Science and Technology Publishing (SCI & TECH)
ISSN: 2632-1017
Vol. 6 Issue 2, February - 2022

Fault Location Fault Location In Power System Networks With Incidence Of Tripping Of Multiple Circuit Breakers

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***Abstract*—In this paper, fault location in power system network with incidence of tripping of multiple circuit breakers is studied. A fuzzy logic-based approach which uses the post fault status of the circuit breakers and relays to calculate the membership grade for each possible fault section is adopted. The membership grade is used to determine the likelihood of each candidate fault section as the actual fault section where the fault occurred. Additionally, the membership grade is used for ranking the fault sections and the maximum selection method is used to select the most possible fault section which is the section with the highest membership grade. Case study power system networks were modeled in MATHLAB and the scheme was simulated for five different case studies. The results show that the scheme is able to use the membership grade values to accurately identify the fault section which there are tripping of multiple circuit breakers in different sections of the power system network. Once the fault section is identified by the scheme, dispatchers would first of all pay attention to the fault section when they are tracing the fault location.**

Keywords*— *Fault Location , Power System Network , Fuzzy Logic, TRIPPING OF CIRCUIT BREAKERS , Maximum Selection Method, Fault Section

1. INTRODUCTION

Generally, whenever there is an expansion in a power system network, new lines, buses and protective devices are added to the network [1,2,3,4,5,6]. There is always a problem of improper time delay coordination between newly installed relay and existing ones. Moreover, the relay time settings in power system are much smaller and consequently it becomes difficult to set the time delays with sufficient accuracy in a complex network [7,8,9,10]. This, often result in multiple tripping of circuit breakers during fault incidents.

However, besides inaccurate relay time settings, faulty relays and circuit breakers can also cause multiple tripping of backup breakers outside the actual location of fault [11,12,13,14]. In such cases, the outage range is very large and it is difficult to judge with reasonable accuracy the section of the network where the fault is located. In cases where multiple faults occur, with many breakers being tripped within a short period many alarm messages will be generated and this will be received by the dispatch center which becomes impossible for the dispatchers to analyze the condition with acceptable accuracy. In case of such failures, serious implications may arise which may affect both the consumer and the power system as line-search for faults is costly and can be inconclusive without accurate information on the location of such faults. This is due to the fact that the actual faulty section or zone must first be identified before the application of any technology to determine the fault distance from a protective device.

In this paper a fuzzy approach is presented for determining fault location on a transmission network with the problem of tripping of multiple circuit breakers. The notable feature of the approach presented in this study therefore, is its ability to first distinguish the actual fault section from the other candidate fault sections in the event of multiple tripping of circuit breakers. By doing so, the approach improves on the system restoration time and also reduces the load loss. The network model and detailed application of the fuzzy logic approach to different case studies are presented and simulation is conducted using MATHLAB software.

2. METHODOLOGY

In this paper, a fuzzy logic-based scheme is presented which will assist power system operators to determine the location of the fault when fault current condition occurs. This is done by using the post fault status of the circuit breakers and relays. The membership grade for each possible fault section is calculated. The objective of this calculation is to determine the likelihood of each candidate fault section as the actual fault section. Moreover, the membership grade provides a convenient means of ranking among possible fault sections and this is the most important factor in fault current location decision making.

During fault current location decision making, the most possible fault section is determined by the maximum selection method. In this method most possible fault section is the one which is having the highest membership grade. MATLAB code for the proposed scheme is developed and used to simulate the system in two different case studies applied to a power- system network.

2.1 STRUCTURE OF THE SYSTEM AND THE REQUIRED DATA

The system structure comprises of the elements associated with the radial power distribution system. The basic components of distribution system are transformers, bus-bars, relays, transmission lines and circuit breaker. In this study, the data for the power distribution system is obtained from the Transmission Company of Nigeria (TCN), Eket transmission station, Akwa Ibom State. The data set consists of the history of alarms received by SCADA, all the operated circuit breakers and relays' information under study are stored in the database. As new alarms are received, they are compared with the existing sets of alarms. If the new alarm set matches with the database already in the system, the faulted section is identified easily. If the alarm set is new, then the membership grade of the new alarm set is calculated. Therefore, a new alarm set will ``be added to the old database with fault recorded for future reference. The real time data first gets compared with the existing one before going into the fuzzy system for further analysis and actions. The transformer parameter and sequence component of the test circuit are presented in Table 1 and Table 2 respectively and the structure of the fault section location expert system is given in Figure 1.

The flowchart shown in Figure 1 gives the step by step approach involved in the fault location process. The process starts with data acquisition. First, the old fault data (DB_{old}) comprising of the number of tripped circuit breakers ($DB_{tripped}$) and the corresponding fault sections (FS_i) identified by dispatchers are stored in the database. The real time status of the different elements attached to the distribution network in acquired through SCADA system and radio wave communication at real time.

Table 1: Transformer parameters.

No of windings Nominal	Voltage (RMS) kV	Base MVA
2	132/33	45
2	132/33	60
2	33/11	15

Source: (TCN, 2012)

Table 2: Sequence component of test circuit.

R+ = R-	0.1579 Ω/km
L+ = L-	0.011 H/km
C+ = C-	5.681F/km

Source: (TCN, 2012)

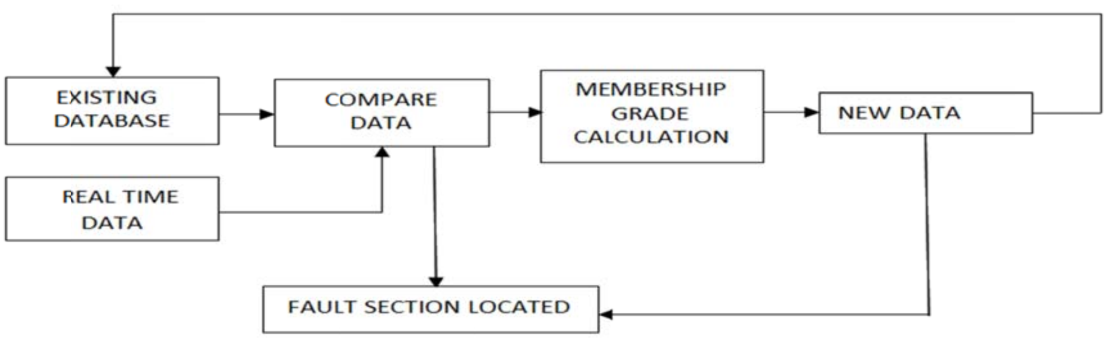


Figure 1: Structure of fault section location expert system.

