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Design and Testing of a Smart Relaying System for IEEE – 9 Bus Network

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Abstract

This article proposes to design and simulate a smart relay. These relays are installed devices that can be added to an electrical circuit and allow remote control. The main purpose of the proposed smart protection is to improve the dynamic performance of the IEEE 9-Bus network and reduce the number of interruptions and outages due to emergencies or accidents in the transmission system. The installation of a protection system with a smart relay using fuzzy logic control. Artificial controllers used to protect the electrical system by separating the parts that have malfunctioned while keeping the parts that did not fault by issuing a disconnection signal or directing the circuit breaker. Therefore, the protection system must be active and resolute by separating the symmetrical and asymmetrical faults from the transmission system and within the local and international standard specifications. It is worth noting that the MATLAB program and mathematical simulation were used to demonstrate the performance of the system. The proposed system is used to protect the transmission line using distance relays as main protection, and the overcurrent relays as a backup. A backup protection relay is used in case of failure main relay. The most important results depict that the time delay due to the logical relay is about 35ms; the proposed smart relay has a faster response than the logical relay.

Keywords: Smart relay, Protective relaying, Fuzzy logic controller, Transmission protection, Microcontroller-based ANN, Distance protection.

1. Introduction

Electromagnetic actuators are used to build early traditional relays. These relays were massive and heavy equipment requiring much room to be installed. Analog electronic components replaced electromechanical actuators with solid-state relays. Even when electromechanical relay-based protection systems proved reliable, compact in size and weight, and easy to set up, maintain, and design relays. Digital and numerical relays have been created, and they serve various functions, including the ability to record signals during malfunctions [1]. Relays are one of the significant pieces of equipment used in power system security. These are the most versatile, cost-effective, and well-known devices for quick and low-cost protection. Relays receive signals from the power system, process them, and act on them based on various settings. The institute of electrical and electronic engineering defines a relay to detect faulty equipment or other abnormal or dangerous power situations and trigger an appropriate control circuit action [2]. Smart relays are installed devices that can be added to any electrical circuit and allow wireless remote control of anything else connected to that circuit. Protective relays continuously monitor the state of the equipment and system they are meant to protect from damage [3 - 4]. The current study can summarized as follows: section 2 presents the protection system components utilization of FLC in power system protection, section 3 focuses on the principle of system protection, section 4 discusses the utilization on of Fuzzy Logic in power system protection, section V presents Utilization of Neural Networks in Power Systems, section 6 discusses modelling and simulation of microcontroller based ANN, section 7 presents transmission protection system test and results and section 8 shows simulink model of smart overcurrent relay and finally conclusion and remarks have been discussed.

2. Protection System Components

It is known that the protection system consists of three main components, which are [3]: relay, transformers for current and voltage measurements and circuit breakers

2.1 Relays

Protective relays are logical devices that detect abnormal power system functioning and send a signal to the breaker to trip or block the breaker. The principle of operation, input numbers, performance characteristics, and technology are all used to classify conservative relays (electromechanical, solid-state, or microprocessor-based). Protective relays can be found in central control rooms, or dedicated relay cabinets were strewn across a substation or switchyard. V.Ts or C. Ts causes a voltage or current drop from higher to lower levels. The majority of Protective relays function to start C.B. While an aberrant action is detected sends a trip signal to C.B., which prevents C.B. from opening its connections when the system is operating normally [4].

2.2 Transformers for Current and Voltage Measurements

C.T. and V.T. are used to convert power system signals from higher to lower levels and prepare separation of the high-electric grid, manipulator and other equipment linked to the auxiliary windings of the transducer. Transducers must follow various standards to perform at varied current and voltage levels and be compatible with the various relays and meters used in the conservative system. In the United States and some other nations, the C.T. is rated 5A, whereas, in Europe, a secondary standard of 1A is also used. For phase-to-phase voltage connections, V.T. secondary windings are rated at 120V or 69.3V, respectively. C.Ts are designed to hold ($If > 50 * IL$), whereas V.Ts are required to hold out against dynamics of electric grid overvoltage. C.Ts are multi-winding transformers that are magnetically connected, but V.T. s, like C.Ts, may feature a capacitive voltage divider for high-voltage systems. [30].

2. 3 Operation Principle of Circuit Breakers

C.Bs are fault disconnecting devices that isolate malfunctioning components and prevent fault current from flowing in the electric grid. When the switches of C. Bs are closed, the grid current flows; when the switches are open, the grid current is halted. Circuit breakers are utilised as switching and fault-interrupting devices since they are intended to retain and break away both load current and fault current. Circuit breakers in power systems are not self-acting. Circuit breakers in power systems turn OFF or ON when a trip or close signal is obtained [5]. The voltage, load current rating, maximum fault current, and fault current interrupting duration are all important properties of circuit breakers. C.Bs come with nominal ratings, among other features. The approach is designed to save money on improving high voltage and current performance testing for a wide range of C.Bs [31]. Requirements for a robust conservative system of effective protection can be achieved in compliance presented in [4], [6]: reliability, selectivity and sensitivity.

3. Principle of System Protection

Setting overcurrent does not reflect the security features of the electric grid. The setting is impossible to achieve in huge networks, and it can be observed that settings may cause severe halt times near the generators. This troubleshooting has a way to the main protection. Ideally, the electric grid is sectionalized into separate zones for complete preservation selectivity. Each region is linked with relays and C.Bs to detect and isolate its internal faults [7]. When the unit protection isolates the fault appropriately, it is critical to offer extra protection to guarantee that the disturbance is isolated. This extra layer of security is known as backup protection. Because the fault is beyond the primary protection zones, backup protection can only remove it. Backup protection must be temporally delayed after the primary protection to permit the typical deposition of the problem by unit protection [7].

