

**AN APPLICATION OF FUZZY LOGIC FOR SHORT-TERM LOAD  
FORECAST OF MALAYSIA LOAD DEMAND**

By

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**FINAL PROJECT REPORT**

Submitted to the Electrical & Electronics Engineering Programme  
in Partial Fulfillment of the Requirements  
for the Degree  
Bachelor of Engineering (Hons)  
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# CERTIFICATION OF APPROVAL

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December 2005

## **CERTIFICATION OF ORIGINALITY**

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.



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Shahril Ikmal Bin Azman

## **ABSTRACT**

This final year project report presents an approach for short-term load forecast problem, based on fuzzy logic technique. As depicted in Chapter 1, in order for all generating stations to operate at maximum efficiency and minimum operating costs, National Load Dispatch Centre must be able to forecast the load demanded by customers. In addition, based on the literature reviews in Chapter 2, conventional methods have several limitations such as require complex mathematical formulation and very time consuming. Apart from that, there are several factors that affect short-term load forecast such as time factors and weather conditions. In Chapter 3 of this report, this project proposes a load forecasting method by using fuzzy logic approach, based on similar days to obtain the next day forecasted load. The fuzzyTECH software is used to develop a one-day-ahead load forecasting model together with Microsoft Excel as the data interface. The test results, as shown in Chapter 4, show that the proposed forecasting method could provide a considerable improvement of the forecasting accuracy especially as it shows how to reduce forecast error to below 3%. Several recommendations for future improvements are included in Chapter 5. The suitability of the proposed approach is illustrated through an application to actual load data of the National Load Dispatch Centre in Bangsar, Kuala Lumpur.

## **ACKNOWLEDGEMENTS**

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## LIST OF ABBREVIATIONS

NLDC	- National Load Dispatch Centre
MW	- MegaWatt
STLF	- Short-term load forecast
MBF	- Membership function
RB	- Rule block
MAPE	- Mean average percentage error
°C	- Degree Celcius

# **CHAPTER 1**

## **INTRODUCTION**

### **1.1 BACKGROUND OF STUDY**

In Malaysia, specifically the peninsular, the government policies such as increases in population, industrial expansion, housing areas etc will normally have big impact on increase in electrical power consumption. Increases in socio-economic standards have also resulted in direct increase in consumption. A number of years ago the use for air-conditioning systems is considered a luxury. As the country increases its socio-economic standards; the use of air-conditioning system on homes are becoming a common necessity and hence the rapid increase in the rate of rise in consumption. A similar phenomenon exists within the commercial and industrial consumers with the rise in air-conditioning use. The central dispatching office like the National Load Dispatch Centre (NLDC) in Bangsar (control centre) distributes the load among the various generating stations so as to operate at maximum efficiency and minimum operating costs. The NLDC normally has to predict daily and seasonal load changes and to regulate the operation of generating units so as to maintain good stability.

### **1.2 PROBLEM STATEMENT**

#### ***1.2.1 Problem identification***

In order for all generating stations to operate at maximum efficiency and minimum operating costs, NLDC must be able to predict the load demanded by their customers. Therefore, this project requires load study analysis in order to perform short-term load forecast of Malaysia load demand using fuzzy logic technique.

### ***1.2.2 Significance of the project***

The purpose of an electrical power system is to generate and supply electrical energy to consumers. The system should be designed and managed to deliver this energy at utilisation points with both reliability and economy. Through this project, NLDC should be able to predict the future load demand, in order to determine the total amount of electrical power to be generated daily for both present and future use. In addition, NLDC will be able to manage electricity generation, plan for plant maintenance, and prevent energy wastage.

## **1.3 OBJECTIVES AND SCOPE OF STUDY**

### ***1.3.1 Objectives of the project***

The successfulness of this project is based on the following objectives:

- To analyse the load behaviour of Malaysia
- To forecast Malaysia load demand using fuzzy logic technique
- To bring benefits to the utility companies
- To gain extra information that relates to the industry

### ***1.3.2 Scope of study***

The scope of study for this project will cover the following areas:

- Electrical load forecasting
- Conventional methods of load forecasting
- Load demand in Malaysia
- The fuzzy logic

#### **1.4 RELEVANCY OF THE PROJECT**

The study required for this project aims at minimising electricity production costs by minimising the amount of energy wastage during generation since short-term load forecasting provides the input for unit commitment. Therefore, having prediction of high accuracy is very important to ensure continuous and reliable supply to the consumers. Based on the trend for the Malaysia load demand and all the literature reviews, this project proved to be very beneficial and relevant with current situation.

#### **1.5 FEASIBILITY OF THE PROJECT**

This project is a two-semester project where the first semester will be mostly on research and study. The required data for the load forecasting will be gathered from the NLDC such that co-operation with the NLDC is vital. In addition, the fuzzyTECH software should be able to fulfill the requirement in developing the load forecasting model. Therefore, this project is feasible to be carried out within the time and scope.

## **CHAPTER 2**

### **LITERATURE REVIEW AND THEORY**

#### **2.1 ELECTRICAL LOAD FORECASTING**

Load forecasting plays an important role in power system planning and operation. Basic operating functions such as unit commitment, economic dispatch, fuel scheduling and unit maintenance can be performed efficiently with an accurate forecast [1].

Load forecasting is classified as long-term, medium-term and short-term load forecasting. Among them long-term and medium-term load forecasting is mainly applied in determining the capacity of generation, transmission, or distribution system additions and the type of facilities required in transmission expansion planning, annual hydrothermal maintenance scheduling, etc. Short-term load forecasting (STLF) mainly provides scientific and accurate prediction aiming at power in hours, days and even weeks. In power utilities, STLF is most essential to dispatching operation and system planning. It has long been recognized that accurate short-term load forecasts represent a great saving potential for electric utility corporations [2].

The art of load forecasting, particularly short-term, became one of the top growing areas of study and significance since the emergence of competition in the energy markets. For these companies it is vital to have good knowledge or to obtain a good forecast of the short-term load with the purpose of fixing prices in advance, according to their supply costs. STLF is a recurrent topic in operative planning activities of companies dedicated to the distribution and trade of energy around the world due to the competitive electricity market, in which an advantage in the previous knowledge of demand could mean the difference between obtaining big benefits or incur in economic losses [3].

In addition, short-term load forecasting also has significant impact on the security of power systems. Deregulation and competition of the power industry are now propelling the utilities to operate the systems at an even higher efficiency. This trend further intensifies the concern as to the accuracy of STLF [4].

## **2.2 IMPORTANT FACTORS FOR FORECASTS**

For short-term load forecasting several factors should be considered such as time factors and weather data. The time factors include the time of the year, the day of the week, and the hour of the day. There are important differences in load between weekdays and weekends. The load on different weekdays also can behave differently. For example, Mondays and Fridays being adjacent to weekends, may have structurally different loads than Tuesday through Thursday. Holidays are more difficult to forecast than non-holidays because of their relative infrequent occurrence [5]. Figure 1 shows current Malaysia load trending in a week from 13<sup>th</sup> June 2005 (Monday) until 19<sup>th</sup> June 2005 (Sunday). From the graphs, during weekdays, the Monday and Friday curves are slightly lower compared to Tuesday, Wednesday and Thursday. Of course, during weekends, Saturday load curve is much lower, with lowest on Sunday.

Weather conditions also influence the load. In fact, forecasted weather parameters are the most important factors in short-term load forecasts. Various weather variables could be considered for load forecasting. Temperature and humidity are the most commonly used load predictors [5]. Figure 2 shows the relationship between weather temperature and the electrical load demand. The curves show that as the temperature increases, the load demand also increases (high air-conditioning load). This proves that weather temperature is suitable to be correlated with the electrical load demand as the inputs for the load forecasting model.

