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Using the Analytic Hierarchy Process in Long-Term Load Growth Forecast

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Abstract: The load growth is the most important uncertainties in power system planning process. The applications of the classical long-term load forecasting methods particularly applied to utilities in transition economy are insufficient and may produce incorrect decisions in power system planning process. This paper discusses using the method of analytic hierarchy process to calculate the probability distribution of load growth obtained previously by standard load forecasting methods.

Key words: Long-term load forecasting, analytic hierarchy process, probability, uncertainties.

1. Introduction

The main objective of power system planning is to determine an investment schedule for the construction of generation plants and interconnection links that provide an economic and reliable supply to the predicted demand over a planning horizon. The criteria are to minimize the overall cost and increase the reliability with different type of constraints. This decision problem becomes more and more complicated because of variety of players involved in the decision-making process and the increased concerns for environmental quality.

Several sources of uncertainty have an important impact on this planning process: load growth rates; economic growth, cost and availability of fuels and technologies; financial constraints; environmental constraints; interest rate; construction time, public opinion etc. [1].

One of the most important elements and priority objectives of a least cost power system planning is to accurately predict load requirements. Many factors affect electric load including population, income, power tariffs, economic activity, governmental energy and environmental policies. In addition, random factors such as weather also affect demand. As a result, there is considerable degree of uncertainty and variability around demand forecasts. Results obtained from the load forecasting process are used in different areas. Long-term load forecasting is applied to expansion problem and long-term capital investment return problem.

Accurate models for long term forecasts are crucial to help electric utility, financial institutions and other participants in energy system planning to make important decisions on purchasing and generating electric power, and infrastructure development. With the deregulation of the energy industries, decision on capital expenditures based on long-term forecasting is also important.

Long-term load forecasting represents the first step in developing future generation, transmission, and distribution facilities. Any significant deviations from the forecast, especially within the new market structure, will result in either overbuilding of supply facilities, or limitation of customer demand.

Many classical approaches have been proposed and applied to long-term load forecasting to estimate model parameters, including static and dynamic state estimation techniques (least error squares technique), methods based on artificial intelligence such as artificial neural network, wavelet networks, fuzzy

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logics, and expert systems. Genetic algorithms have recently received much attention as robust stochastic search algorithms for various problems. Also, so-called end-use and econometric approach is broadly used for medium and long term forecasts [2, 3].

The level of confidence associated with classical forecasting techniques is unlikely to be similar to those utilities in transition country. This is due to differences in the nature of growth, socio-economics conditions, and the occurrence of special events. Under such condition, these forecasting techniques are insufficient to establish demand forecast for long-term power system planning. Consequently, this case requires special consideration either by pursuing the search for more improvement existing forecasting techniques or setting another approach to address the forecasting problem of such systems. Standard approach in this case is to establish several scenarios, mostly three scenarios (low, base and high scenario) with three different supposed future demand condition [4].

In this paper, the results obtained by classical forecasting method are added in order to obtain probability distribution of load growth. The method of analytic hierarchy process is used for this purpose.

2. Analytic Hierarchy Process

An AHP (Analytic Hierarchy Process) is multiple-criteria decision-making approach and was introduced by Saaty [5]. AHP is a decision support tool which can be used to determine complex decision problems, and is one of the more widely applied multiattribute decision making methods. Broad areas in which the AHP has been applied include alternative selection, resource allocation, forecasting, quality function deployment, and many more [4]. AHP has attracted the interest due to the nice mathematical properties of the method and the fact that the required data are easy to access. The basic concept of the approach is to convert subjective assessment of relative importance to a set of overall scores or weight. The pertinent data are derived by using a set of pair wise comparisons. These comparisons are used to obtain the weights of importance of the relative performance measures of alternatives in terms of each individual decision criterion. If the comparisons are not perfectly consistent, then it provides a mechanism for improving consistency. AHP is process that consists of several steps:

(1) Decide upon the criteria for selection and decomposing the problem into a hierarchy.

