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A new approach of point estimate method for probabilistic load flow

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ABSTRACT

This paper analyses the power system load flow using new point estimate method considering uncertainties, which may happen in the power system. These uncertainties may arise from different sources, such as load demands or generation unit outages. A novel probabilistic load flow based on new point estimate method has been proposed in this paper. The proposed method surpasses the previous point estimate methods when generalizing the approach to multiple random variables with various probabilistic distributions. Addressing the results of Monte Carlo simulation method as reference, the new point estimate method is applied to IEEE 14-bus test system and the advantages of this new method have been presented. The results reveal that the proposed point estimate method has less computational burden and time comparing than Monte Carlo simulation method while the accuracy remains at a high level.

1. Introduction

Probabilistic Load Flow (PLF) is an important issue in power system analysis. During the last decade, by increasing the importance of power quality for sensitive loads, the uncertainties in a power system, such as load variation, faults of lines and generator trip have been in great attention. As these events have probabilistic behavior, they are called Random Variables (RVs) and can highly influence on the load flow through the system. It is so important to know these parameters so that protective actions could be done. Some of these parameters are bus voltages, generated active and reactive in slack bus, line currents and some other important factors. All the mentioned parameters are obtained from the load flow calculations.

In order to explain the behavior of RV, a Probability Density Function (PDF) is assigned to each RV. These PDFs can be used in corresponding equations. In such cases, the traditional deterministic load flow does not have reliable results because some parameters like active or reactive power or even bus voltages do not have a deterministic amount. In order to consider these uncertainties, PLF must be utilized to gain reliable results. We should know that the output results of load flow equations are also random parameters, which are described with special PDFs according to the input parameters. The final goal of a PLF is to define these PDFs. In deterministic methods, system parameters such as loads, network configurations and other parameters are considered to be constant, while in an actual grid these time-varying parameters have random nature. Uncertainty of system parameters cannot be studied by deterministic methods; so probabilistic methods are more suitable for this purpose.

Various techniques such as Monte Carlo Simulation (MCS) method, analytical methods and approximate methods have been proposed to deal with these uncertainties based on probability theory [1,2].

MCS [3] generates random values for uncertain input variables, and they are used in deterministic routines to solve the problem in each simulation [4]. When the simulation method is used, the computation efficiency is very important because usually the sample set is very large [5]. This technique has been widely used in power systems analysis to model uncertainty. One of its major disadvantages includes its high cost in terms of computer time and stringent programming requirements to achieve a practical level of program efficiency. For this reason, the development of analytical methods was carried out [6].

In contrast, analytical methods are computationally more effective [4]. The analytical approaches were proposed to reduce the workload of calculation in solving PLF problem. These approaches generally include two components. The first component is to simplify the traditional PLF formulations. The second component is to calculate the convolution of different probabilistic variables by their linear relationships [7]. When the analytical method is used, the accuracy is very important because simplifications in the model of the analytical method may cause corresponding errors in the results [8]. In [9,10], dc-load flow model was used to find the PDFs of network parameters. In [11], a linearized model was used PLF. [12] Used a linearized model of load flow equation by using McLaren's series of sine and cosine functions and an approximation in conversion of multiply to

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Nomenclature

I_j	injected current to bus j
Y_{ij}	admittance between bus j and j
V_j	voltage of bus j
Θ_i	voltage angle of bus i
S_i	apparent power of bus i
Θ_{ij}	angle of ijth element of admittance matrix
P_i	active power of bus i
Q_i	reactive power of bus i
$Z^{(k)}$	kth iteration random variable of Monte Carlo simulation
x_n^k	nth input variable of kth iteration of Monte Carlo simulation
f	random function
$E(Z)$	mean value
$VAR(Z)$	variance value
Z	random variable of point estimate method
x_n	nth input variable of point estimate method
μ_j	expected value of jth variable
σ_j	standard deviation of jth variable
$M_k(x_j)$	the kth central moment of the jth variable
$g(x_j)$	probability density function

