ISSN: 2834-4928

Research Article

Journal of Electrical Electronics Engineering

# A Probabilistic Load Flow Comparison in Distribution Systems by Performing Optimal Capacitors/DERs Sizing and Placement, Simultaneously

**Mohammad Mahbod Khanbabaee and Bahman Abedi***

*Department of Electrical Engineering, Faculty of Electrical and Electronic Engineering, Technical and Vocational University (TVU), Tehran, Iran*

***Corresponding Author**
Bahman Abedi, Department of Electrical Engineering, Faculty of Electrical and Electronic Engineering, Technical and Vocational University (TVU), Tehran, Iran

**Submitted:** 2024, Feb 08; **Accepted:** 2024, Mar 12; **Published:** 2024, Apr 18

**Citation:** Khanbabaee, M. M., Abedi, B. (2024). A Probabilistic Load Flow Comparison in Distribution Systems by Performing Optimal Capacitors/DERs Sizing and Placement, Simultaneously. *J Electrical Electron Eng, 3*(2), 01-10.

## Abstract

*Due to incremental penetrations in distributed energy resources (DER)s over electrical distribution networks, there has been little quantitative analysis of uncertainty investigation beyond distributed resources performance, owing to the inherent nature of solar irradiation and wind blow, as well as the uncertain electrical demand and electric vehicle charging stations. All in all, uncertainty modeling of distribution network elements is an essential tool for performing probabilistic load flow (PLF) analysis beside understanding the probabilistic behavior of a power distribution network. Furthermore, the installation of DERs and capacitors can result in the enhancement of power factor, voltage profile and line losses reduction in power distribution networks. The sizing and location of DERs and capacitor unit should be optimal to maximize the benefits, hence optimal locating and allocating the capacity of DERs have a complete impact on the system losses in the distribution network. When DERs and capacitors are installed in a distribution system, it could impact three-phase short-circuit currents. Genetic Algorithm (GA) is applied to find the optimal place and size of DERs and capacitors considering the minimum three-phase short-circuit current changes. The probability density functions (PDF) of total system losses and voltage deviation of the investigated network obtained from solving PLF by two methods of Monte Carlo simulation (MCS) and Hong's two-point estimation method have been compared before and after optimal placement and sizing of distributed energy resources and capacitors. PLF and GA has been applied on IEEE 33-bus radial distribution system. The results obtained illustrate that voltage deviation and total system losses have been reduced while having minor changes in three-phase short-circuit current, finally the two-point estimation (TPM) method offers a time consuming way, having acceptable results.*

**Keywords:** Probabilistic load flow, Wind, Photovoltaic, Electric vehicles, Distributed Energy Resources, Genetic Algorithm, Power Losses, Voltage deviation, DER placement, Capacitor placement.

## 1. Introduction

Renewable energies have a significant contribution to the development of distribution systems, since the inherent intermittent nature of wind blow and solar irradiations, the greater the penetration of renewable energy sources, the more probabilistic the nature of the power systems will be [1,2]. Power generation of renewable energy resources consist a great deal of uncertainties [24], therefore they impose many challenges for grids and their operators; so that the need for an accurate model that describes the stochastic nature of renewable generation is demanded, thus a comprehensive probabilistic tools in order to model such uncertainties for load flow analysis of the power system is vital [18]. It can inform system operators and planners about the potential for extreme events, helping them understand the probabilistic behavior of a power distribution network and develop contingency plans to minimize their impact. In a conventional power flow analysis, a known set of deterministic values will be considered for each input values like active power of generators and power demand of loads, thus the system will clearly be oblivious to the uncertainties of such input random variables; thus probabilistic methodologies and tools for power system analysis have been considered; This method is known as PLF. [3]. The use of PLF, will make the evaluation of system states variables by considering the probabilistic power generation of renewable energy resources and the probabilistic power demand of loads like EV charging stations, possible. PLF has become increasingly important with the growth of renewable energy sources and the need to integrate stochastic generation into power systems [23]. By the use of probability distributions, the probabilistic load flow quantifies the uncertainties [4]; MCS has been frequently used in probabilistic analyses to include a comprehensive model for uncertain outcomes [6]. Whilst, in distribution systems, the voltage magnitude at buses decreases when they get remote from the substation and the losses almost have huge amounts; According to mentioned literature almost 13% of the total power generated is consumed as $I^2 R$ losses at the distribution network [12]. Renewable energy resources are also being used as distribution generation in distribution power networks for grid reinforcement, reducing power losses and improving voltage profiles and load factors, which is known as on-site generation [13]. DERs generate electricity at or near its installation site, so that the use of this technology can reduce losses along the transmission lines and provide clean and reliable power. Therefore, it is clearly important to determine the most proper location and the amount of generation power of DERs [10,19]. Despite this, the utilization of capacitor banks (CB)s in electrical distribution networks, will consequence some benefits. In Location of buses where the capacitor banks should be placed is decided by fuzzy expert system by incorporating a set of rules into it, Candidate buses should found for capacitor placement using fuzzy system [7]. In a recent work, the swarm optimization algorithm has been chose, the Whale optimization Algorithm (WOA) in order to detect the optimal allocation and sizing of capacitors [5]. By determining the optimal installation location and the optimal capacity of the capacitors, it is possible to control power flow besides doing voltage profile management, power factor correction, improve system stability, and thereby reduction in active energy losses. The installation of DER resources and capacitor banks, can cause significant impacts on distribution networks, particularly the changes in magnitudes and directions of three-phase short circuit currents that may per se lead to false tripping or fail to trip over-current protection relays in the distribution system [11]. The DER placement is formulated as an optimization problem solved using the neuron-genetic network in [9], moreover in [25] recommands an optimal placement and sizing of hybrid solar-wind distributed renewable energy resources using Particle Swarm optimization Algorithm; another study conducted in [26], has tested the performance of the Tiki Taka Algorithm and Archimedes optimization Algorithm , against the older Particle Swarm optimization, in solving the problem of optimal placement of DERs in distribution networks. In this paper Genetic Algorithm (GA) is used in order to perform optimization. GA is a heuristic approach used to determine the most proper location and capacity of DERs and CBs. The objective is to find locations that would lead to minimized losses and changes in three-phase short circuit currents and improved voltage profile across the network, while also meeting the power demand requirements of the customers.