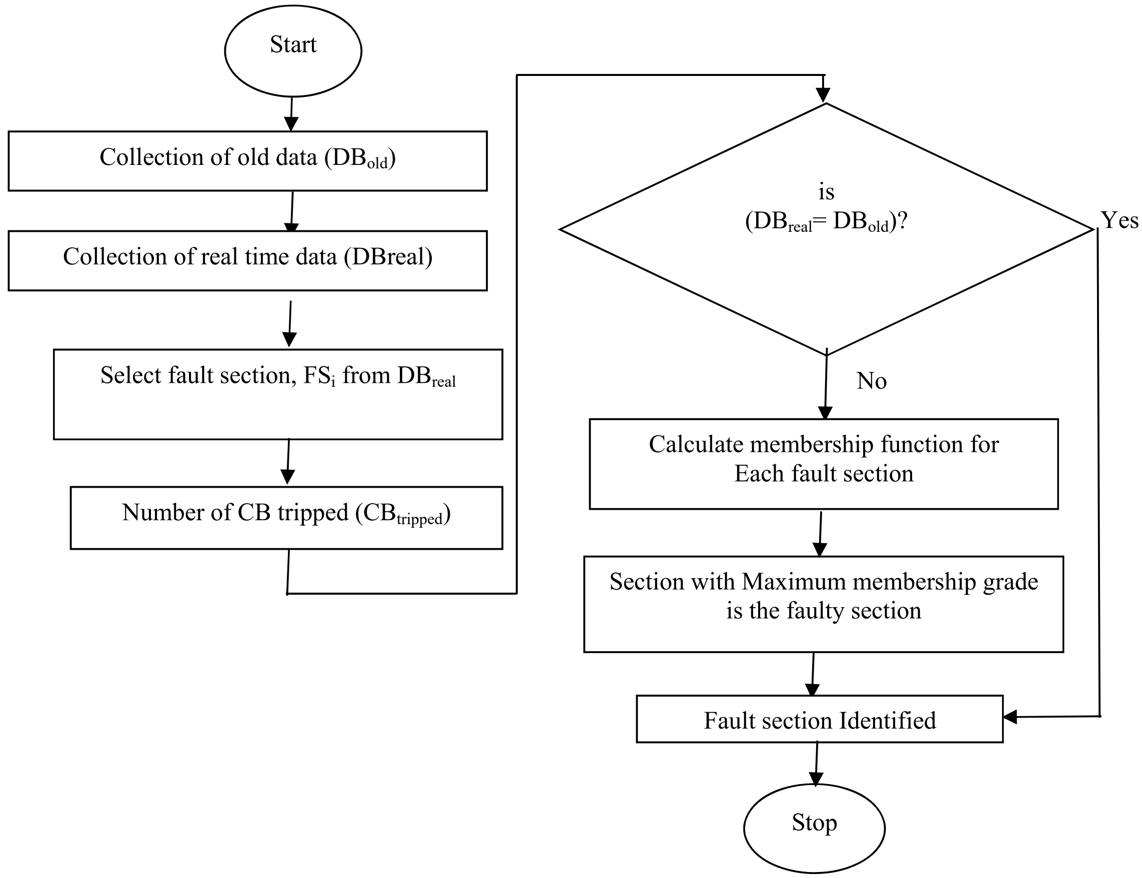


Figure 2: Fault section location flow chat.

The acquired real time fault data is stored in the database called DB_{real}. From the data received all the candidate fault sections are recorded as FS_i. Comparison starts with old database (DB_{old}) to look for if the case registered in DB_{real} is already there or not. If $DB_{realt} = DB_{old}$, then, the fault section is identified and the process ends. Accordingly, the system behaves as a trained module for fast identification of the faulty section. On the other hand, if $DB_{realt} \neq DB_{old}$, then, the data DB_{real} comprising of the $CB_{tripped}$ and the affected fault sections is further sent to the fuzzy expert system. The system will calculate the membership grade for all the relevant faulty sections. The section with maximum membership grade is then identified as the faulty section and the calculated data is added to the old database for future reference. Again, the database is updated with new data and the system gets trained.

2.2 THE FORMULATION FUZZY LOGIC MEMBERSHIP GRADE

The calculation for the membership grade is determined by the pre-fault and post-fault status of the circuit breakers and the relays associated with the faulty section. In practice, there are different levels of protection in the power distribution network. So, if a fault occurred and it is found that the first step protection has operated then the signals in the second and the third step protections are ignored. If the first and second steps of protection have been isolated as the suspected fault section then the signals of third step protection will be ignored. If all three step protections have not been isolated as the suspected fault section then there is no fault in this particular section.

In this paper, the degree of importance of a set of circuit breakers to a probable fault section is determined by whether the breakers are on the primary, the secondary or the tertiary protection to the probable fault section. A set of breakers on the primary protection in relation to a fault section are considered to be more important to the section than the other breakers in the secondary and tertiary protection to such section. Therefore, a higher degree of importance is assigned to each of the breakers that trips in the primary protection to a candidate fault section. Breakers on the secondary protection to a candidate fault section are assigned a degree of importance lower than that of the primary breakers. The circuit breakers on the tertiary protection to a particular fault section are assigned a degree of importance lower than those of the primary and the secondary breakers. Therefore, the membership grade of a candidate fault section is determined as follows;

$$FS_i = \frac{Dp\sum CBp + Ds\sum CBs + Dt\sum CBt}{\sum \text{CBtipped}} \quad (1)$$

Where Fsi is the fault section, D_p is the degree of importance of primary circuit breaker, CB_p is the circuit breaker tripped in primary protection to fault section , D_s is the degree of importance of secondary circuit breaker, CBs is the circuit breaker tripped in secondary protection to fault section, D_t is the degree of importance of tertiary breaker, CB_t is the circuit breaker tripped in tertiary protection to fault section and $CB_{tripped}$ is the total number circuit breakers (in primary, secondary, and tertiary protection) tripped due fault. Let K_{i1} be defined as;

$$K_{i1} = \frac{\sum CBp(i)}{\sum \text{CBtipped}} \quad (2)$$

$$K_{i2} = \frac{\sum CBs(i)}{\sum \text{CBtipped}} \quad (3)$$

$$K_{i3} = \frac{\sum CBt(i)}{\sum \text{CBtipped}} \quad (4)$$

Hence, Equations (1) becomes;

