DISTANCE RELAY PROTECTION OF AN 11 kV DISTRIBUTION SYSTEM PERFORMANCE ENHANCEMENT USING MICROPROCESSORS

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ABSTRACT
Transmission and distribution lines are protected against fault in power network using protection methods and distance relays. This work focused on enhancing the speed of isolating defective circuits from the network by employing a microprocessor to minimize tripping time of the relay. The microprocessor was programmed with the help of information from network-wide fault research. Through the application of Power System Computer Aided Design (PSCAD) software simulations, the designed system's operating time for a line-to-line (LLG) fault between lines ABG occurring at 35 km on the tested line with a fault impedance of 5 Ω was 5.4 ms, while the old system, which was the conventional distance relay system without a microprocessor, had an operating time of 15 ms. In actuality, it was discovered that the new protective mechanism utilizing the microprocessor increased the average operating speed of the distance protection scheme from 6.144 ms to 4.390 ms, leading to boosting around 28.5% in the operating speed or speed of isolating the malfunctioning circuit. Also, the average tripping accuracy was improved from 67.5% to 100% for the developed system which shows 48% increase in accuracy.

Keywords: Operating speed, fault type, fault impedance, distance protection, microprocessor.

1.0 INTRODUCTION

Distance relays have been shown to operate slowly and with some degree of error, notwithstanding their effectiveness in safeguarding power supplies. According to (Hoq *et al*., 2021; Nwachi *et al*., 2022), the following are some of the reasons behind the distance relay's relatively low degree of precision and speed of operations:

(i) Line parameters vary according to atmospheric events, and relay models make use of these line parameters.
(ii) Fault current DC offset values. As a result, the fault current, which serves as the relay's fundamental functional data, contains some sort of "impurity."
(iii) Uncertainty around line parameters since they are usually computed from line data and utilized in relay models; these parameters are also rarely measured.

Additionally, it has been discovered that typical distance relays operate very slowly and have poorer fault isolation and location accuracy (Babu *et al*., 2011; Obi *et al*., 2014; Zayandehroodi *et al*., 2015; Oputa *et al*., 2023). Comparably, it was shown that while the functional speed and precision of distance relays may be reasonable in the event that the system encounters a single kind of fault, this cannot be said in the case of multiple fault types occurring at the same time (Obi *et al*., 2022; Qiuspe and Orduna, 2022). Although it has been discovered that the operations and tripping locations of distance relays rely not only on the fault location but also on the fault kind and fault impedance, the ideal scenario would have distance relays trip at the position where the fault took place (Ezendiokwelu *et al*., 2020; Onwuka *et al*., 2023; Oputa *et al*., 2023).

Researchers are starting to look beyond the distance relay in search of other, better devices for power system protection in light of the aforementioned flaws (and more) in the device and its security strategy. A digital distance relay employing field programmable gate arrays (FPGAs) for fault location and potential circuit isolation was developed in search of a more dependable relaying method. It was shown to have a comparatively higher speed and precision than the typical distance relays (Lata and Cenkeramaddi, 2023).

Also because of the unreliability of these distance relays, Artificial Neural Network (ANN) technology has been used in recent times for protecting power lines and power systems. The ANN has a high degree of robustness and ability to learn and is prepared to work with incomplete and unforeseen input data (Yadav and Dash, 2014; Uzubi *et al*., 2017; Adabayo and Ajala, 2023). However, the data handling of this ANN systems makes it complex in design. The conventional distance relay is rapidly being replaced by microprocessor relays in recent times. These are multifunction relays that are programmable and they are small devices that include several inputs and outputs. The microprocessor-based relay has also been used in the protection of grids, transmission lines, bus bars and even reactive power compensation devices (Zamani *et al*., 2011; Zheng and Zhao, 2014; Aibangbee and Onohaebi, 2015; Narendra *et al*., 2017; Fayyad *et al*., 2022; Taheri *et al*., 2023). Nonetheless, many power system networks currently in operation today employ a conventional distance relay-based protection method (Uzubi *et al*., 2020; Chukwulobe *et al*., 2022; Zhang *et al*., 2022; Zhang *et al*., 2023; Islam *et al*., 2024). Therefore, it is not a great answer to switch from conventional distance relay to ANN and digital relay protections on their own without also enhancing the current distance relay operations. For this reason, by adding a microprocessor to the operations of relay, (Oputa *et al*., 2024) have increased the working speed of these distance relay protection schemes.

However, in this paper, it was demonstrated that in addition to the operational speed improvement by (Oputa *et al*., 2024), we can also improve the tripping zone accuracy of the 11 kV distance relay protection system by incorporating the microprocessor to the relay operations as shown in Figure 1.

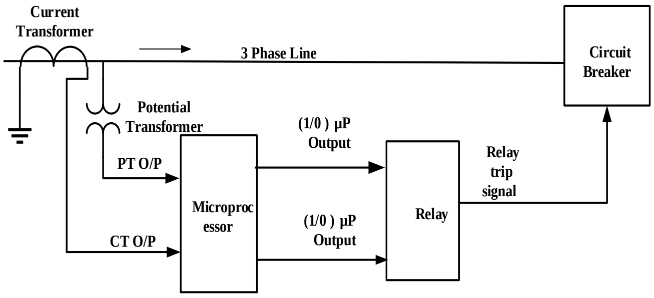

Figure 1: Block diagram for the new microprocessor – controlled relay protection philosophy

2.0 METHODOLOGY

2.1 Test Network for the Study

An 11 kV line of length 43 km, running from Bus 1 to Bus 2 and having 2 – zones, is used in this distance relay protection scheme analysis. The network is as shown in Figure 2.

