ANALYTIC HIERARCHY APPROACH OF LOAD SHEDDING (LS) SCHEME IN AN ISLANDED POWER SYSTEM

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ABSTRACT

In general, the highly development environment in the society or the natural interruptions can cause loss of the power supply due to the burden of the generator. In industries, this can cause million of losses when the shortage of supply occurs. Usually, the supply will be back-upped in the storage system. If the over demand is uncontrolled, or when there is no decision-making in removing a certain load, there will be a trouble in the power system. Certain loads will be removed depending on some importance or criteria such as operating load and area power. This requires some decision-making in order order to choose the best load(s) to be cut off. In order to do that, Multi Criteria Decision Making (MCDM) can be applied in determination of the load shedding scheme in the electric power system. The objective of this thesis is to justify a load shedding scheme for an islanded power system. This thesis proposes methodologies for load shedding scheme for the islanded electric power system by using Analytic Hierarchy Process (AHP), Fuzzy Analytic Hierarchy Process (Fuzzy AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). In this thesis, the load shedding scheme is applied to several systems such as large pulp mill electrical system, IEEE 118 bus test case system, Selangor electrical system and Johore electrical system. Models are built up on the base of analysing correlative factors with examples given to indicate how the AHP, Fuzzy AHP and TOPSIS are applied. From this thesis, a series of analyses are conducted and the results are determined. Analyses are made, and the results have shown that AHP, Fuzzy AHP and TOPSIS can be used in determination of the load shedding scheme in pulp mill system, IEEE 118 bus system, Selangor system and Johore system. Among these three MCDM methods, the results shown by TOPSIS are the most effective solution because of the effectiveness of load shedding is the highest.

ABSTRAK

Secara umumnya, persekitaran pembangunan yang pesat dalam masyarakat atau gangguan semula jadi boleh menyebabkan masalah kehilangan bekalan kuasa yang membebankan penjana kuasa. Dalam industri, keadaan ini boleh menyebabkan kerugian apabila berlaku kekurangan bekalan. Biasanya, bekalan akan disandarkan dalam sistem penyimpanan. Jika permintaan berlebihan tidak dikawal, atau apabila tiada keputusan untuk mengeluarkan beban tertentu, akan menyebabkan masalah dalam sistem kuasa. Beban tertentu akan dikeluarkan bergantung kepada beberapa kepentingan atau criteria seperti beban operasi dan kawasan kuasa. Ini memerlukan beberapa cara membuat keputusan untuk memilih beban yang terbaik untuk diputuskan. Dalam usaha untuk berbuat demikian, *Multi Criteria Decision Making (MCDM)* boleh digunakan dalam penentuan skim penumpahan beban dalam sistem kuasa elektrik. Objektif tesis ini adalah untuk memperbaiki skim penumpahan beban yang sedia ada bagi sistem kuasa yang dipulaukan. Tesis ini mewajarkan kaedah skim penumpahan beban dalam sistem kuasa elektrik dengan menggunakan *Analytical Hierarchy Process (AHP), Fuzzy Analytical Hierarchy Process (Fuzzy AHP)* dan *Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).* Dalam tesis ini, skim penumpahan beban digunakan dalam beberapa sistem seperti sistem elektrik kilang pulpa besar, sistem IEEE 118 bas, sistem elektrik Selangor dan sistem elektrik Johor. Model dibina di atas asas menganalisis faktor-faktor yang berkaitan dengan memberi contoh-contoh untuk menunjukkan bagaimana *AHP, fuzzy AHP* dan *TOPSIS* digunakan. Dari tesis ini, satu siri analisis akan dijalankan dan keputusan akan ditentukan. Analisis dijalankan dan keputusan menunjukkan bahawa *AHP, fuzzy AHP* dan *TOPSIS* boleh digunakan dalam penentuan skim penumpahan beban dalam sistem kilang pulpa, sistem IEEE 118 bas, sistem Selangor dan sistem Johor. Antara ketiga-tiga kaedah *MCDM*, keputusan *TOPSIS* memberi penyelesaian yang paling berkesan kerana keputusan keberkesanan penumpahan beban adalah yang tertinggi.

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LIST OF SYMBOLS AND ABBREVIATIONS

Σ - Summation
α - Value of fuzziness
et al. - And others
etc. - And the rest
m_i - Medium
n - Number
l_i - Lower limit
ui - Upper limit
CR - Alternative
M_i - Pairwise comparison ratio
S_i - Fuzzy synthesis extent
W - Weight
Y,Z - Column
ac - Alternating current
adt/d - Air-dried tons per day
kV - Kilovolt
AHP - Analytic Hierarchy Process
AP - Area power
CI - Consistency Index
CR - Consistency ratio
DCS - Distributed Control System
ETAP - Power system software
GIS - Gas Isolated Substation
GWh - Giga watt hour
HV - High voltage
Hz - Hertz
IEEE - Institute of Electrical and Electronic Engineers
IMS - Information Management System
L - Load
LP - Load power

LS	-	Load Shedding
LV	-	Low voltage
MCC	-	Motor Control Center
MCDM	-	Multi Criteria Decision Making
MW	-	Megawatt
MVA	-	Megavolt ampere
MVAR	-	Megavolt ampere reactive
NIS	-	Negative Ideal Solution
OP.	-	Operating
OL	-	Operating loads
PIS	-	Positive Ideal Solution
PS	-	Power Supply
RC	-	Relative closeness coefficient
REC	-	Rectifier
RI	-	Random Index
S	-	Apparent power
SCADA	-	Supervisory Control and Data Acquisition
SD	-	System Dynamics
SEM	-	Structural Equation Modeling
TG	-	Turbine Generator
TNB	-	Tenaga Nasional Berhad
TOPSIS	-	Technique for Order Preference by Similarity to Ideal Solution
TP	-	Total Power

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CHAPTER 1

INTRODUCTION

1.1 Project background

Load shedding occurs in places where the total electrical load power demand greatly exceeds the amount of power generated by the local power stations or national network power stations. If the load shedding was not done, the generator's overload breakers would automatically shut down the whole power station to protect its alternators from very severe damage. Such damage would be extremely expensive to repair and would take a lot of time to do it.

In general, load shedding can also be the number of loads that must almost instantly be removed from a power system to keep the remaining portion of the system operational. This load reduction is in response to a system disturbance and consequent possible additional disturbances that result in a generation deficiency condition. Common disturbances that can cause this condition to occur include faults, loss of generation, switching errors, lighting strikes, etc. [1].

