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Fuzzy Inference System Approach to Restoration Path Optimization in Power Transmission Lines

Ye Htut Khaing[a]*, Okkar Soe[b]

[a,b]Electrical Power Engineering Department, Yangon Technological University, East Gyogone, Insein Township,Yangon, Myanmar Tel;95-1-966 3249 Fax;95-1-966 3291

[a]Email: uyehtutkhaing.moep.phd@gmail.com

[b]Email: okkarsoe07@gmail.com

Abstract

Power systems have increased in size and complexity and national society depends heavily upon a high level of power system reliability. When the bulk transmission system is subjected to large disturbances there is the possibility of a system wide blackout due to cascading outages. After a partial blackout or system breakdown condition, restoring power system is needed and then power needs to be restored as quickly, stability and reliability as possible and consequently. Outage time after extensive blackouts depends very much on the power system restoration process. Power system restoration is a very challenging task to the operator since the situation is so far from normal conditions. This paper proposes a simulation-based tool MATLAB/SIMULINK that determines suitable restoration transmission lines route with using Fuzzy Inference System for IEEE 6 Bus System.

Keywords: blackout; outage time; restoration process; transmission line routes; Fuzzy Inference System.

1. Introduction

Some of the primary objectives of electrical utilities are customer satisfaction and service reliability. They indeed strongly characterise the service quality. The customer satisfaction can be achieved if customers are supplied as continuously as possible. If power system occurs blackout condition, the operators should be do restoration process as quickly and stability. During blackout or system breakdown condition, the operators in control centres provide information about the actual state of different system variables.

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* Corresponding author.

They have also different types of Energy Management System (EMS) functions that can be used in order to facilitate the assessment of the system and the decision making. The operators carry out analysis on the basis of the above information and, after making a decision, act on the system either directly, by means of the EMS, or by asking the on-site colleagues to execute the control actions. The operator's task is to discover the disturbances in the system's operation [7]. An important aid in this task is given by the visualization of all the elements of the system and their operating status (on/off), as well as by the information about the main system variables (voltage level, load level, branch charge, network configuration etc.).The operators can analyze the actual system state and defined restoration strategy, the operators make step-by-step decisions on restoration actions [1,6].

After a major disturbance in the power system, communication devices are usually overloaded because of client calls which interfere with the communication between the control centres and the substations and the generation sites. Then, some information may not be available to the EMS, but could be communicated from another control centre by telephone [6]. This step-by-step action must be done belatedly.

Therefore, scientific analysis is required to meet the requirements of fast and reliable system restoration. And then, in this paper, the most suitable power system restoration path is analyzed and it will support to do restoration process as quickly and stability.

2. Power System Restoration

Power system restoration after a partial or complete collapse is quite a complex process. Many factor s need to be considered including the operating status of the system, the equipment availability, the restoration time and the success rate of operation. It needs not only a large amount of analysis and verification, but also decisions made by dispatching personnel. Power system restoration is a multi-objective, multi-stage, multi -variable and multi-constraint optimization issue, and is full of non-linearity and uncertainty. It can be described as a typical semi-structured decision-making and it is difficult to obtain a complete solution [9].

The objectives of restoration are to enable the power system to ret urn to normal conditions securely and rapidly, minimize losses and restoration time, and diminish adverse impacts on society.

2.1. Power System Restoration Process

A power system cannot possibly be free from various problems such as line faults, and so on. An essential task in the operation of power systems is restoration after a blackout. The restoration process returns the system back to normal operation after any combination of system components have been lost as a result of an outage. Although a power system is designed and operated in the best circumstances, it still impossible to prevent all contingencies which could cause blackouts. Then the blackout duration is equally important while the physical extent of the blackout is a concern. So, detailed and suitable restoration process with its numerous independent entities is required to ensure that the system [2].

Power system restoration process includes such as:

(i) Assessment of the system status and initial cranking sources, which means that preparation
(ii) Identification and preparation of restoration paths (routes) to build subsystems, network which include generation , transmission and distribution
(iii) Resynchronization of subsystems and restoration of loads
(iv) and then restoration process will be completed [4,5].

The power system restoration process is as shown in Figure1.

3. Restoration Methodology

Many non-structured methods and technologies and object-oriented expert system have been employed in making restoration schemes to address the above objectives, but the establishment and maintenance of a knowledge base of past restorations remains a bottleneck.

