Sudan National Grid Contingency Ranking Through Fuzzy Logic Approach

Mohammed Osman Hassan Mohammed Zain, Israa Salih Hamad Alajab

Abstract: ***The effect of the line outage when rest of system is stable is called contingency study. The outage on the system may be for single line (N-1) contingency or for multiple lines (N-m) contingency where N the total number of lines and m the number of lines out the service. The study of contingency is essential process in planning, operating and control of power systems. The main thrust of contingency studies carried out in power system control centers is to determine the steady state effects of outages. Large power systems require the analysis of all the credible contingence within a very short time so as to exercise the control in the short time available for corrective action. Generally, the system continues to operate in the contingency condition for a considerable duration of time, on occurrence of a line outage. The altered voltage stability margins of all the load buses for the various contingency conditions are to be known prior to monitor and initiate emergency control action to avoid voltage collapse. This study suggests an intelligent technique using fuzzy logic control system to assist in ranking the single contingency (N-1) which occur in the system. The suggested fuzzy logic approach was taken into consideration and applied to the national Sudanese grid.***

Keywords: Contingency Analysis (CA), Fuzzy Inference Systems (FIS), Severity index voltage profile (SI_{vp}), Severity index of line flow (SI_{LF}), Composite Index (CI).

I. INTRODUCTION

The process of investigating whether the system is secure or insecure in a set of proposed contingencies is called 'security analysis or contingency analysis'.

The purpose of power system security analysis is to determine which contingencies cause component limit violations and also the severity of any such violations. Contingencies are ranked based on the value of a scalar performance index PI (or severity index), which measures system stress in terms of circuit overloads.

This may be achieved by predicting the values of the performance index for each line outage and subsequently ranking the contingencies from the most important (largest value of the performance index) to the least important (smallest value of the performance index).

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The traditional procedure for static security assessment is to evaluate a large number of contingency cases, usually all single outages, with a numerical algorithm [1].

II. STATIC SECURITY ANALYSIS

During power systems normal operating conditions the following constraints must be satisfied:

$$P_k^{known} - P_k(\mathbf{v}, \theta) = 0,\ k=1,\ldots,nb \quad (1)$$

$$Q_k^{known} - Q_k(\mathbf{v}, \theta) = 0,\ k=1,\ldots,nb \quad (2)$$

$$V_k^{min} \leq V_k \leq V_k^{max},\ k=1,\ldots,nb \quad (3)$$

$$P_{km} \leq P_{km}^{max},\ \text{for every branch } k\text{–}m \quad (4)$$

Where:
P_k^{known} and Q_k^{known}: are the injected real and reactive power at bus k, respectively.
v: are nodal voltage angle and magnitude vectors.
V_k: is the voltage magnitude at bus k; P_{km} represents real power flow at branch k–m; and nb is the number of system buses. [2]

III. CONTINGENCY ANALYSIS TECHNIQUE

Figure1 illustrates a simple techniques of contingency analysis.

IV. NETWORK PERFORMANCE INDICES

In general, the network stability indices are classified into Bus Voltage Stability Indices (BVSIs), line Voltage Stability Indices (LVSIs), and overall voltage stability indices (OVSIs).

The accuracy of the (OVSIs) is better than the (BVSIs) and (LVSIs) but they are complex and need more computational efforts. Another classification of Voltage stability Indices (VSIs) can be performed based on the main concepts of the (VSIs). [3]

In performance index method with high exponent, the resultant performance index value will depend heavily on loading of the particular line which is loaded closest to its limit [4].

So, Line Flow index (LF index) is used to estimate the maximum load-ability of a particular load bus in the system. The load buses are ranked according to their maximum load-ability, where the load bus having the smallest maximum load-ability is ranked highest. Hence this bus is identified as the weakest bus [5].

