The Development of Congestion Management of a Deregulated Power System Using Fuzzy Logic

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Abstract – *Deregulated power system is a method of altering the existing regulatory structure of the power market in order to: reduce costs, draw new investments in power market and increase efficiency. Reforming the power market into a deregulated system reduce the transmission capacity since there will be more investors occupying the power system causing congestion in lines. Thus, the objectives of this paper is to present congestion management method in a deregulated market by analysing the congestion levels in transmission lines using Fuzzy Logic Approach. The Fuzzy method can be used to classify the levels of congestion in the transmission lines, resulting in easier monitoring of which lines are moderately or heavily loaded for pricing purposes based on usage. Thus, the congestion levels are to be defined depending on the price of power charged and amount of load used by end users. The congestion levels classifications were tested on IEEE Reliability Test System 1996 24 Bus System using its Weekly and Daily Peak Load Data.*

Keywords: *congestion management, deregulated, power system, fuzzy logic*

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I. Introduction

Deregulation of the power sector is unavoidable in today's dynamic market. It is introduced due to several factors, including high demand growth combined with inadequate power system managements, unreasonable tariff policies, allowing power suppliers to compete and for consumers to choose the suppliers they want. Deregulation is needed to meet the global demand for electricity at an affordable price. Mostly in developed countries, the key aim of deregulation of power system is to draw different types of investments. Reformation of power sectors aim to increase efficiency of electricity production and usage.

. Congestions in transmission lines are the results of insufficient transmission capacity to meet the energy demand from end users. Uncontrolled congestion leads to power causes grid disruptions, which creates further outages in an integrated system, affecting the power system's components and bring harm to the power qualities. Congestion in transmission line might leads to price divergence in different submarkets. Efficient congestion managements are important for both short-term and long-term transmission and generation investments.

Previously, congestion issue has been solved by locating a series Flexible Alternative Current Transmission System (FACTS) device. These FACTS devices reduce the flows in extremely congested lines, which allow better utilization of existing grid lines. The devices are installed in different locations based on the power flow index of the lines. The devices will provide a specified amount of active and reactive power into a node in order to regulate the power flow when there is congestion [1]. However, FACTS devices are expensive in order to secure the system. Another method of managing congestion is using demand response program (DRP). However, DRP is not profitable for reducing rescheduling cost as generators no longer run at equal incremental costs [2]. In [3], placement of Thyristor-Controlled Series Capacitor (TCSCs) is used to minimize cost due to congestion based on the factor analyzed [4]. In addition, FACTS controllers are tested using techniques from Linear Programming Method such as Genetic Algorithm, Particle Swarm Optimization [5], Tabu Search and Simulated Annealing [6].

Congestion issues can also be solved using either Classical Method or Linear Programming Method, which are able to solve complex congestion problems. Classical Method, however, is not a preferable choice since its system is complex, weak convergence and is unable to solve real-world large scale power networks. Linear Programming Method is under the Artificial Intelligence (AI), which can solve complicated real-world networks problems. Fuzzy Logic Method is one of the Linear Programming Method that is simpler compared to other AI alternatives. Fuzzy Logic controller can be adapted into both online and offline system, where these two modes will require different setups [7]. Online system is used along with an adaptive controller to obtain a real-time interference; however, it will require a high-speed processor. Meanwhile, offline implementation will require a lookup table which will display all the range of data needed for each fuzzy input and output range.

This paper presents the usage of fuzzy logic approach to solve congestion problems by detecting the congested lines, based on price and customers' load usage. The simulation will be run on MATLAB using the IEEE Reliability Test System (RTS) 1996 24 Bus System's Weekly and Daily Peak Load data as the input for load.

II. Methodology

This section includes an overview of the research methodology used in the review. It contains details about the samples, such as the study's eligibility requirements and how they were collected. This part examines why the design and methods are selected for the research. The instruments that would be used to collect data is also listed, as are the protocols that were implemented to conduct this analysis. The techniques used to interpret the data are often discussed and analyzed.

