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Multi-step ahead forecasting in electrical power system using a hybrid forecasting system

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A B S T R A C T

Managers and researchers have put more emphasis on electrical power system forecasting to obtain effective management in electrical power system. However, enhancing prediction accuracy is not only a highly challenging task, but also a concerned problem in electrical power system. Traditional single algorithms usually ignore the significance of parameter optimization and data preprocessing, which always leads to poor results. Thus, in this paper a novel hybrid forecasting system was successfully developed, including four modules: data preprocessing module, optimization module, forecasting module and evaluation module. In this system, a signal processing approach is employed to decompose, reconstruct, identify and mine the primary characteristics of electrical power system time series in data preprocessing module. Moreover, to achieve high accuracy and overcome the drawbacks of single models, optimization algorithms are also employed to optimize the parameters of these individual models in the optimization and forecasting modules. Finally, evaluation module including hypothesis testing, evaluation criteria and case studies is introduced to make a comprehensive evaluation for this system. Experimental results showed that the hybrid system not only can be able to satisfactorily approximate the actual value, but also be regarded as an effective and simple tool adopted in smart grids.

1. Introduction

Electrical power system (EPS) forecasting is an important task, which plays an irreplaceable role in power system operation and decision-making, such as power generation expansion, dispatch scheduling of generating production, maintenance scheduling, and ensuring a continuous supply of electricity [1]. The accurate electrical power system forecasting not only can assist decision-makers planning electricity management, arranging reasonable operation modes, but also help to reduce the loss of auxiliary power and electricity networks and eventually enhance the security and stability of the electrical power system. On the contrary, poor forecasting accuracy probably increases the cost of electric power companies and sometimes even leads to blackout events [2]. For instance, on August 15, 2003, Northeastern United States and Canada suffered a severe blackout event, which affected 50 million people. Similarly, in 2009, 67 million people experienced a large-area blackout event of Brazil and Paraguay blackouts. Therefore, to achieve good forecasts and timely prevent those events, the development of a scientific, robust, effective and accurate electrical power system forecasting model is extremely desirable.

Recently, high prediction accuracy has already been found significant applications in electrical power system, which has been paid more and more attention by many researchers [3]. However, most previous literature only considered one or two indicators, which usually ignored the significance of three most pivotal indicators (i.e. short-term wind speed (STWS), electrical load (EL) and electricity price (EP)) in EPS [4]. Most importantly, these indicators are not only connected with the power generation, distribution and consumption of electricity and other aspects, but also play an increasingly significant part in the daily operational management of a power utility [5]. Specifically, as growing global energy crisis and environmental pollution, wind energy, connected to the power generation, has been regarded as one of the most significant source of green renewable energy, which is steady, abundantly available, reliable, inexhaustible, widespread, pollution-free, and economical [6]. What's more, it can be effectively employed to satisfy the great majority of worldwide energy demands in future without emission of sulfide, carbon dioxide or other harmful gases [7]. Moreover, owing to the continuous

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increase in the installed capacity as well as the large demands for electricity, the accurate, stable electrical load and electricity price forecasting play vital roles for power producers and consumers [8], and have been gaining increasing global attention, which not only can provide grid system more stability, securely, efficiently, economically and sustainably, but also enable the participants of electricity market to manage their demand for reducing the risk and maximizing the profits according to price variation [9]. Therefore, it is urgent need to implement accurate wind speed, electrical load and electricity price prediction in EPS, as a foundation for establishing a stable, effective and smart grid system, and effectively supplying sustainable, economic and secure electricity.

Over the past several decades, an increasing number of methods have been implemented by many researchers because of the necessity for better forecasting performance of STWS, EL and EP [10]. Generally, these approaches can be broadly divided into three major classifications: conventional (statistical) methods, artificial intelligent techniques and combination/hybrid models [11]. Statistical approaches, such as linear regression models, autoregressive moving average(ARMA), autoregressive integrated moving average (ARIMA), and so on, are known to show some disadvantages in solving nonlinear problems [12]. As a result, they are unfit for accurately forecasting the complex and nonlinear EPS series.