In the modern large interconnected power system, there exists the possibility that under the certain condition, the whole system will be suddenly separated into several islands [2]. A sudden loss of generation due to abnormal conditions such as a generator fault or line tripping could disturb the balance between generations and loads resulting in the system frequency decline. The system power deficit could lead dangerously to the low speed of the generating set and might cause failure in turbines' blades [3].

Notifying that several power system blackouts have occurred recently over the world, voltage stability has become a major concern of power system operators.

Voltage stability refers to the ability of a power system to maintain steady voltages at all the buses in the system after being subjected to a disturbance from a given initial condition [4]. System blackout is the state when the system or large areas of it may completely collapse. This state is usually preceded by a sequence of cascading failure events that knock out transmission lines and generating units [5].

Voltage instability, in particular, results from the inability of the combined transmission and generation system to deliver the power requested by loads. It is a dynamic phenomenon largely drove by the load response to voltage changes. Load shedding is well known to be an effective countermeasure against voltage instability, especially when the system undergoes an initial voltage drop that is too pronounced to be corrected by generator voltages [6].

1.2 Problem statement

According to the statistics provided by Suruhanjaya Tenaga [7], the demand of the electric power was increasing year by year from 2005 to 2008. Figure 1.1 shows the total electricity sales of Tenaga Nasional Berhad (TNB) for the year 2005 to 2008. The total electricity sales increased 5.34% from 2005 to 2006, 5.65% from 2006 to 2007 and 3.85% from 2007 to 2008. The sales increased 15.58% within three years of total electricity sales.

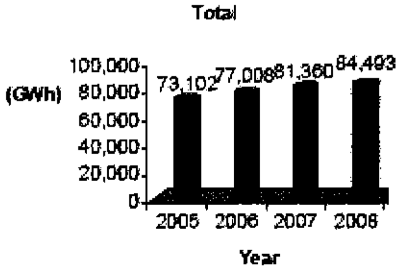

Figure 1.1: The total electricity sales (GWh) of TNB [7]

Figure 1.2 [7] to Figure 1.7 [7] show the electricity sales (GWh) of TNB according to the categories from 2005 to 2008. The sales for the domestic, commercial, industrial, public lighting and agricultural were increasing continuously. The sales increased 18.67% within three years for domestic, 5515 GWh or 25.44% within three years for commercial, 2,957 GWh or 7.97% within three years for industrial, 24.38% from 2005 to 2008 for public lighting and 294.74% for agricultural from 2006 to 2008. On the other hand, only the sales for mining decreased from year 2005 to 2007 but later increased in the year 2008.

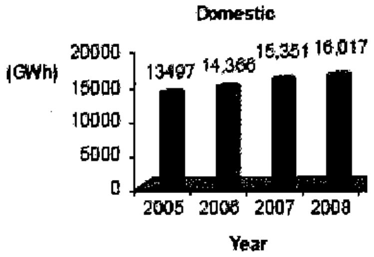

Figure 1.2: The total electricity sales (GWh) of TNB for domestic category [7]

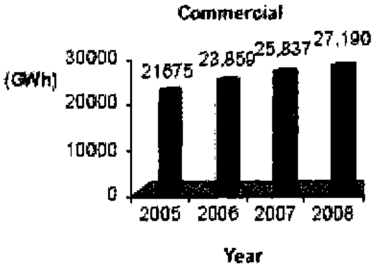

Figure 1.3: The total electricity sales (GWh) of TNB for commercial category [7]

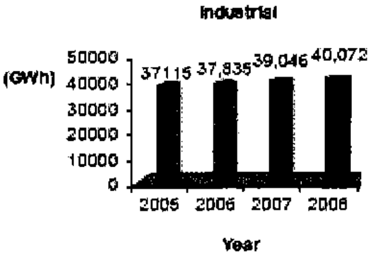

Figure 1.4: The total electricity sales (GWh) of TNB for industrial category [7]

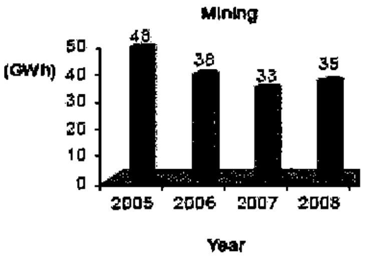

Figure 1.5: The total electricity sales (GWh) of TNB for mining category [7]

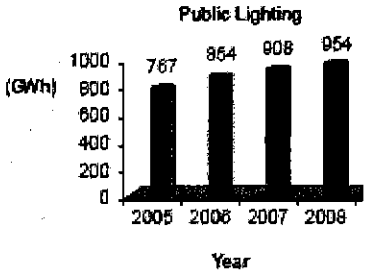

Figure 1.6: The total electricity sales (GWh) of TNB for public lighting category [7]

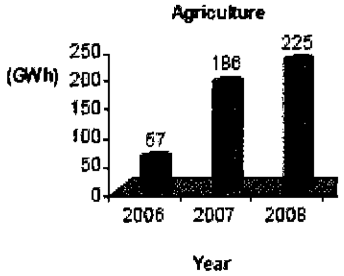

Figure 1.7: The total electricity sales (GWh) of TNB for agriculture category [7]

Figure 1.8 [7] shows the number of transmission system tripping in Peninsular Malaysia with a load loss of 50 MW and above for 2006 to 2008. There were six incidents of tripping without load shedding and one incident with load shedding in 2006, where as nine incidents of tripping without load shedding and one incident with load shedding in 2007. In 2008, six incidents of tripping without load shedding and no incident with load shedding. Therefore, load shedding is important in reducing the incidence of tripping.

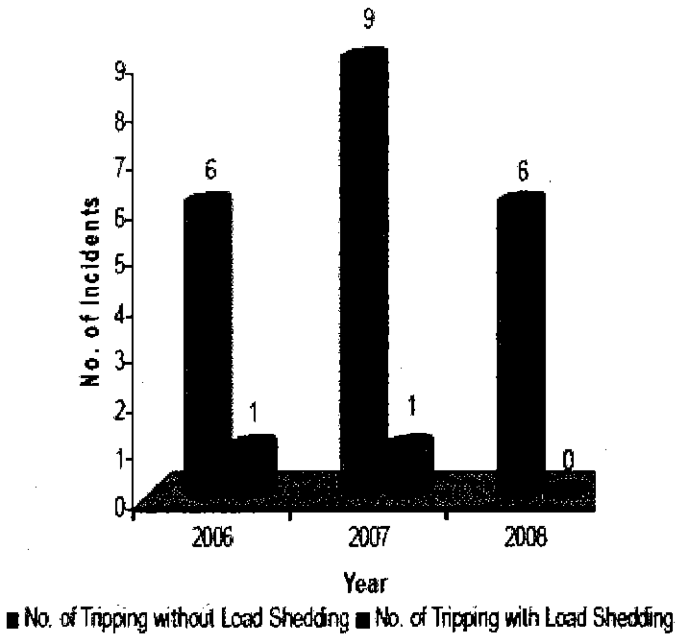

Figure 1.8: The number of transmission system tripping in Peninsular Malaysia with a load loss of 50 MW and above [7]

There are various causes of the electricity supply interruptions such as natural disasters, equipment failures, overload, damaged by third parties, maintenance works, unknown, trees and others. If the interruptions occurred, the electricity Supply Company should take actions to maintain the distribution of the electricity supply of the unaffected area. The company should reduce the interruptions as minimum as possible.