A. System Design

The design of circuit used in this paper is using the RTS 1996 24- Bus System [8]. The IEEE Reliability Test System was created by the IEEE reliability subcommittee in 1979 to produce a standard testing system that could be used to analyses and compare the results from different approaches used.

In this system, there will be two inputs and one output. The first input is price for the electricity, which will be set as low [0.0,0.5], average [0.35,0.80] and high [0.85,1]. As these values are depending on users' preferences, where the common pricing rates used will be either low, average or high.

The next input: load values, will be taken from the RTS-96 System. The data for Weekly Peak Load and Daily Peak Load shown below will be used for simulation as tabulated in Table I and Table II.

TABLE I
WEEKLY PEAK LOAD

SUMMER WEEKS					
HOUR	PEAK LOAD (%)		HOUR	PEAK LOAD (%)	
	WEEKDAY	WEEKEND		WEEKDAY	WEEKEND
12-1AM	64	74	12-1AM	99	93
1-2	60	70	1-2	100	92
2-3	58	66	2-3	100	91
3-4	56	65	3-4	97	91
4-5	56	64	4-5	96	92
5-6	58	62	5-6	96	94
6-7	64	62	6-7	93	95
7-8	76	66	7-8	92	95
8-9	87	81	8-9	92	100
9-10	95	86	9-10	93	93
10-11	99	91	10-11	87	88
11-12PM	100	93	11-12PM	72	80

The output will be congestion levels detected in each of the transmission lines. Thus, a value of [0.0,0.2] is considered as no congestion, a higher value [0.15,0.45] is low congestion, [0.40,0.70] is moderate, [0.65,0.95] high congestion and [0.85,1] is the highest congestion value. These values will reflect the congestion level of each transmission lines; thus, the collection of these values compose a set of fuzzy measures.

TABLE II
DAILY PEAK LOAD

DAY	PEAK LOAD (%)
MONDAY	93
TUESDAY	100
WEDNESDAY	98
THURSDAY	96
FRIDAY	94
SATURDAY	77
SUNDAY	75

B. Fuzzy Logic Approach

Generally, binary sets are made up of two values of logic whether it is true or false, whereas fuzzy logic parameters will be in the intervals of 0 until 1, implying that they are somewhere between completely true and false. Fuzzy logic is a multivalued logic that deals with nearness instead of exact values. It allows ones to function through unclear and contradictory contexts and thus overcome poorly done or unfinished issues. Fig. 1 shows the example of fuzzy logic reasoning method.

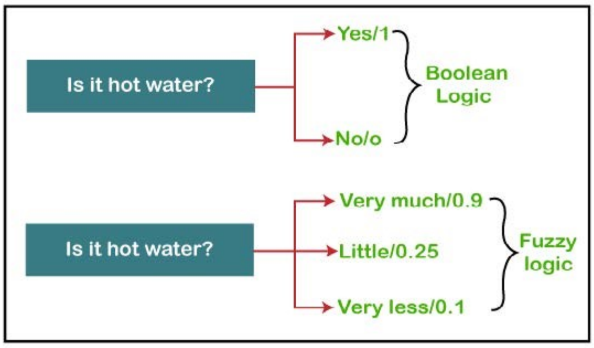


Fig. 1. Example for Fuzzy Logic Reasoning Method

Operational constraints can be represented by this technique. Fuzzy logic may be used with either hardware or software, or a hybrid of the two [6]. Fuzzy reasoning has the advantage of making it easier to arrive at an understandable inference when supplied with indistinct, inaccurate, noisy, or incomplete data. It behaves much like a person might react, except that it responds much quicker. The easy and clear rule-based technique is known as "IF X AND Y than Z". Fuzzy logic is a simpler way of handling and structuring results. Fig. 2 shows the fuzzy logic process which can be described as follows.

a) Fuzzification refers to the mechanism of changing real input parameters into fuzzy values.
b) Defuzzification refers to the mechanism where the output parameters undergo the opposite of fuzzification process. (Converts fuzzy value to a crisp value).
c) Parameters for the inputs are known as "Membership Functions".
    - Each input is divided into a set of values
    - Each input is to be defined
    - Output values will be depending on the rules set for inputs

