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A hybrid forecasting model with parameter optimization for short-term load forecasting of micro-grids

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HIGHLIGHTS

- A hybrid load forecasting model with parameter optimization is proposed.
- Off-line optimization, periodic update and on-line forecasting are designed.
- The results have acceptable forecasting accuracy and time performance.
- The accuracy is affected by load variation in a day and between two adjacent days.

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ABSTRACT

Short-term load forecasting is an important part in the energy management of micro-grid. The forecasting errors directly affect the economic efficiency of operation. Compared to larger-scale power grid, micro-grid is more difficult to realize the short-term load forecasting for its smaller capacity and higher randomness. A hybrid load forecasting model with parameter optimization is proposed for short-term load forecasting of micro-grids, being composed of Empirical Mode Decomposition (EMD), Extended Kalman Filter (EKF), Extreme Learning Machine with Kernel (KELM) and Particle Swarm Optimization (PSO). Firstly, the time-series load data are decomposed into a number of Intrinsic Mode Function (IMF) components through EMD. Two typical different forecasting algorithms (EKF and KELM) are adopted to predict different kinds of IMF components. Particle Swarm Optimization (PSO) is used to optimize the parameters in the model. Considering the limited computation resources, an implementation mode based on off-line parameter optimization, period parameters updating and on-line load forecasting is proposed. Finally, four typical micro-grids with different users and capacities are used to test the accuracy and efficiency of the forecasting model.

1. Introduction

Nowadays, micro-grid (MG) has become an indispensable infrastructure in smart grid. The concept of MG is proposed by the Consortium for Electric Reliability Technology Solutions (CERTSs) to enhance the short-time reliability and flexibility of electric power systems, which consist of distributed energy resources (DERs), customers and energy storage units. It can be further defined as a small electric power system being able to operate physically islanded or interconnected with the utility grids [1–3]. With the growing expectations in the adoption of micro-grids, advanced tools and techniques are required in the optimal operation. Short-term load forecasting is a fundamental and essential task for the operation of a micro-grid. Short-term load forecasting is a key input to micro-grid energy management system for optimal utilization of available resources and efficiency of electric energy with the power grid [4]. The forecasting results would directly affect micro-grid operation strategies and electricity trading. Related study has shown that larger load forecasting errors lead to higher operating cost [5].

In terms of short-term load forecasting, micro-grid is more difficult to realize than large power grid for its higher randomness and lower similarities in history load curves. Additionally, due to the limited capacities on the user side, the load characteristics have less smoothing effect, leading to the higher load fluctuation [4]. There have been several studies focusing on the load forecasting of micro-grid. A bilevel prediction strategy for short-term load forecasting of micro-grids is proposed in Ref. [4]. However, the selected micro-grids have large capacity. The minimum load is

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12 MW, which is almost the same as the load of a medium voltage (e.g. 10 kV) distribution line. As the forecasting method includes a large number of auxiliary steps such as feature selection and parameter optimization, the computation time is about 40 min, which is more reasonable for day-ahead forecasting. In Ref. [6], BP neural network is adopted to forecast micro-grid load from several hours ahead until several days ahead. However, as the example is a small office building that the load variations within each hour may be quite large, the forecasting accuracy still needs to improve further. In Ref. [7], a smart energy management system which includes a forecasting model of power generation to optimize the operation of the micro-grid is presented. In the module, the result of load forecasting is taken into consideration, but the concrete algorithm to deal with the forecasting has not been introduced. A sparse heteroscedastic forecasting model based on Gaussian process is proposed in Ref. [8], which focuses on the day-ahead probabilistic load forecasting in the energy-intensive enterprises. However, the capacity of the example is about 1000 MW, which is equal to the load level of a medium-sized city. The forecasting accuracy does not have obvious advantages over traditional methods such as support vector regression (SVR). In Ref. [9], an optimized scheduling of a micro-grid battery storage system which considers the next-day forecasting load is presented. The load is forecasted through the ARMA (1,1) model. However, the model is more suitable for load data with highly periodic nature. In Ref. [10], a fuzzy neural network with varying learning rates for short-term load forecasting is investigated and has been applied in a real case of a campus micro-grid. A smart micro-grid model which includes demand forecasting and renewable energy forecasting is proposed in Ref. [11]. In the forecasting model, artificial neural network is used for short-term demand forecasting (several hours $\sim$ several days).

