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A fuzzy multiple linear regression based loss formula in electric distribution systems

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Abstract

Estimation of energy loss is an essential task for both operation and planning in electric distribution systems. The energy losses are considered to be uncertain due to measurements. A new method based on fuzzy-c-number clustering and fuzzy multiple linear regression analysis is proposed for developing energy loss formulas to estimate losses in this paper. The proposed method is implemented with three stages. A part of Taipower distribution system in Taipei is used for illustrating the performance of the proposed method.

Keywords: Loss formula; Fuzzy multiple linear regression; Fuzzy clustering; Electric distribution systems

1. Introduction

The purposes of energy loss estimation in distribution systems include conductor size design, substation expansion, rate analysis, loss allocation to customers, energy conversion analysis, and control strategy development, etc. (see [6]). Therefore, exploration of an energy loss (kW h) formula is very essential for a utility in the viewpoint of both operation and planning.

There were many existing literatures related to loss estimation for distribution systems (see [1–5,7–10,14]). A sophisticated model for loss estimation was proposed in [14]. An empirical loss factor equation considering the load composition and various time periods was presented in [7]. An energy formula further considering constant voltages, power factors and resistors was developed in [8]. Capacitors and taps were considered as independent (control) variables in an energy loss formula for the sake of developing proper control strategies in [1]. Unbalanced voltages and currents were used as independent variables for a loss formula in [4]. A measurement based loss formula was

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proposed for residential wiring system in [5]. A simplified loss model for distribution systems was presented in [3]. Other papers [2,9,10] were also related to loss formulas.

On the other hand, regression is a method for fitting variables to a function, which may be linear, nonlinear or multiple. Regression is the determination of coefficients of the fitting function. Similarly, fuzzy regression is developed for fitting fuzzy variables into a fuzzy or real function because engineers usually use fuzzy linguistic sentences to describe engineering phenomena [15,16,18]. The fuzzy multiple linear regression method was proposed in [15,16] for forecasting physical quantities. A new method based on fuzzy clustering incorporated with fuzzy regression to be the cluster-wise fuzzy regression was presented by Yang and Ko [18]. In the power engineering area, the peak load was forecasted using fuzzy regression in [13].

It is known that the loss values can be modeled with fuzzy numbers because the system load and energy source values are uncertain due to measurements [12,13]. In this paper, therefore, a three-stage method based on [18] and fuzzy-c-number (FCN) clustering [17] is proposed for obtaining proper energy loss formulas. The reason for adopting [18] is that this method avoids linear programming used in [15,16]. The FCN algorithm is used first to partition the 24-h energy loss pattern into three clusters covering several segments where each cluster contains several time periods. The three clusters are designed for the peak-, medium-peak and off-peak losses. Then each segment is further clustered into several sub-clusters, which are fitted by fuzzy multiple linear regression. The independent variables are the kW h and kVARh loads in this paper.

A realistic distribution system in Taipower system of Taiwan Power Company is studied in this paper. From the case study results, it is found that the proposed method can efficiently estimate the system kW h losses for engineers.

2. Characteristics of distribution system losses

The distribution losses are more nonlinear and diversified compared with the transmission losses. A part of the distribution (supply) system for Taipower, including two 161/69 kV and 12 69/11.95 /11/6.9 kV transformers, is illustrated in Fig. 1 for depicting the above phenomenon. This supply system, Song-Shan area, is a part of the whole Taipei distribution system.

Song-Shan Supply area is a P/S (primary system) fed from six 161/69 kV lines. There are 12 distribution transformers (69/11/11.95/6.9 kV, 25 MVA) connected to four S/S (secondary systems), namely Nei-Hu, Ming-Shen, Chung-Nun, and Hsin-Ya. Generally, there are two peak loads daily and therefore the energy loss pattern is a two-peak pattern. Table 1 shows the daily kW h loss range for different periods in the Song-Shan supply system. As shown in Table 1, a single formula is inadequate to express the kW h losses in this system. Actually, there are different load characteristics in various hours daily. For example, rotating machine loads are dominated in the peak-load hours while there are TV and light loads in the off-peak load hours (at night). There exist some transition periods between the peak load and off-peak load periods; therefore, medium-peak load hours should be considered. Hence, a partition process is required for this loss pattern. As shown in Table 1, there are seven “segments” in a day: (1, 2), (22–24), (3–7), (12–16), (19–21), (8–11), and (17,18).

After the three periods (peak-load, medium-peak load, and off-peak load) are identified (clustered), one should further examine the loss characteristics in each segment. The realistic