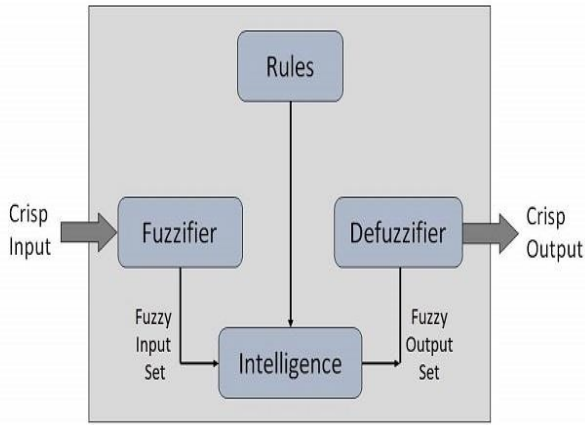


Fig. 2. Fuzzy Logic Process

C. Fuzzy Set Rules

Fuzzy Logic Rules uses the principle of "IF X AND Y, THEN Z". The inputs and output will be based on the previously mentioned values. Thus, the simplified rules of fuzzy logic that are used are tabulated in Table III.

TABLE III
FUZZY SET RULES

LOAD LEVEL	PRICE	CONGESTION
LOW	HIGH	NO CONGESTION
	AVERAGE	
	LOW	
NORMAL	HIGH	LOW
	AVERAGE	MODERATE
	LOW	HIGH
HIGH	HIGH	MODERATE
	AVERAGE	HIGH
	LOW	VERY HIGH

Fig. 3 show the flowchart process for the fuzzy logic. In this paper, we want to determine whether the system belongs to the set of system categorized as low, moderate or high congestion. From Table III, some of the rules are:

(a) If load level is low, and regardless of the price, then there will be no congestion
(b) If load level is normal, and price is low, then there will be high congestion (since usage is high during low price)

(c) If load level is high, and price is high, then there will be moderate congestion (since usage is high regardless of the high charges)

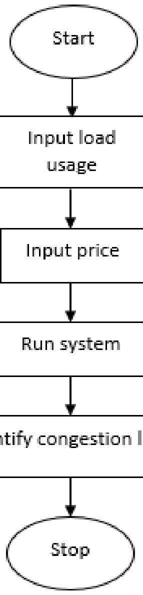


Fig. 3. Flowchart process for Fuzzy Logic

The initial step for the fuzzy design is illustrated in Fig. 4, and the membership functions for load and price are set to three main ranges as shown in Fig. 5 and Fig. 6 respectively.

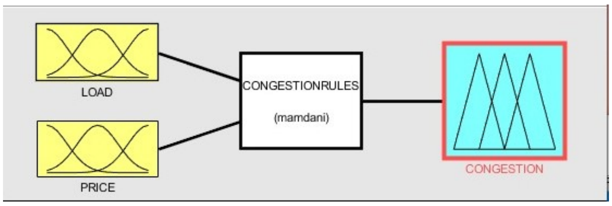


Fig. 4. Initial Step for Fuzzy Design

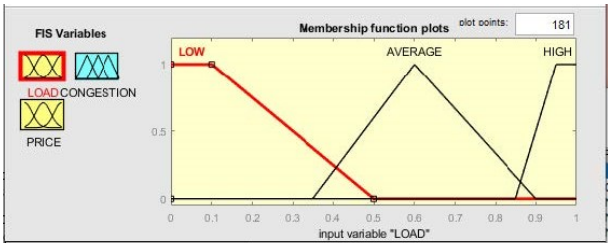


Fig. 5. Load Membership Function

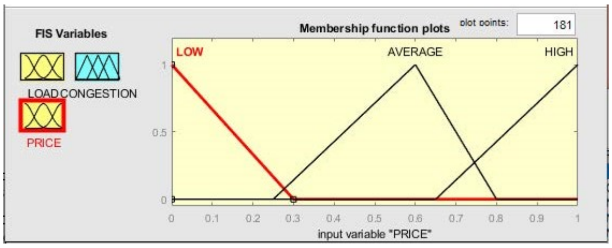


Fig. 6. Price Membership Function

The range set for congestion level is set to no congestion, low, average, high and very high congestions as shown in Fig. 7. Fig. 8 shows the editor for the fuzzy set rules.

