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An emotional learning-neuro-fuzzy inference approach for optimum training and forecasting of gas consumption estimation models with cognitive data

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ABSTRACT

This study introduces an optimum training and forecasting approach for natural gas consumption forecasting and estimation in cognitive and noisy environments by an integrated approach. The approach is based on emotional learning based fuzzy inference system (ELFIS), artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS), and conventional regression. Results are compared to show the suitability of the optimum training model in noisy and uncertain environment. The designated forecasting models use standard inputs and gas demand as their output. The training approach utilizes intelligent and emotional learning mechanism. Furthermore, analysis of variance (ANOVA), mean absolute percentage error (MAPE), normalized mean square error (NMSE) and Duncan's multiple range test (DMRT) are used to test a set of hypothesis and to select the optimum training model. Applicability and superiority of the approach is shown through applying the above models on actual gas consumption data in Iran from 1973 to 2006. The approach is capable of modeling sharp drops or jumps in consumption with appropriate cognitive and emotional signals. This is the first study that uses an integrated approach for optimum training of gas consumption estimation with noisy and cognitive data.

1. Introduction

Energy is a vital input for social and economic development of any nation. The growth in energy consumption is intrinsically linked to the growth in the economy [1]. Various models have been applied to describe and forecast the evolution of energy demand. Authors in [2] used Box–Jenkins time-series analyses (ARIMA) models to formulate the forecasting model for the prediction of energy production and consumption in Asturias, Northern Spain. The trend in current and near future energy consumption from a statistical perspective by considering two factors, namely, increasing population and economic development had been discussed by [3]. Authors in [4] had investigated different univariate-modeling methodologies for the forecasting of monthly electric energy consumption in Lebanon. Three univariate models were used namely, autoregressive, autoregressive integrated moving average (ARIMA) and a novel configuration combining an AR(1) with a high pass filter. An oil and gas supply model (OGSM) has been solved and the projections of oil and natural gas supply and demand to the year 2020 for Canada have been presented [5].

Chow [6] has discussed the sectoral energy consumption in Hong Kong for the period 1984–97 with special emphasis on the household sector. Ediger and Tatlldil [7] used semi-statistical technique to formulate the forecasting model to predict the primary energy demand in Turkey and analysis of cyclic patterns. Reddy and Balachandra [8] looked at various factors that influence the energy demand in India and develop the energy and environmental outlook in the year 2010. This was done by developing an integrated mathematical model incorporating various factors such as GDP, population growth.

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Gorucu et al. [9] trained the ANNs to decide the optimum parameters to be used in forecasting the gas consumption for short-term applications. Gorucu and Gumrah [10] forecasted short term gas consumption by multivariable regression analysis for the capital city of Ankara, Turkey. Gutierrez et al. [11] examined the application of a Gompertz-type innovation diffusion process for stochastic modeling and capturing the growth process of natural-gas consumption in Spain.

Authors in [12] focused on combination of artificial neural-network (ANN) forecasters with application to the prediction of daily natural gas consumption needed by gas utilities. In [13] industrial end-use natural gas consumption is forecasted in a medium-term horizon (1–3 years) with a very high resolution (days) based on a decomposition approach. The forecast was obtained by the combination of three different components: one that captures the trend of the time series, a seasonal component and a transitory component. The model presented in [14] estimates natural-gas demand, based on average trend of the economy development; the model considered natural production/demand maxima of energy carriers. The prognosis was loaded with an error resulting from the use of average data related to annual increases of the national gross product. Other studies presented forecasting models by support vector model and discrete gray forecasting model [15,16].

Electrical consumption was forecasted by integration of neural network, time series and ANOVA [17]. They found that ANN has better estimated values for total electricity consumption. Azadeh et al. [18] develop an integrated artificial neural networks and genetic algorithm framework to predict electrical energy consumption. Authors in [19] proposed an integrated approach based on genetic algorithm, computer simulation and design of experiments for forecasting electrical energy consumption. Azadeh et al. [20] presented an integrated fuzzy system, data mining and time series framework to estimate and predict electricity demand for seasonal and monthly changes in electricity consumption in developing countries such as China and Iran. Azadeh et al. [21] employed an artificial neural network (ANN) approach for annual electricity consumption in high energy consumption industrial sectors. An integrated algorithm was developed for forecasting monthly electrical energy consumption based on artificial neural network (ANN), computer simulation and design of experiments using stochastic procedures [22]. Authors in [23] proposed a new hybrid ANFIS computer simulation for improvement of electricity consumption estimation.