4. Distance Relay Modeling

The distance protection scheme is a widely used conservative scheme to protect HVAC transmission. Many relays have been utilized that measure the impedance at the position of the relay. This component varies with the line length between the relay position and the point of fault occurrence [8]. The basic principle explains the voltage division at the relay by the measured current. The ultimate impedance is measured and compared to the reach point impedance. The power system has two types of faults: symmetrical and unsymmetrical. Unsymmetrical faults are further subdivided into L.G, L.L, and DLG faults [9]. Three-phase and three-phase to-ground faults are symmetrical faults in which all phases are in contact with one another or the ground. When a T.L. fault occurs, the distance relay measures the impedance between the faulty phases in the case of L.L. faults or between the faulty phases and the neutral conductor in the case of ground faults. The disagreed scenario is used for calculating fault impedance for various faults, as listed below [10].

$$Z_{AG} = \frac{V_A}{(I_A + I_0 * 3K_{0)}} \quad (1)$$

$$Z_{BG} = \frac{V_B}{(B + I_0 * 3K_{0)}} \quad (2)$$

$$Z_{CG} = \frac{V_C}{(I_C + I_0 * 3K_{0)}} \quad (3)$$

$$Z_{AB} = \frac{V_A - V_B}{(I_A - I_{B)}} \quad (4)$$

$$Z_{AC} = \frac{V_A - V_C}{(I_A - I_{C)}} \quad (5)$$

$$Z_{BC} = \frac{V_B - V_C}{(I_B - I_{C)}} \quad (6)$$

$$Z_{ABC} = \frac{V_A}{I_A} \stackrel{\text{def}}{=} \frac{V_B}{I_B} \stackrel{\text{def}}{=} \frac{V_C}{I_C} \quad (7)$$

where, $Z_{AG,}Z_{BG}, Z_{CG}$: are the impedances of phase to ground measured in $\boldsymbol{\Omega}$. $Z_{AB}Z_{AC}Z_{BC}$: are the impedances of the line to line measured in $\boldsymbol{\Omega}$. Z_{ABC}: is the three-phase impedance measured in $\boldsymbol{\Omega}$. V_A, V_B, V_C : are the phase voltage measured in V. I_A, I_B, I_C: are the phase current measured in A

$$K_0 \stackrel{\text{def}}{=} \frac{(Z_0 - Z_1)}{(K * Z_1)} \quad (8)$$

Residual compensation factors are I_o: is zero sequence current , Z_0: is Zero − sequence impedance, Z_1: is Positive − sequence impedance, $\boldsymbol{k}$: it depends on the relay design.

So the distance relay provides a trip signal to the suitable breaker. The protection zones mean giving all predetermined impedance a suitable delay time. So, distance relay selectivity was applied near the utilization of various predetermined impedance in correlation with its suitable time delay.

It's popular to give distance relay three zones of protection, but additional zones may be used depending on their implementation [11].

5. Utilization of Fuzzy Logic in Power System Protection

Fuzzy reasoning and fuzzy signal processing methods, which are members of the AI family, have received much attention during the past 15 years. Numerous investigations have been carried out in outstanding research facilities. Numerous decision-making issues can be solved with fuzzy logic. Using F.L.-based decision modules or classifiers, one of the many jobs that may be efficiently completed is the analysis of power system breakdowns and other abnormal events [12].

Fuzzy modelling or classification typically uses different forms of FIS. The FIS scheme functions in several phases, as shown in Figure 1.

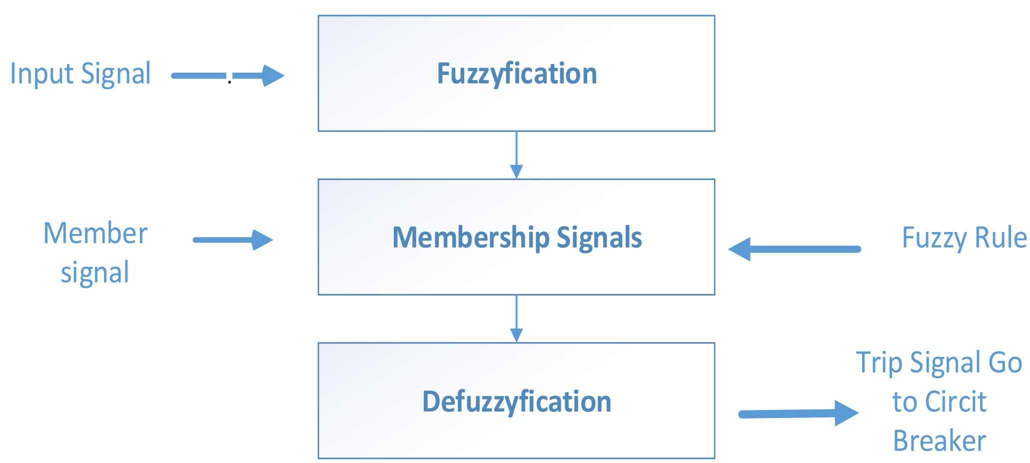

Figure 1 Block diagram of fuzzy logic controller.

• To determine the membership amplitudes of each linguistic word, the fuzzification process compares the input values with membership functions.

• The shaky logic (triggering the basics and providing their fuzzy consequences).

• Defuzzification (aggregating rule results to create a clear response).

The created protection solution uses fuzzy signal processing and comparison to arrive at a trip determination based on training input-output data.

