# Working Time Coordination of Over Current Relay (OCR) and Ground Fault Relay (GFR) in 20 kV Feeder Distribution

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# Working Time Coordination of Over Current Relay (OCR) and Ground Fault Relay (GFR) in 20 kV Feeder Distribution

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**Abstract.** Over current relay (OCR) and ground fault relay (GFR) are used to protect phase to phase faults (3 phase and 2 phase) and single phase faults to ground by giving an open signal to the circuit breaker. In the 20 kV feeder these relays are located in the outgoing circuit breaker (outgoing CB) and one or more reclosers. OCR and GFR working time must be coordinated so that it is selective and can function well as a back up relay. This study analyzes the working time of OCR and GFR on outgoing CB, recloser 1 and recloser 2 on a 20 kV radial feeder due to miscoordination of work when a fault occurs in the recloser 2 protection zone which is located downstream of the existing 20 kV radial feeder. The analysis refers to IEC 60255 standard, IEEE 242-2001 standard and SPLN 52-3:1983. The results of the analysis found that the grading time (Δt) of OCR recloser 1 and recloser 2 was < 2 s, not in accordance with SPLN 52-3:1983, the working time coordination between recloser was 0.2-0.4s. Therefore, coordination of working time is carried out so that the grading time of OCR recloser 1 and OCR recloser 2 becomes 0.2 s, while the grading time of OCR outgoing CB and OCR recloser 1 is 0.4 s according to the standard in order to get a new time multiple setting (TMS). With the new grading time, so TMS recloser 1 is 0.112 and TMS OCR outgoing CB is 0.255. With the new TMS, for $I_{f3\emptyset}$, grading time (Δt) OCR recloser 1 and OCR recloser 2 of 0.2 s for fault location 0% protection zone of recloser 2 and 0.443 s for fault location 100% protection zone of recloser 2. Meanwhile grading time (Δt) of OCR outgoing CB and recloser 1 of 0.4 s for fault location 0% protection zone of recloser 2 and 0.980 s for fault location 100% protection zone of recloser 2. For $I_{f2\emptyset}$, grading time (Δt) OCR recloser 1 and OCR recloser 2 of 0.215 s for fault location 0% protection zone of recloser 2 and 0.519 s for fault location 100% protection zone of recloser 2. Meanwhile grading time (Δt) of OCR outgoing CB and recloser 1 of 0.432 s for fault location 0% protection zone of recloser 2 and 1.189 s for fault location 100% protection zone of recloser 2. Thus in accordance with the standards used.

## INTRODUCTION

The fault causes most power outages in the electric distribution system. Faults cause nearly 80% of distribution system interruptions. Statistically, ground faults account for about 80 percent of all faults occurring on the feeder of power distribution systems. The appropriate percentages of occurrences various faults are : single line to ground fault 70-80% , line-line to ground fault 10-17% , line-line fault 8-10%, and three-phase 2-3% [1,2,3,4]. The distribution feeder contains protection devices, such as outgoing circuit breakers (outgoing CB) and reclosers. Reclosers can protect distribution feeders from temporary fault. Temporary faults in distribution feeder only a few cycles to a few seconds With their "trip and reclose" capability, reclosers can eliminate prolonged outages on distribution systems effectively caused by the temporary fault. When the permanent fault occurs, reclosers will trip permanently [5,6,7]. Outgoing circuit breakers and reclosers contain an Over Current Relay (OCR) to detect phase

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fault and a Ground Fault Relay (GFR) to detect the ground fault. OCR and GFR will detect fault current and give a trip signal to the outgoing circuit breaker and recloser circuit breaker (circuit breaker in recloser)[8,9]. Relay coordination requires a proper adjustment and coordination of pickup current and time dial settings. Selectivity during fault conditions would be achieved by using relays set to operate after different time delays. The feeder relay and breaker, which are downstream, should clear a feeder fault before the supply-side relay and breaker (upstream) could trip [10,11]. Working time coordination between relay according to IEC 60255 standard is 0.4-0.5s, according to IEEE 242-2001 standard is 0.3-0.4s. In Indonesia according to SPLN 52-3:1983 working time coordination between recloser is 0.2-0.4s [12,13,14].