$$Fs_i = K_{i1} D_1 + K_{i2} D_2 + K_{i3} D_3 \quad (5)$$

Where $D_1 = D_p$, $D_2 = D_s$, and $D_3 = D_t$. Therefore, considering probable fault sections B1 (FS_{B1}), B2 (FS_{B2}), L1 (FS_{L1}) and L2 (FS_{L2}) we have

$$FS_{B1} = FS_1 = K_{11}D_1+K_{12}D_2+K_{13}D_3 \quad (6)$$

$$FS_{B2} = FS_2 = K_{21}D_1+K_{22}D_2+K_{23}D_3 \quad (7)$$

$$FS_{L1} = FS_3 = K_{31}D_1+K_{32}D_2+K_{33}D_3 \quad (8)$$

$$FS_{L2} = FS_4 = K_{41}D_1+K_{42}D_2+K_{43}D_3 \quad (9)$$

The set of Equation in matrix form becomes;

$$\begin{pmatrix} Fs_1 \\ Fs_2 \\ . \\ Fs_n \end{pmatrix} = \begin{pmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ . & . & . \\ k_{n1} & k_{n2} & k_{n3} \end{pmatrix} \begin{pmatrix} D_1 \\ D_2 \\ D_3 \end{pmatrix} \quad (10)$$

Further reduction of Equation (10) gives;

$$F(S_i) = \sum_{i=1}^{n} \left(\sum_{j=1}^{3} \left((K_{ij}) (D_j) \right) \right) \; ; \quad \text{Where } i=1, 2...n; \; j=1......3 \quad (11)$$

The actual fault section (A_{FS}) is expressed as ;

$$A_{FS} = \text{Max}\,[(FS_j)] \quad (12)$$

Equation (11) gives the desired result when arbitrary numbers between 0 to 1, representing the degree of importance are assigned to the primary, the secondary and the tertiary breakers tripped in relation to a candidate fault section and in order of their importance to the fault section. The highest value is given to D_p, the lower value to D_s and the least value to D_t. However, to have a result which clearly distinguishes the actual faulty section from the other candidate fault sections there is a need to determine the optimum values of D_p, D_s and D_t. To achieve this, five series of test involving different degree of importance of breakers are considered in the first case study (referred to as, case study 1)

2.3 REFERENCE CASE STUDIES TO VALIDATE THE ANALYTICAL MODEL FOR THE MEMBERSHIP GRADE OF A CANDIDATE FAULT SECTION

The analytical model for the membership grade of a candidate fault section is given in Equation (1). In this section, selected case studies are used to evaluate the effectiveness of the analytical model for the membership grade. The model power system shown in Figure 3 is taken from [15]. The model consists of 28 sections (L1-L8, T1-T8, A1-A4, B1-B8), 40 circuit breakers (CB1-CB40).

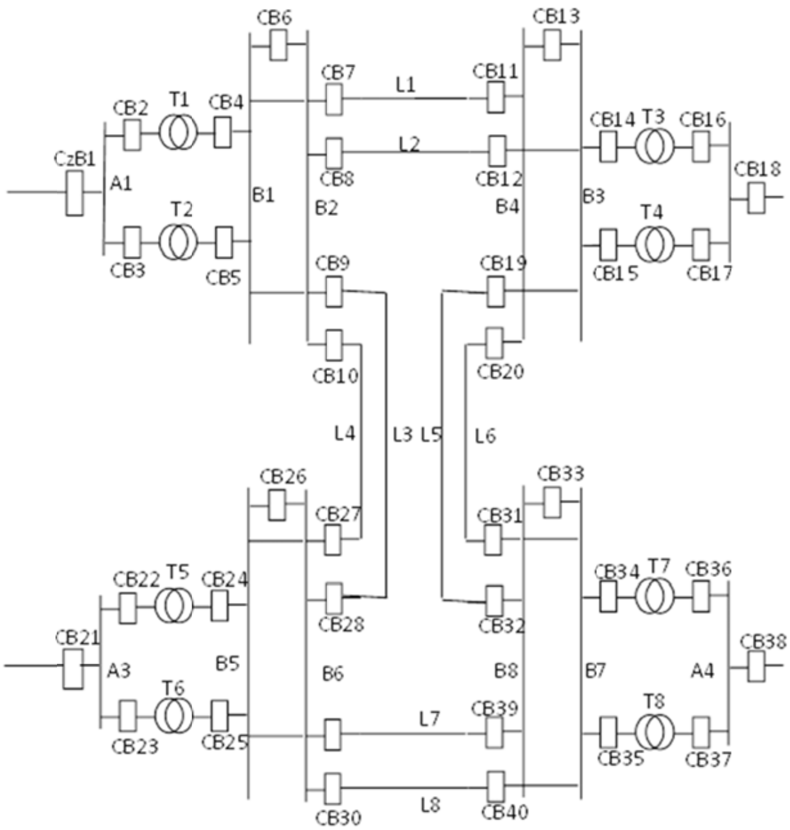


Figure 3: Test network for case study 1, 2 and 3 [15]

2.3.1 CASE STUDY 1:

In the case study 1, considering Figure 3, the circuit breakers tripped are CB4, CB5, CB7, CB9, CB12, and CB27. In case study 1, the affected sections according to the data received through SCADA system is identified as B1, B2, L1, and L2.

For section B1; $CB_p = 4$, $CB_s = 0$, $CB_t = 2$ and CBtripped = 6,

For section B2; $CB_p = 0$, $CB_s = 4$, $CB_t = 2$ and CBtripped = 6

For section L1; $CB_p = 1$, $CB_s = 3$, $CB_t = 2$ and CBtripped = 6;

For section L2; $CB_p = 1$. $CB_s = 0$, $CB_t = 5$ and CBtripped = 6;

From Equation (1), the membership grade for each of the candidate fault section is calculated as shown in ***Series*** 1 to ***Series*** 7 for $0 < D_j \leq 1$ and $D_1 > D_2 > D_3$

SERIES 1

$D_1 = 1$; $D_2 = 0.95$ and $D_3 = 0.9$.

$$\therefore \begin{pmatrix} Fs_1 \\ Fs_2 \\ Fs_3 \\ Fs_4 \end{pmatrix} = \frac{1}{6}\begin{pmatrix} 4 & 0 & 2 \\ 0 & 4 & 2 \\ 1 & 3 & 2 \\ 1 & 0 & 5 \end{pmatrix}\begin{pmatrix} 1 \\ 0.95 \\ 0.9 \end{pmatrix} = \begin{pmatrix} 0.96 \\ 0.93 \\ 0.94 \\ 0.92 \end{pmatrix}$$

$$A_{FS} = \mathrm{Max}\begin{pmatrix} 0.96 \\ 0.93 \\ 0.94 \\ 0.92 \end{pmatrix} = 0.96 = FS_1 = B1$$

