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Point estimate schemes for probabilistic three-phase load flow

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ABSTRACT

This paper applies the point estimate method to account for the uncertainties that affect the evaluation of the steady state operating condition of an unbalanced three-phase power system.

Moreover, since the point estimate method requires that the input random variables are uncorrelated, a suitable adjustment to take into account the correlation is applied. Different point estimate schemes ($2m$, $2m+1$ and $4m+1$ schemes) are presented and tested. The accuracy of the proposed techniques is tested on a three-phase unbalanced IEEE 34-bus test system; the results obtained applying the Monte Carlo simulation are assumed as reference . Both correlated and uncorrelated input random variables are considered, and multimodal probability density functions are tested. The conclusion is that the $2m+1$ scheme gives the best solution in terms of accuracy and computational efforts; in the case of correlated input random variables, an adequate procedure to take into account the correlation must be applied.

1. Introduction

The unbalances in power systems are not always negligible, as in the case of single-phase AC traction plants, electrical furnaces, and long untransposed lines [1]. Several distribution systems are known to have unbalanced lines and line sections carrying a mixture of single-, double-, or three-phase loads [2]. When unbalances are present, single-phase analysis cannot be applied; the use of the three-phase load flow method for the steady state analysis is mandatory [1]. In unbalanced electrical power systems, unavoidable uncertainties affect input data for the evaluation of steady state operating conditions. These uncertainties are due to time variations in phase load demands and network configurations. The behavior of such characteristics can be described only in statistical terms.

Monte Carlo simulation procedures [3] or simplified methods [4,5] can be applied for the probabilistic evaluation of unbalanced power system operating conditions. With the use of simplified methods, computational efforts are reduced significantly, but only the mean values and the covariance matrix of the output random variables can be obtained [4]. Alternatively, approximate probability density functions (pdfs) can be calculated [5].

In this paper, the point estimate method [6] is used to analyze the steady state operating conditions of an unbalanced power system. In particular, this method is applied in the field of the three-phase probabilistic power flow, with reduced computational efforts compared to the classical Monte Carlo simulation procedure. The point estimate method allows us to obtain the first moments of the output random variables of interest through the solution of only a few deterministic three-phase power flows, compared to the enormous number of trials required by the classical Monte Carlo simulation procedure. Once the first statistical moments are known, it is possible to approximate the pdfs of the variables of interest using analytical expressions, such as those based on Gram-Charlier distributions [7,8].

It should be noted that the first point-estimate method was developed by Rosenblueth [9] for symmetric random variables. The method was later extended to deal with non-symmetric random variables [10]. For a model involving n random parameters, the Rosenblueth algorithm requires 2^n model evaluations. Later, in ref. [11], an alternative point-estimate method was proposed that reduced the number of model computations from 2^n to $2n$. The method proposed in ref. [11] was later modified in ref. [12] to further simplify the point selection. The methods in refs. [11,12] are only suitable for problems involving multivariate normal variables. When dealing with non-normal random variables, various normal transformation techniques [13,14] can be employed to map multivariate, non-normal, random variables into that of equivalent multivariate, standard, normal variables for which the methods proposed in refs. [11,12] are applicable.

The $2n$ point-estimate methods do not consider the moment higher than second order. In ref. [6], a new and efficient point-estimate method was developed to calculate the moments of a function with several random variables. The advantages of this

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