TOPSIS METHOD FOR LOAD SHEDDING SCHEME IN JOHORE SYSTEM

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The idea of load-shedding has been introduced as a process that takes place in the face of an overload that makes it impossible to keep several applications running at the same time uniformly. A running example is that of several windows displaying incoming video streams while an incoming situation of overload makes it impossible to maintain the same frame-rate for all windows. A possible solution to the problem is reducing the frame-rate (quality) of one or more windows, or to perform load-shedding [1]. Load-shedding causes the loss of some information but makes it possible to keep all applications running and prevents the system from becoming unstable or even crash. The way applications compete for system's resources are usually unbiased. All applications have the right to the amount of resources that makes them working at full quality [1]. That is, until is possible the system distributes resources equally. When this is not possible something bad happens.

Load shedding is defined as an amount of load that must almost instantly be removed from a power system to keep the remaining portion of the system operational [3]. This load removal is in response to the system that was interrupted which causes a generation deficiency condition and if not properly executed can leads to a total system collapse. Common disturbances that can cause this action to occur include major generation outages or important power transmission line outages, faults, switching errors, lightning strikes [3-4].

Load shedding is happen when there is a huge demand for electricity that exceeds the generation available. Load shedding was implemented to save the cost of supply. It also can save the pollution. For example, if there is a huge consumer of electricity such as factory that could suddenly turn off all its electricity demand, they could agree to do that on request, and it has the same benefit as adding that amount of generation to the electric grid.

By removing amount substances of load can ensure the remaining portion of the system operational. That remaining portion should be only the vital and most critical loads in the system. And the substances amount of load in discussed to be shed or switched off should be from any non-vital loads available in the same disturbed system [4]. By switching off that selected load, the balance between the power generated and load demand could be brought back. Hence, the skill to properly differentiate what load to be shed first and so forth is important in achieving an ideal load shedding module. The process of differentiating can be done by ranking them in hierarchy.

It is normally used in industrial, large commercial and utility operations to make sure the system flow is always in good condition. The emergency loads shedding control required in restoring the power flow solvability and searching the minimum load shedding direction according to the sensitivity vector [5]. This is one of the energy utilities' methods to maintain the stability on the energy generation system by temporary switching off the distribution of energy to different geographical areas.

Therefore in this study, the analysis outcome in interest is to remove loads by ranking them according to their priority. By earning the first rank means that the priority is less as the load shedding module aims is to ensure power continuity to only vital and most critical loads in the system. The module begins with non-vital loads shedding and follows by semi-vital loads removal. The vital loads can only be removed if the system is disturbed by large disturbances such as major generation outages.

Foremost, the analysis is begins by setting a goal and identifies the criteria. These two will frame out the shedding process. And to aid or to simplify the selecting process comprising multiple criteria condition can be chosen from the variety multi-attribute or multi-criteria decision making (MADM/MCDM) technique. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is one of the best known and most widely applied technique MADM/MCDM problems in the real world [7]. It has been known to solve problems in areas such as engineering, government, industry, management, manufacturing, personal, political, social and sports.

In this study, TOPSIS is used to obtain the criteria weight and to rank the selected load into series of sequences. Details of the complete analysis can be read in **Chapter 3 – Methodology**.

1.2 Problem Statements

Problem statement can be understood as a presentation of the study's argument of selecting such research. The interest outcome of this study is to rank the load in hierarchy according to their priority. This is as to assist or illustrated the flow of one load shedding. Load shedding can be initiated whenever a stability of a power system is affected by any disturbances. It can be shed through control theory and manual load shedding operation.

Control theory is defined as the methods and principles to control different systems, processes and objects using system analysis. And for the system to analyse effectively, it requires information about the state of the system. The more information about the system is available, the more accurate and efficient operation will be committed [6]. For example, under frequency relay scheme and programmable logic controller-based load shedding (PLC) are two kinds of control theory approach of shedding load. They rely solely on the data from the frequency measuring systems. These kinds of load shedding principles cannot be programmed with the knowledge gained by the power system engineers. They have to perform numerous system studies that include all of the conceivable system operating conditions and configurations as to correctly design the power system load shedding [2]. Because of numerous variables involved, it is usually difficult, if not impossible to obtain precise frequency characteristic. This unavailability of information for future changes and enhancement of the system will significantly reduce the protection system performance.

