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A Smart Strategy for Blocking the Distance Protection Function during VT Fuse Failure

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Abstract

Saving the electrical power system in stable condition is considered as one of important challenges to avoid any failure of high voltage equipment. Additionally, with the increasing off the critical loads, it's very important to use the accurate protection system that can deal with any abnormal condition. This paper studies one of critical cases that can effect on the coordination of the protection system with the faults during fuse fail condition. Over Head transmission line (OHTL) is the most part in the power system that faces the disturbances, which can be protected by multi-protection functions as line differential function, distance protection function, over current, earth fault, over/under voltage etc. The distance protection function is depending on the line voltage and the load current to calculate the load zone. This paper aims to prevent the falls operation of distance protection function during voltage transformer fuse failure condition.

Keywords

Protection System, High Voltage, Distance Protection, Power System Quality

1. Introduction

With the population growth and the increase of the life standers, the electrical power system has been extended to absorb the required demand power. Besides, the electrical power system became more complex, which leads to classifying the power system to distribution, transmission, and generation to be easy for controlling and saving the reliable and stable system [1]. Therefore, the search for better quality systems is a major highlight for researchers and power system designers to provide customers with reliable, ideal and intolerant power systems. The main objective of using power system protection is to detach the faulty section from the system to make the rest of the portion work without any disturbance [2]. The main idea for using the protection system is to restrict the disturbances during any abnormal condition in the power system, such as faults or equipment failures. The important required action from protection system is isolating a limited disturbed area to continue the power distribution in the balance areas. Sensitivity, selectivity and speed are three important points that are commonly used to describe the functional characteristics of any protective-relaying. There are standard points that should follow in terms of protection system [3]. Protection relays are that the important characteristic of power system protection helps to isolate the faculty part of the electrical system. However, this relay needs to possess certain qualities, such as dependability and selectivety. Over Head Transmission Line (OHTL) is a very important part of the electrical system, which is linked between the generation and the distribution system. The short circuit faults can be classified into symmetrical faults and unsymmetrical faults [4]. The Symmetrical 3-phase faults occur in the system by 5% from the total percentage faults in the power system. The other faults are named as the unsymmetrical faults that are one line to ground (L-G), which occurs by 85% from the faults, line with line fault (LL) which occurs by 10% from the total percentage faults in the power system. Faults occur insulation failure or any abnormal weather condition. So, the protection system should operate to isolate the fault zone to save the power system stability [5]. The basic operation logic of the protection system is depending on the fault current, voltage value and locations. The power flow from the generation to the utility grid is a high dynamic network connecting via OHTL [6].

There are some abnormal conditions in the power system, that can lead to the loss of synchronism between the generation and the load, for example at isolating high-loads from the system, at tripping of one of the generation systems, and at these cases, the mechanical power is not equalized with the required for the electrical loads [7]. A distance protection relay is a name given to the protection, whose action depends on the distance of the feeding point to the fault as shown in **Figure 1**. The time of operation of such protection is a function of the ratio of voltage and current, *i.e.*, impedance. This impedance between the relay and the fault depends on the electrical distance between them [8]. The distance protection function is depending on the load impedance, which continuously calculates the load impedance value by using the transmission line voltage and the load current. The distance protection relay operates only when the ratio of voltage and current falls below a set value. During a fault, the current magnitude increases and the voltage at the fault point decreases. The voltage at the potential transformer region depends on the distance between the PT and the fault. Due to the current transformer and voltage transformer error's value, it's not practical

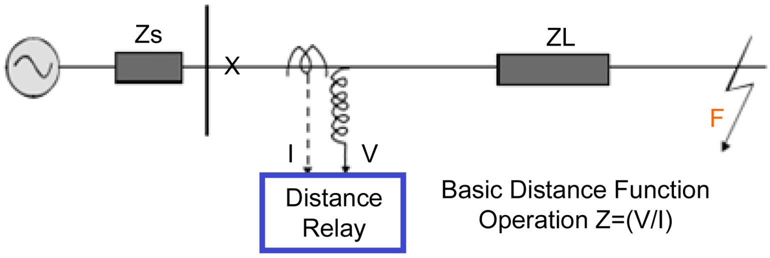

Figure 1. Distance protection design.