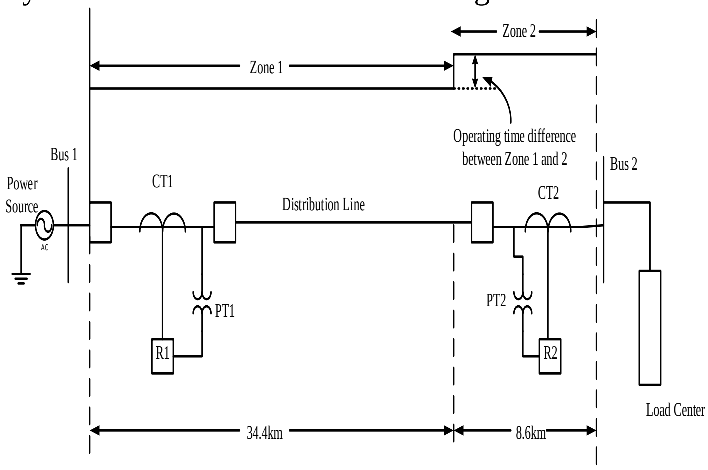

Figure 2: A 2 – zone distance protection of an 11 kV power distribution line.

Zone 1 provides immediate protection to 80% of the 43 km line, or up to 34.4 km, while Zone 2 covers the last 20% of the line, or 34.41 km to 43 km, with a time delay and serves as Zone 1's backup for the first 80% of the line. The line's specifications are displayed in Table 1.

Table 1: Line parameters

Length of Line	43km	
Line Positive sequence resistance (same as negative sequence)	$0.02582 \times 10^{-3}(\Omega/\text{m})$	
Line Positive sequence reactance (same as negative sequence)	$0.1291 \times 10^{-3}(\Omega/\text{m})$	
Line Positive sequence capacitance (same as negative sequence)	$210.10(\Omega/\Omega^{-1})$	
Line Zero sequence resistance	$0.1365 \times 10^{-3}(\Omega/\text{m})$	
Line Zero sequence reactance	$1.021 \times 10^{-3}(\Omega/\text{m})$	
Line Zero sequence capacitance	$423.251710(\Omega/\Omega^{-1})$	
Fault impedance used	Fault ON resistance	10Ω
	Fault OFF resistance	1.0E6 Ω
K	$6.826\angle 4.23°$	
Zone 1 (One)	0.0km to 34.4km	
Zone 2 (Two)	34.41km to 43km	

2.2 Mathematical Modelling of the Conventional Distance Relay/Protection Scheme

A model of the impedance observed by a distant relay for various kinds of line faults has been developed by Onwuka *et al*. (2023).

Impedance seen for a line-to-ground (L-G) fault is given by

$$Z_{seen}^{LG} = \frac{V_a^0+V_a^1+V_a^2}{I_a+K_0 I_a^0} \quad (1)$$

Where V_a=phase voltage, I_a=phase current.

Superscript 0, 1 and 2 are zero, positive and negative sequences.

$$K_0 = \frac{Z_0-Z_1}{Z_1} \quad (2)$$

The potential between the lines is $V_a - V_b$, and the resulting current between the lines is $I_a - I_b$ for line-to-line (L-L) faults between 'a' and 'b'. For this line-to-line (L-L) problem, the impedance that the relay detects is provided by

$$Z_{seen}^{LL} = \frac{V_b-V_c}{I_b-I_c} = \frac{V_a^1-V_a^2}{I_a^1-I_a^2} \quad (3)$$

Also, for a double line-to-ground (L-L-G) fault between lines ‘b’ and ‘c’ to ground, the impedance seen by the relay is given as

$$Z_{seen}^{LLG} = \frac{V_b(or\ V_c)}{I_b+I_c} = \frac{[V_a^0+a^2V_a^1+aV_a^2]or\ [V_a^0+aV_a^1+a^2V_a^2]}{2I_a^0-(I_a^1+I_a^2)} \quad (4)$$

Lastly. For faults involving all 3 phases, the impedance seen by the relay is simply

$$Z_{seen}^{3-\emptyset} = \frac{V_a}{I_a} = \frac{V_a^1}{I_a^1} \quad (5)$$

The speed at which this distance relay operates can be found by using PSCAD software to calculate the execution time of the aforementioned equation.

2.3 PSCAD Model for the Test Network

To design the impedance circle diagram in PSCAD, we take the total impedance Z_t for the length of the line,

$$Z_t = 43(0.02582 + j0.1291)\Omega = (1.11026 + j5.5513)\Omega = 5.66\angle 78.7°\Omega \tag{6}$$

The protection system uses a CT and PT with turns ratio of 300/1 and 500/1 respectively. Thus, transferring this total impedance in the primary sides of the instrument transformers to their secondary sides,

$$Z_{tsec} = \frac{300/1}{500/1} \times 5.66\angle 78.7° = 3.396\angle 78.7°\Omega \tag{7}$$

Hence, Zone 1 covers impedance up to $0.8 \times 3.396\angle 78.7°\Omega = 2.7168\angle 78.7°\Omega$ while Zone 2 covers the entire length of $3.396\angle 78.7°\Omega$.

The modelling of the conventional relay operations in PSCAD is as shown in the block diagram of Figure 3 (Oputa *et al*., 2024).