As consumers, people are desired to have continuously distributed electricity supplies without any interruption. For example, the industry will lose a lot of income if there are shortages in the electricity supplies. This thesis will present a system with load shedding scheme for islanded power systems to overcome the problem during electricity interruptions.

This thesis will present a system with load shedding scheme for islanded power system to overcome the problem during electricity interruptions.

1.3 Project objectives

There are three objectives for this project:

(i) To justify a load shedding scheme for the power system.

(ii) To implement multi-criteria decision-making methods such as AHP, fuzzy AHP and TOPSIS in the load shedding scheme.

(iii) To compare the effectiveness of multi-criteria decision making methods in load shedding scheme.

1.4 Project scope

The purpose of this thesis is to identify the load shedding scheme in an islanded power system. A systematic approach is developed to identify the priority based on the impact of the power system state. Therefore, this thesis will focus on the analysis of power system outages.

The criteria for the determination of "worst case" will be the total load shedding in the post-fault system. The contingencies will cover all possible scenarios, including those which will lead to the islanding of the power system.

1.5 Contribution and claims of originality

The research has proposed and developed a systematic approach by identifying the power system dynamic vulnerability under extreme conditions, for example, with the loss of two or more power supplies. The proposed methods have the following unique features:

(a) New method

The Analytical Hierarchy Process (AHP), Fuzzy Analytical Hierarchy Process (Fuzzy AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) under the Multi-Criteria Decision Making (MCDM) methods are the newly methods that have been used in the load shedding scheme for an islanded power system.

(b) Simplified

The methods that have been applied (AHP, Fuzzy AHP and TOPSIS) are simpler in concept as the load shedding decision is determined based on the information such as criteria and alternatives.

(c) Easy

The methods proposed are easily been applied to the load shedding scheme. The calculation from the analysis is quite simple with a few steps only.

1.6 Related research for load shedding

Table 1.1 shows the previous research about the load shedding. Shokooh *et al.* [1] studies about an intelligent load shedding system application in a large industrial facility. They noticed that the conventional methods of system load shedding are too slow and do not effectively calculate the correct amount of load to be shed. An intelligent load shedding scheme is proposed and comparison is done between intelligent load shedding and conventional load shedding methods.

The disadvantages of Under Frequency Load Shedding (UFLS) with a specific example are illustrated and the factors affecting the frequency dynamics are explained by Shi *et al.* [2]. The concept of Wide Area Measurement System (WAMS)-based load shedding is proposed, and preliminary work on that area is described. Dadashzadeh & Sanaye-Pasand [3] do the simulation and investigation of load shedding algorithms for a real network using dynamic modeling. Several conventional and dynamic load shedding scheme are examined and compared by Dadashzadeh & Sanaye-Pasand.

Amraee *et al.* [4] proposed an improved model for optimal under voltage load shedding. The approach proposed is based in the concept of the static voltage stability margin and its sensitivity value at the maximum loading point or the collapse point. Dola & Chowdhury proposed intentional islanding and adaptive load shedding to avoid cascading outages. The line outages that lead to disastrous consequences are determined, while the intentional islanding scheme and load shedding schemes have been explored.

Cutsem & Vournas [6] provides an overview of emergency voltage stability controls in power systems. Voltage instability mechanisms, countermeasures and system protection schemes are discussed as well as various aspects of emergency controls, including generator voltage control, tap changer modified control and load shedding.

Table 1.1: Summarised information for research projects related to load shedding

Author(s)	Year	Field
Shokooh *et al.*	2005	Intelligent load shedding system application
Shi *et al.*	2005	WAMS-based load shedding
Dadashzadeh & Sanaye-Pasand	2004	Load shedding algorithms for a real network
Amraee *et al.*	2006	Optimal under voltage load shedding
Dola & Chowdhury	2006	Adaptive load shedding
Cutsem & Vournas	2007	Emergency voltage stability controls

1.7 Thesis outline

Chapter 1 highlights about the background of load shedding with problems in the electrical power system. The objectives of this thesis are stated in this chapter. Chapter 2 is the literature review of this project. This chapter will give details about the theory of the application in load shedding problems in the electrical power system. Some previous researches are shown in this chapter.

Chapter 3 discusses about the project procedure and also approach used to implement the project is explained. Chapter 4 shows the results, data analysis and discussion. The load shedding in the electrical power system by using the Analytic Hierarchy Process (AHP), Fuzzy AHP and TOPSIS is discussed in this chapter.

Chapter 5 presents the project conclusions and recommendations. This chapter will discuss about the conclusions of the project and also some future recommendations.

1.8 Summary

This chapter of this thesis discusses about the introduction for the whole project. Firstly, the concept of the load shedding is introduced in the first part. Next, the problem statement is discussed. Then, the next part is about the objectives and scopes of the project. Lastly, the thesis outline is discussed which will give an overview for the reader about the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Load shedding

Load shedding is the term used to describe the deliberate switching off of electrical supply to parts of the electricity network, and hence to the customers. This practice is rare, but is a core part of the emergency management of all electricity networks.

Load shed may cause the loss of some information, but it is possible to keep the other equipments or devices which are more important to operate [8]. Then, the system will operate as normal once the system has been restored.

Load shedding can be required when there is an imbalance between electricity demand (customers' usage) and electricity supply (the ability of the electricity network to generate and transport the required amount of electricity).

2.2 Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is a method for ranking decision alternatives and selecting the best one when the decision maker has multiple criteria. It answers the question, "Which one?". With AHP, the decision maker selects the alternative that best meets his or her decision criteria and develops a numerical score to rank each alternative decision based on how well each alternative meets them [9].

In AHP, preferences between alternatives are determined by making pairwise comparisons. In a pairwise comparison, the decision maker examines two alternatives by considering one criterion and indicates a preference. These comparisons are made using a preference scale, which assigns numerical values to different levels of preference. The standard preferred scale used for the AHP is 1-9 scale which lies between "equal importances" to "extreme importance" where sometimes different evaluation scales can be used such as 1 to 5 [9].