to adjust the distance protection tripping time to operate instantaneously by zero-time delay for 100% of the protected transmission line, also the errors can shift the out of zone fault to the protected area. Hence, the distance protection instantaneous trip is typically set to cover 80% from OHTL which is called the first zone, and the remaining 20% of OHTL can be covered by the time delay of the second zone trip, where the second zone is covered 100% of OHTL and between 20% to 50% of the next small OHTL. In another hand, by assuming the voltage source is failed through a voltage fuse fail, the base operation of the distance protection function will calculate the load impedance as a very low value which will cause a false trip command to the transmission line. Digital technology provides guarantee for the smoothness of network information. Under the premise of ensuring the intelligentization of equipment, the advantages of network information application are given full play to unify the control of the distribution device in the substation system. Primary intelligence and secondary network are the most significant characteristics of smart substation [9]. This article aims to describe the importance of using the VT fuse fail functions for blocking the distance protection function to prevent false operation.

2. Faults Analysis in Transmission System

To analyze the fault, it's important to simulate the fault in three components that's positive sequence and negative sequence and zero sequences, as shown in the below **Figure 2** for positive, negative and zero sequence components [10].

Firstly, the Change in magnitude:

$$a = 1\angle 120^{\circ} \tag{1}$$

$$a^2 = 1\angle 240^{\circ} \tag{2}$$

$$a^3 = 1\angle 360^{\circ} \tag{3}$$

From these equations, useful combinations can arrive

$$\begin{gathered} 1 - a = \sqrt{3}\angle -30^{\circ} \\ a^2 - a = \sqrt{3}\angle 270^{\circ} \end{gathered} \tag{4}$$

Or

$$\begin{gathered} 1 + a + a^2 = 0 \\ 1 - a^2 = \sqrt{3}\angle 30^{\circ} \end{gathered} \tag{5}$$

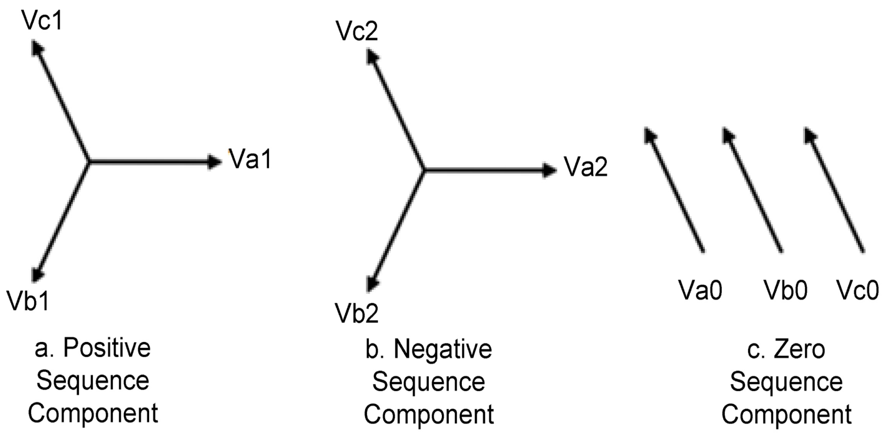

Figure 2. Positive, negative, and zero sequence components in the power system.

Or

$$a - a^2 = \sqrt{3}\angle 90^\circ \tag{6}$$

Any three-phase system of phasors will always be the sum of the three components.

"+VE" sequence: $V_{a1}V_{b1}V_{c1}$

"−VE" sequence: $V_{a2}V_{b2}V_{c2}$

"0" sequence: $V_{a0}V_{b0}V_{c0}$

The original system phase components can be presented from V_a, V_b and V_c

$$\begin{bmatrix} V_a = V_{a0} + V_{a1} + V_{a2} \\ V_b = V_{b0} + V_{b1} + V_{b2} \\ V_c = V_{c0} + V_{c1} + V_{c2} \end{bmatrix} \tag{7}$$

From Equations (1) to (5) Zero sequence component

$$V_{a0} = V_{b0} = V_{c0}$$

Positive sequence component

$$V_{b1} = a^2 V_{a1}, \quad V_{c1} = aV_{a1}$$

Negative sequence component

$$V_{b2} = aV_{a2}, \quad V_{c2} = a^2 V_{a2}$$

V_a, V_b and V_c can be expressed in terms of phase "a" component only as:

$$V_a = V_{a0} + V_{a1} + V_{a2}$$

$$V_b = V_{a0} + a^2 V_{a1} + aV_{a2}$$

$$V_c = V_{a0} + aV_{a1} + a^2 V_{a2}$$

This equation can be accomplished in a matrix form:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} \tag{8}$$

Equation (8) can be written as:

$$A = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix}, \quad \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = A \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix}$$

This equation can be reversed in order to obtain the positive, negative and zero sequences from the system phasors.

