Energy Conversion and Management 58 (2012) 1–9

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

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

Energy demand forecasting in Iranian metal industry using linear and nonlinear models based on evolutionary algorithms

Mehdi Piltan, Hiva Shiri, S.F. Ghaderi *

Department of Industrial Engineering, Faculty of College Engineering, University of Tehran, Iran

ARTICLE INFO

Article history:
Received 9 June 2010
Received in revised form 28 December 2011
Accepted 29 December 2011
Available online 30 January 2012

Keywords:
Forecasting
Energy demand
Industrial sector
Evolutionary algorithm

ABSTRACT

Developing energy-forecasting models is known as one of the most important steps in long-term planning. In order to achieve sustainable energy supply toward economic development and social welfare, it is required to apply precise forecasting model. Applying artificial intelligent models for estimation complex economic and social functions is growing up considerably in many researches recently. In this paper, energy consumption in industrial sector as one of the critical sectors in the consumption of energy has been investigated. Two linear and three nonlinear functions have been used in order to forecast and analyze energy in the Iranian metal industry, Particle Swarm Optimization (PSO) and Genetic Algorithms (GAs) are applied to attain parameters of the models. The Real-Coded Genetic Algorithm (RCGA) has been developed based on real numbers, which is introduced as a new approach in the field of energy forecasting. In the proposed model, electricity consumption has been considered as a function of different variables such as electricity tariff, manufacturing value added, prevailing fuel prices, the number of employees, the investment in equipment and consumption in the previous years. Mean Square Error (MSE), Root Mean Square Error (RMSE), Mean Absolute Deviation (MAD) and Mean Absolute Percent Error (MAPE) are the four functions which have been used as the fitness function in the evolutionary algorithms. The results show that the logarithmic nonlinear model using PSO algorithm with 1.91 error percentage has the best answer. Furthermore, the prediction of electricity consumption in industrial sector of Turkey and also Turkish industrial sector is reinvestigated, the results indicate significant improvement.

1. Introduction

Energy is a vital input for industrial sector. With increasing industrial activities in the country, the demand for energy is also increasing. Developing energy-forecasting models is one of the most important steps in long-term planning for sustainable energy supply toward economic development and social welfare. Nowadays, in addition to the traditional economic aspects of energy, social, political, security and environmental aspects have increased the importance of energy forecasting of studies more than before. Industry is one of the major energy-consuming sectors using energy as a production factor for developing the economy. Forecasting energy consumption in industries requires advanced intelligent tools such as evolutionary algorithms. In industry, energy is used both in the building components for cooling, heating and lighting, which varies according to the workforce increase, building extension and weather condition, and in the operational process for mechanical and electronic processing. One of the overriding characteristics in the industrial sectors is the heterogeneity of industries, products, equipment, technologies, processes and energy uses. Adding to this heterogeneity is that the industrial sectors include not only manufacturing but also agriculture, mining and construction. These varieties of industries range spread widely from highly energy intensive activities to low energy intensive activities.

In this paper, energy consumption in the industrial sector has been investigated and analyzed. The aim of the present study is the investigation of the influential factors on the consumption of energy and also prediction of energy consumption in the industrial sector.

In recent years, evolutionary algorithms have entered the forecasting field and are increasingly being applied because of their ability to solve complicated problems. Genetic Algorithms (GAs), Particle Swarm Optimization (PSO), Simulated Annealing (SA) and Ant Colony Optimization (ACO) are samples of algorithms that have been applied in this area with notable results [1–11]. Ozturk and Ceylan presented some linear and nonlinear models based on GA to estimate electricity consumption in Turkish industrial sector. Their presented model is based on four variables: population, gross national product (GNP), import and export. Based on their findings, the use of import and export variables leads to the improvement of the results [12]. In a similar study, Ceylan and Ozturk using GA

* Corresponding author. Tel.: +98 21 82084161; fax: +98 21 88013102.
E-mail address: ghaderi@ut.ac.ir (S.F. Ghaderi).

0196-8904/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enconman.2011.12.022

forecast energy consumption in Turkey [2]. Azadeh and Tarverdian using GA and the integration of GA and simulation proposed models for forecasting monthly electricity consumption in Iran with more accurate results in comparison with time series model [3]. Canyurt and Ozturk forecast fossil fuel (oil, coal, natural gas) consumption demand using GA [4]. Toksari proposed an energy forecasting model based on ACO. Toksari considered GDP as the first economical index in his model and then presented three scenarios for the prediction of energy demand from 2006 to 2025 and finally the relative estimation errors of the ACO model are the lowest when they are compared with the Ministry of Energy and Natural Resources (MENR) projection [5]. Unler used for the first time PSO algorithms in forecasting electricity consumption in Turkey and compared the results of his research with those of ACO algorithm which indicated an improvement in the results [13]. Kiran et al. propose a new hybrid method of PSO and ACO to predict energy demand of Turkey [1]. Lee and Tong combine residual modification with genetic programming sign estimation to minimize gray forecasting errors [11]. Yu et al. present a hybrid algorithm of PSO and GA to optimize energy demand estimating for China. In their model, coefficients of the three forms of the model (linear, exponential and quadratic model) are optimized by their proposed hybrid model [14]. Shafie-khah et al. use PSO to optimize the network structure of their model for forecasting of electricity price [15]. Pousinho et al. combine PSO and adaptive-network-based fuzzy inference system, for short-term wind power prediction [16]. Yu and Zhu use an improved hybrid algorithm called PSO–GA to find parameters of their linear, exponential, and quadratic models for energy demand forecasting in China [17].