In the pairwise comparison matrix, the value 9 indicates that one factor is extremely more important than the other, and the value 1/9 indicates that one factor is extremely less important than the other, and the value 1 indicates equal importance. Therefore, if the importance of one factor with respect to the second factor is given, then the importance of the second factor with respect to the first is the reciprocal. The ratio scale and the use of verbal comparisons are used for weighting of quantifiable and non-quantifiable elements [9].

Since 1977, Saaty [10] proposed AHP as a decision aid to solve unstructured problems in economics, social and management sciences. AHP has been applied in a variety of contexts: from the simple everyday problem of selecting a school to the complex problems of designing alternative future outcomes of a developing country, evaluating political candidacy, allocating energy resources, and so on. The AHP enables the decision-makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under multiple criteria environment in the conflation [9].

The application of the AHP to the complex problem usually involves four major steps [9].

(a) Break down the complex problem into a number of small constituent elements and then structure the elements in a hierarchical form.

(b) Make a series of pairwise comparisons between the elements according to a ratio scale.

(c) Use the eigenvalue method to estimate the relative weights of the elements.

(d) Aggregate the relative weights and synthesis them for the final measurement of given decision alternatives [9].

The AHP is a powerful and flexible multi-criteria decision-making tool for dealing with complex problems where both qualitative and quantitative aspects need to be considered. The AHP helps analysts to organise the critical aspects of a problem into a hierarchy rather like a family tree [9].

The essence of the process is decomposition of a complex problem into a hierarchy with a goal at the top of the hierarchy, criteria and sub-criteria at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy [9]. Figure 2.1 illustrates the scheme of the Analytic Hierarchy Process (AHP).

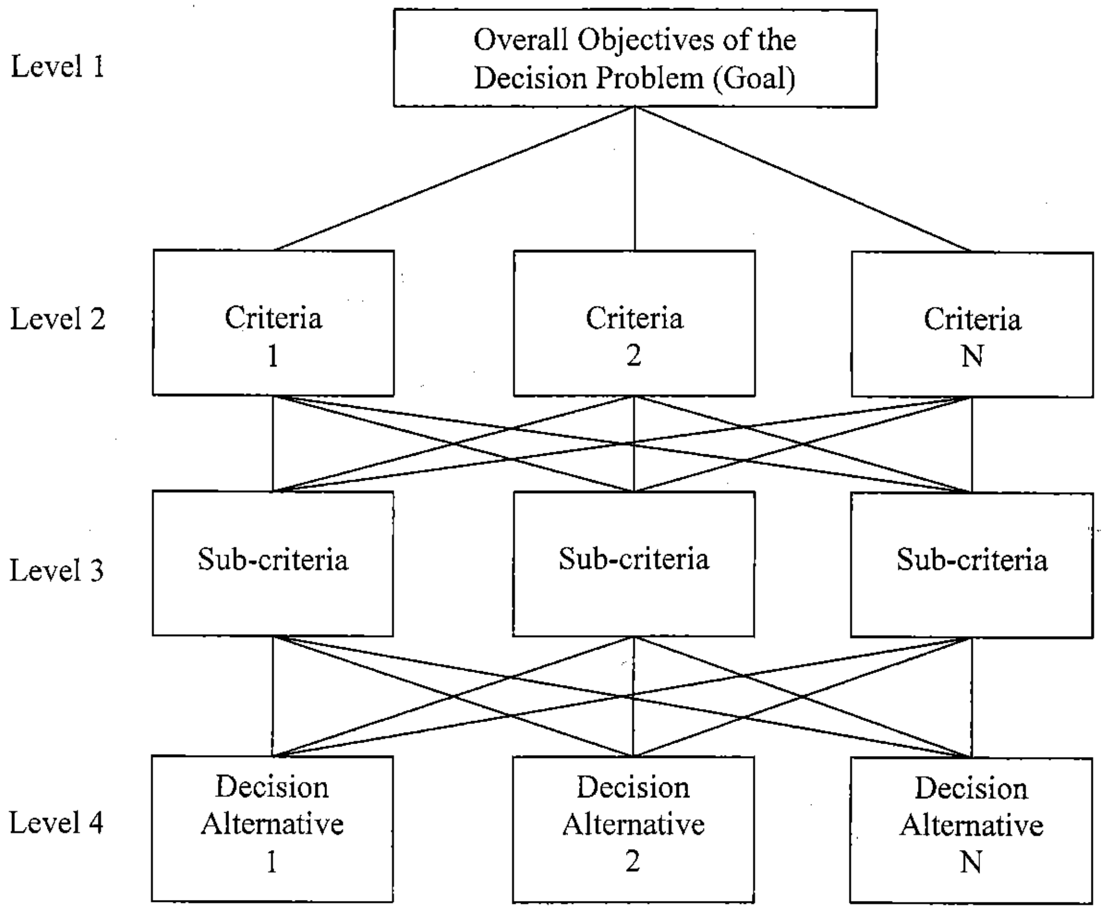

Figure 2.1: The Analytic Hierarchy Process (AHP) scheme [11]

Elements at the given hierarchy levels are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level. The method computes and aggregates their eigenvectors until the composite final vector of weight coefficients for alternatives are obtained. The entries of the final weight coefficient vector reflect the relative importance (value) of each alternative with respect to the goal stated at the top of the hierarchy [9].

A decision maker may use this vector according to his particular needs and interests. To elicit pairwise comparisons performed at a given level, a matrix A is created in turn by putting the result of pairwise comparisons of element i with element j into the position a_{ji} as given in Equation (2.1) [9].

$$A = \begin{array}{c|cccccccc|}
 & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & . & C_n \\
\hline
C_1 & 1 & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} & . & a_{1n} \\
C_2 & a_{21} & 1 & a_{23} & a_{24} & a_{25} & a_{26} & . & a_{2n} \\
C_3 & a_{31} & a_{32} & 1 & a_{34} & a_{35} & a_{36} & . & a_{3n} \\
C_4 & a_{41} & a_{42} & a_{43} & 1 & a_{45} & a_{46} & . & a_{4n} \\
C_5 & a_{51} & a_{52} & a_{53} & a_{54} & 1 & a_{56} & . & a_{5n} \\
C_6 & a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & 1 & . & a_{6n} \\
. & . & . & . & . & . & . & 1 & . \\
C_n & a_{n1} & a_{n2} & a_{n3} & a_{n4} & a_{n5} & a_{n6} & . & 1 \\
\hline
\end{array} . \tag{2.1}$$

where

n = criteria number to be evaluated

C_i = i^{th} criteria, $(i=1,2,3,\ldots..,n)$

A_{ij} = importance of i^{th} criteria according to j^{th} criteria $(j=1,2,3,\ldots..,n)$ [9]

After obtaining the weight vector, it is then multiplied by the weight coefficient of the element at a higher level (that was used as the criterion for pairwise comparisons). The procedure is repeated upward for each level, until the top of the hierarchy is reached.

