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# OVER CURRENT RELAY COORDINATION SYSTEM CONSIDERING DISTRIBUTED GENERATION

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***Abstract***

*Today, electricity is one of the important components to drive the industrial process and other daily human activities. While the continuity of power supply through the power system grid is impressionable from disturbances such as a short circuit. In addition, the rapid development of distributed generation (DG) technology triggers the industry to use DG technology to maintain power quality and support for industrial processes. This paper proposed the coordination of over current relay (OCR) considering distributed generation (DG) to provide an extraordinary protection system in an electrical system network. The relay is coordinated with the other relay equipment to enhance the system more reliable, secure, and stable. To examine the efficacy of the proposed approach, the radial distribution system model is utilized in this paper where the DG is installed in bus 6. To compute the protection coordination index (PCI) and coordination time interval (CTI), the DG capacity is varied from 100 KVA to 1000kVA. From the simulation result, it could be seen that the installed DG that allowed in bus 6 was 900kVA because the CTI value reached convergence value as of 0.294 second for higher DC capacity than 900kVA. Moreover, the higher of DG capacity was injected to electrical system, the higher of PCI values was obtained.*



***Keywords:***
*Over current relay; distributed generation; CTI; PCI*

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## 1. Introduction

The growth of the industry in many countries is rapidly increasing in the last decade. So far, most of the industry is driven by generation sources using fossil fuels to supply the electricity in supporting the industrial processes. The continuity of good power supply in industry requires appropriate coordination of protection systems to avoid the electrical system from blackout events due to faults such as short circuit [1]. This fault has potential to cause severe damage to industrial equipment which can disrupt system production. To overcome this problem, a relay as an electrical safety device is utilized to protect the distribution system in the industry from a disturbance that can be localized quickly and prevented it to spread out to other areas.

Relay is a power system tool to protect the distribution system grid when the faults such as short circuit are occurred [2]. Moreover, many industries are now installing distributed generation to reduce the effect of fossil fuels on the environment and employed as backup power when there are any faults occurred. Generally, a short circuit occurring in the generator unit will increase its capacity by 6-8 times the existing generator rating. This condition will make the relay easily distinguish between normal conditions and any disturbances that occur to the distribution system due to the wide margin between loading situation and disturbance. Integration of DG to distribution system grid degrades the margin between the loaded system or under disturbance condition. The relay is difficult to distinguish between fault conditions or loading in this situation. In addition, this issue has significant impact to the power quality of electrical distribution system in industry. So far, to tackle this problem, it is required an appropriate protection system [3]. Several studies have been reported in according to the utilization of DG in electrical distribution system such as fault current limiter based [4], multi agent base protection scheme, dual setting protection scheme, voltage–current based protection [5]. Among studies mentioned above regarding to the effect of DG to electrical distribution network, voltage–current based protection is renowned method over other approaches. In this study, radial distribution system is utilized as a test system with the main fault is occurred in generator where the current of short-circuit as of 6-8 times from current rating in normal condition.

The use of DG type such as photovoltaic (PV) in electrical distribution system trigger a thin margin between the normal rated current and fault current values. In this condition, the relay is difficult to recognize the system in normal loading or under fault conditions. When a disturbance occurs, the current flow in the electrical distribution system will increase 110% up to 150% more than in a normal condition. To overcome this issue, the coordination of the protection system relay is a must. This paper proposed the coordination of over current relay considering the effect of DG integration in the electrical distribution systems in the industry. To examine the proposed approach, the DG capacity about 100kVA to 1000kVA is employed to the electrical distribution system.

The rest of the paper is organized as follows. System modeling are explained in Section 2. Protection system coordination is described in Section 3. Simulation result and discussion are illustrated in Section 4. Conclusion is given in Section 5.