This study analyzes working time coordination OCR and GFR in an existing 20 kV distribution feeder. The existing feeder has outgoing CB, recloser 1 and recloser 2 as protection devices, each of which contains OCR and GFR. The analysis was carried out because there was data on the failure of working time coordination between recloser 1 and recloser 2 when there were faults in the recloser 2 protection zone

## METHOD

The method in this study is a calculation based on Figure 1. Analyses are performed on the feeder to obtain:

a. Fault current value occurs in the protection zone of recloser 2.
   Fault current calculations are conducted for 5 fault location : 0%, 25%, 50%, 75% and 100% of feeder 2 because of miscoordination occur between recloser 1 and recloser 2.
b. Working time of OCR and GFR in outgoing CB, recloser 1, and recloser 2.
   Base on the faults currents, the working time of existing OCR and GFR be calculated.
c. Identification of OCR and GFR miscoordination at recloser 1 and recloser 2.
   Grading time OCR and GFR on outgoing CB, recloser 1, and recloser 2 be compared with standard.
d. It was improved of OCR working time on outgoing CB and recloser 1 with be synchronized with standard.

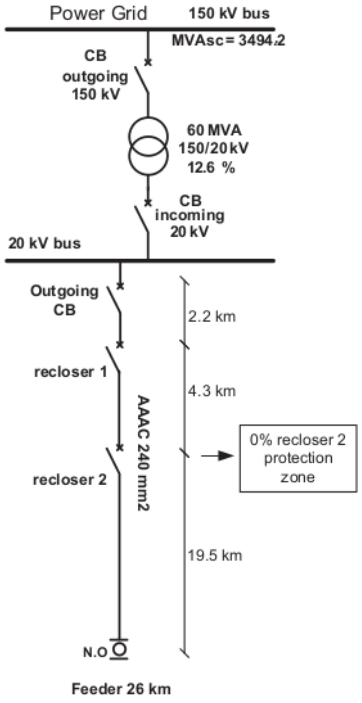


**FIGURE 1.** Single line study

## RESULTS AND DISCUSSION

### Fault Current Value Occurs in Protection Zone of Recloser 2

To find out the working time of the OCR and GFR relays on the outgoing CB, recloser 1 and recloser 2, the value of the fault current is needed. The calculation of the OCR working time requires the value of line to line fault current, while the GFR working time requires the value of ground-fault current. In this study, because it is suspected that there was a error coordination between recloser 1 and recloser 2, so the value of the fault current is used in the recloser 2 protection zone. The calculation of the OCR working time uses a 3-phase and 2-phase fault current, while the calculation of the GFR working time uses a 1-phase to ground-fault current. The analysis assumes that the fault occurs in 5 locations in the recloser 2 protection zone, at a distance 0%, 25%, 50%, 75% and 100% of the length recloser 2 protection zone.

**TABLE 1**. The Impedance at the fault location

| Distance (%) of Recloser 2 Protection Zone | Total Impedance (grid, transformer, feeder) | |
|---|---|---|
| | Zeq_positive = Zeq_negative (Ohm) | Zeq_Zero (Ohm) |
| 0 | 3.064 | 13.042 |
| 25 | 4.729 | 21.122 |
| 50 | 6.399 | 29.204 |
| 75 | 8.070 | 37.288 |
| 100 | 9.746 | 45.371 |

Table 1 shows the positive, negative, and zero sequence impedances, which refer to Figure 1, the sum of the power grid impedance, transformer impedance, and feeder impedance. For example, impedance of distance 0% of recloser 2 protection zone means sum of power grid impedance + transformer impedance + feeder impedance along from the 20 kV bus to the initial (0%) of the recloser 2 protection zone is 2.2 km + 4.3 km + 0% x 19.5 = 6.5 km feeder. The longer of fault location distance, the bigger the fault impedance.

When faults occur at a distance 0% of recloser 2 protection zone, the value of 3-phase ($I_{f3\phi}$), 2-phase ($I_{f2\phi}$), and 1-phase to ground ($I_{f\phi\_G}$) fault current are calculated below :

$$(\boldsymbol{I_{f3\emptyset}}) = \frac{V/\sqrt{3}}{Zeq\_positive} = \frac{20{,}000/\sqrt{3}}{3.064} = 3{,}768.86\ A \quad (1)$$

$$(\boldsymbol{I_{f2\emptyset}}) = \frac{V}{Zeq\_positive+Zeq\_negative} = \frac{20{,}000}{3.064+3.064} = 3263.83\ A \quad (2)$$

$$(\boldsymbol{I_{f\emptyset\_G}}) = 3x\frac{V/\sqrt{3}}{Zeq\_positive+Zeq\_negative+Zeq\_Zero} = \frac{20{,}000}{3.064+3.064+13.042} = 1539.62\ A \quad (3)$$