(2) Create a judgment matrix by pair-wise comparing the entire factor at one level of the hierarchy with respects to each factor in immediately preceding level.

(3) Compute the eigenvector of the judgment matrix for the largest eigenvalue.

(4) Calculate the composite priority vector from the local priorities associated with each judgment matrix and rating the alternative.

One of the most crucial steps in many decision-making methods is the accurate estimation of the pertinent data. Often qualitative data cannot be known in terms of absolute values. For instance, questions like “What is the worth of regulators authority on load growth?”. Although information about these questions are vital in making the correct decision, it is very difficult, if not impossible, to quantify them correct. Therefore, many decision making methods attempt to determine the relative importance, or weight, of the alternatives in terms of each criterion involved in given decision-making problem [6].

In approach based on pair wise comparisons, which was proposed by Saaty [5], the decision-maker has to express his opinion about the value of one single pair wise comparison at a time. Each choice is a linguistic phrase like “A is more important than B”, or “A is of the same importance as B”, or “A is a little more important than B” and so on. The main problem with pair wise comparisons is how to quantify the linguistic choices selected by the decision maker during their evaluation. According to scale proposed by Saaty (Table 1), the decision-maker has to choose his answer

Table 1 Saaty's scale for pair wise comparison.

Intensity	Definition	Explanations
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly one favor over another
5	Strong importance	Experience and judgment strongly one favor over another
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The importance of one over another affirmed on the highest possible order
2,4,6,8	Intermediate values	Used to present compromise between the priorities listed above

among 17 possible discrete choices as a set of integer numbers.

The decision problem is decomposed into a multi-level hierarchical structure of objectives, criteria, sub criteria and alternatives in order to decompose the problem into a hierarchy of sub problems which can more easily be comprehended and subjectively evaluated. This is the most creative and important part of decision-making. Structuring the decision problem as a hierarchy is fundamental to the process of the AHP.

Starting from the second level of the hierarchy, each entity is given a weight by pair wise comparison of factors in that level respect to every factor in the upper level. This process will create, for decision problem with n-layer hierarchy, a set of judgment matrices [A] generated for each of (n-1) evaluation levels. To create a judgment matrix with m factors, at least (m-1) ratio questions need to be asked. If denoting the relative importance of i-th factor with respect to j-th factor by a_{ij}, than the relative importance of j-th factor with respect to i-th factor would be $1/a_{ij}$ and the importance of every factor with itself (a_{ii}) is equal to one. The matrix obtained in this way is called "reciprocal judgment matrix" or "pair-wise comparison matrix".

The next step is creation of a judgment matrix and to extract the relative importance implied by the previous comparisons. Saaty asserts that to answer this question one has to estimate the right principal eigenvector of the obtained judgment matrix. The eigenvector analysis is a unique technique to determine the relative ranking of factors with respects to a certain objective. This procedure uses the eigenvector analysis to calculate the individual and overall influence of factors on the goal. The priority vector which gives the ranking of the factors is obtained by normalizing the principal eigenvector p of judgment matrix which is obtained by solving the eigenvalue problem:

$$[A]\cdot p = \lambda_{max}\cdot p \quad (1)$$

where λ_{max} is the principal or the largest real eigenvalue of judgment matrix. The priorities in the n-level hierarchy with respect to the goal can be calculated using the following matrix equation:

$$\begin{bmatrix} p_{1,n}^{1,1} \\ p_{2,n}^{1,1} \\ \cdots \\ \cdots \\ p_{n,n}^{1,1} \end{bmatrix} = \begin{bmatrix} p_{1,n}^{1,n-1} & p_{1,n}^{2,n-1} & \cdots & p_{1,n}^{m_{n-1},n-1} \\ p_{2,n}^{1,n-1} & p_{2,n}^{2,n-1} & \cdots & p_{2,n}^{m_{n-1},n-1} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ p_{m_n,n}^{1,n-1} & p_{m_n,n}^{2,n-1} & \cdots & p_{m_n,n}^{m_{n-1},n-1} \end{bmatrix} \cdots\cdots \begin{bmatrix} p_{1,3}^{1,2} & p_{1,3}^{2,2} & \cdots & p_{1,n}^{m_2,2} \\ p_{2,3}^{1,2} & p_{2,3}^{2,2} & \cdots & p_{2,n}^{m_2,2} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ p_{m_3,3}^{1,2} & p_{m_3,3}^{2,2} & \cdots & p_{m_3,3}^{m_2,2} \end{bmatrix} \cdot \begin{bmatrix} p_{1,2}^{1,1} \\ p_{2,2}^{1,1} \\ \cdots \\ \cdots \\ p_{m_2,2}^{1,1} \end{bmatrix}$$

where m_i is the number of elements at level i and $p_{i,j}^{k,l}$ is the priority of element i at level j with respect to element k at level l.

The consistency of the above matrix can be evaluated. Comparisons made by this method are subjective and the AHP tolerates inconsistency through the amount of redundancy in the approach. If this consistency index (CI) is above required level then answers to comparisons may be re-examined. CI is calculated as

$$CI = (\lambda_{max} - n)/(n-1) \quad (2)$$

This CI can be compared with that of a random matrix (RI). Saaty suggests the value of the ratio CI/CR should be less than 0.1.

The rating of each alternative is multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to get global ratings [7].

3. Case Study

The accurate forecast of long-term load demand is difficult to be made due to uncertain nature of the forecasting process. Therefore, any long-term load demand forecasting, by nature is unreliable. In this case, forecasting of future energy demand is always performed on the basis of different scenarios.

Scenario can be defined as a hypothetical sequence of events constructed to focus on the causality of the process and decisions. There can be several types of scenario, mainly formed on the basis on the affections of scenario-makers as optimistic and pessimistic scenario. Very popular, although very subjective, are scenarios with probability of occurrence. Some include single, dominant issues as economic expansion, environmental aspects or technological dominance. Scenario analysis is one of the most popular approach for assessing the impact of various factors of uncertainty because prepare entities for rapid adjustment to changing conditions; rely less on computer support and more on developing ideas and discussions; it encourages people to think creatively. Scenarios are well suited to situations where they can identify several crucial factors that cannot be easily foreseen in situations where uncertainty is high and where the future may be dictated by events that have no base in the past.

The sample study illustrate how the analytic hierarchy process [5] can be used to calculate the probability distributions of the before establish load growth forecast scenarios [4]. Standard approach is to establish three different scenarios (low, base and high scenario) with three different supposed future demand conditions. The supposed main factors in the case study affecting load growth are changes in economic conditions, customer behavior including end-use practices and response to technology changes, and DSM (demand side management) impacts, mainly on load demand and energy. Fig. 1 shows the hierarchical structure consisted of three layers, from main goal down to the three objectives (high load growth, base load growth and low load growth).

Starting from second layer of the hierarchy, pair-wise comparison of relative importance between each pair of factors at that level with respect to every connected factor on the upper layer is made. The result of these pair-wise comparisons is judgment matrices to each level, as given in Table 2.

For example, the supposed intensity of importance on ratio questions "How much important is the factor 'economic conditions' in comparison with 'customer behavior' and 'DSM impacts' is 3 (weak importance) and 5 (strong importance) respectively?" (according to scale proposed by Saaty [5]). Table 2 also gives the local priority vector associated with each judgment matrix for each evaluation level calculated using the eigenvector prioritization method.