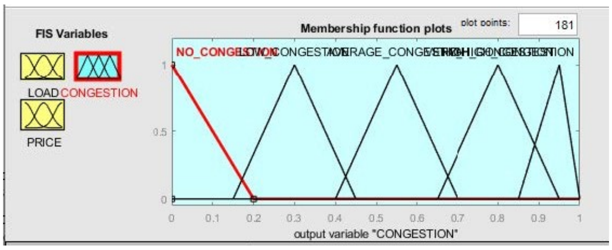
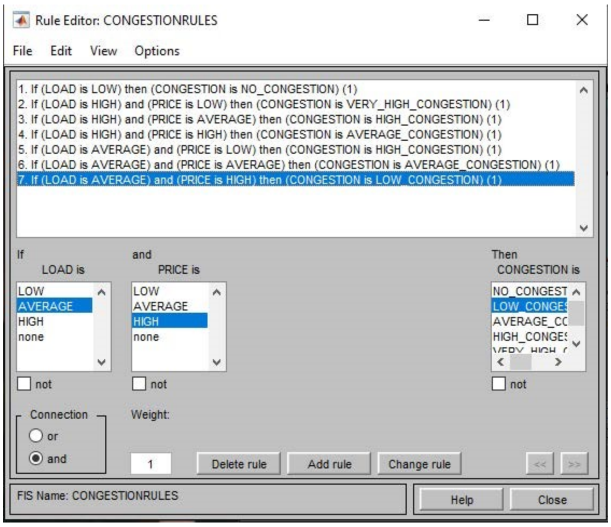


Fig. 7. Congestion Level Membership Function



1. If (LOAD is LOW) then (CONGESTION is NO_CONGESTION) (1)
2. If (LOAD is HIGH) and (PRICE is LOW) then (CONGESTION is VERY_HIGH_CONGESTION) (1)
3. If (LOAD is HIGH) and (PRICE is AVERAGE) then (CONGESTION is HIGH_CONGESTION) (1)
4. If (LOAD is HIGH) and (PRICE is HIGH) then (CONGESTION is AVERAGE_CONGESTION) (1)
5. If (LOAD is AVERAGE) and (PRICE is LOW) then (CONGESTION is HIGH_CONGESTION) (1)
6. If (LOAD is AVERAGE) and (PRICE is AVERAGE) then (CONGESTION is AVERAGE_CONGESTION) (1)
7. If (LOAD is AVERAGE) and (PRICE is HIGH) then (CONGESTION is LOW_CONGESTION) (1)

LOAD is: LOW, AVERAGE, HIGH, none

PRICE is: LOW, AVERAGE, HIGH, none

Weight: 1

FIS Name: CONGESTIONRULES

Fig. 8. Fuzzy Set Rules

III. Fuzzy Logic Results

From the completion of the fuzzy logic design, the membership functions of load, price and congestion level can be tested. The results will be shown on the Fuzzy Rule Viewer and Fuzzy Surface Viewer. Fuzzy Rule Viewer will analyze the results based on the values set for the inputs which are load level and price, and the results will show the congestion level. The accuracy of Fuzzy Logic is mainly influenced by two matters; 1) it is impossible to obtain an accurate mathematical domain for the system's model and 2) the output only produces estimations for the problems to be solved [9]. Thus, the accuracy of the results using this system will be mainly depending on the accuracy of the input data or the expected results required by the user.

In this paper, the level of each parameter needed are displayed in a graph as shown in Fig. 9. While for the Surface Rule Viewer, the results are shown in a three-axis graph as in Fig. 10. However, the parameters shown are still similar as those in Fuzzy Rule Viewer. For instance, in Fig. 10, the inputs values are set to 0.8 (load) and 0.5 (price), the output will be 0.55 (congestion level).

These steps are repeated by changing the load values from RTS-96 and prices range used.