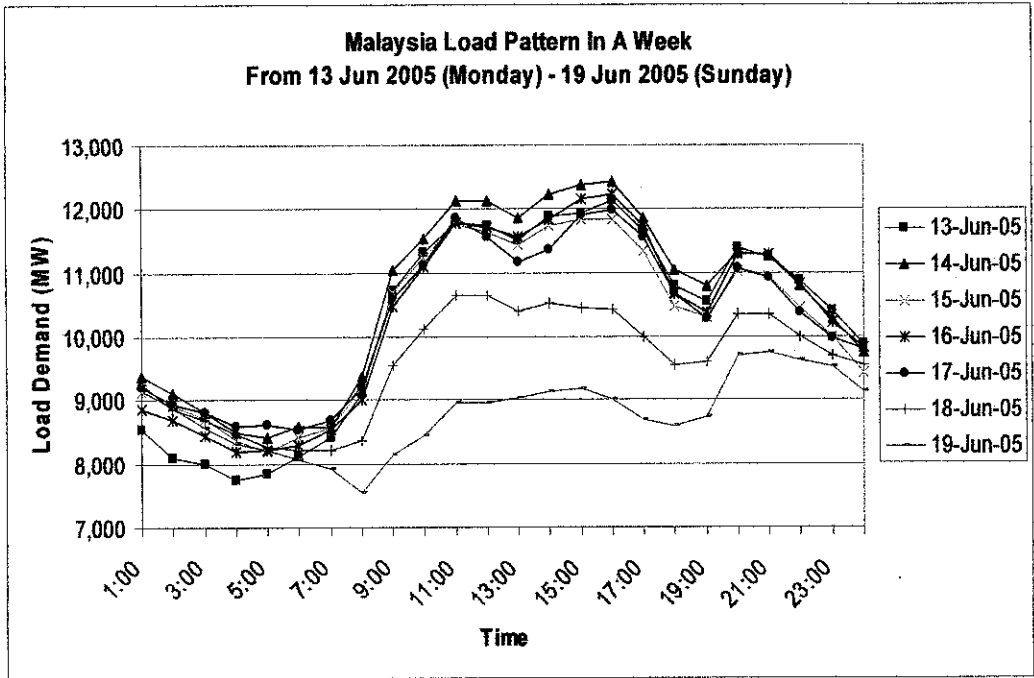


Figure 1 : Malaysia load pattern in a week

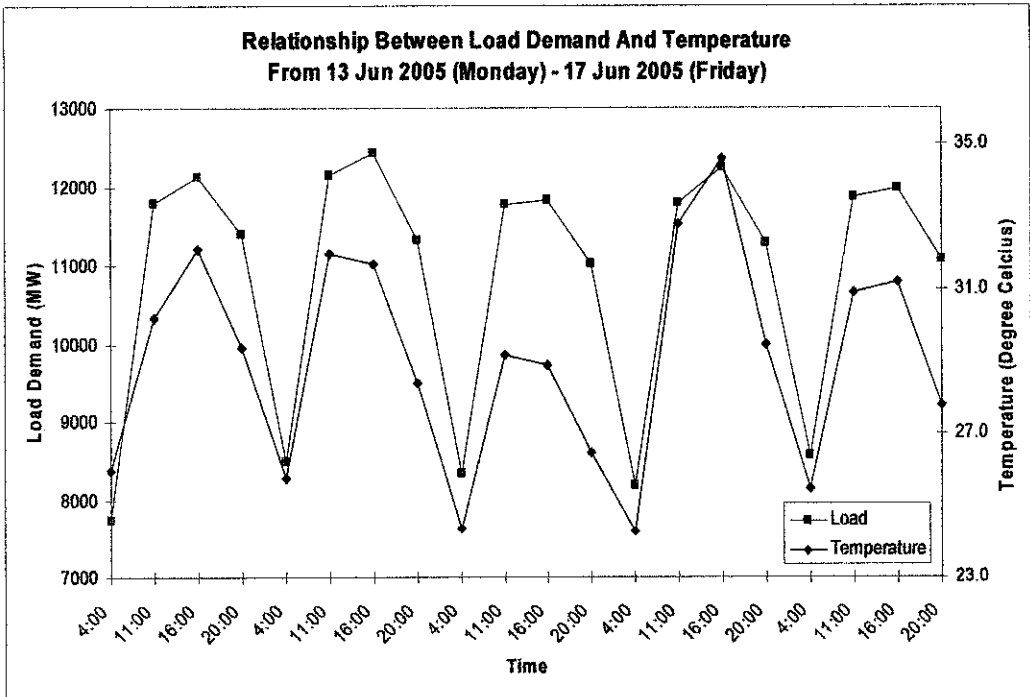


Figure 2 : Relationship between load demand and weather temperature



## 2.3 CONVENTIONAL METHODS OF LOAD FORECASTING

Diverse methods for short-term load forecasting have been tested with different degrees of success. There are two main tendencies of models for short-term forecast; the causal or conventional models which outline the relationships among load and factors influencing it, mainly social and weather variables and the time series models which outline the relationships with values observed in the past.

The “similar day” approach has been used in forecasting applications where the dependant variable is highly correlated with the meteorological variables and the calendar location. The method purposes to search in history a very similar day based in some known explaining independent variables, generally of climate and time (day of the week, month, etc.) and to predict the dependant variable, in this case the electric energy demand, in accordance to what had happened to this variable in the similar day found. It is important to note that in this method there are no mathematical functions found for explaining variables.

Conventional methods in short-term load forecasting are among others; regression models, Box and Jenkins transfer functions, optimization techniques, non-parametric regression, structural models, curve adjustment procedures and there are some more recent methods whose results are compared with the ones mentioned such as expert systems, artificial neural networks, fuzzy inference and Neuro-fuzzy models.

Expert systems have been also used in load forecasting. These systems are heuristic models, which usually can include both quantitative and qualitative factors. A typical approach is trying to imitate the reasoning of a human operator. The idea then is to reduce the analogical thought behind the intuitive forecasting to formal logic steps. A popular approach has been to develop rules based on fuzzy logic.

## 2.4 LOAD DEMAND IN MALAYSIA

The total power drawn by the customers fluctuates between wide limits, depending on the time of the day. Demand studies are required by the utility in order to assess and plan the amount of electricity being generated; in order to match those loads consumed by users. A typical load curve is as shown in Figure 3 recording usage within a 24-hour period.

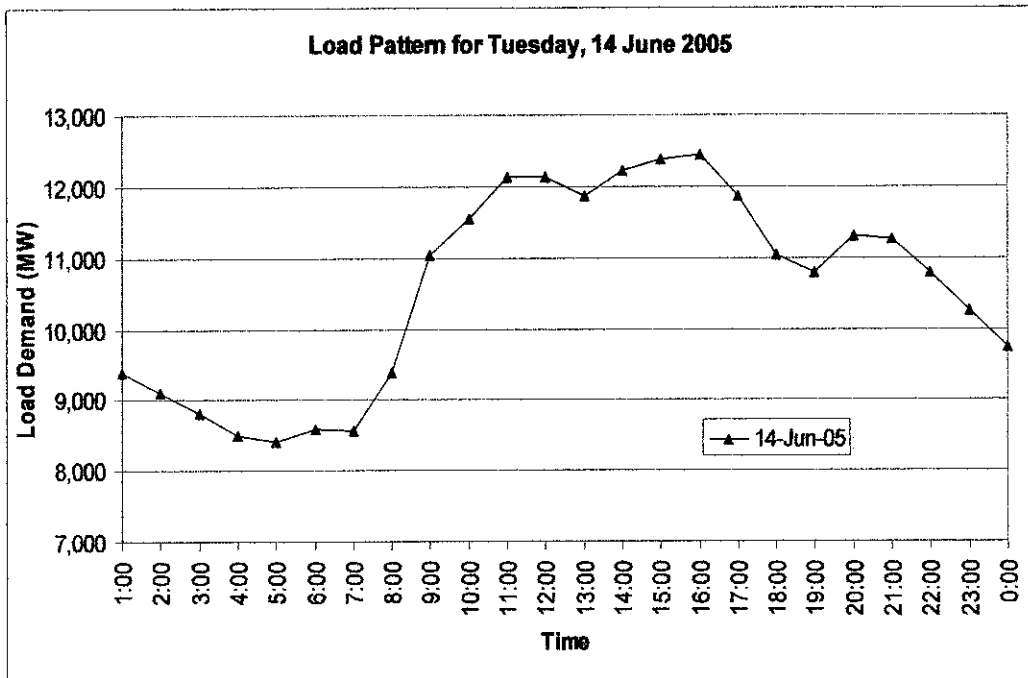


Figure 3 : Load pattern for Tuesday, 14 June 2005

On a typical day; from midnight 2300 hours to 0500 hours, minimal activity contributes to the low-demand. However it could be observed that a continuous 24 hours demand is available. After 0500 hours we could anticipate activities when people starts to wake-up and prepare themselves for the daily activity which may mean people going to work or students going to their classes. At about 0800 in the morning we would expect that the government offices begin their daily activities and loads related to air-conditioning which is a major load in government office complexes provide major consumption within the system.

The private sector in the country generally begins their businesses at 0900 and hence the bulk power could be seen consumed beginning this point of time; where both the industrial as well commercial centre starts to consume power for their operation. Shopping centres on the other hand will begin their business at 1000 hours; another stage of increase in consumption. Later in the afternoon one would expect the load begin to decline at 1700 when the government offices starts to close, followed by the commercial and industrial sector; leaving the shopping centres to continue to operate until 2200 hours where the consumption begins to decline to the minimum level.

A similar curve gives information on how best engineers have to plan for the operation of their generators in order to cope with the demand; whilst trying to achieve optimum economic operation [6].

## **2.5 FUZZY LOGIC**

### ***2.5.1 The concept of fuzziness***

In using our everyday natural language to impart knowledge and information, there is a great deal of imprecision and vagueness, or fuzziness. Such statements as “Ibrahim is tall” and “Ismail is young” are simple examples. In the given examples, terms such as tall and young are fuzzy in the sense that they cannot be sharply defined. However, as humans, we do make sense out of this kind of information, and use it in decision making [7].

### ***2.5.2 Mathematical modeling***

The mathematical modeling of fuzzy concepts was presented by Professor Lotfi A. Zadeh from the University of California, Berkeley in 1965. His contention is that meaning in natural language is a matter of degree. If we have a proposition such as “Ismail is young”, then it is not always possible to assert that it is either true or false. When we know that Ismail’s age is  $x$ , then the “truth”, or more correctly, the “compatibility” of  $x$  with “is young”, is a matter of degree. If the proposition is “Ismail is under 22 years old” and we know Ismail’s age, then we can give a yes or no answer to whether the proposition is true or not. This can formalized a bit by

considering possible ages to be the interval  $[0, \infty)$ , letting  $A$  be the subset  $\{x : x \in [0, \infty) : x < 22\}$ , and then determining whether or not Ismail's age is in  $A$ . But "young" cannot be defined as an ordinary subset of  $[0, \infty)$ . Zadeh was led to the notion of fuzzy subset. Clearly, 18 and 20 years old are young, but with different degrees: 18 is younger than 20. This suggests that membership in a fuzzy subset should not be on a 0 and 1 basis, but rather on a 0 to 1 scale, that is the membership should be an element of the interval  $[0, 1]$ . This is handled as follows. An ordinary subset  $A$  of a set  $U$  is determined by its indicator function, or characteristic function  $X_A$  defined by

$$X_A(x) = \begin{cases} 1 & , x \in A \\ 0 & , x \notin A \end{cases}$$

The indicator function of a subset  $A$  of a set  $U$  specifies whether or not an element is in  $A$ . It either is or is not. There are only two possible values the indicator function can take. This notion is generalized by allowing images of elements to be in interval  $[0, 1]$ , rather than being restricted to the two element set  $\{0, 1\}$ .