## 2. Uncertainty and Modeling Network Elements

Uncertainty modeling of distribution network elements is an essential step in performing PLF analysis in a power distribution network. In order to perform PLF analysis, the uncertain parameters of the distribution network, such as load demands and power generation of renewable-based DERs need to be modeled, using various probabilistic distributions. The mentioned uncertainty modeling is critical for capturing the variable operating points of distribution networks and reflecting them in the PLF analysis. Uncertainty modeling of distribution network elements can provide valuable insight into the probabilistic behavior of the distribution network under different scenarios, such as peak loads, penetration of renewable generations, and switching operations. The following elements are wind turbines, PV cells, EV charging stations and loads.

### 2.1 Probabilistic Model of Wind Turbine (WT)

The generated power of a WT depends on high level of uncertainties due to the variable wind speed that can be instantaneous, hourly, daily and seasonal in the site where they are installed; a probabilistic distribution for wind power output which is being commonly used, is the Weibull distribution, as it can capture the unique wind speed characteristics at each location, as given in Eq. (1) [22].

$$f(v) = \frac{K_w}{C_w}\left(\frac{v}{C_w}\right)^{K_w - 1} \exp\left[-\left(\left(\frac{v}{C_w}\right)^{K_w}\right)\right] \tag{1}$$

Where v is the wind speed in meter per second, and $C_w$ and $K_w$ are scale parameter in meter per second and the shape parameter of Weibull distribution respectively. The power generated by the turbine will be calculated through the wind speed samples using the following Eq. (2).

$$P_{wt}(v) = \begin{cases} 0 & if\, v < V_{ci} \\ P_R(A + Bv + Cv^2) & if\ V_{ci} < v < V_r \\ P_R & if\ V_r < v < V_{cc} \\ 0 & if\ V_{co} < v \end{cases} \tag{2}$$

Where v is wind speed, $V_{ci}$ is cut-in wind speed , $V_{co}$ is cut-out wind speed , and $V_r$ is the measured speed of wind turbine in meter per second, PR is the nominal power of turbine in MW and A,B and C are the wind turbine related coefficients.

### 2.2 Probabilistic Model of Photovoltaic Panels

The generated power of a PV module highly depends on solar irradiance and ambient temperature of the site, which can change the behavior of power generation of solar panels. Several probabilistic distribution functions can be used in order to model and characterize these parameters [14-15], researchers of this work used normal distribution function to generate the probabilistic distribution function of solar irradiation and ambient heat temperature as given in Eq. (3).

$$P_{PV} = P_{STC} \times \frac{G_{ING}}{G_{STC}} \times (1 + k(T_c - T_r)) \tag{3}$$

Where $P_{STC}$, $G_{STC}$ and $T_r$ are the nominal power of photo voltaic cell, solar irradiation and ambient reference temperature in centigrade under standard conditions respectively, $G_{ING}$ is the solar irradiation value, k is the temperature coefficient for maximum power, $T_C$ is the temperature surrounding the cell.

### 2.3 Probabilistic Model of EV Charging Station

In PLF analysis, a probabilistic modeling of electric vehicle (EV) charging stations is important to capture the stochastic behavior of EV charging demand. The Poisson distribution is often used to model the number of EVs charging at a specific location over a certain time interval, as it is a discrete probability distribution that considers the occurrence of an event in a given time period.

The Poisson distribution can be used to model the arrival rate of EVs at charging stations, as well as the charging power for each EV. The charging demand power depends on variety of factors, such as battery capacity, charging rate, and state of charge. The utilization of charging stations can also be modeled using the Poisson distribution, which represents the probability that a charging station is available for charging as shown in Eq. (4).

$$f(k;\lambda)=\frac{e^{-\lambda}\lambda^{k}}{k!} \tag{4}$$

The mean and standard deviation of this distribution are λ and √λ, respectively.

### 2.4 Load Probabilistic Model

The load demand in deterministic models will be identified constant; Behavioral patterns of consumers will result in variable demand in each load bus. In probabilistic studies since load prediction is initially random, the normal distribution models are the most frequently used in order to describe the electric load prediction uncertainty of each bus using normal PDF as given in Eq. (5) [8].

$$f(P_L)=\frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(P_L-\mu)^2}{2\sigma^2}\right) \tag{5}$$

Where µ and σ are the load's mean and standard deviation.

