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The Test Bench for Simulation Phase Fault and Ground Fault Analysis Protection Concept Using Symmetrical Components

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ABSTRACT

Various laboratory experiment platforms have been developed to provide students with theoretical knowledge and practical experience. Understanding concepts related to the process for determining the design of protection settings requires practical experience, which can be achieved by repeated trials. In this paper, the mechanism of a ground fault in a medium voltage feeder is done using a simulator substation as a case study. This process must be carried out twice, once for the ground-fault relays protection based on residual currents and then repeated based on residual voltage. For further understanding of the electrical distribution network, the system will be operated at 20 kV on the primary and 380 V on the secondary. The model uses smaller nominal voltages consisting of 380 V on the primary and the secondary. The result of one phase fault protection mechanism works well at each point of interference, and voltage transformers are protected from overheating and damage. The lowest value of the single-phase to ground short circuit that occurs at the fault location at the farthest point of interference from the protection relay location is used for the threshold setting on the voltage relay. The one phase fault protection mechanism works well at each point of interference, and the voltage transformer is protected from overheating and damage. For residual current ground fault protection effective, the threshold setting of phase fault inverse time delay with threshold setting I> is 1.5 ampere, and instantaneous I>> is 7.5 ampere. The effective threshold setting for residual ground fault protection wasUo> = 22% dan UO>> = 33,2%.

KEYWORDS
Residual voltage
Residual current
Solid grounding
High resistance grounding
Ungrounding system

INTRODUCTION

Laboratory practicum is essential to learning electrical power engineering at the polytechnic level. Various laboratory practice platforms have been developed and widely used to equip students with theoretical knowledge and practical experiences. Laboratory models that are almost similar to the real conditions in the laboratory are complex and expensive, while relying only on software learning resulted in a lack of physical understanding of the phenomena and hands-on experiences.

This paper is the result of development in the electric power system laboratory at the Bandung State Polytechnic to provide practical experience for students regarding the concept of

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determining the design of protection residual voltage and residual current settings. This instrument complements the previous learning process, which only utilizes software. The device is simpler than the laboratory equipment, which is nearly similar to the real condition, but it has the advantage of being able to perform repeated tests easily and safely.

The aim of this study is to design and implement a simulation of the protection system mechanism related to symmetrical fault and asymmetrical fault disturbance. In-depth on the Protection Scheme for Residual Voltage Sequence for High Resistant grounding and ungrounding system. Residual current sequence for solid grounding system. The simulator can display the performance of a protection system and test it with direct interference with a short circuit in the network.

LITERATURE REVIEW

Several developments have been extensively researched. Idris & Patakor at the Merlimau Polytechnic developed the principle of phase and ground protection for use in diploma programs [1]. Enayati & Ortmeyer at Clarkson university [2], and Smolarczyk & Rasolomampionona developed laboratory-scale relay test units for further development, communication schemes and software integration with SCADA systems [3]. Mehta et al. developed special hardware for numerical overcurrent relay simulation [4], and the integrated complex distribution system was developed by Tang et al. [5]. Guerrilla et al. developed a miniature smart grid model used for research and education [6]. The difference with Idris & Partaker's research in feeder protection is by entering network parameters, and the difference with other laboratory developments is the application of technology. This research will focus on instilling the competence of setting settings in solid-state relays and numerical relays in feeder protection applications.

The research roadmap is made following the references [7-10]. Heskitt (2013) at California Polytechnic State University, San Louis Obispo, successfully designed a ground fault protection simulator on a network with a 120kV/4.8kV connected Delta/Delta power transformer, and a 4800V/120V voltage transformer, a 120 V secondary voltage connected to an open delta, connected to the Basler-59N overvoltage protection relay [7]. Borjas (2017) at Michigan Technology University USA developed a distribution system simulator of 12 kV on the primary and 480 V on the secondary, which was reduced to 240 V on the primary and 24 V on the secondary. Current and voltage are connected to the Schweitzer 751-A relay, which provides load monitoring and a ground fault detection scheme [8]. Suhono et al. (2019) developed a hardware simulator that can properly describe the ground fault protection scheme using a break delta transformer in an ungrounded system. The nominal voltage simulator simulates 380 V on the primary and secondary. The ground fault protection system scheme uses an overvoltage relay (59N), a voltage transformer on the primary with a grounded star connection and an open delta secondary grounded [9]. Simulator for Overcurrent Phase and Ground Fault Protection with Microprocessor Based Relays is the result of a product design for the study of phase fault and ground fault protection. In this study, an electric power distribution system at a voltage of 20 kV on the primary and 380 V on the secondary was developed at the Electrical Power Distribution System Laboratory, Department of Electrical Engineering, Bandung State Polytechnic [10].