$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = A^{-1} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{9}$$

With considering,

$$A^{-1} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}$$

3. Distance Protection Topology

OHTL has an impedance per kilometer related to its design and construction which will be a function of OHTL length. The distance protection function looks at load current and the grid voltage, that use these values for impedance calculation related to Ohm's law. Conventional time-stepped distance protection is illustrated in **Figure 3**. The delayed second zones can be accelerated by confirming the fault into the protected zones depending on the communication scheme as shown in **Figure 4** [11].

4. Distance Protection Solution during VT Fail

It's not practical to design the distance protection that can operate during the non-fault condition regarding the failure of feed the voltage to the measurement unit, that will consider the calculation in the protected zone. Using the fuse fail functional to block the distance protection is very important to prevent the false

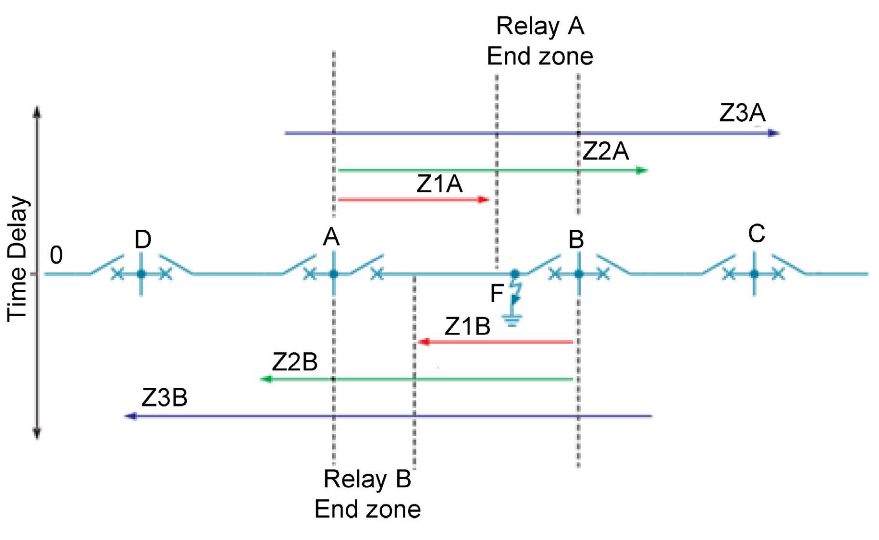

Figure 3. Distance protection zones coordination.

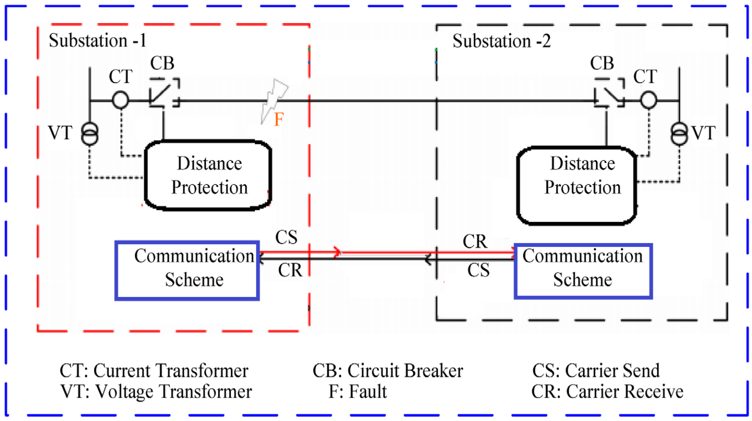

Figure 4. Distance accelerating scheme for the delayed zone.

operation of the distance protection function. The proposed solution in this paper is presented in three ways to block the distance function as shown in the below Figure 5 and Figure 6 for an example to block distance protection zone-1 and zone-2 respectively [13].