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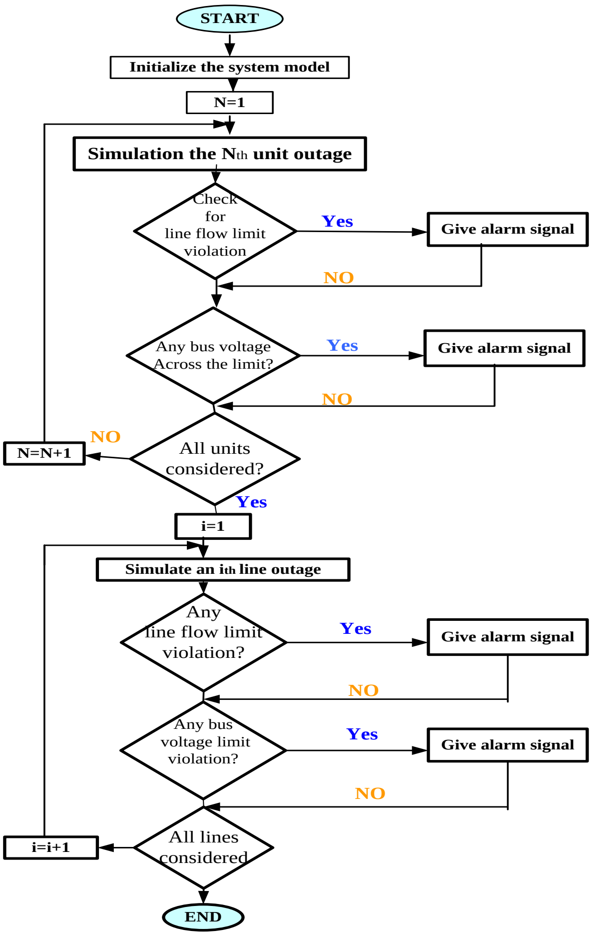

Fig 1: A simple technique for contingency analysis.

Also ranking all possible contingencies based on their impact on the system voltage profile (VP index) will help the operators in choosing the most suitable remedial actions before the system moves toward voltage collapse. [6]

A. Voltage Profile Index (I_{VP})

The voltage profile of each bus is represented in this thesis as indicator to voltage stability and used in contingency ranking.

B. Line Flow Index (ILF)

The line flow index which used in this thesis is the loading index which based on real power flow loading as:

$$I_{LF} = \frac{P_{Li}}{P_{Lmax}} \quad (5)$$

Where:

I_{LF} = index of Line Flow.

P_{Li} = the real power loading for line i.

P_{Lmax} = the maximum real power loading in the system.

V. FUZZY LOGIC SYSTEM

A. What is Fuzzy Logic

Fuzzy logic is all about the relative importance of precision; how important is it to be exactly right when a rough answer will do?

Fuzzy logic is a fascinating area of research because it does a good job of trading off between significance and precision, something that humans have been managing for a very long time.

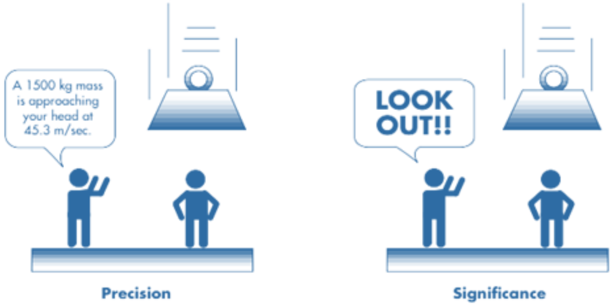

Fig 2: precision and significance in real world.

Fuzzy logic is a convenient way to map an input space to an output space. Between the input and the output it may put a box that does the work. What could go in the box? Any number of things: fuzzy systems, linear systems, expert systems, neural networks, differential equations, interpolated multi-dimensional lookup tables, or even a spiritual advisor, just to name a few of the possible options.

Clearly the list could go on and on, as Lotfi Zadeh, who is considered to be the father of fuzzy logic, once remarked: “In almost every case you can build the same product without fuzzy logic, but fuzzy is faster and cheaper. [7]

B. Fuzzy Implementation

Because of the integrated nature of MATLAB’s environment, it is possible to create tools to customize the Fuzzy Logic Toolbox or harness it with another toolbox, such as the Control System, Neural Network, or Optimization Toolbox.

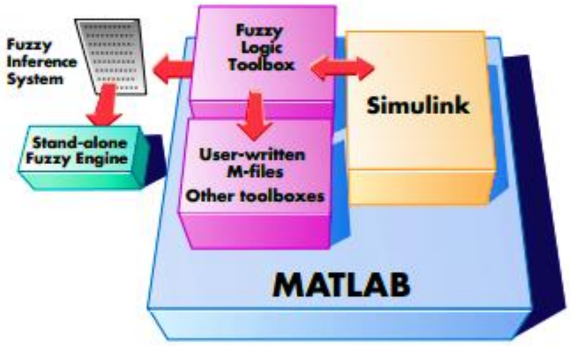

Fig 3: Integrality environment of fuzzy toolbox in MATLAB.