6. Utilization of Neural Networks in Power Systems

A massively parallel distributed processing unit called a neural network store made experimental knowledge accessible. One can find a low-level biological model in physiology or genetics, such as an artificial neural network. Like the brain, the network takes input signals and then internally processes them by activating neurons to create output signals [1- 4]. Depending on the operation, any layer has a variety of neurons. An illustration of this is the multi-layer perceptron, which comprises two or more neural networks linked to produce a cascaded multi-layer perceptron. One network's output becomes another's input, etc. [12].

7. Modeling and Simulation of Microcontroller-Based ANN

A microcontroller is one method for alternately controlling these subsystems as needed. It is done with the assistance of the proposed microcontrollers using ANN that regularizes the relay trip signals. The microcontroller prioritizes providing the trip signal for the readiest unit or primary protection relay to switch off the fault through the related C.B. IEEE - 9 bus network used in this study consists of three generators located in buses one, two and three, seven transmission lines that connect the buses, nine bus bars in the network and three transformers in which transformer number one between buses two and seven, and transformer two between buses nine and three whilst transformer three is located between buses one and four.

Table 1 lists load data of IEEE 9 buses and Table 2 shows bus data of IEEE 9 buses, respectively.

Table 1 Load Data of IEEE 9 buses.

Frome buse	To Bus	P MW	Q Mvar	Line Loss	
				MW	Mvar
1	2	47.024	5.514	0.381	0.199
1	4	103.50	-25.023	1.600	3.997
2	3	36.633	1.317	0.233	0.725
3	9	11.390	-11.405	0.051	0.152
4	5	11.520	-70.30001	0.620	1.070
4	6	30.3433	1.291	0.175	0.577
5	7	8.216	68.414	0.786	1.376
6	9	-27.806	13.579	0.092	0.460
7	8	-42.572	7.039	0.571	1.357
8	9	36.846	9.327	0.300	0.885

Table 2 Bus data of IEEE 9 buses.

Bus No.	Voltage	Angle degree	Load		Generation		Injection
			MW	Mvar	MW	Mvar	Mvar
1	1.030	0.000	0.000	0.000	150.137	150.137	-0.36
2	1.016	-1.280	10.000	5.000	0.000	0.000	0.000
3	1.007	-2.364	25.000	15.000	0.000	0.000	0.000
4	1.021	-2.617	60.000	40.000	0.000	0.000	0.000
5	1.040	-3.258	10.000	5.000	80.000	80.000	322.186
6	1.012	-3.665	100.000	80.000	0.000	0.000	0.000
7	1.011	-3.483	80.000	60.000	0.000	0.000	0.000
8	1.20	-1.561	40.000	20.000	120.000	120.000	20.529
9	1.008	-2.820	20.000	10.000	0.000	0.000	0.000

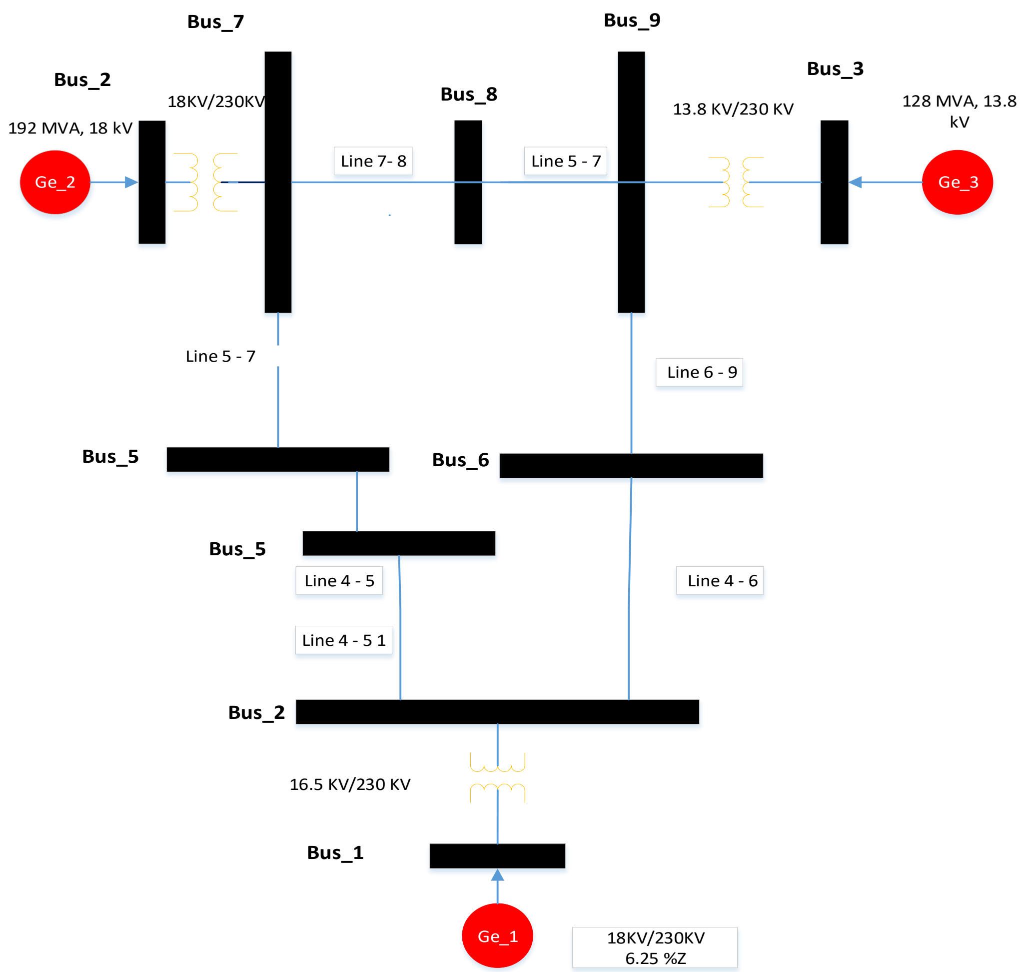

Figure 2 Single line diagram for IEEE - 9 bus.