The most useful methodologies for power system restoration process are as follows;

- Heuristic Algorithms
- Network Reduction Techniques
- Fuzzy Inference System (FIS)
- Expert System
- Graph Theory (Petri-net) [7]

In this paper, Fuzzy Inference System (FIS) will be used to decide restoration path optimization in proposed system.

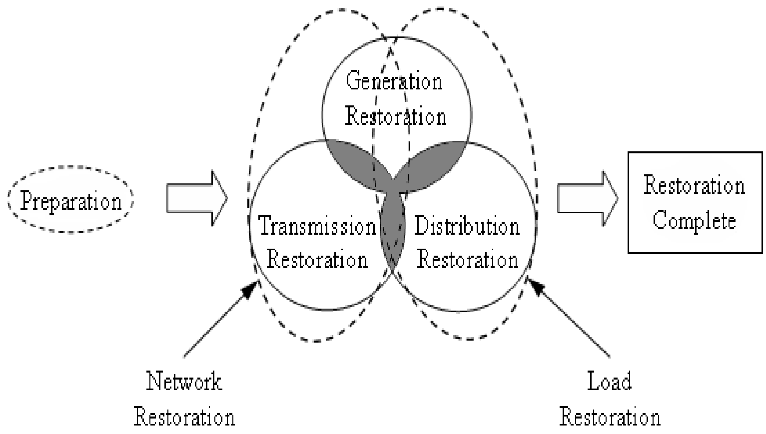

Figure 1: Power System Restoration Process

3.1. Fuzzy Inference System (FIS)

Fuzzy logic (Fuzzy Inference System) was developed by Zadeh in 1964 to address uncertainty and imprecision, which widely exist in the engineering problems. FIS was first introduced in 1979 for solving power system problems.

Fuzzy set theory can be considered as a generalization of the classical set theory. In classical set theory, an element of the universe either belongs to or does not belong to the set. In a fuzzy set theory, the association of an element can be continuously varying. Mathematically, a fuzzy set is a mapping (known as membership function) from the universe of discourse to the closed interval [0, 1].

Membership function is the measure of degree of similarity of any element in the universe of discourse to a fuzzy subset [3]. The membership function is usually designed by taking into consideration the requirement and constraints of the problem. Fuzzy logic implements human experiences and preferences via membership functions and fuzzy rules (AND rule and OR rule).

Due to the use of fuzzy variables, the system can be made understandable to a non-expert operator. In this way, fuzzy logic can be used as a general methodology to incorporate knowledge, heuristics or theory into controllers and decision makers.

The advantages of fuzzy theory are as follows:

(i) It more accurately represents the operational constraints of power systems and
(ii) Fuzzified constraints are softer than traditional constraints.

Momoh have presented the overview and literature survey of fuzzy set theory application in power systems. A recent survey shows that fuzzy set theory has been applied mainly in voltage and reactive power control, load and price forecasting, fault diagnosis, power system protection/relaying, stability and power system control, etc, [8].

3.2. Flow Chart of Restoration Path Optimum

The flow chart of restoration path optimum incorporate fuzzy inference system for this paper schemes can be seen in figure 2.

In this flow chart, 100% (1 pu) is the most perfect value and under of 50% (0.5 pu) is the worst condition. If so, 75% (0.75 pu) will be chosen to decide for restoration path optimum.

4. Proposed System

This system is based on IEEE 6 Bus System, which has three generators, number of eleven 400kV lines (branches) and single line diagram of this proposed system is as shown in figure 3.

Load data, generators data and branches data are as shown in table 1, 2 and 3.