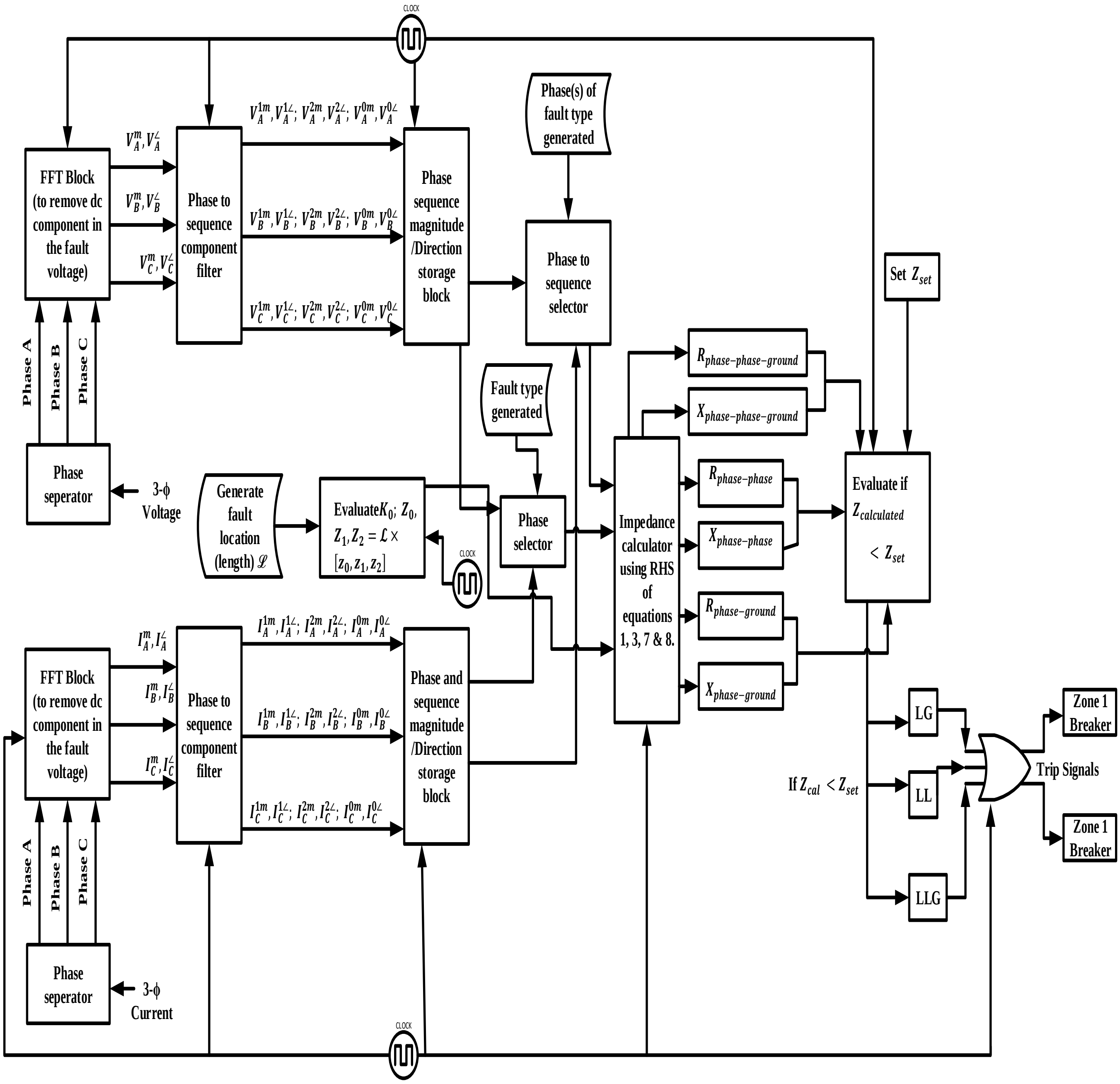

Figure 3: Block diagram of distance relay model in PSCAD

On the other hand, the PSCAD model of the protection system for the developed/improved microprocessor-relay controlled protection system is displayed in Figure 4. It should be pointed out that this specific model does not make use of the sequence components. The fault evaluation results are compared to the line current and bus voltage (fault current and voltage at fault) to determine how much of a high or low signal will be sent by the microprocessor to the relay

