Electrical Power and Energy Systems 54 (2014) 268–276

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Robust electricity consumption modeling of Turkey using Singular Value Decomposition

Kadir Kavaklioglu *

Pamukkale University, Computer Science Department, Denizli, Turkey

ARTICLE INFO

Article history:
Received 24 February 2013
Received in revised form 1 July 2013
Accepted 13 July 2013

Keywords:
Electricity consumption
Singular Value Decomposition
Turkey

ABSTRACT

Multivariable regression method is used to model Turkey's electricity consumption through a nonlinear relationship. Electricity consumption is modeled as a function of four demographic and economic indicators such as, population, gross domestic product per capita, imports and exports. The second order model includes 15 coefficients for bias, first degree terms and second degree terms. Data preprocessing is applied to transform all variables to have zero mean and percent relative variance. Singular Value Decomposition is applied to reduce the dimensionality of the problem and to provide robustness to the estimations. Variance and covariance information in the data set is used to determine the number of important dimensions in the data. Electricity consumption of Turkey is modeled using annual data from 1970 to 2011. The results show that electricity consumption can be robustly modeled using Singular Value Decomposition.

1. Introduction

Today, we heavily depend on electricity in every aspect of our lives from bare necessities to luxuries that we cannot give up. It is one of the major indicators for our standard of living. Majority of electricity is produced by coal-fired power plants, hydroelectric plants, nuclear plants and natural gas fired thermal power plants. All these plants are very costly investments and especially nuclear and hydroelectric plants have long construction times. In addition, these power plants affect the environment negatively, to varying degrees, due to their waste, emissions or ecological changes that they create. Especially fossil power plants contribute significantly to the global warming through their CO_2 emissions that facilitate the greenhouse effect. These issues put governments and other organizations in policy making in a difficult position to make decisions about building new capacity as well as implementing life extension programs at the existing power plants. There are also risks involved in supply and electric power infrastructure and these risks need to be addressed [1,2]. These issues are so important that they motivated researchers toward advance power technologies. It is therefore extremely important to model and predict electricity consumption reliably in order to avoid insufficient or excess capacity.

Turkey is expected to have increasing electricity demand in the future as its economy is expanding and its standard of living is improving. However, there are complications in this expected trend as national and global economic volatility can cause large scale fluctuations in the general behavior. The problem is amplified by the fact that Turkey has limited energy resources and is heavily dependent on imported fossil fuels for its electricity generation. Turkey's overall energy consumption also shows a similar picture. According to a report published in 2006 by World Energy Council Turkish National Committee (WEC-TNC), imported oil and gas contribute about 62% of Total Primary Energy Supply (TPES) of Turkey and it imported 77% of its energy needs in 2004 [3]. Because of all the factors mentioned, building models for Turkey's electricity consumption is essential. Ministry of Energy and Natural Resources (MENR) and State Planning Organization (SPO) of Turkey perform modeling and prediction of electricity demand. Model for Analysis of Energy Demand (MAED) is used by MENR that historically produced consumption predictions that are on the high side for the intermediate to long term. Therefore, there is a need for developing alternative methods for modeling electricity consumption.

There are various studies in the literature about the relationship among energy consumption and socio-economic indicators. Ebohan [4], Kavrakoglu [5], Say and Yucel [6], Uri [7], Yu and Been [8], Gilland [9] and Niu et al. [10] are examples of such studies that

Abbreviations: ANN, Artificial Neural Network; GDPC, Gross Domestic Product per Capita; MAED, Model for Analysis of Energy Demand; MENR, Ministry of Energy and Natural Resources; RMSE, Root Mean-Squared Error; SPO, State Planning Organization; TEIAS, Turkish Electricity Transmission Company; TPES, Total Primary Energy Supply; TUIK, Turkish Statistical Institute; WEC-TNC, World Energy Council Turkish National Committee.

* Address: Pamukkale University, Computer Science Department, 20070 Kinikli, Denizli, Turkey. Tel.: +90 258 296 3329; fax: +90 258 296 3262.
E-mail addresses: kadir.kavaklioglu@pau.edu.tr, kadir.kavaklioglu@outlook.com

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.07.020

show strong correlation among these parameters. Some researchers studied these types of relationships especially for Turkey. Balat [11] studied energy consumption and economic growth for Turkey in the past two decades whereas Altinay and Karagol [12] reported their results on electricity consumption and economic growth. Sari and Soytas [13] investigated energy consumption, employment and income for Turkey.