C. Fuzzy Interface System

Fuzzy inference is the process of formulating the mapping from a given input to an output using involves all of: membership functions, fuzzy logic operators, and if-then rules. Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox: Mamdani-type and Sugeno-type. These two types of inference system vary somewhat in the way outputs are determined. Mamdani’s fuzzy inference method is the most commonly seen fuzzy methodology. [7]

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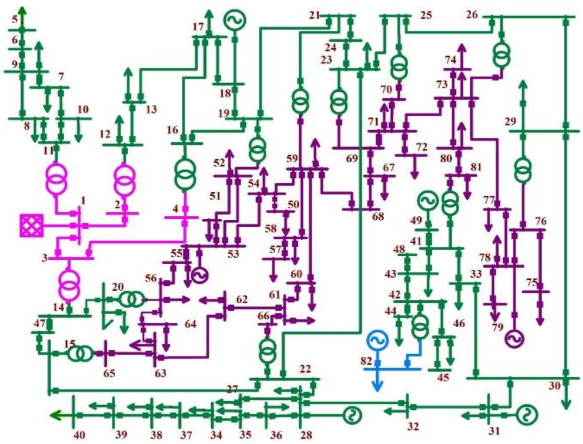
VI. SIMULATION

A. National Sudanese grid characteristics.

The total number of transmission lines is eighty one (81) and the transmission line charge supplies the required reactive power with total line length of 5469.735 km. The data was taken at normal load condition with total loading of 1553.3 MW and 1083.3 MVAr and the total generation of 1603.517 MW, and 227.008 MVAr. The total generation in the grid is generated from seven power plants in Sudan (Merwi, Garri, Rosieres, Sennar, Kosti, Khartoum north, and Girba) and the eighth generator is the tie line feeder from Ethiopia to Port Sudan power plant. Figure 4 shows the single line diagram of the grid.

Table-I: National Sudanese Grid Characteristics.

Number of Buses	82
Number of Lines	81
Number of Generators	8
Number of Transformers	15
Total connected Loads	53



■ 500 kV, ■ 220kV,■110kV, ■ 66Kv.

Fig 4: Single line diagram of national Sudanese grid.

VII. FUZZY LOGIC APPROACH.

A. Fuzzification

A membership function of trapezoidal type "trapmf" was created on the Mamdani model membership function editor at (FIS) toolbox in order to find the severity indices for the buses, i.e severity indices of Voltage Profile (SI_{VP}), also another membership function with the same type was created to find the Severity Indices of Line Flow (SI_{LF}).

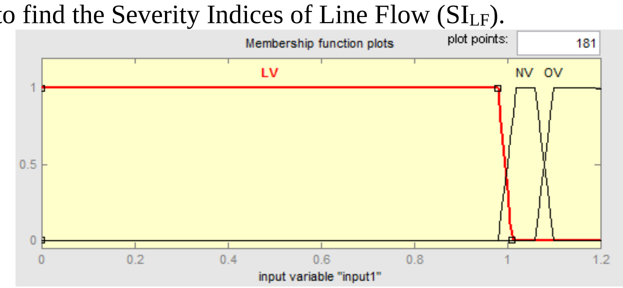


Fig 5: Voltage profile membership function.

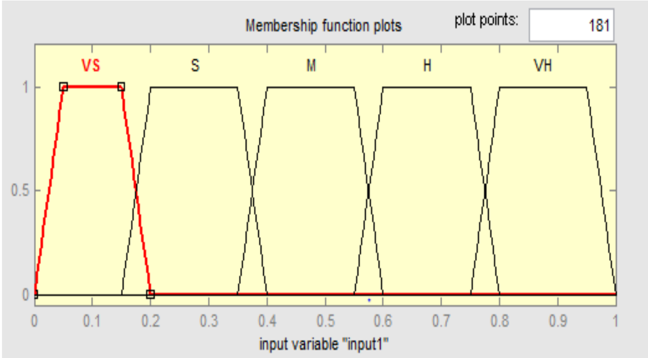


Fig 6: Line flow membership function.