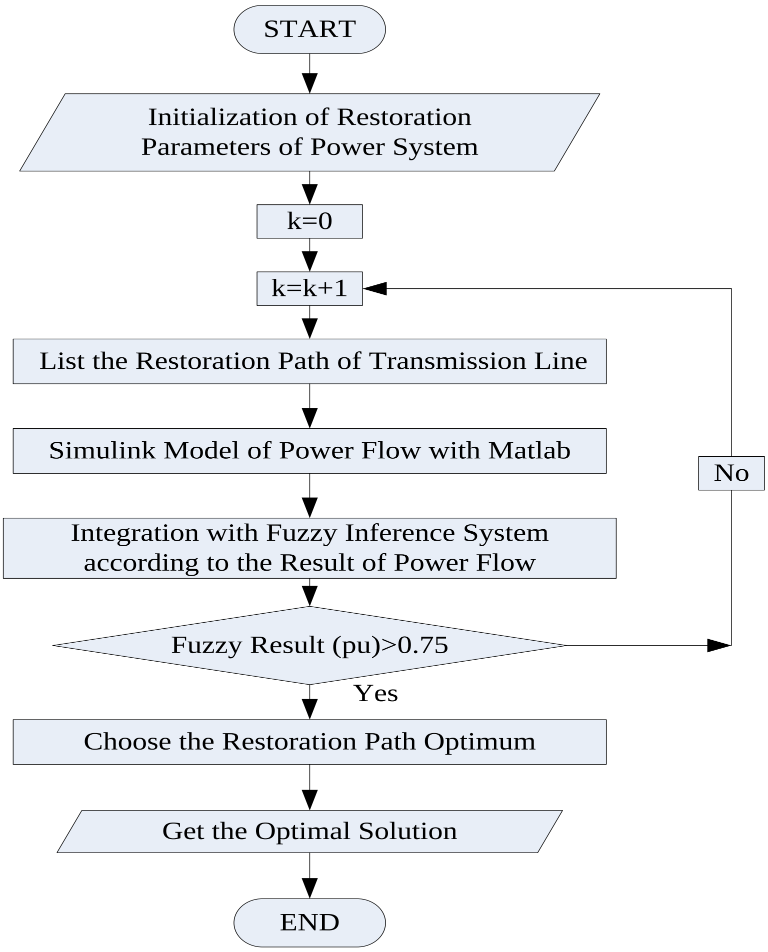

Figure 2: Flow Chart of Restoration Path Optimum incorporate with Fuzzy Inference System

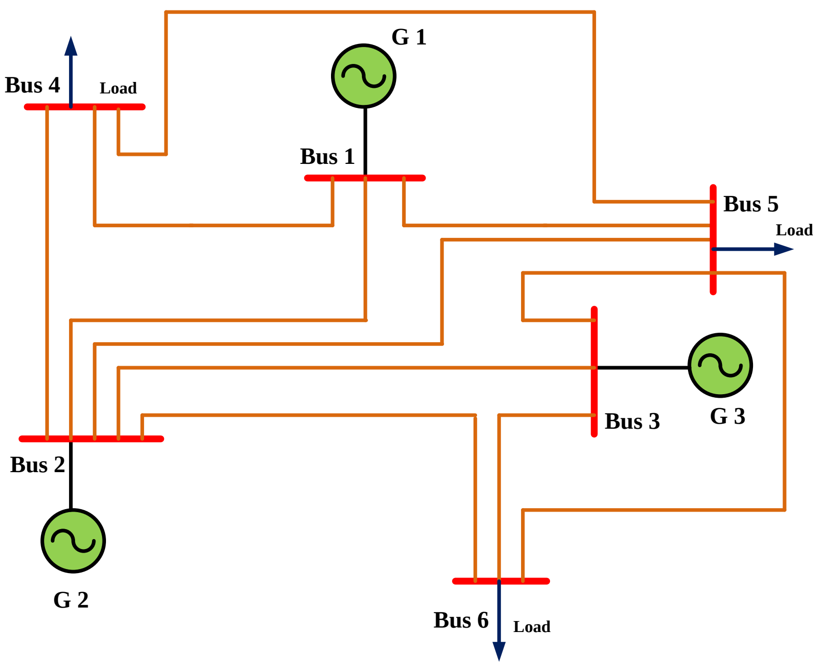

Figure 3: Single Line Diagram of 6 Bus for Proposed System

Table 1: Load Data for Proposed System

Bus Number	Power Rating (MVA)	Voltage Rating (KV)	Active Power (p.u.)	Reactive Power (p.u.)
4	100	400	0.9	0.2957
5	100	400	1.0	0.32 86
6	100	400	0.9	0.2957

Table 2: Parameters of Generators for Proposed System

Bus No	Power Rating (MVA)	Voltage Rating (kV)	Active Power (p.u.)	Voltage Magnitude (p.u.)	Max Reactive Power (p.u.)	Min Reactive Power (p.u.)	Max Voltage (p.u.)	Min Voltage (p.u.)
1	100	400	0.9	1.05	1.5	- 0.5	1.1	0.9
2	200	400	1.4	1.05	1.5	- 0.5	1.1	0.9
3	100	400	0.6	1.05	1.5	- 0.5	1.1	0.9

5. Simulation for Proposed System

MATLAB/SIMULINK can be used to simulate power system faults and protective relay algorithm and easily create new model and then power system stability can be observed according to simulation results. Therefore, for automatic interactive systems MATLAB/SIMULINK is selected.

