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How to deal with uncertainties in electric power systems? A review

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ABSTRACT

In electric power systems, there exist many diverse uncertain parameters such as loads, electricity price, wind power generation and photovoltaic power generation. In power system studies, appropriate modeling and handling of these uncertain parameters is essential. In this paper, the sources of uncertainties in power systems are described and different uncertainty handling methods in power systems are classified and reviewed in details, mentioning the merits and demerits of each method. Based on the conducted review, some directions for future research are delineated.

1. Introduction

In electric power systems, we are facing different uncertain parameters [1–5]. Restructuring of power systems along with proliferation of renewable energy integration, not only have increased the severity of uncertainties, but also have introduced new uncertain parameters in power systems. Load forecasting errors, photovoltaic and wind power generation, charging/discharging behavior of electric vehicles, stochastic topology of power systems and forecasted electricity price are some sources of uncertainty in electric power systems. The classification of sources of uncertainty in electric power systems can be seen in Fig. 1 [2]. As this figure shows, power system uncertain parameters can be categorised into two categories; Technical parameters and economical parameters. Each category has itself been subdivided into two subcategories.

To have a realistic modeling and making better decisions in electric power systems, the uncertainties must be taken into account. The common approaches for dealing with power system uncertainties can be classified into three main categories. In the approaches of the first category, referred to as probabilistic approaches, uncertain parameters are modeled by probability density functions (PDF's) and are dealt with different probabilistic strategies such as Monte Carlo simulation (MCS), scenario-based analysis and point estimate method (PEM). In the approaches of the second category, referred to as possibilistic approaches, uncertain parameters are represented by fuzzy membership functions and dealt with fuzzy arithmetic. The third category includes hybrid probabilistic-possibilistic approaches wherein some uncertain parameters are represented by PDF's and are dealt with probabilistic strategies, while other uncertain parameters are represented by fuzzy membership functions and are dealt with possibility theory. In this paper, different uncertainty handling techniques in power systems are classified and reviewed in details. The paper can give the reader an idea how to deal with different kinds of uncertainties in electric power systems. The rest of the paper is organised as follows; in the second section, different uncertainty handling approaches in power systems are classified and reviewed in details. In the third section, an overall review of different uncertainty handling techniques in electric power systems is presented and finally, the fourth section contains conclusions.

2. Classification and review of uncertainty handling approaches in power systems

The common approaches for dealing with power system uncertainties can be classified into three main categories; namely, probabilistic approaches, possibilistic approaches and hybrid probabilistic-possibilistic approaches [2]. In this section, those approaches are described and reviewed. A classification of the common uncertainty handling techniques in electric power systems can be seen in Fig. 2.

2.1. Probabilistic approaches

Probabilistic approaches are the most commonly used approaches in handling power system uncertainties. In these approaches, uncertain parameters are modeled by probability density functions (PDF's) and

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Abbreviations: PDF, Probability density function; MCS, Monte Carlo Simulation; PEM, Point estimate method; SBA, Scenario-based analysis; PV, Photovoltaic; MF, Membership function; IGDT, Information gap decision theory; DNO, Distribution network operator; DR, Demand response; UC, Unit commitment; PSO, Particle swarm optimisation; GA, Genetic algorithm; DE, Differential evolution; ABC, Artificial bee colony; PEV, Plug-in electric vehicle; GenCo, Generation company

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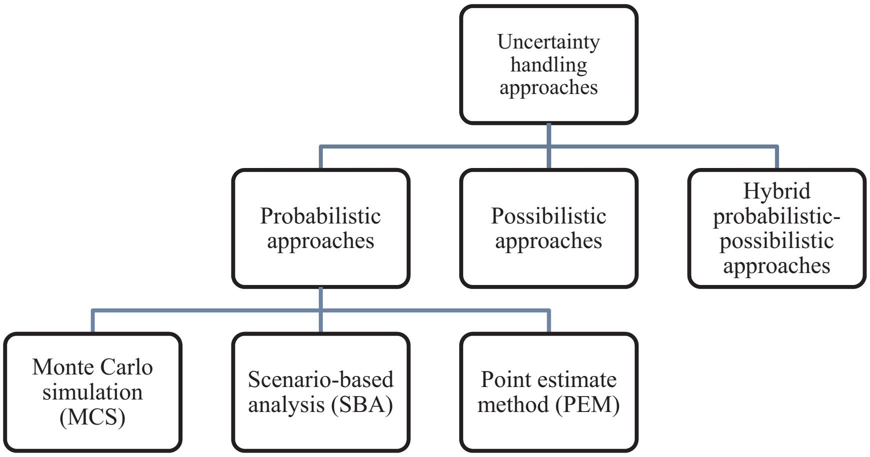

Fig. 1. Sources of uncertainty in electric power systems [2].