For a fuzzy set  $A : U \rightarrow [0, 1]$ , the function  $A$  is called the membership function, and the value  $A(u)$  is called the degree of membership of  $u$  in fuzzy set  $A$ .

Of course, for a fuzzy concept, different functions  $A$  can be considered. The choice of the function  $A$  is subjective and context dependent and can be a delicate one. But the flexibility in the choice of  $A$  is useful in applications, as in the case of fuzzy control [7].

Here are two examples of how one might model the fuzzy concept "young". Let the set of all possible ages of people be the positive real numbers. One such model (refer to Figure 4), decided upon by a teenager might be

$$Y(x) = \begin{cases} 1 & , x < 25 \\ \frac{40-x}{15} & , 25 \leq x \leq 40 \\ 0 & , 40 < x \end{cases}$$

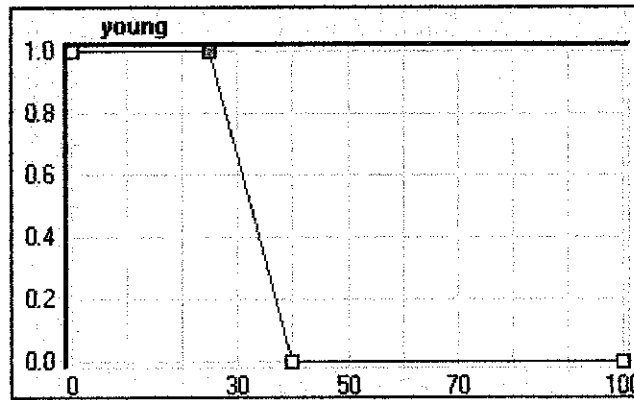


Figure 4 : A membership function of “young”

An older person might model it differently (refer to Figure 5), say with the function

$$Z(x) = \begin{cases} 1 & , \quad x < 40 \\ \frac{80-x}{40} & , \quad 40 \leq x \leq 60 \\ \frac{70-x}{20} & , \quad 60 < x \leq 70 \\ 0 & , \quad 70 < x \end{cases}$$

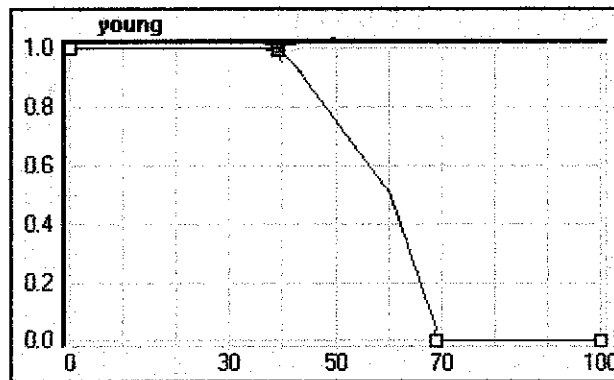


Figure 5 : Another membership function for “young”

Fuzzy logic approach has an advantage of dealing with nonlinear parts of the forecasted load curves, and also, when there is an abrupt change in environmental or weather variables. Therefore, fuzzy models have received much attention from power engineers in the past few years and many interesting applications to fuzzy sets in the power field have been reported [8].

## **CHAPTER 3**

### **METHODOLOGY**

#### **3.1 SYSTEM DESIGN APPROACH**

Before the model can be completed, there are several steps which need to be followed. After gathering data from NLDC, the first step is to identify all the required inputs and outputs variables. The second step is to analyse the relationship between the inputs and outputs parameters. Using the fuzzyTECH software, the membership functions for all the variables can be established after the first two steps. Then, the fuzzy rule block can be constructed. The fuzzy rule block is the medium which connects between the inputs with the outputs based on the IF-THEN rule. After the model is completed, simulation can be performed to obtain the load forecasts. Performing error analysis will determine the accuracy of the model. The MAPE required must not be higher than 3%. Retuning the system be performed if the MAPE exceeds the requirement. Figure 6 simplifies the system design approach of this project.

#### **3.2 TOOLS REQUIRED**

For this project, two main software are required, the fuzzyTECH and Microsoft Excel. fuzzyTECH is the software for fuzzy logic-base solution. This software provides simple yet powerful user interface for developing the load forecasting model especially for beginners since all the fuzzy logic algorithms are embedded within the program. However, fuzzyTECH does not provide the interface for data management. Alternatively, fuzzyTECH can be linked together with software for data interfacing such as the Microsoft Excel. The DDE Links function, which is embedded inside the fuzzyTECH, can be used to link the system with the worksheet of the Microsoft Excel. Apart from that, Microsoft Word is used for documentation.

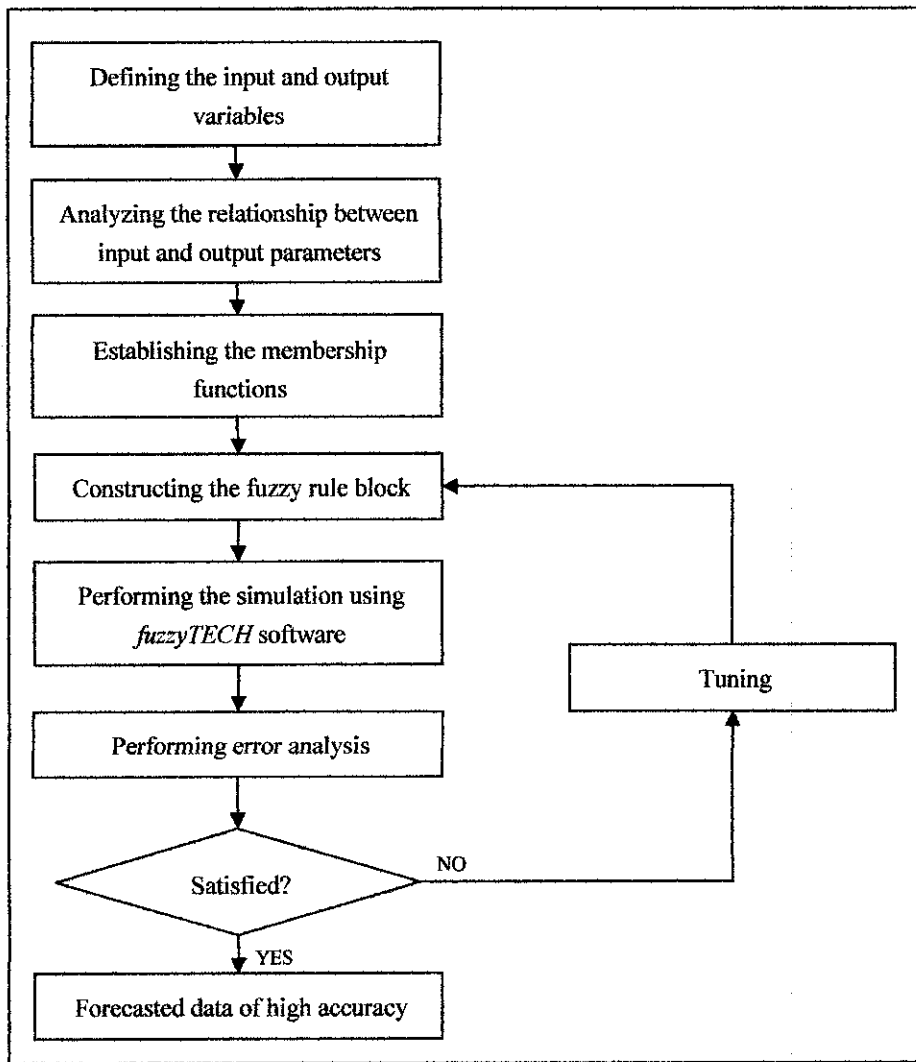


Figure 6 : Flowchart of the system design approach

### 3.3 ERROR CALCULATION

The load forecast by the fuzzy logic forecaster is compared to the actual load data so that the error can be calculated. The principal statistic used to evaluate the performance of these models, mean absolute percentage error (MAPE), is defined as

$$MAPE = \frac{1}{N} \sum_{i=1}^N \frac{|P_A^i - P_F^i|}{P_A^i} \times 100$$

where  $PA$  is the actual load,  $PF$  is the forecasted load and  $N$  is the number of data points.