5.1. Black-Start Power Source

Usually, black-start power sources include the units with self-start ability such as hydroelectric generating units, fuel and gas turbine units and support power provided by adjacent interconnected systems. The black-start resource procurement decision can integrate with a restoration planning model using optimization [9]. For this proposed system, Generator No 2 will be chosen because of its relatively generation capacity for reactive power co-operation.

Table 3: Parameters of Branches for Proposed System

Line Number	From Bus	To Bus	Power Rating (MVA)	Voltage Rating (kV)	Resistance (Ω/km) (p.u.)	Reactance (H/km) (p.u.)	Suseptance (F/km) (p.u.)	Current Limit (p.u.)	Active Power Limit (p.u.)	Reactive Power Limit (p.u.)
1	2	3	100	400	0	0.2500	0.1260	0.3082	1.5	0.75
2	3	6	100	400	0	0.1000	0.0420	1.3973	1.5	0.75
3	4	5	100	400	0	0.4000	0.1680	0.1796	1.5	0.75
4	3	5	100	400	0	0.2600	0.1050	0.6585	1.5	0.75
5	5	6	100	400	0	0.3000	0.1260	0.2000	1.5	0.75
6	2	4	100	400	0	0.1000	0.0420	1.3740	1.5	0.75
7	1	2	100	400	0	0.2000	0.0840	0.2591	1.5	0.75
8	1	4	100	400	0	0.2000	0.0840	0.9193	1.5	0.75
9	1	5	100	400	0	0.3000	0.1260	0.8478	1.5	0.75
10	2	6	100	400	0	0.2000	0.1050	0.9147	1.5	0.75
11	2	5	100	400	0	0.3000	0.0840	0.7114	1.5	0.75

