

Parameter	No DG	Bus 122	Bus 122,94	Bus 122,94,71
Total Active Power loss(KW)	541.24	422.206	419.05	423.68
Total Reactive Power loss(Kvar)	628.91	490.309	486.63	491.86
Mean Minimum voltage	0.8618	0.868	0.863	0.866
Mean Maximum voltage	0.8815	0.9163	0.9106	0.9064
Minimum Voltage	0.8182	0.8513	0.8469	0.8417
Mean Under voltage	46.2%	42.9%	43%	43.4%

4. Conclusion

The paper show the comparative result of PEM and MCS method. 42.36 sec computational time of MCS is reduced to 2.95 sec by PEM and accuracy of MCS is also maintain by the PEM. Hence for the large system it is efficient and fast to use PEM.Hourly variation of solar irradiance is consider using beta distribution. The minimum voltage of 0.8182 is improve to 0.8513 at scheme 1, which is the best case considering the improvement in per unit voltage. DG at the end bus is more efficient considering the improvement in pu voltage. similarly considering the power loss reduction DG at bus 122, 94 is consider the best case as it has maximum loss reduction as compare to other cases. The mean of minimum voltage is 0.86 and remain almost same due to the intermittency of solar output and mean of maximum voltage of 0.8815 is improve to 0.9163 for DG at 122 at scheme 1 is the best improvement in voltage and there is no chance of over voltage in the system due to DG penetration.

PV connection in distribution system reduces the branch power loss, reduces the under voltage probability but increases the chance for improvement in voltage. Hence probability analysis is used to view the best cases and worst cases at each buses, which is used to analyse the uncertainty, power loss and maintain the reliability of the system.

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