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Research and application of a hybrid forecasting framework based on multi-objective optimization for electrical power system

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A B S T R A C T

Electrical power system (EPS) forecasting plays a significant role in economic and social development but it remains an extremely challenging task. Because of its significance, relevant studies on EPS are especially needed. More specifically, only a few of the previous studies in this area conducted in-depth investigations of the entire EPS forecasting and merely focused on modeling individual signals centered on wind speed or electrical load. Moreover, most of these past studies concentrated on accuracy improvements and usually ignore the significance of forecasting stability. Therefore, to simultaneously achieve high accuracy and dependable stability, a hybrid forecasting framework based on the multi-objective dragonfly algorithm (MODA) was successfully developed in this study. The framework consists of four modules—data preprocessing, optimization, forecasting, and evaluation modules. In this framework, MODA is employed to optimize the Elman neural network (ENN) model as a part of the optimization module to overcome the drawbacks of single-objective optimization algorithms. In addition, data preprocessing and evaluation modules are incorporated to improve forecasting performance and conduct a comprehensive evaluation for this framework, respectively. Empirical results reveal that the developed forecasting framework can be an effective tool for the planning and management of power grids.

1. Introduction

The power industry is an important basic industry needed for national economic and social developments. Moreover, electrical safety affects the overall state of economic development, sustained harmony in society, lives of the common people, and security of property. As most people are aware of, the electrical power system (EPS) is a complex system—which simultaneously accomplishes generation, transmission, distribution, and sale of electric energy—playing an important role in social and economic developments. Furthermore, the control provided by EPS contributes to the orderly management of electricity and reasonable operational plans, energy and cost saving, and substantial economic and social benefits [1]. Hence, researches that focus on EPS have immense political and economic importance for the whole society. Many studies related to EPS have been conducted, namely dynamic operation and control strategies for microgrid hybrid power systems [2], connection decisions of distribution transformers [3], forecasting issues including electricity load forecasting [4], wind power forecasting [5], wind speed forecasting [6], solar radiation forecasting [7], output power of photovoltaic plants [8], and so on. In general, many problems still exist in the hybrid generation system, and researchers have made in-depth exploration and analysis focusing on unsymmetrical faults [9], microgrid distribution ground fault [10], and unbalanced distribution network fault [11], etc. For instance, Qu et al. [12] proposed a novel intelligent damping controller to reduce power fluctuations, voltage support and damping in hybrid power multi-systems. The EPS forecasting is a very promising area in hybrid power system, which also plays a significant role in the operation of hybrid power systems. However, it remains an extremely challenging task. Therefore, this study focuses on the forecasting issues with the goal of developing an effective forecasting framework.

There are three main signals connected to generation,

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List of abbreviations

EPS	Electrical power system
ARMA	Autoregressive moving average process
ARIMA	Autoregressive integrated moving average
NWP	Numerical weather prediction
DFS	Date-framework strategy
MERRA	Modern-era retrospective analysis for research and applications
WIND Toolkit	Wind integration national dataset Toolkit
IEAM	Improved environment adaptation method
AnEn	Analog ensemble
AI	Artificial intelligence
ANN	Artificial neural network
GPR	Gaussian process regression
RFNN	Random fuzzy neural networks
MLP	Multi-layered perceptron
ELM	Extreme learning machine
KELM	Kernel extreme learning machine
GRNN	Generalized regression neural network
ENN	Elman neural network
BPNN	Back propagation neural network
SVM	Support vector machine
SVR	Support vector regression
LSSVM	Least square support vector machine
GNM	Generalized neuron model
NSW	New south wales
SG	Singapore
WT	Wavelet transform
PMSG	Permanent magnet synchronous generator
EMD	Empirical mode decomposition
EEMD	Ensemble empirical mode decomposition
CEEMDAN	Complete ensemble empirical mode decomposition with adaptive noise
ICEEMDAN	Improved complete ensemble empirical mode decomposition with adaptive noise
IMFs	Intrinsic mode functions
PSO	Particle swarm optimization
GABICS	Genetic algorithm binary improved cuckoo search
CS	Cuckoo search
SAPSO	Self-adaptive particle swarm optimization
DA	Dragonfly algorithm
BDA	Binary dragonfly algorithm
MODA	Multi-objective dragonfly algorithm
MOPSO	Multi-objective particle swarm optimization
DM	Diebold-Mariano
FE	Forecasting effectiveness
AE	Average error
MAE	Mean absolute error
RMSE	Root mean square error
NMSE	Normalized mean square error
MAPE	Mean absolute percentage error
FB	Fractional bias
IA	Index of agreement
TIC	Theil's inequality coefficient
RE	Relative error
RE_{MAPE}	Decreased relative error of MAPE
WTG	Wind turbine generator

