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A Cooperative Ant Colony Optimization-Genetic Algorithm approach for construction of energy demand forecasting knowledge-based expert systems

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ABSTRACT

Knowledge-based expert systems are becoming one of the major tools for scientists and engineers nowadays, since they have many attractive features and can be called upon to deal with real/complex engineering application problems which are not easy to solve by orthodox methods. Meanwhile, increasing worldwide demand for different types of energy requires development of advanced intelligent forecasting tools to provide a basis from which decisions and plans can be made. This study presents a new approach called "Cooperative Ant Colony Optimization-Genetic Algorithm" (COR-ACO-GA), to construct expert systems with the ability to model and simulate fluctuations of energy demand under the influence of related factors. The proposed approach has two main stages, at the first stage it uses genetic algorithms to generate data base of the expert system, and at the second stage it adopts ant colony optimization to learn linguistic fuzzy rules such that degree of cooperation between data base and rule base increases and consequently performance of the algorithm improves. We evaluate capability of COR-ACO-GA by applying it on three case studies of annual electricity demand, natural gas demand and oil products demand in Iran. Results indicate that COR-ACO-GA provides more accurate-stable results than adaptive neuro-fuzzy inference systems (ANFISs) and artificial neural networks (ANNs), and can assist decision makers in making appropriate decisions and plans for a coming period.

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1. Introduction

Knowledge based systems (KBSs) are artificial intelligent tools working in a narrow domain to provide intelligent decisions with justification [24]. Knowledge is acquired and represented using various knowledge representation techniques rules, frames and scripts. The basic advantages offered by such system are documentation of knowledge, intelligent decision support, self learning, reasoning and explanation. Expert systems, case-based reasoning systems and artificial neural networks (ANNs) are all particular types of knowledge-based systems; however, some researchers believe that ANNs are different, and exclude it from this category [4].

These intelligent tools are becoming more and more widespread nowadays to solve complicated practical problems in various fields [9,10,29,52,58,59], because of their flexibility, symbolic reasoning, and explanation capabilities [50].

Meanwhile, energy is a vital input for social and economic development of any nation [6]; accordingly, increasing worldwide demand for different types of energy resources requires development of suitable forecasting methods and algorithms which can accurately make predictions about future performance.

An accurate forecast aids in decision-making and planning for the future. Forecasts empower people to modify current variables in the present to predict the future to result in a favorable scenario [38].

2. Literature review

Various techniques have been proposed for energy demand forecasting over different time intervals of short term, medium term and long term. These methods can be categorized into two groups of conventional and intelligent techniques.

A number of studies have compared capability of these two groups in the field of energy demand forecasting and they have found that intelligent systems have more accurate results than conventional approaches [2,26,36,48,63,64].

There are also studies in the literature related to energy demand forecasting using variety of intelligent approaches.

Pao [57] used ANN for forecasting Taiwan's electricity consumption, and found that ANNs are suitable tools for load forecasting problems. Hamzacebi [39] explored forecast of Turkey's net electricity energy consumption on sectoral basis until 2020 by

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applying ANNs, and mentioned that the reasons behind choosing ANNs are the ability of ANNs to forecast future values of more than one variable at the same time and to model the nonlinear relation in the data structure.

Toksarı [62] proposed forecasting models for Turkey's net electricity energy generation and demand by employing Ant Colony Optimization (ACO), and applied the models to indicate Turkey's net electricity energy generation and demand until 2025.

Abou El-Ela et al. [1] applied a modified ANN as an alternative technique for long-term peak load forecasting in order to improve the results accuracy. The modified technique was applied on the Egyptian electrical network dependent on its historical data to predict the electrical peak load up to year 2017.

Geem and Roper [34] proposed an artificial neural network model to efficiently estimate the energy demand for South Korea. They tested the accuracy of the results by root mean squared error and the outcomes showed that the proposed model could forecast the energy demand with high accuracy and without having any overfitting problem.

Kıran et al. [45] proposed two models based on artificial bee colony (ABC) and particle swarm optimization (PSO) techniques to estimate electricity energy demand in Turkey. They incorporated gross domestic product, population, import and export figures of Turkey as inputs. They made a comparison with ant colony optimization and obtained that relative estimation errors of the proposed models were lower than ACO.

In drawing conclusions, each of the intelligent techniques has advantages and disadvantages. One approach to deal with complex real world problems is to integrate the use of several intelligent technologies in order to combine their different strengths and overcome a single technology's weakness to generate hybrid models that provide better results than the ones achieved with the use of each isolated technique [38].

