# Adaptive Protection Scheme in Distribution Networks

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**Abstract.** The protection system is very broad in scope and essential in the distribution system to maintain continuity of service. The 20 kV distribution network in Indonesia currently uses a conventional protection system, due to the update of the power flow configuration to multisource, the protection system needs to be evaluated. This research was conducted by comparing several scenarios using the IEEE 33-bus test system. The test aims to determine the most effective coordination scheme used in 20 kV distribution networks with and without distribution plants. So that it can be determined the type of relay, the amount of current and the Time Multiple Setting of the relay pickup to avoid the occurrence of Sympathetic Trip and Protection Blinding. The benefits of the proposed tests and results are to improve the selectivity and effectiveness of the relays despite changing system conditions.

**Keywords:** *distribution generator, 20kV distribution network, multisource, protection system.*

## 1 Background

The reliability of a system is influenced by several factors, including infrastructure quality, network maintenance, weather conditions, network complexity and topology, and protection systems. During fault conditions, abnormal currents flow through equipment installed in the network, which can reduce the life and efficiency of the equipment and disrupt the availability of supply. Protection equipment such as switching and protection relays are widely used to identify and isolate the faulted area from the operational network. Protection equipment such as power breakers (PMTs) and protection relays are widely used to identify and isolate disturbed areas of the operational network, working according to predefined settings or known as conventional protection. Conventional protection relays usually only sense the flow of unidirectional power from the source to the load which will only work when the relay senses a power flow that exceeds the predetermined setting current so that the relay gives the command to the PMT to work.

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Along with the development of the distribution network system, where renewable energy is the only clean energy alternative, it causes changes in network topology, reliability level and network operation patterns. One of them, Distributed Generation (DG) is a generator that is placed at the point of load so that it can reduce distribution losses, increase the reliability of distribution system operations, and reduce investment in the construction of transmission systems and substations due to increased loads.

The presence of DG in the distribution system can cause changes in the distribution system power flow and will increase the amount of fault current flowing into the system depending on the fault point, capacity and number of DG in the distribution system. Conventional protection schemes that work on this system do not consider the impact of DG so that they are not effective in protecting the system due to the network becoming multi-sources. The protection problem as a result of the presence of DG in the distribution system is the occurrence of protection blindness and sympathetic tripping which can disrupt the coordination between the main and backup relays. Therefore, it is necessary to select the right protection scheme to overcome the problems that arise due to the presence of DG.

The main purpose of adaptive protection is to be able to change relay settings to suit power system conditions. Relays in adaptive protection are digital relays with automatic settings where the relay can perform its own settings such as calculating the size and location of the fault itself and quickly isolating the fault area so that the damage does not spread to other areas of the system. Adaptive protection is expected to operate with the characteristics: reliable (operates when needed), safe (should not be operated unnecessarily), selective (only the minimum number of fault devices required should operate), and fast (fault isolation), which is better than conventional protection. The protection scheme in the test uses an IEEE-33 bus system by placing several DGs on the busbar and using directional overcurrent relays and directional earth fault relays. This relay coordination will include phase and ground faults. The test operation method uses 3 scenarios, namely not connected to DG, connected to DG, and not connected to GI source but connected to 2 types of DG. To maintain relay coordination, the relay at the farthest point from the source will trip in the shortest time.

# 2 Distribution Protection System

## 2.1 Distribution Generator Influence

The purpose of protection relay technology is to protect distribution, transmission, substation and generation assets. Problems that often occur due to the presence of generators connected to the distribution system are:

### 2.1.1 Frequency, Voltage and Power Flow

Voltage and frequency regulation problems are common due to imbalances in power generation and consumption. Voltage and frequency variations arise due to the difference between generated power and active and reactive power consumption. Especially in island systems, DG must participate in active frequency control. The voltage and frequency of the system can change very quickly, so it is necessary to regulate this problem, which causes conventional protection to not work optimally.

### 2.1.2 Short Circuit Current

The value of the magnitude of the short circuit current of a system depends on the power flow and power generated, so that when a system disturbance occurs it causes a very large current to flow to the point of interference from the source to the point of interference. In distribution systems with distribution generators connected in parallel can reduce system impedance and cause an increase in the total fault current, so the system requires additional protection to be able to change and coordinate according to the situation.

