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On possibilistic and probabilistic uncertainty assessment of power flow problem: A review and a new approach

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A B S T R A C T

As energy resource planning associated with environmental consideration are getting more and more challenging all around the world, the penetration of distributed energy resources (DERs) mainly those harvesting renewable energies (REs) ascend with an unprecedented rate. This fact causes new uncertainties to the power system context; ergo, the uncertainty analysis of the system performance seems necessary. In general, uncertainties in any engineering system study can be represented probabilistically or possibilistically. When sufficient historical data of the system variables is not available, a probability density function (PDF) might not be defined, while they must be represented in another manner i.e. possibilistically. When some of system uncertain variables are probabilistic and some are possibilistic, neither the conventional pure probabilistic nor pure possibilistic methods can be implemented. Hence, a combined solution methodology is needed. This paper proposes a new analytical probabilistic- possibilistic tool for the power flow uncertainty assessment. The proposed methodology is based upon the evidence theory and joint propagation of possibilistic and probabilistic uncertainties. This possibilistic–probabilistic formulation is solved in an uncertain power flow (UPF) study problem.

Contents

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1. Introduction

Power flow (PF) assessment of electrical power systems is of essential tools for both system operation and planning. Deterministic PF analysis requires precise values of demand, generation, and network conditions. More and more uncertainties emerge in world-wide power systems as a by-product of restructuring on one hand and the unprecedented penetration of uncertain distributed energy resources (DERs) especially renewable energies (REs) on the other. Distributed generations (DGs) are defined as electric resources interconnected to the distribution networks [1]. The implementation of DGs has many technical [2], socio-economic [3] and environmental [4] benefits but they, especially those harvesting REs, bring about additional uncertainties in the system performance that must be studied clearly [5].

In such uncertain conditions, deterministic PF calculation cannot precisely reveal the state of system; therefore, uncertainty point of view analysis would be of significant interest. Generally, probabilistic power flow (PPF), aiming to assess bus voltages and line flows in response to the uncertain system parameters, is recognized as a desirable tool in both power system planning and operation. This tool informs system engineers over the future system conditions and helps them in the decision making process in such an uncertain environment. Probabilistic methods are of the main approaches being dealt with such uncertainties, where they can be applied when sufficient historical data regarding uncertain variables is available. Usually, there are some uncertain variables that their historical data are incomplete or obtained by experience; hence, the possibilistic theory might be used to model their uncertainty associated with imperfection as well as imprecision. This is not all the thing, consider the case in which some variables are probabilistic and some are possibilistic which is a common case in real world. In such circumstance, a joint propagation of probabilistic and possibilistic uncertainties would be fruitful. This work is motivated by the joint propagation of these kinds of uncertainties in the PF problem, the so-called uncertain power flow (UPF) study.

So far, various techniques have been used for uncertainty analysis of engineering systems. In the early seventies and for the first time, the system load uncertainty was considered in a probabilistic analysis of PF problem [6]. Till now, many probabilistic approaches have been suggested. Monte Carlo simulation (MCS) is the frequently used simulation-based probabilistic method. In [7], the effects of wind power integration on the power system PF problem solutions are studied by the MCS. Generally, MCS is recognized as a system-size independent technique; however, it may have a long execution time [8]. In [9] and [10], the PPF problem was studied by the combined Cumulant and Gram–Charlier expansion theory. In [11], the integration of wind farms in AC-PPF problem was studied. In [12], in order to reduce the computational burden, a discrete frequency domain convolution technique using fast Fourier transformation (FFT) is proposed. In [13], a point estimation-based method (PEM) was developed for the PPF problem. In [5], the Unscented Transformation (UT) was used for probabilistic studies of the PF problem.

As noted before, probabilistic methods are applicable when sufficient historical data about uncertain variables or their PDF are available. Generally, there are some uncertain variables in any system that their PDF are not available due to variety of reasons such as imprecise historical data, privacy reasons and so forth. In this situation, the possibility theory can be utilized to cope with this kind of uncertainties. In [14–16], fuzzy modeling has been used to reflect the uncertainties in the PF problem. As a general rule, any engineering system has different types of uncertainties especially in its input variables. In real world, some uncertain variables are probabilistic and some are possibilistic, in which neither pure probabilistic nor pure possibilistic techniques can be implemented alone but a new combinatorial solution is needed. Indeed, a joint propagation of probabilistic and possibilistic uncertainties must be carried out [17]. Hence, a possibilistic–probabilistic tool to evaluate the uncertainty of engineering systems is of huge interest. The main contribution of this work is to develop a new methodology for UPF studies using evidence theory to joint propagation of probabilistic and possibilistic uncertainties applied to power system PF studies, taking into account uncertainties associated with the load, wind, and solar power generation as probabilistic uncertain parameters and the gas turbine distributed generation (DG) and electric vehicles (EVs) as uncertain possibilistic variables. To this end, the uncertainties are first modeled appropriately; thereafter, the proposed method is devised by adaptation of evidence theory to the problem. In the following, the proposed methodology is applied on test systems including a 9-bus and a realistic 574-node distribution system. Note that in the recent published works e.g. [17], the MCS has been used for probabilistic frame work in the joint algorithm which itself suffers from computational effort. On the contrary, in this work, the Unscented Transformation (UT) method whose application in the PPF problem has been confirmed in [5] is proposed as probabilistic frame work of the joint algorithm. The proposed method has greatly reduced the computational burden while remaining the desired accuracy compared to the MCS-based method proposed in [17].

The remainder of the paper is structured as follows. Section 2 presents the PF and UPF formulation, briefly. Section 3 discusses about probabilistic uncertainty modeling and some of its approaches. It also introduces the Unscented Transformation (UT) method. In Section 4, the possibilistic uncertainty modeling is given. In Section 5, the uncertainties in the PF problem and their modeling are introduced. Section 6 presents the evidence theory and the proposed algorithm for joint propagation of probabilistic and possibilistic uncertainties. Simulation results will come in