# CHAPTER 4

## RESULTS AND DISCUSSION

### 4.1 MODEL STRUCTURE

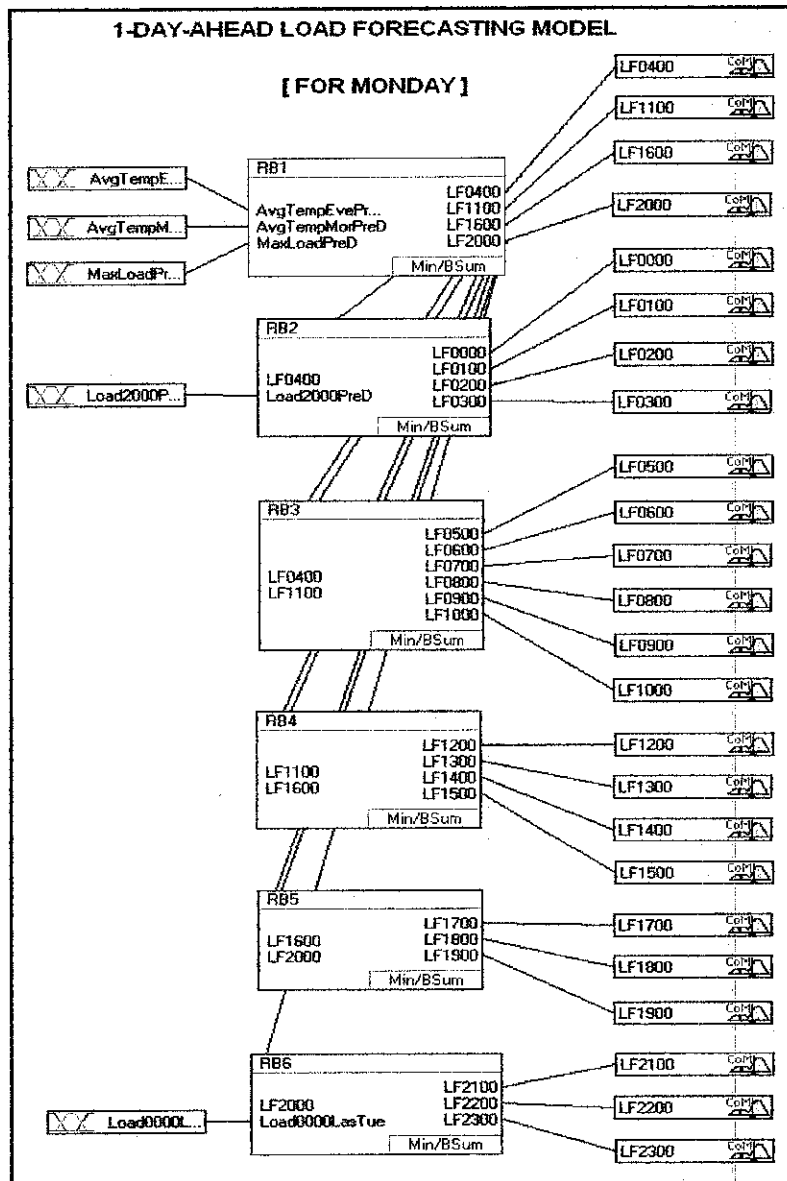


Figure 7 : One-day-ahead with hourly interval model structure



For this project, all the predictions will be based on the following model (refer to Figure 7). The model consists of three parts; fuzzy inputs (left side), fuzzy rule blocks (middle) and fuzzy outputs (right side). The model shown is specifically for Monday forecasts since each model is based on similar day pattern. Therefore, there will be seven models to complement the days in a week. Figure 8 illustrates how the model structure works. There are five inputs altogether, marked by the numbers. The first three inputs are to obtain the forecasts at 0400, 1100, 1600 and 2000. These four points are classified as important hours for observation by the NLDC. The last two inputs are correlated with the previous four outputs to obtain the forecasts of each hour in between. The main reason for input number 4 is, so that power systems engineer will be able to forecast the next day load demand the night before. The forecast data can then be delivered to the dispatching unit as early as possible.

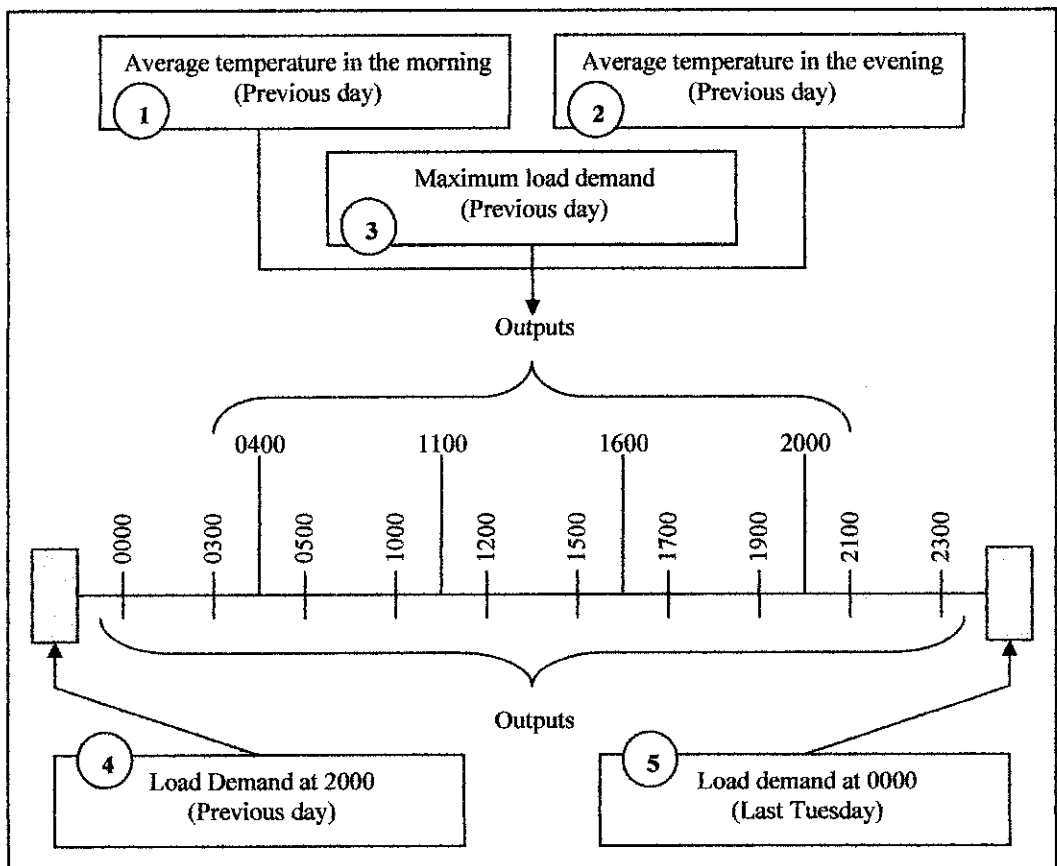


Figure 8 : Simple illustration of the model structure

## 4.2 INPUT AND OUTPUT PARAMETERS

There are five input parameters for the model. The minimum and maximum values for each parameter are based on the data from the past two months. These conditions also apply to the output parameters. The input and output parameters (for Monday forecast model) are shown in the following tables:

VL = *very\_low*                      M = *medium*                      VH = *very\_high*  
 L = *low*    H = *high*

Table 1 : Input parameters

No.	Variable	Unit	Minimum	Maximum	Terms
1.	Average temperature in the morning (previous day)	°C	24	36	L, M, H
2.	Average temperature in the evening (previous day)	°C	24	36	L, M, H
3.	Maximum load demand (previous day)	MW	9336	10224	VL, L, M, H, VH
4.	Load demand at 2000 (previous day)	MW	9336	10011	VL, L, M, H, VH
5.	Load demand at 0000 (last Tuesday)	MW	9653	9887	VL, L, M, H, VH

Table 2 : Output parameters

No.	Variable	Unit	Minimum	Maximum	Terms
1.	Load forecast at 0000	MW	8994	9887	VL, L, M, H, VH
2.	Load forecast at 0100	MW	7945	8701	VL, L, M, H, VH
3.	Load forecast at 0200	MW	7696	8380	VL, L, M, H, VH
4.	Load forecast at 0300	MW	7491	8210	VL, L, M, H, VH
5.	Load forecast at 0400	MW	7497	7894	VL, L, M, H, VH
6.	Load forecast at 0500	MW	7370	7855	VL, L, M, H, VH
7.	Load forecast at 0600	MW	7657	8126	VL, L, M, H, VH

8.	Load forecast at 0700	MW	7854	8401	VL, L, M, H, VH
9.	Load forecast at 0800	MW	8661	9106	VL, L, M, H, VH
10.	Load forecast at 0900	MW	10180	10714	VL, L, M, H, VH
11.	Load forecast at 1000	MW	10760	11313	VL, L, M, H, VH
12.	Load forecast at 1100	MW	11345	11877	VL, L, M, H, VH
13.	Load forecast at 1200	MW	11359	11913	VL, L, M, H, VH
14.	Load forecast at 1300	MW	10982	11760	VL, L, M, H, VH
15.	Load forecast at 1400	MW	11563	12093	VL, L, M, H, VH
16.	Load forecast at 1500	MW	11696	12144	VL, L, M, H, VH
17.	Load forecast at 1600	MW	11641	12246	VL, L, M, H, VH
18.	Load forecast at 1700	MW	11282	11690	VL, L, M, H, VH
19.	Load forecast at 1800	MW	10343	10798	VL, L, M, H, VH
20.	Load forecast at 1900	MW	10180	10682	VL, L, M, H, VH
21.	Load forecast at 2000	MW	10812	11385	VL, L, M, H, VH
22.	Load forecast at 2100	MW	10650	11252	VL, L, M, H, VH
23.	Load forecast at 2200	MW	10180	10862	VL, L, M, H, VH
24.	Load forecast at 2300	MW	9633	10453	VL, L, M, H, VH

### 4.3 MEMBERSHIP FUNCTIONS

In fuzzy logic, each term (linguistic variable) has its own membership function. Each membership function is defined for any input value by the degree of membership function. An input may consist of more than one term and all the terms are associated together and displayed in one graph. The following figures plot the membership functions of the inputs and outputs for Monday forecast model.