4.1. Adding an Auxiliary Contact to VT MCB

It's very important to protect the voltage transformer from the short circuit. The short circuit will consume a very high current which direct will damage the voltage transformer secondary coil. That can protect by fuses or Miniature Circuit Breaker (MCB). So, by using an auxiliary contact from the secondary connection from the miniature circuit breaker to be used as a binary input to the distance for block the function. Figure 7 shows the adding of auxiliary contact to the VT miniature circuit breaker.

4.2. Adding Fuse Fail to Relay

This way is depending on the fuse fail relay that can feed on both winding in the line voltage transformer to compare both measuring coils with using the binary output from the fuse fail relay to be used a binary input for blocking the distance protection relay as shown in Figure 8 and Figure 9.

4.3. Using Internal Fuse Fail Function

In the numerical distance protection relay, it's possible to use the internal fuse fail function which depends on the changing in the voltage and currents, as shown in Figure 10 [14]. During the faults, the voltage will decrease and the current will increase, but if the voltage became zero and the current is not affected its means the VT is failed and there is no actual fault in the transmission line which direct will block the distance protection function.

5. Simulation and Case Study

The proposed analysis in this part has been validated with the protection numerical relays to shows the test result created by the secondary injection kit

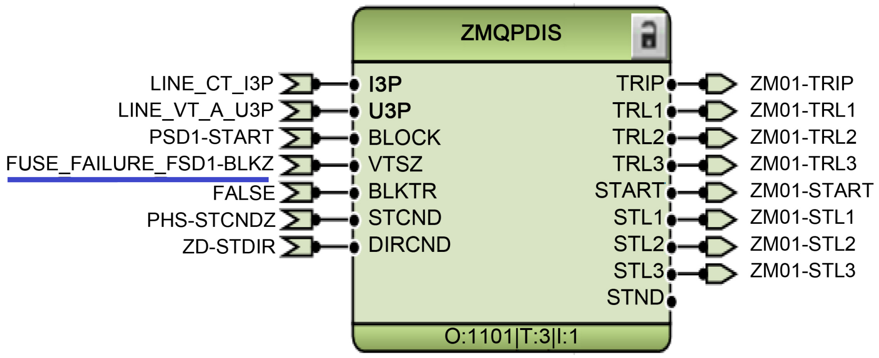

Figure 5. Using the binary input to block zone 1 distance function.

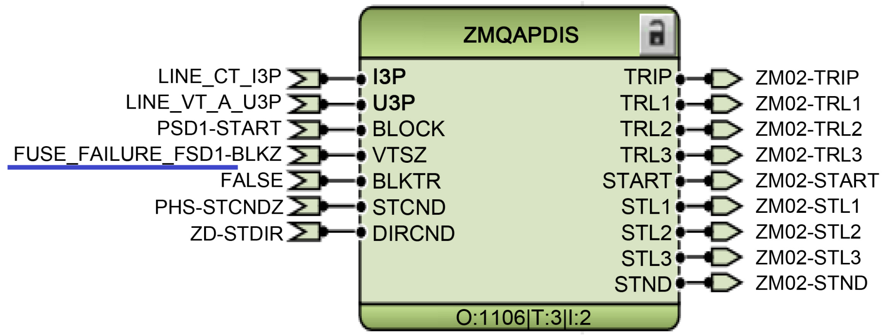

Figure 6. Using the binary input to block zone 2 distance function.

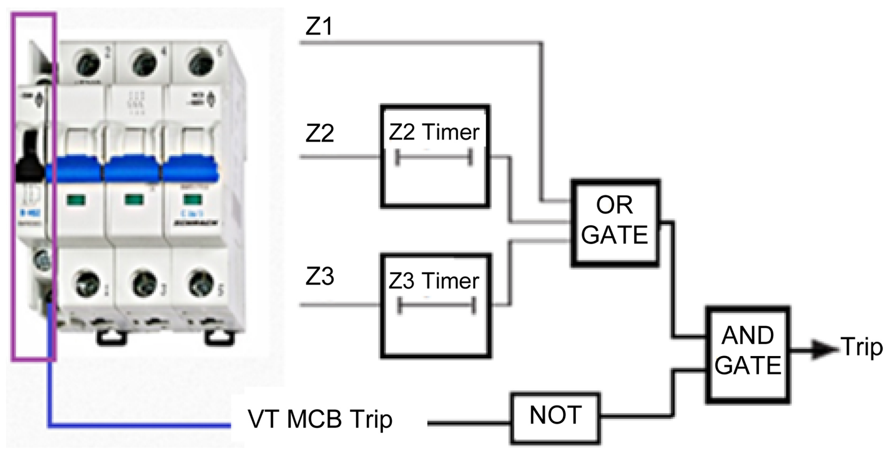

Figure 7. Adding an auxiliary contact to VT MCB.

software to simulate the distance protection function during symmetrical fault analysis. Also, this part simulates the distance blocking during VT fuse fail.