distribution, and consumption in the EPS, namely short-term wind speed data, electrical power load data and electricity price data, which are all crucial for planning and managing a power grid [13]. To be specific, firstly, wind energy exhibits the most consistent and rapid deployment of power generating capacities than any other renewable energy resources [14]. In 2015, the global wind power industry reached an annual market growth of 20% with the installation generating units having more than 60 000 MW capacities. In China alone, the total capacity of new installations made by the wind power industry was 30 500 MW. By the end of 2015, the total global capacity reached 432 419 MW, gaining a cumulative growth of 17% [15]. However, the intermittent and stochastic characteristics of wind speed pose many challenges, i.e., the increase of costs and the decrease of reliability and stability of EPS [16]. One way to tackle these challenges is to improve forecasting accuracy for wind speed and wind power [17]. Secondly, the basic information for establishing the scheduling plan and reducing management risk—which is a decisive part of EPS risk management [18]—includes future changes in the power load series. Evidently, if the forecasting accuracy of the electrical power load could be improved, then enormous economic benefits could be achieved [19]. Finally, the cost of electricity is related to the aspects of consumption as these play vital roles in balancing the generation and consumption of electricity. Thus, a highly accurate cost forecasting is of great significance for the whole EPS and electricity market [20].

As discussed above, an effective forecasting method is one of the most crucial tools employed in EPS management [21]. However, despite its significance, relevant research for the whole EPS is still poor. More specifically, most recent analyses are focused on modeling individual signals, with either wind speed or electrical power load dominating. Therefore, it is quite urgent and necessary to develop a novel and robust forecasting framework for these three key signals of EPS. Depending on the computational principle involved, forecasting algorithms can be classified into four categories: statistical, physical, artificial intelligence, and hybrid algorithms.

Statistical algorithms attempt to find the relationship between past and future values in a time series, and to develop statistical and mathematical models for better real-time forecasting [22]. The forecasting performance of statistical models can be improved under the condition that input variables are convergent in the normal distribution [23]. The typical statistical model, autoregressive integrated moving average (ARIMA), is widely employed in the forecasting fields, such as short-term load forecasting [24], wind speed forecasting [25], electricity demand forecasting [26] and electricity price forecasting [27]. Physical algorithms utilize physical variables, such as temperature and humidity, to achieve time series forecasting [22]. However, the physical model consumes large amounts of computing resources. The numerical weather prediction (NWP) model, acknowledged as one of the most widely used physical forecasting model for wind speed forecasting [28], electricity demand forecasting [29], wind power forecasting [30], and wind resource assessment [31], is designed to solve atmospheric equations and identify atmospheric changes. To the best of the knowledge of the authors, artificial intelligence algorithms have been widely employed in many fields, including electric load forecasting [32,33], wind speed forecasting [34,35], electricity price forecasting [36], assessment of wind resources [37], energy optimization and analysis modeling [38], optimization of transesterification process [39], analysis and forecasting of oil consumption [40] and so on, mainly because of the flexibility,