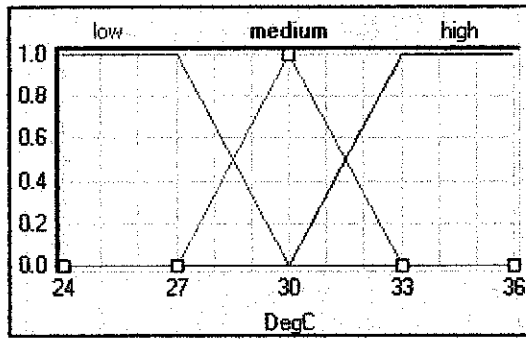


Figure 9 : MBF for average temperature in the morning and evening (previous day)

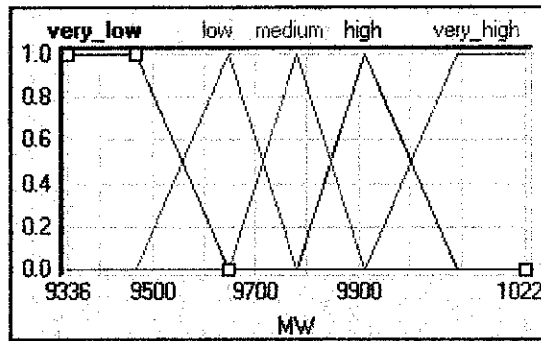


Figure 10 : MBF for maximum load demand (previous day)

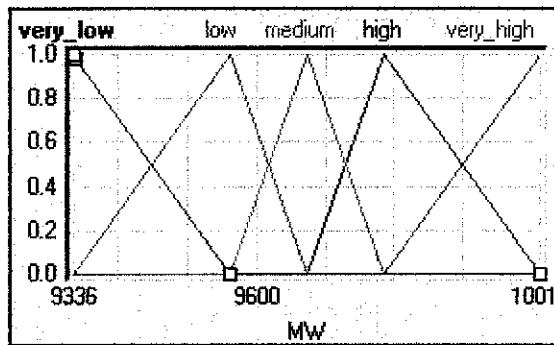


Figure 11 : MBF for load demand at 2000 (previous day)

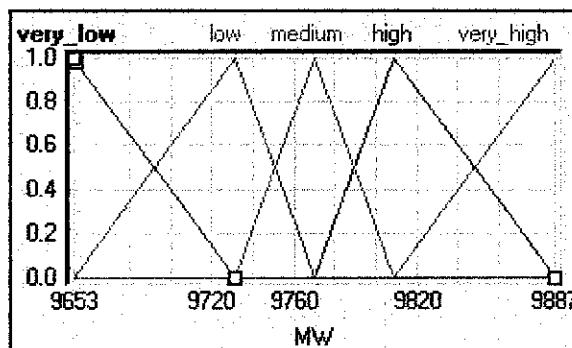


Figure 12 : MBF for load demand at 0000 (previous day)

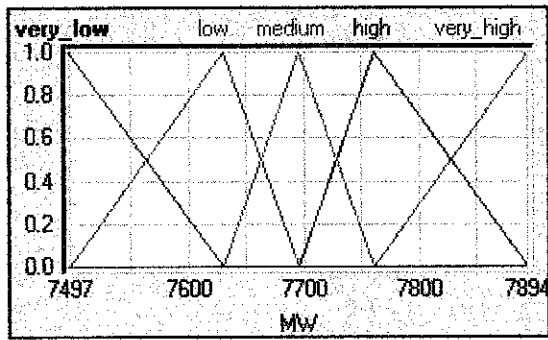


Figure 13 : Output MBF for load forecast at 0400

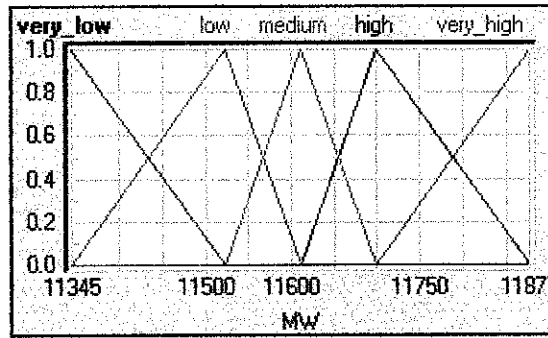


Figure 14 : Output MBF for load forecast at 1100

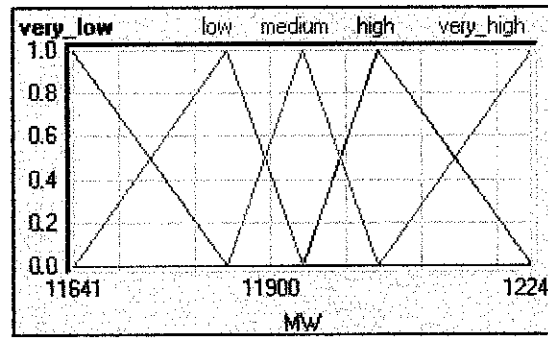


Figure 15 : Output MBF for load forecast at 1600

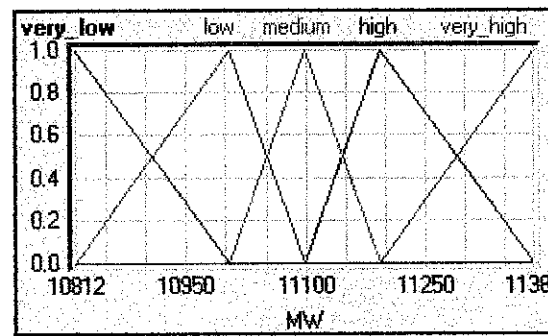


Figure 16 : Output MBF for load forecast at 2000

#### 4.4 RULE BLOCK

The rule block is the heart of the system where the control strategy for the fuzzy logic system lies within. Using linguistic variable, the operator will be able to determine how the inputs will affect the output, based on the IF-THEN rule. All the rules are set based on the analysis and experience of the operator with the historical data. The fuzzyTECH simplifies the operation by having the operator only to manipulate the linguistic variables. Table 1 lists all the rules for RB1. Other rule blocks are attached in the appendix section.

Table 3 : Spreadsheet rule editor for RB1

#	IF			THEN				THEN			
	AvgTemp1	AvgTemp2	MaxLoadF	DoS	LF0400	DoS	LF1100	DoS	LF1600	DoS	LF2000
1	medium	low	very_low	1.00	very_low	1.00	very_low	1.00	low	1.00	low
2	medium	medium	very_low	1.00	low	1.00	low	1.00	low	1.00	medium
3	medium	high	very_low	1.00	medium	1.00	medium	1.00	medium	1.00	medium
4	medium	low	low	1.00	low	1.00	low	1.00	low	1.00	low
5	medium	medium	low	1.00	medium	1.00	medium	1.00	medium	1.00	medium
6	medium	high	low	1.00	medium	1.00	medium	1.00	medium	1.00	medium
7	medium	low	medium	1.00	low	1.00	low	1.00	medium	1.00	medium
8	medium	medium	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium
9	medium	high	medium	1.00	high	1.00	high	1.00	medium	1.00	medium
10	medium	low	high	1.00	medium	1.00	medium	1.00	medium	1.00	medium
11	medium	medium	high	1.00	medium	1.00	medium	1.00	medium	1.00	medium
12	medium	high	high	1.00	high	1.00	high	1.00	high	1.00	high
13	medium	low	very_high	1.00	medium	1.00	medium	1.00	medium	1.00	medium
14	medium	medium	very_high	1.00	high	1.00	high	1.00	high	1.00	high
15	medium	high	very_high	1.00	very_high	1.00	very_high	1.00	high	1.00	high
16	high	low	very_low	1.00	very_low	1.00	low	1.00	medium	1.00	medium
17	high	medium	very_low	1.00	low	1.00	low	1.00	medium	1.00	medium
18	high	high	very_low	1.00	medium	1.00	medium	1.00	high	1.00	medium
19	high	low	low	1.00	low	1.00	low	1.00	medium	1.00	medium
20	high	medium	low	1.00	medium	1.00	medium	1.00	high	1.00	medium
21	high	high	low	1.00	high	1.00	high	1.00	high	1.00	high
22	high	low	medium	1.00	low	1.00	low	1.00	medium	1.00	medium
23	high	medium	medium	1.00	medium	1.00	medium	1.00	high	1.00	high
24	high	high	medium	1.00	high	1.00	high	1.00	high	1.00	high
25	high	low	high	1.00	medium	1.00	medium	1.00	high	1.00	high
26	high	medium	high	1.00	high	1.00	high	1.00	high	1.00	high
27	high	high	high	1.00	high	1.00	high	1.00	very_high	1.00	high
28	high	low	very_high	1.00	medium	1.00	medium	1.00	high	1.00	high
29	high	medium	very_high	1.00	high	1.00	high	1.00	high	1.00	high
30	high	high	very_high	1.00	very_high	1.00	very_high	1.00	very_high	1.00	high

## 4.5 FORECAST RESULTS

The project will present the forecasting results from Monday (27 June 2005) until Thursday (30 June 2005).

### 4.5.1 Input parameters

Table 4 : Input parameters to forecast load on Monday, 27 June 2005

<b>Input Variable</b>	<b>Value</b>
Average temperature in the evening (previous day)	28 °C
Average temperature in the morning (previous day)	32 °C
Load demand at 0000 (last Tuesday)	9653 MW
Load demand at 2000 (previous day)	9511 MW
Maximum load demand (previous day)	9838 MW

Table 5 : Input parameters to forecast load on Tuesday, 28 June 2005

<b>Input Variable</b>	<b>Value</b>
Average temperature in the evening (previous day)	28 °C
Average temperature in the morning (previous day)	32 °C
Load demand at 0000 (last Wednesday)	9646 MW
Load demand at 2000 (previous day)	11109 MW
Maximum load demand (previous day)	11954 MW

Table 6 : Input parameters to forecast load on Wednesday, 29 June 2005

<b>Input Variable</b>	<b>Value</b>
Average temperature in the evening (previous day)	30 °C
Average temperature in the morning (previous day)	33 °C
Load demand at 0000 (last Thursday)	9401 MW
Load demand at 2000 (previous day)	11149 MW
Maximum load demand (previous day)	12100 MW

Table 7 : Input parameters to forecast load on Thursday, 30 June 2005

<b>Input Variable</b>	<b>Value</b>
Average temperature in the evening (previous day)	30 °C
Average temperature in the morning (previous day)	33 °C
Load demand at 0000 (last Friday)	9811 MW
Load demand at 2000 (previous day)	10915 MW
Maximum load demand (previous day)	11779 MW