## 3. Probabilistic Load Flow

PLF is a computational method, used to analyze power system behavior under uncertain and varying conditions, such as fluctuations of power generation of renewable energy resources and changes in load demands. Unlike deterministic load flow analysis, which assumes fixed values for these parameters, PLF takes into account the probabilistic nature of the parameters and computes the probability density function of the system variables [18]. A set of probabilistic methods are being used for PLF calculations, in this paper MCS and two-point estimate method (TPM) are being utilized. Since the input values are random, so that the output variables will definitely be random. In other words, in case of the existence of even an uncertain input variable, this results in the uncertainty of all output variables; then uncertain output may include probability distributions of voltage, power flow of branches, and other system variables at different sites and time intervals. While performing PLF by input random variables the probabilistic equations can be depicted as follows:

$$Y=f(X) \tag{6}$$

$$X=[P_D\ \ Q_D\ \ P_{RER}\ \ Q_{RER}\ \ \dots]^T \tag{7}$$

Where X is the input random variables vector which includes active and reactive powers of loads and generation units, etc., and Y is the vector of unknown variables of the network such as magnitudes and angles of voltages, power of slack bus, reactive powers of PV buses.

## 4. Deterministic Load Flow

In the following paper backward-forward sweep algorithm is used to evaluate the distribution networks deterministic load flow [16-17], (DLF), this method divides the feeder into sections and analyzes each section separately. The method starts with backward sweep analysis where the end nodes are analyzed first and the power flow is traced back to the source. This allows for the determination of voltages and currents for each section. The next step is the forward sweep analysis, where the calculations begin at the source and propagate through the network. The algorithm runs iteratively until a stable solution is reached. This method is more efficient for radial distribution networks where the number of lines is significantly fewer than the number of buses. It is also useful for analysis of large-scale distribution networks that have a considerable number of branches in a particular area. The backward forward sweep load flow analysis provides rapid calculation, accurate results, and requires less computational power compared to other iterative methods.

## 5. Comparison of PLF and DLF

The main difference between PLF and deterministic load flow is in how they handle uncertainty in power system parameters; deterministic load flow assumes that all system parameters, such as load demand, generator output, and line impedances, can be accurately determined and are fixed. It then calculates the steady-state behavior of the power system under these fixed conditions. This method is useful for analyzing power system operation under normal conditions, but it does not account for potential variations in the parameters that could occur due to factors such as weather, equipment failures, or changes in demand.

PLF, on the other hand, takes into account the probability distributions of the uncertain parameters and calculates their potential impact on the power system. PLF performs multiple simulations of the power system for a range of possible parameter values, generating a probability density function (PDF) for each system variable.

In summary, while deterministic load flow provides a snapshot of the power system under specific fixed conditions, PLF offers a more comprehensive and probabilistic analysis that covers the ever-changing nature of power system parameters.

## 6. Monte Carlo Simulation

MCS is a combined random variables method based on simulation for solving load flow equations under the existence of uncertainties and probabilistic states; in addition, this method is mostly used under complex circumstances of the system like nonlinearity or having more than two uncertain parameters. MCS allows for the propagation of uncertainty through the distribution network model by generating random samples from the probability distributions of the uncertain parameters. These samples are then applied to the network model to calculate the load flow for each sample.

## 7. Two-Point Estimation Method (TPM)

Two-Point Estimation Method can be used in the PLF analysis to estimate the uncertainty associated with the load and generation in a power system. Hong's Two-Point Estimation Method is a deterministic method that calculates the minimum and maximum bounds of the input data and then takes the weighted average of these values to estimate the output variable from the probability distribution.

Once the minimum and maximum values are estimated, the average value can be calculated using Two-Point Estimation Method. This average value provides an estimate of the most likely level of load and generation in the power system, given the uncertainty associated with the input data [21].

Using Two-Point Estimation Method in PLF analysis helps to improve power system planning and operations by providing a more accurate estimate of the system conditions. The formulation of the proposed method is described as follows [27]:

Instead of each random variable, $x_l$ two certain variables of $x_{l,1}$ and $x_{l,2}$ are inserted in the PLF equations, which are obtained using the following equation:

$$x_{l,1} = \mu_{x_l} + \xi_{l,1}.\sigma_{x_l}$$
$$x_{l,2} = \mu_{x_l} + \xi_{l,2}.\sigma_{x_l} \tag{8}$$

In which $\xi_{l,1}$, $\xi_{l,2}$ is the standard location of random variable, $x_l$. The standard locations and weights of random variable of $x_l$ are computed by:

$$\xi_{l,1} = \frac{\lambda_{l,3}}{2} + \sqrt{m + \left(\frac{\lambda_{l,3}}{2}\right)^2}, \quad \xi_{l,2} = \frac{\lambda_{l,3}}{2} - \sqrt{m + \left(\frac{\lambda_{l,3}}{2}\right)^2} \tag{9}$$

And

$$w_{l,1} = -\frac{\xi_{l,2}}{m(\xi_{l,1} - \xi_{l,2})}, \quad w_{l,2} = \frac{\xi_{l,1}}{m(\xi_{l,1} - \xi_{l,2})} \tag{10}$$

Where $\lambda_{l,3}$ denotes the skewness of the random variable $x_l$:

$$\lambda_{l,3} = \frac{E\left[(x_l - \mu_{x_l})^3\right]}{(\sigma_{x_l})^3} \tag{11}$$

Finally, the mean value and standard deviation of the outputs Y is obtained using the following equations:

$$\mu_Y = E(Y) \tag{12}$$

$$\sigma_Y = \sqrt{E(Y^2) - (E(Y))^2} \tag{13}$$

## 8. Comparison of TPM and MCS Method

TPM and MCS methods are both techniques used in PLF analysis in order to estimate the uncertainty associated with the load and generation in a power system. However, the two methods obviously differ in the approach they take to estimate the system variables.