## 2. System Modelling

### *A. Distributed Generation*

With the rapid growth of renewable energy technology and smart grids, distributed generation (DG) plays a key role in electrical distribution systems. DG is often utilized as supplementary power to maintain the electrical power network stable, reliable, and secure. Nowadays, DG is part of distributed energy resources (DREs) as energy storage and responsive loads [6]. The more advanced technology of renewable energy, the bigger the capacity size of DG for installation in a large-scale electrical distribution system. A brief overview of the most common DG technologies and their capacity sizes is illustrated in Table 1. DG can be applied to shave the peak load for a specific time, combined heat and power, continuous power, and emergency power.

Table 1. DG type and their capacity size

| No | DG Type | Capacity Size |
|---|---|---|
| 1 | Combine cycle gas turbine | 35 – 400 MW |
| 2 | Internal combustion engine | 5kW – 10 MW |
| 3 | Combustion turbine | 1 – 250 MW |
| 4 | Micro turbine | 35 kW – 1MW |
| 5 | Fuel cell | 200kW – 2MW |
| 6 | Battery storage | 0.5 – 5MW |
| 7 | Small hydro | 1 – 100 MW |
| 8 | Micro hydro | 25kW – 1MW |
| 9 | Wind turbine | 200W – 3MW |
| 10 | Photovoltaic array | 20W – 100kW |
| 11 | Solar thermal | 1 – 10MW |
| 12 | Biomass gasification | 100kW – 20MW |
| 13 | Geothermal | 5 – 100MW |
| 14 | Ocean energy | 0.1 – 1MW |

### *B. Electrical Distribution System*

The electrical distribution system in this study consists of eleven generator units driven by a gas engine generator (GEG) and divided into 3 large sub-network areas. In existing normal conditions, the generator unit is utilized to supply the electrical load needs. Spinning reserve is also prepared as supplementary power if one of the generator units is interrupted from the distribution system grid to avoid load shedding [9]. The distribution system model has two voltage rating values of 0.38kV and 20kV. The distribution system with 0.38kV is utilized to supply the load with a small capacity. While the 20kV distribution system is especially employed to supply the feeder with load for high voltage. In addition, a distribution system with a high voltage of around 20kV is to maintain the reliability of its system.

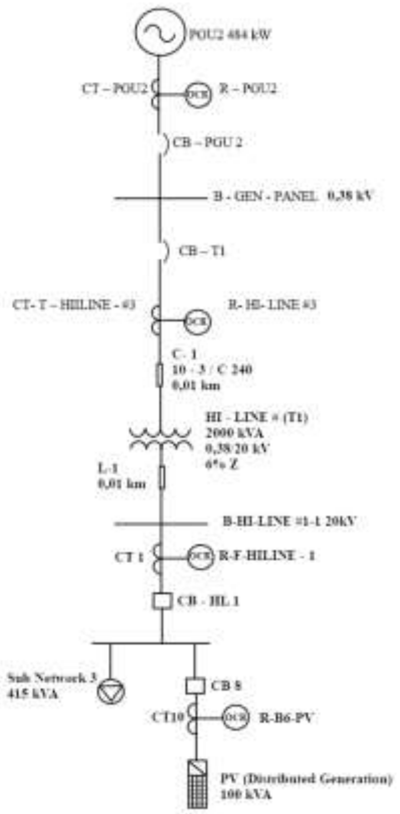

Figure 1. Proposed coordination of over-current relay (OCR)

The electrical distribution system network utilized in this study is depicted in Fig. 1. All data and distribution system models are taken from [7]. The coordinated over-current relay in this study is conducted in sub-network 3 with 484 kW of power supply PGU2 and connected through a 2000kVA of HI-LINE#(1) transformer which is located in HI-LINE #3. In this research study, over current relay R-B6-PV, over current relay R-F-HILINE-1, over current relay R-HI-LINE #3, and over current relay R-PGU2 will be coordinated to maintain the reliability of system due to integration of DG in this distribution network.

