Computational Intelligence Based Technique for Load Shedding Scheme

Lukman Hakim Hamron
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
e-mail: akimhbw89@gmail.com

***Abstract*—Losses in generation and overloading effect are two phenomena that may occur due to progressing demand at the load side. This may lead to system instability in forms of voltage and frequency. In order to avoid this problem, the under voltage load shedding scheme can be performed to shed some amount of load before the disturbance occur. This paper presents computational intelligence technique for load shedding. The study involves the development of fuzzy rules in order to make decision on load shedding. This method functions will determine the selected bus for load shedding and amount of load that needs to be shed depending on the measured minimum voltage of the system. The result of this paper will show the performance of under voltage load shedding scheme in determining power system stability by shedding some amount of the load demand. The technique has been validated on the IEEE 30-bus system and MATLAB software is used to run the simulation.**

***Index Terms*—voltage collapse, system stability, fuzzy logic, under voltage load shedding**

I. INTRODUCTION

In power system operation, the balance between load demand and the available generation is important to make sure the stability of the system is in good condition [1]. Nowadays, there are many situation occur where the demand load have reached the limit of an available generation in certain place. When this condition occurs, there will be same situation as in 2005 where there was power outage in Malaysia where many states of Malaysia's northern peninsular, including Perlis, Perak, Penang and Kedah due to the occurred fault. This situation happened due to the load demand used by the user has exceed the limit that the available generation can support. From this situation a load shedding scheme is initiated to avoid the system from collapsed [2]. There are many factories have take improvement step to prevent this phenomena happening again by developing a new alternative extensively to ensure the power system network operates in the normal steady state condition conveniently [3].

A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable drop in voltage [4]. The main factor for instability is the inability of the power system to meet the demand of increased reactive power. Literally, it will cause the system collapse.

There are several studies that indicate about voltage stability of the power system. One of these studies is about estimating the voltage stability of power system [5]. This study is based on the fast calculation of indicators of risk of voltage instability has been developed. These indicators can detect on-line voltage instability and signal the tendency towards a critical situation.

Several methods have been developed to prevent the voltage from collapse. In this paper load shedding is applied to the selected bus so the voltage minimum will increase and the system become stable. This technique is proposed to make sure the system in a balanced condition. In [6], there are several methods to perform the load shedding technique such as under-voltage load shedding and under-frequency load shedding. The best way to perform load shedding scheme in a system is by minimizing the amount of load to be shed [7] for voltage collapse prevention. In [7], the paper study about the practical approach to perform the load shedding scheme.

In order to perform the developed technique, a fuzzy logic algorithm was proposed. This algorithm provides solution as decision making to determine which load bus that need to be shed and how much load will be shed to make sure the system recover to the normal operation. Fuzzy logic was a useful algorithm where it can be used in wide area of study. In [8], fuzzy logic was used to solve the unit commitment problem. While in [9], fuzzy load shedding based algorithm is performed by using voltage stability indicator for averting voltage collapse. In this paper, fuzzy logic is performed by monitoring the minimum voltage by running the load flow. Then under voltage load shedding will be perform to get the system back to normal operation. The variable is selected from the load flow results.

This paper presents computational intelligence based technique for load shedding scheme. The study involves the development of fuzzy rules in order to make decision on load shedding. Results from the experiment indicated that the proposed technique is successful to solve the load shedding problems. The load levels increase are divided into several different loading factors. The fuzzy technique is applied to each case to select load bus to be shed and to calculate the amount load to be shed to prevent voltage instability.

II. UNDER-VOLTAGE LOAD SHEDDING

When a transmission system becomes stressful due to the overload, the voltage instability or voltage collapse could be experience by the system [10]. The philosophy of UVLS is that whenever the system is perturbed and voltage drops to a certain pre-selected level for a certain pre-determined time period, then selected loads may be cut off [11]. In some research, by shedding some of the loads in a system the voltage magnitude will recover to its normal level. In practical, load shedding schemes requires coordination between protection engineers and system planners to set up the amount to be shed without affecting its security.

Data below shows the acceptable range value to be the reference during generation of data. Some function has been created to devide the results to determine their range of stable voltage.