#### 4.5.2 Error analysis

Table 8 : Forecast error analysis for Monday, 27 June 2005

<b>Time</b>	<b>Forecasted Load</b>	<b>Actual Load</b>	<b>Absolute Error (MW)</b>	<b>Absolute Error (%)</b>
0:00:00	9330	8888	442	4.97
1:00:00	8260	8559	299	3.49
2:00:00	7981	8148	167	2.04
3:00:00	7791	7970	179	2.25
4:00:00	7679	7824	145	1.85
5:00:00	7603	7770	167	2.15
6:00:00	7872	7880	8	0.10
7:00:00	8085	8070	15	0.18
8:00:00	8865	8712	153	1.76
9:00:00	10425	10358	67	0.64
10:00:00	11025	11134	109	0.98
11:00:00	11589	11860	271	2.29
12:00:00	11628	11686	58	0.50
13:00:00	11403	11442	39	0.34
14:00:00	11850	11864	14	0.12
15:00:00	11957	11824	133	1.13
16:00:00	11994	11954	40	0.33
17:00:00	11520	11564	44	0.38
18:00:00	10608	10672	64	0.60
19:00:00	10473	10303	170	1.65
20:00:00	11146	11109	37	0.34
21:00:00	10951	11059	108	0.98
22:00:00	10465	10620	155	1.46
23:00:00	9975	10152	177	1.74
			<b>MAPE</b>	<b>1.37</b>



Table 9 : Forecast error analysis for Tuesday, 28 June 2005

<b>Time</b>	<b>Forecasted Load</b>	<b>Actual Load</b>	<b>Absolute Error (MW)</b>	<b>Absolute Error (%)</b>
0:00:00	9466	9514	48	0.51
1:00:00	8748	9101	353	3.88
2:00:00	8526	8822	296	3.36
3:00:00	8124	8461	337	3.98
4:00:00	7934	8278	344	4.15
5:00:00	7929	8212	283	3.45
6:00:00	8131	8393	262	3.12
7:00:00	8318	8561	243	2.84
8:00:00	9015	9086	71	0.78
9:00:00	10594	10571	23	0.22
10:00:00	11061	11103	42	0.38
11:00:00	11683	11748	65	0.55
12:00:00	11714	11678	36	0.31
13:00:00	11509	11519	10	0.08
14:00:00	11991	11937	54	0.46
15:00:00	12058	12040	18	0.15
16:00:00	12105	12100	5	0.04
17:00:00	11534	11515	19	0.17
18:00:00	10725	10569	156	1.47
19:00:00	10421	10326	95	0.92
20:00:00	11227	11149	78	0.70
21:00:00	11019	10927	92	0.85
22:00:00	10540	10584	44	0.42
23:00:00	10057	10234	177	1.73
			<b>MAPE</b>	<b>1.44</b>

Table 10 : Forecast error analysis for Wednesday, 29 June 2005

<b>Time</b>	<b>Forecasted Load</b>	<b>Actual Load</b>	<b>Absolute Error (MW)</b>	<b>Absolute Error (%)</b>
0:00:00	9545	9,780	235	2.40
1:00:00	9156	9,090	66	0.72
2:00:00	8813	8,753	60	0.69
3:00:00	8479	8,506	27	0.31
<b>4:00:00</b>	<b>8317</b>	<b>8,293</b>	<b>24</b>	<b>0.29</b>
5:00:00	8170	8,197	27	0.33
6:00:00	8331	8,340	9	0.10
7:00:00	8547	8,449	98	1.17
8:00:00	9128	8,903	225	2.53
9:00:00	10630	10,224	406	3.98
10:00:00	11187	10,908	279	2.56
<b>11:00:00</b>	<b>11807</b>	<b>11,426</b>	<b>381</b>	<b>3.33</b>
12:00:00	11763	11,455	308	2.69
13:00:00	11590	11,113	477	4.29
14:00:00	11990	11,498	492	4.27
15:00:00	12047	11,676	371	3.18
<b>16:00:00</b>	<b>11946</b>	<b>11,779</b>	<b>167</b>	<b>1.41</b>
17:00:00	11593	11,243	350	3.11
18:00:00	10703	10,361	342	3.30
19:00:00	10383	10,120	263	2.59
<b>20:00:00</b>	<b>11229</b>	<b>10,915</b>	<b>314</b>	<b>2.88</b>
21:00:00	11004	10,760	244	2.27
22:00:00	10481	10,377	104	1.00
23:00:00	10053	9,831	222	2.26
			<b>MAPE</b>	<b>2.15</b>

Table 11 : Forecast error analysis for Thursday, 30 June 2005

<b>Time</b>	<b>Forecasted Load</b>	<b>Actual Load</b>	<b>Absolute Error (MW)</b>	<b>Absolute Error (%)</b>
0:00:00	9535	9,401	134	1.42
1:00:00	9044	9,065	21	0.23
2:00:00	8756	8,691	65	0.75
3:00:00	8567	8,385	182	2.17
<b>4:00:00</b>	<b>8351</b>	<b>8,338</b>	<b>13</b>	<b>0.15</b>
5:00:00	8256	8,206	50	0.60
6:00:00	8384	8,154	230	2.82
7:00:00	8540	8,424	116	1.37
8:00:00	9146	8,869	277	3.12
9:00:00	10524	10,385	139	1.34
10:00:00	11172	11,036	136	1.23
<b>11:00:00</b>	<b>11713</b>	<b>11,619</b>	<b>94</b>	<b>0.81</b>
12:00:00	11710	11,527	183	1.59
13:00:00	11564	11,189	375	3.35
14:00:00	11958	11,718	240	2.04
15:00:00	11938	11,662	276	2.37
<b>16:00:00</b>	<b>11962</b>	<b>11,668</b>	<b>294</b>	<b>2.52</b>
17:00:00	11479	11,217	262	2.34
18:00:00	10694	10,337	357	3.45
19:00:00	10428	10,221	207	2.03
<b>20:00:00</b>	<b>11177</b>	<b>10,933</b>	<b>244</b>	<b>2.23</b>
21:00:00	11059	10,892	167	1.53
22:00:00	10546	10,480	66	0.63
23:00:00	10178	10,078	100	0.99
			<b>MAPE</b>	<b>1.71</b>