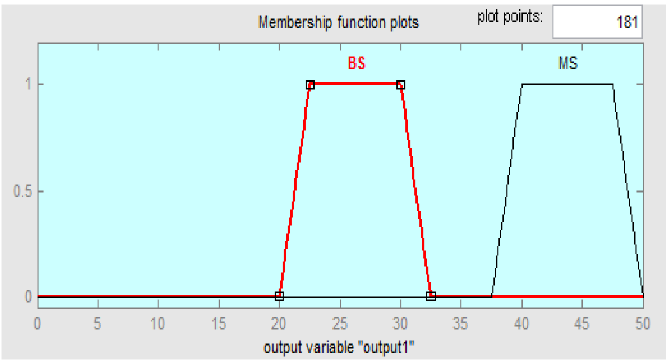


Fig 7: Severity index of voltage profile membership function.

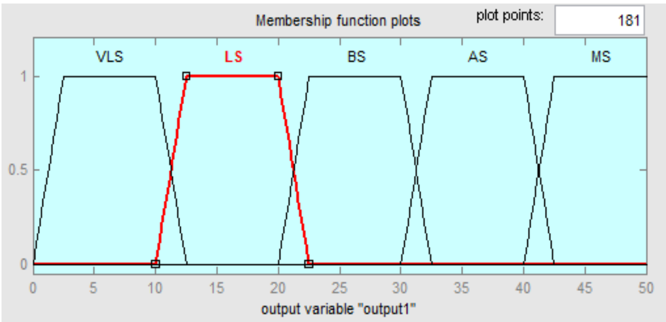


Fig 8: Severity index of line flow membership function.

The fuzzification process completes by setting the if-then rules as the required setting in table-II.

Table-II: Fuzzy Rules

<table>
<tr><td colspan="5">Input</td><td colspan="5">Output</td></tr>
<tr><td colspan="5">Voltage profile</td><td colspan="5">SI_{VP}</td></tr>
<tr><td>LV</td><td colspan="3">NV</td><td>OV</td><td>MS</td><td colspan="3">BS</td><td>MS</td></tr>
<tr><td colspan="5">Line flow index</td><td colspan="5">SI_{LF}</td></tr>
<tr><td>VS</td><td>S</td><td>M</td><td>H</td><td>VH</td><td>VLS</td><td>LS</td><td>BS</td><td>AS</td><td>MS</td></tr>
</table>

Where:

LV= Low Voltage, NV= Normal Voltage, OV= Over Voltage, MS= More Severe, BS= Below Severe, VS= Very Small, S = Small, M= Medium, H= High, AS= Above Severe, VH= Very High, LS= Less Severe. VLS= Very Less Severe.

This rules were set on the rule editor of both voltage profile and line flow membership functions as shown in fig (9, and 10).

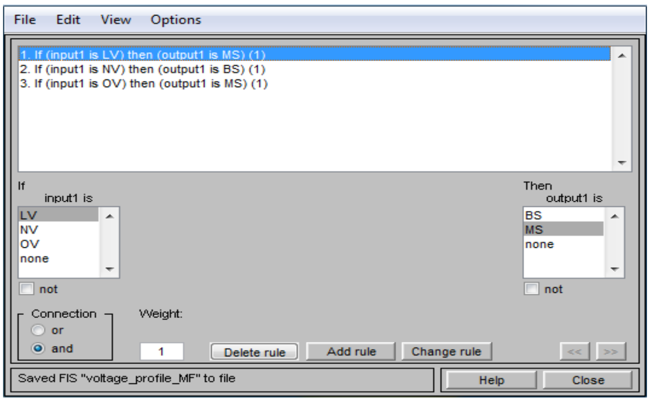


Fig 9: The rules editor of voltage profile membership function.

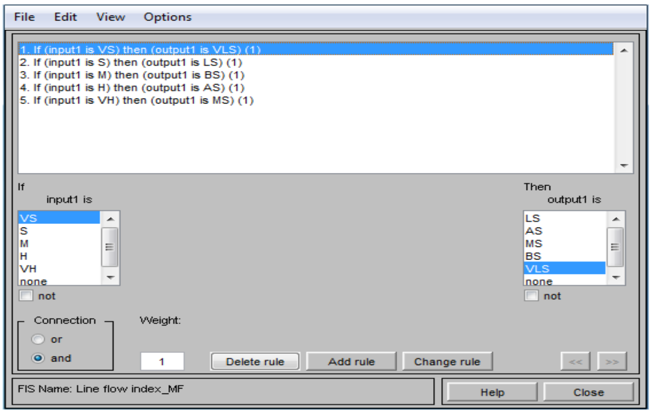


Fig 10: The rules editor of line flow membership function.