5.1. Simulation Three Phase Distance Protection Function

The simulated experiment in this paper used by a secondary injection kit, the operating voltage for the simulated system is 115 kV, the voltage transformer ratio is (115 kV/115V) and the current transformer ratio is (1200 A/1A) [12]. This experiment simulated by a protection IEDs type distance protection relay with three phase symmetrical fault. **Figure 11** shows the quadrature impedance for

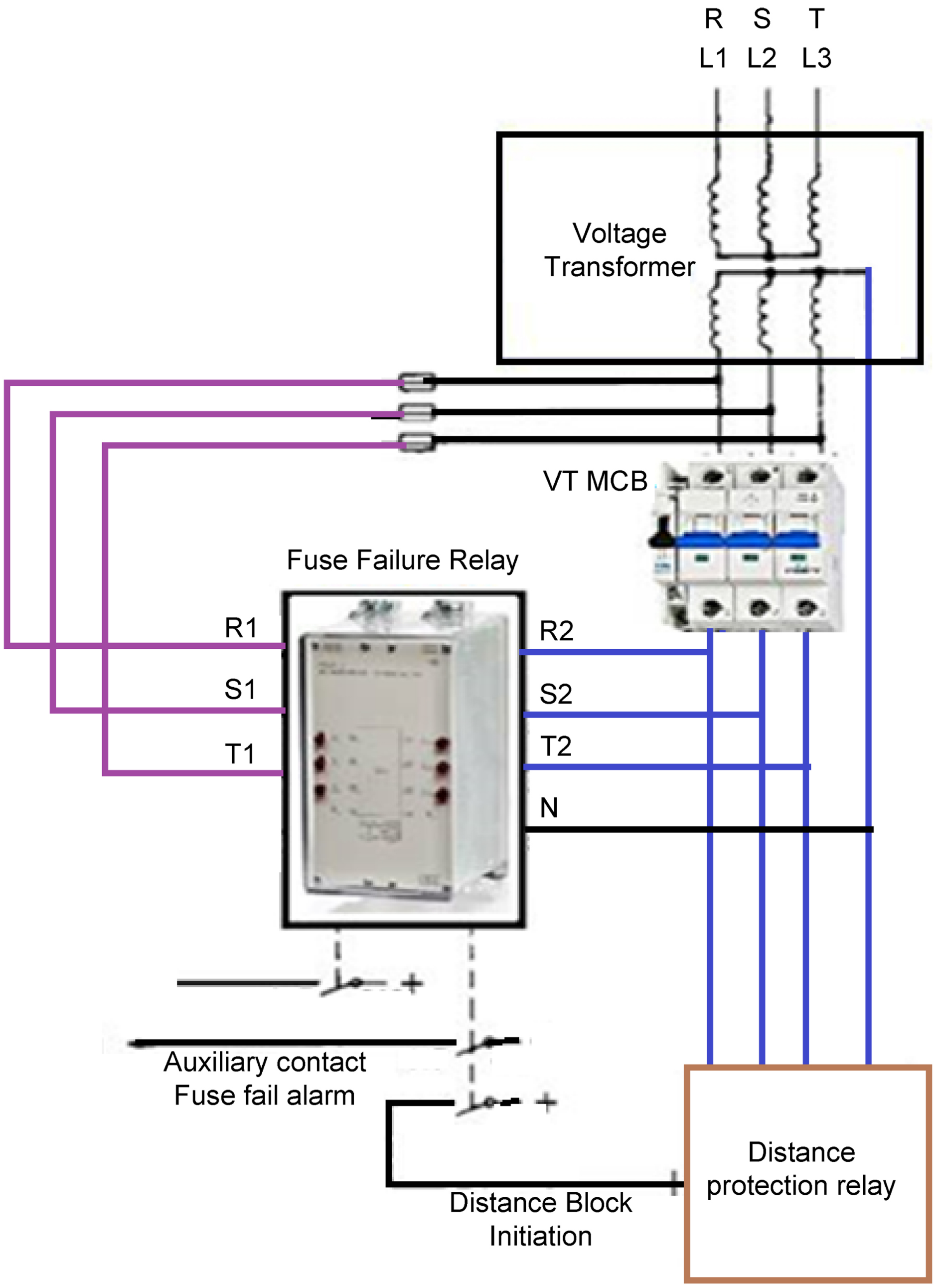

Figure 8. Using the fuse fail relay and MCB for blocking.