Meanwhile, **manual** load shedding operation relies on the system operator. He will select a contingency in which the system is affected. The shedding will be carried out after the operator confirms the execution. The arrangement of shedding which load is made based upon a hierarchy load shedding module [4]. This kind of shedding is suitable for equipment overloading like generators, grid transformer of a reactor and 33kV bus under frequency. And it is known as slow load shedding and the algorithm is framed on a symptom-based approach.

Even though the first example is known as the primary load shedding which is framed on generation deficit and the shedding command is generated through fast actuating relays, but it does not means it is more reliable. For any reliable load shedding, ensuring of data validity is a must. The data is in terms digital and analogue inputs come through a field interface which is validated before using in a program [4].

Thus in assisting the shedding to be more effective either to the control theory approach or to the manual load shedding operation, it is best to develop a reliable load shedding module by illustrating the respective loads in hierarchy form. The top load in the hierarchy conveys the meaning of less priority load therefore should be removed first and immediately. In contrast to the bottom of the hierarchy is by far the most important and vital load. The removal of the final load should only be made if the power system is still in jeopardy, as the system main concern is to ensure the continuity of power to that group of load.

In short, the primary purpose of this study is to illustrate a flow or in other words, to form a hierarchy structure of load shedding priority in providing an adequate tool for decision support to the operator calls. And likely, the results of this study may also help in improving load shedding execution so that the areas of weakness or lack of knowledge could be exposed to those who are responsible for shaping and creating a better protection for power system.

1.3 Project Objectives

Structured objectives were developed with an aim of illustrating an ideal scheme of shedding loads upon disturbances effects on any power system. The objectives are:

a) To implement TOPSIS the multi criteria decision making methods in the load shedding scheme
b) To evaluate TOPSIS performances by performing in Johore electrical system
c) To evaluate the effectiveness of multi criteria decision making method in load shedding

1.4 Project Scopes

The system study was carried out using the Microsoft Excel software application. The following salient points are taken into consideration:

a) The system study is carried out to rank load priority for load shedding scheme as one of the defense scheme/protection system for Johore Electrical System.
b) For this analysis, only power generated and load demand were taken into consideration.

CHAPTER 2

LITERATURE REVIEW

2.1 What is TOPSIS?

In the task of making management decisions and prognoses of possible results, analyst usually has to deal with complex system of interdependent criteria (resources, required results or goals) that has to be analysed. There are a variety of multiple criteria techniques to aid selection in conditions of multiple criteria. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is one of the best known and most widely applied techniques multi-attribute or multi-criteria decision making (MADM/MCDM) problems in the real world [7].

TOPSIS had successfully helps in deciding manufacturing applications such as selecting a manufacturing process or robotic processes. Process attributes with direct cost implication are not always explicitly identified and their indirect cost and benefits are generally not well quantified. Thus, O.L. Chan and Celik Parkan used TOPSIS in determined the preference ranking with respect to operational benefits [8]. Not only that, TOPSIS also makes way into corporate and financial areas. It has been used in comparing company performances and financial ratio performance within a specific industry [8]. C. M. Feng and R.T. Wang applied the TOPSIS in evaluating the procedure performance for highway buses with the financial ratio consideration affecting the production, marketing, execution efficiency. Pinporn Maikaew and Patcharaporn Yanpirat also made the same approach by means of applying the TOPSIS in a financial market in Thailand such as stock investments taking into account the corporate financial and nonfinancial performances of the firms considered under uncertain environments.

TOPSIS introduced by Hwang and Yoon determined the priority of any criteria based on the shortest distance from the (positive) ideal solution (PIS) and the farthest from the negative ideal solution (NIS) [8]. The principle behind TOPSIS is simple: The chosen alternative should be as close to the ideal solution as possible and as far from the negative-ideal solution as possible. The ideal solution is formed as a composite of the best performance values exhibited (in the decision matrix) by any alternative for each attribute. The negative-ideal solution is the composite of the worst performance values. Proximity to each of these performance poles is measured in the Euclidean sense (e.g., square root of the sum of the squared distances along each axis in the attribute space), with optional weighting of each attribute.