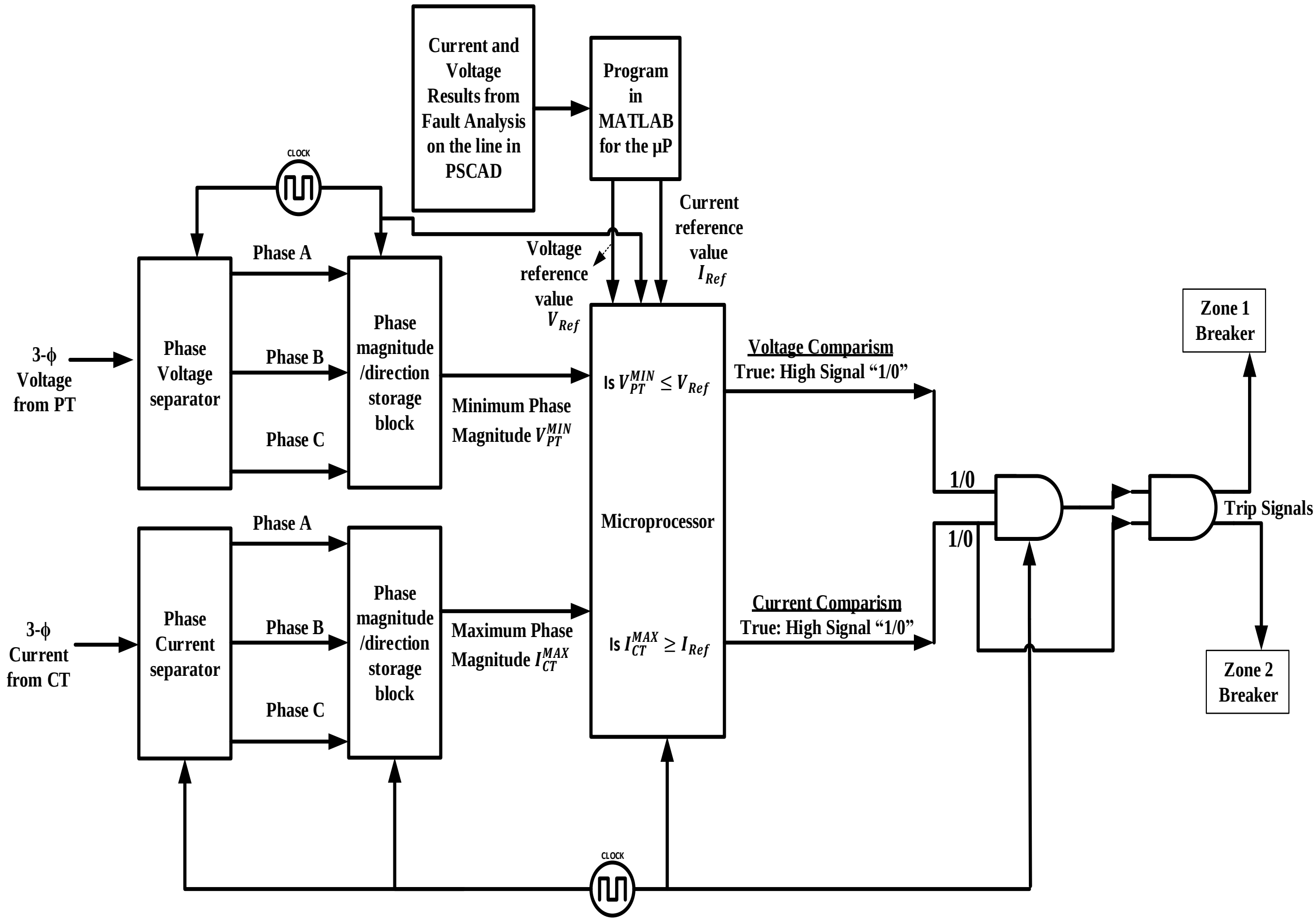

Figure 4: Block diagram of microprocessor controlled – relay model in PSCAD

3.0 RESULTS AND DISCUSSION

3.1 Fault Analysis of the System

The multi-run program in PSCAD is used to analyze the faults in the system for selected fault impedances of 0.1Ω, 0.5Ω, 1Ω, 5Ω, and 10Ω for ten instances of fault (AG, BG, CG, AB, AC, BC, ABG, ACG, BCG, and ABC faults). These faults were simulated at 50 meters (from bus 1 on the transmitting end), 8.6 kilometers, 17.2 kilometers, 25.6 kilometers, 34.4 kilometers, 35 kilometers, and 42.7 kilometers down the line. There were 250 results (run numbers) for the faults in Zone 1 and 100 results for Zone 2 out of the 350 sets of results that were recorded. Figures 5a and 5b, respectively, show a plot of the voltage at fault and the fault current for each of the ten different fault types, for each of the various fault impedance values, and for each of the locations mentioned above.