The overall weight coefficient, with respect to the goal for each decision alternative is then obtained. The alternative with the highest weight coefficient value should be taken as the best alternative. The Analytical Hierarchy Process is a well known decision-making analytical tool used for modeling unstructured problems in various areas, e.g., social, economic, and management sciences [9].

Table 2.1 shows the fundamental scale of values to represent the intensities of judgments. There are several intensities of importance. Each of the intensities of the importance is attached with the definition and explanation. Table 2.1 can be used as the reference when proceed to do the AHP analysis [12].

Table 2.1: The fundamental scale of absolute numbers [12]

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favour one activity over another
6	Strong plus	
7	Very strong	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption

A number of research projects on the application and using of analytical hierarchy process (AHP) approach have been found in the last decade ago. Lin *et al.* [13] applied the analytical hierarchy process in power lines maintenance. The main issue of this paper is to arrange for the power lines maintenance scientific and logical in the power department. Power lines maintenance is a complex process with many influencing factors, which cover the knowledge of kinds of subjects, such as management, security, scheming and so on.

Dougligeris & Pereira [14] applied the analytical hierarchy process in a telecommunications quality study to solve the specific problem that the customer faced in choosing a telecommunication company that best specifies the consumers' needs. The evolution of technology has enabled the simultaneous cost reduction and quality improvement in the services offered. Customers have the opportunities to determine and purchase the quality of communication services that they need, by balancing their cost and value.

Kang & Seong [15] proposed a procedure for evaluating alarm-processing system regard to integrating a series of deviations in a nuclear power plant control room. Yang *et al.* [16] applied the analytic hierarchy process in location selection for a company. The location decision often depends on the type of business. For industrial location decision, the strategy is minimising the costs while for service organization, the strategy focuses on maximising revenue.

Frair, Matson & Matson [17] proposed an undergraduate curriculum evaluation with the analytic hierarchy process. A model of the problem for undergraduate curriculum designed is developed based on the responses from the affected parties (students, faculties, employers, *etc.*), curriculum components (design, science, math, *etc.*) and curriculum alternatives.

According to the above literature, it is found that the application of the analytical hierarchy process is widely used. It can be applied to power system [13], telecommunication [14], electrical and electronic [15], business [16], education [17], and so on. Table 2.2 shows the summarised information for the research projects related to the AHP.

Table 2.2: Summarised information for research projects related to AHP

Author(s)	Year	Field
Lin *et al*	2006	Power lines maintenance
Dougligeris & Pereira	1994	Telecommunications quality study
Kang & Seong	1999	Alarm-processing system
Yang *et al.*	2008	Location selection
Frair, Matson & Matson	1998	Undergraduate curriculum evaluation

2.3 Fuzzy Analytical Hierarchy Process

There is an extensive literature that addresses the situation where the comparison ratios are imprecise judgments. In most of the real-world problems, some of the decision data can be precisely assessed while others cannot. Humans are unsuccessful in making quantitative predictions, whereas they are comparatively efficient in qualitative forecasting [9].

Essentially, the uncertainty in the preference judgments gives rise to uncertainty in the ranking of alternatives as well as difficulty in determining consistency of preferences. These applications are performed with many different perspectives and proposed methods for fuzzy Analytical Hierarchy Process (fuzzy AHP). In this study, Chang's [18] extent analysis on fuzzy AHP is formulated for a selection problem.

The fuzzy AHP technique can be viewed as an advanced analytical method developed from the traditional AHP. Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision making problems based on decision maker's judgments, fuzziness and vagueness existing in many decision-making problems may contribute to the imprecise judgments of decision makers in conventional AHP approaches [9].

Many researchers who have studied the fuzzy AHP which is the extension of the Saaty's theory, have provided evidence that fuzzy AHP shows relatively more sufficient description of these kind of decision making processes compared to the traditional AHP methods.

Pan [19] applied the fuzzy AHP approach for selecting the suitable bridge construction method. Lo & Wen [20] proposed a fuzzy-AHP-based technique for the decision of design feature selection in Massively Multiplayer Online Role-Playing Game (MMORPG) development. Li & Huang [21] applied fuzzy AHP to develop innovative designs for automated manufacturing systems. Dagderiren & Yuksel [22] developed fuzzy AHP model behaviour-based safety management. Chamodrakas *et al.* [23] integrated fuzzy AHP for selecting an electronic marketplaces' supplier. Gumus applied fuzzy AHP for evaluation of hazardous waste transportation firms. Cakir & Canbolat [25] designed a decision support system assisting a sensible multi-criteria inventory classification. Table 2.3 shows the summarised information for the research projects related to the fuzzy AHP.

Table 2.3: Summarised information for research projects related to fuzzy AHP

Author(s)	Year	Field
Zhu, Jing & Chang	1999	Basic theory of fuzzy AHP
Pan	2008	Bridge construction method
Lo & Wen	2010	Multiplayer online role-playing game development
Li & Huang	2009	Automated manufacturing system
Dagderiren & Yuksel	2008	Behavior-based safety management
Chamodrakas *et. al*	2010	Electronic marketplace
Gumus	2009	Hazardous waste transportation firm
Cakir & Canbolat	2008	Web-based decision support system

In complex systems, the experiences and judgments of humans are represented by linguistic and vague patterns. Therefore, a much better representation of this linguistic can be developed as quantitative data. This type of data set is then refined by the evaluation methods of fuzzy set theory. On the other hand, the AHP method is mainly used in nearly crisp (non-fuzzy) decision applications and creates and deals with a very unbalanced scale of judgment [9].

Therefore, the AHP method does not take into account the uncertainty associated with the mapping. The AHP's subjective judgment, selection and preference of decision-makers have great influence on the success of the method. The conventional AHP still cannot reflect the human thinking style. Avoiding these risks on performance, the fuzzy AHP, a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems [9].

Chang's extent analysis on fuzzy AHP depends on the degree of possibilities of each criterion. According to the responses on the question form, the corresponding triangular fuzzy values of the linguistic variables are placed and for a particular level of the hierarchy the pairwise comparison matrix is constructed.

Subtotals are calculated for each row of the matrix and new (l, m, u) set is obtained, then in order to find the overall triangular fuzzy values for each criterion, $Li/\Sigma l_i$, $my/\Sigma m_i$, $ui/\Sigma u_i$, $(i=1, 2,\dots, n)$ values are found and used as the latest $M_i(l_i, m_i, u_i)$ set for criterion M_i in the rest of the process. In the next step, membership functions are constructed for each criterion and intersections are determined by comparing each couple [9].