2.2 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 equipment or devices which are more important to operate [11]. 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).

The objective of power system operation is to keep the electrical flows and bus voltage magnitudes and angles within acceptable limits (in a viable region of the state space), despite changes in load or available resources. Security may be defined as the probability of the system's operating point remaining in a viable state space, given the probabilities of changes in the system (contingencies) and its environment (weather, demand, etc.)

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 to meet this demand). In some area, widespread load shedding is almost always a result of a deficit or restriction in generation and/or on the transmission network.

When there is a shortfall in the electricity supply, there can be a need to reduce demand very quickly to an acceptable level, or risk the entire electricity network becoming unstable and shutting down completely. This is known as a "cascade" event, and can end in a total or widespread network shutdown affecting very large areas of a country.

In order to protect the overall security of the national grid, it is sometimes necessary for electrical authority companies to direct the relevant market participants(distribution and transmission companies) to instigate a localised load shed event, effectively reducing electricity demand by quickly disconnecting consumers from the grid.

Load shedding normally happens in two ways:

(i) Automatic Load Shedding

This is a result of concurrent failures of major element(s) in the national grid (e.g. co-incidental generator or key transmission line failures), resulting in protection schemes initiating the automatic isolation of additional parts of the national grid, to protect the entire grid from cascading to a total blackout. Automatic load shedding always occurs on the transmission system level, with the result being large amounts of electricity and large blocks of customers taken off supply in a very short time. Typical load reduction amounts can be in the order of 1000MW – 2000MW, affecting hundreds of thousands of customers.

(ii) Manual (Selective) Load Shedding

This occurs where time is available (typically up to 30mins) to make selective choices on what customers are shed. Selective load shedding often occurs on the distribution system level, and typically requires medium to small amounts of electricity to be "shed" in a short time. Typical load reduction amounts can be in the order of 50MW – 100MW, affecting tens of thousands of customers at a time.[11]

2.3 Load shedding events in Malaysia

Load shedding as previously defined in Chapter 1 is said to be an amount of load that must almost instantly be removed from a power system to keep the remaining portion of the system operational [2]. This protection action is in response to the system that was disturbed by either major generation outages or important power transmission line outages, faults, switching errors or lightning strikes which causes a generation deficiency condition and if not properly executed can lead to a total system collapse [2-3].

Thereupon, through tremendous studies it has been proven that by removing a substances amount of load can ensure a portion of the system operational. That remaining portion should be only the vital and most critical loads in the system. And the supposed loads that were shed or switched off should be from any non-vital loads available in the same disturbed system [4]. This fast mitigation helps in bringing back the balance between the power generated and load demand.

With that intention in interest, load shedding has been practiced by electric utility company around the world as early as ones could remember. It is known as the last-resort measure used by an electric utility company in avoiding a total blackout of the power system. Load shedding is common or even a normal daily event in many developing countries where electricity generation capacity is underfunded or infrastructure is poorly managed. On the other hand, in developed countries this kind of measure is rare because demand is accurately forecasted, adequate infrastructure investment is scheduled and networks are well managed; such events are considered an unacceptable failure of planning and can cause significant political damage to responsible governments.

Malaysia is one of the developing countries and is not exempted from this practice. As shown in Figure 2.1, by practicing the load shedding the numbers of tripping events in Peninsular Malaysia were much less compared to the tripping taken by non-load shedding action. The average is null to 5.6 in 2007-2009 alone.