Min(Vm)<0.95 = unstable
0.95<min(Vm)<1.05 = stable

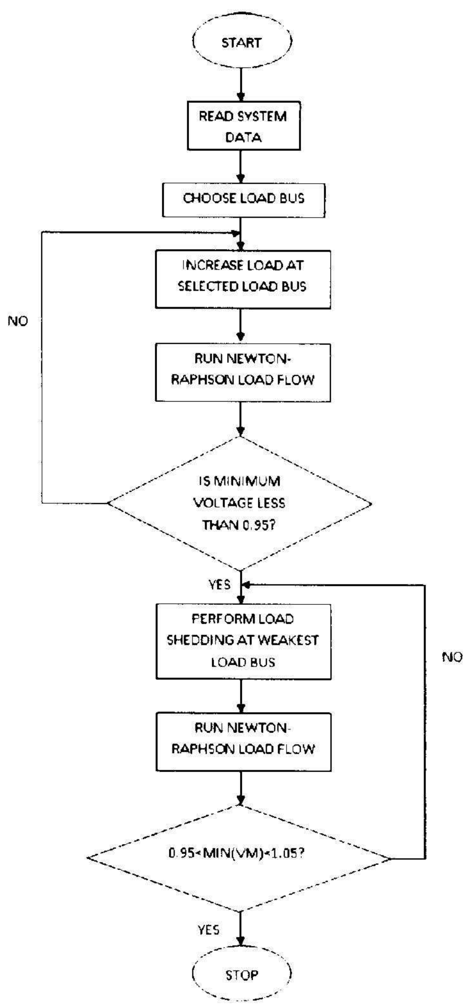


Figure 1: Flowchart of load shedding process.

The objective of a UVLS scheme is to restore reactive power balance in the power system, to prevent voltage collapse and to keep a voltage problem within a local area rather than allowing it to spread out by shedding some loads [12].

III. IEEE 30-BUS TEST SYSTEM

The test system used in this study is the IEEE-30 RTS. The system has six generators, four under load tap changing transformers, two shunt capacitor and thirty seven lines. In the base case the total system load is 2.834 pu, the swing bus (bus number 1) generates real power of 2.5687 pu, while the other generators generate 0.4 pu real power. Figure 1 illustrates the single line diagram of IEEE 30-bus system.

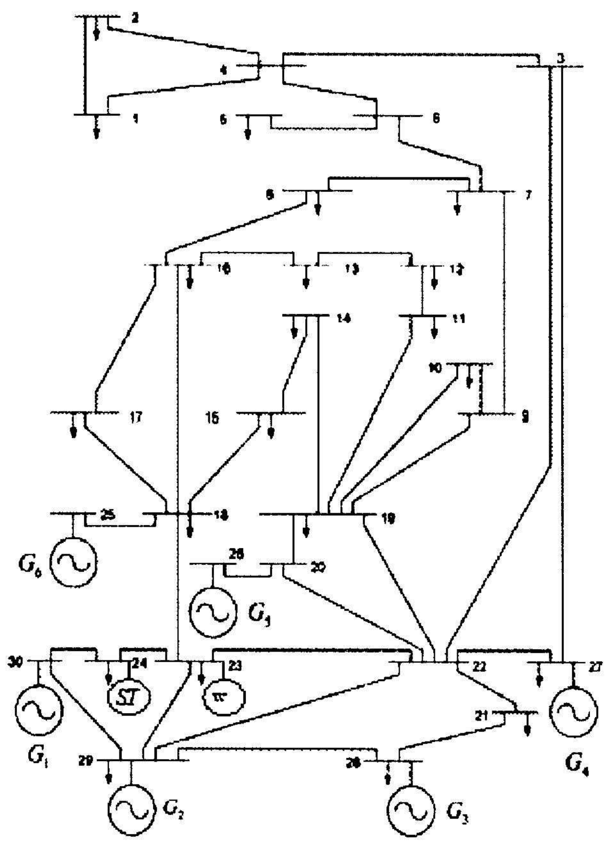


Figure 2: IEEE 30-BUS TEST SYSTEM
(Source: ljs.academicdirect.org)

IV. DATA GENERATION

Fuzzy logic load shedding need data to perform the rules. As IEEE 30 bus system, it has five generator buses, one slack bus, 6 intermediate buses and eighteen load buses. The load shedding technique is performed by creating several conditions. Load factor is increased in order to indicate load variation in the system. By increasing the load bus, the system stability will change and may cause voltage instability due to the load increase in the system. Load shedding then perform by selecting the weakest bus.