SERIES 2

$D_1 = 1$; $D_2 = 0.9$ and $D_3 = 0.8$. ∴

$$\begin{pmatrix} Fs_1 \\ Fs_2 \\ Fs_3 \\ Fs_4 \end{pmatrix} = \frac{1}{6}\begin{pmatrix} 4 & 0 & 2 \\ 0 & 4 & 2 \\ 1 & 3 & 2 \\ 1 & 0 & 5 \end{pmatrix}\begin{pmatrix} 1 \\ 0.9 \\ 0.8 \end{pmatrix} = \begin{pmatrix} 0.95 \\ 0.87 \\ 0.88 \\ 0.83 \end{pmatrix}$$

$$A_{FS} = \mathrm{Max}\begin{pmatrix} 0.95 \\ 0.87 \\ 0.88 \\ 0.83 \end{pmatrix} = 0.95 = FS_1 = B1$$

SERIES 3

$D_1 = 1$; $D_2 = 0.8$ and $D_3 = 0.7$.

$$\therefore \begin{pmatrix} Fs_1 \\ Fs_2 \\ Fs_3 \\ Fs_4 \end{pmatrix} = \frac{1}{6}\begin{pmatrix} 4 & 0 & 2 \\ 0 & 4 & 2 \\ 1 & 3 & 2 \\ 1 & 0 & 5 \end{pmatrix}\begin{pmatrix} 1 \\ 0.8 \\ 0.7 \end{pmatrix} = \begin{pmatrix} 0.9 \\ 0.77 \\ 0.98 \\ 0.75 \end{pmatrix}$$

$$A_{FS} = \mathrm{Max}\begin{pmatrix} 0.9 \\ 0.77 \\ 0.8 \\ 0.75 \end{pmatrix} = 0$$

SERIES 4

D1 = 1; D2 = 0.7 and D3 = 0.5. ∴

$$\begin{pmatrix} Fs_1 \\ Fs_2 \\ Fs_3 \\ Fs_4 \end{pmatrix} = \frac{1}{6}\begin{pmatrix} 4 & 0 & 2 \\ 0 & 4 & 2 \\ 1 & 3 & 2 \\ 1 & 0 & 5 \end{pmatrix}\begin{pmatrix} 1 \\ 0.7 \\ 0.5 \end{pmatrix} = \begin{pmatrix} 0.83 \\ 0.63 \\ 0.68 \\ 0.58 \end{pmatrix}$$

$$AFS = Max\begin{pmatrix} 0.83 \\ 0.63 \\ 0.68 \\ 0.58 \end{pmatrix} = 0.83 = FS1 = B1$$

SERIES 5

D1 = 1; D2 = 0.5 and D3 = 0.25. ∴

$$\begin{pmatrix} Fs_1 \\ Fs_2 \\ Fs_3 \\ Fs_4 \end{pmatrix} = \frac{1}{6}\begin{pmatrix} 4 & 0 & 2 \\ 0 & 4 & 2 \\ 1 & 3 & 2 \\ 1 & 0 & 5 \end{pmatrix}\begin{pmatrix} 1 \\ 0.5 \\ 0.25 \end{pmatrix} = \begin{pmatrix} 0.75 \\ 0.42 \\ 0.5 \\ 0.38 \end{pmatrix}$$

$$AFS = Max\begin{pmatrix} 0.75 \\ 0.42 \\ 0.5 \\ 0.38 \end{pmatrix} = 0.75 = FS1 = B1$$

SERIES 6

$D_1 = 1$; $D_2 = 0.5$ and $D_3 = 0.15$.

$$\therefore \begin{pmatrix} Fs_1 \\ Fs_2 \\ Fs_3 \\ Fs_4 \end{pmatrix} = \frac{1}{6}\begin{pmatrix} 4 & 0 & 2 \\ 0 & 4 & 2 \\ 1 & 3 & 2 \\ 1 & 0 & 5 \end{pmatrix}\begin{pmatrix} 1 \\ 0.5 \\ 0.15 \end{pmatrix} = \begin{pmatrix} 0.72 \\ 0.38 \\ 0.47 \\ 0.29 \end{pmatrix}$$

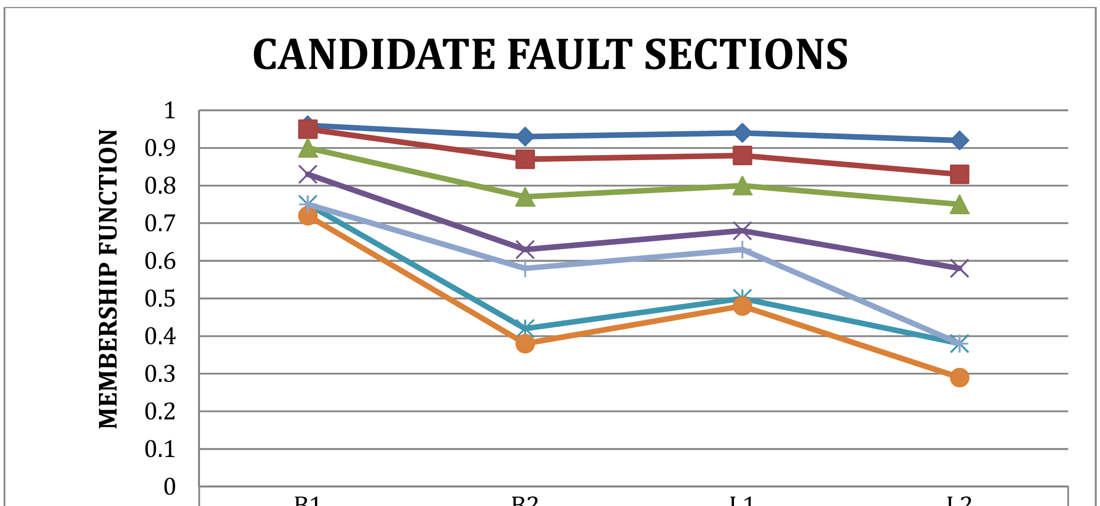
$$A_{FS} = Max\begin{pmatrix} 0.72 \\ 0.38 \\ 0.47 \\ 0.29 \end{pmatrix} = 0.72 = FS_1 = B1$$

SERIES 7

$$D_1 = 1;\ D_2 = 0.75 \text{ and } D_3 = 0.25.\ \therefore \begin{pmatrix} Fs_1 \\ Fs_2 \\ Fs_3 \\ Fs_4 \end{pmatrix} = \frac{1}{6}\begin{pmatrix} 4 & 0 & 2 \\ 0 & 4 & 2 \\ 1 & 3 & 2 \\ 1 & 0 & 5 \end{pmatrix}\begin{pmatrix} 1 \\ 0.75 \\ 0.25 \end{pmatrix} = \begin{pmatrix} 0.75 \\ 0.58 \\ 0.63 \\ 0.38 \end{pmatrix}$$

$$A_{FS} = Max\begin{pmatrix} 0.75 \\ 0.58 \\ 0.63 \\ 0.38 \end{pmatrix} = 0.75 = FS_1 = B1$$

From the calculations, the 4andidate fault sections based on the breakers degree of importance are given in Figure 4 while the comparison between the candidate fault sections based on breakers degree of importance is shown in Table 3.