The technology used has reached the use of phasor measurement unit (PMU)-based communication technology, showing that research on the development of practicum modules has been very advanced. Software development for simulation of protection and a variety of related applications therei[11-17]. Reference [11] has designed and built a practical laboratory through the use of hardware-in-the-loop power simulation for the physical components of a photovoltaic inverter, which are connected in real time. The result is the ability to understand the operation of the integration effect of distributed generators, which includes power sharing between synchronous generators, voltage control using on-load tap changers, and short circuits on distributed generators based on inverters and microgrid operations.

Ref[12] has designed and manufactured the rate of change of frequency (ROCOF) and rate of change of power (ROCOP) used for ANFIS training for the islanding detection method. The results showed that the islanding methods were faster compared to the frequency relay methods. The design and manufacture approach uses the voltage magnitude and phase angle obtained from Phasor Measurement Units (PMUs) as the input vectors to SVM, and the output vector is the Voltage Stability Margin Index (VSMI) [13]. The effectiveness of the proposed approach is tested using the New England 39-bus test system and the Indian Northern Region Power Grid (NRPG) 246-bus real system [14]. Open-source protection IED for research and education using multiterminal HVDC grids presents an open-source, low-cost protection intelligent electronic device (IED) prototype for use in a laboratory environment. In particular, the IED design, its fastest measured performance, example results for different fault scenarios, and an assessment of its use in education are shown. The open-source IED is useful to accelerate industrial and academic research, as well as to enable education in protection for MTDC grids [15]. The application of the learning method using Hybrid Project-Based Learning in Hybrid Synchro phasor and GOOSE-Based Passive learning for Islanding schemes using voltage and frequency sensors [16].

The zero sequence voltage and the current scheme will be closely related to the study of single-phase short circuits for ground and earth protection. The open phase conditions usually produce very low fault currents and are difficult to detect in conventional protective relay schemes, and this study proposes a new Open Phase Detection (OPD) scheme which is suitable for grounded distribution networks. The OPD approach proposed was based on the Residual Current Multiplying Factors (RCMFs) obtained online [17].

Designing using the software and testing in a hardware test-bed in real-time loops show an increase in protection performance for a solution in the case of system expansion in underground mining, which increases the voltage level [18]. The occurrence of a phase-to-ground fault in a power system causes capacitive currents to flow from a different location to the point of failure, which reduces the selectivity of the ground overcurrent relay. The solution proposed here to overcome this loss of selectivity uses a ground-directional over-current algorithm [19]. This paper clarifies the single-phase ground fault current flow directions and their phasor diagrams for high-resistance grounding (HRG) power systems and recommends the usage of the connection I CGF = – 3I CO for HRG power systems in conversion from "phasor" to "vector" to present phase-to-ground fault current with respect to phase-neutral fault voltage, and two-phase fault current to ground [19].

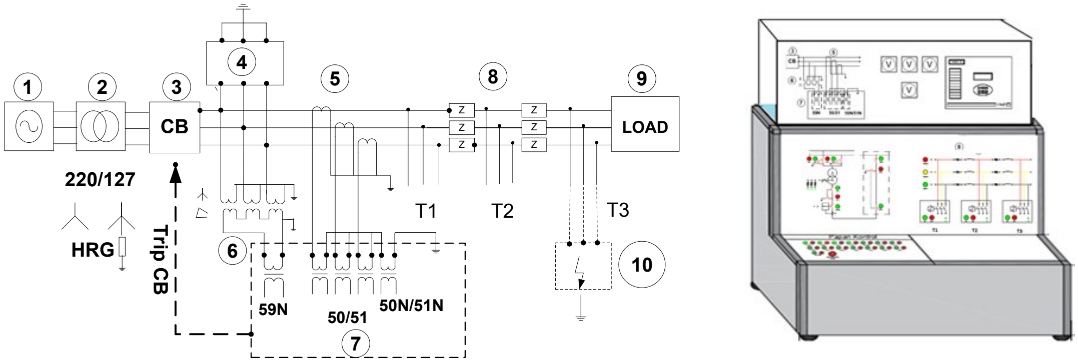
Designed and implemented a virtual model that is accurate from the feeder protection relay using ANSI and COMTRADE (Std C37.111) functions to interact with online simulation subjects for various disturbances scenarios was done [20]. The proposed methodology includes robust synchronization between power system simulation and virtual relay response. The results validation integrates distribution system simulation software running with remote control for time-based simulation, then reproducing voltage and current signals with virtual relay operation. Performance was assessed in three case studies comparing real protection equipment and virtual relay operation under the same fault scenario.