V. FUZZY LOGIC ALGORITHM

The fuzzy system consists of three parts which are fuzzification, fuzzy inference and defuzzification [13-15]. In fuzzification, it will involve the process of transforming input variable into a membership for linguistic terms of fuzzy sets. While fuzzy inference system is used as a drawing conclusion from the set of fuzzy rules. The fuzzy rule is a set of if-then linguistic term [15]. For the defuzzification, it converts the fuzzy output values back into output actions. In this paper, fuzzy logic algorithm is allowed to determine the suitability of each bus and the one with the highest suitability chosen for load shedding. The FLS Editor displays general information about the fuzzy inference system.

A. Bus Selection for load shedding

The fuzzy FIS Editor for selected bus load shedding is illustrated in Figure 3, 4 and 5. The input variable of the FIS Editor are voltage magnitude (Vm) which divides into four categories as shown in Figure 4 and loading factor in Figure 3. The output is the percentage of selected bus to be shed also divides into 4 categories as shown in Figure 5.

Inputs: Lf (Loading factor) Trapezoidal membership function as shown in Figure 3
VM (Voltage Magnitude) Triangle membership function as shown in Figure 4.
Output: PSBLS (Percentage Selected Bus Load Shedding) Triangle membership function as shown in Figure 5.

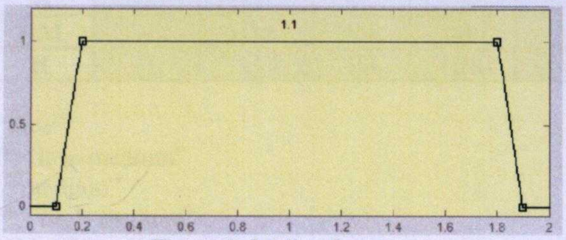


Figure 3: loading factor

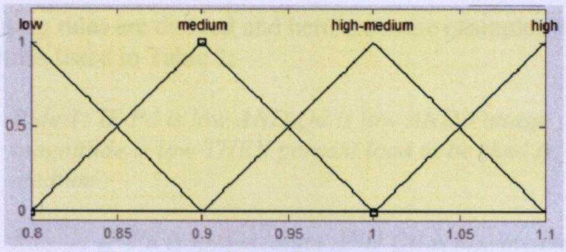


Figure 4: Voltage Magnitude (Vm)

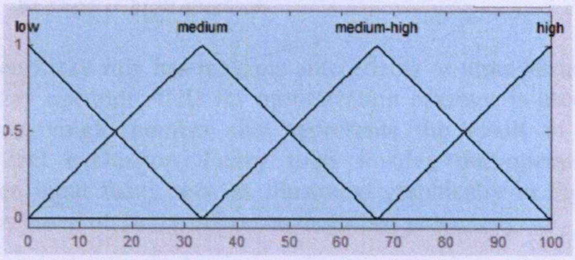


Figure 5: Percentage selected bus

In fuzzy logic system, an IF-THEN basic rule-based system is used. IF statement is refer as antecendent while THEN statement is as consequent. In this section, fuzzy rule system is determined to form decision on the fuzzy input derived from the voltage magnitude and loading factor. For this fuzzy to find the selected bus for load shedding, 4 rules were developed which are:

Rule 1: IF loading factor is 1.1 AND Voltage magnitude is low THEN percent selected bus is high

Rule 2: IF loading factor is 1.1 AND Voltage magnitude is medium THEN percent selected bus is high-medium

Rule 3: IF loading factor is 1.1 AND Voltage magnitude is high-medium THEN percent selected bus is medium

Rules 4: IF loading factor is 1.1 AND Voltage magnitude is high THEN percent selected bus is low

B. Algorithm for Amount of Load to be Shed

The fuzzy FIS Editor for selected bus load shedding is illustrated in Figure 6, 7, 8 and 9. The input variable of the FIS Editor are voltage magnitude (Vm), active power (Pd) and reactive power (Qd) while the output is the percentage amount of load to be shed.