Hong's TPM allows for a relatively quick and simple estimation process, making it more applicable for smaller power systems with fewer inputs. However, this method may underestimate the uncertainty associated with the input data since it relies on a limited range of input data.

MCS method provides a more accurate estimate of the output variables since it takes into account the full range of variability in the input data with several iterations to proceed to the final result. However, this method is computationally intensive, making it more appropriate for larger power systems with more inputs; furthermore, although the consequences of this method has an adequate accuracy but the major problem of this method is that the calculation process of this method is Time-consuming. In PLF analysis, MCS method is often preferred because it provides more detailed and accurate representations of uncertain variables, such as the load and generation data. By considering the correlation between inputs, Monte Carlo method can generate probability distributions of output variables. Also, MCS method is particularly useful when dealing with a large amount of uncertain data.

However, Hong's TPM remains a useful tool for load flow analysis, particularly for smaller systems with fewer input variables. It provides a fast and straightforward method of analysis that can be used to estimate the output variables.

In conclusion, while both methods provide valuable contributions to PLF analysis, Monte Carlo method is often preferred for its statistical accuracy, while Hong's Two-Point Estimation Method is a useful diagnostic tool when time and computational resources are limited. The choice between the two methods depends on the size and complexity of the power system, the accuracy required and the availability of computational resources.

## 9. Fundamental of Genetic Optimization Algorithm

The integration of DERs into distribution networks can improve system efficiency, reduce losses, and improve voltage profiles. In further, Capacitors in distribution networks are used to improve voltage regulation by reducing reactive power demand and consequently, mitigating voltage drops; however, locating the best placement and capacity of DERs and Capacitors can be complex and time-consuming. Genetic optimization algorithms (GOAs) can be a useful tool for finding the optimal configuration of DERs and Capacitors in the distribution network, the objective is to find locations and power capacity values which the installation of DER and Capacitor would lead to maximum benefits such as reduced losses, improved voltage profile and improved reliability, as it may not be provided in a non-optimal situation.

GOAs are a type of optimization method that use the principles of genetics and natural selection to evolve a population of candidate solutions over a series of generations. In the context of placement and sizing of DERs and Capacitors, GOAs are used to look for the optimal configuration of DER and Capacitor locations and capacities based on a set of objective functions. Installing DERs and capacitors in a distribution system can cause changes in three-phase short-circuit currents. DERs can inject power to the distribution systems which can alter the short-circuit current levels. Capacitors, on the other hand, can help reduce short-circuit currents by improving the power factor of the system. changing the three-phase short-circuit current in a distribution system could require the protection relays to be reconfigured or adjusted to ensure proper operation. Thus, changes in the short-circuit current levels, such as those caused by the installation of DERs and capacitors, could impact the operation of protection relays; Therefore, when DERs and capacitors are installed, their impacts on the system including three-phase short-circuit currents should be considered and necessary adjustments should be made to ensure the system's stability and reliability, failure to consider such impacts could lead to stability and reliability issues in the system. In such situations, it is necessary to reevaluate the protection settings, depending on the magnitude and nature of the changes in the short-circuit current levels, the relay settings may need to be updated or the relays may need to be replaced with devices that are better suited for the new operating conditions. In order to avoid these changes in the protection topology of the system, the minimization of the changes in three-phase short circuit current of the system will be added to the objective function of the optimization algorithm that can help ensure the safety and reliability of the distribution system. During the GOA evolution process, the solutions evolve over several generations through genetic operators, such as selection, crossover, and mutation. The fitness evaluation is performed at each generation to select the best solutions, which are then carried forward to the next generation. This process continues until a satisfactory solution is reached.

## 10. Proposed Optimal Placement and Sizing of DER and Capacitor Methodology

This approach is a computational approach for identifying the best locations and sizes of DER sources and capacitors in a power distribution system to minimize power losses and voltage deviations while minimizing changes in three-phase short-circuit currents. The genetic algorithm evaluates multiple combinations of DER and capacitor locations, sizes, load demand, and other system parameters to identify an optimal configuration of DERs and capacitors that meets the defined objectives while satisfying any constraints. The resulting placement and sizing of DER resources and capacitors can help to mitigate the impact of power fluctuations, reduce the transmission and distribution losses, and provide substantial benefits to the network and the customers. It can also enhance the resilience and reliability of the power distribution system, which is increasingly important for critical infrastructure and emergency services [20].

- Define the objective function: The objective function is to minimize the power losses and voltage deviation while minimizing the changes in the three-phase short circuit current of the distribution system with the installation of capacitors and DERs. The power loss is calculated by subtracting the output power from the input power of the transmission lines, while the voltage deviation is the difference between the actual voltage and the standard voltage level.
- Define the variables: The variables that affect the performance of the system include the type and size of the capacitors and DERs, as well as their locations in the distribution system.
- Define the constraints: The constraints are the limitations of the system, such as the maximum capacity of the capacitors and DERs, the distance between the installations, and the voltage limits.
- Implement the genetic algorithm: The genetic algorithm is used to determine the best placement and sizing of capacitors and DERs to minimize power losses and voltage deviation. The algorithm starts with a random population of individuals, and each individual represents a possible solution. The individuals are evaluated based on their fitness, which is determined by the objective function. The fittest individuals are selected for reproduction, and the process is repeated until the optimal solution is reached.