Fortunately, as the artificial intelligent technology rapid developed in recent years, more and more different intelligence algorithms, such as support vector machines (SVMs), expert system, fuzzy logic system (FLs) and artificial neural networks (ANNs) [13], etc. have been presented. Among these developed methods, ANNs has received considerable attention because of their ability to effectively deal with engineering problems (i.e. design and optimization of a solar power plant [14], optimization of district heating system aided by geothermal heat pump [15], potential assessment of solar thermal power plant [16], time series prediction [17], etc.). For instance, Arslan and Yetik [18] applied ANN tool to optimize the supercritical ORC-Binary in the Simav geothermal field. Moreover, Arslan [19] developed an ANN model to evaluate the Kalina power systems using geothermal resources. As for prediction, Ren et al. [20] applied back propagation neural network (BPNN) to forecast 6-hourly average wind speed from Jiuquan prefecture of Gansu province in China, and the results showed that the performance of BPNN is superior to that of ARIMA. Panapakidis et al. [21] utilized day-ahead electricity price data to explore the potential of ANN based models, and the experimental results indicated that the ANN combined with clustering algorithm can be taken as powerful forecasting methods to adjust market price strategy.

Due to the inner weaknesses of each individual method as well as the intermittent and instability of the EPS series, traditional single algorithms cannot completely mine and capture the characteristics of time series, which often lead to poor forecasting performance, especially when dealing with non-linear problems [22]. Hence, with the hope of obtaining higher prediction accuracy, the combination/hybrid models have emerged that aggregated the advantages of multiple separate methods including different individual forecasting models, optimization algorithms and signal processing tools i.e. singular spectrum analysis (SSA), empirical mode decomposition (EMD), ensemble empirical mode decomposition (EEMD), which have been widely utilized in many different applications. In addition, it has been proved that the mean absolute error of the combination and hybrid model is lower than that of an individual model [10]. In other words, the combination and hybrid models can perform better than individual models. For example, after processing the load series with EMD, Liu et al. [23] applied particle swarm optimization (PSO) to optimize the parameters of the proposed model for short-term load forecasting of micro-grids. Wang et al. [24] applied wavelet transform to decompose the historical data into a set of components from low-to-high frequency, and then applied the genetic algorithm (GA) and BPNN to forecast the short-term wind speed.

However, some drawbacks can also occur to the conventional ANNs, such as easily trapping into local minimum value, the difficulty of choosing parameters, requiring large training samples [25], the questions about their structure parameter determination [26], which always result in combination and hybrid models showing inaccurate forecasts. In contrast, a novel machine learning technology first developed by Cortes and Vapnik [27], SVM possesses some advantages in terms of effectively solving the learning problems of small sample size, pattern recognition with high dimension and nonlinearities. However, traditional SVM has a relatively complicated calculation process and slow convergence speed that easily leads to unsatisfactory forecasting results [28]. To address the problems of SVM, an improved technique-least squares support vector machine (LSSVM) was presented [29]. Its nature is to translate a quadratic programming problem into solving linear equations, consequently accelerating problem-solving and improving computational convergence [25]. So far, LSSVM has been regarded as an efficient method and widely utilized to handle forecasting problems in many fields, such as wind speed forecasting [30], crude oil price forecasting [31], electricity price and load forecasting [32], pollutants forecasting [33], and so on.

Base on the above-mentioned and analysis, in this paper a novel robust hybrid forecasting system was developed with the hope of obtaining more stable and accurate prediction results in EPS, which mainly includes four modules: data preprocessing module, optimization module, forecasting module and evaluation module. Specifically, after obtaining the real and useful signals of EPS by applying CEEMD data preprocessing module, LSSVM optimized by the novel whale optimization algorithm (WOA) in the optimization module are utilized as hybrid forecasting model for EPS series forecasting in the forecasting module. Finally, evaluation module including hypothesis testing, evaluation criteria and case studies is introduced to make a comprehensive evaluation for this system. Additionally, half-hour and hourly wind speed series from Penglai and Chengde in China, both half-hour electric load data from New South Wales of Australia and Singapore, and half-hour and hourly electricity price time series from New South Wales as well as the Diebold-Mariano (DM) test in the evaluation module are all introduced to make a comprehensive evaluation for this system. The main contributions in this study are summarized as follows:

(a) **Focusing on wind speed, electrical load and electricity price time series, simultaneously.** Most previous articles focused only on wind speed, electrical load or electricity price, which usually ignore the significance of the three indicators in EPS. Thus, in this paper a novel robust hybrid forecasting system was successfully developed, which not only can display satisfactory forecasting accuracy, but also easily be implemented well for time series prediction.
(b) **Focusing not only on single-step forecasting, but also on multi-step forecasting.** One-step wind speed, electrical load and electricity price time series predictions have been widely adopted in many studies, but their predicted results are sometimes insufficient to ensure the reliability and controllability of electrical power system. Therefore, multi-step predictions with various time