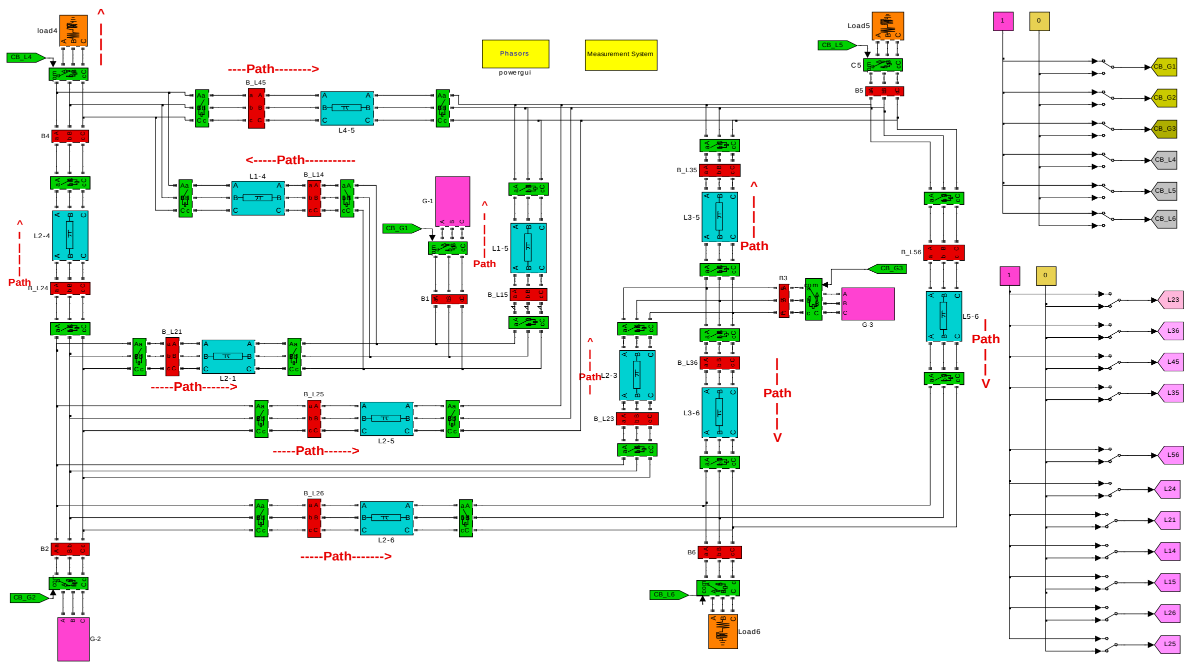

Figure 4: Simulation Model for Proposed System

The simulation model of proposed system is shown in figure 4 and results of voltage and frequency for all three cases are carried out by using MATLAB/ SIMULINK. The cases for restoration path of transmission lines cases are listed below in table 4.

Table 4: Restoration Path Transmission Lines Cases

Operation Time (s)	Path Lines		
	Case 1	Case 2	Case 3
0.1	2-3	2-3	2-3
0.15	2-4/2-1	3-5	3-5
0.2	3-5	3-6	1-5
0.25	2-6	2-4/2-1	4-5
0.3	1-5	1-4	5-6
0.35	1-4	4-5	1-4
0.4	2-5	1-5	2-4/2-1
0.45	4-5	2-6	2-6
0.5	3-6	2-5	2-5
0.55	5-6	5-6	3-6

5.2. Simulation Result for Case 1

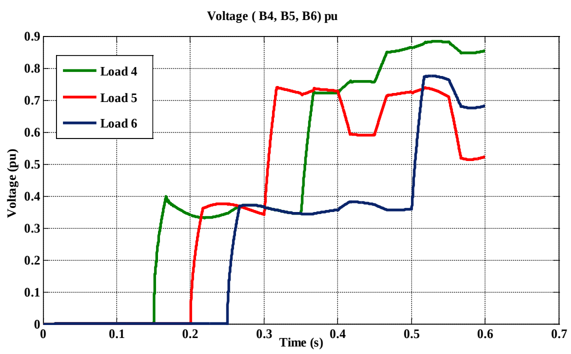

Figure 5: Simulation Result for Case 1

5.3. Simulation Result for Case 2

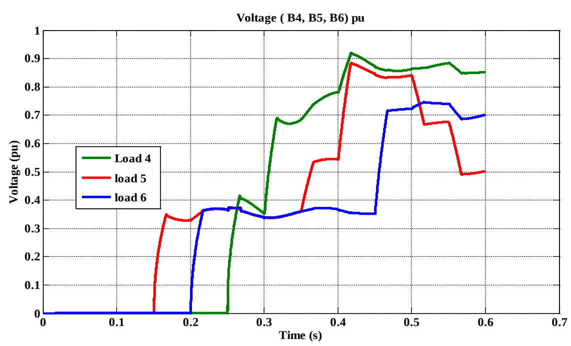

Figure 6: Simulation Result for Case 2

5.4. Simulation Result for Case 3

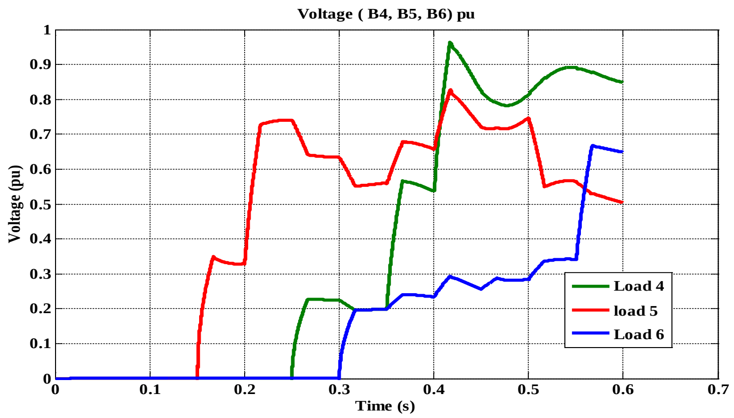

Figure 7: Simulation Result for Case 3

In simulation result figure 5, peak voltage (pu) can be clearly seen for load4, load5 and load6 (0.886, 0.742, 0.778). There are peak value of 0.92, 0.885 and 0.747 in case 2 and 0.965, 0.827 and 0.667 in case 3 for Load 4, 5 and 6 which are clearly seen in result figure 6 and 7.