These rules are illustrates perfectly on the rule viewer as shown in figures (11, and 12).

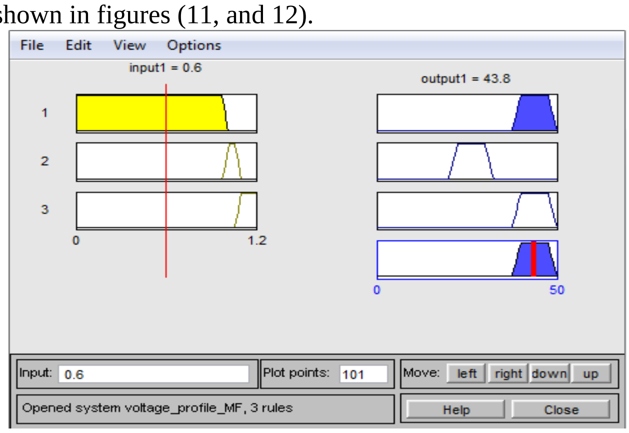


Fig11: The rules viewer of voltage profile membership function.

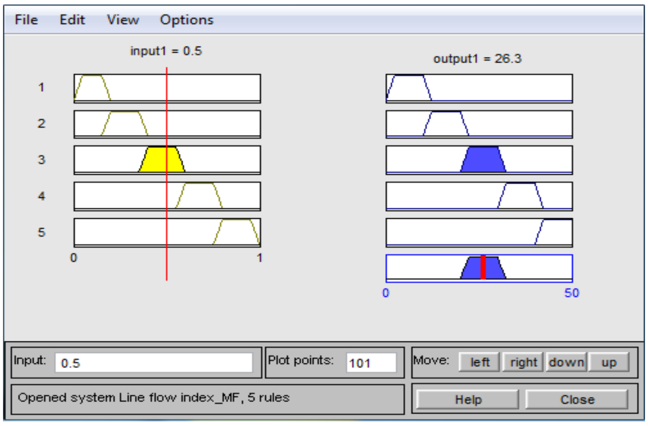


Fig12: The rules viewer of line flow membership function.

B. Defuzzification

The FIS block of voltage profile is shown in fig13, the linguistic variables for this block are the voltage profile data of the system, and the linguistic values are the severity indices of the voltages. The fuzzy logic controller of the block includes the voltage profile membership function which designed previously on Mamdani membership function editor, it was inserted in the block as shown in fig14. The same action was applied to line flow membership function as shown in fig 15, and fig16.

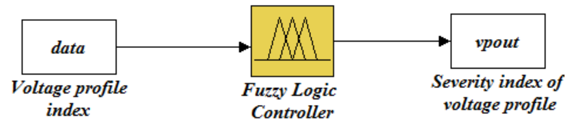


Fig13: Voltage Profile FIS block.

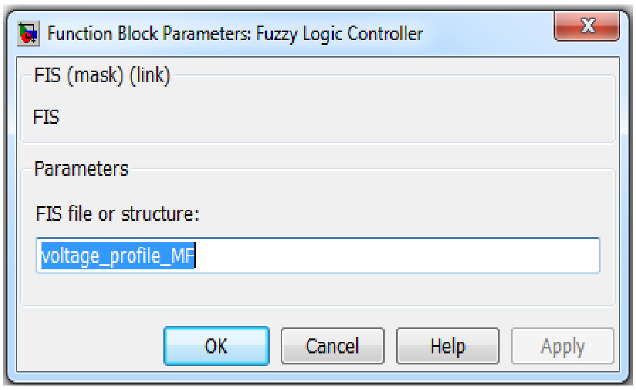


Fig14: Parameters setting on fuzzy logic controller at Voltage Profile FIS block.

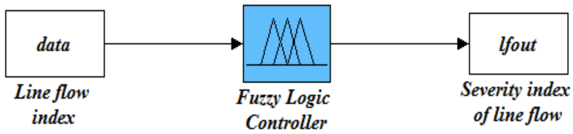


Fig15: Parameters setting on fuzzy logic controller at Voltage Profile FIS block.