### 2.1.3 *Protection blinding*

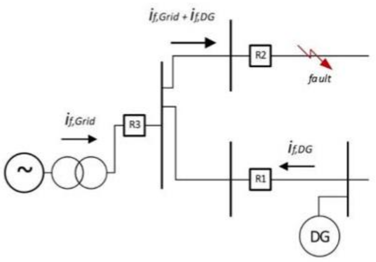



**Figure 1** Underreach protection

The protection system installed on the loop network must be able to protect the network at a certain distance. This distance is commonly referred to as the relay range which is determined by the minimum fault current that can be detected by the relay. With the contribution of DG into the distribution system, it will increase the total short circuit level and change the magnitude and direction of the fault current which can compromise the sensitivity of the feeder relay. *Protection blinding* or also called *protection underreach* occurs due to a decrease in the range of the feeder relay, it can cause mis operation of the relay.

### 2.1.4 Sympathetic Tripping

A phenomenon in the electricity system where a disturbance or failure in one part of the distribution system causes a disturbance or trip in another part that is not directly affected by the disturbance caused by the distribution generator. This causes blackouts in undisturbed parts of the system. This problem occurs due to the non-directional relay cannot distinguish the direction of the fault and the overcurrent relay on the feeder is set with different characteristics, pickup currents, and delay times.

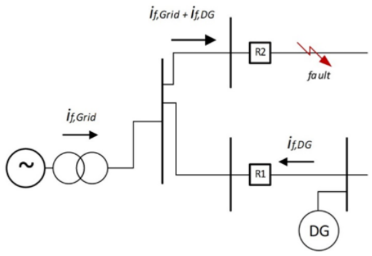



**Figure 2** Sympathetic Tripping

## 2.2 Adaptive Protection

Adaptive protection is a protection system that can change the response to a disturbance based on system conditions and disturbance currents. Adaptive protection is very suitable for use in *mirco grid* and *island grid* systems where relays require communication between relays, IEDs and *control center units*. Communication is the main part in the implementation of adaptive protection schemes, all relays contained in the system will communicate with each other to obtain information on changes in system conditions. In simple terms, adaptive protection is able to work alone with *real time* measurements and update the most suitable relay settings without any human intervention.

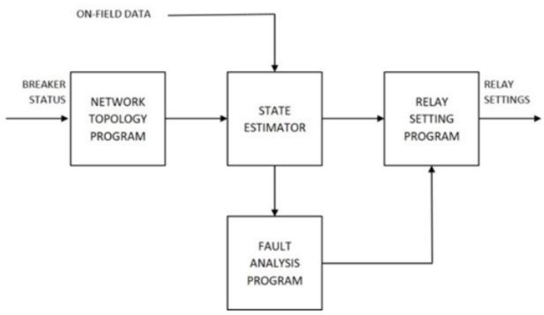



**Figure 3** Adaptive Protection Scheme

Adaptive protection is one of the simple approaches with reasonable implementation costs, thus making it a favorable solution. Adaptive protection methods require knowledge of the *mirco grid* network configuration to perform power flow and short circuit calculations to identify the ideal relay settings for each possible setup. It can also rely on communication methods to update the settings at each network reconfiguration.

### 2.3 Tripping Time

The calculation of the relay working time setting depends on the type of curve used by the safety. There are several types of overcurrent curves, including IEEE, IEC, and IAC. The test will use the IEC curve which is widely applied in distribution networks.

$$T = TMS \times \left[ \frac{K}{\left(\frac{I}{I_{pickup}}\right) - 1} \right] \tag{1}$$

Where T is the operating time. TMS is the time multiplier setting. I is the input current on the secondary side. I pickup is the pickup current setting. K and E are constants, with the constant values for each IEC curve being:

**Table 1** IEC curve constant

| No. | IEC Curve | K | E |
|---|---|---|---|
| 1 | IEC Curve A | 0.14 | 0.01 |
| 2 | IEC Curve B | 13.5 | 1.0 |
| 3 | IEC Curve C | 80 | 2.0 |
| 4 | IEC Short Inverse | 0.05 | 0.04 |

## 3 Methodology

Calculation of power flow, fault current, and TMS settings is done by collecting the necessary data, namely system voltage, load on each bus, line length, conductor type, conductor impedance, and power on the external grid. Tests and calculations use the IEEE-33 bus system in accordance with actual conditions. The length of the line and the type of conductor on all buses are the same, namely 1 Kms XLPE 3x150mm$^2$. The flowchart of this research is shown in Figure 4.