summation. The author in [13] used another method for simplification of the load flow equations. The main disadvantage of these techniques is that they need mathematical assumptions to simplification [7]. Approximate methods provide an approximate description of the statistical properties of output RV. This method was used in many papers relating to PLF. A number of studies [14–17] have been conducted to investigate PLF via approximate methods. In particular, all the papers of the previous list use the Point Estimate Method (PEM) to solve some probabilistic problems. In [18] the PEM is used to analyze the steady state operating conditions of an unbalanced power system. In [19] the valuation of the steady state operating condition of an unbalanced three-phase power system is performed in presence of uncertainties and wind farms. In [20] the analysis was performed considering correlated and uncorrelated input random variables. In [21], the Third-Order Polynomial Normal Transformation (TPNT) technique was employed to transform a multivariate non-normal dependent random variables group into a multivariate standard normal independent one. Incorporating three-point estimate method with TPNT technique, a TPNT-based three-point estimate method is proposed to solve PLF problems with non-normal dependent variables. In [22], finally, the PEM replace the probability distribution of the random parameters of a model with a finite number of discrete points in sample space selected in such a way to preserve limit probabilistic information of involved RVs. Like MCS method, PEMs use deterministic procedures in order to solve probabilistic problems by using only few first statistical moments of probability functions such as mean, variance, skewness and kurtosis coefficients. The PEM in this procedure is somehow better than MCS method as it has less computational efforts and consumed time since a smaller volume of data is required. The PEMs have some drawbacks associated with them. Increasing the number of estimating points is necessary to improve accuracy and preciseness in the previous PEMs. In the previous PEMs the estimated points may be outside the region in which the RV is defined especially for some RV with relatively large standard deviation, such as variables having a lognormal or exponential distribution. So, in these situations, PEM does not show appropriate results in comparison with MCS. The new Point Estimate Method (new PEM) is an approach to remove the above limitation associated with previous PEMs in which it is easier to increase the number of estimated points since the estimating points are independent of the RV in its original space [23].

In this paper, a new PEM has been presented to solve PLF, since in an actual power grid; there are many uncertain parameters with various probabilistic distributions and relatively large standard deviations. Thus, the new PEM is the approach to gain preciseness while the computational issues are also taken into account.

2. Probabilistic Load Flow (PLF)

2.1. Problem formulation

Load flow equations can be derived by using the network configurations, bus voltages and current injections. The current injected into bus can be written as:

$$[I_i] = [Y_{ij}][V_j] = \sum_j Y_{ij} V_j \tag{1}$$

where Y_j is the network admittance matrix, I_j is the matrix of injected current to each bus and V_j is the bus voltage matrix [24].

Complex power can be calculated as follows:

$$S_i = V_i I_i^* = V_i \left(\sum jY_{ij} V_j\right)^* = \sum_j |V_i||V_j||Y_{ij}| e^{j(\theta_i - \theta_j - \theta_{ij})} \tag{2}$$

where θ_i is the angle of V_i, θ_j is the angle of V_j and θ_{ij} is the angle of the ijth element of the admittance matrix. By expansion of the above equation and separating the real part and imaginary part of the equation:

$$P_i = \sum_j |V_i||V_j||Y_{ij}| \cos(\theta_i - \theta_j - \theta_{ij}) \tag{3}$$

$$Q_i = \sum_j |V_i||V_j||Y_{ij}| \sin(\theta_i - \theta_j - \theta_{ij}) \tag{4}$$

Eqs. (3) and (4) can be solved by using iteration technique such as Gauss–Seidel and Newton Raphson. It is important to mention that this equation must be written only for PV and PQ busses.

2.2. Monte Carlo Simulation method (MCS method)

The complexity of the analytical relations between the conversion system parameters, and in particular, their nonlinearity, addresses to the use of the well-known Monte Carlo method [25,26].

Usually, Monte Carlo methods are used to simulate a prescribed random behavior of the network loads. That is, random number generators are used to assign specific probability distributions to certain parameters of the loads, thus reflecting the RVs in the load's operating condition. In this way, deterministic models of the load can then be used to generate the random active and reactive power. The advantage of this approach is in the possibility of simulating a wide variety of random load characteristics until the resulting statistics agree with available field measurements. The disadvantage is that this method is computationally intensive and time consuming since it is difficult to determine how to adjust the load random models in order to produce desired results.

In the MCS method variables are calculated for each randomly generated set of input variables as below:

$$Z^{(k)} = f\left(x_1^{(k)}, x_2^{(k)}, \ldots, x_n^{(k)}\right) \tag{5}$$