### 4.5.3 Graph of comparison

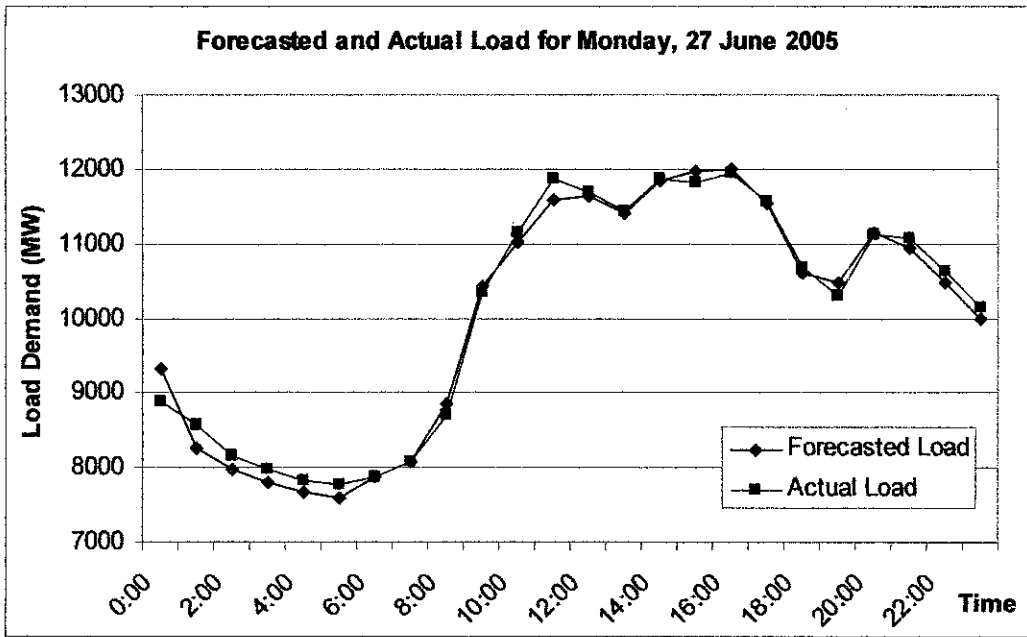


Figure 17 : Forecasted and actual load for Monday, 27 June 2005

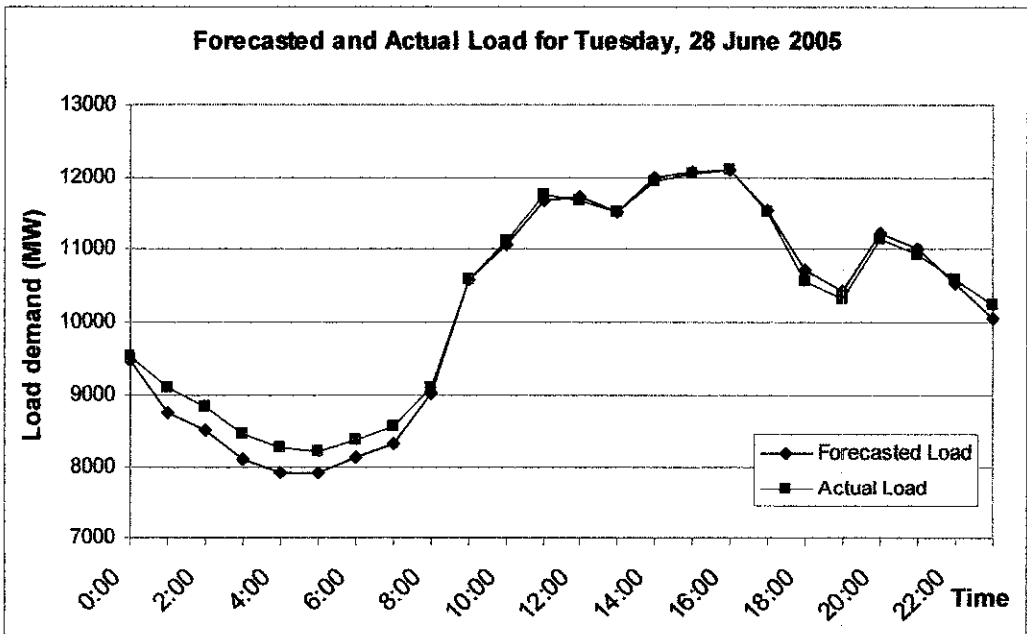


Figure 18 : Forecasted and actual load for Tuesday, 28 June 2005

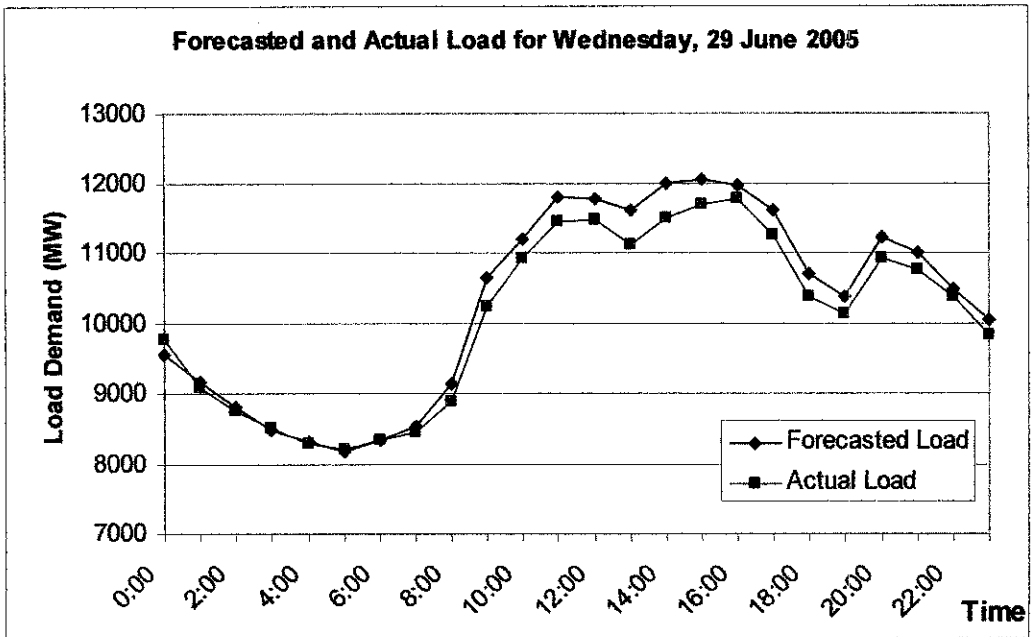


Figure 19 : Forecasted and actual load for Wednesday, 29 June 2005

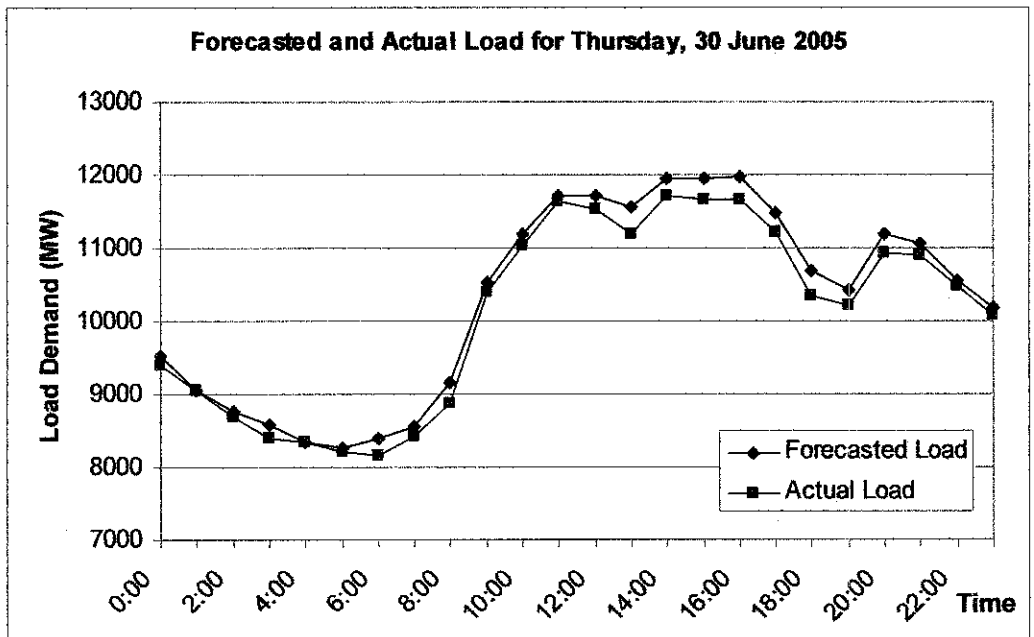


Figure 20 : Forecasted and actual load for Thursday, 30 June 2005

## 4.6 DISCUSSION

The results indicate that the MAPE for each forecast is below the 3% requirement. However, the largest absolute error is 4.97%. The variation between each absolute error shows that the forecast result depends on variation of the historical data since the range between the minimum and maximum for each MBF is determined based on the data from the past two months. Therefore, each prediction is based on the behaviour of the historical data. For example, the prediction error for 29 and 30 June are higher because the actual loads are lower compare to data from the past two months. Nevertheless, this model can be considered reliable only for prediction of normal days since prediction of public holidays and festive seasons require further analysis on the historical data.

## **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATIONS**

#### **5.1 CONCLUSION**

Accurate load forecasting is very important for electric utilities in a competitive environment created by the electric industry deregulation. The literature reviews for this project cover various aspects including the types and other methods of load forecasting as well as factors that affect the accuracy of the forecasts such as time factors and weather conditions. For better understanding of the load dynamics and its statistical properties to implement appropriate models, analysis on the trend of the Malaysia load demand is very important.

The fuzzyTECH software simplifies the implementation of fuzzy logic for the load forecasting model since fuzzy logic requires advanced mathematical modeling. Several steps are required in building the model which include establishing the membership functions of every input and output as well as the rules block that holds the control strategy for the whole system based on IF-THEN rule.

From the test results, a very high average accuracy has been obtained from the use of the fuzzy logic load forecaster. The advantage of this model is that it requires minimal input information and minimum instructions for industry personnel. For some requirements, this methodology may be all that is necessary. Therefore, this project proves that the fuzzy logic technique can be used to forecast the load demand with high accuracy that is below 3% error.

## 5.2 RECOMMENDATIONS

Although the system successfully predicted the load demand with high accuracy, it still has several limitations. This leaves plenty of room for further improvements. There are other type of variables which can be utilised such as humidity and energy level. For even greater accuracy, the use of additional weather variables may be required. Since this model is developed to forecasts only the normal days, perhaps further research can be done so that it can also perform forecasts for public holidays or festive seasons. The fuzzyTECH has several other computational methods and for this model, the computational method used is the Centre of Maximum (CoM) method. This method is set by default since it is suitable for most fuzzy logic applications. The last recommendation is that learning courses be given to the ones involve with this project in order to obtain greater understanding on the concept of fuzzy logic.



## REFERENCES

- [1] Tomonobu Senjyu, Paras Mandal, Katsumi Uezato and Toshihisa Funabashi ; **“Next Day Load Curve Forecasting Using Hybrid Correction Method”** ; *IEEE Trans. Power Systems, Vol. 20, No. 1, February 2005* ; page 102-109 ;
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- [7] Hung T. Nguyen and Elbert A. Walker ; **“A First Course in Fuzzy Logic”** ; 2<sup>nd</sup> Edition ; Chapman & Hall / CRC ; 2000 ; page 1-5 ; and
- [8] Tomonobu Senjyu, Paras Mandal, Katsumi Uezato and Toshihisa Funabashi ; **“Next Day Load Curve Forecasting Using Hybrid Correction Method”** ; *IEEE Trans. Power Systems, Vol. 20, No. 1, February 2005* ; page 102-109.