Inputs: Pd (Active Power) Triangle membership function as shown in Figure 6
Qd (Reactive Power) Triangle membership function as shown in Figure 7
VM (Voltage Magnitude) Trapezoidal membership functions as shown in Figure 8.
Output: PAL (Percentage amount of load to be shed) Triangle membership function as shown in Figure 9.

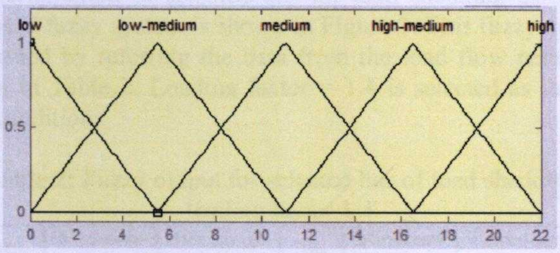


Figure 6: Active Power (Pd)

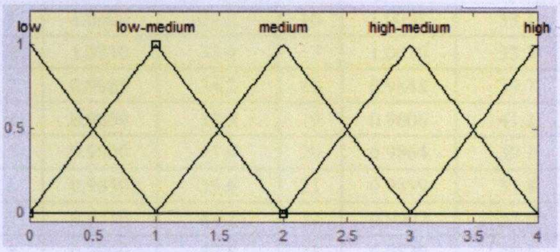


Figure 7: Reactive Power (Qd)

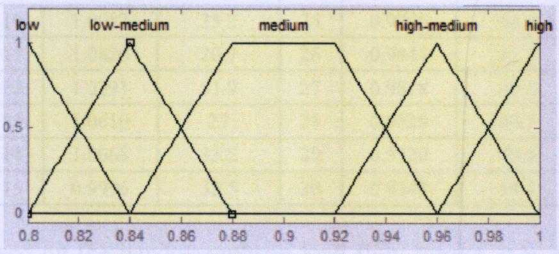


Figure 8: Voltage Magnitude (Vm)

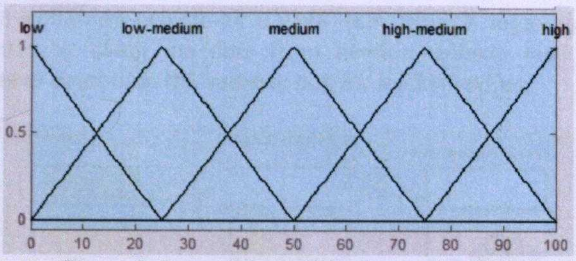


Figure 9: Percentage Amount Load to be shed

The fuzzy analysis of this method was developed using the same technique as described in the previous method. The fuzzy rules to find the amount load to be shed are as in Table 1. It is necessary to establish a meaningful system for representing the linguistic variables in the matrix. For this case the following will be used:

Table 1: Fuzzy decision matrix

AND		Voltage Magnitude				
		L	LM	M	HM	H
Pd, Qd	L	M	M	LM	LM	L
	LM	HM	M	M	LM	LM
	M	HM	HM	M	M	LM
	HM	H	HM	HM	M	M
	H	H	H	HM	HM	M

"L": "low"
"LM": "low-medium"
"M": "medium"
"HM": "high-medium"
"H": "high"

25 fuzzy rules are derived and here are some examples of the fuzzy rules listed in Table 1:

Rule 1: IF Pd is low AND Qd is low AND Voltage magnitude is low THEN percent load to be shed is medium

Rule 2: IF Pd is low-medium AND Qd is low-medium AND Voltage magnitude is low THEN percent load to be shed is high-medium

When fuzzy rule has multiple antecedents or input variable, the fuzzy operator AND for minimization operator is used to obtain a single number that represents the result of the antecedent evaluation. Fuzzy rules involve the operations between input fuzzy sets, as illustrated graphically in Figure 10. It is based on fuzzy inference described previously.