Three inputs (Results of Load4, Load5 and Load6) are decided by FIS mamdani type to choose suitable output as shown in figure 8.

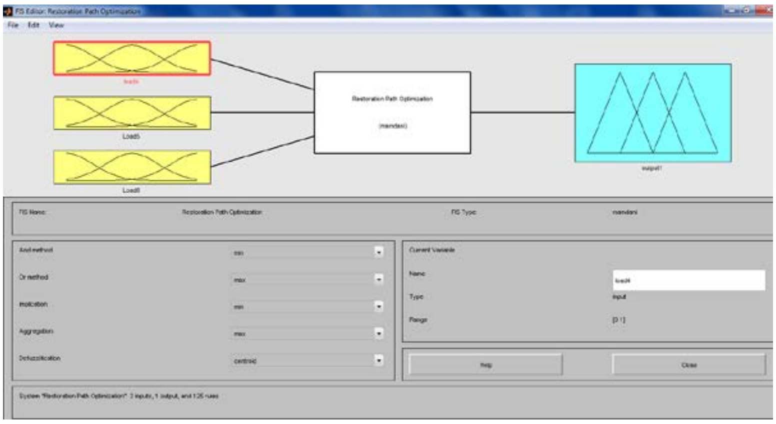

Figure 8: FIS Model for Proposed System

All of three inputs variables are composed for triangular-shaped membership function. The input1 (Load4) of FIS variable is as shown figure 9. The range of its membership function is 0 to 1. And then, it is related to negative values, -0.25 ≤ input ≤ 0.25.

The input 2 (Load5) of FIS variable is as shown figure10, the range of its membership function is 0 to 1. And then, it is related to negative values, -0.4 ≤ input ≤ 0.4.

The input 3 (Load6) of FIS variable is as shown figure 11 and the range of its membership function is also 0 to 1. And then, it is related to negative values, -0.25 ≤ input ≤ 0.25.