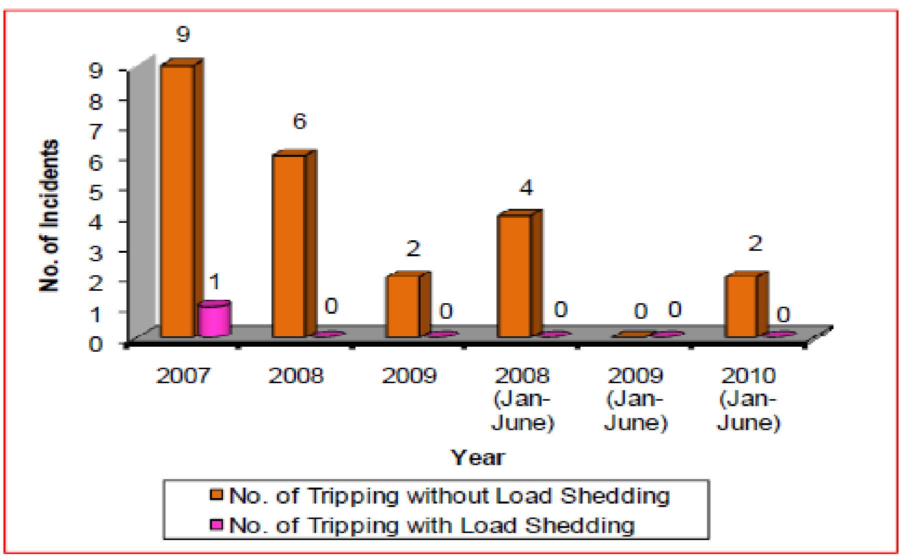

Figure 2.1: Number of Transmission System Tripping in Peninsular Malaysia with a Load Loss of 50MW and above for first half year of 2008 – 2010 and in the year 2007-2009 [9]

Table 2.1: Statistics of transmission system tripping with a load loss of 50MW and above for the first half year of 2010 [9]

Perkara / *Indicators*	Jan	Feb	Mar	Apr	May	June
Bilangan Pelantikan *No. of Tripping without Load Shedding*	0	1	0	0	0	1
Bilangan Lucutan Beban *No. of Tripping with Load Shedding*	0	0	0	0	0	0
Kehilangan Beban Maksimum (MW) *Maximum Load Loss (MW)*		56				61.5
Tenaga Yang Tidak Dibekalkan Semasa Pelantikan (MWj) *Unsupplied Energy due to Tripping (MWh)*		112.1				57.3
Purata Tenaga Tidak Dibekalkan Setiap Pelantikan (MWj) *Average Unsupplied Energy per Trip (MWh)*		112.1				57.3
Purata Tempoh Setiap Pelantikan (Jam:Minit) *Average Duration per Trip (Hour)*		2:00				0:56
Tenaga Tidak Dibekalkan Semasa Lucutan Beban (MWj) *Unsupplied Energy During Load Shedding (MWh)*	0	0	0	0	0	0

By referring to Table 2.1, in the first half of 2010 Peninsular Malaysia experienced tripping events only twice without load shedding action compared to none when with load shedding. A 56MW and 61.5MW loads were shed in February and June, respectively which caused a discontinuity of 112.1 MW/h and 57.3 MW/h supplied energy to the customers as seen in Table 2.1. The causes were numerous; with process and quality of works hold the majority of 56.7% in contrast to the least cause natural disaster with only 0.1% (refer to Figure 2.1). But still, they only caused two tripping events in the first six months of 2010.