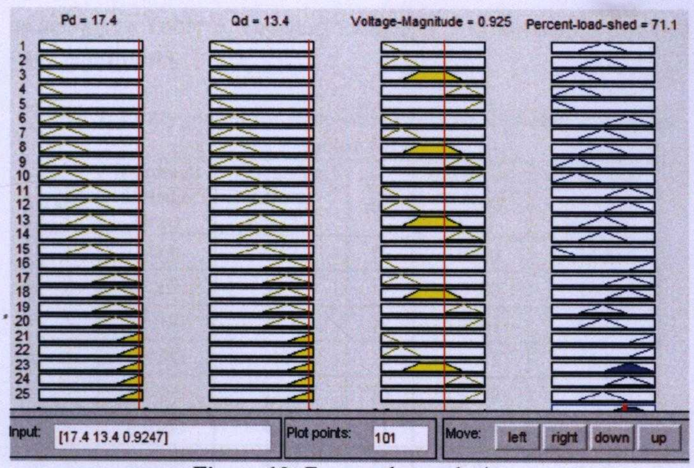


Figure 10: Fuzzy rules analysis

As illustrated in Figure 10, the rows of plots represent the rules while the columns represent the variables. The first three columns of plots (yellow) show the membership functions of the input variables, while the fourth column of plots (blue) shows the membership functions of the output.

VI. RESULTS AND DISCUSSION

Several cases has been selected to represent the output of the program. This study is conduct to show how reliable of computational intelligence system to perform the load shedding in a system.

A loading factor = 1.4

Determination of selected bus for load shedding using the proposed fuzzy system is shown in Figure 9. This fuzzy system performed by referring the data from the load flow results as shown in Table 2. Loading factor = 1.4 is selected as the test case conditions.

Table 2: Fuzzy output for selected bus of load shedding at loading factor 1.4

Bus No.	Minimum Voltage (Vm)	Percentage selected bus (%)	Bus No.	Minimum Voltage (Vm)	Percentage selected bus (%)
1	1.0600	27.2	16	1.0098	33.1
2	1.0230	32.4	17	1.0010	33.3
3	0.9983	34.2	18	0.9848	39.7
4	0.9859	39.3	19	0.9806	41.2
5	0.9800	41.4	20	0.9864	39.1
6	0.9850	39.6	21	0.9899	37.8
7	0.9710	44.2	22	0.9907	37.5
8	0.9900	37.8	23	0.9829	40.4
9	1.0256	32.2	24	0.9730	43.6
10	1.0082	33.2	25	0.9706	44.3
11	1.0820	20.7	26	0.9444	51.5
12	1.0291	31.9	27	0.9818	40.8
13	1.0610	27	28	0.9820	40.7
14	1.0068	33.2	29	0.9520	49.5
15	0.9996	33.5	30	0.9348	54.1

Based on the newton-raphson load flow results, it is shown that the minimum voltage of the system has dropped below the stable condition which at 0.9348 p.u.. Fuzzy logic system operates by using the data from newton-raphson load flow results to determine the suitable bus for load shedding.

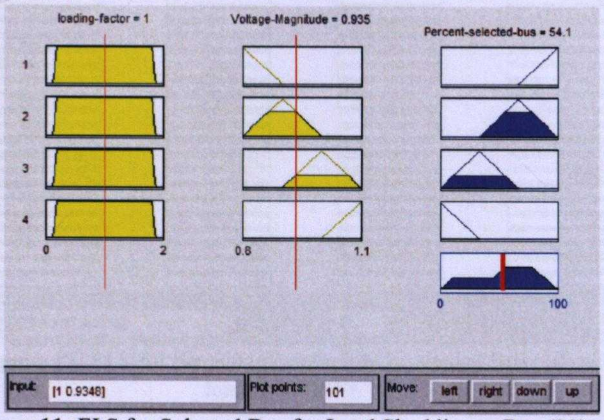


Figure 11: FLS for Selected Bus for Load Shedding at Bus (30) with 1.4 loading factor

As illustrated in Figure 11, it shows that bus 30 is the weakest in the system. Therefore bus 30 is selected as the appropriate bus to perform the load shedding. Figure 10 below shows the fuzzy based load shedding system to determine the amount load to be shed at bus 30.