	B1	B2	L1	L2
Series 1	0.96	0.93	0.94	0.92
Series 2	0.95	0.87	0.88	0.83
Series 3	0.9	0.77	0.8	0.75
Series 4	0.83	0.63	0.68	0.58
Series 5	0.75	0.42	0.5	0.38
Series 6	0.72	0.38	0.48	0.29
Series 7	0.75	0.58	0.63	0.38

Figure 4: Candidate fault sections based on breakers degree of importance.

Table 3 : Comparison between the candidate fault sections based on breakers degree of importance

	$\|FS_1-FS_2\|$	$\|FS_1-FS_3\|$	$\|FS_1-FS_4\|$	$\|FS_2-FS_3\|$	$\|FS_2-FS_4\|$	$\|FS_3-FS_4\|$	**Sum of differences**
Series 1	0.03	0.02	0.04	0.01	0.01	0.02	0.13
Series 2	0.08	0.07	0.12	0.01	0.04	0.05	0.37
Series 3	0.13	0.1	0.15	0.03	0.02	0.05	0.48
Series 4	0.2	0.15	0.25	0.05	0.05	0.1	0.8
Series 5	0.33	0.25	0.37	0.08	0.04	0.12	1.19
Series 6	0.34	0.24	0.43	-0.1	0.09	0.19	1.19
Series 7	0.17	0.12	0.37	-0.05	0.2	0.25	1.06

Therefore, breakers' degree of importance in series 5 give a clear contrast between the membership grade of the actual fault section and those of the other candidate section. In series 5, set of breakers on the primary protection in relation to a fault section are considered to be of utmost importance to the section and a value of 1 is assigned to each of the breakers. Breakers on the secondary protection to a candidate fault section are considered to have less degree of importance than those of the primary and a value of 0.5 is assigned to each of them. The circuit breakers on the tertiary protection are considered to have less degree of importance than those of the secondary and a value of 0.25 is assigned to each of the tertiary breakers. Consequently, for this case study, the degree of importance for the primary (D_1), the secondary (D_2) and the tertiary (D_3) breakers for further calculation will be 1, 0.5 and 0.25 respectively.

In the case of B2, the breakers that tripped in the primary zone are nil, whereas beakers that tripped in the secondary and the tertiary zones are four (CB4, CB5, CB7, and CB9) and two (CB12 and CB 27) respectively. Therefore, the membership grade calculation gives less value than the section B1. In the case of line L1, one breaker (CB7) tripped in the primary zone, three breakers (CB4, CB5, and CB9) tripped in the secondary zone and 2 breakers (CB12 and CB27) tripped in the tertiary zone. Therefore, the membership grade calculated for this section gives higher value than B2. For L2, only 1 breaker (CB12) operated in the primary zone and 5 breakers (CB4, CB5, CB7, CB9 and CB27) operated in the tertiary zone.

2.3.2 CASE STUDY 2:

Considering Figure 3, the circuit breakers tripped in this case study are CB4, CB5, CB6, CB7, CB9, and CB11. In case study 2, the probable fault sections are identified as B1, B2, and L1. For section B1, 5 breakers (CB4, CB5, CB6, CB7 and CB9) tripped in the primary zone, 1 breaker (CB11) tripped in the secondary zone, whereas none tripped in the tertiary zone. For B2 1 breaker (CB6) tripped in the primary zone ,4 breakers (CB4, CB5, CB7 and CB9) tripped in the secondary zone and 1 breaker (CB11) in the tertiary zone. For L1, 2 breakers (CB7 and CB11) tripped in the primary zone, 4 breakers (CB4, CB5, CB6, and CB9) tripped in the secondary zone and none tripped in the tertiary zone. From Equation (1) the membership grade calculated for the identified sections namely; B1, B2, and L1 are 0.9167, 0.541, and 0.667 respectively.

2.3.3 CASE STUDY 3:

Considering Figure 3, the circuit breakers tripped are CB7, CB8, CB11, CB12, CB29, CB30, CB39, and CB40. The probable fault sections are identified as L1, L2, L7and L8.for each of the identified fault sections 2 breakers tripped in the primary zone, none tripped in the secondary zone whereas 6 tripped in the tertiary zone. From Equation (1) fault section membership grade calculated for each of the identified sections is 0.437.

2.4 LOCALIZED CASE STUDIES

In order to apply this method of fault section location to an existing network in Nigeria, the model is also tested on the radial transmission/distribution network of Power Holding Company of Nigeria (PHCN) Plc. The particular radial transmission/distribution network used is located in the Eket transmission control center and it comprises of 132/33kV 45 MVA,132/33 kV 60 MVA, and 33/11 kv 15 MVA power transformers as shown in Table 1. The line reactance, inductance and capacitance, as well as the sequence components data needed for the study is shown in Table 2. The radial power network single line diagram is shown in Figure 5.

The model power system in Figure 5 is further broken into well labeled sections for the purpose of fault section location as shown in Figure 6. The model consists of 27 sections (L1-L13, T1-T5,B1-B9) and 27 circuit breakers (CB1-CB27).