Most of the effective parameters in evolutionary-algorithm-based forecasting have been investigated in this study. These parameters include:

1. Implemented evolutionary algorithms and their parameters.
2. Forecasting models and the relationship between dependent and independent variables.
3. Applied fitness function in the algorithms (error criterion).

In the previous studies, the first and second parameters have been considered. The third parameter which had a critical role in the convergence of algorithms toward an optimum solution was selected but there were not enough consideration to fitness functions' effects. Mean Square Error (MSE), Root Mean Square Error (RMSE), Mean Absolute Deviation (MAD) and Mean Absolute Percent Error (MAPE) are four functions which have been used as the fitness function in the evolutionary algorithms and the results show that the fitness function has a notable impact on the accuracy of the model.

The proposed Real-Coded GA (RCGA) is different from the previous GA models. In this developed model, real numbers have been used for the description of GA's chromosomes instead of Binary-Coded GA (BCGA) coding. A RCGA uses a vector of floating-point numbers in place of 0's and 1's for implementing chromosome encoding. The crossover operator of a real-coded GA is constructed by borrowing the concept of linear combination of vectors from the area of convex set theory. The random mutation operator proposed for real-coded GA operates on the gene by introducing into it a perturbation that is a random number in the range of 0–1 in the feature's domain. With some modifications of the genetic operators, the RCGA has resulted in better performance than the BGA for continuous problems [18]. Electricity consumption in the Iranian industrial sector is selected as the case study, In addition, another case study in Turkey and also its industrial sector has been done to verify the validity of the model. The data in the Turkish electricity consumption have been extracted from Ozturk and Ceylan [12] and the accuracy of the models was investigated by using different algorithms, models and fitness functions. The results from the three mentioned case studies illustrated the significant impact of fitness function on forecasting error and the relative superiority of MAD to other fitness functions and also RCGA algorithm is overlay better than the Binary GA (BGA).

This paper has two main contributions. The first is the proposed method of using genetic algorithm. The contribution in the proposed BCGA is that the convergence process is based on mutation operator instead of crossover operator also in the proposed BCGA parameters are changing by adding and subtracting them like the manual calculation. The second contribution is the variables and the model that we used to estimate the electricity consumption in Iran metal industry accurately. The proposed model takes into account new variables like gas price as the alternative fuel for the electricity and investment in equipment.

2. Materials and methods

Evolutionary algorithms are based on random search of solution space. In real world systems, estimation of functions in a linear form and without considering the interaction between variables needs many simplifications particularly in models with social and economic variables that include complex interaction. For example, consider the following linear model:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_m X_m \tag{1}$$

Suppose that Y is considered as household electricity consumption, X_1 is population, X_2 is Gross Domestic Product (GDP), and X_3 is electricity price. The impacts of electricity price on GDP could not be eliminated [2,13]; even population growth rate may have a complex relation with GDP [14]. Therefore some nonlinear functions are used for forecasting.

$$Y = f(X_1, X_2, \cdots, X_m, \beta_k) \quad k = 0..p;\ m, p \in Z \tag{2}$$

Complexity in applying classical methods such as regression for determining constant parameters (β_i) has led to the use of EAs methods. These methods generally find near optimum solutions in a proper time not necessarily the best solution. Criterion for the appropriateness of parameters has a reverse relationship with the error value of the model which is calculated from the difference between actual value and estimated value. In other words, the smaller the amount of error in the model, the closer the actual value to the estimated value which enhances the validity of the model.

To compare the use of different error criteria, Mean Absolute Percent Error (MAPE) in Eq. (3), was chosen as the base criterion.

$$\text{MAPE} = \frac{1}{n} \times 100 \times \sum_{i=0}^{n} |Y_{\text{observed}} - Y_{\text{predicted}}| / Y_{\text{observed}} \tag{3}$$

where n is the number of years whose data are available and used to train the model. The flowchart of our algorithm is shown in Fig. 1.

2.1. Genetic algorithm

A GA is a procedure that attempts to mimic the genetic evolution of a species. Specifically, GA simulates the biological processes that allow the consecutive generations in a population to adapt to their environment. The adaptation process is mainly applied through genetic inheritance from parents to children and through survival of the fittest. Therefore, GA is a population-based search methodology. These algorithms were described by Goldberg [6] and have been taken into consideration in solving optimizing problems. The most important advantage of GAs is their ability to use accumulative information about the initial unknown search space in order to move the next searches into better spaces [1]. GA