In fuzzy logic approach, for each comparison the intersection point is found, and then the membership values of the points correspond to the weight of that point. This membership value can also be defined as the degree of possibility of the value. For a particular criterion, the minimum degree of possibility of the situations, where the value is greater than the others, is also the weight of this criterion before normalisation. After obtaining the weights for each criterion, they are normalised and called the final importance degrees or weights for the hierarchy level [9].

2.4 Technique for Order Preference by Similarity to Ideal Solution

TOPSIS is known as the "Technique for Order Preference by Similarity to Ideal Solution". This method is a unique technique to identify the ranking of all alternatives considered. In the TOPSIS method, the decision making matrix and weight vector are determined as crisp values and a positive ideal solution (PIS) and a negative ideal solution (NIS) are obtained from the decision matrix [26].

In other words, PIS is a set of the best value of criteria while NIS is a set of worst values achievable of criteria. This method is applied to make wide-ranging evaluation of samples where it measured the distances between the index value vector of each sample and ideal solution along with the negative ideal solution of the comprehensive evaluation [27].

Hwang and Yon [28] are the first who introduces the TOPSIS method. Hwang and Yon describe multiple decisions making as follows: multiple decisions making is applied to the preferable decision (such as assessment making priorities and choices) between available classified alternatives over the multiple attributes or criteria. It assumes that each criterion requires to be maximised or minimised. Therefore, the ideal positive and negative values of each criterion are identified, and each alternative judge against this information.

It is noted that, in this typical multiple criterion decision making (MCDM) approach, weights of attributes reflect the relative importance in the decision making process. Each evaluation of criteria entails diverse opinions and meanings. Hence, the assumption that each evaluation criterion is equally important is prohibited [29].

TOPSIS method consists of two artificial alternatives hypothesis, which are 'Ideal Alternative' and 'Negative Ideal Alternative'. 'Ideal Alternative' represents the best level of all attributes considered while the 'Negative Ideal Alternative' represented the worst attributes values. With these two hypotheses, sets of calculations using eigenvector, square rooting and summations to obtain a relative closeness value of the criteria tested. These values of relative closeness, TOPSIS ranked the whole system by selecting the highest value of the relative closeness as the best attributes in the system.

Krohling & Campanharo [30] did a case study of accidents with oil spill in the sea by using TOPSIS approach. Wang *et al.* [31] applied TOPSIS to supplier selection. Sun & Lin [32] used TOPSIS for evaluating the competitive advantages of shopping websites. Wang & Chang [33] developed an approach in evaluating initial training aircraft under a fuzzy environment for the Taiwan Air Force Academy. Chamodrakas & Martakos [34] applied TOPSIS method for energy efficient network selection in heterogeneous wireless networks. Table 2.4 shows the summarised information for the research projects related to the TOPSIS.

Table 2.4: Summarised information for research projects related to TOPSIS

Author(s)	Year	Field
Krohling & Campanharo	2011	Accidents with oil spill in the sea
Wang *et al.*	2009	Supplier selection
Sun & Lin	2009	Competitive advantages of shopping online
Wang & Chang	2007	Initial aircraft training
Chamodrakas & Martakos	2011	Heterogenerous network selection

2.5 Pulp mill electrical system general information [35]

The mill electrical voltage levels are divided into several categories such as:

(i) 3-phase, 50Hz voltage level is divided to:
High voltage : 110kVac
Medium voltage : 35kVac and 6kVac
Low voltage : 690Vac and 400Vac

(ii) 3×Turbine generator: 2×120MW+90MW=330MW connected to the public grid with 80MVA transformer but limited import to 60MVA due to shortage power in the grid.

Total load installed in a mill wide is about 249MW (including the redundant units). The estimated highest operating load capacity is about 158MW and normal operating load is 130MW at 3,000 air-dried tons per day (adt/d) of production capacity.

The electrical load shedding coverage is focused on 35kV incoming feeders to each plant which excludes 35kV feeder to boiler and water treatment plant and 6kV motor feeders in each mill and arranged the priority table with manual and automatic options (excluded 690Vac incoming feeder due to huge cost additional). Notes: 6kV include in the load shedding system only for monitoring and the 6kV Smart Motor Control Center (MCC) is a conventional type. This is the purpose to gather the most information.

In order to design the pulp mill's electrical load shedding Supervisory Control and Data Acquisition (SCADA) system, the person in charge must have basic knowledge and process concept of a pulp mill and is required to work closely with process department. In addition, he/she must be capable to plan for an integrated system to fulfil the plant process and electrical distribution stability needs, and possesses the knowledge of the behaviour of a Steam Turbo Generator (TG) or electrical system and mill wide control system.

For example, the Load Shedding System should consist of a pulp storage tank with level indication. This is to decide when part of the mill should start the load shedding as it depends on the load and priority if TG trips, boiler trips or if some fault disturbing the stability of system frequency. Besides, the TG Frequency vs. Voltage and load characteristic curve should also be studied.

The purpose of electrical load shedding SCADA system is to provide mill wide load shedding to stabilize the power distribution system during any abnormal circumstances, collect information for maintenance, diagnostic and historical purposes, ON-OFF control for the switcher, metering purposes and etc.

This is an important part of mill wide electrical system because the technology, which combines the electrical system, communication system with fully digitalised information of protection relay is for maintenance convenience. This electrical load shedding SCADA system is different from the Mill wide Distributed Control System (DCS).

They are totally separated systems but share the same information on some processed data, creating a database to the DCS Information Management System (IMS) system. The systems are separated in order to segregate the control territories so that the electrical SCADA system will not affect the mill process operation. Two operation modes of load shedding are:

(i) Island mode (disconnect to the public grid)

(ii) Parallel mode (connects to the public grid)

2.5.1 Island mode [35]

The load shedding on island mode with 2 circumstances is designed:

(a) 110kV bus bar frequency, as the frequency is directly related to a turbine generator turning speed. If the frequency drops, the turbine is overloaded and the steam will be insufficient or internal fault occurred and causes frequency dip.

(b) Tripping of the turbine generators, the electrical system will immediately lose electricity not less than 40MW (During this condition, the other turbine running the generator is not able to cover the load in a short duration but will manage to take 10~15MW and another 20MW from the public grid). At such condition, the load shedder cannot depend on the busbar frequency due to slow responses but can depend on the setting made in the column of the TG trip. All settings will be done by the process engineer according to the mill production conditions or the automotive cyclic calculation and trip loads as per TG's power loses. This concept is convenient for the engineers during emergency cases.