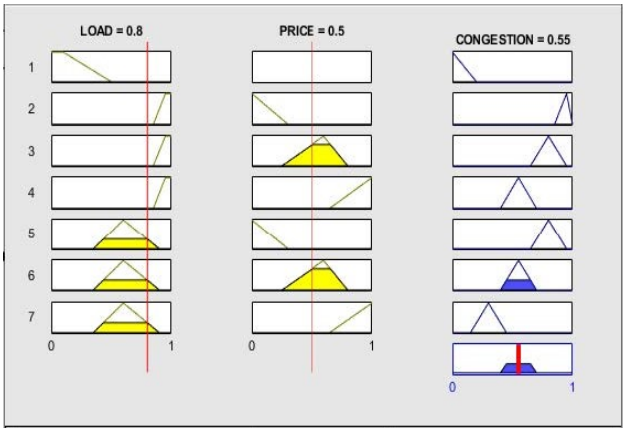
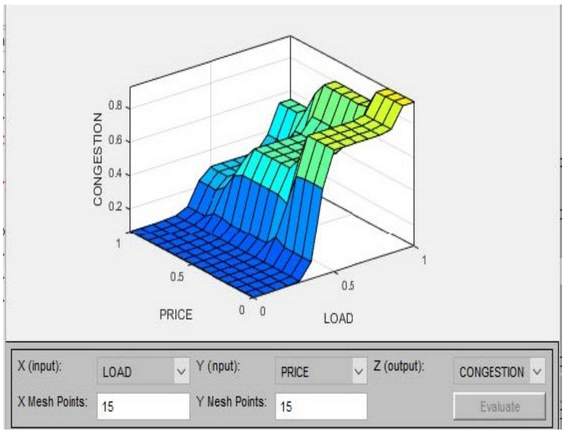


Fig. 9. Fuzzy Rule Viewer



X (input): LOAD
Y (input): PRICE
Z (output): CONGESTION
X Mesh Points: 15
Y Mesh Points: 15

Fig. 10. Fuzzy Surface Viewer

IV. Simulation Result

The testing results from weekly load data and daily load data are tabulated below in Table IV and Table V.

TABLE IV
CONGESTION LEVEL FOR WEEKLY PEAK LOAD DATA

WEEK	PEAK LOAD	PRICE		
		CHEAP (0.150)	AVERAGE (0.525)	EXPENSIVE (0.900)
1	0.862	0.682 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
2	0.900	0.688 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
3	0.878	0.685 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
4	0.834	0.935 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
5	0.880	0.685 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
6	0.841	0.901 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
7	0.832	0.935 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
8	0.806	0.938 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
9	0.740	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
10	0.737	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
11	0.715	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)

12	0.727	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
13	0.704	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
14	0.750	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
15	0.721	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
16	0.800	0.938 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
17	0.754	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
18	0.837	0.934 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
19	0.870	0.683 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
20	0.880	0.685 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
21	0.856	0.682 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
22	0.811	0.937 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
23	0.900	0.688 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
24	0.887	0.686 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
25	0.896	0.688 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
26	0.861	0.682 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
27	0.755	0.942 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
28	0.816	0.937 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
29	0.801	0.938 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
30	0.880	0.685 (Moderate congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
31	0.722	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
32	0.776	0.941 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
33	0.800	0.938 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
34	0.729	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)

35	0.726	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
36	0.705	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
37	0.780	0.940 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
38	0.695	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
39	0.724	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
40	0.724	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
41	0.743	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)

TABLE V
CONGESTION LEVEL FOR DAILY PEAK LOAD DATA

WEEK	PEAK LOAD	PRICE		
		CHEAP (0.150)	AVERAGE (0.525)	EXPENSIVE (0.900)
1	0.930	0.688 (Moderate congestion)	0.800 (High congestion)	0.500 (Moderate congestion)
2	1.000	0.688 (Moderate congestion)	0.800 (High congestion)	0.500 (Moderate congestion)
3	0.980	0.688 (Moderate congestion)	0.800 (High congestion)	0.500 (Moderate congestion)
4	0.960	0.688 (Moderate congestion)	0.800 (High congestion)	0.500 (Moderate congestion)
5	0.940	0.688 (Moderate congestion)	0.800 (High congestion)	0.500 (Moderate congestion)
6	0.770	0.941 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)
7	0.750	0.943 (Very high congestion)	0.800 (High congestion)	0.550 (Moderate congestion)