RESEARCH METHOD

Hardware Simulator Design

Figure 1 is a functional design that displays the relationships between function elements that become the framework in the simulator manufacturing process. The protection object of the substation protection system is the MV network, which is divided into three points of disturbance zone. Short circuit testing is performed at the point of a disturbance at the substation, at 50% of the channel length and 100% of the channel length. Short circuit in the substation to simulate the disturbance at the transformation point, meaning that the impedance is the transformer impedance. Simulate the greatest disturbance value of the 3-phase short circuit testing for the study of breaking capacity selection of equipment at the substation. Phase-ground short circuit testing for selection studies determines the value of NGR (Neutral Grounding Resistor) resistance. MV network short-circuits testing in point. 50% of the channel length is used to get the fast overcurrent relay setting value instantaneous (AANSI CODE-50). SUTM short circuit testing at the point. 100% channel length for relay settings overcurrent time delay overlag (ANSI CODE-51). In Figure 1 (a) the device consists of: 1. Power supply 3-phase 380 volt; 2. Power transformer wye/secondary wye installed with high resistance grounded; 3. CB Simulator; 4. Voltmeter; 5. Current transformer; 6. Potential transformer (wye/open delta); 7. Relay protection IED Vamp 40; 8. MV Network impedance; 9. Load; 10. Short circuit test;

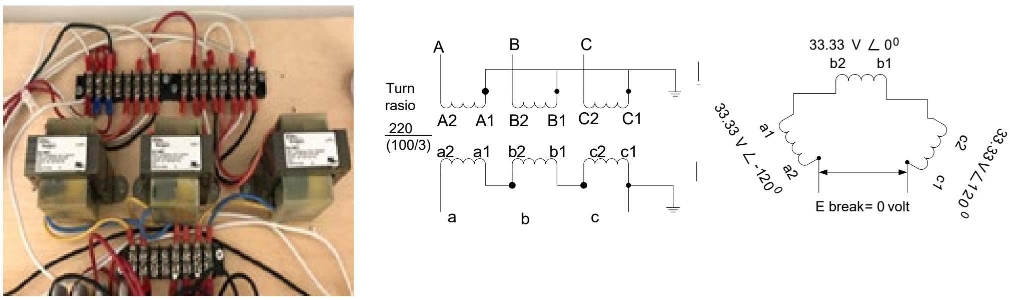
The zero sequence voltage sensors used are 3 voltage transformers with a ratio of 220 V/ (100/3), rating 1 ampere. The zero sequences current sensor uses 3 current transformers, each 30/5, burden 1 VA to get a measurement current above 10% of the load for primary accuracy purposes CT is wound with 6 turns to obtain a reduction ratio of turns to 5/5. The IED Vamp 40 device is used as overcurrent and overvoltage protection for ground disturbances, and this device is also connected to a PC to obtain measurement data in a phasor diagram. Computerized measuring protection mechanisms and devices developed using the Vamp 40 intelligent device.



(a) (b)

Figure 1. Hardware simulator (a) circuit diagram; (b) construction

Figure 2(a) shows the Wiring of the Residual Voltage Sequence, while Figure 2(b) shows primary and secondary winding for the protection sensor using a zero sequence current from a current transformer with a star connection on the primary and secondary sides. Fig 2(c) Zero sequence voltage sensor of a voltage transformer with a star connection on the primary side and an open delta connection on the secondary side.



(a) (b) (c)

Figure 2. (a) The Wiring of Residual Voltage Sequence (b) primary and secondary winding (c) secondary break delta

Residual Current Sequence Modeling

The disturbances are classified into symmetrical and asymmetrical parts. Fig. 3 shows different asymmetrical fault cases. The major feature of these disturbances is the large value of the negative component, such that there are the following theoretical cases. Fig 2 shows there are (a) three-phase fault and three-phase to ground fault, (b) single line to ground fault, (c) line to ground fault, (d) double line to ground fault.