**TABLE 2**. Fault current at % distance of recloser 2 protection zone

| Distance (%) of Recloser 2 Protection Zone | $I_{f3\emptyset}$ (A) | $I_{f2\emptyset}$ (A) | $I_{f\emptyset\_G}$ (A) |
|---|---|---|---|
| 0 | 3768.86 | 3263.83 | 1539.62 |
| 25 | 2441.25 | 2114.12 | 1132.81 |
| 50 | 1804.29 | 1562.52 | 896.01 |
| 75 | 1430.70 | 1238.98 | 741.07 |
| 100 | 1185.19 | 1026.38 | 631.82 |

Table 2 shows value of 3-phase ($I_{f3\emptyset}$) , 2-phase ($I_{f2\emptyset}$) and 1-phase to ground ($I_{f\emptyset\_G}$) fault current that occur at distance 0%, 25%, 50%, 75% and 100% protection zone of recloser 2. From table 2, the farther the distance, the smaller the 3-phase ($I_{f3\emptyset}$), 2-phase ($I_{f2\emptyset}$) and 1-phase to ground ($I_{f\emptyset\_G}$) fault current because the Impedance of feeder

is directly proportional with the length of feeder. The biggest fault current is $I_{f3\emptyset}$ because for symmetrical fault, only a positive sequence of Impedance is used in fault current calculation as equation (1).

## Working Time of OCR and GFR at Outgoing CB, Recloser 1 and Recloser 2

Table 3 shows working time OCR & GFR at outgoing CB, recloser 1, and recloser 2 because of fault current that occurs at recloser 2 protection zone in the various distance. OCR works because of $I_{f3\phi}$ and $I_{f2\phi}$ , while GFR work because of $I_{f\emptyset\_G}$. For example, when $I_{f3\emptyset}$ occur at 0% recloser 2 protection zone, OCR on outgoing CB will work 0,732 s after the fault. If $I_{f2\emptyset}$ occur at the same location, OCR at outgoing CB will work 0,788 s after the fault. Meanwhile, if $I_{f\emptyset\_G}$ occurs at 0% recloser 2 protection zone, GFR on outgoing CB will work after 1,109 s after the fault.

**TABLE 3**. Working time OCR & GFR because fault current at recloser 2 protection zone

| Distance (%) of Recloser 2 Protection Zone | Working Time Relay Outgoing CB (s) | | | Working Time Relay Recloser 1 (s) | | | Working Time Relay Recloser 2 (s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | OCR | | GFR | OCR | | GFR | OCR | | GFR |
| | $(I_{f3\emptyset})$ | $(I_{f2\emptyset})$ | $(I_{f\emptyset\_G})$ | $(I_{f3\emptyset})$ | $(I_{f2\emptyset})$ | $(I_{f\emptyset\_G})$ | $(I_{f3\emptyset})$ | $(I_{f2\emptyset})$ | $(I_{f\emptyset\_G})$ |
| 0 | 0.732 | 0.788 | 1.109 | 0.218 | 0.234 | 0.426 | 0.149 | 0.159 | 0.125 |
| 25 | 0.931 | 1.023 | 1.309 | 0.274 | 0.298 | 0.486 | 0.185 | 0.200 | 0.141 |
| 50 | 1.148 | 1.289 | 1.517 | 0.331 | 0.368 | 0.544 | 0.221 | 0.244 | 0.156 |
| 75 | 1.395 | 1.608 | 1.741 | 0.395 | 0.448 | 0.601 | 0.260 | 0.293 | 0.171 |
| 100 | 1.689 | 2.012 | 1.985 | 0.468 | 0.544 | 0.660 | 0.304 | 0.349 | 0.186 |