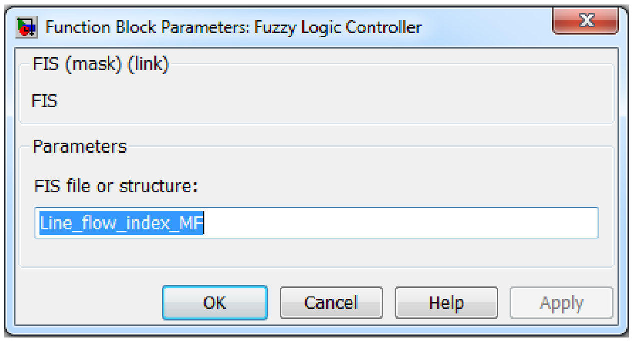


Fig16: Parameters setting on fuzzy logic controller at

Line flow FIS block.

Fig17 gives detailed description for the fuzzy approach to find the total severity index for contingency case (composite index (CI)).

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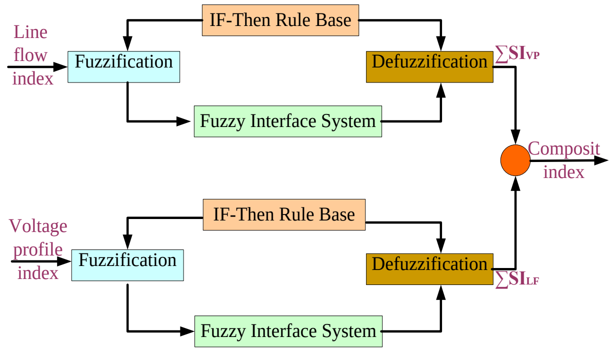

Fig17: Fuzzy logic base algorithm.

VIII. NATIONAL GRID (CA) RESULTS USING FUZZY LOGIC APPROACH.

For purpose of simplicity, five contingencies of national grid was taken on consideration these five cases are clarified in table-III.

Table-III: Reference data for the five contingencies under consideration.

Contingency NO.	Type of Contingency	From	To
1	Line 23	Bus 61	Bus 62
2	Line37	Bus66	Bus61
3	Line 20	Bus53	Bus54
4	Line26	Bus59	Bus60
5	Line 10	Bus1	Bus2

A. Contingency [1] Analysis (Line 23 outage)

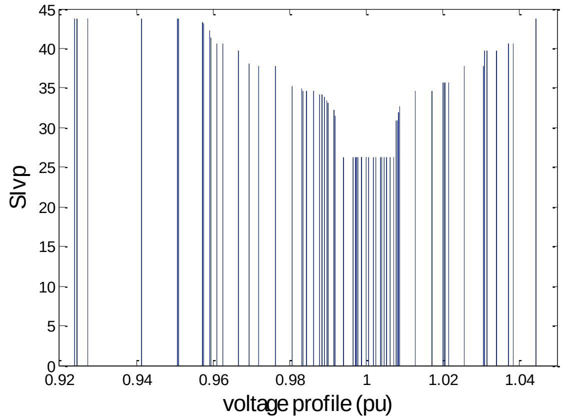

Fig18: Severity index voltage profile (SIVP) at line23.

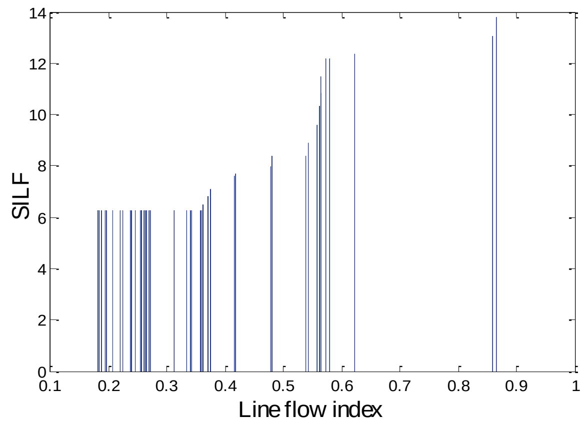

Fig19: Severity index line flow (SILF) at line23.