8. Transmission Line Protection System Test and Results

Usually, a distance relay is used for overhead transmission line protection. It compares the regional current and voltage at one end of the transmission line. An impedance relay depends on the length of the line. The distance relay is modelled and simulated according to equations (1-7) in chapter two. Rules for fault detection and diagnosis using fuzzy logic control are listed in the table 3. Figure 3 clarifies the proposed microcontroller computer flowchart.

Table 3 Rules for faults detection and diagnosis using FLC.

Faults Type	Z_a	Z_b	Z_c	Z_{ab}	Z_{ac}	Z_{bc}	Z_{abc}
Healthy Case	High	High	High	High	High	High	High
A-G	Low	High	High	High	High	High	High
B-G	High	Low	High	High	High	High	High
C-G	High	High	Low	High	High	High	High
A-B	High	High	High	Low	High	High	High
A-C	High	High	High	High	Low	High	High
B-C	High	High	High	High	High	Low	High
ABC	High	High	High	High	High	High	Low

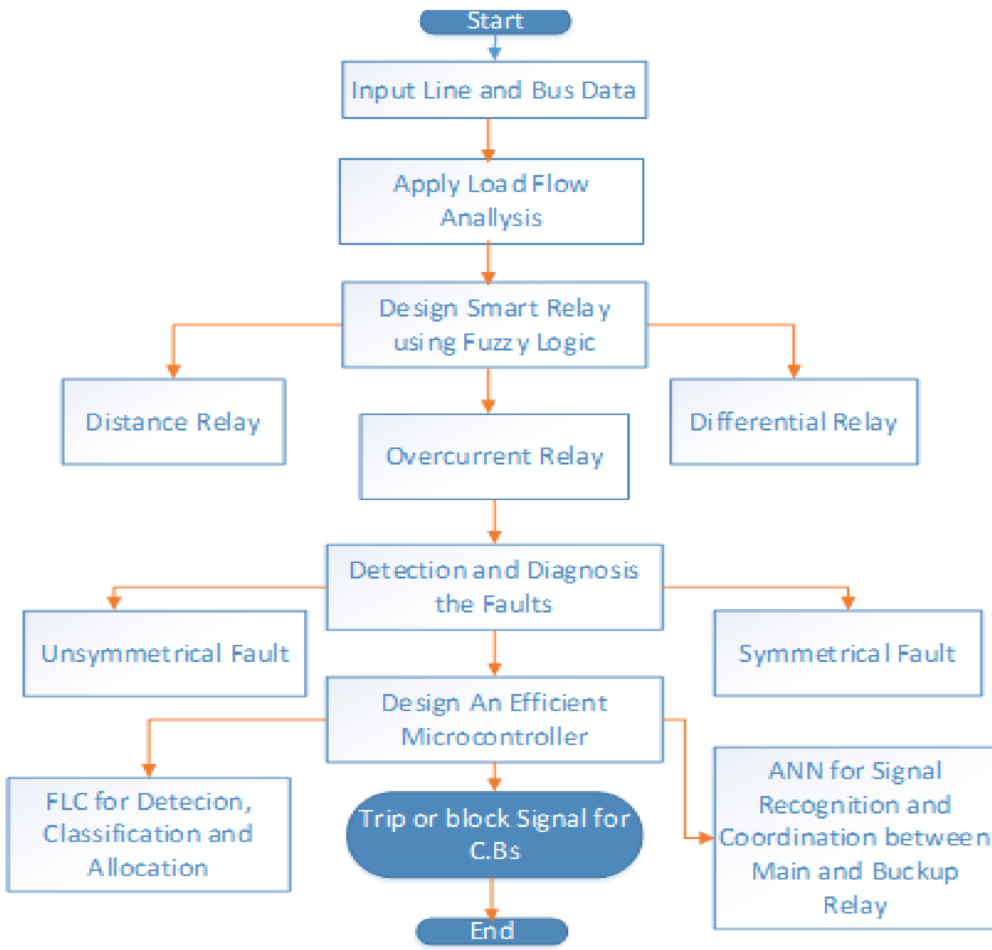

Figure 3 Computer flowchart for the proposed microcontroller.

Figure 4 shows the fuzzy logic design from the fuzzy logic toolbox in MATLAB software R2019. This indicates the type of fuzzy inference system (FIS) used. There are different methods used in defining rules, and the defuzzification method.

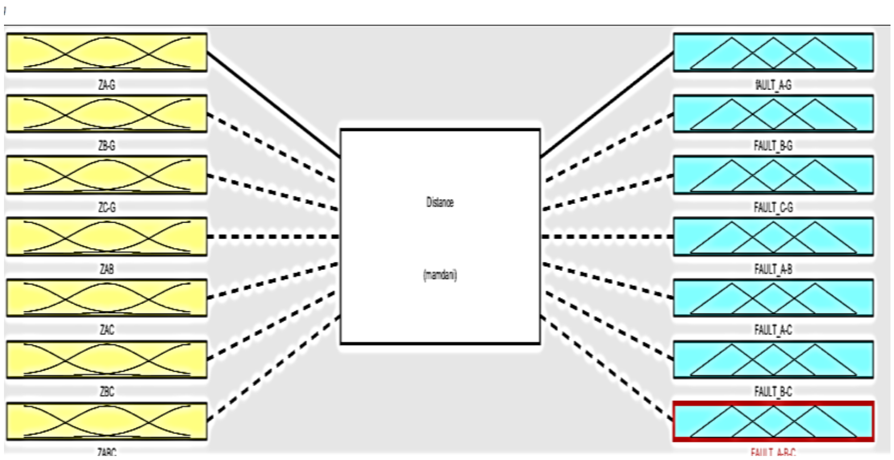

Figure 4 Fuzzy logic design of smart distance relay.