Parikh et al. [1] estimated demand projections of petroleum products and natural gas in India. They considered GDP and population as inputs of their NG estimation model. Petruseva [24] presented an algorithm which solves the shortest path problem in an arbitrary deterministic environment with n states with an emotional agent in linear time. Yoo et al. [25] estimated households' demand function for natural gas by applying a sample selection model using data from a survey of households in Seoul. Khashman [26] has developed a modified backpropagation (BP) learning algorithm, namely, the emotional backpropagation (EmBP) learning algorithm. The new algorithm had additional emotional weights that were updated using two additional emotional parameters: anxiety and confidence. The proposed "emotional" neural network was implemented to a facial recognition problem, and the results have been compared to a similar application using a conventional neural network. Azadeh et al. [27] forecasted short term natural gas consumption by ANFIS and showed that ANFIS has outperformed ANN and conventional methods for natural gas consumption estimation.

Authors in [28] applied an intelligent controller to govern the dynamics of electrically heated micro-heat exchanger plant. To build the neurofuzzy model, a locally linear learning algorithm, namely, locally linear mode tree (LoLiMoT) has been used. Then, an intelligent controller based on brain emotional learning algorithm has been applied to the identified model. Gadanho [29] presented the ALEC agent architecture which had both emotive and cognitive learning, as well as emotive and cognitive decision-making capabilities to adapt to real-world environments.

Kurokawa et al. [30] have developed a system that can characterize an emotion of an e-Learning user by analyzing his/her facial expression and biometric signals. The criteria used to classify the eight emotions were based upon a time sequential subjective evaluation of emotions as well as a time sequential analysis of facial expressions and biometric signals. Lucas et al. [31] used two techniques that have successfully been used in other intelligent modeling and control applications. Firstly, the authors used a neuro-fuzzy locally linear model tree system for data driven modeling of the machine. Secondly, the authors used a neural computing technique, based on a mathematical model of amygdala and the limbic system, for emotional control of the washing machine.

Estimating the future trend has been an interesting and important problem in human mind for many decades. Moreover, there is a need for new and novel methods for process optimization when there is not enough process data at the operation stage [32]. Authors in [33] presented a multi-step method to generate a nearly optimal solution and consequently selecting best sets of variables in regression. In [34] an algorithm was presented for estimation of a regression function by linear functions. Authors of [35] and [36] used traditional methods for oil and gas production and consumption estimations. Brabec et al. [37] used non-linear mixed effects approach for prediction of gas consumption. They also present the policy analysis implications in oil and gas industries. However, most of previous studies in this area are concentrated with crisp data and certain environment. Moreover, there is no research as how to optimize the forecasting capabilities of regression functions in noisy and cognitive environments. This paper presents an intelligent and effective approach based on emotional learning algorithm to deal with such uncertainty, noisiness and complexity for gas consumption estimation in the period 1973–2006.

Recent developments in the use of emotional learning algorithms have shown significant advancement and improvement in the emotional learning-based forecasting models. Q-learning [38] is a simple way for agents to learn how to act optimally in controlled Markovian domains. Wang et al. [39] proposed a new method, called backward Q-learning, as an integration of Sarsa algorithm and Q-learning to avoid the disadvantages of these two algorithms, to stick in the local minimum and long learning time. Lotfi and Akbarzadeh [40] proposed the brain emotional learning-based pattern recognizer (BELPR) to solve multiple input–multiple output classification and chaotic time series prediction problems. Lotfi and Akbarzadeh [41] proposed a Fuzzy Adaptive Brain-Inspired Emotional Decayed Learning named Fuzzy ADBEL that models the forgetting process and inhibitory mechanism of the emotional brain. In the model, the fuzzy decay rate simulates

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