2.5.2 Parallel mode [35]

The overall function of load shedding is similar to the island mode but the only deviation is that the frequency-based load shedding function will be deactivated (the reason is the public grid system is too huge compared to the electrical mill system which is only 330MW. Therefore, any disturbance from the external system will affect the mill system tremendously. So the decoupling protection relay setting at Gas Insulated Substation (GIS) – 140-ES is the critical point that protects the mill system from external factors.)

For example, if the feeder connected to the public grid senses huge outflow of current from the plant, the protection relay of the feeder will isolate the system within 15 minutes.

This is to avoid the mill wide electrical system from interruption due to heavy external fault occurred in public overhead transmission line. The load shedding will be activated and the load will be isolated according to the supply lost from the public grid.

Most cases that caused the load shedding function to activate were due to the tripping of recovery boilers. Recovery boiler is the main steam generator to produce about 60% of the electricity. If the recovery boiler trips, the steam will reduce rapidly.

The operators need to act fast to start the load shedding function manually (as it has not tripped the turbine generator yet) in order to keep the turbine generator to continue running.

Initially, the operation of the mill was unable to be saved due to lack of knowledge and experience of the load factor. However, after training is provided, the operator in charge can act wisely and promptly.

Normally within 10 minutes, the operator is able to manage and communicate with each plant to do the load shed selection manually to prevent the TG frequency to drop to 48Hz and to trip the generator by the turbine generator protection system. This helps to ease the pressure of production loss.

2.6 Calculation tool

Microsoft Excel has the basic features of all spreadsheets that using a grid of cells arranged in numbered rows and letter-named columns to organise data manipulations like arithmetic operations such as plus, minus, times and divide. It has a battery of supplied functions to answer statistical, engineering and financial needs. In addition, it can display data as line graphs, histograms and charts, and with a very limited three-dimensional graphical display.

In this thesis, all the calculations are performed by using the Microsoft Excel. The results of the analysis are presented either in histogram or pie chart.

2.7 Summary

This chapter has discussed about the literature reviews for this project. The purposes and conditions for the undergo load shedding process is discussed. Then, the classical AHP and fuzzy AHP are discussed. A few previous researches are mentioned for AHP and fuzzy AHP. Lastly, the TOPSIS is discussed.

CHAPTER 3

METHODOLOGY

3.1 Analytical Hierarchy Process procedure

Analytical hierarchy process (AHP), created by Professor Saaty in Pittsburgh University in the United State, is a decision analysis method that brings quantitative and qualitative analysis together. It is a simple and convenient decision-making method that can provide an approach to the complex decision-making problems with multiple targets, multiple criteria and no architectural characteristic.

AHP is a decision-making process in which a problem is first broken down into a hierarchy of interrelated decision elements and then uses the pairwise comparison that determined by the user to give the order in which factors affect a decision, consistency of the respondent, and a prioritized list of the decisions to be made. The process of AHP analysis is as shown below.

(a) Develop the weights for the criteria

$$A_C = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \end{array}, i = 1,2,\ldots,n;\ j = 1,2,\ldots,n \qquad (3.1)$$

where

$C_1, C_2, \ldots, C_n$ are the criteria,

a_{ij} represents the rating of C_i with respect to C_j

Table 3.1 shows the data used in the AHP analysis. The total operating load for five areas is 99.5MW. The total area power for five areas is 158.93MW. The first step in the AHP is to develop the weights for the criteria. A single pairwise comparison matrix of the criteria is developed. The ratio of the total operational load to the total of area power and vice versa had been obtained as shown in Table 3.2.

Table 3.1: The data used in AHP for the pulp mill system

No	Area	OP. Load (MW)	Area Power (MW)
1	ClO_2 REC	27.4	28.83
2	NaOH REC	21.5	22.63
3	RB	12.6	30.5
4	PDM	17.4	26.57
5	FL	20.6	50.4
	Total	99.5	158.93

Table 3.2: The pairwise comparison table of criteria for the pulp mill system by using AHP

Criteria	OP. Load	Area Power
OP. Load	1	0.626
Area Power	1.597	1

The ratio of the total operating load of total operating load is 1. The ratio of the total operational load to total area power is (99.5 ÷ 158.93) = 0.626. The ratio of total area power to the total operating load is (158.93 ÷ 99.5) = 1.597. The ratio of total area power to total area power is 1.

There are two criteria needed to be considered in order to achieve the goal. Thus, the number of roots, $n = 2$. The root of the product for each criterion can be obtained by using Equation (3.2). The result of the root of the product is shown in Table 3.3. The second root of the product for OP. is 0.791 while the second root of the product in the Area Power is 1.264. The total second root of product is 2.055.

$$n^{th}\ root\ of\ product = \sqrt[n]{product\ of\ each\ row} \tag{3.2}$$

where

n = positive integer number.

Table 3.3: The root of the product of criteria for the pulp mill system by using AHP

Criteria	2^{nd} Root of the Product
OP. Load	0.791
Area Power	1.264
Total	2.055

The weights among the criteria are shown as in Equation (3.3). The weight for operating load is (0.791 ÷ 2.055) = 0.385 while the weight for area power is (1.264 ÷ 2.055) = 0.615.

$$weight = \frac{n^{th}\ root\ of\ product}{\sum(n^{th}\ root\ of\ product)} \tag{3.3}$$

$$W_C = \begin{bmatrix} \text{Weight for operating load} \\ \text{Weight for area power} \end{bmatrix}$$

$$W_C = \begin{bmatrix} 0.385 \\ 0.615 \end{bmatrix}$$

(b) Develop the weights for the alternatives

The second step in AHP is to develop the rating for each of the alternatives in operating load. The pairwise comparison of alternative operating load is shown as in Table 3.4. The ratio of ClO_2 REC to ClO_2 REC is (27.4 ÷ 27.4) = 1. The ratio of ClO_2 REC to NaOH REC is (27.4 ÷ 21.5) = 1.274. The ratio of ClO_2 REC to RB is (27.4 ÷ 12.6) = 2.175. The ratio of ClO_2 REC to PDM is (27.4 ÷ 17.4) = 1.575. The ratio of ClO_2 REC to FL is (27.4 ÷ 20.6) = 1.330.

There are totally 5 alternatives under the operating load section. So, the number of roots, $n = 5$. The 5th root of the product is 1.3427 for ClO_2 REC, 1.1059 for NaOH REC, 0.7212 for RB, 0.9337 for PDM and 1.0687 for FL. The total 5th root of product is 5.1723. Therefore, the weights of alternatives in operating load are as shown in Table 3.4.

