Energy 126 (2017) 144–164

Contents lists available at ScienceDirect

Energy

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

Long-term electrical energy consumption formulating and forecasting via optimized gene expression programming

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ARTICLE INFO

Article history:
Received 15 June 2016
Received in revised form
2 February 2017
Accepted 2 March 2017
Available online 6 March 2017

Keywords:
Electrical energy consumption
Forecasting
Gene expression programming
Optimization

ABSTRACT

This study formulates the effects of two different historical data types on electrical energy consumption of ASEAN-5 counties. On this basis, optimized GEP (gene expression programming) is applied to precisely formulate the relationships between historical data and electricity consumption. The optimized GEP is a more recent extension of GEP with high probability of finding closed-form solution in mathematical modeling without prior knowledge about the nature of the relationships between variables. This merit is provided by balancing the exploration of solution structure and exploitation of its appropriate weighting factors through use of a robust and efficient optimization algorithm in learning process of GEP. To assess the applicability and accuracy of the proposed method, its estimates are compared with those obtained from ANN (artificial neural network), SVR (support vector regression), ANFIS (adaptive neuro-fuzzy inference system), rule-based data mining algorithm, GEP, linear and quadratic models optimized by PSO (particle swarm optimization), CSA (cuckoo search algorithm) and BSA (backtracking search algorithm). The simulation results are validated by actual data sets observed from 1971 until 2011. The results confirm the higher accuracy of the proposed method as compared with other artificial intelligence based models. Future estimations of electrical energy consumption in ASEAN-5 countries are projected up to 2030 according to rolling-based forecasting procedure.

1. Introduction

Today, existing grids are under pressure to deliver the growing demand for power, as well as provide a stable and sustainable supply of electricity. These complex challenges are driving the evolution of smart grid technologies. Since the smart grid is taken as the future power grid development goal. The construction of the smart grid will exert significant impacts on the electric power industry. In smart grid environment, the capacity of DGs (distributed generators), T&D (transmission and distribution) system's efficiency will be optimized, thus it brings a challenge to the grid's stability while storing the electricity for future use has lots of difficulty and requires huge investment. Improper and inaccurate forecasts on this area will lead to electricity shortage, energy resource waste, loss of profit due to the penalty paid for under/over estimate of electricity consumption and even grid collapse. Therefore, accurate electricity demand forecasting is essential to move towards the smart grid technology [1].

According to the time horizon, the electricity consumption forecasting is classified as short-term, medium-term and long-term forecasts.

Short-term forecasting (several days ahead in hourly steps) has attracted substantial attention due to its importance for power system control, economic dispatch and the order of unit commitment in electricity markets.

Midterm forecasting (several months ahead in weekly or longer steps) is especially interesting for companies operating in a deregulated environment, as it provides them with valuable information about the market need of energy, scheduling the maintenance of the units, the fuel supplies, electrical energy imports/exports.

Long-term (years ahead in annual or longer steps) forecasting has been always playing a vital role in power system management

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http://dx.doi.org/10.1016/j.energy.2017.03.009
0360-5442/

and planning. The accuracy of long-term load forecast directly impacts on effectiveness of energy trading, system reliability, O&M (operation and maintenance) costs, T&D expanding, and generators scheduling. Moreover, accurate long-term power load forecasting can provide reliable guidance for power grid development and power construction planning, which is also important for the sustainable development of any country.

Accurate forecasts are also a prerequisite for decision makers to develop an optimal strategy that includes risk reduction and improving the economic and social benefits. The accurate long-term load forecast gives the more realistic spectrum of future country's energy sources consumption for moving towards sustainable development in a globalizing world while the growing global population is driving an even greater increase in the electricity consumption.

EEC (electrical energy consumption) reflects the degree of economic development, and much evidence supports a causal relationship between economic growth and energy consumption. ASEAN (Association of Southeast Asian Nations) is one of the largest economic zones in the world with rapid and relatively stable economic growth. In fact, ASEAN has experienced much lower volatility in economic growth since 2000 than the European Union [2]. If ASEAN considered as a single economic entity, it would already rank as the sixth-largest economy in the world, trailing the US, China, Japan, Germany, and the United Kingdom [3].

ASEAN is a major global hub of manufacturing and trade, as well as one of the fastest-growing consumer markets in the world [2]. As the region seeks to deepen its ties and capture an even greater share of global trade, its economic profile is rising which directly reflects on EEC.

