Energy Conversion and Management 95 (2015) 371–384

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Simultaneous day-ahead forecasting of electricity price and load in smart grids

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ARTICLE INFO

Article history:
Received 22 November 2014
Accepted 6 February 2015

Keywords:
MIMO predictor
Smart grids
QOABC algorithm
Wavelet packet transform
Generalized mutual information
Load and price forecasting

ABSTRACT

In smart grids, customers are promoted to change their energy consumption patterns by electricity prices. In fact, in this environment, the electricity price and load consumption are highly corrected such that the market participants will have complex model in their decisions to maximize their profit. Although the available forecasting mythologies perform well in electricity market by way of little or no load and price interdependencies, but cannot capture load and price dynamics if they exist. To overcome this shortage, a Multi-Input Multi-Output (MIMO) model is presented which can consider the correlation between electricity price and load. The proposed model consists of three components known as a Wavelet Packet Transform (WPT) to make valuable subsets, Generalized Mutual Information (GMI) to select best input candidate and Least Squares Support Vector Machine (LSSVM) based on MIMO model, called LSSVM-MIMO, to make simultaneous load and price forecasts. Moreover, the LSSVM-MIMO parameters are optimized by a novel Quasi-Oppositional Artificial Bee Colony (QOABC) algorithm. Some forecasting indices based on error factor are considered to evaluate the forecasting accuracy. Simulations carried out on New York Independent System Operator, New South Wales (NSW) and PJM electricity markets data, and showing that the proposed hybrid algorithm has good potential for simultaneous forecasting of electricity price and load.

1. Introduction

The current electricity grid performs rather stable, but, issues such as improving the energy efficiency, the purpose of large-scale renewable energy integration and the reduction in environment emission need a new grid model which is called smart grid [1]. In fact, it makes a two-way flow exchange with customers, providing advanced information and options, power export capacity, customers and improved energy efficiency as shown in Fig. 1 [2].

Note that there are great correlations between market participants in smart grid. Hereby, the electricity-market participants need reliable tools to maximize their profit which depends on accurate electricity price and load forecasting [3,4]. In recent years, many researches have been dedicated to forecasting in electricity markets. Most of them predict price signals [5–7] and load signals [8,9] in separated form. These forecasting techniques can be generally classified into two groups: classical and intelligent computing techniques. Classical computing methods consist of some well-known strategies such as Auto-Regressive Integrated Moving Average (ARIMA) [5], the Generalized Auto-Regressive Conditional Heteroskedastic (GARCH) model [6], Dynamic Regression (DR) and Transfer Function (TF) models [7].

Intelligent computing methods use data-driven structures, where input–output mapping is learned from historical samples. Artificial Neural Network (ANN) [10], Fuzzy Neural Network (FNN) [11] and Support Vector Regression (SVR) based on ARIMA [12] belong to this group.

Furthermore, hybrid methods combining intelligent and classical computing structures also exist such as Mutual Information (MI) + Wavelet Transform (WT) + Fuzzy Neural Network (MI + WT + FNN) based on Evolutionary Particle Swarm Optimization (EPSO) [13], MI + WT + SVM based on Gravitational Search Algorithm (GSA) [14], hybrid intelligent scheme [15] and SSA method [16]. A hybrid model by using WT combined with ARIMA and GARCH techniques was suggested in [17]. During the past few decades, various approaches have been developed for time series forecasting, among them the ARIMA model has been found to

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http://dx.doi.org/10.1016/j.enconman.2015.02.023
0196-8904/

be one of the most popular models due to its statistical properties, as well as the well-known Box–Jenkins methodology in the modeling process. By matching the empirical autocorrelation patterns with the theoretical ones, it is often possible to identify one or several potential models for the given time series. Dong et al. [18] reported an improved forecasting algorithm that detached high instability and daily for electricity price of New South Wales (NSW) in Australia based on empirical mode decomposition, seasonal adjustment and ARIMA model. Also, a novel hybrid intelligent model is reported by Mandal et al. [19] that utilizes a data filtering approach based on WT model, an optimization algorithm based on firefly method, and a soft computing technique based on fuzzy ARTMAP (FA) network in order to forecast day-ahead electricity prices in the Ontario electricity market. To reduce the arithmetic complexity, Wu et al. [20] suggested a Recursive Dynamic Factor Analysis (RDFA) method where the Principal Components (PCs) were recursively tracked with efficient subspace tracking method and the PC scores were further tracked and forecasted recursively using Kalman Filter (KF) technique.