## Identification of OCR and GFR Miscoordination at Recloser 1 and Recloser 2

Table 4 shown the grading time (Δt) of OCR & GFR of recloser 1 and recloser 2. The working time OCR & GFR at outgoing CB aren't included because miscoordination occurs between recloser 1 and recloser 2 when there were faults in the recloser 2 protection zone. For example fault occur at 0% distance of recloser 2 protection zone. When fault is $I_{f3\emptyset}$, OCR at recloser 2 will work 0,149 s meanwhile at recloser 1 will work 0,218 s after the fault, so different working time (grading time/Δt) is 0,069 s. If the fault is $I_{f2\emptyset}$. OCR at recloser 2 will work 0,159 s, recloser 1 will work 0,234 s after the fault, so the grading time is 0,075 s. For $I_{f\emptyset\_G}$, GFR at recloser 2 will work 0,125 s meanwhile at recloser 1 will work 0,426 s after the fault, so different working time (grading time/Δt) is 0,302 s. From table 4 can be seen grading time (Δt) between OCR at recloser 1 and recloser 2 < 0,2 s when $I_{f3\emptyset}$ and $I_{f2\emptyset}$ occur at reclose 2 protection zone. It's mean not appropriate with IEC 60255 standar, IEEE 242-2001 standar and SPLN 52-3:1983. It can cause both recloser 1 and recloser 2 will work when $I_{f3\emptyset}$ and $I_{f2\emptyset}$ occur. Meanwhile the grading time (Δt) between GFR at recloser 1 and recloser 2 for $I_{f\emptyset\_G}$ when there were faults in the recloser 2 protection zone > 0,2 s. So miscoordination of working time between OCR at recloser 1 and recloser 2 can occur for $I_{f3\emptyset}$ and $I_{f2\emptyset}$ at reclose 2 protection zone.

**TABLE 4**. OCR & GFR grading time of recloser 1 and recloser 2

| Distance (%) of recloser 2 protection zone | t OCR (s) | | | t OCR (s) | | | t GFR (s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cause by $I_{f3\emptyset}$ | | | Cause by $I_{f2\emptyset}$ | | | Cause by $I_{f\emptyset\_G}$ | | |
| | Rec 2 | Rec 1 | Δt | Rec 2 | Rec 1 | Δt | Rec 2 | Rec 1 | Δt |
| 0% | 0.149 | 0.218 | 0.069 | 0.159 | 0.234 | 0.075 | 0.125 | 0.426 | 0.302 |
| 25% | 0.185 | 0.274 | 0.089 | 0.200 | 0.298 | 0.098 | 0.141 | 0.486 | 0.345 |
| 50% | 0.221 | 0.331 | 0.110 | 0.244 | 0.368 | 0.124 | 0.156 | 0.544 | 0.388 |
| 75% | 0.260 | 0.395 | 0.134 | 0.293 | 0.448 | 0.155 | 0.171 | 0.601 | 0.430 |
| 100% | 0.304 | 0.468 | 0.163 | 0.349 | 0.544 | 0.195 | 0.186 | 0.660 | 0.473 |

## Improved of OCR Working Time on Outgoing CB and Recloser 1

The improvement of OCR working time in recloser 1 and outgoing CB is carried out referring to the grading time between relay according to IEC 60255 standard 0.4-0.5 s, IEEE 242-2001 standard 0.3-0.4 s, and according to SPLN 52-3:1983 grading time coordination between recloser is 0.2-0.4 sec. Selected OCR grading time between recloser 1 and recloser 2 is 0.2 seconds, while the OCR grading time between outgoing CB and recloser 2 is 0.4 seconds. This time grading is useful for calculating the time multiple setting (TMS) OCR on recloser 1 and outgoing CB. TMS calculation uses the largest fault current, namely three-phase fault ($I_{f3\emptyset}$) at 0% protection zone of recloser 1 and outgoing CB. This is to ensure the grading time between OCR recloser 1 and recloser 2 when there is $I_{f3\emptyset}$ or $I_{f2\emptyset}$ at least 0.2 s. The smaller the fault current, the slower the OCR will work. So the grading time between OCR recloser 1 and OCR recloser 2 will be slower if the fault location is further from 0% of the recloser 2 protection zone. The OCR working time on recloser 2 still uses the existing condition, 0.149 s, when there is a three-phase fault at 0% recloser 2 protection zone, which is 3768.86 A. So the OCR working time on recloser 1 becomes 0.149 s + 0.2 s = 0.349 s and working time OCR outgoing CB becomes 0.349 s + 0.4 s = 0.749 s. Because the OCR working characteristics used are standard inverse, the Tms OCR in recloser 1 and outgoing CB becomes:

$$\mathrm{Tms}_{Recloser\ 1} = tw\ x\ \frac{\left(I_{f3\emptyset}/\mathrm{Iset}\right)^{0.02} - 1}{0.14} = 0.349\ x\ \frac{(3768{,}86/420)^{0{,}02} - 1}{0{,}14} = 0.112 \quad (4)$$

$$\mathrm{Tms}_{outgoing\ CB} = tw\ x\ \frac{\left(I_{f3\emptyset}/\mathrm{Iset}\right)^{0.02} - 1}{0.14} = 0.749\ x\ \frac{(3768{,}86/480)^{0.02} - 1}{0.14} = 0.225 \quad (5)$$

