Novel Method to Estimate Peak Electric Load Demand: ANN and Principal Components

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Abstract: - Cross correlation and eigen values from the principal component analysis are used to illustrate the contributions of the variances explained by important factors. The peak electric load depends on many factors and it is shown that at least five factors among the major seven factors can explain the maximum variance in the system. From this analysis a neural network model is constructed to capture the season peak electric load pattern. The developed neural network model accounts the effect of extreme temperature and humidity factors in addition to the sudden peak load in Al-Ain area. The Neural network model for seasonal peak load estimation improves over statistical model by a factor 3.5% in mean square error and 5.6% in mean absolute error. Also the method improves in mean absolute relative percentage by a factor of 5.5%. Hence economical operations of the power plants are ensured for long term operations and planning.

Key-Words: - Seasonal Peak Electric Load, Meta-Model, Principal Component, Correlation

1. Introduction
This paper reports the applicability of neural network models on load estimation for Al-Ain district’s electric utility company. The objective is to accomplish suggestions on choosing the most appropriate model(s), as there is need to estimate the load accurately at all time spans. The work provides the basis for an automatic load prediction to be used in a real-time environment. There are some properties, which are considered important:

- The model should be automatic and able to adapt quickly to changes in the peak electric load behavior for Al-Ain city.
- Generalized models are developed for use in many different cases and utilities in UAE.
- The Al-Ain peak load prediction model can be updated with new available data. The time period closest to the prediction time can be estimated as accurately as possible.
- The Al-Ain peak load model is reliable and exceptional circumstances do not give rise to unreasonable estimates.
- The difficult weather condition in Al-Ain, especially large variation of temperatures, is taken care of.
- The Al-Ain load model is an integral part of the energy management system.

1.1 Peak Load Factors
Generally, the peak load of an electric utility is composed of different consumption units. A large part of the electricity is consumed by industries and business units. Another part is used by private people in forms of heating, lighting, cooking, laundry, and other domestic activities. Also many services offered by society demand electricity, for example street lighting, etc. Factors affecting the load depend on the consumption pattern. The industrial load is usually determined by the level of the production. The load is often quite steady, and it is possible to estimate its dependency on different production levels. Industrial units also add uncertainty in the estimates. Although, the Al-Ain city is not an industrial city, but the possibility of unexpected events, like machine breakdowns or shrinkage in market demand, cause large unpredictable disturbances in the load level. Many social and behavioral factors also determine consumption pattern. For example, significant social events, holidays, popular TV-programs, affect the peak electric load (Karanta 1990, Kim et al. 1995).

The Al-Ain weather is the most important individual factor, the reason largely being the air conditioning of houses, which becomes more intensive as the temperature rises. Al-Ain is an oasis city in the middle of the UAE desert. A large part of the consumption is used by the private people and other small electricity customers. The approach in peak load estimation is to concentrate on the aggregate load of the whole utility. This reduces the number of factors that can be taken into account. The meteorological conditions cause large variation in aggregated load. In addition to the temperature, humidity has an influence in peak electric load (Chow and Leung 1996, Kallio 1985, Khotanzad et al. 1996).

The various seasonal effects and cyclical behaviors as well as occurrences of legal and religious holidays are important. The other factors causing disturbances can be classified as random factors. These are usually small, although large social events and popular TV
programs add uncertainty in the estimates. Industrial units, however small number in Al-Ain city may be, can cause relatively large disturbances.

2. Econometric Peak Load Models
A precise peak electric load assessment is necessary for economic load dispatch. The better the estimate, the more closely the power generation cost of the company can be configured to minimum level. If the load estimation is higher than the actual load, power-generating units will be needlessly activated, but if the estimate is too low, the deficit has to be made up through the operation of small standby power units that can be brought online relatively quickly. Such operational planning is expensive in nature compared to large generating units. The large generating units may take more than twenty four hours to go online from a cold state. Therefore, they cannot be used to respond to sudden load changes in real time.