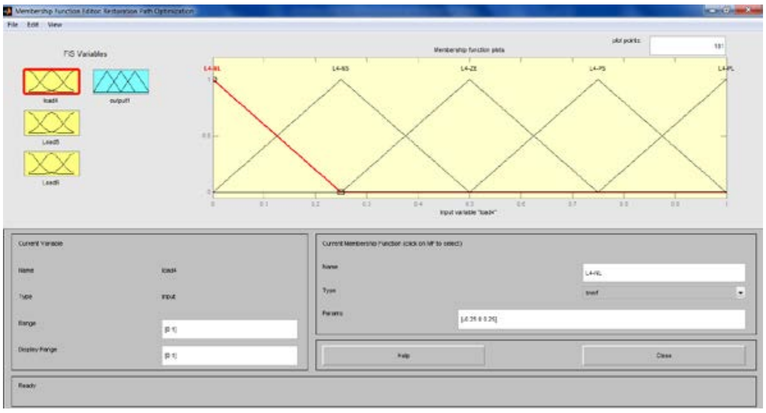

Figure 9: Membership function of Input 1 for proposed system

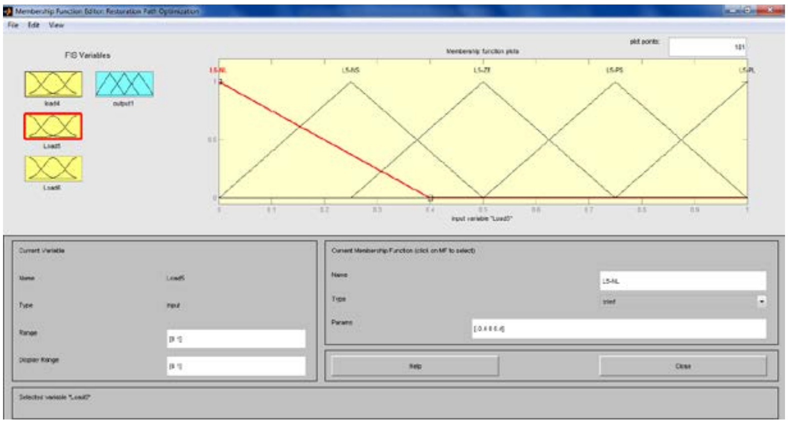

Figure 10: Membership function of Input 2 for proposed system

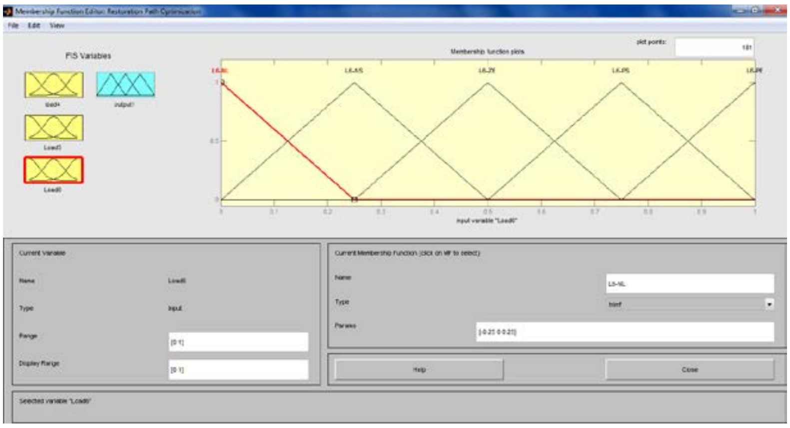

Figure 11: Membership function of Input 3 for proposed system

The input variable of output is composed for gaussian membership function and it is as shown figure 12 which has the range of its membership function is also 0 to 1. And then, it is related to negative values,-0.07078 ≤ input ≤ 0.07078.

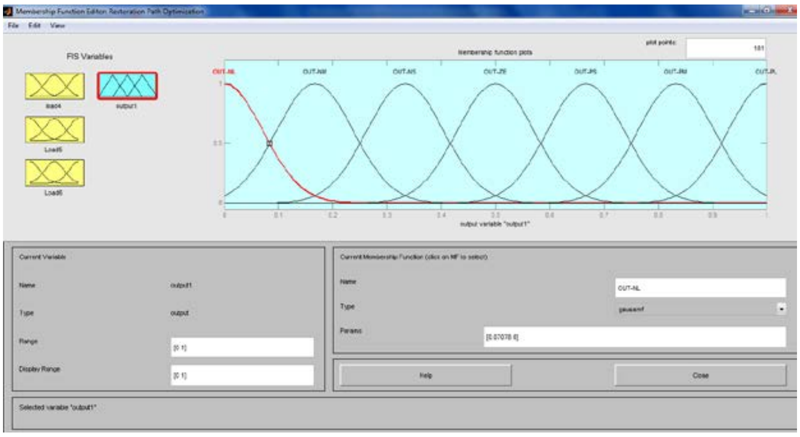

Figure 12: Membership Function of Output for Proposed System

The base rule is composed for 125 rules that represent from simulations. In the inference process the Method of Mamdani was used and the smallest (absolute) value of maximum was applied in defuzzification process. Fuzzy rules for this proposed system is as shown in table 5. And then, FIS rule editor and rule viewer are as shown in figure 13 and 14.