*C. Over Current Relay*

There are many types of relays utilized for electrical protection systems and one of important relays in industries is over current relay (OCR). OCR is a kind of relay working when there is any disturbance caused by a short circuit between phase to phase such as a three-phase or two-phase short circuit. These faults trigger an excessive current in the distribution system network.

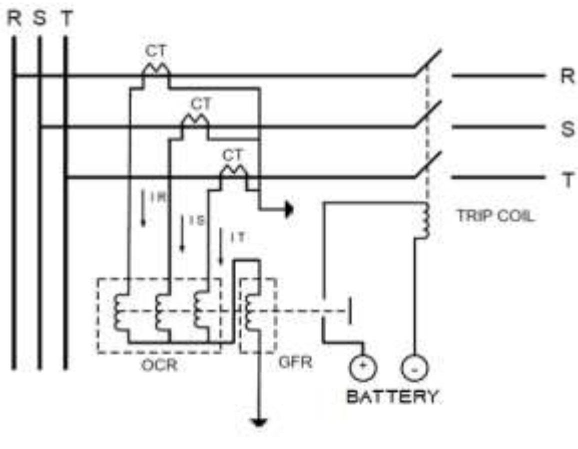


Figure 2. Over current relay (OCR) circuit installed in electrical distribution system grid

Over current relay (OCR) detects the current flow in the distribution network by working in conjunction with a current transformer (CT). The working principle of OCR is when the current transformer (CT) is reading abnormality conditions in the distribution system and the OCR will send signal to circuit breaker to disconnect a power from distribution system. when the current is over the current setting value ($I_{set}$). OCR only works as backup protection if there are any transformers with large capacity in the distribution line. Moreover, there are inverse time relay characteristics for OCR such as OCR with inverse time, OCR with definite time, and OCR with instantaneous time. The overcurrent relay circuit is depicted in Fig. 2.

*D. OCR Setting*

1. *OCR with definite time characteristic*

This OCR type is set based on its OCR's working time by neglecting the amount of current fault. It can be said that all currents through its pick-up set point will be disconnected by the pre-setting time of OCR. The OCR with definite time characteristic is shown in Fig. 3.

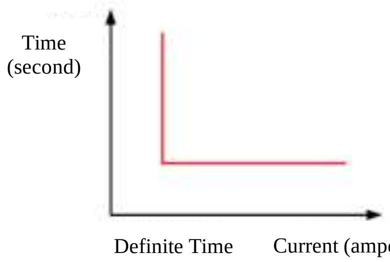


Figure 3. Over current relay (OCR) with definite time characteristic

2. *OCR with inverse time characteristic*

This OCR type works depending on its amount of current value reciprocal to time delay. The large current value through the OCR results in a fast time delay. This kind of OCR is figured out by the comparison current curve called the time current characteristic (TCC) to the IEC standard. The curve of OCR with inverse time characteristic has several types of curves including long time inverse, very inverse, short time inverse, dan extreme inverse [8]. This OCR type has two components that should be adjusted including the setting of pick-up current and the setting of time dial. In the setting of pick-up current, the OCR will select the larger current than the maximum load current during system operation. The pick-up current value is determined by the number of tap values as defined in (1).

$$Tap = \frac{I_{set}}{NCT} \tag{1}$$

where $I_{set}$ is a pick-up current in ampere. The determination of pick-up current is based on the British BS-142 standard where it lies on intervals $1.05\, I_{FLA} < I_{SET} < 1.4\, I_{FLA}$. In addition, $I_{FLA}$ is maximum equipment current.

While a time dial is utilized to determine the operating time of OCR where the determination of time dial for each curve of inverse time characteristic is computed by (2). Coefficient of inverse time dial is shown in Table 2.

$$td = \frac{k * T}{\beta * \left[\frac{I}{I_{set}}\right]^{\propto} - 1} \tag{2}$$

where, $td$ is operating time (second), $T$ is time dial, $I$ is current (ampere), $I_{set}$ is pick-up current (ampere), $k$ is the 1-th inverse coefficient, $\alpha$ is the 2-nd inverse coefficient, and $\beta$ is the 3-rd inverse coefficient.