Figure 5 contains two memberships; if the fault occurs, the impedance value is small because of the current increase, and the second is membership when no-fault occurs. It contains two memberships, the fault and no-fault, and the signal goes to the circuit breaker. Figure 6 shows MATLAB simulation for smart distance relay.

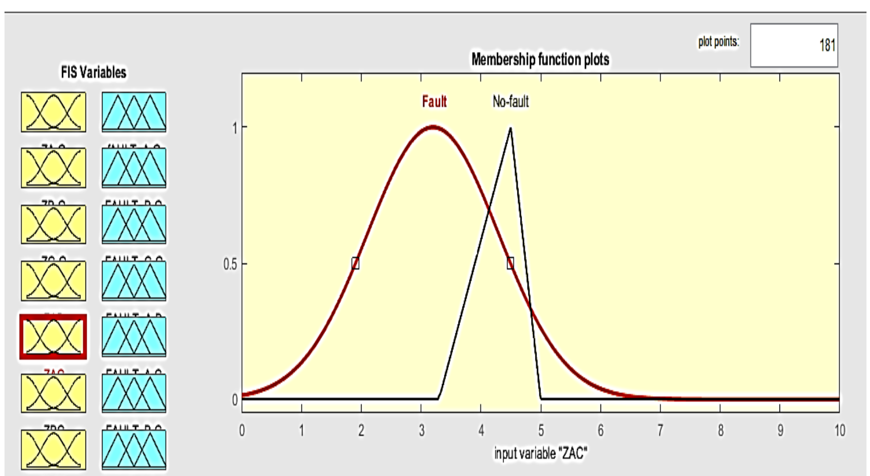

Figure 5 Membership function for the input of distance relay.

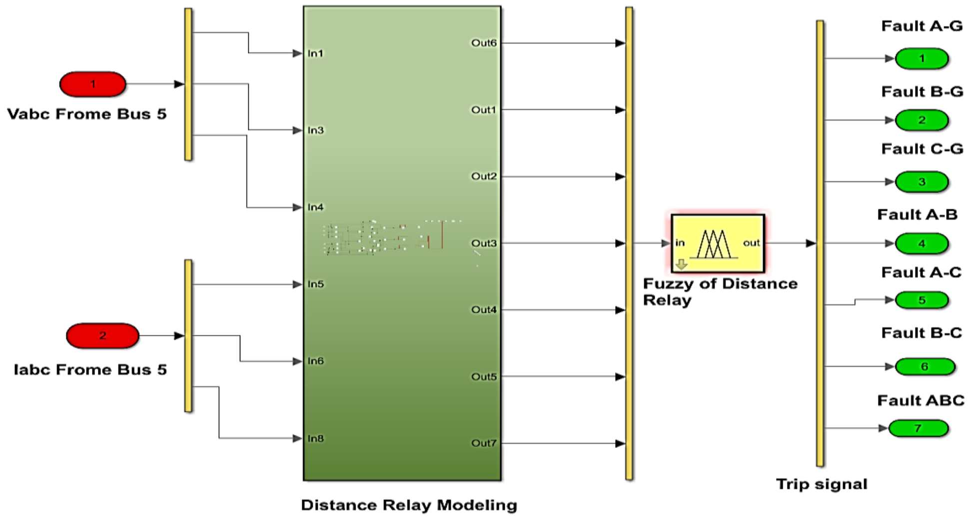

Figure 6 MATLAB simulation for smart distance relayژ

9. Simulation and Discussion:

Based on the above study, the case study system uses an overcurrent relay as a local backup protection mechanism in this subsection. The relay must be built to detect the current level and send a trip signal to the circuit breaker (normal operation value) for all currents exceeding the setting value. There is a tolerance of 15% to 20% from normal operation about differential overcurrent relay. T.L.'s primary protection relay is a distance relay that detects the line's impedance, while the local backup protection relay is an overcurrent relay. Figure 7 shows the phase AG fault applied to the system at the midpoint of T.L No. 11 for intervals (0.4 - 0.5) s. Table 4 lists maximum short circuit current for distance protection.

Table 4 Maximum SCC for distance protection.

Type of Fault	I_a (A)	I_b (A)	I_c (A)
Healthy Case	3000	3000	3000
A-G	6850	3200	3207
B-G	3220	7200	3220
C-G	3180	3217	630
A-B	6150	6850	338
A-C	6000	3250	6550
B-C	3260	6840	6350
ABC	7750	7750	7750

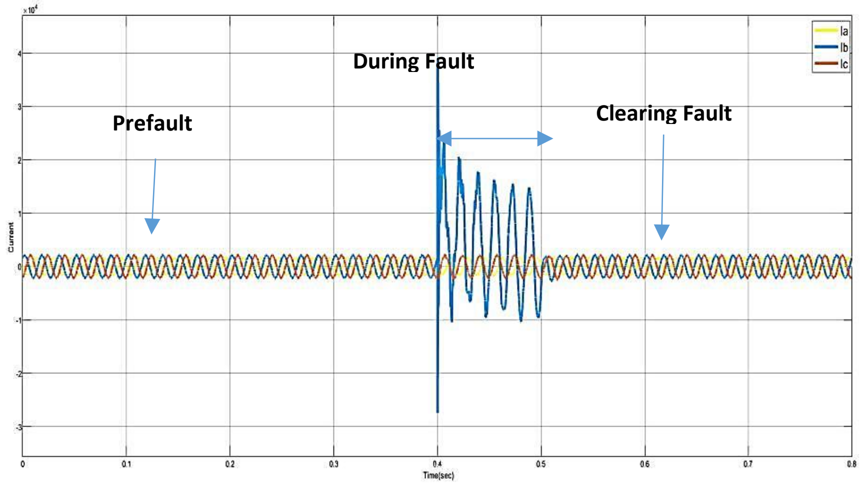

Figure 7 Phase (b) to ground fault at the midpoint of T.L between No. 4 -5.