Currently, research results of short-term load forecasting for micro-grids are still limited. The accuracy of forecasting results varies considerably for micro-grids with different capacities and load characteristics. Part of these researches have high computational complexity. Considering the development of demand response in smart grid, the small load capacity on the user-side (such as small residential areas and commercial buildings) would be an important user type of micro-grid. In addition to guaranteeing the forecasting accuracy, the computational complexity should also be reduced to be easily implemented on normal computers or embedded terminal devices.

According to the above analysis, the problems of micro-grid short-term load forecasting exist in three aspects: (1) compared to large power grid, the load of micro-grid is more difficult to forecast for the smaller capacity and higher randomness; (2) complex forecasting models would increase requirement and cost on computational resources, leading to difficulty in application and promotion among users; (3) the relationship between load characteristics and the corresponding forecasting accuracy is lack of analysis and summary.

In order to solve these problems, a novel hybrid model with parameter optimization for load forecasting of micro-grid is proposed. It is composed of Empirical Mode Decomposition (EMD), Extended Kalman Filter (EKF), Extreme Learning Machine with Kernel (KELM) and Particle Swarm Optimization (PSO). Empirical Mode Decomposition (EMD) could gradually decompose the time-series of load data into components of different scales and trends. Two typical different algorithms (EKF and KELM) compose a dual-core prediction model to forecast these components which are of different characteristics. PSO is used to optimize the parameters in the model. Considering the computational resources in the user-side is limited, an implementation method based on off-line parameter optimization and on-line forecasting is proposed. The optimization process of parameters takes much time and hence be calculated off-line on the high-performance servers. The on-line forecasting process is carried out on normal computers or embedded system in the user-side's micro-grid. Considering the varying energy consumption in the user side, the parameters are updated periodically through communication networks. Finally, four kinds of micro-grids with different load characteristics are taken as examples to verify this method. Two of them are the load of small residential areas and the other two are the load of commercial buildings. Several characteristic indices are extracted separately from the history time series of loads of the four micro-grids. The relationship between the indices and the forecasting accuracy is to be analyzed and concluded.

The content of this paper is organized as follows. Section 2 analyzed the micro-grid load characteristics. The fundamental theory related to the proposed hybrid model is introduced in Section 3. In Section 4, a hybrid model based on EMD, EKF, EKLM and POS for short-term load forecasting of micro-grid is proposed. Section 5 introduces the implementation method of short-term load forecasting for micro-grid, aiming at reducing the computational cost without loss of forecasting accuracy. Case study and related analysis of results are presented in Section 6. Finally, conclusions are given in Section 7.

2. Analysis of micro-grid load characteristics

2.1. Indices of load characteristics for micro-grid

In the forecasting problems, the results of forecasting errors strongly depend on the stochastic volatility of target time series. As we know, the load of micro-grid has larger volatility compared with traditional large power system [12]. In order to correctly discuss the difference of load characteristics between the micro-grid and large power system, four types of indices are selected to analyze the forecasting difficulties of micro-grid, as shown in Fig. 1.

(1) Load variations in several months

Normalized mean square V is used to express the load variations in several months. The sampling values of load power is normalized into $[0,1]$. And then the variance among load points is calculated. The load value of the i-th sampling point is set as x_i. N is the total sampling number of load data. The calculation method is shown as follows.

$$V = \frac{1}{N}\sum_{i=1}^{N}(x_i' - \mu') \tag{1}$$

where $\mu' = \frac{1}{N}\sum_{i=1}^{N} x_i'$, $x_i' = \frac{x_i}{\max(x)}$, $i = 1, \ldots, N$.

(2) Load variations between two adjacent days

The load variations between two adjacent days are presented through two indices: the average difference between two adjacent days D_{avg} and the maximum difference between two adjacent days $D_{\max}$. To guarantee the direct comparison of computation results, daily load curves has been normalized on the basis of the first power value on that day. The load curve of the j-th day is described by X_j. N_d is the total number of days in the sample data. The calculation method is shown as follows.

$$D_{avg} = \frac{1}{N_d - 1}\sum_{j=1}^{N_d - 1}\sqrt{\frac{\Delta X_j \Delta X_j^T}{L}};\ \Delta X_j = X_{j+1} - X_j \tag{2}$$

$$D_{\max} = \max\left(\sqrt{\frac{\Delta X_j \Delta X_j^T}{L}}\right);\ j = 1, \ldots, N_d - 1 \tag{3}$$