Table 2. Coefficient of inverse time dial

| Curve type | Coefficient | | |
|---|---|---|---|
| | $k$ | $\alpha$ | $\beta$ |
| *Standard inverse* | 0.14 | 0.02 | 2.970 |
| *Very inverse* | 13.50 | 1.00 | 1.500 |
| *Extremely inverse* | 80.00 | 2.00 | 0.808 |

3. *OCR with an instantaneous time characteristic*

This OCR type has a basis of operation without time delay, but it can work with a fast time. The coordination scheme of this OCR type for medium distribution system level is called instantaneous setting. This OCR type works based on the setting of the short circuit current, and the circuit breaker (CB) will be opened very fast around 80 ms. This OCR type is illustrated in Fig. 4.

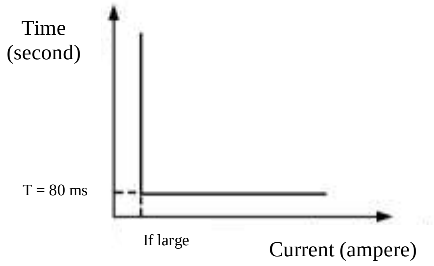


Figure 4. Over current relay (OCR) with instantaneous time characteristic

The OCR with an instantaneous time characteristic will work if there is a current flowing higher than a pre-setting pick-up current. The setting of pick-up current is determined by a minimum short circuit current such as two-phase fault. The setting of short circuit current is defined in (3).

$$I_{set} \leq 0{,}8\, I_{sc\,min} \tag{3}$$

The aims of coordination relay based on current, and time are to result in time delay for the over-current relay as an electrical distribution system. Moreover, to avoid the primary relay and backup relay working at the same time, it is required a time delay for a backup relay. The interval time for relay working time or grading time is set to 0.2 - 0,3 seconds.

## 3. Proposed Protection System Coordination

The procedures to coordinate the over-current relay in an electrical distribution network considering the distributed generation are described as follows [10]:

1) Collect the electrical distribution system data including generator, distribution line, transformer, and load.
2) Collect the appropriate DG capacity data for installation in the electrical distribution system.
3) Collect the data of OCR.
4) Design the electrical distribution system using ETAP 12.6.
5) Run a power flow program to obtain the voltage, active and reactive power, current, and power factor of the electrical distribution system.
6) Conduct a short circuit (SC) simulation to obtain the minimum value of SC current and SC fault current in each phase. Furthermore, the simulation of the star protection device is also carried out to determine the relay parameters along with the coordination system that has been modeled.
7) Calculate the coordination time interval value (CTI).
8) Compute the protection coordination index (PIC) value to determine the effect of DG.
9) There are two conditions that should be checked after obtaining all relay parameters in the simulation process as follow:
   a. Yes, if the simulation results show that the coordination of OCR matches the standard of IEEE 242.
   b. No, if the simulation results provide that the coordination of OCR doesn't fulfill the standard of IEEE 242. In this condition, the OCR parameters should be re-setting.
10) Print out the simulation results.

## 4. Simulation Result and Discussion

*A. Time Current Curve (TCC) Curve Analysis*

To simplify and easily read the plotting curve of time current curve (TCC) from the simulation results, the coordination strategy of OCR is divided into three stages. At stage 1, the coordination of OCR is conducted between the R-PGU2 relay and R-HI-LINE #1 relay. The current time curve of the OCR coordination is shown in Fig. 5.