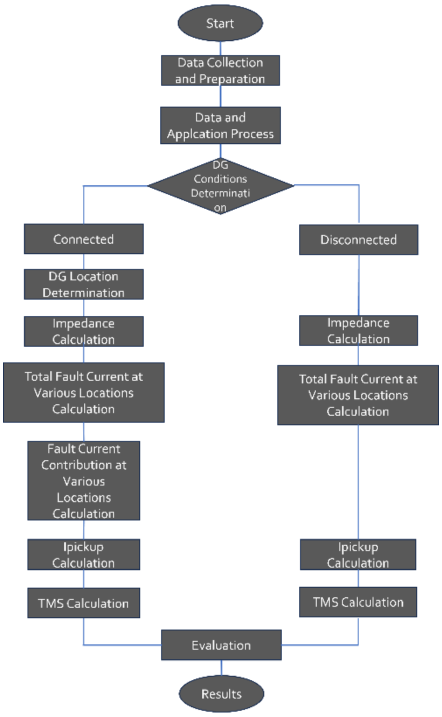



**Figure 4** Flowchart

**Table 2** Test System Source Data

| Bus | Voltage (kV) | Active Power (MW) | Reactive Power (MVAR) |
|---|---|---|---|
| External Grid | 20.1 | 14.5 | 12.4 |
| Gen 01 | 6.3 | 2 | 2.5 |
| Gen 02 | 6.3 | 2 | 0.3 |
| Gen 03 | 6.3 | 2 | 2.5 |
| PV | 0.6 | 0.9 | 0 |

**Table 3** Test System Load Data

| Bus | Active Power (MW) | Reactive Power (MVAR) |
|---|---|---|
| B1 | 0.6 | 0.5 |
| B2 | 0.6 | 0.5 |
| B3 | 0.5 | 0.5 |
| B4 | 0.6 | 0.5 |
| B5 | 0.6 | 0.5 |
| B6 | 0.6 | 0.5 |
| B7 | 0.5 | 0.5 |
| B8 | 0.7 | 0.6 |
| B9 | 0.5 | 0.4 |
| B10 | 0.6 | 0.5 |
| B11 | 0.5 | 0.4 |

| | | |
|---|---|---|
| B12 | 0.5 | 0.5 |
| B13 | 0.6 | 0.5 |
| B14 | 0.8 | 0.6 |
| B15 | 0.5 | 0.4 |
| B16 | 0.8 | 0.6 |
| B17 | 0.5 | 0.4 |
| B18 | 0.5 | 0.4 |
| B19 | 0.6 | 0.5 |
| B20 | 0.6 | 0.5 |
| B21 | 0.6 | 0.5 |
| B22 | 0.6 | 0.5 |
| B23 | 0.6 | 0.5 |
| B24 | 0.6 | 0.5 |
| B25 | 0.6 | 0.5 |
| B26 | 0.6 | 0.5 |
| B27 | 0.6 | 0.5 |
| B28 | 0.5 | 0.5 |
| B29 | 0.5 | 0.4 |
| B30 | 0.6 | 0.5 |
| B31 | 0.5 | 0.4 |
| B32 | 0.5 | 0.4 |
| B33 | 0.6 | 0.5 |

The same data used in the system for each scenario include:

## 3.1 Scenario I

In the test, there is 1 external grid source which is the main supply of power flow in the system, with relay data in table 4.

**Table 4** Scenario I Relay Data

| **Relays** | **Relay Type** | **Relay Direction** | **CT Ratio** |
|---|---|---|---|
| OCR 1 | OCR/GFR | None | 1000/5 |
| B2-3 | OCR/GFR | None | 1000/5 |
| B2-19 | OCR/GFR | None | 1000/5 |
| B3-4 | OCR/GFR | None | 1000/5 |
| B3-23 | OCR/GFR | None | 1000/5 |
| B6-26 | OCR/GFR | None | 1000/5 |

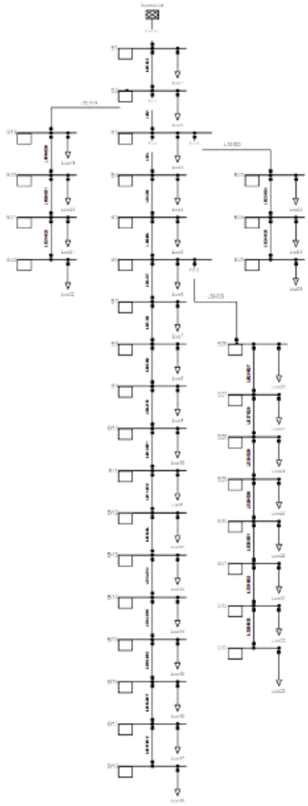


**Figure 5** IEEE-33 bus Test System without DG

## 3.2 Scenario II

In the test, there are 1 external grid source and 3 distribution generator units that are the main suppliers of power flow in the system, with relay data in table 5.