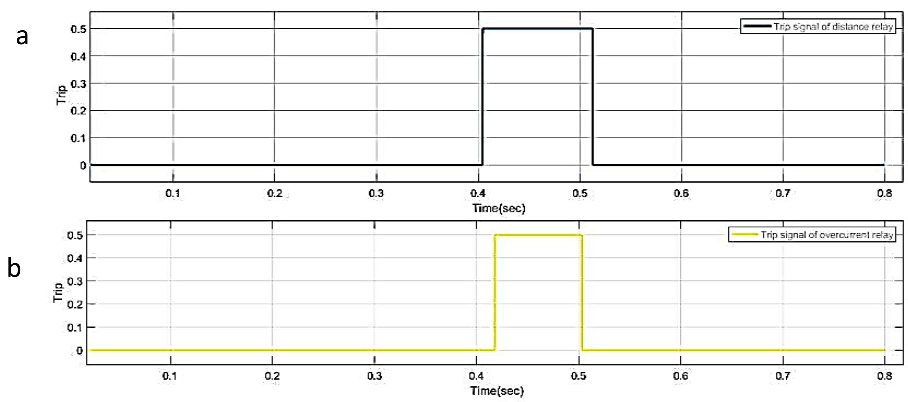

Figure 8 IEEE 9 bus transmission line protection

(a) Distance relay trip signal, (b) Overcurrent relay trip signal

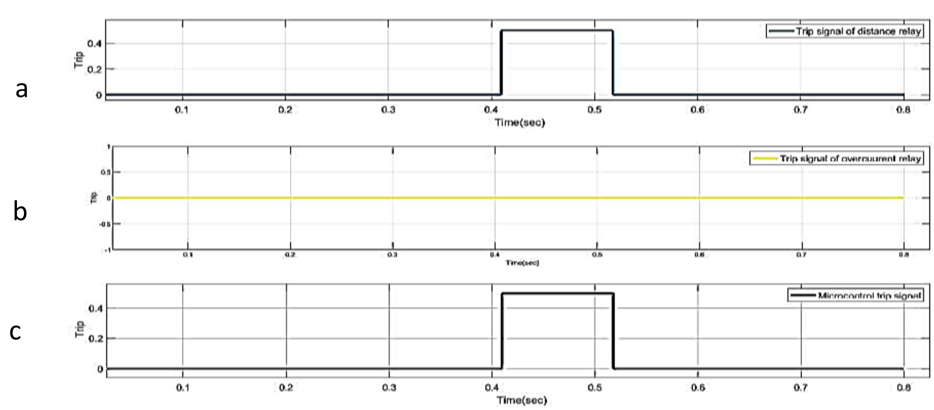

Figure 9 Microcontroller-based ANN trip during fault at the midpoint of T.L in Busbar No.11

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(a) Main protection signal (b) Backup protection signal