At bus 30 with 1.4 loading factor, the value of active power and reactive power are 14.84MW and 2.66MVAR respectively.

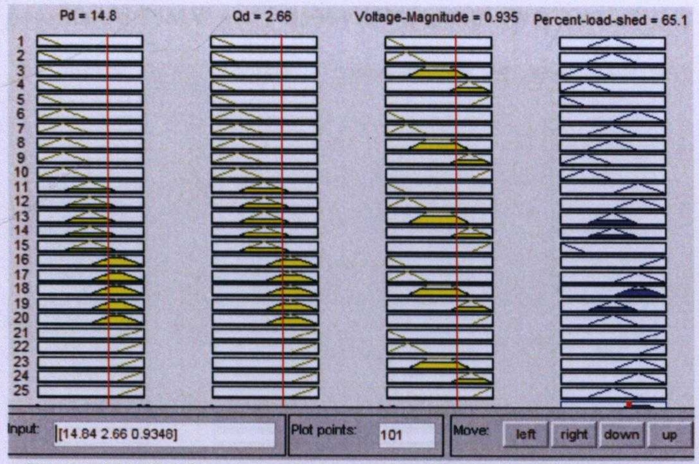


Figure 11: FLS for percentage amount to be shed at Bus (30) with loading factor = 1.4

Based on the Figure 10, it is shown that fuzzy based load shedding system decided to shed the amount of load up to 65.1%. As the results, the amount of load to be shed is 9.6608MW and 1.7317MVAR. The voltage increased at bus 30 from 0.9348 p.u. to 0.9864 p.u. while the minimum voltage at the system increases to 0.9631 p.u. at bus 26. It is shown that the system is improved to a stable condition.

B. loading factor = 1.5

Determination of selected bus for load shedding using the proposed fuzzy system is shown in Figure 9. This fuzzy system is performed by referring to the data from the load flow results as shown in Table 3. Loading factor = 1.5 is selected as the test case conditions.

Table 3: Fuzzy output for selected bus of load shedding at loading factor 1.5

Bus No.	Minimum Voltage (Vm)	Percentage selected bus (%)	Bus No.	Minimum Voltage (Vm)	Percentage selected bus (%)
1	1.060	27.2	16	0.9969	34.8
2	1.0230	32.4	17	0.9880	38.5
3	0.9916	37.1	18	0.9697	44.6
4	0.9782	42	19	0.9655	45.8
5	0.9800	41.4	20	0.9719	43.9
6	0.9765	42.5	21	0.9761	42.6
7	0.9649	45.9	22	0.9768	42.4
8	0.9800	41.4	23	0.9674	45.2
9	1.0173	32.8	24	0.9569	48.1
10	0.9961	35.2	25	0.9546	48.8
11	1.0820	20.7	26	0.9260	56.7
12	1.0171	32.8	27	0.9671	45.3
13	1.0510	28.9	28	0.9721	43.9
14	0.9930	36.5	29	0.9344	54.2
15	0.9853	39.5	30	0.9155	60.1

Based on the newton-raphson load flow results, it is shown that the minimum voltage of the system has dropped below the stable condition which is 0.9155 p.u. Fuzzy logic system operated by using the data from newton-raphson load flow results to determine the selected bus for load shedding.

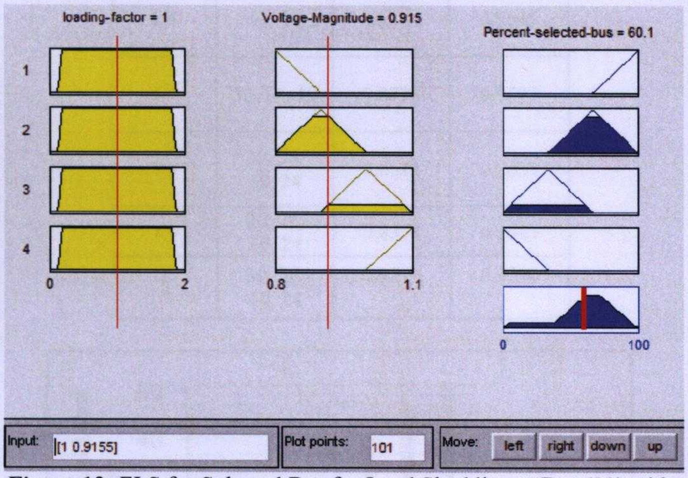


Figure 12: FLS for Selected Bus for Load Shedding at Bus (30) with loading factor = 1.5

From the result above, it shows that bus 30 is the weakest in the system. Therefore bus 30 is selected as the appropriate bus to perform the load shedding. Figure 14 shows the fuzzy based load shedding system to determine the amount load to be shed at bus 30.