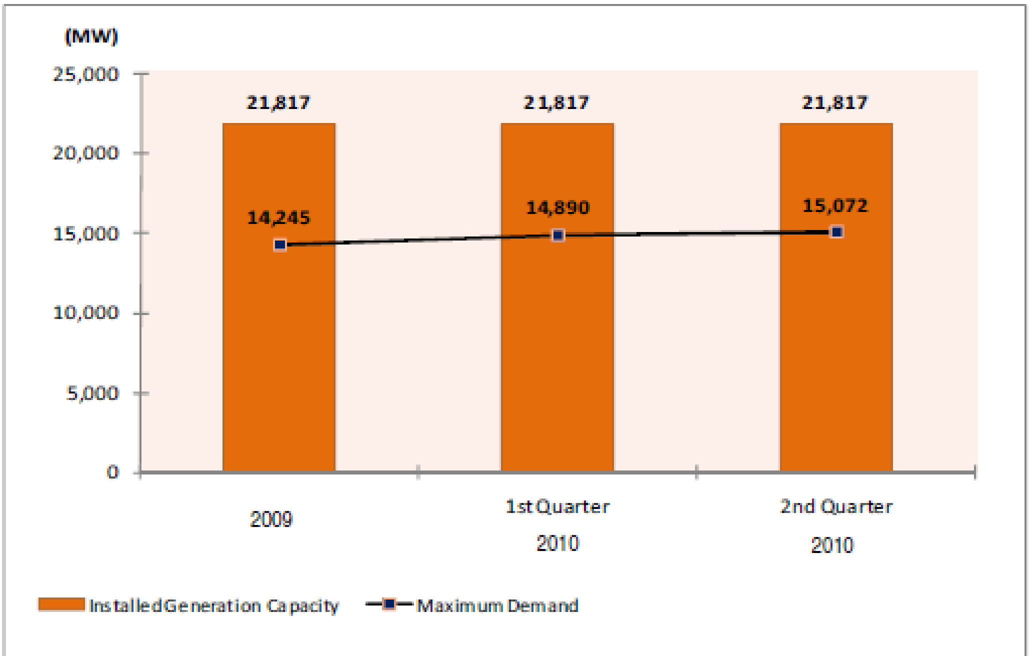

Figure 2.2: Maximum demand and installed generation capacity in Peninsular Malaysia for the first half year of 2010 [9]

Thus, by analyzing the data from Figure 2.2 one can clearly come to a conclusion that customers demand continues to grow with each year despite the unscheduled interuptions event. Therefore, it is the duty of Tenaga Nasional Berhad (TNB) to ensure the continuity in load feeding as the progress of the industrial and technological relies in the reliability and credibility of such companies. Any contingency that could bring catastrophic impact to the power system either to Peninsular Malaysia power network has to be prudently mitigated. There are many ways for the companies to mitigated the problem and among them is the famed load shedding. By far load shedding is a last-resort measure taken by the company if and only if prior precaution steps fail to balance back the supply (power generated) and demand (loads/customers). Load shedding can be implemented by many ways, which will be explained next.

2.4 TOPSIS techniques in a multiple criteria situation

TOPSIS is known as the Technique for Order Preference by Similarity to Ideal Solution introduced by Hwang and Yoon [10]. It shares the similarity with AHP as it also helps in to identify the ranking of all the alternatives considered. The differences are the decision making matrix and weight vector are determined as crisp values, while the outputs of the decision matrix are a measured distances between the index value vector of each sample and ideal solution along with the negative ideal solution of the comprehensive evaluation known as the positive ideal solution (PIS) and a negative ideal solution (NIS) [10]. PIS is considered as the best value of criteria while NIS is the worst value of criteria.

PIS and NIS are determined through a set of TOPSIS steps. The list of alternatives to a decision maker is classified through the TOPSIS's two artificial alternative hypotheses which are 'Ideal Alternative' and 'Negative Ideal Alternative'. Ideal Alternative represents the best level of all attributes while the Negative Ideal Alternative represents the worst attributes value. Next, sets of calculations using eigenvector, square rooting and summations to obtain a relative closeness value of the criteria are tested. Then through the values of relative closeness, TOPSIS will ranked the whole system by selecting the highest value of the relative closeness as the best attributes in the system.

The uniqueness of TOPSIS in handling a situation with many criteria to consider to makes this technique the best method in offering an alternative to a load shedding scheme. Load shedding scheme is also a situation that has more than one criterion to consider upon before deciding which load to be shed accordingly.

CHAPTER 3

METHODOLOGY

3.1 Technique For Order preference By Similarity to Ideal Situation (TOPSIS) Procedures

TOPSIS stands for Technique For Order preference By Similarity to Ideal Situation. It was originally introduced by Hwang and Yoon in 1981[14] with further developments by Yoon in 1987 [14] and Hwang, Lai and Liu in 1993. Basic principle for TOPSIS is quiet simple: The chosen alternative should be as close to the ideal solution as possible and as far from the negative-ideal solution as possible. The ideal solution is formed as a composite of the best performance values exhibited (in the decision matrix) by any alternative for each attribute. The negative ideal solution is the composite of the worst performance values. Proximity to each of these performance poles is measured in the Euclidean sense (e.g., square root of the sum of the squared distances along each axis in the attribute space), with optional weighting of each attribute.