From the defuzzificaton results above, the value of the composite index for line 23 (CI_{line23}) contingency is:

$$CI_{line23} = \sum (\sum SI_{VP} + \sum SI_{LF})_{line23} \quad (6)$$

$$CI_{line23} = 2539.4040 + 429.2228 = \underline{\mathbf{2968.6268}} \quad (7)$$

B. Contingency [2] Analysis (Line 37 outage)

The composite index for line37 (CI_{line37}) contingency is:

$$CI_{line37} = \sum (\sum SI_{VP} + \sum SI_{LF})_{line37} \quad (8)$$

$$CI_{line37} = 2494.3840 + 428.9414 = \underline{\mathbf{2923.3254}} \quad (9)$$

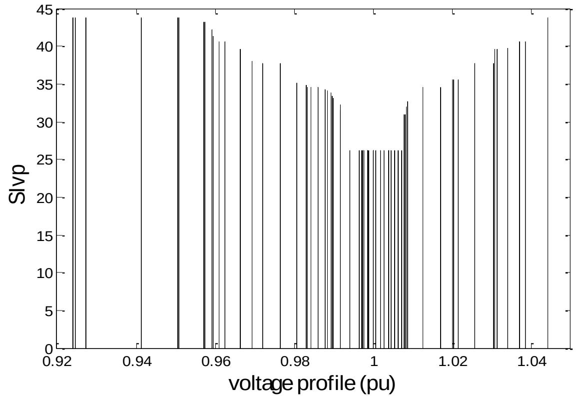

Figure 20: Severity index voltage profile (SI_{VP}) at line37.

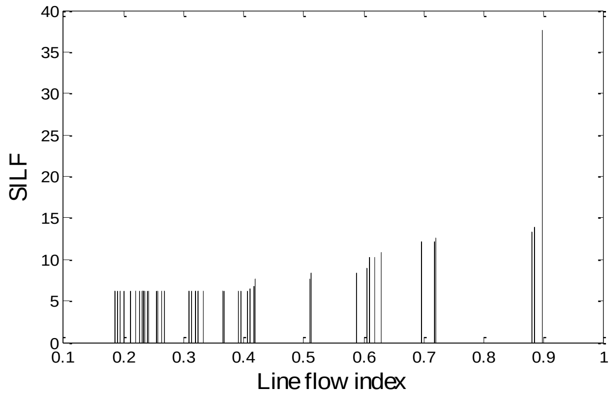

Figure 21: Severity index line flow (SILF) at line37.

C. Contingency [3] Analysis (Line 20 outage)

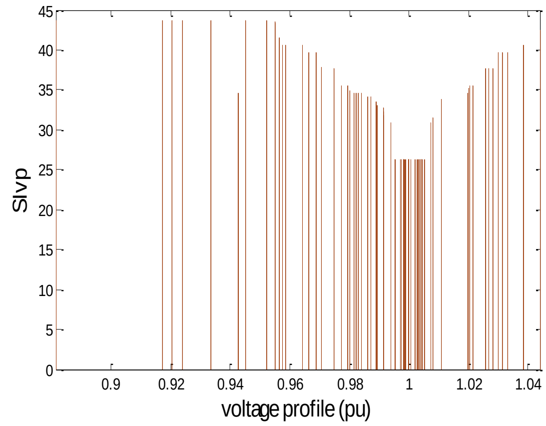

Fig22: Severity index voltage profile (SIVP) at line20.

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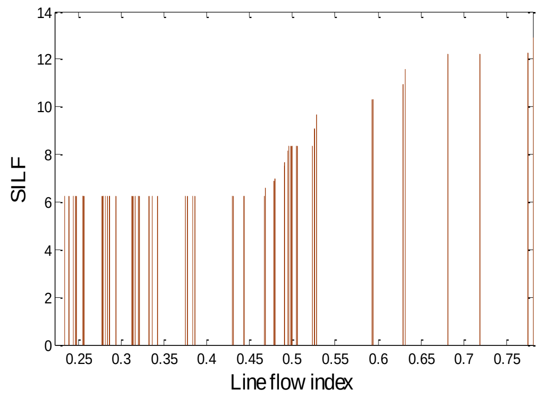

Fig23: Severity index Line flow index (SILF) at line20.