The overall priority vector, i.e. the composite priority vector from the bottom layer with respect to the top layer, is computed according to Eq. (1):

$$\begin{bmatrix} 0,1047 & 0,081 & 0,0719 \\ 0,637 & 0,7306 & 0,279 \\ 0,2583 & 0,1884 & 0,6491 \end{bmatrix} \cdot \begin{bmatrix} 0,6571 \\ 0,1466 \\ 0,1963 \end{bmatrix} = \begin{bmatrix} 0,0948 \\ 0,5804 \\ 0,3248 \end{bmatrix}$$

The resulting overall priority vector is given below and indicates that the relative weight, in this case, probability of high, base, and low load growth is 0.095; 0.58; 0.325 respectively (3).

$$\begin{matrix} high \\ base \\ low \end{matrix} = \begin{bmatrix} 0,0948 \\ 0,5804 \\ 0,3248 \end{bmatrix} \tag{3}$$

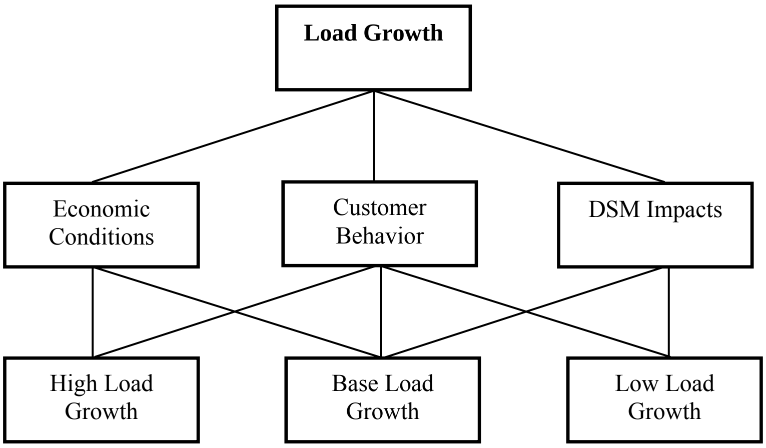

Fig. 1 Hierarchy for load growth assessment.

Table 2 Judgment matrices and priority vectors.

Level 2.1 load growth				
Economic conditions	1	3	5	0.6571
Customer behavior	1/3	1	1/2	0.1466
DSM impacts	1/5	2	1	0.1963
Level 3.1 economic conditions				
High load growth	1	1/5	1/3	0.1047
Base load growth	5	1	3	0.6370
Low load growth	3	1/3	1	0.2583
Level 3.2 customer behavior				
High load growth	1	1/7	1/3	0.0810
Base load growth	7	1	5	0.7306
Low load growth	3	1/5	1	0.1884
Level 3.3 DSM impacts				
High load growth	1	1/5	1/7	0.0719
Base load growth	5	1	1/3	0.2790
Low load growth	7	3	1	0.6491

4. Conclusion

Forecasting of electricity is one of the basic activities during power system planning process. Accurate load forecasting is very important for power system planning process, especially in a competitive environment created by the electric industry deregulation [8]. Unfortunately, it is difficult to forecast load demand accurately over a long-term period. This is due to a large number of factors that affect forecasting process, many of them uncertain and uncontrollable. There are always a number of uncertainties regarding future socio-economic conditions, national economy restructuring and energy developments. In a transition country, this is magnified by dependence on regional trade and political stability [4]. Consequently, the results of the classical long-term forecasting methods are insufficient to establish accurate demand forecast for long-term power system planning. Many load forecasting problems in practical usually are solved by experts with the judgment and experience. Usual approach, in those conditions, is to prepare several scenarios, mostly three scenarios (Reference, Low, and High) for expected electric energy growth rate [9, 10]. It is useful, in that case, to make further effort to make probability assessment of load growth in order to support the decision making process. In this paper, method of analytic hierarchy process is used for this purpose. In case study, the assumed hierarchical structure consisted of three layers, from main goal down to the three objectives (high load growth, base load growth and low load growth), whereby the probability is estimated based on a number of expert opinions considering the subjects affecting influencing factor. The obtained resulting global priority vector, represents the relative weight, in this case, the probability of occurrence of a load growth rate.

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