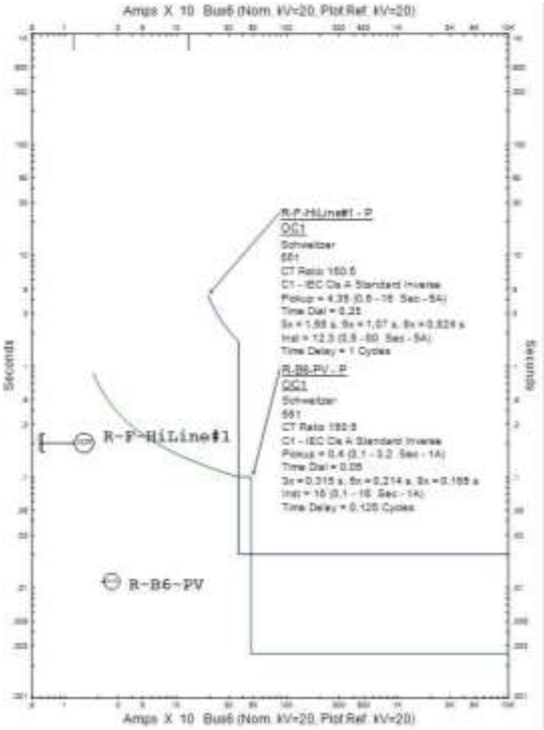


Figure 5. Plotting curve of OCR coordination at step 1

From TCC plotting curve as shown in Fig. 5, if there is a minimum short-circuit fault in the load (Bus 6), the R-F-HILINE #1 relay will react to protect the system where the instant value of its relay works at the same time with the inverse of the R-B6-PV relay. This condition is prohibited according to the cascade method and protection system standard. More than one OCR can't work at the same time because it will cause losses and the safe zone get the effect where it should be disconnected and didn't get the power flow.

At stage 2, R-F-HILINE#1 relay and R-HILINE #3 relay are coordinated, and the results are shown in Fig. 6.

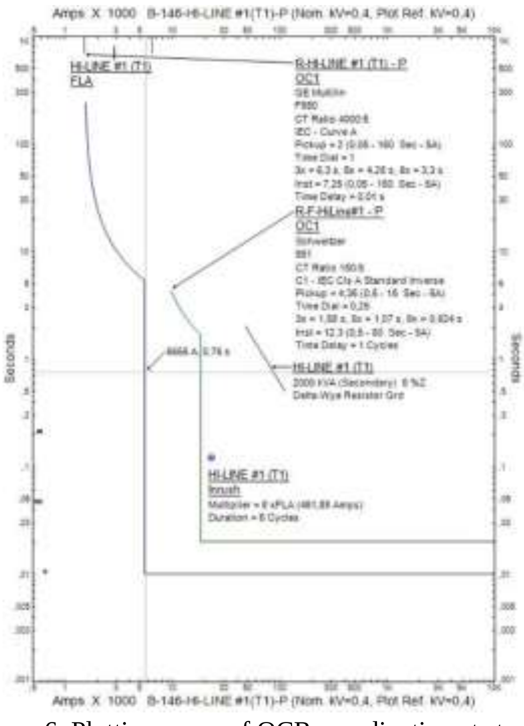

Figure 6. Plotting curve of OCR coordination at stage 2

It could be seen from Fig. 6 that if there is any short circuit current occurred at HI-LINE #1(T1) transformer at 5,655 kA, R-HILINE#3 relay will respond fastly as 0.75 seconds. If the R-F-HILINE#3 relay failed to respond to the faulted, R-F-HILINE #1 will work. TCC is on above the R-HILINE #3 relay and leads to the R-F-HILINE #1 relay. This condition is prohibited because it violates the arrangement of relay time working and may it should be conducted in the layered scheme.

At stage 3, R-HILINE #3 relay and R-PGU2 relay are coordinated. The results are illustrated in Fig. 7.