**Table 5** Scenario II Relay Data

| Relays | Relay Type | Relay Direction | CT Ratio |
|---|---|---|---|
| OCR 1 | OCR/GFR | Forward | 1000/5 |
| OCR GEN 1 | OCR/GFR | None | 1000/5 |
| OCR GEN 2 | OCR/GFR | None | 1000/5 |
| OCR GEN 3 | OCR/GFR | None | 1000/5 |
| B2-3 | OCR/GFR | Forward | 1000/5 |
| B2-19 | OCR/GFR | Forward | 1000/5 |
| B3-4 | DOCR/DGFR | Forward | 1000/5 |
| B3-23 | OCR/GFR | Forward | 1000/5 |
| B6-26 | OCR/GFR | Forward | 1000/5 |

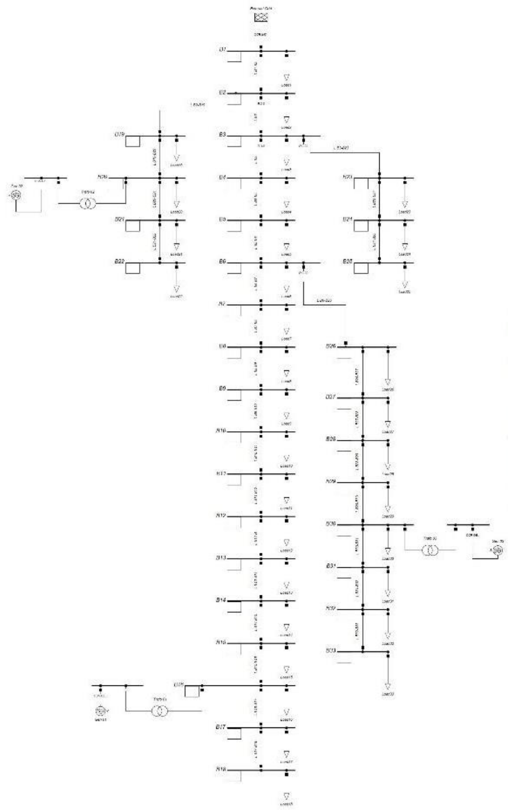


**Figure 6** IEEE-33 bus Test System with DG

## 3.3 Scenario III

In the test, there are 3 units of distribution generators and 1 unit of on-grid PV system that become the main supply of power flow in the system, with relay data in Table 6.

**Table 6** Scenario III Relay Data

| Relays | Relay Type | Relay Direction | CT Ratio |
|---|---|---|---|
| OCR GEN 1 | OCR/GFR | None | 1000/5 |
| OCR GEN 2 | OCR/GFR | None | 1000/5 |
| OCR GEN 3 | OCR/GFR | None | 1000/5 |
| B2-3 | OCR/GFR | Forward | 1000/5 |
| B2-19 | OCR/GFR | Forward | 1000/5 |
| B3-4 | DOCR/DGFR | Forward | 1000/5 |
| B3-23 | OCR/GFR | Forward | 1000/5 |
| B6-26 | OCR/GFR | Forward | 1000/5 |