distance protection symmetrical fault which discusses the boundaries results in Table 1. Figure 12 shows the created test result for the trip time, which discusses the boundaries results in Table 2.

5.2. VT Fuse Fail Simulation

The simulation of VT fuse fail can be implemented by normal load injection to the protection distance relay, with applying setting of VT MCB trip after healthy condition. The below Table 3 shows the distance function protection blocking for distance zone faults.

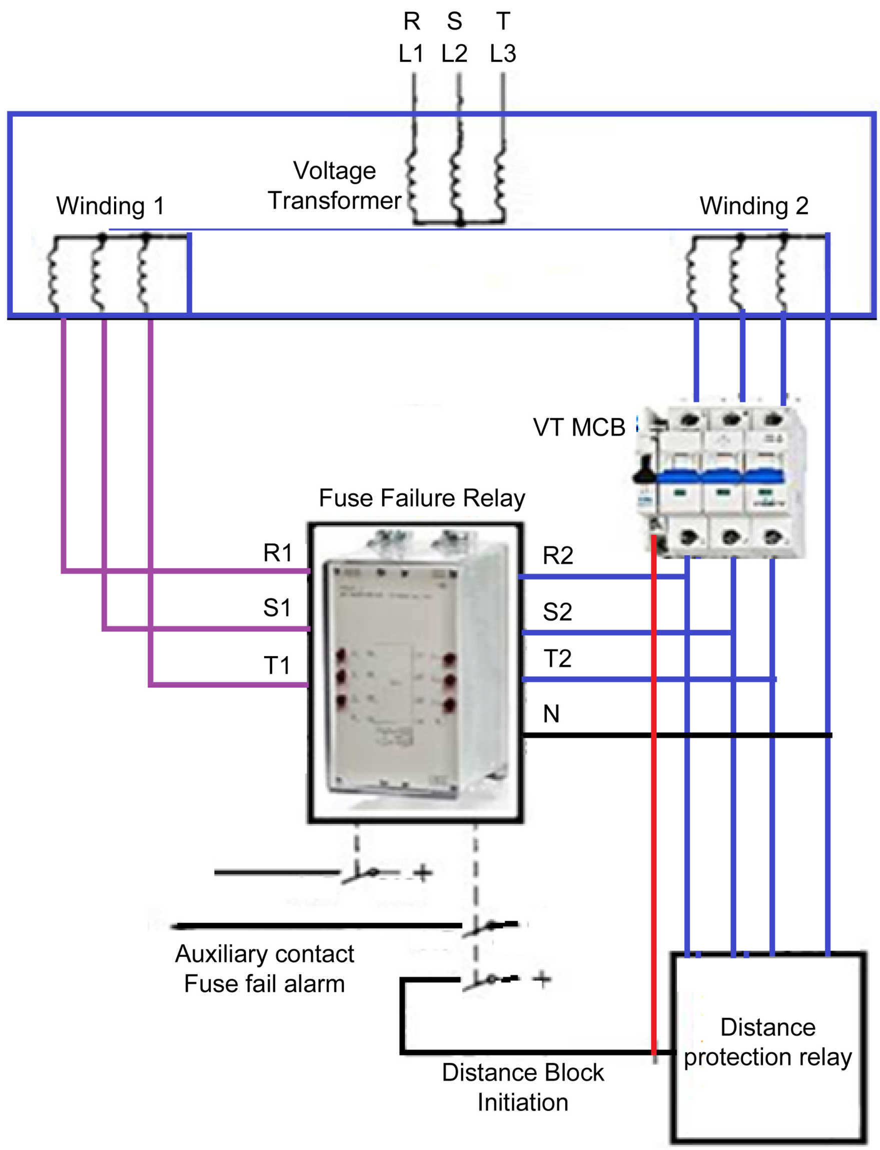

Figure 9. Using the fuse fail relay at 2 winding VT and MCB for blocking.