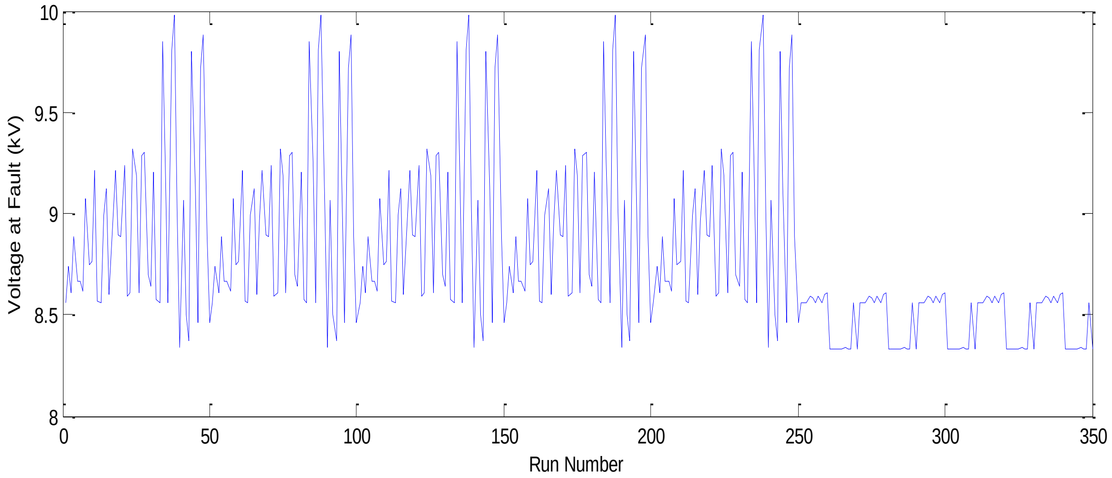

Figure 5a: Results of voltage at fault from fault analysis

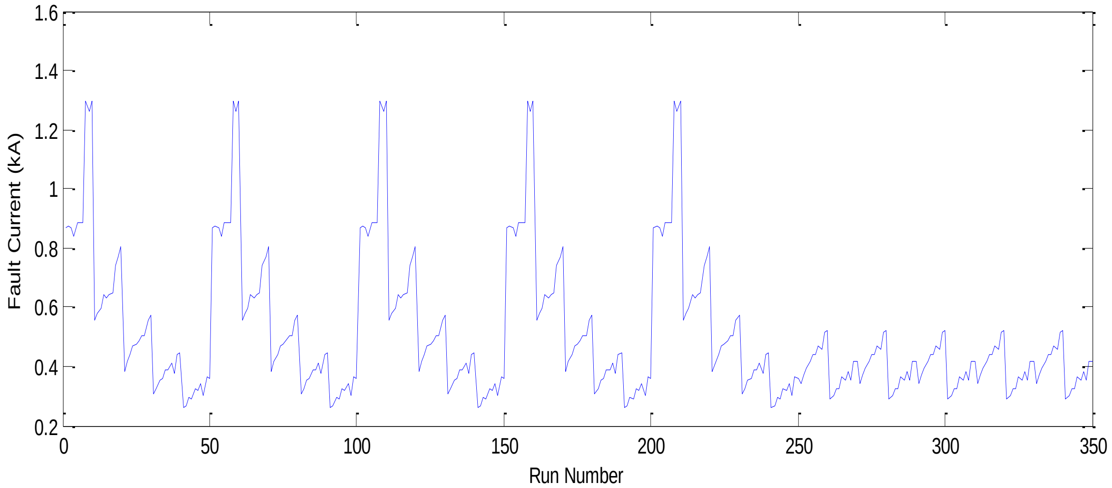

Figure 5b: Results of fault current from fault analysis

3.2 System Protection Analysis

This section compared the ways in which the test system is protected for various fault kinds, fault regions, and fault impedances by the designed microprocessor-controlled relay protection systems vs the typical distance relay protection technique.

Considering simulating a 10 Ω, LL fault on the line (from bus 1) between line A and line B to ground (ABG) at Zone 1 (10 km). According to Figures 6a and 6b, respectively, the trip location for the conventional or typical distance relay protection was inappropriately in Zone 2 and the trip signal was sent to the breaker after 12 ms. On the other hand, in the established microprocessor-controlled system, as seen in Figures 7a and 7b, the tripping occurred suitably in Zone 1 and the tripping signal was conveyed to the breaker after 3.5 ms.

