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Composite system reliability assessment using fuzzy linear programming

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Abstract

Composite power system reliability evaluation refers to assessment that considers both, generation and transmission facilities. The conventional dc load flow-based crisp linear programming (CLP) model used in composite power system reliability evaluation is modified as a fuzzy linear programming (FLP) model including fuzzy constraints and objective functions. This fuzzy linear programming model can include uncertainties that exist in certain variables and overcome the limitations of minor constraint violations in crisp linear programming model. This fuzzy optimization model is employed to test the system outage contingencies and to determine the degree of difficulty due to these contingencies. Fuzzy-based adequacy indices are obtained after all the selected contingencies have been analyzed using contingency enumeration approach. The effectiveness of the developed model is tested on the IEEE-14 bus system.

Keywords: Composite power system reliability; Contingency enumeration approach; dc load flow; Fuzzy linear programming; Fuzzy number; Adequacy index

1. Introduction

The conventional dc flow-based crisp linear programming (CLP) model [1] used in composite system reliability evaluation method is formulated as an optimization problem with crisp constraints. The CLP is often insufficient in real life situation. In reality, certain coefficients that appear in CLP problems may not be assessed precisely or only qualitative estimates of these coefficients are available. In addition, the given fixed values of constraint limits have to be met all the times. Any violation of a single constraint by even a small amount renders the solution infeasible or it may lead to over-conservative solutions. In many of the real life problems, there are situations where small violations of these limits are sometimes acceptable. In this regard, the constraints may be classified either as ‘hard’ or ‘soft’. For example, generation output is a ‘hard’ constraint whereas transmission line flow is a ‘soft’ one. Fuzzy linear programming (FLP) [2] is an extension of CLP and deals with such imprecise coefficients and ‘soft’ constraints by using fuzzy variables. In fuzzy environment, the decision maker could accept small violations of the constraints and attach different degrees of importance to the violations of different constraints.

Saraiva et al. [3] use fuzzy numbers to define loads in composite power system reliability evaluation using Monte-Carlo simulation. The authors propose a set of new indices reflecting the integration of probabilistic models and fuzzy concepts and discuss the application of variance reduction techniques (a simulation approach) if fuzzy numbers define loads. Saraiva and Sousa [4] extend this work with some new developments. The two main new developments are: fuzzy load duration curve and modeling of failure and repair rates using trapezoidal fuzzy number (TrFN). Saman and Singh [5] develop a Genetic Algorithm-based method for composite system state evaluation where the system constraints are represented by fuzzy membership functions. Choi et al. [6] propose a new fuzzy effective load duration curve (ELDC)

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model for reliability evaluation of composite power system using fuzzy set theory considering the flexibility and ambiguity of capacity limitation and over load of transmission lines which are subjective matter characteristics. A number of papers on bibliographic review of the applications of fuzzy set theory in power systems are found in literature [7–10].

In the present study, the conventional dc load flow-based CLP model is modified into a FLP model including fuzzy constraints and fuzzy objective functions. The FLP is then converted into an equivalent crisp optimization model using the concept of fuzzy mathematical programming [2]. The developed equivalent crisp optimization model is used in contingency enumeration approach to evaluate adequacy indices [11]. The effectiveness of the developed model is tested using a 14-bus system and the results are compared with the conventional one.

2. Formulation of fuzzy optimization model

The conventional dc flow-based CLP model used in composite power system reliability evaluation is converted into a FLP model including fuzzy constraints and objective functions. Using fuzzy sets, membership functions are defined for system loads, transmission line flow constraints, load curtailments and objective function. Then inequality constraints, equality constraints and bounds on fuzzy variables are formulated. The model also includes the crisp constraints. The proposed fuzzy optimization model is developed in a systematic manner in the following subsections.

2.1. Membership function of fuzzy load

Triangular fuzzy number (TFN) is used to represent fuzzy load. The membership function is defined below:

$$M_d(x)=\begin{cases} \dfrac{x-(1-s)d}{d-(1-s)d}=\dfrac{x-(1-s)d}{sd}, & (1-s)d \le x < d \\ \dfrac{(1+s)d-x}{(1+s)d-d}=\dfrac{(1+s)d-x}{sd}, & d < x \le (1+s)d \\ 1, & x = d \\ 0, & \text{elsewhere} \end{cases} \tag{1}$$

It is to be noted here that when the membership functions are defined, certain percentage values are needed to obtain the range of the fuzzy parameters at minimum and maximum degrees of membership grades. These percentage values are sometimes assumed or obtained from expert's opinion. In Eq. (1), s represents such a percentage value.

2.2. Membership function of fuzzy capacity of transmission line

Small violations of transmission flow limits may be acceptable during stressed situations of the power systems. There are usually two flow limits for each transmission line, namely normal and emergency limits [12]. When there is a real need, sometimes, system operator is forced to violate the normal limits and allowed to operate the system within emergency limits, keeping in mind the economical operation of the system. However, the emergency limits can never be violated. The conventional crisp optimization model fails to incorporate such a situation in the formulation. Fuzzy set theory has the capability to deal with such situations.

In this study, transmission line flow limits are represented using a trapezoidal fuzzy number (TrFN). The membership function is defined below:

$$M_f(x)=\begin{cases} \dfrac{-(1+p)f^{\mathrm{m}}-x}{-(1+p)f^{\mathrm{m}}-(-f^{\mathrm{m}})}=\dfrac{(1+p)f^{\mathrm{m}}+x}{pf^{\mathrm{m}}}, & -(1+p)f^{\mathrm{m}} \le x < -f^{\mathrm{m}} \\ \dfrac{(1+p)f^{\mathrm{m}}-x}{(1+p)f^{\mathrm{m}}-f^{\mathrm{m}}}=\dfrac{(1+p)f^{\mathrm{m}}-x}{pf^{\mathrm{m}}}, & f^{\mathrm{m}} < x \le (1+p)f^{\mathrm{m}} \\ 1, & -f^{\mathrm{m}} \le x \le f^{\mathrm{m}} \\ 0, & \text{elsewhere} \end{cases} \tag{2}$$

Here, p represents the percentage value similar to s as in Eq. (1).

2.3. Membership function of load curtailment

The amount of load curtailment from a bus depends upon the load available on that bus. Load curtailment from a bus will be fuzzy because the load is fuzzy.

The membership function of load curtailment is defined in Eq. (3).

$$M_r(x)=\begin{cases} \dfrac{(1+s)d-x}{(1+s)d-d}=\dfrac{(1+s)d-x}{sd}, & d \le x \le (1+s)d \\ 1, & x \le d \\ 0, & x > (1+s)d \end{cases} \tag{3}$$

2.4. Membership function of objective function

The present study concentrates on determination of 'crisp maximizing solution' [2] based on fuzzy constraints and fuzzy objective function. Before proceeding to define mem-