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Artificial immune simulation for improved forecasting of electricity consumption with random variations

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ABSTRACT

This paper presents an integrated algorithm for forecasting annual electrical energy consumption based on Artificial Immune System (AIS), Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and computer simulation. Computer simulation is developed to generate random variables for annual electricity consumptions in selected countries. Most recent studies are concerned with deterministic data sets which could enhance relative error. However, this study utilizes fitted random variables as input data to decrease the relative error. Mean Absolute Percentage Error (MAPE) is used for evaluating the results and selecting the best forecasting model. To show the applicability of the proposed algorithm, the annual electricity consumptions for 16 countries from 1980 to 2006 are considered and the proposed algorithm is applied to the corresponding historical data. Three considered meta-heuristics (i.e. AIS, GA, and PSO) are compared with each other in estimation of electricity consumption in the selected countries. The comparison is made based on MAPE for the test period data. For the selected countries, AIS method with the Clonal Selection Algorithm (CLONALG) shows satisfactory results when applied with simulated data and has been selected as the preferred method. This is the first study that uses an integrated AIS-simulation for improved forecasting of electricity consumption with random variations.

1. Introduction

Increasing worldwide demand for electricity requires developments in methods and algorithms for its forecasting. Paving this way, artificial intelligence approaches has been found considerable attention. The estimation of electrical energy demand based on economic and non-economic indicators may be achieved by certain statistical, heuristic, mathematical and simulation models. These forecasting models might be linear or non-linear. Due to the fluctuations of electricity demand indicators, the non-linear forms of the equations may forecast electrical energy demand more effectively. The non-linearity of these indicators and electrical energy demand has led to search for intelligent solution methods such as neural networks, fuzzy regression, and meta-heuristics.

In this paper, three meta-heuristics namely Genetic Algorithms (GAs), Artificial Immune System (AIS) and Particle Swarm Optimization (PSO) are considered to forecast electricity consumption around the world. AIS, GA and PSO are stochastic search techniques which possess extensive and powerful applications.

Computer simulation could also be used as an accompanying tool with these techniques [3]. This study uses computer simulation to generate random variables to be used in meta-heuristics, while previous studies only use available raw data for them. Moreover, the integration of meta-heuristics and simulation is proposed as an alternative forecasting approach in this study and it is compared with meta-heuristics alone. Many research studies had been developed related to electricity forecasting. By increasing the importance of energy consumption, Vesma [42] describes a unique management method for the detection and diagnosis of avoidable waste of consumable resources.

Among a vast variety of approaches, Artificial Intelligence (AI) has received particular attention in energy demand prediction [6] and specially in short-term electrical energy forecasting [34]. In Metaxiotis et al. [34], AI techniques used in short term forecasting including genetic algorithm, artificial neural networks (ANNs) and expert systems had been discussed. Wang et al. [43] proposed a combined approach of first-order one-variable gray differential equation and seasonal time series model and to improve the forecasting accuracy, an adaptive parameter learning mechanism was applied. They illustrated the higher forecasting accuracy of their proposed model when compared with gray differential equation using statistical electricity demand data of Australia. Also, recent studies show the integration of GA and neural networks for short-term estimation and prediction of electrical energy consumption [5].

In the middle term forecasting, Bhattacharya and Basu [10] and Basu et al. [7] used Kalman Filter techniques as a basic of their work. Jaramillo-Morán et al. [26] used neural filters to forecast monthly electric demand. The estimation of Turkey's energy

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demand based on economic indicators using GA was reported by Ceylan and Ozturk [14]. Also authors in Ozturk et al. [37] estimated industrial electricity demand using GA. Transport energy demand in Turkey by GA has been estimated in [22]. GA with fuzzy logic controller (FLC) have been combined in Osman et al. [36] so that the search region is able to adapt toward the promising area and the boundary intervals are monitored by FLC and it is modified each time.

In long-term section, Kermanshahi and Iwamiya [30] used back Jordan recurrent network and propagation network for the forecasting of Japan's electricity energy consumption. Electrical energy consumption in Iran has been estimated and forecasted by GA in [4]. The trend in current and near future energy consumption from a statistical perspective by considering two factors, namely, increasing population and economic development was discussed in [27]. Kankal et al. [28] proposed a model for improvement of modeling energy consumption in Turkey based on four socio-economic and demographic variables (GDP, population, import and export amounts) using artificial neural network (ANN) and regression analyses. Chen and Wang [16] proposed a collaborative approach for Long-term power load forecasting. In their approach different expert-configured models are combined to reach more comprehensive and more in-depth forecasts.