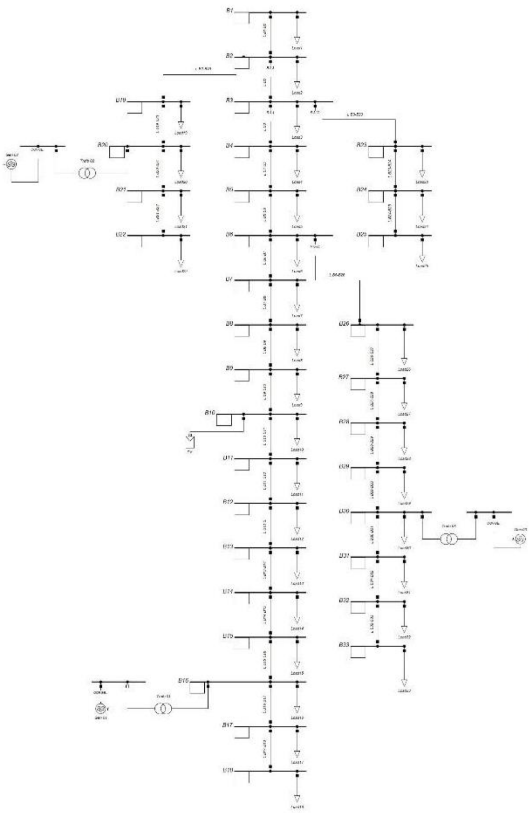


**Figure 7** IEEE-33 Bus Test System with DG and PV on grid

# 4 Results and Analysis

## 4.1 Short Circuit Current Calculation

The adaptive protection scheme uses the amount of short circuit current to determine the most appropriate time delay on the test system. The results of the calculation of the amount of short circuit current are carried out using PF 2020. The amount of short circuit current is influenced by several things such as source impedance, source distance to the fault point, line impedance, type of short circuit fault, system voltage and system operating conditions.

From the above calculations, it can be seen that the farther the fault point is from the source, the smaller the short circuit current generated. The results of the short circuit current calculation in scenario II are greater than scenario I at the same bus due to the current flowing to the fault point comes from the external grid and DG. While the calculation results of scenario III on the same bus are smaller due to the source impedance and the resulting system voltage are smaller than the other scenarios.

**Table 7** Short circuit current comparison for all scenarios (in kA)

| No. | Bus | Scenario I | | Scenario II | | Scenario III | |
|---|---|---|---|---|---|---|---|
| | | 3 phs | 1 phs | 3 phs | 1 phs | 3 phs | 1 phs |
| 1 | B1 | 2.623 | 2.623 | 3.374 | 3.159 | 1.115 | 0.927 |
| 2 | B2 | 2.531 | 2.494 | 3.292 | 3.014 | 1.12 | 0.928 |
| 3 | B3 | 2.465 | 2.393 | 3.22 | 2.892 | 1.126 | 0.932 |
| 4 | B4 | 2.399 | 2.297 | 3.148 | 2.775 | 1.131 | 0.936 |
| 5 | B5 | 2.334 | 2.205 | 3.076 | 2.663 | 1.137 | 0.94 |
| 6 | B6 | 2.27 | 2.117 | 3.004 | 2.557 | 1.142 | 0.944 |
| 7 | B7 | 2.207 | 2.035 | 2.917 | 2.447 | 1.137 | 0.94 |
| 8 | B8 | 2.147 | 1.956 | 2.833 | 2.344 | 1.131 | 0.936 |
| 9 | B9 | 2.087 | 1.883 | 2.751 | 2.248 | 1.126 | 0.933 |
| 10 | B10 | 2.03 | 1.813 | 2.672 | 2.157 | 1.12 | 0.929 |
| 11 | B11 | 1.975 | 1.747 | 2.595 | 2.073 | 1.115 | 0.925 |
| 12 | B12 | 1.921 | 1.686 | 2.522 | 1.994 | 1.11 | 0.921 |
| 13 | B13 | 1.87 | 1.627 | 2.452 | 1.921 | 1.104 | 0.917 |
| 14 | B14 | 1.82 | 1.573 | 2.385 | 1.852 | 1.099 | 0.913 |
| 15 | B15 | 1.773 | 1.521 | 2.32 | 1.787 | 1.094 | 0.91 |
| 16 | B16 | 1.736 | 1.479 | 2.259 | 1.727 | 1.094 | 0.91 |
| 17 | B17 | 1.683 | 1.426 | 2.188 | 1.664 | 1.073 | 0.895 |
| 18 | B18 | 1.641 | 1.382 | 2.12 | 1.605 | 1.058 | 0.884 |
| 19 | B19 | 2.465 | 2.393 | 3.2 | 2.879 | 1.115 | 0.925 |
| 20 | B20 | 2.411 | 2.308 | 3.109 | 2.75 | 1.115 | 0.925 |
| 21 | B21 | 2.334 | 2.205 | 3.001 | 2.617 | 1.094 | 0.91 |
| 22 | B22 | 2.27 | 2.117 | 2.897 | 2.493 | 1.078 | 0.899 |
| 23 | B23 | 2.399 | 2.297 | 3.111 | 2.751 | 1.11 | 0.921 |
| 24 | B24 | 2.334 | 2.205 | 3.003 | 2.618 | 1.094 | 0.91 |
| 25 | B25 | 2.27 | 2.117 | 2.898 | 2.494 | 1.078 | 0.9 |
| 26 | B26 | 2.207 | 2.035 | 2.917 | 2.447 | 1.137 | 0.94 |
| 27 | B27 | 2.147 | 1.956 | 2.832 | 2.344 | 1.131 | 0.936 |
| 28 | B28 | 2.087 | 1.883 | 2.75 | 2.247 | 1.126 | 0.932 |
| 29 | B29 | 2.03 | 1.813 | 2.671 | 2.157 | 1.12 | 0.928 |
| 30 | B30 | 1.985 | 1.756 | 2.594 | 2.073 | 1.121 | 0.929 |
| 31 | B31 | 1.921 | 1.686 | 2.507 | 1.986 | 1.099 | 0.914 |
| 32 | B32 | 1.87 | 1.627 | 2.424 | 1.906 | 1.083 | 0.903 |
| 33 | B33 | 1.82 | 1.573 | 2.344 | 1.831 | 1.068 | 0.892 |
| 34 | Gen 01 | 0 | 0 | 3.864 | 4.465 | 2.566 | 2.394 |
| 35 | Gen 02 | 0 | 0 | 4.323 | 4.843 | 2.594 | 2.403 |
| 36 | Gen 03 | 0 | 0 | 4.074 | 4.637 | 2.601 | 2.397 |