## 11. Proposed Algorithm

The proposed method is divided into four main steps: (1) performing PLF in the presence of DERs and loads using backward/forward sweep load flow method to create an initial PLF data base (2) statistical calculations of MCS and two-point estimation method (3) Optimal placement and sizing of DERs and capacitors using genetic optimization method (4) placing DERs and capacitors in their optimized locations and setting their optimal values and perform the PLF respectively.

Step 1 Placement of Electric loads, EV charging stations and PV and WT type DERs, having uncertainty at specified buses.
Step 2 Collecting data for initial load flow samples by creating random samples from the probability distributions of the uncertain parameters for random input variables Calculating samples for output variables by performing load flow. Continuing the above procedure until the number of iterations reaches a specific value.
Step 3 performing MCS in order to estimate PDF of the output variables.
Step 4 Carrying out two-point estimation method; Obtaining values of weight coefficients and $\xi_{l,1}$, $\xi_{l,2}$ and $\lambda_{l3}$ of random variables using Eqs. (9)-(11).
Determining position of estimation points $x_{l,1}$ , $x_{l,2}$ by Eq. (8)
Obtaining variable Y using estimation points (Eq. (6)).
Calculating the mean and standard deviation of the output using Eqs. 12 and 13 and weight coefficients of estimated points. Estimating PDF of the output variables using torques obtained in the previous step.
Step 5 Comparing the results of the Two-point estimation method with the Monte Carlo method
Step 6 Carrying out the optimal placement and sizing of DERs and capacitor banks using the genetic optimization algorithm method and obtaining the optimal place and generation capacity of DER resources and capacitor banks.
Step 7 Repeating steps two to five after placing DERs and capacitor banks in their optimized locations and adjusting their optimal values according to the values obtained from the optimization algorithm.
Step 8 Comparing probability density functions of output variables obtained before and after the optimization process.

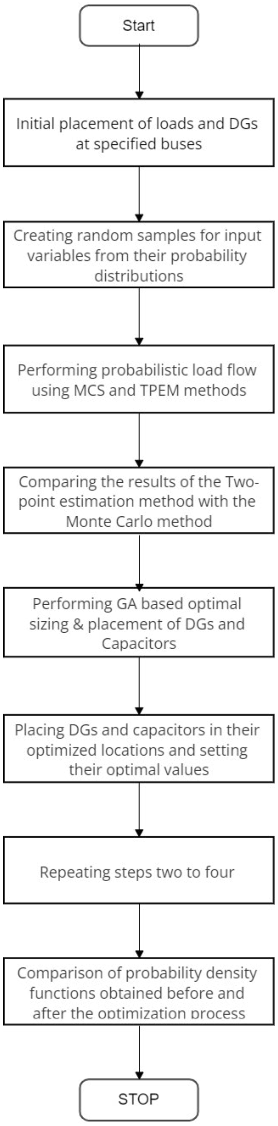


**Figure 2.** Flow Chart of the Proposed Algorithm

## Case Study

In order to perform Load flow analyzation and to determinations, the proposed methods are tested on the modified IEEE 33_Bus distribution networks.

Sbase = 100 MVA, Vbase= 11 Kv. It should be mentioned that these studies are performed in MATLAB on a PC with a 1.80 GHz processor and 12 GB RAM.

An IEEE 33-bus radial distribution test system is shown in Fig. 1; this system has one feeder with four laterals and 32 branches.

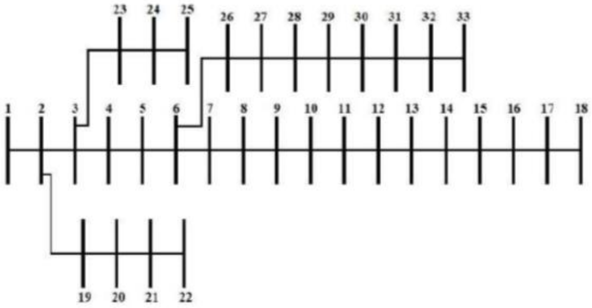


**Figure 1.** 33 Bus Radial Distribution Test System.

## 12. Results and Discussion

The generated program is carried out on the 33-bus test system. Obtained PLF results for 33-bus test system without placement of DER and Capacitor are tabulated in Table 1.

| | MCS | | TPM | |
|---|---|---|---|---|
| | Mean | Std. | Mean | Std. |
| $\|V_{17}\|$ | 0.954967 | 0.00968931 | 0.954281 | 0.00573816 |
| $P_{20-21}$(MW) | 0.181987 | 0.0480249 | 0.189251 | 0.0486186 |
| $Q_{27-28}$(MVAR) | - 0.883654 | 0.000411833 | -0.88366 | 0.00041119 |
| Voltage Deviation (PU) | 0.209694 | 0.0257975 | 0.211422 | 0.0157444 |
| Total Losses (MW) | 0.126298 | 0.0164939 | 0.125618 | 0.00801071 |
| Processing Time (sec) | 387.88 | | 25.9552 | |