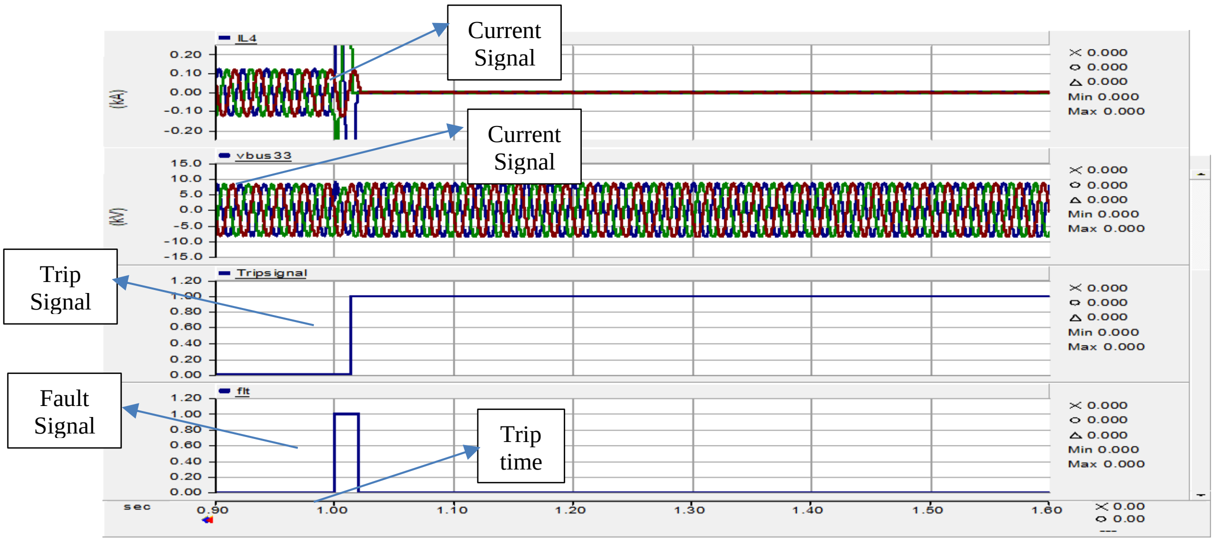

Figure 6a: Trip signal for 10 Ω, LLG at 10 km for conventional system

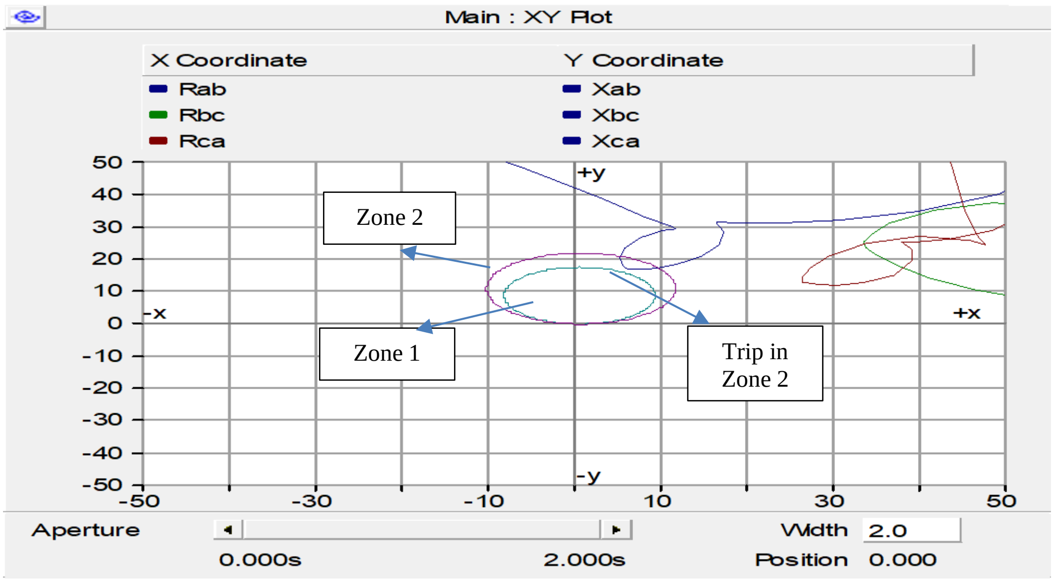

Figure 6b: Trip Location for 10 Ω, LLG at 10 km for conventional system

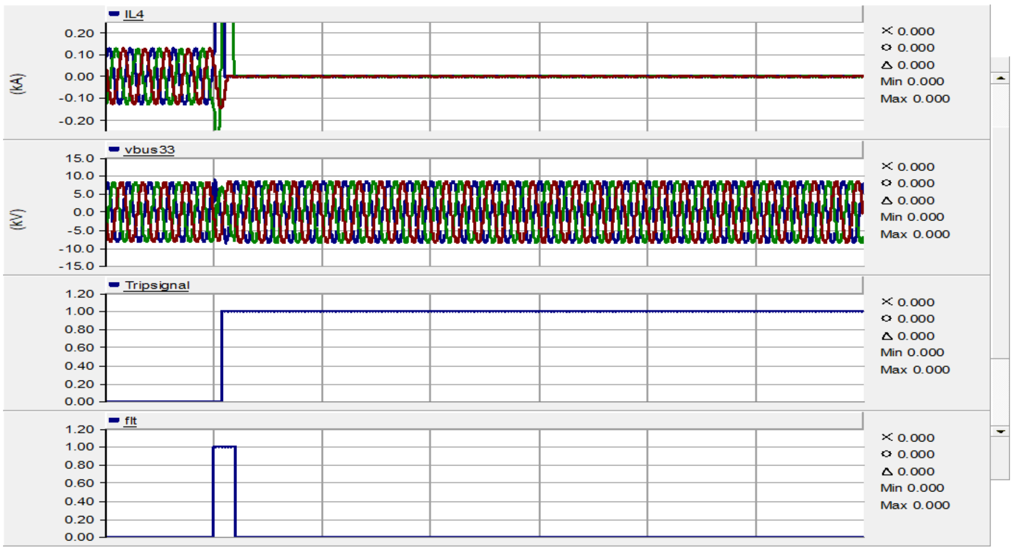

Figure 7a: Trip signal for 1 Ω, LLG at 10 km for developed system

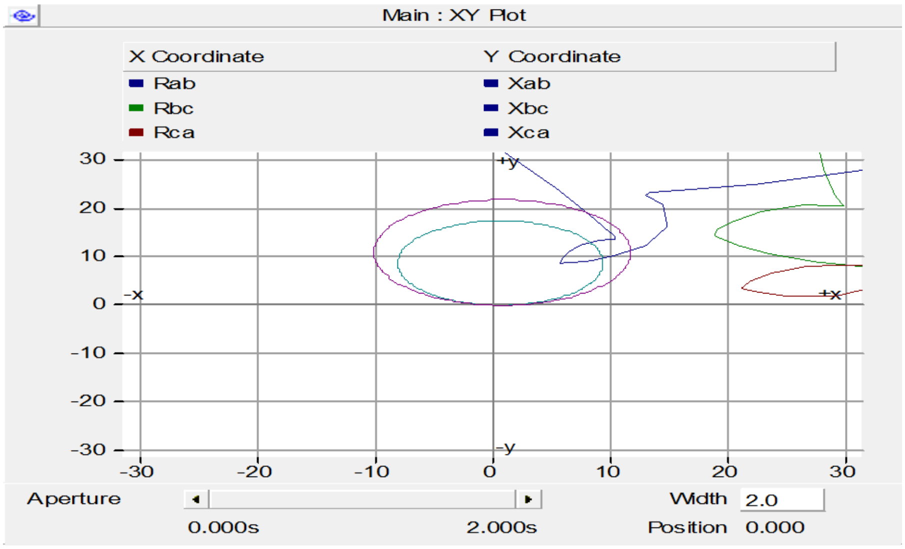

Figure 7b: Trip Location for 1 Ω, LLG at 10 km for developed system

Similarly, for a simulated 0.5 Ω, LL fault between line A and line B (AB) at a location of 35 Km on the line (zone 2), the conventional distance relay protection sends trip signal to the breaker after 15 ms and the trip location was inappropriately in Zone 1 as shown in Figures 8a and 8b respectively. On the other hand, the developed microprocessor-controlled system trips the breaker after 5.3 ms and the tripping occurred appropriately in Zone 2 as shown in Figures 9a and 9b.