Ying and Pan [64] applied the adaptive neuro-fuzzy inference system (ANFIS) model to forecast the regional electricity loads in Taiwan and demonstrated the forecasting performance of this model. Their finding indicated that based on the mean absolute percentage errors and statistical results ANFIS model had better forecasting performance than the regression model, artificial neural network model, support vector machines with genetic algorithms (SVMG) model, recurrent support vector machines with genetic algorithms (RSVMG) model and hybrid ellipsoidal fuzzy systems for time series forecasting (HEFST) model.

Li and Su [47] proposed a hybrid genetic algorithm-hierarchical adaptive network-based fuzzy inference system (GA-HANFIS) model for forecasting energy demand of buildings. In this model, hierarchical structure decreases the rule base dimension. Both clustering and rule base parameters are optimized by GAs and ANNs. They applied the model to predict a hotel's daily air conditioning consumption for a period over 3 months. The results obtained by the proposed model indicated that it possesses better performance than ANNs in terms of forecasting accuracy.

Ghanbari et al. [35] proposed an intelligent Ant Colony Optimization-Simulated Annealing (ACO-SA) methodology to model short-term electricity loads in Iran and compared the outcomes to single ant colony and single simulated annealing. Results showed that ACO-SA outperforms rest of the methods and is able to cope with short-term electricity load problems successfully.

Lee and Tong [46] developed an improved grey forecasting model by combining residual modification with genetic programming. They considered a real case of Chinese energy demand and demonstrated the effectiveness of the proposed forecasting model.

Chen [20] proposed fuzzy-neural approach to forecast the long-term load in Taiwan and improved both the precision and accuracy of long term load forecasting by 40% and 99%, respectively. In addition, the proposed methodology made it possible to accurately forecast the average and peak values of the annual energy consumption at the same time.

Akdemir and Çetinkaya [3] employed adaptive neural fuzzy inference system (as one of the most famous artificial intelligence methods which has been widely used in literature) for long-term load forecasting. They evaluated their proposed model by means of mean absolute error and mean absolute percentage error and obtained error values 1.504313 and 0.82439, respectively. They found success of adaptive neural fuzzy inference system for energy demand forecasting up to 99.17%.

Cárdenas et al. [15] presented an electricity consumption-forecasting framework configured automatically and based on ANFIS with the objective of giving support to an intelligent energy management system. They implemented their proposed system in an independent section of an automotive factory, which was selected for the high randomness of its main loads and they found successful results.

3. Problem statement

One of the most popular approaches is the hybridization between fuzzy logic and GAs leading to genetic fuzzy systems (GFSs) [22]. A GFS is basically a fuzzy system augmented by a learning process based on evolutionary computation, which includes genetic algorithms, genetic programming, and evolutionary strategies, among other evolutionary algorithms (EAs) [31].

There are several researches which have used GFSs for variety of forecasting problems and they have obtained promising results [25,38,37,60].

In spite of the fact that GFSs have been demonstrated to be a powerful tool for extraction of forecasting knowledge-based systems, there is not any research in the literature that deals with energy demand forecasting by means of GFSs. So, this paper presents a new GFS type called Cooperative Ant Colony Optimization-Genetic Algorithm (COR-ACO-GA) to construct a knowledge-based system with the ability to model and analyze fluctuations of energy demand.

The superiority and applicability of COR-ACO-GA will be shown for three case studies of Iran and results will be compared with ANFIS and ANN, since these tools are two of the most widely used intelligent time series forecasting tools [44,54] and have been applied to variety of energy demand forecasting studies.

4. Methodology

4.1. Cooperative Ant Colony Optimization-Genetic Algorithm (COR-ACO-GA)

Nowadays fuzzy rule-based systems are successfully applied to a wide range of real-world problems from different areas. In order to design an intelligent system of this kind for a concrete application, several tasks have to be performed. One of the most important and difficult ones is to derive an appropriate knowledge base (KB) about the problem being solved. The KB stores the available knowledge in the form of fuzzy linguistic IF–THEN rules. It is composed of the rule base (RB), constituted by the collection of rules in their symbolic forms, and the data base (DB), which contains the linguistic term sets and the membership functions defining their meanings [13].

The difficulty presented by human experts to express their knowledge in the form of fuzzy rules has made researchers develop automatic techniques to perform this task. In this sense, a large amount of methods has been proposed to automatically generate fuzzy rules from numerical data. They usually use complex rule generation mechanisms such as neural networks [55] or genetic

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