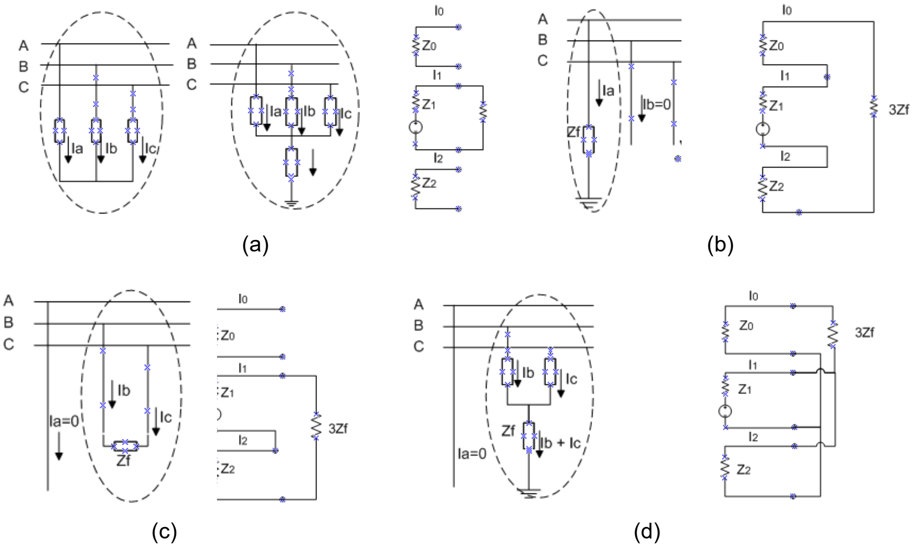


Figure 3. The design of symmetrical and asymmetrical fault disturbance test

Residual Voltage Sequence Modeling

The zero-sequence current component of the current is the summing of the three currents from a current transformer, as is shown in Fig. 1(a). The neutral connection of the three current transformers, referred to as the residual circuit, is equal to 3Io. The zero-sequence voltage component is summing the three voltages in a circuit called a broken delta, as shown in Fig. 1(b). The connection of the three voltage transformers, referred to as the residual circuit, is equal to 3Vo.

Zero sequence.

$$I_0 = \frac{1}{3}(I_a + I_b + I_c) \tag{1}$$

$$V_0 = \frac{1}{3}(V_a + V_b + V_c) \tag{2}$$

Ground disturbances also create values in the positive and negative sequence circuits, which have historically been of less value to the protection engineer than zero sequences. The reason is that the positive and negative sequence circuits required complex positive or negative sequence filtering to develop those sequence components.

Positive sequence

$$I_1 = \frac{1}{3}(I_a + a\,I_b + a^2 I_c) \tag{3}$$

$$V_1 = \frac{1}{3}(V_a + V_b + V_c) \quad (4)$$

Negative sequence

$$I_2 = \frac{1}{3}(I_a + I_b + I_c) \quad (5)$$

$$V_5 = \frac{1}{3}(V_a + V_b + V_c) \quad (2)$$

Protection Scheme for Residual Voltage Sequence

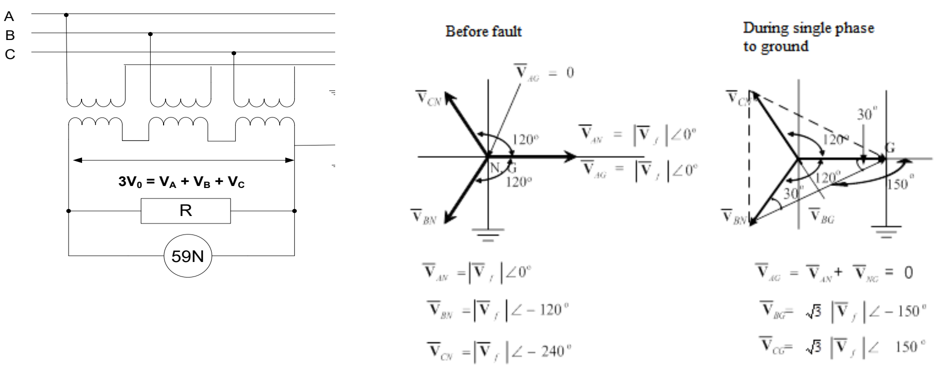


Figure 4. Break Delta Network and Overvoltage Relay (59N)

The concept of protection of zero sequence voltage characteristics in a not grounded system when a single-phase fault occurs on the ground is shown in Figure 4. Voltage transformers in an open break delta relationship will give an increasing voltage signal in the event of a ground disturbance. The overvoltage protection relay ground disturbance will detect ground disturbances and give Circuit Breaker commands to break up. When a ground fault occurs, the voltage will rise three times the phase voltage to a neutral. This voltage will be detected in the open break delta transformer terminal.

Test Protection Performance in Various Short-circuit Interferences. When one phase to ground interference occurs, the operating system will continue. In this condition, cable insulation and equipment are under pressure. The effect that occurs during a zero-voltage disturbance at the interrupted phase and the continuous phase voltage rises to √3 nominal voltages. The phase difference between the undisturbed phases drops from 120 degrees to 60 degrees. When a ground fault occurs, the voltage will increase three times the phase voltage to neutral. This voltage will be detected in the open break delta transformer terminal.