At bus 30 loading factor = 1.5, the value of active power and reactive power are 15.9MW and 2.85MVAR respectively.

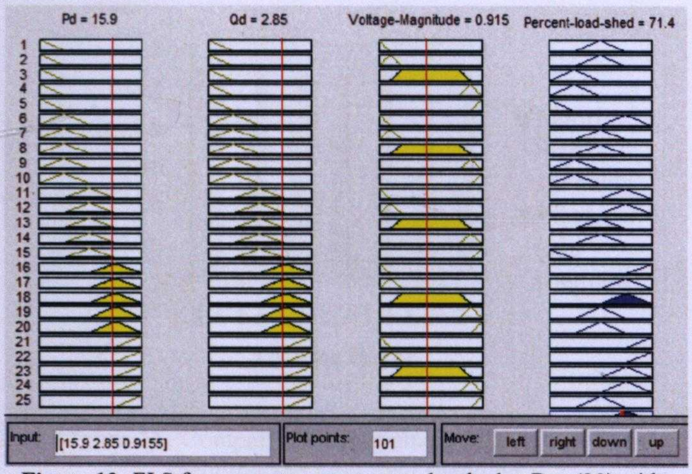


Figure 13: FLS for percentage amount to be shed at Bus (30) with loading factor = 1.5

Based on the Figure 14, it is shown that fuzzy based load shedding system decided to shed the amount of load up to 71.4%. As the results, the amount of load to be shed is 11.3526MW and 2.0349MVAR. The voltage increased at bus 30 from 0.9155p.u. to 0.9757 p.u. while the minimum voltage in the system increase from 0.9155 p.u. to 0.9469 p.u. at bus 26. It shows that the system is still in unstable condition.

Therefore the program decides to shed load at bus 26 as the next step to make the system in stable condition. At bus 26 with loading factor= 1.5, the value of active power and reactive power are 5.25MW and 3.45MVAR respectively.

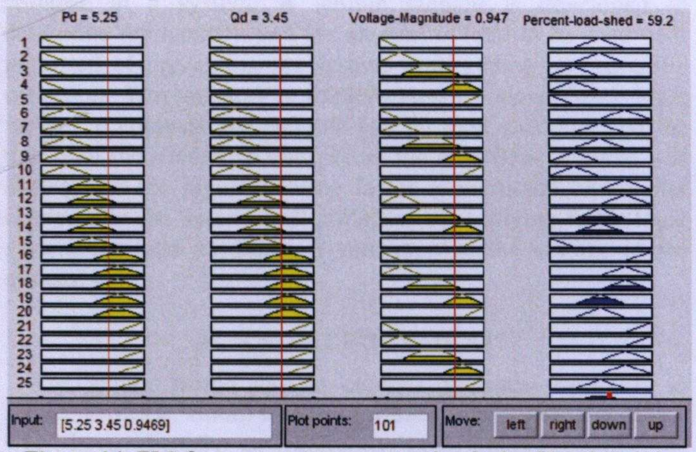


Figure 14: FLS for percentage amount to be shed at Bus (26) with loading factor = 1.5

Based on the Figure 15, it is shown that fuzzy based load shedding system decided to shed the amount of load up to 59.2%. As the results, the amount of load to be shed is 3.108MW and 2.0424MVAR. The voltage increased at bus 26 from 0.9469 p.u. to 0.9699 p.u.. The minimum voltage in the system increase to 0.9700p.u. at bus 7. It is shown that the system is improved to a stable condition.

As the result, the total amount load to be shed in loading factor = 1.5 is 14.4606MW and 4.0773MVAR.