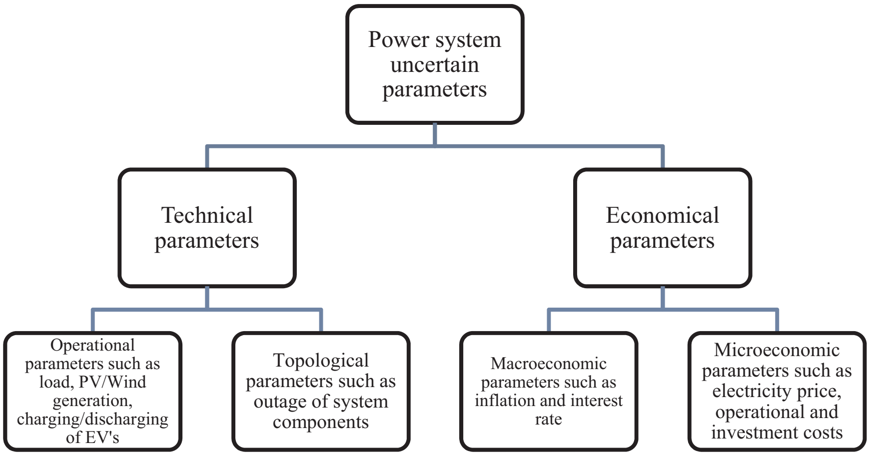

Fig. 2. Classification of uncertainty handling techniques in electric power systems.

are dealt with different probabilistic strategies such as Monte Carlo simulation (MCS), scenario-based analysis (SBA) and point estimate method (PEM). Here, first, the most common PDF's used for different uncertain parameters in power systems are introduced.

- Load

Ideally, due to the forecasting errors, in power system planning and operation studies, the loads should not be assumed as certain deterministic parameters. Instead, they are commonly modeled as a Gaussian PDF whose mean is equal to the forecasted value. In most cases, a fraction of forecasted load value is taken as the standard deviation of PDF [6,7].

$$PDF\,(S)=\frac{1}{\sqrt{2\pi\sigma}}exp\left[-\frac{(S-\mu)^2}{2\sigma^2}\right] \tag{1}$$

Where S denotes apparent power of load, σ and μ respectively represent mean (forecasted) and standard deviation of apparent power.

In Fig. 3, the typical PDF of a load with mean of 100 kW and standard deviation of 5 kW has been depicted.

- Wind power generation

The generated power of a wind turbine mainly depends on the wind speed [6,8–15]. The wind speed of a wind turbine is commonly modeled as a Weibull PDF which is characterised by the following equation [6,16,17].

$$PDF\,(v)=\left(\frac{K}{C}\right).\left(\frac{v}{C}\right)^{K-1}exp\left(-\left(\frac{v}{C}\right)^{K}\right) \tag{2}$$

Where K and C respectively denote shape factor and scale factor of Weibull function.

The generated power of a wind turbine is a function of wind speed that characterised by the equation below.

$$P\,(v)=\begin{cases} 0 & v\le v_{in}^{c}\;\; or\;\; v\ge v_{out}^{c}\\ \frac{v-v_{in}^{c}}{v_{rated}^{c}-v_{in}^{c}} & v_{in}^{c}\le v\le v_{rated}^{c}\\ P_r & else\end{cases} \tag{3}$$

Where v_{in}^{c} and v_{out}^{c} respectively represent cut in speed and cut out speed of wind turbine in m/s, v_{rated}^{c} denotes turbine's rated speed and P_r denotes rated power of wind turbine [6].

In Fig. 4, the PDF of wind speed has been depicted and in Fig. 5, output power of a wind turbine versus wind speed has been illustrated. In these figures, the following parameters have been used. $K=1.75$, $v_{in}^{c}=3m/s$, $v_{out}^{c}=25m/s$, $v_{rated}^{c}=13m/s$, $C=8.78$ and $P_r=0.5kW$.

- Photovoltaic power generation

The generated power of a PV generator mainly depends on solar irradiation [6,18–21]. Solar irradiation is commonly characterised by Beta distribution function as follows [6].

$$PDF\,(s)=\begin{cases}\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha).\Gamma(\beta)}.\;s^{\alpha-1}.\;(1-s)^{\beta-1} & if\;\;0\le s\le 1\\ 0 & otherwise\end{cases} \tag{4}$$