It should be noted that the pervious forecasting methods on price or load signals have a similar form. In other words, in smart grid, the consumers' activities can change by predicted load (price) while this correlation between price and load has not been considered (e.g., in [5–9]). Albeit, few forecasting methods [21–23] have considered the effect of price signals into load forecasting models in a simple way (therefore, they are not suitable to show the correlation between price and load signals). Note that these methods were valuable in the time because in the unidirectional grid the customers could not respond to electricity price signals [23]. But, with the emergence of the smart grids, electricity customers will be enabled to control their consumption patterns for reliability, economic, or environmental reasons. Therefore, there is a strong requirement in the electric power markets for accurate and robust tools that properly forecast electricity price and load signals in simultaneous form, unlike to available methods which only forecast price and load separately. Thus, the main contributions of this paper are as follows:

(i) To cover the difficulties of the available feature selection methods, a new feature-selection method, named as Generalized Mutual Information (GMI) is proposed which utilizes three-way interaction information mechanism as a measure of feature redundancy. It uses a forward greedy search to select features which have highest interaction information with the features already chosen, and offers highest relevance in view of uncertainties into price and load signals.
(ii) WPT is used to decompose the price (load) signal into multiple subsets at different frequencies. To the best of authors' knowledge, other scientific papers use the Discrete Wavelet Transform (DWT) as a pre-processing filter. The DWT just contains the approximate coefficients while due to the non-linear pattern [14] of electricity price and load signals, it may lose some valuable detailed information. Then the next approximate coefficients vector is split once more. While, the WPT employed in this paper, decomposes both the approximate and detail coefficients, providing a flexible analysis of WPT. Note that the basic formulation of WPT is similar to DWT.
(iii) To choose the best branch of WPT tree to decrease the computation time, the Shannon entropy criteria is proposed in the pre-processing model. Shannon entropy measures the expectedness of future values of the price series according to the probability distribution.
(iv) This paper presents the MIMO-LSSVM model as a new forecast engine to cover nonlinear pattern in the electricity price and load signals simultaneously.
(v) In the MIMO-LSSVM model, choosing inappropriate adjusting variables can result in under-fitting or over-fitting. To avoid this, its variables must be accurately adjusted. Thus, this model is converted to an optimization problem in this

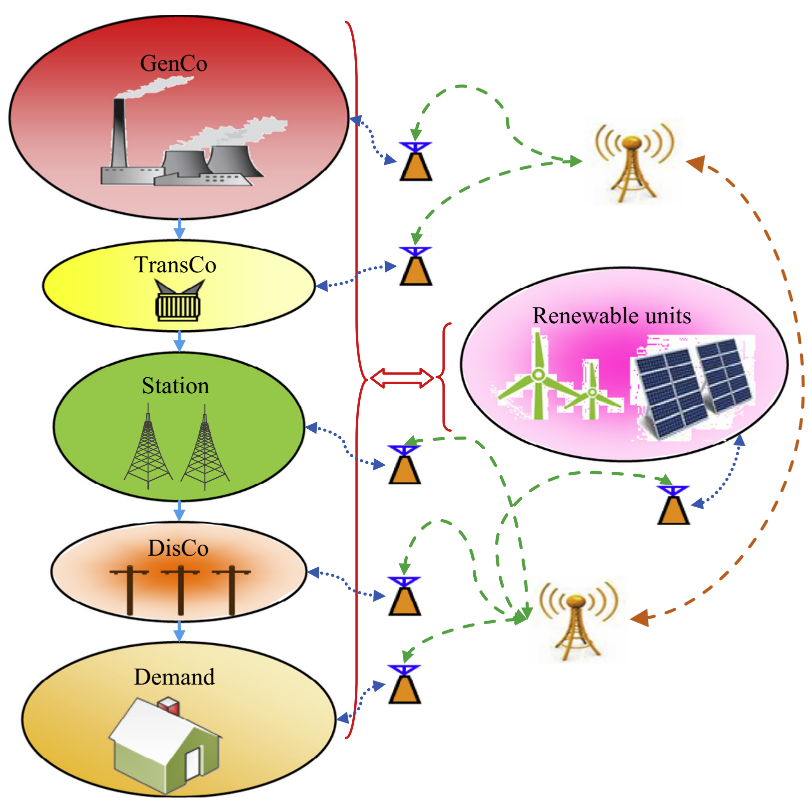

Fig. 1. Overview of smart grid.