## 4.2 Calculation of Pickup Current and TMS

Determination of the pickup current for each relay is obtained by comparing the results of the short circuit current calculation with the nominal current at each point. As for the determination of the delay time for tripping time relays starting from the farthest point from the source that will trip with the shortest time and successively towards the source with a larger time delay with a time difference of 0.2 s in order to fulfill the basic aspects of protection that is selective. TMS in this study uses inverse time (SI) characteristics.

**Table 8** Pickup Current and TMS Settings for Each Scenario

| Relays | Scenario I | | Scenario II | | Scenario III | |
|---|---|---|---|---|---|---|
| | Pickup Current (A) | Time Delay (S) | Pickup Current (A) | Time Delay (S) | Pickup Current (A) | Time Delay (S) |
| OCR 1 | 320 | 0.15 | 320 | 0.15 | - | 0.15 |
| OCR GEN 1 | - | - | 640 | 0.24 | 640 | 0.20 |
| OCR GEN 2 | - | - | 640 | 0.28 | 640 | 0.23 |
| OCR GEN 3 | - | - | 640 | 0.2 | 640 | 0.17 |
| B2-3 | 200 | 0.13 | 200 | 0.13 | 200 | 0.13 |
| B2-19 | 200 | 0.11 | 200 | 0.11 | 200 | 0.11 |
| B3-4 | 200 | 0.09 | 200 | 0.09 | 200 | 0.09 |
| B3-23 | 200 | 0.07 | 200 | 0.07 | 200 | 0.07 |
| B6-26 | 200 | 0.05 | 200 | 0.05 | 200 | 0.05 |

## 4.3 Adaptive Relay Coordination`

To be able to avoid the occurrence of sympathetic trip and protection blinding, it is necessary to arrange coordination between the installed relays, both as main protection and as backup protection. It should be noted in the test, that the fault current flowing on each bus is different. Disturbances at the farthest point from the source must be able to be blocked by the nearest relay from the point of disturbance and a more distant relay as a safety backup. The fault location is the same for each scenario. The relay coordination results obtained from the test are shown in table 9.