The historical Al-Ain load profiles, the weather information are used in the determination of the peak electric load estimation, based on their relative importance. Time series models (Moghram and Rahman ,1989; Box and Jenkins 1976), regression models (Fung and Rao, 1993; Marquez et. al, 1991; Thompson, 1976; Papalexopoulos, et. al, 1990), and expert systems (Peng et. al., 1992; William, 1996; Sforna, 1995; Dash, et. al, 1997; Bakirtzis, et. al, 1995; Mirinda and Saraiva, 1992; Rahman and Bhatnagar 1988) have been proposed to solve electrical load demand as a function of weather variables and social activities. Time series (Hagan and Behr, 1987) models employ historical load data for extrapolation to obtain future loads. These models consider that the load trend is stationary, and view any abnormal data as bad data. Regression models (Haida, 1994) analyze the relationship between load, weather, and social activities. The disadvantage with regression models is that they require complex modeling techniques. It is computationally complex to uncover the underlying relationship among various factors. Expert systems (Ho et al., 1992) use expert’s experience and knowledge to capture the relationship between social activities, weather, and future loads. To capture the expert’s experience and knowledge (Rahman and Hazim, 1993; Vale et. al, 1994), if then, rules transform the information into a computer model. Such models lack the desired accuracy and have difficulty in producing accurate estimate in the case of rapid weather changes (Chen, et. al, 1992; Shin-Tzo, et. al, 1992, Asbury, 1975). A model developed for one utility cannot easily be modified for another utility and installation.

During the last several years, artificial neural networks (ANN) have been applied to the load estimation problem with considerable success. The power generating companies need a system that can make accurate estimate ahead of time. A newly developed self-adaptive ANN training method is used to identify optimum input parameter set, and obtain more accurate peak electric load estimate for the Al-Ain distribution company in UAE.

3. Electricity Distributions in UAE
The services offered by the UAE federal Ministry of Electricity and Water have grown very substantially over the last few. Electricity has reached every dwelling in the UAE. However, demand has also spiraled in the intervening years, so much so that maximum demand in Al-Ain city reached 1,020 MW in 2000.

In order to cope with the demands for more than 124,000 energy consumers; the Ministry is linking all its generating plants in a single grid. The first and second phases of the grid linked areas of the east coast, Fujairah, Qidfa, Khor Fakkan and Dibba, and the west coast, Ajman, Umm al-Qaiwain and Ras al-Khaimah, to the Central Zone. The plan is to link Dhaid power generation station in the Central Zone with the main station in Fujairah in the Eastern Zone. The new grid shall facilitate the distribution of power to the stations according to the needs of each area, at the same time meeting the growing demand of electricity in the Northern Emirates. UAE will be linked to the gulf cooperation council (GCC) grid throughout the Arabian Peninsula. In addition the ministry planed for the installation of 200 megawatt gas turbines in Qidfa in Fujairah and Nakheel in Ras al-Khaimah, all of which will increase output to the Northern Emirates, stabilizing power supply and meeting the increasing demand for power in the area.

Al-Ain Distribution Co. (AADC or the Company) was formed from the electricity and water distribution functions of the former Water & Electricity Department for deregulation and to be more cost effective. The Company is responsible for the sale and distribution of water and electricity, including operations, maintenance, meter reading, and customer billing. AADC provides services to 100,000 customers throughout the eastern portion of Emirate of Abu Dhabi, excluding Abu Dhabi City. The water and electricity distribution is under the overall control of the Abu Dhabi Water and Electricity Authority (ADWEA). The Company consists of 3 main Divisions; namely Power Network, Water Distribution and project. The five main Departments are Human Resources, Information Technology, Contracts & Purchase, Finance and sales.

4. The Load Profile of Al-Ain District
Quarterly energy demand in Al-Ain district is shown in figures. There is steady demand growing each year compared to the previous year’s total demand. The summer months are hot and humid leading to maximum pick demand to register. The winter months
are relatively cooler and the load demand fall to the minimum peak compared to the summer months.

There is gradual increase in energy demand over the years as can be seen from figures. The demand of the Al-Ain city is supplemented by other power houses from elsewhere in UAE. Max and min energy demand are the indications how the power plants are to be scheduled for electricity generations. As the temperature and humidity varies, the demand for energy also varies. The peak electric load, the temperature as well as humidity has cyclic trends as can be seen from the data and figure 1, 2 and 3. The available complete set of data is used to train the artificial neural network (ANN) and the data for the last one year is used for validation purpose. A newly developed self-adaptive ANN training method is used to model the Al-Ain peak electric load consumption pattern. The training method does not require one to arbitrary set learning rates to train the ANN. The new training method automatically selects the appropriate learning rates depending on the training pattern and nature of the error function.