The TMS is used to check the working time coordination between OCR in outgoing CB, recloser 1, and recloser 2 if there is a fault current in the recloser 2 protection zone. Table 5 shows the new working time coordination of OCR recloser 2, OCR recloser 1 and OCR outgoing CB using the new TMS values. For example, when $I_{f3\phi}$ occurs in the 0% recloser 2 protection zone, recloser 2 will work 0.149 s after the fault. If OCR recloser 2 fails to work, recloser 1 will work 0.349 s after the fault, and if OCR recloser 2 and OCR recloser 1 fail to work, then OCR outgoing, CB will work as the last backup 0.749 s after the fault.

If $I_{f2\emptyset}$ occurs at 0% recloser 2 protection zone, recloser 2 will work 0.159 s after the fault. If OCR recloser 2 fails to work, recloser 1 will work 0.374 s after the fault and if OCR recloser 2 and OCR recloser 1 fail to work, then OCR outgoing CB will work as the last backup 0.806 s after the fault. The working time of OCR recloser 2, OCR recloser 1 and OCR outgoing CB when an $I_{f2\emptyset}$ occurs is slower than when an $I_{f3\emptyset}$ occurs because smaller fault current value.

**TABLE 5**. Working time OCR because fault current at recloser 2 protection zone

| Distance (%) of recloser 2 protection zone | OCR Recloser 2 (s) | | OCR Recloser 1 (s) | | OCR Outgoing CB (s) | |
|---|---|---|---|---|---|---|
| | ($I_{f3\emptyset}$) | ($I_{f2\emptyset}$) | ($I_{f3\emptyset}$) | ($I_{f2\emptyset}$) | ($I_{f3\emptyset}$) | ($I_{f2\emptyset}$) |
| 0 | 0.149 | 0.159 | 0.349 | 0.374 | 0.749 | 0.806 |
| 25 | 0.185 | 0.200 | 0.461 | 0.476 | 0.953 | 1.046 |
| 50 | 0.221 | 0.244 | 0.529 | 0.588 | 1.174 | 1.319 |
| 75 | 0.260 | 0.293 | 0.631 | 0.716 | 1.426 | 1.645 |
| 100 | 0.304 | 0.349 | 0.747 | 0.868 | 1.727 | 2.057 |

Figure 2 shows the grading time (Δt) between OCR recloser 1 and OCR recloser 2 and also between OCR outgoing CB and OCR recloser 1, when $I_{f3\phi}$ occurs in the protection zone of recloser 2. The grading time between OCR recloser 1 and recloser 2 is 0.2 s for the fault occurs at 0% and 0.443 s for the fault occurs at 100% of the recloser protection zone 2. Meanwhile the grading time between OCR outgoing CB and recloser 1 is 0.4 s for the fault occurs at 0% and 0.980 s for the fault occurs at 100% of the recloser protection zone 2.

Figure 3 shows the grading time (Δt) between OCR recloser 1 and OCR recloser 2 and also between OCR outgoing CB and OCR recloser 1, when $I_{f2\emptyset}$ occurs in the protection zone of recloser 2. The grading time between OCR recloser 1 and recloser 2 is 0.215 s for the fault occurs at 0% and 0.519 s for the fault occurs at 100% of the recloser protection zone 2. Meanwhile, the grading time between OCR outgoing CB and recloser 1 is 0.432 s for the fault occurs at 0% and 1.189 s for the fault occurs at 100% of the recloser protection zone 2.