The testing results with various types of short circuit interference indicate that this protection system only protects against one phase voltage to the ground. From this test, overcurrent protection of phase disturbances is still needed to provide phase disturbance protection.

RESULTS AND DISCUSSION

The Result of Residual Current Sequence Protection Mechanism

The scheme of protection residual current and residual voltage performance testing is carried out in two ways. These two testing mechanisms are used to compare when there is a disturbance. The scheme of protection residual current using the test results for disturbances in a solid earthing earth system is shown in Table 1. Meanwhile, the test for residual voltage performance testing uses a 100-ohm earthing system, the representation of High Resistance Grounding is shown in Table 2.

Table 1. Moisture content (%) of robusta coffee beans after drying

Fault type	Phase A		Phase B		Phase C	
	Magnitude (Ampere)	Angle (degree)	Magnitude (Ampere)	Angle (degree)	Magnitude (Ampere)	Angle (degree)
Normal operation	1	0	1	240	1	120
One phase open	0	0	1	240	1	240
Single line to ground	6,3	0	1	240	1	120
Line-to-line	1	0	6,75	240	6,75	120
Line-to-line to ground	1	0	7,93	240	7,93	120
Three-phase	7,81	0	7,81	240	7,81	120
Three-phase to ground	7,81	0	7,81	240	7,81	120

The measurement results of the magnitude of the short circuit voltage test in a solid grounding system are shown in Table 1, with current measurements using a digital voltmeter. The current magnitude under normal conditions is one ampere, while the voltage angle refers to the basic concept of a three-phase voltage system, and the angle voltage does not change during a disturbance.

The threshold setting of phase fault relay inverse time delay I> is 1.5 ampere, and instantaneous I>> is 7.5 ampere (Table 1). Selected 1.5 amperes under normal network conditions is 1 ampere. The safety factor due to resetting the relay ratio and safety margin is 1.5, so the threshold setting of phase fault relay inverse time delay I> is 1.5 x 1 ampere is 1.5 amperes.

The threshold setting of phase fault relay instantaneous I>> is 7.5 ampere, which was chosen considering that instantaneous operation only operates on three-phase disturbances and two-phase disturbances to the ground so that the two-phase disturbances will operate are inverse time delay relays.

The threshold setting of ground fault relay inverse time delay Io>> is 0.75 A. This value is taken from a factor of 0.5 from the phase fault threshold. The threshold setting of instantaneous Io>> is 5.5 amperes, and the value taken is smaller than the single line-to-ground short circuit fault value of 6.3 amperes.

In Figure 5, according to the threshold setting of phase fault, inverse time delay with the threshold setting I> is 1.5 amperes, and instantaneous I>> is 7.5 amperes. Shows that a phase fault inverse time delay is not detected when a single phase fault occurs. The relay operates in an inverse time delay on a single-phase fault to ground. Meanwhile, in line-to-line, line-to-line to ground, three-phase, and three-phase to ground disturbances, the relay operates instantaneously.