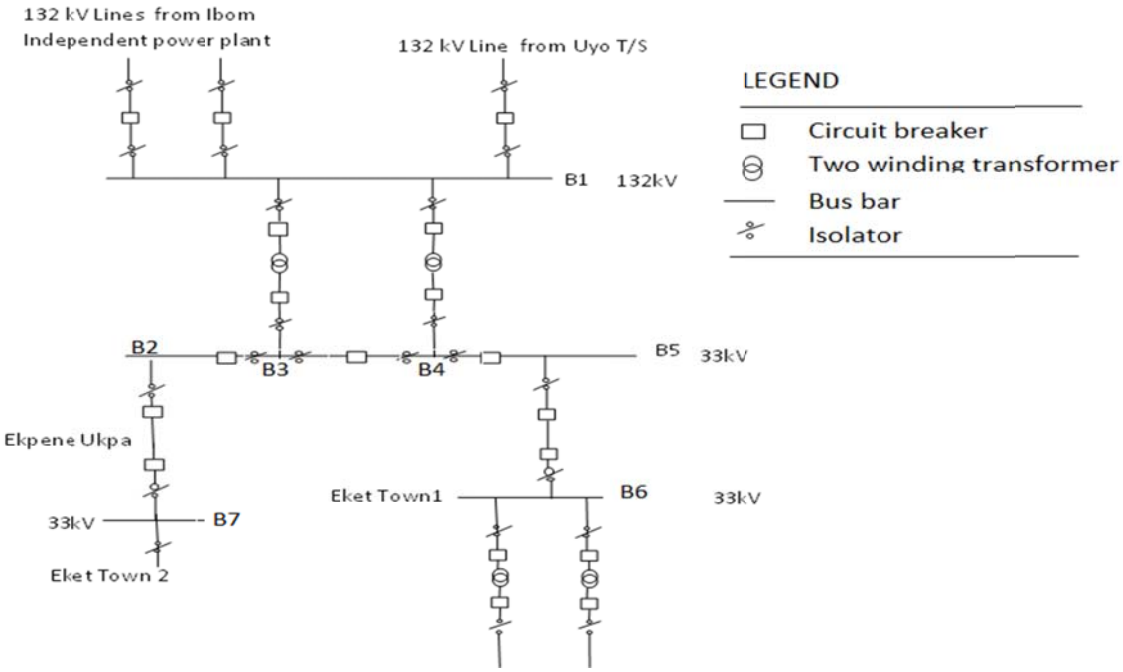


Figure 5: Single line diagram of the radial power network

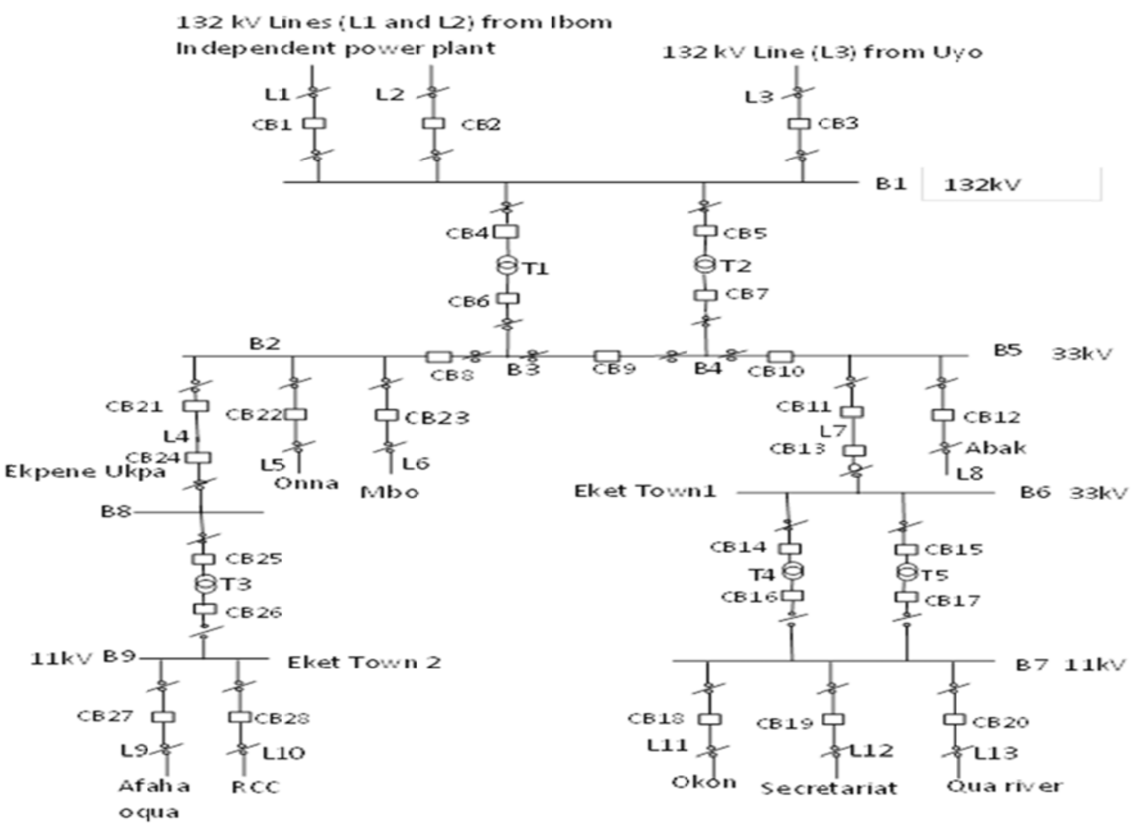


Figure 6: Test network for case study 4 and

5

2.4.1 CASE STUDY 4

With reference to Figure 6, the circuit breakers tripped are CB6, CB22, CB24, CB7 and CB25. In the case study 4, the probable fault sections are identified as B2, B8, L4 and L5. For section B2, 1 breaker (CB22) tripped in the primary zone, 2 breakers (CB6 and CB24) tripped in the secondary zone, whereas 1 breaker (CB25) tripped in the tertiary zone. For B8 2 breakers (CB24 and CB25) tripped in the primary zone, none tripped in the secondary zone whereas 2 breakers (CB6 and CB22) tripped in the tertiary zone. For L4, 1 breaker (CB24) tripped in primary zone, 2 breakers (CB22 and CB25) tripped in the secondary zone and 1(CB6) tripped in the tertiary zone. For L5, 1 breaker (CB22) tripped in the primary zone, none tripped in the secondary zone and 3(CB6, CB24 and CB25) tripped in the tertiary zone. From Equation (1) the membership grade calculated for the identified sections B2, B8, L4 and L5 are 0.5625, 0.625, 0.5625 and 0.4375 respectively.

2.4.2 CASE STUDY 5:

With reference to Figure 6, the circuit breakers tripped are CB7, CB11, and CB13. The probable fault sections are identified as B5, and L7. For section B5, 1 breaker (CB11) tripped in the primary zone, 2 breakers (CB7 and CB13) tripped in the secondary zone, whereas none tripped in the tertiary zone. For L7 breakers (CB11 and CB13) tripped in the primary zone, none tripped in the secondary zone whereas 1 breaker (CB7) tripped in the tertiary zone. From Equation (1) membership grade calculated for sections B5, and L7 are 0.6667 and 0.75 respectively.