**Table 9** Relay Operation Time (s)

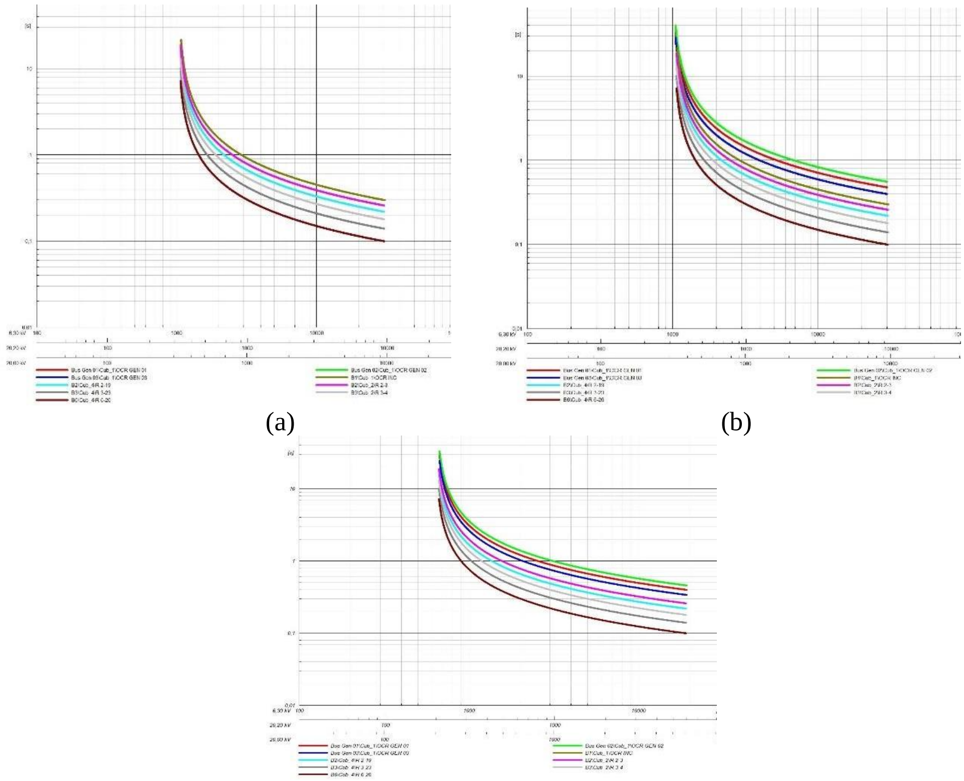
| Fault Location | Scenario I | | | Scenario II | | | Scenario III | | |
|---|---|---|---|---|---|---|---|---|---|
| | Main | Backup 1 | Backup 2 | Main | Backup 1 | Backup 2 | Main | Backup 1 | Backup 2 |
| B3 | R 2-3 | OCR INC | - | R 2-3 | OCR INC | - | R 3-4 | R 6-26 | R 2-19 |
| | 0.4367 | 0.5039 | | 0.4161 | 0.5134 | | 0.4765 | 0.5571 | 11.513 |
| B5 | R 3-4 | R 2-3 | OCR INC | R 3-4 | R 2-3 | OCR INC | R 6-26 | R 3-4 | R 2-19 |
| | 0.3108 | 0.4489 | 0.518 | 0.2971 | 0.4291 | 0.5306 | 0.5401 | 0.9571 | 11.698 |
| B17 | R B3-4 | R B2-3 | OCR INC | R B3-4 | R B2-3 | OCR INC | R 6-26 | R 3-4 | R 2-19 |
| | 0.3732 | 0.5391 | 0.6221 | 0.3724 | 0.538 | 0.677 | 0.6428 | 1.1679 | 1.4274 |
| B22 | R 2-19 | OCR INC | - | R 2-19 | OCR INC | - | R 3-4 | R 2-19 | R 6-26 |
| | 0.3854 | 0.5255 | | 0.3547 | 0.5463 | | 0.499 | 0.6099 | 0.6146 |
| B25 | R 3-23 | R 2-3 | OCR INC | R 3-23 | R 2-3 | OCR INC | R 3-23 | R 3-4 | R 6-26 |
| | 0.2452 | 0.4554 | 0.5255 | 0.2135 | 0.4411 | 0.5464 | 0.286 | 0.493 | 0.5987 |
| B33 | R 6-26 | R 3-4 | R 2-3 | R 6-26 | R 3-4 | R 2-3 | R 6-26 | R 3-4 | R 2-19 |
| | 0.1978 | 0.3561 | 0.5144 | 0.1822 | 0.3532 | 0.5102 | 0.2788 | 1.1254 | 1.3755 |

From the three test scenarios, the relays installed in the system work according to the conditions and direction of the fault. For each fault location point, there is at least one main relay and one backup relay. The main and backup relays work in accordance with the TMS that has been set with the appropriate fault direction pickup in the forward and reverse directions, so that the test results by placing the fault point at different Bus locations are obtained:

- In scenarios I and II Bus B3 Relay R2-3 will work as the main relay and OCR Relay INC will work as a backup relay, while Relay R3-4 works as a backup relay with Reverse direction protection so that R3-4 does not work,
- In scenarios II and III Bus B3, Relay R2-3 does not work due to the direction of the disturbance read is the reverse direction, while Relay R3-4 works as the main relay and R6-26 works as a backup relay to secure the undisturbed bus.