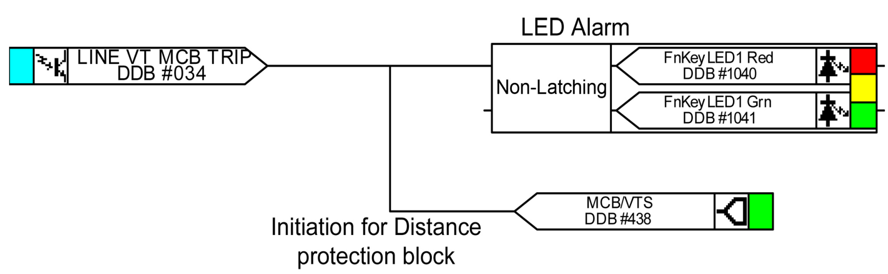

Figure 10. Using the internal function fuse fail to block the distance protection function.

6. Conclusion

Rapidly growing electricity demand deregulated electricity market systems, and restructured operation of power delivery systems are stressed the power grid operation. In such a situation, the speed of fault clearance is very important to

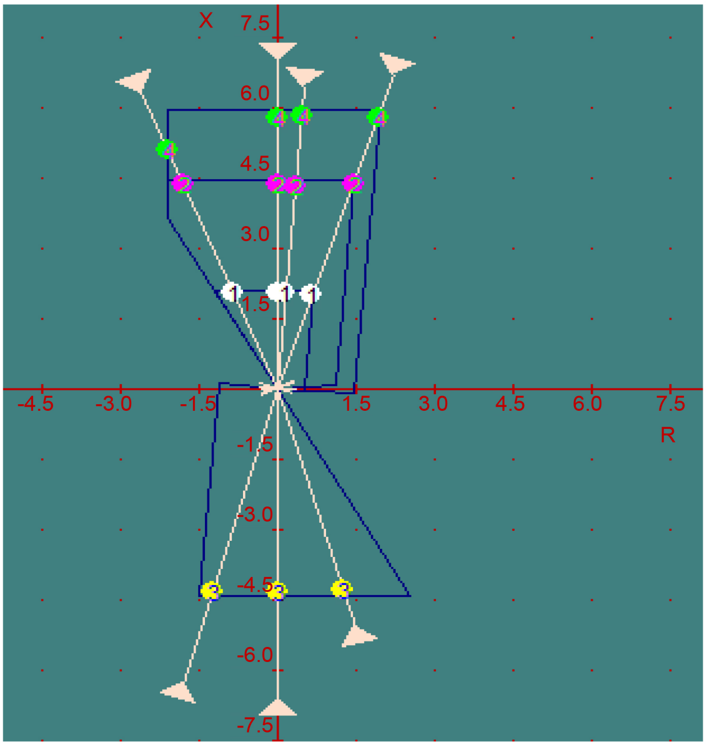

Figure 11. Actual quadrature three phase distance.