The steps of TOPSIS are listed below:

Step 1: Established the decision matrix

First, create the decision matrix for the analysis. The decision matrix consisting of m alternative and n criteria with the intersection of each alternative and criteria given as x_{ij}. Then form a matrix (x_{ij}) m x n for analysis purposed.

Step 2: Normalized the Decision matrix

The decision matrix is then normalized by using normalization method using the Equation (3.8):

$$r_{ij} = \frac{x_{ij}}{\sqrt{(\sum x_{ij}{}^{2})}} \quad (3.8)$$

where :

x_{ij} represents the intersection of each alternative and criteria

r_{ij} represents the normalized the intersection of each alternative and criteria

i = 1, 2,3 …, m; j = 1, 2, 3, …, n.

Step 3: Weighted normalized decision matrix is constructed

Weighted normalized decision matrix is then constructed by multiplying the decision matrix to its associated weighted.

$$v_{ij} = w_j . r_{ij}, \quad (3.9)$$

where :

r_{ij} represents the decision matrix

W_j represents the weighted matrix

i = 1, 2,3 …, m; j = 1, 2, 3, …, n.

Step 4: Positive and negative ideal solutions are determined

Then, the ideal alternatives and negative ideal alternatives have to be identified. For this, let J be the set of benefit criteria and J' be the set of non-benefit criterion. The calculation to PIS and NIS are as shown below:

(i) Positive ideal solution.

PIS = {v1*, …, vn*} (3.10)

where v* = {max (vij) if j ∈ J; min (vij) if j∈J' }

(ii) Negative ideal solution.

NIS = {v1', …, vn'} (3.11)

where v' = {min (vij) if j ∈J; max (vij) if j∈J' }

Step 5: The distance of each alternative determined

After determine the Positive ideal solution and Negative ideal solution, the distance of each alternative can be determined by using equation 3.12 for positive ideal solution and equation 3.13 for negative ideal solution:

$$d_i = \sqrt{\left[\sum_j (v_j^* - v_{ij})^2\right]} \text{ , i= 1,…,m} \quad (3.12)$$

For negative ideal solution:

$$d_{ni} = \sqrt{\left[\sum_j (v_j' - v_{ij})^2\right]} \text{ , i= 1,…,m} \quad (3.13)$$

Step 6: The relative closeness to ideal reference point is calculated

Next, calculate the value of Relative Closeness (RC) which can be found using equation 3.14 below:

$$RC = \frac{sni}{sni+si} \tag{3.14}$$

Where: si = positive ideal solution and

sni = negative ideal solution

Step 7: The ranking of alternative is determined

Finally the results can be rank from largest to the smallest where the largest value is the less priority whereas the smallest value is the most important. The step can be simplified as shown in Figure 3.5, a step by step flowchart to brief the TOPSIS method.

Hwang and Yoon [14] are the first who introduce the TOPSIS method. Hwang and Yoon describe multiple decisions making as follow: multiple decisions making is applied to preferable decision(such as assessment making priority and choice) between available classified alternatives over the multiple attributes or criteria. It assumes that each criterion require to be maximized or minimized. 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) approaches, weights of attributes reflect the relative importance indecision making process. Each evaluation of criteria entails diverse opinions and meanings. Hence assumption that each evaluation criterion is equally importance is prohibited [14].

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 value. 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 [14].