**Table 1. Before placement of DER and Capacitor for 33 Bus Test System**

After optimal placement and sizing of DER and Capacitor the obtained PLF results are tabulated in Table 2.

| | MCS | | TPM | |
|---|---|---|---|---|
| | Mean | Std. | Mean | Std. |
| $\|V_{17}\|$ | 0.983529 | 0.007380 | 0.982921 | 0.004635 |
| $P_{20-21}$(MW) | 0.181617 | 0.0474407 | 0.187784 | 0.0478866 |
| $Q_{27-28}$(MVAR) | - 0.0810736 | 0.0002157 | -0.0810748 | 0.0002129 |
| Voltage Deviation (PU) | 0.0489234 | 0.0213739 | 0.0504361 | 0.013751 |
| Total Losses (MW) | 0.022691 | 0.007986 | 0.0218846 | 0.0029916 |
| Processing Time (sec) | 427.527 | | 39.8666 | |

**Table 2. After placement of DER and Capacitor for 33 Bus Test System**

According to the MCS method, which is based on repetition, it reaches the optimal solution over a longer period of time; But the obtained answers are closer to reality, that's why this method is considered the basis of calculations. Since the two-point estimation method has fewer input points than the MCS method, thus this method is faster to reach the optimal solution than the MCS method. Comparison of the output of the load flow variables shows that Hong's Two-point estimation method follow the MCS results well, therefore this method has an acceptable accuracy in estimating the standard deviation of the output variables in a shorter period of time. The simulations revealed that two-point estimation method produce accurate answers and significantly minimize the PLF problem's calculation time. It is noted that by comparing Voltage deviation and total losses of the system before and after optimal DER and Capacitor placement, the percentage of total loss and Voltage deviation reduction after allocation of DER and Capacitor are equal to 82.03% and 76.66% respectively.

The voltage profile before and after placement of DER and Capacitor is graphically represented in Fig. 2.

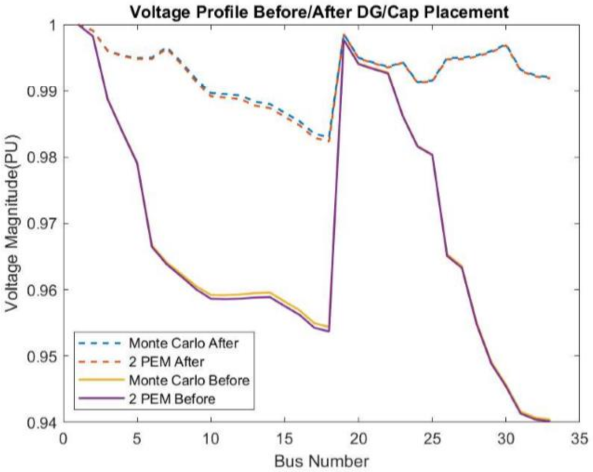


**Figure 2.** Graphical representation for comparison of Voltage profile with and without DER and Capacitor for 33 bus test system.

The power loss in each line before and after placement of DER and Capacitor is compared in Fig. 3. It is observed that the power loss at each line has been greatly reduced.

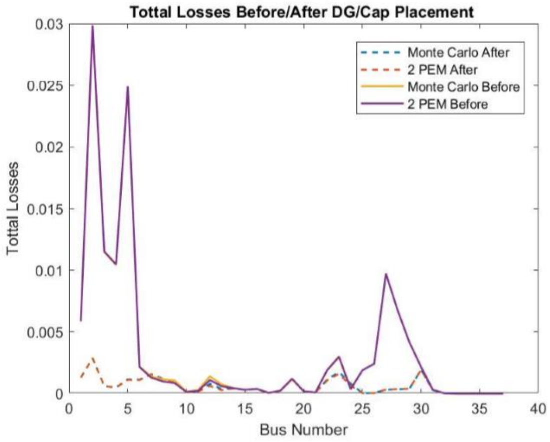


**Figure 3**. Graphical representation for comparison of total system losses with and without DER and Capacitor for 33 bus test system.

On the graphical representations, it is clear that the results of the PLF reached by Monte Carlo method and two-point estimation coincide significantly, for both modes before and after optimal placement and sizing of DERs and Capacitors.

The Voltage angle before and after placement of DER and Capacitor is graphically represented in Fig. 4.

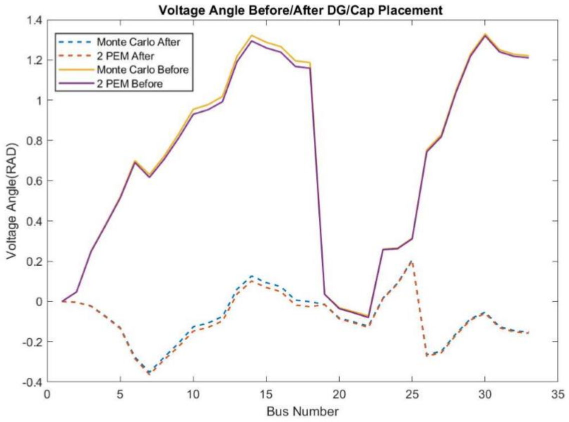


**Figure 4.** Graphical representation for comparison of Voltage angle with and without DER and Capacitor for 33 bus test system.

It can be mentioned that the comparison of voltage angle of the buses before and after the placement of DERs and Capacitors reveals that the proposed work tested on 33 bus test system, have had a noticeable effect in improving the voltage angles.