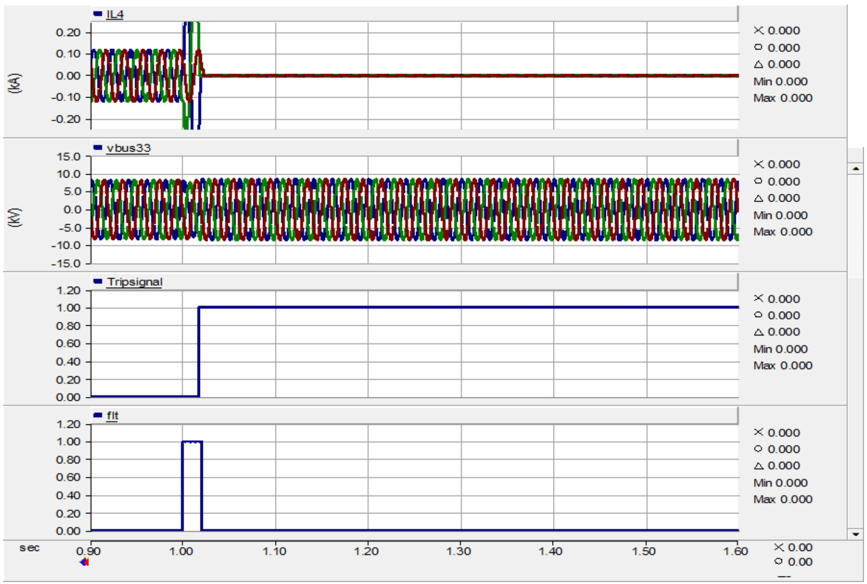

Figure 8a: Trip signal for 0.5 Ω, LL at 10 km for conventional system

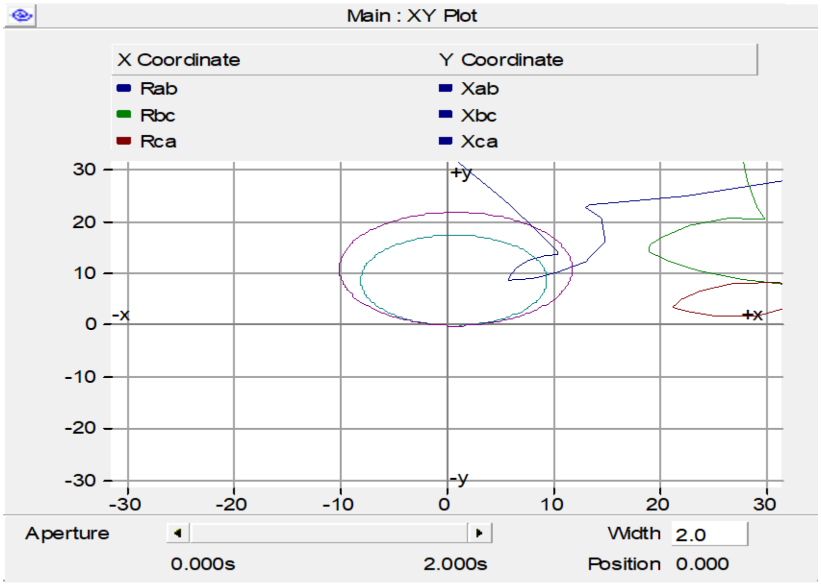

Figure 8b: Trip Location for 0.5 Ω, LL at 10 km for conventional system

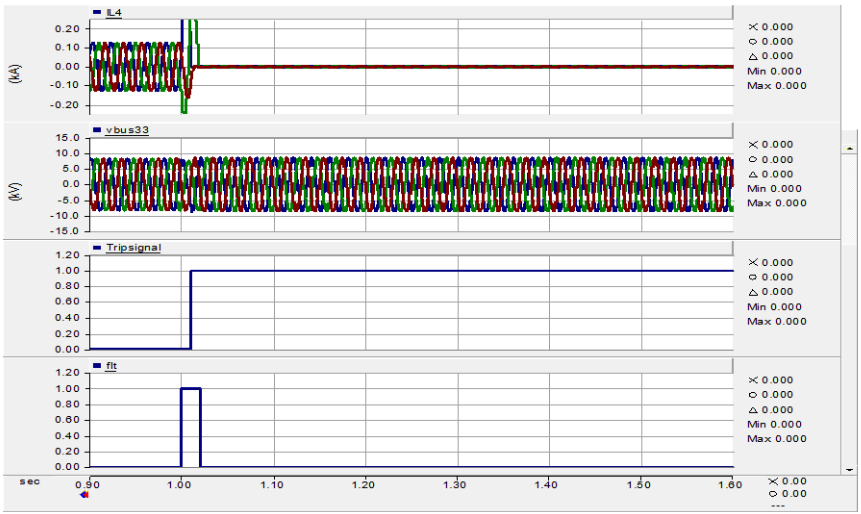

Figure 9a: Trip signal for 0.5 Ω, LL at 10 km for developed system

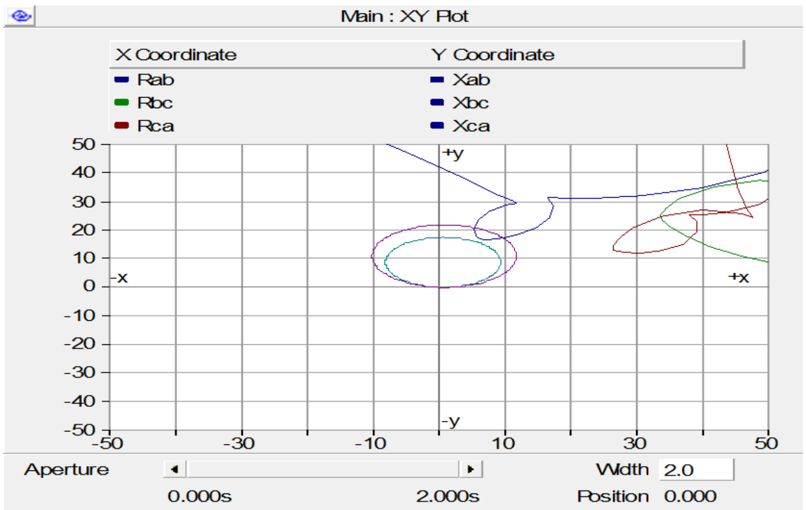

Figure 9b: Trip Location for 0.5 Ω, LL at 10 km for developed system

From simulations in PSCAD for different fault impedance values, fault locations and fault types, a comparison of how the conventional relay system and the developed microprocessor – controlled relay system gives protection to the line is recorded in Table 2.