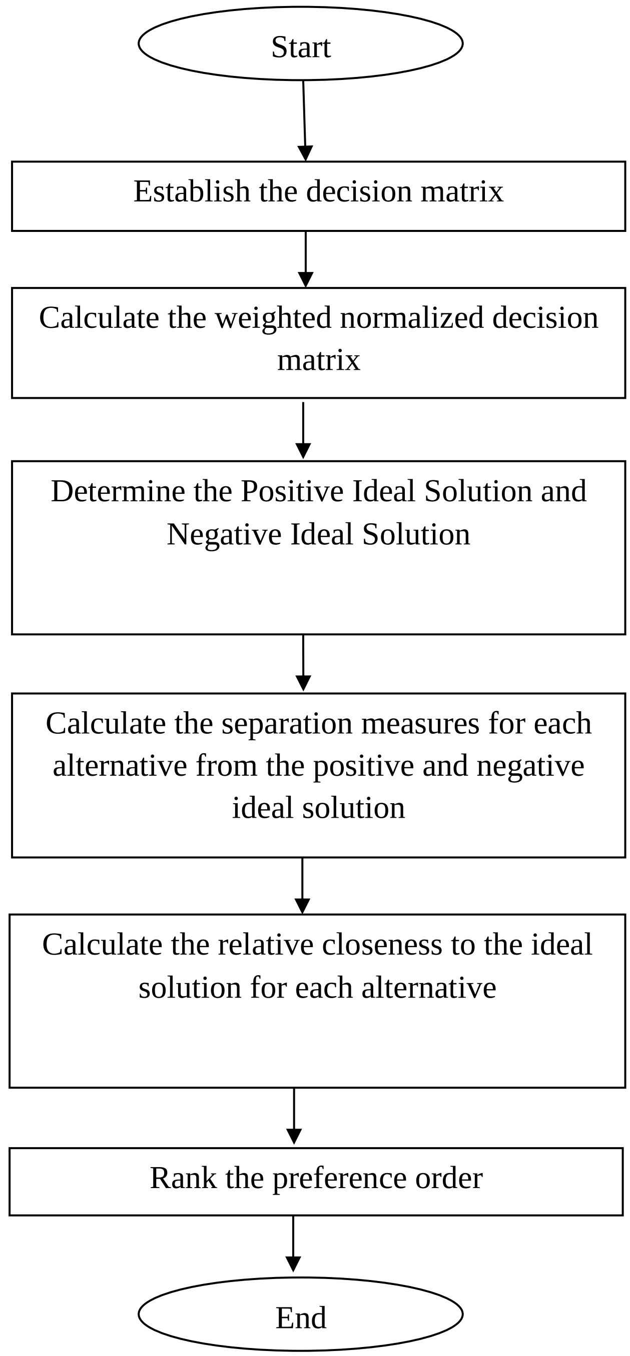

Figure 3.1: Flowchart of the TOPSIS solution procedure.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Load Shedding Scheme In The Johore System By Using Technique for Order Preference by Similarity to Ideal Solution

(a) Step 1

The data for alternatives over criteria is identified to form a set of decision matrix as shown in Equation 4.1.

$$\text{Alternative} = \begin{pmatrix} \text{STUL-T1 (42)} \\ \text{STUL-T2 (43)} \\ \text{BKPG-T (64)} \\ \text{AKHR132 (1102)} \\ \vdots \\ \text{PGPSGT3A1 (9142)} \end{pmatrix} \qquad \text{Criteria} = \begin{pmatrix} a1 & a2 \\ b1 & b2 \\ c1 & c2 \\ \vdots & \vdots \\ z1 & z2 \end{pmatrix} \tag{4.1}$$

$$\text{Criteria in matrix form} = \begin{pmatrix} 0.0000 & 0.0000 \\ 0.0000 & 0.0000 \\ 0.0000 & 0.0000 \\ 70.514 & 0.0000 \\ \vdots & \vdots \\ 0.719 & 137.713 \end{pmatrix} \tag{4.2}$$

(b) Step 2

The arithmetic of the square of original values is obtained as shown in Equation (4.3). Square root of sum of column by column, Y and Z are shown as in Equation (4.4).

Arithmetic of the square of original values

$$\text{Criteria}^2 = \begin{pmatrix} 0.0000 & 0.0000 \\ 0.0000 & 0.0000 \\ 0.0000 & 0.0000 \\ 4972.224 & 0.0000 \\ \vdots & \vdots \\ 0.517 & 18964.870 \end{pmatrix} \tag{4.3}$$

Square root of sum of column by column, Y and Z

$$\begin{bmatrix} Y \\ Z \end{bmatrix} = \sqrt{(\text{Criteria}^2)^T \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix}} \tag{4.4}$$

$$\begin{pmatrix} Y \\ Z \end{pmatrix}^T = (2713.339 \quad 512.135)$$

The value for Y is 2713.339 while for Z is 512.135. The normalized data is shown as in Equation (4.5).