The composite index for line20 (CI_{line20}) contingency is:

$$CI_{line20} = \sum (\sum SI_{VP} + \sum SI_{LF})_{line20} \qquad (10)$$

$$CI_{line20} = 2461.7530 + 451.8530 = \underline{\mathbf{2913.6060}} \qquad (11)$$

D. Contingency [4] Analysis (Line 26 outage)

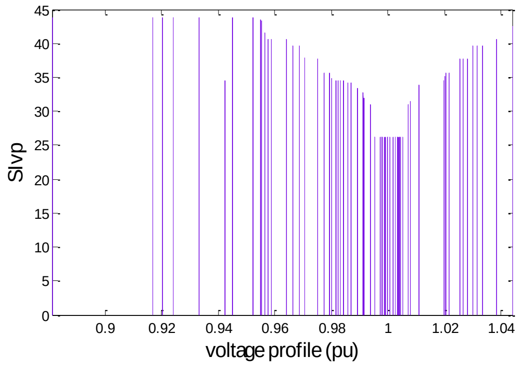

Fig24: Severity index voltage profile (SIVP) at line26.

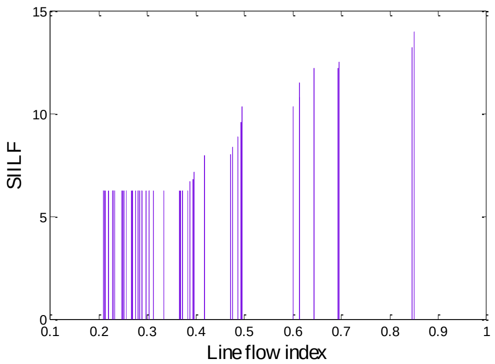

Fig25: Severity index line flow (SILF) at line26.

E. Contingency [5] Analysis (Line 10 outage)

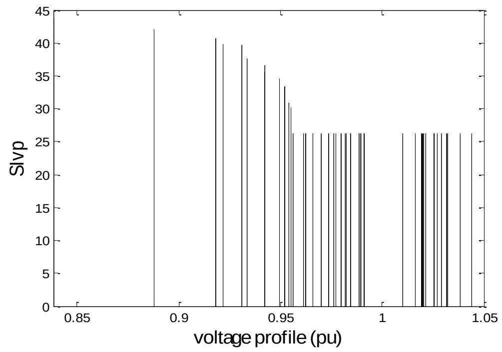

Fig26: Severity index voltage profile (SI_{VP}) at line10.

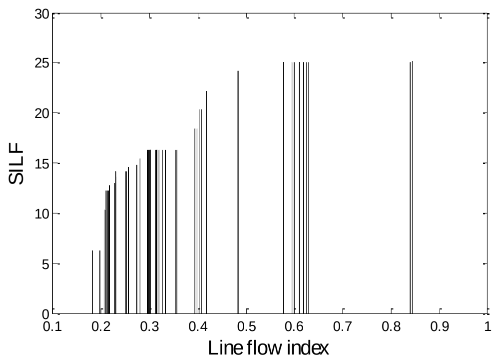

Fig27: Severity index line flow (SIVP) at line10.

Table-IV: Results of composite index

Cont. NO.	Cont. Type	$\sum SI_{VP}$	$\sum SI_{L.F}$	**CI**	**Ranking**
1	Line 23	2539.404	429.2228	2968.6268	1
2	Line37	2494.384	428.9414	2923.3254	2
3	Line 20	2461.753	451.853	2913.606	3
4	Line26	1708.767	344.5316	2053.2986	4
5	Line 10	812.3472	987.7966	1800.1438	5

*CI: $\sum(\sum SI_{VP}, \sum SI_{LF})$

IX. CONCLUSION

Fuzzy logic controller represents system ranking depending on the composite index, where the most severe line outage possesses the higher value of the composite index and the lower composite index expresses the less severe element. Composite index gives detailed information about the severity of the network, it consists of two indices (voltage profile index and line flow index) so; it more accrue and processioned. Hence, it gives details about the source of severity by noting the more high value of the two indices which form the composite index. Fuzzy logic controller also divide the severe level of the system (below severe, above severe, most severe, less severe, etc.) and assist to propose optimal solution for system security. The severity of the system with composite index may refer to voltage problem if the summation of voltage profile in the composite index has the higher value, this means that the system may be less severe by improving the system voltage by one of the compensation techniques. On the other hand the severity of the system may refer to line loading if the summation of line flow has the higher effect, this means that; the system require load shading or any power improvement techniques.

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