Table 5: Fuzzy output for total sheddable load

Loading Factor	Selected load bus for load shedding	Fuzzy output (percentage)	Total sheddable load Pd (MW)	Total sheddable load Qd (MVar)
1.4	30	66.4%	9.6608	1.7317
1.5	30, 26	71.4% 59.2%	14.4606	4.0773
1.6	30, 26	75% 63.5%	16.276	4.6168
1.7	30, 26, 19	75.1% 75% 61.7%	27.2979	8.6875
1.8	30, 26, 19, 24	77.4% 75% 64% 61.7%	40.0991	17.1099
1.9	30, 26, 19, 24	80.4% 75% 75% 65.6%	45.5613	19.3758
2.0	30, 26 19, 24	83.7% 76.1% 75% 71.1%	49.6928	21.3086

Table 4: Fuzzy output for minimum voltage

Loading Factor	Selected load bus for load shedding	Min(Vm) before load shedding	Min(Vm) after load shedding
1.4	30	0.9348	0.9631
1.5	30, 26	0.9155	0.9700
1.6	30, 26	0.899	0.9645
1.7	30, 26, 19	0.8778	0.9597
1.8	30, 26, 19, 24	0.8612	0.9659
1.9	30, 26, 19, 24	0.8374	0.9641
2	30, 26, 19, 24	0.8213	0.9524

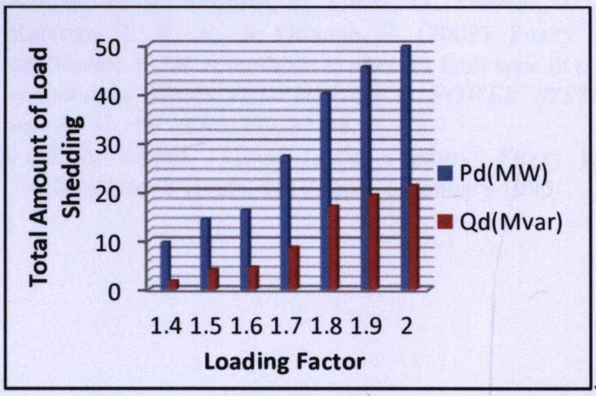
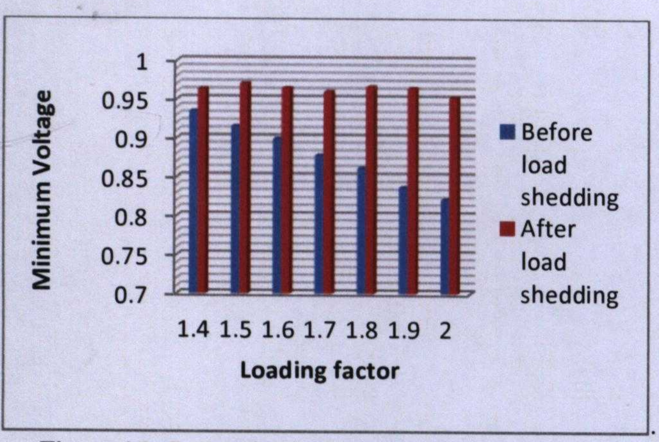


Figure 15: Total amount to be shed at each loading factor



.**Figure 16:** Comparison minimum voltage before load shedding and after load shedding

Table 4 and Table 5 shows the full results of load shedding scheme. The load shedding start at loading factor 1.4 is because system is still stable at loading factor 1.1, 1.2, 1.3. Based on the Table 5, it is shown that the more loading factor is increased, the amount of load to be shed also will increased. Besides that, the minimum voltage in Table 4 also increased after the load shedding scheme is performed.

VII. CONCLUSION

In this paper, UVLS has been applied to avoid voltage collapse in a system. A simple method is developed to determine the location and the amount of load to be shed with purposed of preventing the system from getting into unstable condition. This method is implemented by using fuzzy logic system to compute the suitable bus for load shedding and the values of the sheddable load. From the load flow solution, it is shown that the higher loading factor is increased, the higher chance that the system will collapse. By applying fuzzy logic system for load shedding, it can improve the voltage in the system.

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