5. Strategic Planning and Load Profile Analysis
To address the long term plan and future expansion, it is best to address the maximum peak load profile. The planning based on the peak load considers the power generation requirements for any season, without any power shortage. The Al-Ain weather in general has two distinct characteristics and can be classified as summer and winter seasons. The summer is long spell and is classified as hot summer month during June, July, August, and September. Then gradually, the weather begins to be mild, during October, November. The weather during December, January and February is cooler relatively compared to the rest of the year. The other months are the transition between the hot summer and winter period. The Al-Ain city is located in the middle of desert but the city is green. The night times are relatively cooler than during the Day time. To analyze, the peak load behavior of the Al-Ain city the data is grouped into four segments. The monthly peak load is accumulated as quarterly peak load.

6. ANN for Al-Ain peak electric load profiling

An artificial neural network (ANN) is a computational system inspired by the functioning of the human brain. The system is made up of highly interconnected processing elements called artificial neurons (Zurada, 1992, Piras and Buchenel, 1996). The neural network is an architecture that can learn arbitrary mappings from analog or digital inputs of any dimensionality to analog or digital outputs of any dimensionality. The architecture applies incremental supervised learning of recognition categories and multidimensional maps in response to arbitrary sequences of analog or binary input vectors, which represent set of features. An approach based on artificial neural network is developed to determine the load profile for the Al-Ain city. The neural net consists of a number of nodes or neurons connected by links. The nodes in the neural network can be divided into three layers: the input layer, the output layer, and one or more hidden layers. The nodes in the input layer receive input signals from an external source and the nodes in the output layer provide the target output signals. The output of each neuron in the input layer is the same as the input to the
neuron. The algorithm in Table 3 show the ANN training phases for the Al-Ain city peak load profile.

6.1 Factors and Correlation Analysis
To see the relationships among the various factors that contribute the peak load the correlation among the factors are shown in figure 4a. The factors that are used to see the statistical properties and relationships between the predictors are listed below.
1. Bias term: For Perceptron Model
2. First Quarter Seasonal Variations
3. Second Quarter Seasonal Variations
4. Third Quarter Seasonal Variations
5. Fourth Quarter Seasonal Variations
6. Humidity
7. Temperature

The color contour map suggests the degree of association between the factors.

6.2 Load estimation with ANN
The best ANN model among many others is a 7-5-1 ANN configuration that models the Al-Ain peak electric load pattern. ANN load profiling is a dynamic approach in the sense that the load is predicted sequentially using the previous value of the load along with the load value predicted by a self-adaptive ANN system for the next time interval.

The network model consists of three layers. The input layer has processing elements or nodes, representing the power load at the previous time interval and the other representing associated system variables to predict the power load for the next time interval. The hidden layer consists of a number of nodes used for computation purposes. The number of hidden nodes must be determined experimentally by a simulation experiment. The output layer consists of a single node representing the neural network’s prediction of the power load at the next time interval. The terms are defined as:
- \(X(t)\) = the predicted result at time \(t\) via ANN;
- \(X(t-1)\) = the actual power load at time \(t - 1\);
- \(X_{s-1}(t)\) = the maximum humidity at time \(t\)
- \(X_{d-1}(t)\) = the maximum temperature at time \(t\)

In this research, the performance results by different ANN configurations are utilized to determine the best neural network configurations. The peak load model for the Al-Ain city is expressed as:

\[
P = \frac{1 - \sum_{b}^{p} \theta_{b}^{t} \mid B = 1 \mid \sum_{n}^{s} \phi_{n}^{t} \mid B = 1 \mid (1 - B)Z(t)}{1 - \sum_{a}^{Q} \beta_{a}^{t} \mid A = 1 \mid \sum_{s}^{Q} \delta_{s}^{t} \mid A = 1 \mid B(t)}
\]

where
- \(Z(t)\) = normalized load time series;
- \(A(t)\) = white noise time series;
- \(B\) = backward shift operator;
- \(s\) = seasonal terms;
- \(p\) = order of auto-regressive non-seasonal time series;
- \(SP\) = order of auto-regressive seasonal time series;
- \(Q\) = order of moving average non-seasonal time series;
- \(SQ\) = order of moving average seasonal time series;
- \(\theta_{b}, \phi_{n}, \beta_{a}, \delta_{s}\) = model coefficients.