According to the WB (World Bank) data bank, ASEAN's electricity consumption has changed dramatically since the early 1970s with average annual growth rate of 8.58% that is almost two (2.7) time more than the average annual growth rate of the global EEC. Only the five largest economies in this area (ASEAN-5 countries); Malaysia, Indonesia, Singapore, Thailand, and Philippines consumed 47.03 MTOE in 2011 as shown in Fig. 1, which ranked the ASEAN as the world's sixth-largest electricity consumer, behind the China, US, Japan, Russia, and India. So, long-term forecasting of EEC to manage a power system, and fulfill power requirements with consideration of economic growth in the future is one of the most critical and challenging issues for sustainable development of ASEAN countries.

1.1. Literature review

To address the difficulties involved in long-term energy consumption forecasting whereas, there is an implicit relationship among historical data, different techniques have been proposed to achieve a robust model with high accuracy.

In this framework, the techniques can be classified into statistical models including regression-based model and time series methods such as ARIMA (auto regressive integrated moving average) and GM (gray model); and AI (artificial intelligence) based approaches including ANN (artificial neural network), fuzzy method, SVR (support vector regression), KBES (knowledge-based expert system), metaheuristic techniques and GP (genetic programming) [4].

The ARIMA model is one of the most popular models for a time series forecasting when there is no missing sample within the time series and the time series is stationary [5]. Although ARIMA models are quite flexible as they can represent several different types of time series, namely pure AR (auto regressive), pure MA (moving average) and combined ARMA (AR and MA), their major limitation is the pre-assumed linear form of the model [6]. GM is a practical approach in time series forecasting due to its simplicity and ability to characterize an unknown system with incomplete information within the time series. The main principle of this approach to extract hidden information from incomplete data is to process the data indirectly through data mapping to the state space. In spite of this mechanism, the original GM is not suitable for long-term energy consumption forecasting due to disability of this approach to reflect the growth trends within different period into behavioral modeling of unknown systems [7].

In the past decade, the AI-based approaches are considered as enhanced alternatives to statistical models for energy consumption forecasting. AI-based approaches often guarantee a satisfying degree of estimation accuracy while independent and dependent variables faced too much fluctuation. Table 1 outlines the summary of AI-based approaches, which have been employed for long-term energy consumption forecasting.

ANN is the most widely used technique among the AI-based approaches, which has been applied in the field of energy management [8–11]. The capability of ANN to precisely learn, store, and recall information from experience, discover the relation between input and output variables, and extract various discriminators in complex environment makes this method especially attractive for long-term energy consumption forecasting.

SVR is another AI-based technique, which has been employed as a powerful predictive technique in energy consumption forecasting due to its ability to adapt and capture complex relationships in the input data [12]. A significant advantage of SVR is that this method guarantees that the global minimum is found during the training phase, while ANN is trapped in local minima. Unlike ANN, SVR is less prone to over fitting due to independently of computational complexity to dimensionality of the input space. Moreover, SVR has a simpler geometric interpretation and it gives sparse solution [13].

The fuzzy logic system successfully applied in Ref. [14] for energy consumption forecasting. This approach is based on predefined rules (if-then) that lack the ability to learn and adapt themself to new condition. In Ref. [15], the authors applied combination of fuzzy system and ANN (Neuro-Fuzzy) to overcome this drawback. A specific approach in neuro-fuzzy development is the ANFIS (adaptive neuro-fuzzy inference system), which is considered to be a universal estimator capable for short, medium, and long-term energy consumption forecasting [16].

Furthermore, an effective practice to increase the forecasting accuracy and address the nonlinearity involved in long-term forecasting is integrating several techniques into a hybrid form. An integrated algorithm for forecasting energy consumption based on MLP (multi-layer perceptron) ANN, computer simulation and design of experiments is developed in Ref. [17]. The integration of fuzzy system and data mining approach is presented in Ref. [18]. Data mining approach is applied to extract the rules for constructing fuzzy system estimation in this study. In Ref. [19], a hybrid ANFIS and computer simulation is proposed to improve the accuracy of energy consumption forecasting.

Despite the satisfactorily performance of ANN, SVR, ANFIS, and hybrid form of these methods for energy consumption forecasting, the main shortcoming still is black-box problem that they do not provide the knowledge of process for obtaining a solution. Hence, they are not capable of generating a definite prediction equation based on the input historical data [20].

In order to cope with the difficulties associated with energy consumption modeling, different forms of mathematical expressions optimized by metaheuristic methods have been proposed to use historical data for formulation the energy consumption.

Metaheuristic methods have been applied as efficient tools to provide realistic estimation models by optimizing the coefficients of predefined mathematical expressions. These methods are