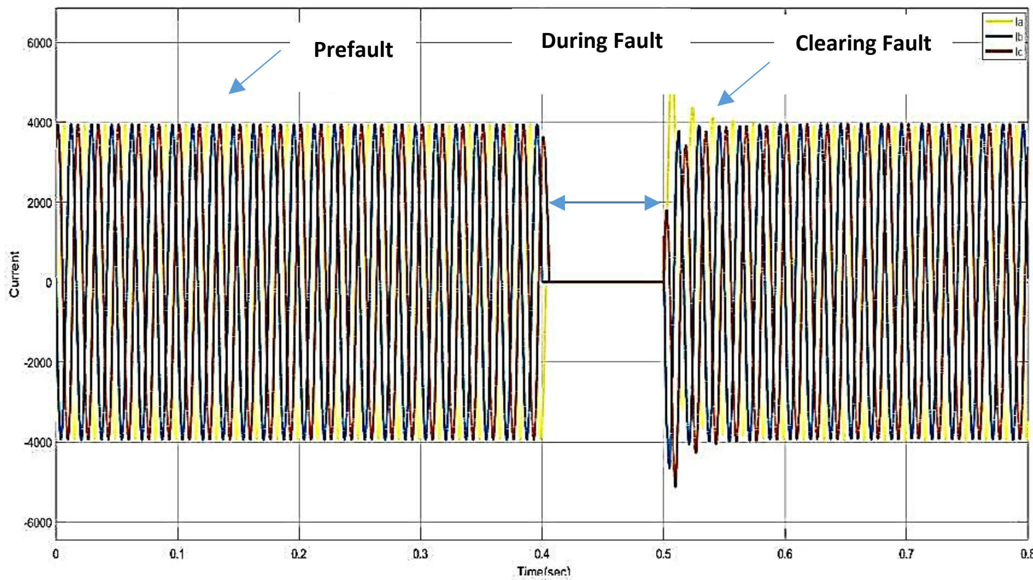

Figure 10 Fault current waveforms at transformer terminal

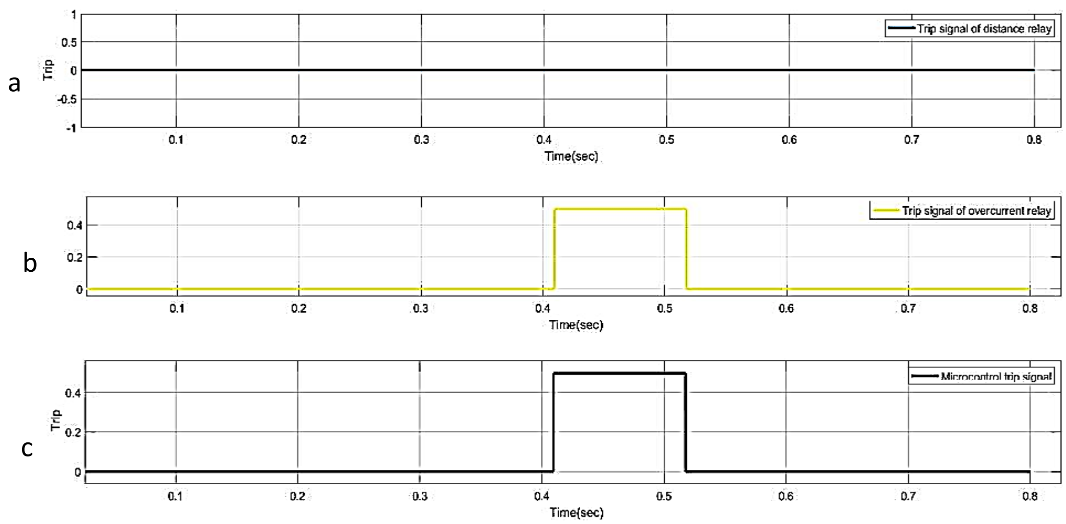

Figure 11 Microcomputer-based ANN trip during fault at the midpoint of T.L between No. 4 -5 (a) Distance protection failure (b) Overcurrent protection signal.

During the period (0 - 0.4) sec., the relay operates regularly during the time interval (0 - 0.8) sec. as shown in Figure 16. The proposed protective relaying isolates the specified transformer from the grid after (0.4) sec. Figure (11 - c) shows that when a fault occurs, the microcontroller sends a trip signal to the primary unit protection, and it cannot clear the fault through the specified C.B, shown in figure (11 - a), while the overcurrent detects the fault as well simultaneously, shown in figure (11-b). The microcontroller organizes the proposed smart protection relaying between primary and secondary protection relays.

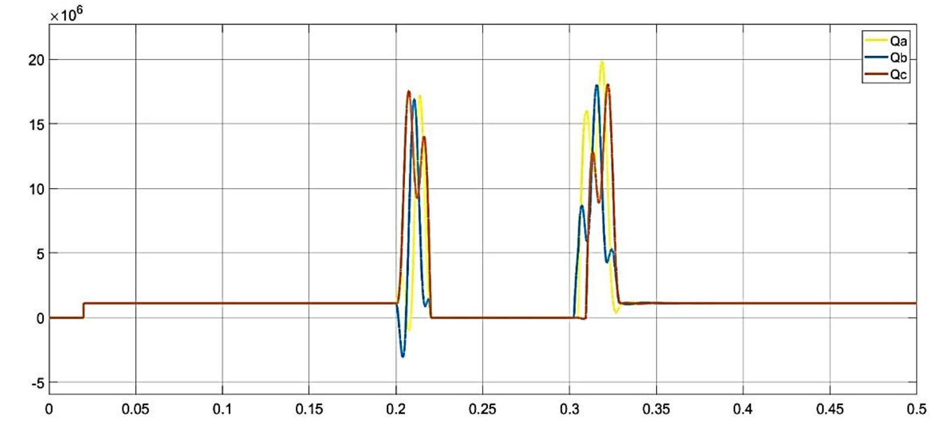

Figure 12 Effect of three–phase fault on measuring reactive power in Mvar.

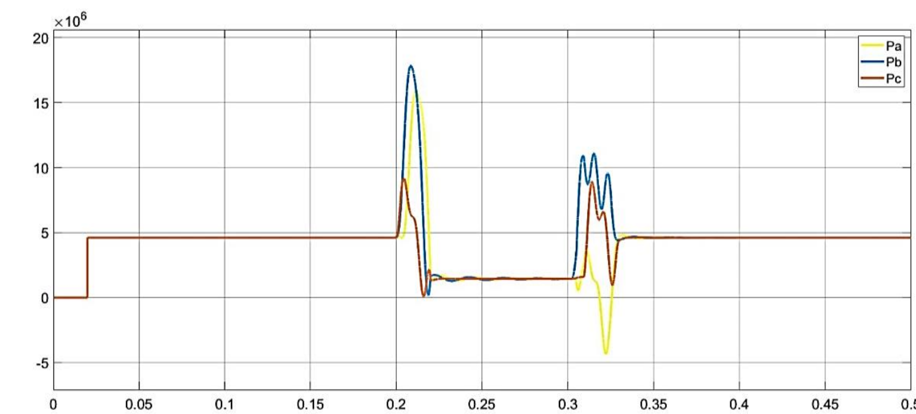

Figure 13 Effect of three–phase fault on measuring active power in MW.