The forecast errors made by best ANN configuration and results are reported in corresponding table. The mean absolute errors (MAE), root mean square errors (RMSE) and other error measures are used to judge the ANN model.

6.3 Performance measure of ANN Model
Performance of the Al-Ain peak electric load ANN architecture is evaluated by comparing the accuracy of the estimate, the efficiency of the model, and its
relative ease of use and maintenance. Accuracy is computed by comparing the deviation from the actual peak loads. To implement it is also important that the model is easy to use and maintain with respect to adapting to new data.

The accuracy of the presented neural network is checked against the mean absolute percentage error. In performed tests, the mean absolute percentage errors are up to 4% range. The mean percentage error is about 0.75%. The DW statistics is found to be 0.68 to detect serial autocorrelation.

6.4 The ANN training results
The training results are reported with ANN training. Different ANN configurations are trained with the Al-Ain peak electric load in addition to the weather data. The results are superior to the traditional statistical multivariate analysis. The comparative results are displayed with ANN training and statistical multivariate forecasting methods. The developed load curve is compared with the actual load curve for the Al-Ain city. The neural load profile corresponds in most parts very well with the real load profile.

A self-adaptive training method is used to train the ANN to step quickly in the direction, in which the error decreases most. The self-adaptive parameter is called the learning rate and automatic generations of momentum term help to avoid oscillation around the minimum. The Root Mean Square Error determines the learning error. ANN is trained in order to determine a network with optimal learning behavior. Best result is archived with input data, sorted according to the influence factors (maximum temperature, season, maximum humidity) and network architecture with one hidden layer and about 5 neurons in the hidden layer. The inputs to the ANN are peak load, maximum temperature, and maximum humidity.

7. Conclusion and Policy Recommendations
The worsening summer heat stress both people and energy systems. To provide adequate electricity the power industry should respond by building generating units. Inadequate supply of electricity would aggravate the unit prices and the summer seasons would face difficulty. Some mechanisms and planning is needed to prevent the costs from further burdening the low income residents.

Table 1: Error Measure (Al-Ain Peak Load: Multivariate and ANN Model)

<table>
<thead>
<tr>
<th></th>
<th>DW: reg</th>
<th>DW: ANN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error: Reg</td>
<td>2.3386</td>
<td>0.6810</td>
</tr>
<tr>
<td>Error: ANN</td>
<td>Sum</td>
<td>0.02</td>
</tr>
<tr>
<td>Mean % err:Reg</td>
<td>0.0095</td>
<td>0.1807</td>
</tr>
<tr>
<td>Mean % err:ANN</td>
<td>Sum</td>
<td>0.0095</td>
</tr>
<tr>
<td>Mean Abs Error</td>
<td>Sum</td>
<td>1825.98</td>
</tr>
<tr>
<td>Mean Relative % err</td>
<td>Sum</td>
<td>1.0086</td>
</tr>
<tr>
<td>RMS</td>
<td>Mean</td>
<td>0.0029</td>
</tr>
<tr>
<td>RMS</td>
<td>Mean</td>
<td>0.0024</td>
</tr>
</tbody>
</table>

7.1 Policy Recommendations
The gradual increase in summer cooling requirements in the Al-Ain region put burden in the electric power industry’s ability to meet increasing summer peak loads. The industry should take climate change into account to provide electric power. As the climate
warms, the industry can adapt combination of four solutions:

- Construct local power plants to keep up with the rising demand
- Construct additional transmission lines to bring more power into the Al-Ain area
- Upgrade local power lines to distribute electricity to customers
- More aggressive energy efficient policy is required to reduce summer peak electric loads.

The proposed load management curve is efficient for planning purpose. In comparison with statistical model the developed peak electric load estimation method improves by a factor of 3.5% in mean square error, 5.6% in mean absolute error and also improves by a factor of 5.5% in mean relative absolute percentage error. Such improvements in estimation translate into economic operation of the Al-Ain power plants.

It is shown here how the crenellation can be interpreted using a color contour map to help identifying the dominant factors contributing the peak electric load demand. The principal component analysis shows the variance explained by the individual eigen-values corresponding to the factors associated with peak electric load model. Such analysis makes the analysis robust in peak load estimation.

References


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