V. Discussion

Table IV and V tabulate the results of congestion levels implemented on the RTS-96 24 Bus System. From table IV, each week shows different congestion levels when the prices and load usage are changed. The levels of congestion existing in this system only varies from moderate to very high congestion, as there are no days or weeks where load usage is relatively low. It can be said that congested lines are mainly caused by high load when prices are low. Based on the results in both Fig. 11 and Fig. 12, it is shown that congestions mostly occur when prices of the electricity are cheap. When prices are high, the congestion levels are moderate, since users limit their usage to prevent paying high rates. Thus, it can be said that the congestion level mainly depends on the price charge for electricity. Consumers might have high consumption if price is too cheap, and low consumption if price is too expensive. These kind of variation in prices will need a particular pricing method in order to benefit both parties (electricity supplier and consumer).

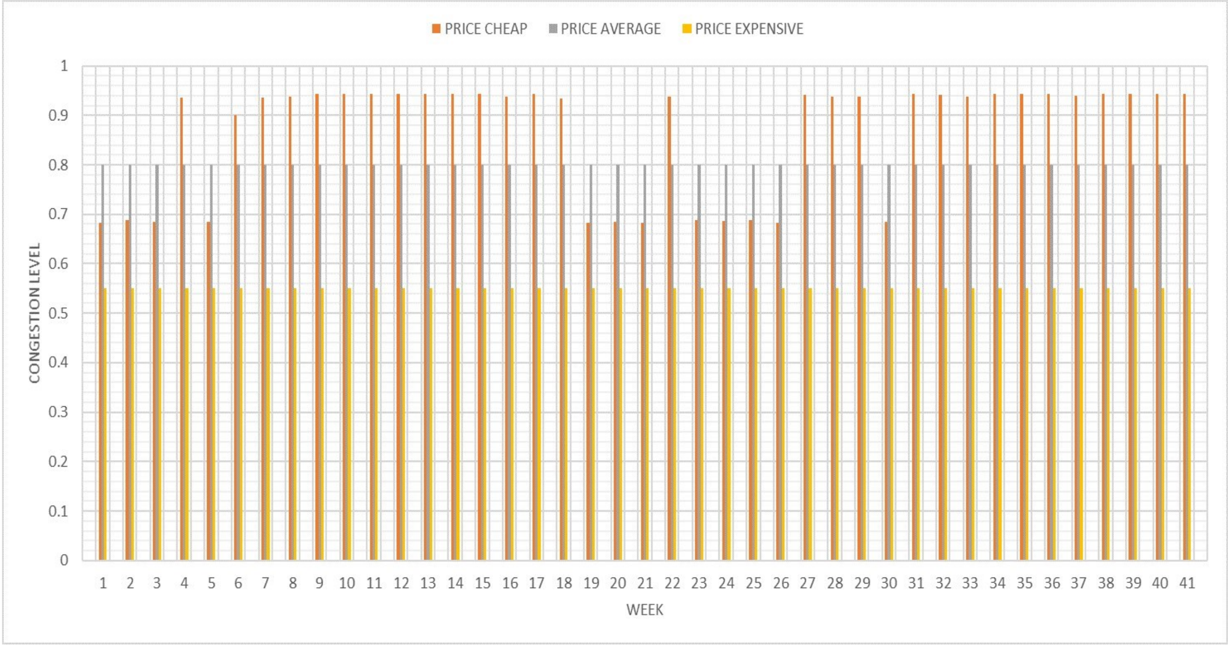


Fig. 11. Graph for Weekly Load Data

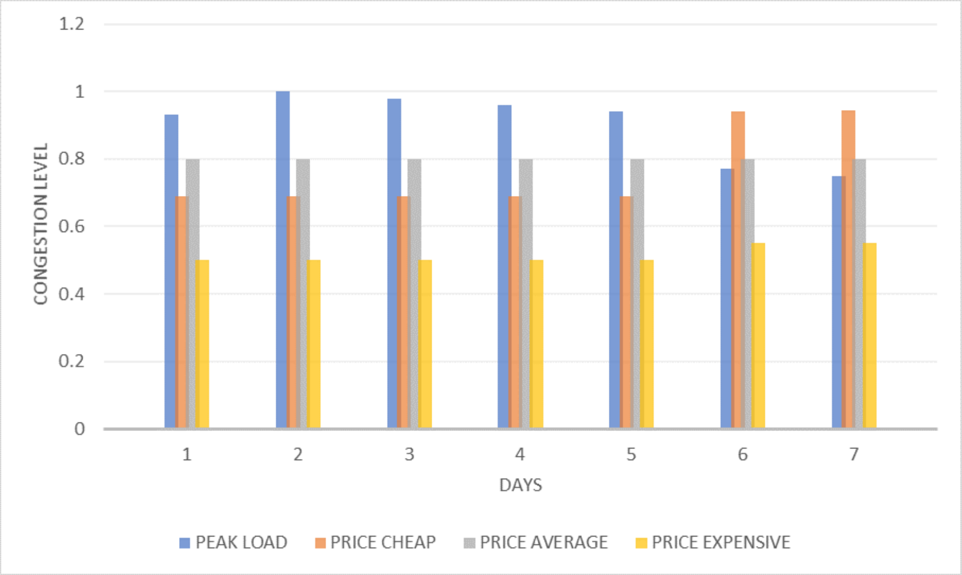


Fig. 12. Graph for Daily Load Data

Malaysia current tariff for electricity can be improved better according to customer's usage. Among the three main electric companies in Malaysia (Tenaga Nasional Berhad (TNB), Sarawak Energy Berhad (SEB) and Sabah Electricity Sdn. Bhd. (SESB)), TNB have the highest charges for their consumers, followed by SESB and lastly SEB. These differences in tariff can be changed to be uniform in order to promote better services to consumers. The two most common methods for pricing are Nodal Pricing Method and Zonal Pricing Method [10]. Concept of Nodal Pricing is charging different prices at different individual buses. The price for a node is basically the price difference between the generator and the destination place. Nodes in the transmission lines are priced respectively according to their measured power flow [3]. Consumers are priced individually and does not pay extra fees due to usage from