There are various studies on modeling electricity consumption. Amina et al. studied a hybrid approach based on fuzzy wavelet neural network model [14]. Chen and Wang reported long term forecasting by a collaborative fuzzy neural approach [15]. Kermanshahi and Iwamiya studied neural networks whereas Lienert and Lochner worked on the interdependencies in modeling energy systems [16,17]. There are also numerous studies on energy and electricity modeling and prediction for Turkey. Analysis of cyclic patterns in historical data approach was used to predict primary energy demand in Turkey by Ediger and Tatlidil [18]. Energy forecasting of Turkey was performed by Yumurtaci and Asmaz [19] based on the population and energy consumption increase rates per capita for the period of 1980 and 2050. Artificial neural networks (ANN) were used by Sozen et al. [20] to predict Turkey's net energy consumption. An ant colony energy demand estimation model was developed by Toksari [21] for Turkey. An interesting method named gray prediction with rolling mechanism (GPRM) was used by Akay and Atak [22] to predict Turkey's total and industrial electricity consumption. Sozen and Arcaklioglu [23] also used ANNs to estimate the future consumption. Hamzacebi [24] predicted Turkey's electricity consumption with ANN's using a time series type network structure. There are also numerous published work in the area of load following [25–27] where researchers used different methods for consumption forecasting. This review of the literature has shown that model sensitivity and robustness issues are usually not addressed and there is a need for research in the field of electricity consumption modeling.

One of the crucial elements of any modeling study is to determine all the input variables that influence the output variable of interest. In lieu of the literature search presented in the preceding paragraphs, four socioeconomic variables are identified as the input variables to model Turkey's electricity consumption. These input variables are population, Gross Domestic Product per Capita (GDPC), import and export values. In terms of population, it is easy to understand that it will affect consumption since more people means more energy consumption. Imports and exports of Turkey are strong indicators of manufacturing activity, and therefore they have strong relationship to electricity consumption. Finally, GDPC is an indicator for overall living standards and therefore influences the electricity use.

Another important aspect of a modeling study is to pick a form of the model that can handle the nature of the problem. Almost all of the relationships in real world are nonlinear and the form of the model should have the ability to capture nonlinearities. For instance, neural networks accomplish this by incorporating nonlinear transfer functions in their processing elements (neurons). It has been shown that artificial neural networks can perform nonlinear mappings to any given degree of accuracy [28]. Unfortunately, local model accuracy is never the only performance parameter, although being an important measure. A good model should also have good generalization performance since one of the major uses of a model is to use the model beyond training domain. On the other hand, a given modeling methodology should also have reasonable global optimization characteristics. One can never reach the best possible model if the methodology cannot reach true global minimum by getting trapped in local minima.

In addition, a modeling method should be well suited for issues related to input and output data sets. Every data set we have is guaranteed to be noisy and/or erroneous measurements or calculations. For instance, the population variable, that is one of the inputs used in this research, was used to be measured by door-to door people counting in 5-year periods and interpolated for the years in between. Recently, Turkey is using a new system that uses the addresses of people in official records. Either way, one can easily recognize that these methods would never yield the actual population of the country. On top of being noisy and/or erroneous, the data may not be available at every point an analyst may want. All the data used in this study is annual, although quarterly or monthly data would be better. Models with good interpolation characteristics can overcome this issue and compensate for sparse data.

One last issue a good modeling methodology should take care of is the degree of freedom problem. Although being mentioned last here, it may become the most important issue for some modeling tasks, such as the one presented in this paper. This problem stems from the fact that most of the time; the input variables used to model an output variable are not independent of each other. For instance, exports and gross domestic product per capita are two of the inputs used in this research and we know that they affect each other. The result in such cases is models that are highly sensitive so that a small change (error) in inputs may lead to substantial changes at the output that would reduce reliability of the results. Dimension of the data should be reduced to the actual dimension of the problem. However, we do not have any heuristic way of determining the best set of independent inputs for a given problem. Therefore, a theoretically sound way of dimensionality reduction method should be applied that makes the models robust.

Based on the arguments presented so far, multiple least squares regression with Singular Value Decomposition technique was applied to model Turkey's electricity consumption. Population, GDPC, imports and exports are selected to be the input variables to estimate the electricity consumption. A second order nonlinear model was used to handle the nonlinearities in the data. Least squares regression was applied to compute model parameters. Singular Value Decomposition (SVD) was applied to input data sets for dimensionality reduction and the results are compared. An overview of the present paper is as follows: Section two explains what SVD is along with some of its relevant properties. Section three describes in detail how the methodology is applied to electricity consumption modeling. Section four presents the results obtained during this research and discussion of these results. The conclusions of this research are given in section five.

2. Singular value decomposition

Singular Value Decomposition is one of the most powerful techniques in linear algebra for both theoretical and computational analysis. Most applications featuring SVD make use of robustness and dimensionality reduction properties of this matrix decomposition method. SVD also allows us to incorporate the geometrical nature of our data using vector spaces. In essence, a matrix can be viewed as an operator mapping a vector space into another vector space (sometimes into itself) and SVD gives us excellent insight into how this mapping takes place.

Applications of SVD in linear algebra include but not limited to finding the rank of a matrix, finding the inverse of a matrix, finding the pseudo-inverse when the matrix is not invertible, computing the condition number of a matrix, solving linear systems and solving least squares problems. The fields of application cover from engineering and sciences, social sciences and education to business areas. Refs. [29–31] give a through overview of both theory and applications of SVD.