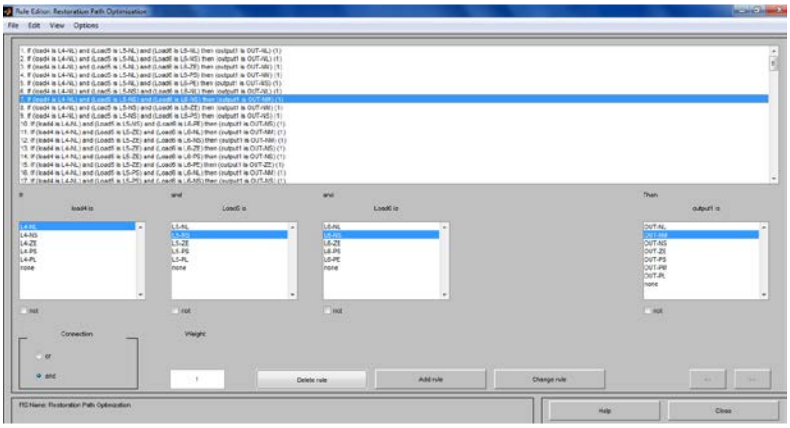

Figure 13: FIS Rule Editor for Proposed System

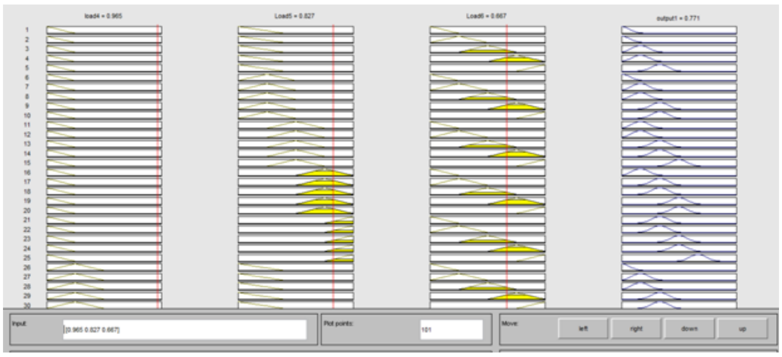

Figure 14: FIS Rule Viewer for Proposed System

Table 5: Fuzzy Rule Table for Proposed System

AND	AND	L6				
		NL	NS	ZE	PS	PL
L4-NL	L5-NL	NL	NL	NM	NM	NS
	L5-NS	NL	NM	NM	NS	NS
	L5-ZE	NM	NM	NS	NS	ZE
	L5-PS	NM	NS	NS	ZE	ZE
	L5-PL	NS	NS	ZE	ZE	PS
L4-NS	L5-NL	NL	NM	NM	NS	NS
	L5-NS	NM	NM	NS	NS	ZE
	L5-ZE	NM	NS	NS	ZE	ZE
	L5-PS	NS	NS	ZE	ZE	PS
	L5-PL	NS	ZE	ZE	PS	PS
L4-ZE	L5-NL	NM	NM	NS	NS	ZE
	L5-NS	NM	NS	NS	ZE	ZE
	L5-ZE	NS	NS	ZE	ZE	PS
	L5-PS	NS	ZE	ZE	PS	PS
	L5-PL	ZE	ZE	PS	PS	PM
L4-PS	L5-NL	NM	NS	NS	ZE	ZE
	L5-NS	NS	NS	ZE	ZE	PS
	L5-ZE	NS	ZE	ZE	PS	PS
	L5-PS	ZE	ZE	PS	PS	PM
	L5-PL	ZE	PS	PS	PM	PM
L4-PL	L5-NL	NS	NS	ZE	ZE	PS
	L5-NS	NS	ZE	ZE	PS	PS

	L5-ZE	ZE	ZE	PS	PS	PM
	L5-PS	ZE	PS	PS	PM	PM
	L5-PL	PS	PS	PM	PM	PL

Table 6: Analysis of Restoration Path Optimization

Cases	**Inputs (Peak value of Simulation result voltage (pu))**			**Outputs (with FIS)**
	Load4	**Load5**	**Load6**	
Case1	0.886	0.742	0.778	0.754
Case2	0.92	0.885	0.747	0.766
Case3	0.965	0.827	0.667	0.771

In three cases of simulation result, frequency doesn't deviate clearly. But, voltage deviates and then activate and reactive power also clearly change. Therefore, fuzzy logic controls only the simulation result of voltage (pu) in this paper. Table 6 shows the analysis of restoration path optimization in power transmission lines with fuzzy inference system (FIS) for proposed system.

6. Conclusion

In this study, the Fuzzy Inference System controller has been decided for voltage level of proposed system. The comparison of three cases transmission lines are developed in MATLAB as shown above figures. The result of simulation with MATLAB is shown that the voltage level of all three cases to restore after black outage condition. FIS controller has been successfully applied to choose the most suitable restoration path transmission line for proposed system. In this paper, Modelling and simulation analysis of IEEE 6 Bus system is clearly described in this study.

7. Recommendation

For the reliable power system, restoration process is necessary and restoration path optimization transmission line is also essential. This paper presents, the most suitable power system restoration path optimization is analyzed for power transmission lines with using MATLAB/SIMULINK and FIS.

According to the flow chart of restoration path optimum incorporate with FIS, simulation results of output values in all three cases are above from limitation. Accordingly, the detail of simulation result on each cases are, 75% for case1 and 76% for case 2 and then case 3 has 77%. Among them, case3 has the best output value for restoration path optimization. Therefore, power needs to be restored as quickly, stability and reliability as possible and consequently, restoration path case3 is recommended.

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