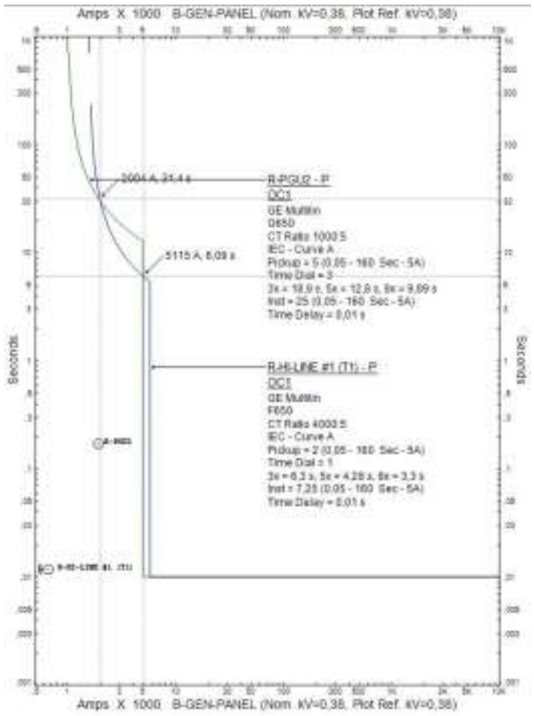


Figure 7. Plotting curve of OCR coordination at stage 3

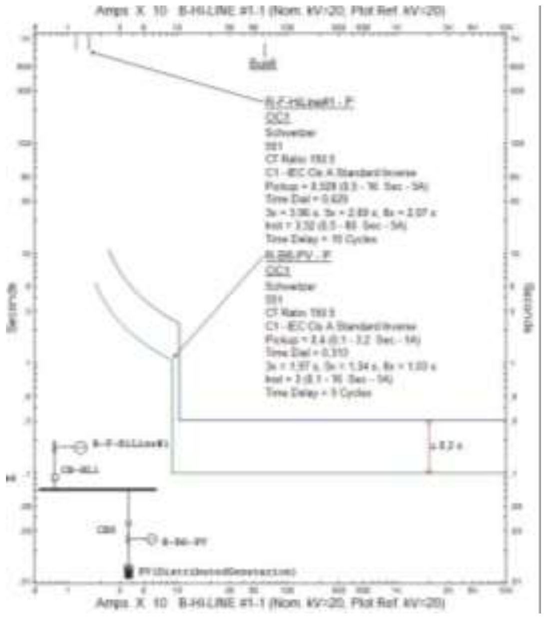


Figure 8. Plotting curve of re-setting OCR coordination at stage 1

It could be seen from Fig. 7 that if there is a short circuit current of 2.004 kA, the R-HILINE#3 relay works with the R-PGU2 relay at the same time, this condition is prohibited because it violates the rules of the relay working time sequence.

It could be concluded that over current relay should be re-setting to obtain a good coordination relay. The computation of this condition is using ETAP software. TCC curve which are result in re-setting of OCR relay is defined in Figs. 9-10 for stage 1 to 3.

By re-setting of R-B6-PV relay and R-F-HILINE#1 relay values, the TCC curve is obtained as shown in Fig. 8. The OCR has worked in multi-stage and sequence. The grading time for the time delay between the primary relay and backup relay has complied with IEEE 242 standards as 0.2 s to 0.4 s. In the OCR relay for stage 1, the primary relay grading time with a backup relay is 0.2 s.