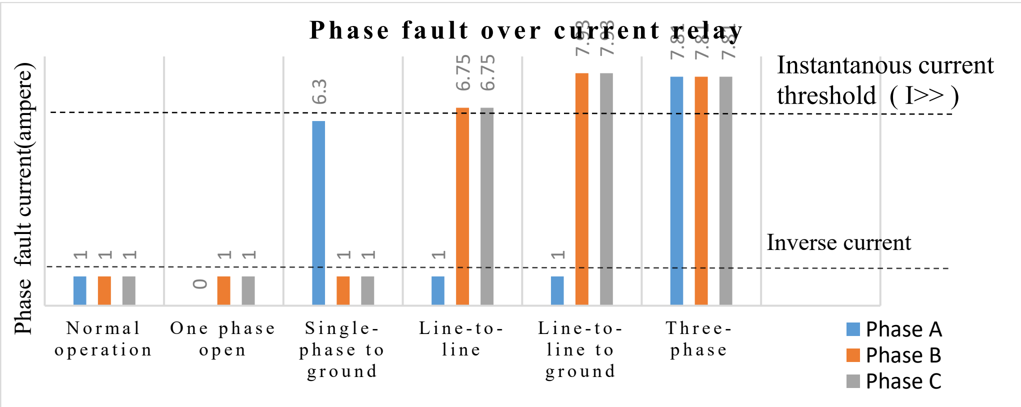


Figure 5. Phase protection system threshold setting in various disturbances

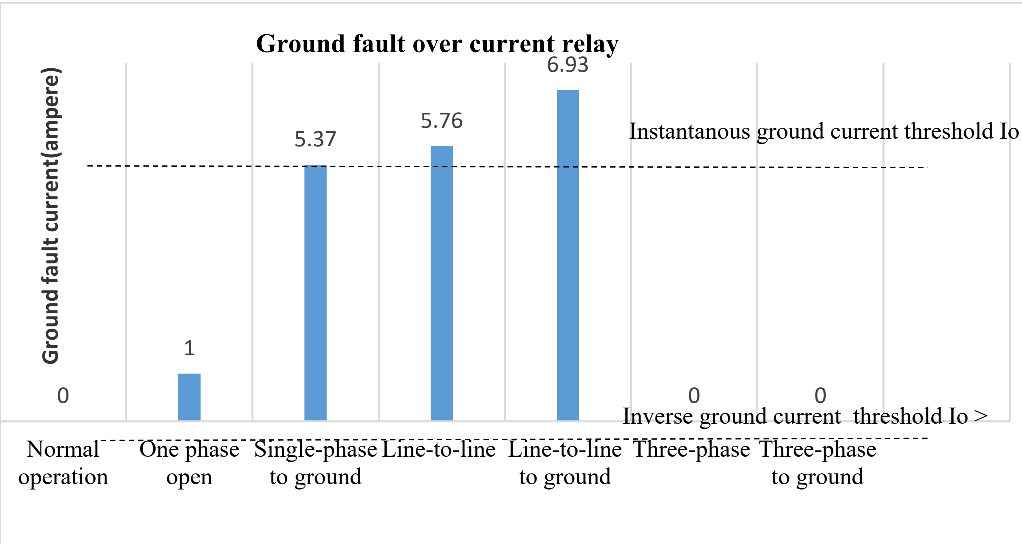
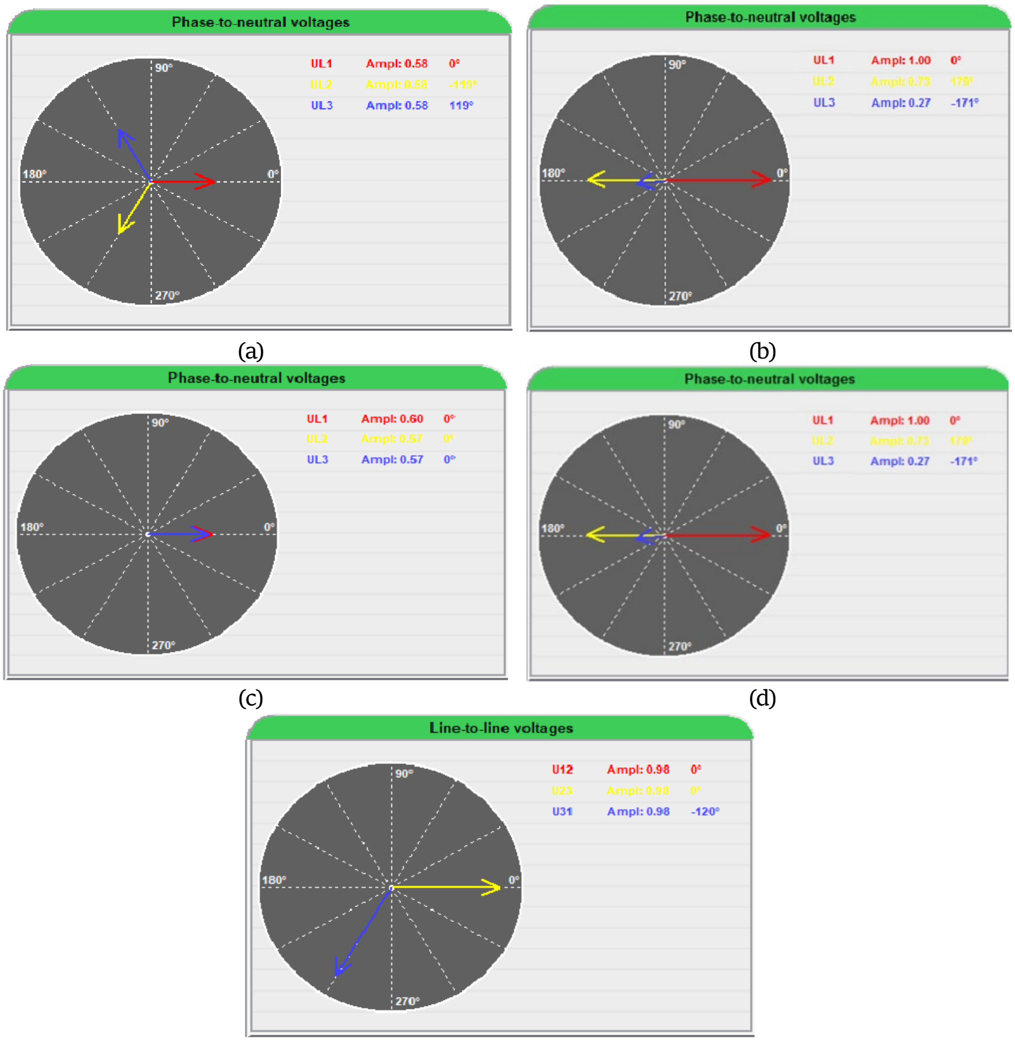