REFERENCES

1. Shokooh, F., Dai, J. J., Shokooh, S., Tastet, J., Castro, H., Khandelwal, T. & Donner, G.. An Intelligent Load Shedding (ILS) System Application in a Large Industrial Facility. *Industry Applications Conf, 2005. Fourtieth IAS Annual Meeting Conf. Record of the 2005, 1.* 2005. pp. 417 - 425.
2. Shi, B., Xie, X. & Han, Y.. WAMS-based Load Shedding for Systems Suffering Power Deficit. *Transmission & Distribution Conf. & Exhibition: Asia & Pacific 2005.* 2005. pp. 1 - 6.
3. Dadashzadeh, M. R. & Sanaye-Pasand, M.. Simulation and Investigation of Load Shedding Algorithms for a Real Network using Dynamic Modeling. *39th International Universities Power Eng. Conf. 2004, 3.* 2004. pp. 1111 - 1115.
4. Amraee, T., Mozafari, B. & Ranjbar A.M.. An Improved Model for Optimal Under Voltage Load Shedding: Particle Swarm Approach. *2006 Power India Conf.* 2006.
5. Dola, H. M. & Chowdhury, B. H.. Intentional Islanding and Adaptive Load Shedding to Avoid Cascading Outages. *2006 Power Eng. Society General Meeting.* 2006. pp. 1 - 8.
6. Cutsem, T. V. & Vournas, C. D.. Emergency Voltage Stability Controls: an Overview. *IEEE 2007 Power Eng. Society General Meeting.* 2007. pp. 1 - 10.
7. Suruhanjaya Tenaga. (2009). Interim Report on the Performance of the Electricity Supply in Malaysia for the First Half Year of 2009. Retrieved on March 26, 2010, from http://www.st.gov.my/phocadownload/statistics_of_interim_on_the_performance_of_the_electricity_supply_in_malaysia_2009.pdf

8. CitiPower & Powercor Australia (2010). Load Shedding. Retrieved on March 26, 2010, from http://www.powercor.com.au/docs/pdf/Customer%20Information/Fact%20Sheet%20-%20Load%20Shedding.pdf

9. Ozdagoglu, A. & Ozdagoglu, G. (2007). Comparison of AHP and Fuzzy AHP for the MMulti-criteria Decision Making Process with Linguistic Evaluations. Retrieved on March 26, 2010 from http://www.iticu.edu.tr/Kutuphane/dergi/f11/M00178.pdf

10. Saaty, T. L.. *The Analytical Hierarchy Process.* Mc Graw Hill, New York. 1980.

11. Goh, H. H. & Kok, B. C.. Application of Analytic Hierarchy Process (AHP) in Load Shedding Scheme for Electrical Power System. *2010 9th International Conference on Environment and Electrical Engineering (EEEIC).* 2010. pp. 365 - 368.

12. Saaty, T. L. & Vargas, L. G.. *Decision Making with the Analytic Network Process.* Springer, Pittsburgh. 2006.

13. Lin, Z., Gao, L., Zhang, D., Ren, P. & Li, Y.. Application of Analytical Hierarchy Process in Power Lines Maintenance. *Proceedings of the 6th World Congress of Intelligent Control and Automation, 2.* 2006. pp. 7596 - 7599.

14. Douligeris, D. & Pereira, I. J.. A Telecommunications Quality Study using the Analytic Hierarchy Process. *IEEE Journal of Selected Areas in Communications, 12.* 1994. pp. 241 - 250.

15. Kang, H. G. & Seong, P. H.. A Methodology for Evaluating Alarm-Processing Systems using Informational Entropy-based Measure and the Analytic Hierarchy Process. *IEEE Journal of Nuclear Science, 46.* 1999. pp. 2269 - 2280.

16. Yang, C. L., Chuang, S. P., Huang, R. H. & Tai, C. C.. Location Selection Based on AHP/ANP Approach. *Industrial Eng. & Eng. Management 2008 IEEM.* 2008. pp. 1148 - 1153.

17. Frair, L., Matson, J. O. & Matson, J. E.. An Undergraduate Curriculum Evaluation with the Analytic Hierarchy Process. *28th annual Forntiers in Education Conf. 1998, 3.* 1998. pp. 992 - 997.

18. Zhu K. J., Jing Y., & Chang, D. Y.. A Discussion on Extent Analysis method and Applications of Fuzzy AHP. *European Journal of Operational Research, 116*. 1999. pp. 450 – 456.

19. Pan, N. F.. Fuzzy AHP Approach for Selecting the Suitable Bridge Construction Method. *European Journal of Operational Research, 176(3)*. 2008. pp. 1795 – 1810.

20. Lo, Y. F. & Wen, M. H.. A Fuzzy-AHP Based Technique for the Decision of Design Feature Selection in Massively Multiplayer Online Role-playing Game Development. *Expert Systems with Applications, 37(12)*. 2010. pp. 8685 – 8693.

21. Li, T. S. & Huang, H. H.. Applying TRIZ and Fuzzy AHP to Develop Innovative Design for Automated Manufacturing System. *Expert Systems with Applications, 36(4)*. 2009. pp. 8302 – 8312.

22. Dagdeviren, M. & Yuksel, I.. Developing a Fuzzy Analytic Hierarchy Process Model for Behavior-based Safety Management. *Information Scinces, 178(6)*. 2008. pp. 1717 – 1733.

23. Chamodrakas, I., Bats, D. & Martakos, D.. Supplier Selection in Electronic Marketplaces using Satisficing & Fuzzy AHP. *Expert Systems with Applications, 37(1)*. 2010. pp. 490 – 498.

24. Gumus, A. T.. Evaluation of Hazardous Waste Transportation Firms by using a Two Step Fuzzy AHP and TOPSIS Methodology. *Expert Systems with Applications, 36(2)*. 2009. pp. 4067 – 4074.

25. Cakir, O. & Canbolat, M. S.. A Web-based Decision Support System for Multi-criteria Inventory Classification using Fuzzy AHP Methodology. *Expert Systems with Applications, 35(3)*. 2008. pp. 1367 – 1378.

26. Dashti, Z., Pedram, M. M. & Shanbehzadeh, J.. A Multi-criteria Decision Making Based Method for Ranking Sequential Patterns. *International Multi Conference of Engineers and Computer Scientist 2010, 1*. 2010.

27. Xue, D., Zhao, Q. L. & Guo, X. Y.. TOPSIS MMethod for Evaluation Customer Service Satisfaction to Fast Food Industry. *IEEE International Conference on Service Operations and Logistics and Informatics 2008 , 1*. 2008. pp. 920 – 925.