3 RESULTS AND DISCUSSION

The fault sections membership grade for case study 1 is given in Table 4 and Figure 7. From Table 4 and Figure 7, the maximum membership grade calculated for fault sections belongs to B1 and so this is the most probable faulty section of all the given zones. Therefore dispatchers would first of all pay attention to this section.

Also, the fault sections membership grade for case study 2 is given in Table 5 and Figure 8. From Table 5 and Figure 8 maximum membership value calculated belongs to B1 and so this is the most probable faulty section of all the given zones. Again, the fault sections membership grade for case study 3 is given in Table 6 and Figure 9.

From Table 6 and Figure 9 maximum membership value calculated belongs to L1,L2, L7, and L8.Therefore, these are the faulty sections in the power system Network. It can be seen from Table 6 and Figure 9 that the membership values calculated for the probable fault sections (L1, L2, L7, and L8) are the same. This is because the number of the primary, the secondary and the tertiary circuit breakers tripped for each of these sections are equal. Therefore, all these sections are considered and traced by dispatchers for fault in the power system network.

The fault sections membership grade for case study 4 is given in Table 7 and Figure 10. From Table 7 and Figure 10 maximum membership value calculated belongs to B8.Therefore, B8 is the faulty section in the power system network. Furthermore, the fault sections membership grade for case study 5 is given in Table 8 and Figure 11. From Table 8 and Figure 11 maximum membership value calculated belongs to L7.Therefore, L7 is the faulty section in the power system Network.

Table 4: Fault sections membership grade for case study 1

Tripped circuit breakers	Possible fault section	Membership grade
CB4, CB5, CB7, CB9, CB12 and CB27	B1	0.75
CB4, CB5, CB7, CB9, CB12 and CB27	B2	0.4167
CB4, CB5, CB7, CB9, CB12 and CB27	L1	0.5
CB4, CB5, CB7, CB9, CB12 and CB27	L2	0.375

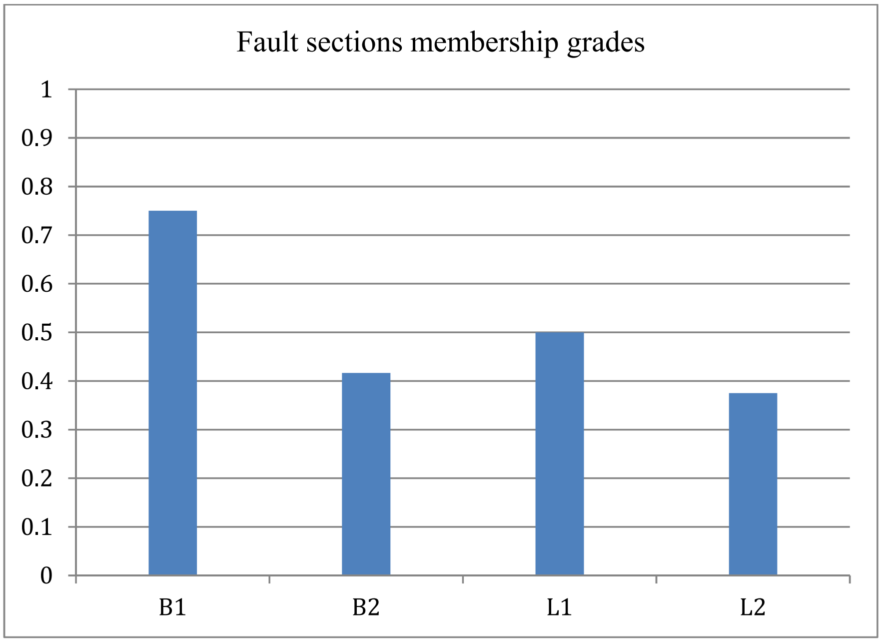


Figure 7: Membership grades of possible fault sections for case study1

Table 5: Fault Sections Membership Grade for Case Study 2

Tripped circuit breakers	Possible fault section	Membership grade
CB4, CB5, CB6, CB7, CB9 and CB11	B1	0.9167
CB4, CB5, CB6, CB7, CB9 and CB11	B2	0.541
CB4, CB5, CB6, CB7, CB9 and CB11	L1	0.667

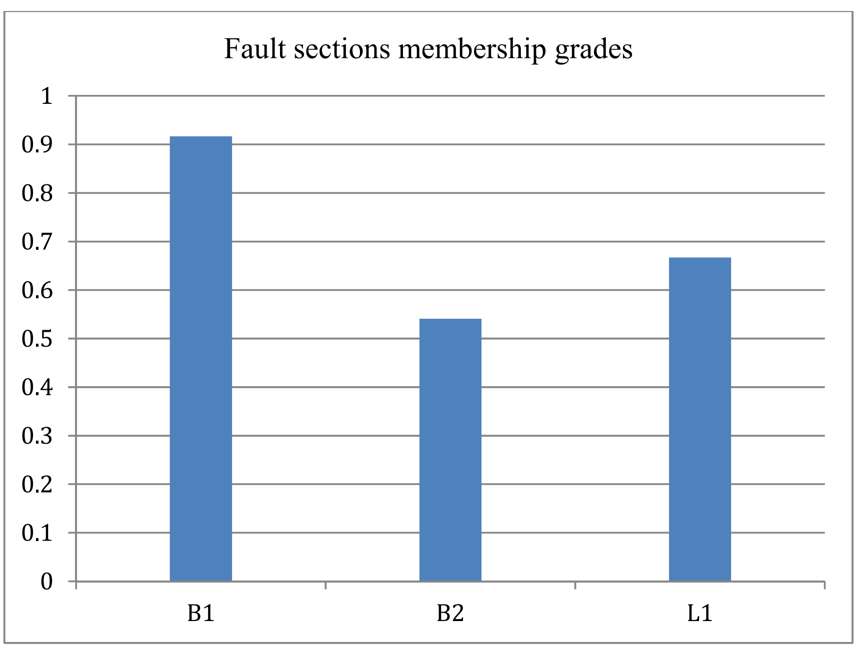


Figure 8: Membership grades of possible fault sections for case study2

Table 6: Fault sections membership grade for case study 3

Tripped circuit breakers	Possible fault section	Membership grade
CB7, CB8, CB11, CB12, CB29, CB30, CB39 and CB40	L1	0.4375
CB7, CB8, CB11, CB12, CB29, CB30, CB39 and CB40	L2	0.4375
CB7, CB8, CB11, CB12, CB29, CB30, CB39 and CB40	L7	0.4375
CB7, CB8, CB11, CB12, CB29, CB30, CB39 and CB40	L8	0.4375