The application of meta-heuristic search algorithms in demand forecasting have been received great attention and plenty of research works have been recently published in the literature. Assareh et al. [1] used GA and PSO to build two forms (exponential and linear) of oil demand forecasting based on socio-economic indicators. Later, Behrang et al. [8] proposed to use Gravitational Search Algorithm to find coefficients of linear and non-linear forecasting models of oil demand in Iran. Kaveh et al. [29] presented the application of Harmony Search technique and Charged System Search algorithm to estimate transport energy demand in Iran, based on socio-economic indicators.

Kiran et al. [31] proposed the use of artificial bee colony (ABC) and Particle Swarm Optimization (PSO) techniques to estimate quadratic electricity energy demand model in Turkey. They showed that their proposed techniques outperform the models estimated by ant colony optimization. Kiran et al. [32] developed a hybrid approach based on Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) for energy demand in Turkey. They showed that the quadratic models estimated with the proposed hybrid optimization method estimate energy demand with lower error than single PSO or ACO. Behrang et al. [9] demonstrated the application of the Bee Algorithm technique to estimate total energy demand in Iran, based on socioeconomic indicators of population, gross domestic product, import, and export data. Hong et al. [25] used chaotic GA to find the best parameters of support vector regression (SVR) applied to model seasonal changes in electric load. In their work, the application of GA was enhanced by chaos optimization algorithm to avoid local optimization.

Yu et al. [44] proposed a hybrid algorithm based on PSO and GA for energy demand estimating in China. The coefficients of the three forms of the model (linear, exponential, and quadratic) were estimated by PSO–GA using factors, such as GDP, population, economic structure, urbanization rate, and energy consumption structure, that affect demand.

As reviewed above, meta-heuristic based algorithms have widely used for demand forecasting and some researchers reported the advantage of meta-heuristics hybridization to improve forecasting accuracy. Two points should be expressed here. First, none of the previous studies addressed the random variation might exist in the input data. The authors believe that to know the random mechanism in the input data could help improving the accuracy of forecasting because based on this known mechanism, simulation can be employed to generate more data for model construction. Availability of more data with no debate improves the accuracy and reliability of forecasting results. Second, the application of Artificial Immune System (AIS) has not been reported in the previous literature and this study for the first time applies AIS and simulation for improved electrical demand forecasting. In this paper, AIS and in particular the Clonal Selection Algorithm (CLONALG), GA and PSO are investigated to forecast the electrical consumption.

The rest of the paper is organized as follows. Section 2 presents the methodology of proposed algorithm. In particular, the special characteristics of three meta-heuristics and the way they are applied to the problem of electricity function estimation are presented. Section 3 describes the case studies and the application of the proposed algorithm to the case studies. Finally, Section 4 concludes the paper.

2. The proposed algorithm and methodology

The proposed algorithm is presented in Fig. 1. This algorithm begins with selecting a demand model and collecting the related data. Models can be linear or non-linear, logarithmic or quadratic. Socioeconomic indicators include GDP, population, import, export and structural indicators. The collected data is divided into training data and test data. The training data are used to estimate model parameters and test data are used to examine the accuracy of the forecasting models. Then this algorithm preprocesses the data with Box–Jenkins method in order to find the appropriate time series models for each of the dependent and independent variables in the model. Based on these derived time series, a global electrical demand model is formed and its coefficients are estimated with the meta-heuristics. Here, the algorithm proceeds into two main streams; right stream and left stream. In the right stream the meta-heuristics with the actual collected data are used to estimate and forecast electricity demand. In the left stream, the actual collected data along with the simulated data generated according to the random mechanism in the data are used to estimate the demand model. To simulate the random variation in the data, the algorithm needs to estimate the probability distribution functions (PDFs) associated with each variable in the model. The algorithm finds the best fitted PDFs and construct the simulation based on these PDFs. Once the simulated data are generated, these data are used to estimate the model based on AIS, GA and PSO. The accuracy of each method is calculated in terms of MAPE for the test data. In the last step, this algorithm selects the preferred method based on minimum MAPE. The methodology for implementation of AIS, PSO and GA are presented in Sections 2.1–2.4.

2.1. Artificial Immune System

2.1.1. How biological immune system works

For learning the AIS method, knowing the way that human biological immune system works is very important. In Luh and Chueh [33], there is a complete description of biological immune system working logic. The principles of this system are shown in Fig. 2. We skip complete describing of this system and leave it for the reader to read the reference.

There are three immunological principles basically used in AIS methods. These include the immune network theory, the mechanisms of negative selection, and the clonal selection principles. In this paper, only clonal selection algorithm from Castro and Timmis [13] will be used.

2.1.2. Clonal Selection Algorithm (CLONALG)

Generally, the clonal selection principle is used as a basis for the establishment of the Clonal Selection Algorithm (CLONALG) [13]. The general view of the algorithm is showed in Fig. 3. First, an