## 4.4 Pickup Current Curve

The characteristics of the fault current curve are set to ensure that the relay can work sequentially from the relay closest to the fault point to the relay behind it. The choice of curve type is essential in determining the sensitivity and selectivity of the installed relay. The use of characteristic curves in the three scenarios is an inverse relationship curve where the greater the fault current, the faster the relay time works, with the standard inverse (SI) type. The curve can be visualized as follows:



(a) (b)

(c)

**Figure 8** Standard Inverse Characteristic Curve: (a) Scenario I, (b) Scenario II, (c) Scenario III

## 4.5 Comparison with Actual Conditions

There are several adaptive protection methods, namely static relay setting groups, multiple relays stating groups, programmable relay stating groups, model-driven relay settings, machine learning protection settings, algorithm protection settings, multi-agent protection settings and automated or self-setting protection methods. Of the several types of methods, the test is included in the static relay setting groups method. Where this method can be used for islanding and grid networks connected to several sources. Before implementing an adaptive protection system on the distribution network, the relay will not be able to work optimally. This protection system uses communication between relays in real time so that each relay can determine its function as the main relay or backup relay. Setting time and pickup current can change according to the desired conditions if needed. Thus, the use of adaptive protection in distribution networks can reduce the occurrence of sympathetic trips and protection blinding. For application in actual conditions, it still uses a conventional relay with a pickup current setting of 1.2 times the nominal current, causing the relay to be less effective.

# 5 CONCLUSIONS

Through the test, the most appropriate protection scheme for each network configuration can be determined. Adaptive protection can accommodate disturbance security patterns by changing relay settings according to the operating conditions of distribution generators. The condition of unconnected distribution generators has only one power flow so it does not require a directional relay on the system. While the condition of parallel connected distribution generators causes the system to have two directions of power flow so that it requires a directional relay and the setting conditions in both conditions will be different. Adaptive protection schemes are very suitable to be applied to distribution systems that are developing today, especially in areas that have the potential for renewable energy.

## References

[1] R. C. S. P. Tambun, K. M. Banjar-Nahor, N. Hariyanto, F. S. Rahman and R. Rahmani, "Adaptive Protection Coordination Scheme for Distribution System under Penetration of Distributed Generation," 2021 3rd International Conference on High Voltage Engineering and Power Systems (ICHVEPS), Bandung, Indonesia, 2021, pp. 355-360, doi: 10.1109/ICHVEPS53178.2021.9600981. keywords: {Adaptive systems; Short-circuit currents; Production facilities; Distributed power generation; Topology; Power systems; Impedance; DG Penetration; Adaptive Protection Scheme; Contribution Current},

[2] A. Y. Abdelaziz, H. E. A. Talaat, A. I. Nosseir, and A. A. Hajjar, "An adaptive protection scheme for optimal coordination of overcurrent relays," 2002. [Online]. Available: www.elsevier.com/locate/epsr

[3] T S S Senarathna and K T M Udayanga Hemapala, "Review of adaptive protection methods for microgrids" AIMS Energy, Volume 7, Issue 5, 557-578, Sept. 2019, doi: 10.3934/energy.2019.5.557.

[4] S. Voima, H. Laaksonen, and K. Kauhaniemi, "Adaptive Protection Scheme for Smart Grids."

[5] R. M. Tumilty, M. Brucoli, G. M. Burt, and T. E. Green, "Approaches to network protection for inverter dominated electrical distribution systems".

[6] M. Y. Shih, A. Conde, Z. Leonowicz, and L. Martirano, "An Adaptive Overcurrent Coordination Scheme to Improve Relay Sensitivity and Overcome Drawbacks due to Distributed Generation in Smart Grids," IEEE Transactions on Industry Applications, vol. 53, no. 6, pp. 5217- 5228, Nov. 2017, doi: 10.1109/TIA.2017.2717880.

[7] F. e. a. Coffele, " "An Adaptive Overcurrent Protection Scheme for Distribution Networks"," IEEE Transactions on Power Delivery, April 2015.

[8] S. e. a. Kunsman, "Processes, Issues, Trends and Quality Control of Relay Settings," IEEE Power System Relay Committee, March 2007.

[9] S. e. a. Kunsman, "Processes, Issues, Trends and Quality Control of Relay Settings," in IEEE Power System Relay Committee, March 2007.

[10] V. A. Papaspiliotopoulos, G. N. Korres, V. A. Kleftakis, and N. D. Hatziargyriou, "Hardware-In-the-Loop Design and Optimal Setting of Adaptive Protection Schemes for Distribution Systems with Distributed Generation," IEEE Transactions on Power Delivery, vol. 32, no. 1, pp. 393-400, Feb. 2017, doi: 10.1109/TPWRD.2015.2509784