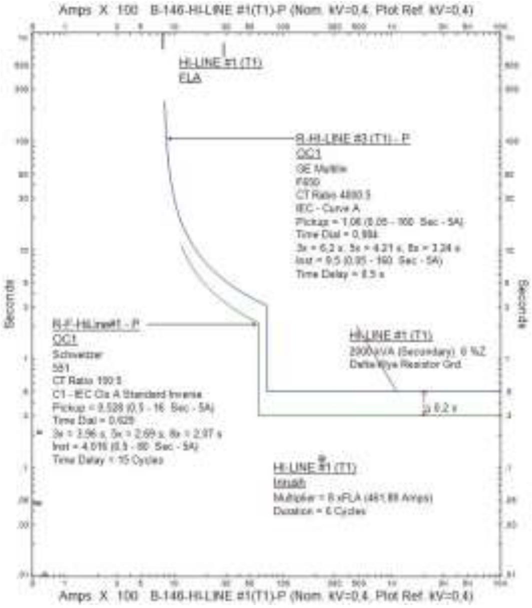


Figure 9. Plotting curve of re-setting OCR coordination at stage 2

At stage 2, after resetting the OCR as shown in Fig. 9, if there are faults at the transformer, the R-F-HILINE#1 relay will work first and the R-HILINE#3 relay will work as a backup relay when R-F-HILINE#1 relay fails to work. The time interval between primary and backup relays has matched the standards used by IEEE 242 as of 0.2s.

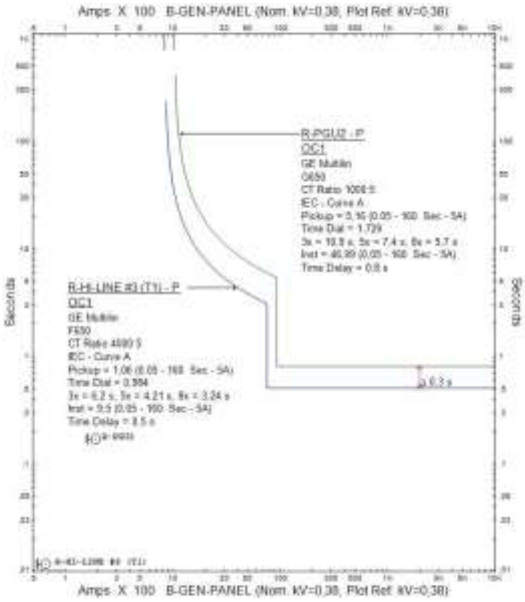


Figure 10. Plotting curve of re-setting OCR coordination at stage 3

At stage 3, after re-setting the OCR as shown in Fig. 10, if there are any faults occurred, R-HILINE#3 relay works firstly and R-PGU2 relay will work as a backup relay when R-F-HILINE#3 relay fails to work. The time interval between primary and backup relays has matched the standards used by IEEE 242 as of 0.3s.

*B. Determination of DG Locations*

The placement of DG in this study refers to the protection coordination index (PCI) value obtained by comparing the DG power to be added to the system with the total coordination time interval (CTI) value. The greater PCI value is obtained, the smaller possible changes to the protection system. The type of installed DG in this study is photovoltaic with100 kVA. To examine the effect of DG on the protection system short circuit test conducted and DG capacity is increased from 100 kVA to 1000 kVA. This condition is conducted to determine the PCI value. The data of the short-circuit current at the bus with injected DG power is depicted in Table 2. The CTI value can be seen in Fig. 11.

Table 3. Minimum short circuit current at Bus 6

| DG Capacity (kVA) | Isc Min Bus6 (A) |
|---|---|
| 100 | 654 |
| 200 | 660 |
| 300 | 668 |
| 400 | 673 |
| 500 | 678 |
| 600 | 683 |
| 700 | 687 |
| 800 | 692 |
| 900 | 695 |
| 1000 | 700 |