Figure 6. Residual current protection threshold on a solid grounding in various disturbances

Figure 6 shows the Residual Current Sequence Protection Mechanism according to the threshold setting of ground fault relay inverse time delay Io>> is 0.75 A, instantaneous Io>> is 5.5 amperes. This relay will detect all types of disturbances. In the inverse time delay on one phase open fault, and a single line to ground. Meanwhile, in line-to-line, line-to-line to ground, three-phase, and three-phase to ground disturbances, the relay operates instantaneously.

The Result of Residual Voltage Sequence Protection Mechanism

The result of the measurement of the phasor diagram for the magnitude of the short circuit voltage test in high resistance grounding 100 ohms is displayed from Vamp-40. Fig 7 shows there is (a) normal condition, (b)single line to ground fault, (c) double line to ground fault, (d) three-phase fault and (e) one phase open fault.



(e)

Figure 7. Phasor Diagram for the magnitude of short circuit voltage test in high resistance grounding 100 ohm

Figure 7 (a) is a normal condition without interference. The measurement results from the vampset application under normal conditions show that the voltage between the phases has an angle difference of 119°. This result is not much different from the calculation result, which is 120°. Figure 7 (b) When a single phase fault occurs, the angle difference between the phases should drop from 120° to 60° and the voltage to be interrupted becomes 0°. Figure 7(c). The phasor diagram on the double line to ground fault. Fault measurement results of the vampset with the calculations have compatibility. That is, there is no difference in the angle between the phases or equal to 0°. Figure 7(d) Three-phase fault Phasor diagram of a three-phase to ground vampset measurement results with calculations having suitability, that is, there is no difference in angle between the phases or equal to 00 because all voltages have a value of 0 V or no voltage. Figure 7(e) In the phasor diagram of an open single-phase fault, it is evident that the phasor R is not present in the figure because phase R is simulated as an open or disconnected phase. The voltage on the R phase becomes 0-volt or no voltage.

Table 2. and Table 3. illustrate when the power distribution system experiences a short circuit fault and uses the OVR vamp 40 protection system. The tests were carried out on two grounding systems, namely, the floating grounding system and high resistance. Table 2 is the measurement result of the short circuit test on the floating earth system grounding system. Table 3 is the result of measuring the short circuit test on the grounding system with a high grounding system (100 ohms). The measurement results used an analogue measuring device in the protection practicum module, while the relay voltage was measured using a three-phase digital voltmeter to the ground.

Table 2. The magnitude of the short circuit voltage test in the ungrounding system

Fault type	Phase A		Phase B		Phase C	
	Magnitude (volt)	Angle (degree)	Magnitude (volt)	Angle (degree)	Magnitude (volt)	Angle (degree)
Normal operation	120	0	130	-120	125	120
One phase open	0	0	110	-120	120	120
Single line to ground	0	0	220	150	230	150
Line-to-line	127	0	63.5	180	63.5	180
Line-to-line to ground	0	0	0	0	204	0
Three-phase	0	0	0	0	0	0
Three-phase to ground	0	0	0	0	0	0

Table 3. The magnitude of the short circuit voltage test in high resistance grounding 100 ohm

Fault type	Phase A		Phase B		Phase C	
	Magnitude (volt)	Angle (degree)	Magnitude (volt)	Angle (degree)	Magnitude (volt)	Angle (degree)
Normal operation	122	0	120	-120	130	120
One phase open	0	0	110	-120	120	120

Fault type	Phase A		Phase B		Phase C	
	Magnitude (volt)	Angle (degree)	Magnitude (volt)	Angle (degree)	Magnitude (volt)	Angle (degree)
Single line to ground	0	0	220	150	228	150
Line-to-line	127	0	63.5	180	63.5	180
Line-to-line to ground	0	0	0	0	200	0
Three-phase	0	0	0	0	0	0

It can be seen that the test results on the two grounding systems are not much different from the calculation results. Therefore, the test has obtained the correct and appropriate results. From the short circuit test on the floating grounding system and grounding system, it can be proven that when a fault occurs, the phase voltage that is experiencing a short circuit will drop to 0 volts. In contrast, on a phase that is not disturbed, the phase voltage rises to the root of three-phase to neutral (VLN) voltages.