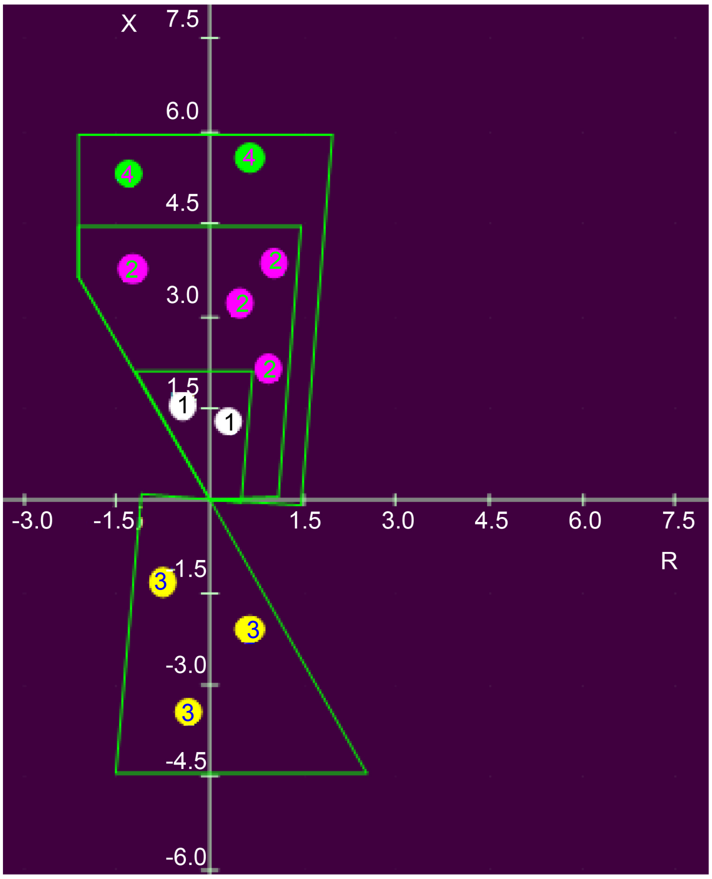

Figure 12. Actual trip time for the symmetrical distance test.

Table 1. Impedance results at symmetrical fault simulation.

NO	R (Ω)	X (Ω)	Z (Ω)	Z phi	Zones
1	0.000	2.024	2.024	90.0	1
2	0.000	4.357	4.357	90.0	2
3	0.000	5.761	5.761	90.0	4
4	−0.823	2.023	2.184	112.2	1
5	−1.779	4.370	4.719	112.2	2
6	−2.076	5.099	5.506	112.2	4
7	0.000	−4.331	4.332	270.0	3
8	0.170	2.022	2.029	85.2	1
9	0.363	4.314	4.329	85.2	2
10	0.487	5.795	5.815	85.2	4
11	0.671	1.994	2.103	71.5	1
12	1.464	4.354	4.594	71.5	2
13	1.935	5.756	6.072	71.5	4
14	1.278	−4.315	4.501	286.5	3
15	−1.237	−4.360	4.533	254.2	3

Table 2. Timing test results at symmetrical fault simulation.

NO	R (Ω)	X (Ω)	Z (Ω)	Z phi	Setting Time - Second	Trip Time - Second	Zone
1	−1.328	5.314	5.478	104.1	1.200	1.224	4
2	−1.200	3.771	3.958	107.7	0.400	0.423	2
3	0.300	1.286	1.321	76.9	50.00	0.027	1
4	0.514	3.214	3.255	81.0	0.400	0.425	2
5	1.071	3.857	4.003	74.5	0.400	0.426	2
6	0.685	5.571	5.613	83.0	1.200	1.226	4
7	−0.428	1.542	1.601	105.6	50.00	0.024	1
8	0.985	2.142	2.358	65.4	0.400	0.425	2
9	−0.771	−1.371	1.573	240.7	0.800	0.829	3
10	0.685	−2.142	2.249	287.8	0.800	0.827	3
11	−0.300	−3.471	3.484	265.1	0.800	0.829	3

Table 3. VT fuse fail simulation.

Zone No	With VT fail	Without VT fail
1 Forward	Blocked	23.0 msec
2 Forward	Blocked	439 msec
3 Reverse	Blocked	830 msec
4 Forward	Blocked	1.0 Sec

maintain the system stability. Distance protection primarily uses two zones of protection to cover protection for the entire line distance. Typically, zone-1 covers 80% of the protected line length and operates instantaneously and Zone-2 is set to be an intentional overreaching zone to cover the 100% protected line. Zone-2 operates with a predefined time delay of about 15 - 20 cycles (300 - 400 ms). But it's not correct to design the distance protection that can operate during the non-fault condition regarding the failure of feeding the voltage to the measurement unit, which will consider the calculation in the protected zone. Using the fuse fail to function to block the distance protection is very important to prevent the false operation of the distance protection function. The proposed solution in this paper is presented in three ways. The first presented way is using an auxiliary contact from the secondary connection from the miniature circuit breaker to be used as a binary input to the distance for block the function. The second presented way is depending on the fuse fail relay that can feed from both winding in the line voltage transformer to compare both measuring coils with using the binary output from the fuse fail relay to be used a binary input for blocking the distance protection relay. The third way is depending on the internal fuse failing to function in the distance relay for blocking the distance relay.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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