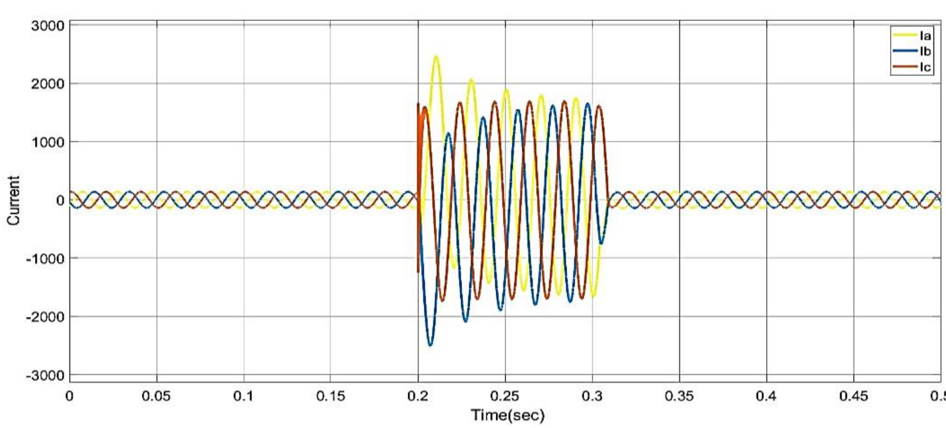

Figure 14 Effect of three–phase fault on full load current measured in A.

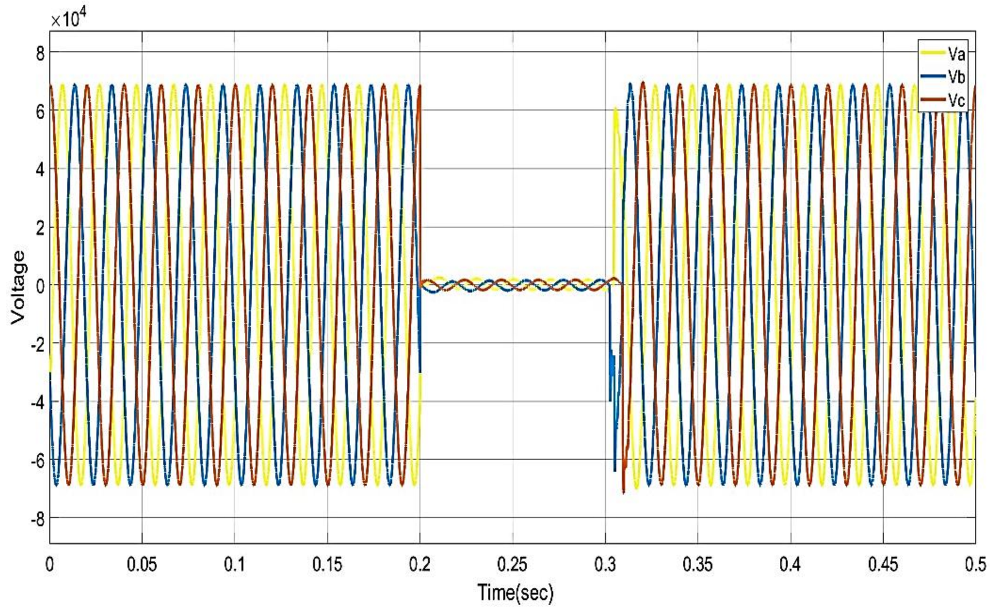

Figure 15 Effect of three–phase fault on full load voltage measured in V.

10. Conclusion

The design of an intelligent relying system for IEEE 9-bus is accomplished in this study. The proposed protection system improves the system's performance during fault occurrence while; in the case of the proposed protection system, only the faulty transmion line is isolated, increasing the reliability of the power system. The microcontroller-based ANN used in the proposed system helps control the main and backup protection operation and coordinate the relay operations. The proposed smart relay has low complexity and low processing time, suitable for real-time protection. The microcontroller-based FFANN used in the proposed system helps control the main and backup protection operation and coordinate the relay operations. Online monitoring and protection of the power system elements as soon as possible to avoid excessive damage.

The accuracy of the proposed approach is quite high. The proposed method is quite effective in a wide range of electrical networks. The simulation results illustrate the transmission line changes in voltage and current before, during and after fault clearing in various zones**.** The proposed smart relay has low complexity and low processing time, suitable for real-time protection. The most important results depict that the time delay due to the logical relay is about 35ms; the proposed smart relay has a faster response than the logical relay.

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تصميم واختبار نظام الترحيل الذكي لشبكة (IEEE(9Bus

الخلاصة: *ان الهدف الاساسي من منظومة الحماية الذكية المقترحة في الدراسة الحالية هو تحسين الاداء الديناميكي لشبكات* ***(IEEE(9BUS*** *بهدف تقليل التوقفات وانقطاع التيار الكهربائي الناجمة من الحوادث الطارئة أو التخريب في نظام النقل الكهربائي من خلال تركيب نظام حماية مع مرحل ذكي والذ ي يتم التحكم به بواسطة متحكم منطقي ضبابي او متحك م ذكاء اصطناعي لحماية المنظومة الكهربائية عن طريق فصل الاجزاء التي حدث عليها العطل مع الإبقاء على الأجزاء التي لم يحدث عليها العطل بإصدار او طلب أصدار إشارة فصل الى قاطع الدورة الكهربائي المسؤول المباشر او القريب على الجزء المتضرر في الشبكة الكهربائية. أن النظام المقترح لحماية خطوط النقل الكهربائية يكون من نوع مناولات المسافة كحماية أساسية ومناولات التيار المرتفع كحماية داعمة واحتياطية في حالة فشل عمل المناول الأساسي وتم تصميمة باستخدام متحكم المنطق الضبابي وكذلك مسيطرات دقيقة تم تصميمها باستخدام الشبكة العصبية الاصطناعية تستعمل لتنظيم عمل وأداء المناولات الكهربائية. أهم النتائج أن التأخير الزمني بسبب الترحيل المنطقي يبلغ حوالي 35 مللي ثانية ؛ أي أن المرحل الذكي المقترح له استجابة أسرع مقارنة بالمرحل المنطقي.*