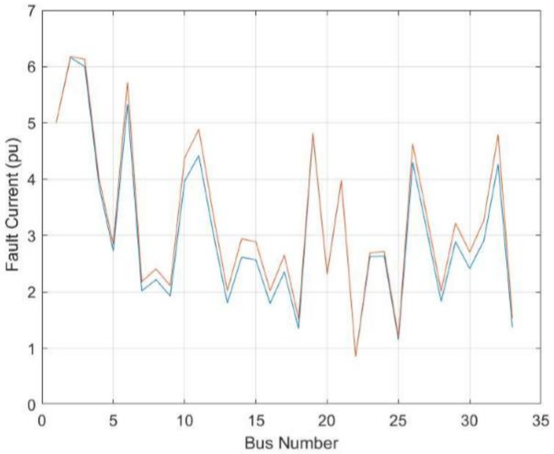


**Figure 5.** Graphical representation for comparison of Three-phase short circuit current with and without DER and Capacitor for 33 bus test system.

It is obvious that in the graphic curves, according to the proviso that was determined in the objective function of the genetic algorithm to minimize the changes of the three-phase short-circuit current, the it is obvious that three-phase short-circuit current in the different buses of the system in the state before and after the installation of DER sources and the capacitors have not changed significantly and have remained noticeably constant.

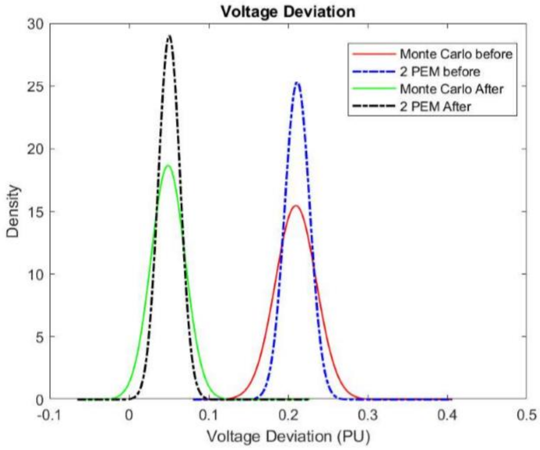
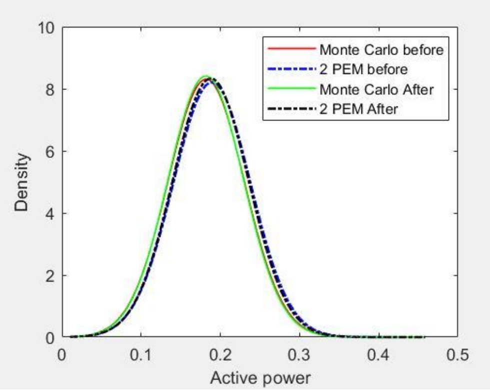


**Figure 6.** Comparison of PDFs of voltage deviation obtained of the results of the PLF reached before and after the placement of DERs and Capacitors



## 13. Conclusion

In this paper the PLF by MCS and Two-point estimation method is applied before and after the optimal placement and sizing of DERs and capacitor banks using Genetic Algorithm is proposed where minimization of losses and voltage deviation as well as minimizing changes in the three-phase short circuit current is considered as main criteria. The obtained results show that the bus voltage profile of the system and the total power losses of system buses have been noticeably enhanced, having a minor change in three-phase short-circuit current values, Besides the graph obtained from solving the PLF using the TPM, while being faster than the MCS, corresponds to the graph obtained from solving the PLF by MCS to a very favorable extent. The PDFs of the output variables of the investigated network, like bus voltage magnitude and active and reactive power flow of branches obtained from solving PLF by two methods of MCS and Hong's TPM, have been compared before and after optimal placement and sizing of DERs and CBs. The accuracy of the MCS is higher than the TPM due to the higher number of iterations in solving the problem. The calculation time in the MCS is about ten times longer than the TPM method.

## References

1. Shargh, S., Mohammadi-Ivatloo, B., Seyedi, H., & Abapour, M. (2016). Probabilistic multi-objective optimal power flow considering correlated wind power and load uncertainties. *Renewable Energy, 94*, 10-21.
2. Rahmani, K., Kavousifard, F., & Abbasi, A. (2017). Consideration effect of wind farms on the network reconfiguration in the distribution systems in an uncertain environment. *Journal of Experimental & Theoretical Artificial Intelligence, 29*(5), 995-1009.
3. Liu, Y., Gao, S., Cui, H., & Yu, L. (2016). Probabilistic load flow considering correlations of input variables following arbitrary distributions. *Electric Power Systems Research, 140,* 354-362.
4. Huynh, V. K., Ngo, V. D., Le, D. D., & Nguyen, N. T. A. (2018). Probabilistic power flow methodology for large-scale power systems incorporating renewable energy sources. *Energies, 11*(10), 2624.
5. Osama, A., Zeineldin, H. H., HM, E. F. T., & El-Saadany, E. F. (2023). Optimal Placement and Sizing of Capacitor Banks in Radial Distribution Systems Using the Whale Optimization Algorithm. In *2023 IEEE PES Conference on Innovative Smart Grid Technologies-Middle East (ISGT*

*Middle East)* (pp. 1-5). IEEE.