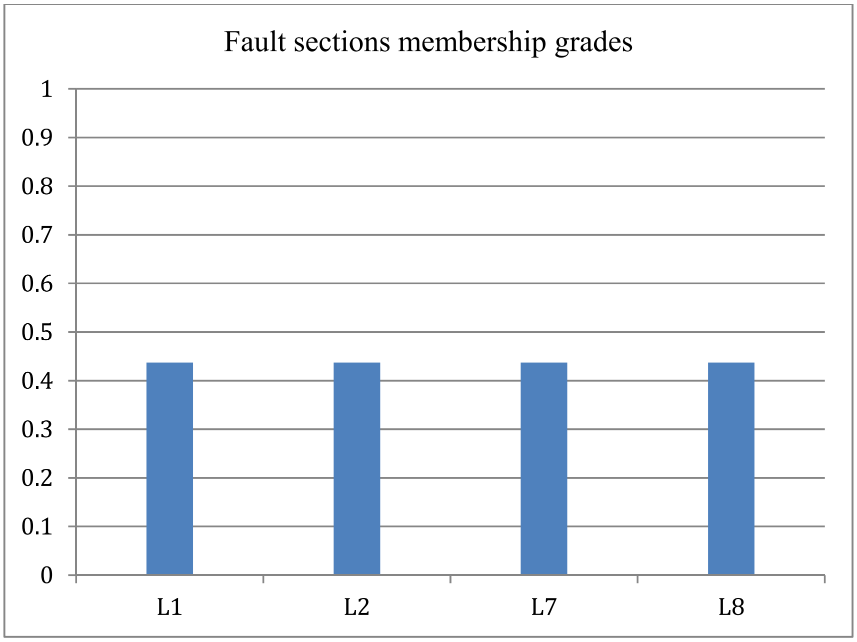


Figure 9: Membership grades of possible fault sections for case study 3

Table 7: Fault sections membership grade for case study 4

Tripped circuit breakers	Possible fault section	Membership grade
CB6, CB22, CB24, CB7 and CB25	B2	0.5625
CB6, CB22, CB24, CB7 and CB25	B8	0.625
CB6, CB22, CB24, CB7 and CB25	L4	0.5625
CB6, CB22, CB24, CB7 and CB25	L5	0.4375

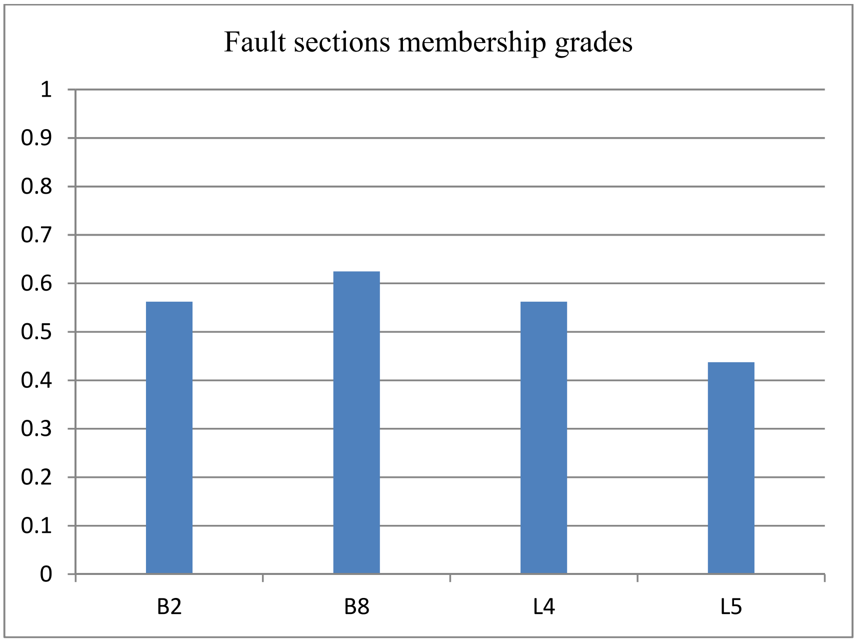


Figure 10: Membership grades of possible fault sections for case study 4

Table 8: Fault Sections Membership Grade for Case Study 5

Tripped circuit breakers	Possible fault section	Membership grade
CB7, CB11, and CB13	B5	0.6667
CB7, CB11, and CB13	L7	0.75

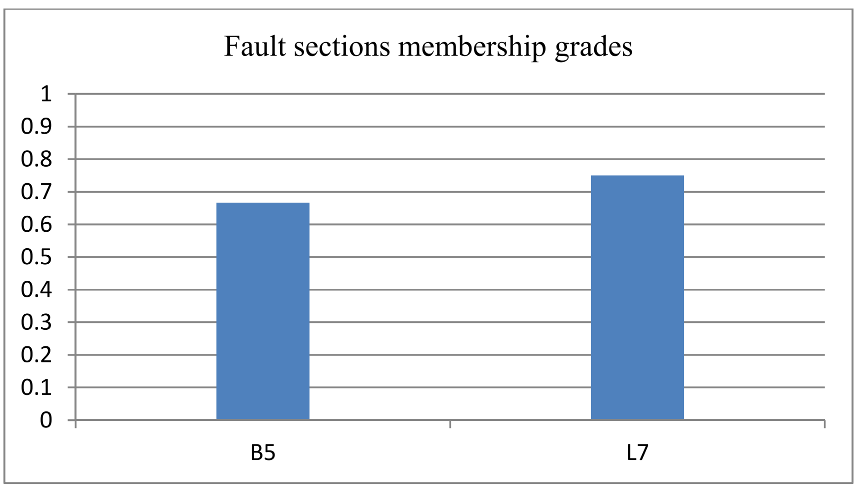


Figure 11: Membership grades of possible fault sections for case study 5

4. CONCLUSION

A fuzzy logic-based scheme which will assist power system operators to determine the location of the fault when fault current condition occurs in a power system network is presented. The scheme works by using the post fault status of the circuit breakers and relays to calculate the membership grade for each possible fault section. The membership grade is used to determine the likelihood of each candidate fault section as the actual fault section where the fault occurred. Furthermore, the membership grade is used for ranking the fault sections and the maximum selection method is used to select the most possible fault section which is the section with the highest membership grade. MATLAB code was developed and used to simulate the system in different case studies applied to a power- system network. The results shows that the scheme is effective in identifying the fault section when there are tripping of multiple circuit breakers in the power system network.

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