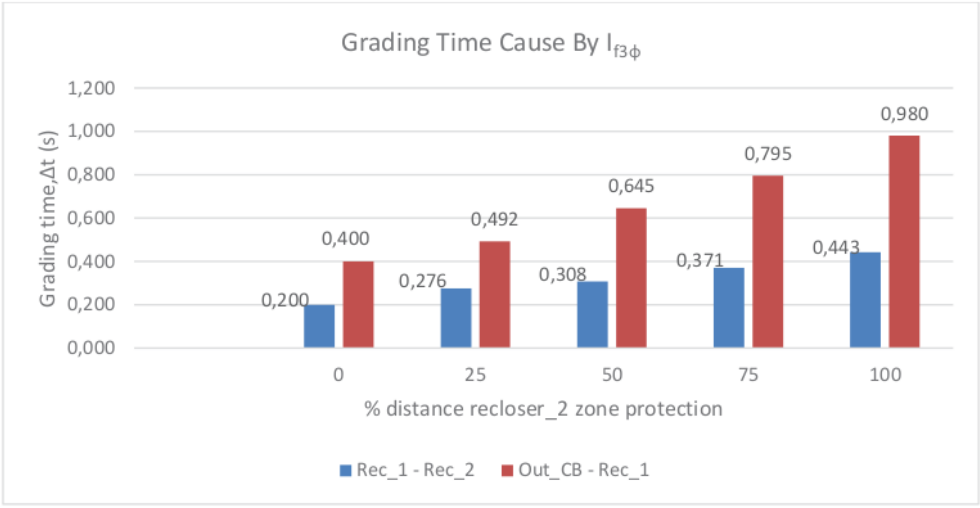


**FIGURE 2.** Grading time OCR recloser 1 to recloser 2 & grading time OCR outgoing CB to recloser 1 cause by $I_{f3\phi}$

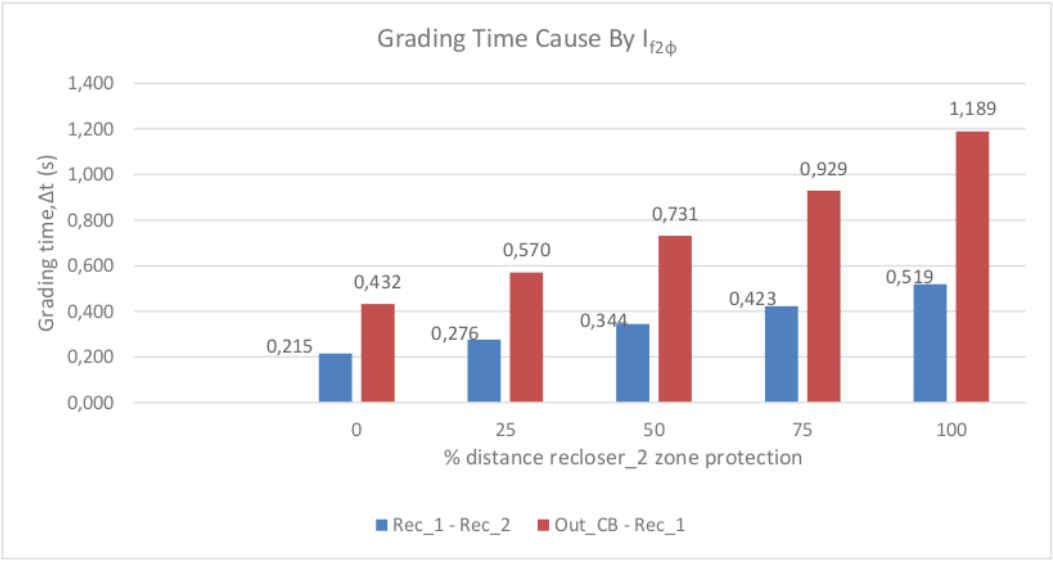


**FIGURE 3.** Grading time OCR recloser 1 to recloser 2 & grading time OCR outgoing CB to recloser 1 cause by $I_{f2\phi}$

With the new TMS, miscoordination of OCR recloser 1 and OCR recloser 2 can be resolved and working time coordination between OCR outgoing CB and OCR recloser 1 can be improved.

## CONCLUSIONS

1. Miscoordination of working time between recloser 1 and recloser 2 when a fault occurs in the recloser 2 protection zone is only caused by phase to phase fault.
2. With TMS recloser 1 of 0.112, were resulted grading time (Δt) OCR recloser 1 and OCR recloser 2 of 0.2 s for fault location 0% protection zone of recloser 2 and 0.443 s for fault location 100% protection zone of recloser 2.

3. With TMS, outgoing CB of 0.225 resulted in a grading time (Δt) of OCR outgoing CB and recloser 1 of 0.4 s for fault location 0% protection zone of recloser 2 and 0.980 s for fault location 100% protection zone of recloser 2.

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