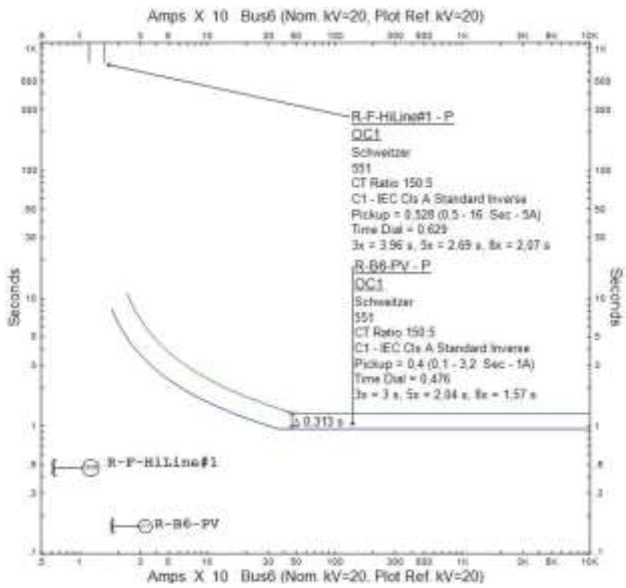


Figure 11. Plotting curve of CTI value

CTI value is illustrated in Table 3. The greater DG capacity is obtained, the smaller CTI value is achieved. It could be seen from Table 3 that the CTI value converges to 0.294 s after DG injected to the system with 900kVA. The maximum DG capacity is allowed to be injected to the electrical distribution system as 900KVA. The PCI value is depicted in Table 4.

Table 4. CTI Value at Bus 6

| DG Capacity (kVA) | CTI (Second) |
|---|---|
| 100 | 0.327 |
| 200 | 0.321 |
| 300 | 0.317 |
| 400 | 0.313 |
| 500 | 0.309 |
| 600 | 0.305 |
| 700 | 0.301 |
| 800 | 0.297 |
| 900 | 0.294 |
| 1000 | 0.294 |

Table 5. PCI Value at Bus 6

| DG Capacity (kVA) | PCI |
|---|---|
| 100 | 0.30581 |
| 200 | 0.62305 |
| 300 | 0.94637 |
| 400 | 1.27795 |
| 500 | 1.29449 |
| 600 | 1.96721 |
| 700 | 2.32558 |
| 800 | 2.69360 |
| 900 | 3.06122 |
| 1000 | 3.40136 |

A sequence of OCR operations for the electrical distribution system before and after installed DG could be seen in Tables 5-6.

Table 6. Sequence of OCR Operations at Bus 6 without DG

| Time (ms) | ID | Condition |
|---|---|---|
| 10 | R-HILINE#3 | Phase – OCI – 50 |
| 70 | CBT1 | Tripped by R-HILINE#3 Phase – OCI – 50 |
| 80 | CBPGU2 | Phase |
| 817 | R-F-HILINE#1 | Phase – OCI – 50 |
| 917 | CB-HL1 | Tripped by R-F-HILINE#1 Phase – OCI – 50 |
| 1227 | CBT1 | Phase |
| 31201 | RPGU2 | Phase – OCI – 50 |
| 31231 | CBPGU2 | Tripped by RPGU2 Phase – OCI – 50 |

Table 7. Sequence of OCR Operations at Bus 6 with DG

| Time (ms) | ID | Condition |
|---|---|---|
| 100 | R-B6-PV | Phase – OCI – 50 |
| 200 | CB8 | Tripped by R-B6-PV Phase – OCI – 50 |
| 300 | R-F-HILINE#1 | Phase – OCI – 50 |
| 400 | CB-HL1 | Tripped by R-F-HILINE#1 Phase – OCI – 50 |
| 500 | R-HILINE#3 | Phase – OCI – 50 |
| 560 | CBT1 | Tripped by R-HILINE#3 Phase – OCI – 50 |
| 1227 | CBT1 | Phase |
| 18877 | RPGU2 | Phase – OCI – 50 |
| 18907 | CBPGU2 | Tripped by RPGU2 Phase – OCI – 50 |

It could be seen from Tables 5-6 that there are differences in the working order of the OCR relay. In the existing system model, there is an error in the sequence of OCR working time. After adding the DG, it causes the OCR working time to be degraded.

## 5. Conclusions

This paper has investigated the effect of DG on protection systems in the electrical distribution systems. There are many errors related to relay working order and violate the standard of the protection system. It is complex to determine the locations of DG to match the protection system standard. Resetting of OCR causes getting slower OCR operating time, but standard grading time and CTI already meet standard. DG injection at distribution system caused resetting protection systems component for almost 50% based on this study. For Future research needs more parameter such as voltage drop, loadability and stability system.

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