Table 2: Comparison between conventional and developed protection schemes

Fault Parameters			**Conventional Protection Scheme**		**Developed Microprocessor Based Relay Protection Scheme**	
Fault Location (km)	**Fault Impedance (Ω)**	**Fault type**	**Trip time (ms)**	**Trip zone**	**Trip zone**	**Trip time (ms)**
10.00	0.1	LG (AG)	5.00	Zone 1	Zone 1	3.3
		LL (AB)	7.50	zone 1	Zone 1	3.3
		LLG (ABG)	6.25	Zone 1	Zone 1	3.3
		3 Phase	6.25	Zone 1	Zone 1	3.3
10.00	0.5	LG (AG)	6.25	Zone 1	Zone 1	3.4
		LL (AB)	6.25	Zone 2	Zone 1	3.3
		LLG (ABG)	6.25	Zone 1	Zone 1	3.4
		3 Phase	6.25	Zone 1	Zone 1	3.3
10.00	1.0	LG (AG)	6.25	Zone 1	Zone 1	3.5
		LL (AB)	7.50	Zone 2	Zone 1	3.4
		LLG (ABG)	7.00	Zone 1	Zone 1	3.5
		3 Phase	6.25	Zone 1	Zone 1	3.5
10.00	5.0	LG (AG)	6.25	Zone 1	Zone 1	3.4
		LL (AB)	11.25	Zone 1	Zone 1	3.4
		LLG (ABG)	6.25	Zone 2	Zone 1	3.5
		3 Phase	7.50	Zone 1	Zone 1	3.5
10.00	10.0	LG (AG)	13.00	Zone 1	Zone 1	3.5
		LL (AB)	11.00	zone 1	Zone 1	3.6
		LLG (ABG)	12.00	Zone 2	Zone 1	3.5
		3 Phase	15.00	Zone 1	Zone 1	3.5
35.00	0.1	LG (AG)	8.75	Zone 2	Zone 2	5.2
		LL (AB)	13.75	Zone 1	Zone 2	5.1
		LLG (ABG)	7.50	Zone 2	Zone 2	5.2
		3 Phase	8.75	Zone 2	Zone 2	5.2
35.00	0.5	LG (AG)	8.75	Zone 1	Zone 2	5.2
		LL (AB)	15.00	Zone 1	Zone 2	5.3
		LLG (ABG)	8.75	Zone 2	Zone 2	5.3
		3 Phase	8.75	Zone 2	Zone 2	5.2
35.00	1.0	LG (AG)	10.00	Zone 1	Zone 2	5.4
		LL (AB)	13.75	Zone 1	Zone 2	5.4
		LLG (ABG)	10.00	Zone 1	Zone 2	5.4
		3 Phase	8.75	Zone 2	Zone 2	5.3
35.00	5.0	LG (AG)	15.00	Zone 1	Zone 2	5.4
		LL (AB)	13.75	Zone 1	Zone 2	5.5
		LLG (ABG)	15.00	Zone 2	Zone 2	5.4
		3 Phase	15.00	Zone 1	Zone 2	5.4
35.00	10.0	LG (AG)	17.50	Zone 2	Zone 2	5.6
		LL (AB)	14.30	Zone 2	Zone 2	5.6
		LLG (ABG)	18.80	Zone 2	Zone 2	5.6
		3 Phase	20.00	Zone 2	Zone 2	5.5

3.3 Discussion of Results

According to the results, the developed protection system transmits the trip signal to the CB at the proper tripping position and in a comparatively shorter amount of time than the traditional distance relay protection scheme, regardless of the fault type, fault impedance value, or location of the fault. Indeed, Equations (8) and

(9) can be used to calculate the average operating speed (AOS) and average accuracy of each protective scheme, respectively as;

$$AOS = \frac{\sum_{i=1}^{40} Triptime_i}{40} \tag{8}$$

$$\%\ accuracy = \frac{\sum_{i=1}^{40} TripPi}{40} \times 100 \tag{9}$$

Where $Triptime_i$ is the protection mechanism's operating time for the ith protection study case, TripPi is the precise amount of traveling that was done (a total of 40 protection study cases in all for the conventional and designed protection systems).

If $TripQ_i$ is the inaccurate tripping location done, then note that,

$$\sum_{i=1}^{40} TripP_i + \sum_{i=1}^{40} TripQ_i = 40 \tag{10}$$

For the conventional distance relay protection scheme,

$$AOS_{CRS} = \frac{\sum_{i=1}^{40} Triptime_i}{40} = \frac{245.75}{40} = 6.144ms \tag{11}$$

while for the developed protection scheme,

$$AOS_{\mu PS} = \frac{\sum_{i=1}^{40} Triptime_i}{40} = \frac{175.6}{40} = 4.390ms \tag{12}$$

Similarly, for the 40 tests carried out, the number of times the conventional distance relay tripped accurately is

$$\sum_{i=1}^{40} TripP_i = 27 \tag{13}$$

Hence, the average accuracy of the conventional distance relay protection scheme is

$$\%\ accuracy = \frac{27}{40} \times 100\% = 67.5\% \tag{14}$$

For the developed protection system, all the tests carried out tripped at the appropriate location, hence, the average tripping accuracy is 100%. Hence, the fault impedance and type of fault had no effect in the tripping location in the developed system but only depended on the location of the fault occurrence.

4.0 CONCLUSION

The average accuracy in tripping location of the 11 kV distance protection scheme has been improved from 67.5% to 100% while the average isolation speed has also been improved from an average of 6.144 ms to 4.39 ms by controlling the distance relay by microprocessors. This indicated a 48% and 28.5% increase in accuracy and speed respectively in the protection scheme.

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