## **APPENDICES**

**APPENDIX A**  
**SPREADSHEET RULE EDITOR FOR RB2**

Table 12 : Spreadsheet rule editor for RB2

#	IF		THEN		THEN		THEN		THEN	
	LF0400	Load2000	DoS	LF0000	DoS	LF0100	DoS	LF0200	DoS	LF0300
1	very_low	very_low	1.00	very_low	1.00	low	1.00	low	1.00	very_low
2	very_low	low	1.00	low	1.00	low	1.00	low	1.00	low
3	very_low	medium	1.00	medium	1.00	low	1.00	low	1.00	low
4	very_low	high	1.00	medium	1.00	medium	1.00	low	1.00	low
5	very_low	very_high	1.00	high	1.00	medium	1.00	low	1.00	low
6	low	very_low	1.00	low	1.00	low	1.00	low	1.00	low
7	low	low	1.00	low	1.00	low	1.00	low	1.00	low
8	low	medium	1.00	medium	1.00	medium	1.00	medium	1.00	low
9	low	high	1.00	medium	1.00	medium	1.00	medium	1.00	medium
10	low	very_high	1.00	high	1.00	medium	1.00	medium	1.00	medium
11	medium	very_low	1.00	low	1.00	low	1.00	medium	1.00	medium
12	medium	low	1.00	low	1.00	medium	1.00	medium	1.00	medium
13	medium	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium
14	medium	high	1.00	high	1.00	medium	1.00	medium	1.00	medium
15	medium	very_high	1.00	high	1.00	high	1.00	medium	1.00	medium
16	high	very_low	1.00	low	1.00	medium	1.00	medium	1.00	medium
17	high	low	1.00	medium	1.00	medium	1.00	medium	1.00	medium
18	high	medium	1.00	medium	1.00	medium	1.00	medium	1.00	high
19	high	high	1.00	high	1.00	high	1.00	high	1.00	high
20	high	very_high	1.00	high	1.00	high	1.00	high	1.00	high
21	very_high	very_low	1.00	low	1.00	medium	1.00	high	1.00	high
22	very_high	low	1.00	medium	1.00	medium	1.00	high	1.00	high
23	very_high	medium	1.00	medium	1.00	high	1.00	high	1.00	high
24	very_high	high	1.00	high	1.00	high	1.00	high	1.00	high
25	very_high	very_high	1.00	very_high	1.00	high	1.00	high	1.00	very_high

## APPENDIX B

### SPREADSHEET RULE EDITOR FOR RB3

Table 13 : Spreadsheet rule editor for RB3

#	IF		THEN		THEN		THEN		THEN		THEN		THEN	
	LF0400	LF1100	DoS	LF0500	DoS	LF0600	DoS	LF0700	DoS	LF0800	DoS	LF0900	DoS	LF1000
1	very_low	very_low	1.00	very_low	1.00	very_low	1.00	low	1.00	low	1.00	low	1.00	very_low
2	very_low	low	1.00	low	1.00	low	1.00	low	1.00	low	1.00	low	1.00	low
3	very_low	medium	1.00	low	1.00	low	1.00	medium	1.00	low	1.00	low	1.00	medium
4	very_low	high	1.00	low	1.00	low	1.00	medium	1.00	medium	1.00	medium	1.00	medium
5	very_low	very_high	1.00	low	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	high
6	low	very_low	1.00	low	1.00	low	1.00	low	1.00	low	1.00	low	1.00	low
7	low	low	1.00	low	1.00	low	1.00	low	1.00	low	1.00	low	1.00	low
8	low	medium	1.00	low	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium
9	low	high	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium
10	low	very_high	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	high
11	medium	very_low	1.00	medium	1.00	low	1.00	low	1.00	low	1.00	low	1.00	low
12	medium	low	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	low
13	medium	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium
14	medium	high	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	high
15	medium	very_high	1.00	medium	1.00	high	1.00	high	1.00	high	1.00	high	1.00	high
16	high	very_low	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	low
17	high	low	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium
18	high	medium	1.00	high	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium
19	high	high	1.00	high	1.00	high	1.00	medium	1.00	high	1.00	high	1.00	high
20	high	very_high	1.00	high	1.00	high	1.00	high	1.00	high	1.00	high	1.00	high
21	very_high	very_low	1.00	high	1.00	medium	1.00	medium	1.00	medium	1.00	medium	1.00	low
22	very_high	low	1.00	high	1.00	high	1.00	medium	1.00	medium	1.00	medium	1.00	medium
23	very_high	medium	1.00	high	1.00	high	1.00	medium	1.00	high	1.00	high	1.00	medium
24	very_high	high	1.00	high	1.00	high	1.00	high	1.00	high	1.00	high	1.00	high
25	very_high	very_high	1.00	very_high	1.00	very_high	1.00	high	1.00	high	1.00	high	1.00	very_high

**APPENDIX C**  
**SPREADSHEET RULE EDITOR FOR RB4**

Table 14 : Spreadsheet rule editor for RB4

#	IF		THEN		THEN		THEN		THEN	
	LF1100	LF1600	DoS	LF1200	DoS	LF1300	DoS	LF1400	DoS	LF1500
1	very_low	very_low	1.00	very_low	1.00	very_low	1.00	low	1.00	very_low
2	very_low	low	1.00	low	1.00	low	1.00	low	1.00	low
3	very_low	medium	1.00	low	1.00	low	1.00	low	1.00	medium
4	very_low	high	1.00	low	1.00	low	1.00	medium	1.00	medium
5	very_low	very_high	1.00	low	1.00	medium	1.00	medium	1.00	high
6	low	very_low	1.00	low	1.00	low	1.00	low	1.00	low
7	low	low	1.00	low	1.00	low	1.00	low	1.00	low
8	low	medium	1.00	low	1.00	medium	1.00	medium	1.00	medium
9	low	high	1.00	medium	1.00	medium	1.00	medium	1.00	medium
10	low	very_high	1.00	medium	1.00	medium	1.00	medium	1.00	high
11	medium	very_low	1.00	medium	1.00	low	1.00	low	1.00	low
12	medium	low	1.00	medium	1.00	medium	1.00	medium	1.00	low
13	medium	medium	1.00	medium	1.00	medium	1.00	medium	1.00	medium
14	medium	high	1.00	medium	1.00	medium	1.00	medium	1.00	high
15	medium	very_high	1.00	medium	1.00	high	1.00	high	1.00	high
16	high	very_low	1.00	medium	1.00	medium	1.00	medium	1.00	low
17	high	low	1.00	medium	1.00	medium	1.00	medium	1.00	medium
18	high	medium	1.00	high	1.00	medium	1.00	medium	1.00	medium
19	high	high	1.00	high	1.00	high	1.00	high	1.00	high
20	high	very_high	1.00	high	1.00	high	1.00	high	1.00	high
21	very_high	very_low	1.00	high	1.00	medium	1.00	medium	1.00	low
22	very_high	low	1.00	high	1.00	high	1.00	medium	1.00	medium
23	very_high	medium	1.00	high	1.00	high	1.00	high	1.00	medium
24	very_high	high	1.00	high	1.00	high	1.00	high	1.00	high
25	very_high	very_high	1.00	very_high	1.00	very_high	1.00	high	1.00	very_high

**APPENDIX D**  
**SPREADSHEET RULE EDITOR FOR RB5**

Table 15 : Spreadsheet rule editor for RB5

#	IF		THEN			THEN		
	LF1600	LF2000	DoS	LF1700	DoS	LF1800	DoS	LF1900
1	very_low	very_low	1.00	very_low	1.00	low	1.00	very_low
2	low	very_low	1.00	low	1.00	low	1.00	low
3	medium	very_low	1.00	medium	1.00	medium	1.00	low
4	high	very_low	1.00	medium	1.00	medium	1.00	low
5	very_high	very_low	1.00	high	1.00	high	1.00	low
6	very_low	low	1.00	low	1.00	low	1.00	low
7	low	low	1.00	low	1.00	low	1.00	low
8	medium	low	1.00	medium	1.00	medium	1.00	low
9	high	low	1.00	medium	1.00	medium	1.00	medium
10	very_high	low	1.00	high	1.00	high	1.00	medium
11	very_low	medium	1.00	low	1.00	low	1.00	medium
12	low	medium	1.00	low	1.00	medium	1.00	medium
13	medium	medium	1.00	medium	1.00	medium	1.00	medium
14	high	medium	1.00	high	1.00	medium	1.00	medium
15	very_high	medium	1.00	high	1.00	high	1.00	medium
16	very_low	high	1.00	low	1.00	low	1.00	medium
17	low	high	1.00	medium	1.00	medium	1.00	medium
18	medium	high	1.00	medium	1.00	medium	1.00	high
19	high	high	1.00	high	1.00	high	1.00	high
20	very_high	high	1.00	high	1.00	high	1.00	high
21	very_low	very_high	1.00	low	1.00	low	1.00	high
22	low	very_high	1.00	medium	1.00	medium	1.00	high
23	medium	very_high	1.00	medium	1.00	medium	1.00	high
24	high	very_high	1.00	high	1.00	high	1.00	high
25	very_high	very_high	1.00	very_high	1.00	high	1.00	very_high

## APPENDIX E

### SPREADSHEET RULE EDITOR FOR RB6

Table 16 : Spreadsheet rule editor for RB6

#	IF		THEN		THEN		THEN	
	LF2000	Load0000	DoS	LF2100	DoS	LF2200	DoS	LF2300
1	very_low	very_low	1.00	very_low	1.00	low	1.00	low
2	very_low	low	1.00	low	1.00	low	1.00	low
3	very_low	medium	1.00	low	1.00	low	1.00	low
4	very_low	high	1.00	low	1.00	medium	1.00	medium
5	very_low	very_high	1.00	low	1.00	medium	1.00	medium
6	low	very_low	1.00	low	1.00	low	1.00	low
7	low	low	1.00	low	1.00	low	1.00	low
8	low	medium	1.00	low	1.00	medium	1.00	medium
9	low	high	1.00	medium	1.00	medium	1.00	medium
10	low	very_high	1.00	medium	1.00	medium	1.00	medium
11	medium	very_low	1.00	medium	1.00	low	1.00	low
12	medium	low	1.00	medium	1.00	medium	1.00	medium
13	medium	medium	1.00	medium	1.00	medium	1.00	medium
14	medium	high	1.00	medium	1.00	medium	1.00	medium
15	medium	very_high	1.00	medium	1.00	high	1.00	high
16	high	very_low	1.00	medium	1.00	medium	1.00	medium
17	high	low	1.00	medium	1.00	medium	1.00	medium
18	high	medium	1.00	high	1.00	medium	1.00	medium
19	high	high	1.00	high	1.00	high	1.00	high
20	high	very_high	1.00	high	1.00	high	1.00	high
21	very_high	very_low	1.00	high	1.00	medium	1.00	medium
22	very_high	low	1.00	high	1.00	medium	1.00	medium
23	very_high	medium	1.00	high	1.00	high	1.00	high
24	very_high	high	1.00	high	1.00	high	1.00	high
25	very_high	very_high	1.00	very_high	1.00	high	1.00	high