commercial businesses that consume higher energy. Nodal Pricing offers better pricing system that strives to transparency [10]. Meanwhile, the basic idea of Zonal Pricing Method is charging uniform prices inside a zone. Network nodes are combined into one zone which share the same price, known as Zonal Pricing [11]. In zonal pricing, zones with high congestion are those who consume high energy while zones with low congestion are those who consume less energy. Zonal Pricing is less transparent when it comes to pricing. Consumers that fall under the same zone will have to pay high electricity bills regardless of the usage [3]. This will be unfair for those in industrial zones since they must pay higher values even though the congestion is mainly caused by commercial businesses. If deregulated system is to be applied fully in Malaysia, the generation and distribution companies can charge the price to the consumer according to the congestion level in the transmission line. If there is high demand in a highly congested line, higher price will be charged to the consumer that uses the electric utility which transmit through that line. This pricing strategy that is based on Fuzzy Logic is a better way to control energy usage in order to prevent congestion in lines.

VI. Conclusion

A deregulated power system is a reliable system that can be used in worldwide application to increase quality of the current controlled system used. In this paper, one of the ways to control congestion is by using Fuzzy Logic Approach. Managing congestion problems involve dealing with approximation, since the level of congestion can be predicted and divided into a certain interval.

The usage of Fuzzy Logic Approach can be used to identify the congestion level in transmission lines. Since the congestion level are known, it is easier for utility brokers to decide on the charges set for consumers. The results used are from energy usage in IEEE RTS96, which are the weekly and daily load. In order to manage congestion, the pricing methods suggested are Zonal and Nodal Pricing method.

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