6. Abbasi, A. R., Khoramini, R., Dehghan, B., Abbasi, M., & Karimi, E. (2015). A new intelligent method for optimal allocation of D-STATCOM with uncertainty. *Journal of Intelligent & Fuzzy Systems, 29*(5), 1881-1888.
7. Isac, S. J., Kumar, K. S., & Kumar, P. V. (2013). Optimal capacitor placement in radial distribution system to minimize the loss using fuzzy logic control. In *International Conference On Smart Structures And Systems-ICSSS'13* (pp. 33-40). IEEE.
8. Fattahi, H., Abdi, H., Khosravi, F., & Karimi, S. (2019). Numerical and Analytical Solution of Probabilistic Optimal Power Flow Problems Considering Renewable Energy Resources Uncertainty. *Computational Intelligence in Electrical Engineering, 10*(2), 49-72.
9. Kazeem, B., Alor, M., & Okafor, E. N. C. (2017). Optimal placement of distributed generation in power distribution systems using neuro-genetic Algorithm. In *2017 IEEE 3rd International conference on electro-technology for national development (NIGERCON)* (pp. 898-904). IEEE.
10. Bhumkittipich, K., & Phuangpornpitak, W. (2013). Optimal placement and sizing of distributed generation for power loss reduction using particle swarm optimization. *Energy procedia, 34*, 307-317.
11. Zhan, H., Wang, C., Wang, Y., Yang, X., Zhang, X., Wu, C., & Chen, Y. (2015). Relay protection coordination integrated optimal placement and sizing of distributed generation sources in distribution networks. *IEEE Transactions on Smart grid, 7*(1), 55-65.
12. Ng, H. N., Salama, M. M. A., & Chikhani, A. Y. (2000). Classification of capacitor allocation techniques. *IEEE Transactions on power delivery, 15*(1), 387-392.
13. Rugthaicharoencheep, N., Nedphograw, S., & Wanaratwijit, W. (2011). Distribution system operation for power loss minimization and improved voltage profile with distributed generation and capacitor placements. In *2011 4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT)* (pp. 1185-1189). IEEE.
14. Kavousi-Fard, A., Abbasi, A., & Baziar, A. (2014). A novel adaptive modified harmony search algorithm to solve multi-objective environmental/economic dispatch. *Journal of Intelligent & Fuzzy Systems, 26*(6), 2817-2823.
15. Carpinelli, G., Caramia, P., & Varilone, P. (2015). Multi-linear Monte Carlo simulation method for probabilistic load flow of distribution systems with wind and photovoltaic generation systems. *Renewable Energy, 76,* 283-295.
16. Abbasi, A., & Seifi, A. (2008). A novel method mixed power flow in transmission and distribution systems by using master-slave splitting method. *Electric Power Components and Systems, 36*(11), 1141-1149.
17. Augugliaro, A., Dusonchet, L., Favuzza, S., Ippolito, M. G., & Sanseverino, E. R. (2008). A new backward/forward method for solving radial distribution networks with PV nodes. *Electric Power Systems Research, 78*(3), 330-336.
18. Abbasi, A. R. (2022). Comparison parametric and non-parametric methods in probabilistic load flow studies for power distribution networks. *Electrical Engineering, 104*(6), 3943-3954.
19. Gopu, P., S. Naaz, and K. Aiman. (2021). Optimal placement of DER using genetic algorithm. in *2021 International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT).* IEEE.
20. Kowsalya, M. I. A. M. (2014). Optimal distributed generation and capacitor placement in power distribution networks for power loss minimization. In *2014 International Conference on Advances in Electrical Engineering (ICAEE)* (pp. 1-6). IEEE.
21. Mohseni-Bonab, S. M., Rabiee, A., Mohammadi-Ivatloo, B., Jalilzadeh, S., & Nojavan, S. (2016). A two-point estimate method for uncertainty modeling in multi-objective optimal reactive power dispatch problem. *International Journal of Electrical Power & Energy Systems, 75,* 194-204.
22. Pishgar-Komleh, S. H., Keyhani, A., & Sefeedpari, P. (2015). Wind speed and power density analysis based on Weibull and Rayleigh distributions (a case study: Firouzkooh county of Iran). *Renewable and sustainable energy reviews, 42*, 313-322.
23. Wang, C., Liu, C., Tang, F., Liu, D., & Zhou, Y. (2020). A scenario-based analytical method for probabilistic load flow analysis. *Electric power systems research, 181*, 106193.
24. Davoodi, A., Abbasi, A. R., & Nejatian, S. (2022). Multi-objective techno-economic generation expansion planning to increase the penetration of distributed generation resources based on demand response algorithms. *International Journal of Electrical Power & Energy Systems, 138*, 107923.
25. Cortez, H. L., Broma, J. C. P., & Magwili, G. V. (2022). Optimal placement and sizing of hybrid solar-wind distributed generation in distribution network using particle swarm optimization algorithm. In *2022 International Conference on Electrical, Computer and Energy Technologies (ICECET)* (pp. 1-6). IEEE.
26. Ivanov, O. (2022). Metaheuristic Approaches for DER Placement Optimization in Electrical Grids: A comparison between PSO, Tiki-Taka and Archimedes Optimzation Algorithms. in *2022 International Conference and Exposition on Electrical And Power Engineering (EPE).* IEEE.
27. Abedi, B., et al., *An improved TPM-based distribution network state estimation considering loads/DERs correlations.* 2021. 103(3): p. 1541-1553.