From the test it can also be proven that the highest measured relay voltage is when a single phase short circuit fault to the ground is equal to 52.8 Volts in the high resistance earthing system and 58.3 Volts in the floating earthing system. Because this test has been carried out at the farthest point of the system (100%, the most distant point representation), the OVR voltage threshold setting can use the results from the largest test for the safety factor.

For the results of the phasor diagram data obtained through the vampset application, some data are in accordance with the calculations, namely the phasor diagram when normal conditions, two-phase to ground fault conditions, three-phase to ground fault conditions and one-phase open condition. For a single-phase-to-ground phasor diagram, the measured angle differences experience a discrepancy which can be caused by fault readings that are too fast. An open single-phase fault is carried out to determine whether an open or broken phase will cause an increase in voltage or not. The test results show that the effect of an open single-phase fault does not cause overvoltage, but the disturbed phase loses its source of voltage. The grounding system does not affect the magnitude of the voltage disturbance, so the test results from the two grounding systems are almost the same.

Table 4. The magnitude of the Break Delta Network and Overvoltage Relay (59N) in the ungrounding system and high resistance grounding 100 ohm

Fault type	The magnitude of the Break Delta Network and Overvoltage Relay (59N)		Circuit Breaker	Function
	Magnitude (volt)	Angle (degree)		
Normal operation	0,7	0	Not Trpped	Normally
One phase open	0,34	0	Not Trpped	Normally

Fault type	The magnitude of the Break Delta Network and Overvoltage Relay (59N)		Circuit Breaker	Function
	Magnitude (volt)	Angle (degree)		
Single line to ground	52,8	0	Tripped	Function U0>>
Line-to-line to ground	34,87	0	Tripped	Function U0>
Three-phase	0,23	0	Not Trpped	Normally
Three-phase to ground	0,23	0	Not Trpped	Normally

Table 4 shows the results of tests carried out on a floating and high resistance grounding system with various phase-to-ground short circuit disturbances and one phase open on the OVR function on the vamp 40 relays. The relay function was found has been running according to the settings used properly. When the relay senses a disturbance, the OVR gives a signal so that the CB immediately trips. When the test is carried out when a single-phase to-ground short circuit condition and a two-phase to-ground fault, the system experiences a trip because it is successfully protected by Vamp 40.

The Vamp 40 relay in the OVR trip function corresponds to the specified time, namely 2 seconds for a two-phase short circuit fault and 0.5 seconds for a single-phase short circuit fault. This is because the characteristics of the time used is a certain working time (definite time) so that the size of the voltage does not affect working time. In the event of a three-phase short circuit to ground fault and an open single-phase fault, the OVR function on the vamp 40 relay does not work because there is no interference. This is because the relay voltage read on the two disturbances is very small, 0 volts. Therefore, relay vamp 40 cannot work securely.

CONCLUSION

The phase of over current fault will be operated in all symmetrical and asymmetrical disturbances except for open one-phase fault disturbance. The ground of over current fault will be operated only in asymmetrical fault. The threshold setting of ground fault relay inverse time delay Io>> is 0.75 A, and this value is taken from a factor of 0.5 from the phase fault threshold. The threshold setting of instantaneous Io>> is 5.5 amperes, the value taken is smaller than the single line-to-ground short circuit fault value of 6.3 amperes.

The Residual Voltage Sequence can work effectively to protect in floating and high resistance earthing systems only during one-phase-to-ground and two-phase-to-ground short circuit disturbances because in three-phase-to-ground short-circuit disturbances and one-phase open disturbances, the relay voltage is zero. Simulation and testing of phase-to-ground short circuit disturbances and open single-phase disturbances have been successfully carried out, and the protection module can work to secure the system. In addition, the vamp 40 relays can be connected properly to a computer so that adjustments can be made via the vampset. The threshold setting is correct at U_0> = 22% and U_0>> = 33.2%. The voltage threshold setting is obtained from the lowest result of the one-phase-to-ground short circuit test for U_0>> and the results of the two-phase-to-ground short circuit test soil for U_0 >= 22%. The working time setting is carried out following the default of Vamp 40. The function of using the open break delta configuration on the protection module is in accordance with the requirements of the Vamp 40 relay with the OVR 59N function, namely for measuring residual voltage.

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