The normalized data :

$$\begin{pmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \\ r_{31} & r_{32} \\ r_{41} & r_{42} \\ \vdots & \vdots \\ r_{n1} & r_{n2} \end{pmatrix} = \begin{pmatrix} 0.0000 & 0.0000 \\ 0.0000 & 0.0000 \\ 0.0000 & 0.0000 \\ 0.0260 & 0.0000 \\ \vdots & \vdots \\ 0.0003 & 0.2689 \end{pmatrix} \quad (4.5)$$

(c) Step 3

In this step, the weight decision matrix is built by multiplying these normalized values with their corresponding weight, w_j. The process is shown as in Equation (4.6).

Sum of criteria :

LP = a1 + a2 + a3 + ... + a102

= 5884.680

AP = b1 + b2 + b3 + ... + b102

= 1436.084

Identifying single pairwise comparison matrix :

$$A = \begin{pmatrix} \text{Load /Load} & \text{Load/ Area} \\ \text{Area / Load} & \text{Area / Area} \end{pmatrix} \quad (4.6)$$

$$= \begin{pmatrix} 1.0000 & 4.098 \\ 0.244 & 1.0000 \end{pmatrix}$$

$$A^2 = \begin{pmatrix} 1.0000 & 16.7914 \\ 0.0596 & 1.0000 \end{pmatrix}$$

Total of column, C1 and C2 :

$$(C1 \quad C2) = (1 \quad 1) \cdot A2$$

$$= (1.0596 \quad 17.7914)$$

Normalized each column, B

$$B = \begin{pmatrix} 1.0000/1.0596 & 16.7914/17.7914 \\ 0.0596/1.0596 & 1.0000/17.7914 \end{pmatrix}$$

$$= \begin{pmatrix} 0.944 & 0.944 \\ 0.056 & 0.056 \end{pmatrix}$$

The W_1 variable represents the weight for the operating load while the W_2 variable represents the area power criteria. From Equation (4.7), the area power is more important where it has the higher weight.

Average of row, W_1 and W_2

$$W_1 = \frac{1}{2}(0.944 + 0.944) \qquad (4.7)$$

$$= 0.944$$

$$W_2 = \frac{1}{2}(0.056 + 0.056)$$

$$= 0.056$$

The W_1 and W_2 variables are then used to multiply with the normalized decision matrix to obtain the weight decision matrix as shown in Equation (4.8).

$v_{ij} = W_j \cdot r_{ij}$

$$\begin{pmatrix} v_{11} & v_{12} \\ v_{21} & v_{22} \\ v_{31} & v_{32} \\ v_{41} & v_{42} \\ \vdots & \vdots \\ v_{n1} & v_{n2} \end{pmatrix} = \begin{pmatrix} 0.0000 & 0.0000 \\ 0.0000 & 0.0000 \\ 0.0000 & 0.0000 \\ 0.0245 & 0.0000 \\ \vdots & \vdots \\ 0.0003 & 0.0151 \end{pmatrix} \quad (4.8)$$

(d) Step 4

The ideal alternative and negative ideal alternative solution can be determined as shown in Equation (4.9).

$$\begin{aligned} PIS &= \{ 0.8318, 0.0000\} \\ NIS &= \{ 0.0000, 0.0333\} \end{aligned} \quad (4.9)$$

(e) Step 5

The distance between the alternatives with the positive and negative ideal solutions is as shown in Equation (4.10) and Equation (4.11).

(i) For Positive Ideal Solution

$$\begin{pmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \\ \vdots \\ s_n \end{pmatrix} = \begin{pmatrix} 0.8318 \\ 0.8313 \\ 0.8318 \\ 0.8073 \\ \vdots \\ 0.8318 \end{pmatrix} \quad (4.10)$$

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