Optimizing the protection coordination of DGR (Directional Ground Relay) to overcome sympathetic disturbances and reduce energy not supplied on Toboali Substation

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Abstract. Along with the operation of the Toboali Substation, studies needed to improve reliability. The ground disturbance that occurs in a feeder can cause a sympathetic trip in another feeder and effect the blackout of Toboali system. This is due to the choice of loop operating patterns on feeders and buses that tend to be close together. From the results of simulation and optimization of directional ground relay coordination it was found that before the improvement of energy not supplied due to sympathetic disturbances on the Toboali system was 51,261 MWh/year and after the improvement of energy not supplied became 21,170 MWh/year. Expected this optimization of protection coordination improves reliability and reduces the energy not supplied due to sympathetic disturbances that occur in Toboali substation.

1. Introduction
Toboali substation was built to strengthen the electricity system on Bangka Island, especially the South Bangka regency. Besides, PLN's focus is to reduce fossil fuels as diesel fuel. In its operation, there are several obstacles to supply existing feeders that are already operating. One of the impediments is the occurrence of a sympathetic trip on feeders in the Toboali substation. This disturbance can cause an unnecessary trip to a feeder because the relay is set only with the current value. The sympathetic trip often occurs if a ground fault in a feeder affected a healthy feeder as if disturbed as well. By optimizing the current value settings and adding the direction settings, is expected to reduce this sympathetic trip. In this study, evaluating and recalculating the set to get the value and direction of the disturbance that is appropriate for feeders supplied from this substation.

2. Research Methodology
In this study, the evaluation feeder protection coordination, sympathetic trip and energy not supplied will compare to conditions before and after the operation of the Toboali substation. The simulation uses ETAP software with Newton Rahpson's method. All data use measurement update data in the field so that the simulation results will be very close to the real output.

3. Result and Discussion

3.1. Data of Toboali system (before the operating of substation)
The configuration according to detailed physical data and a single line diagram. Some of the detailed physical data of the Toboali system shown in table 1.
Table 1. Data of Toboali System (before the operating of substation)

| Bus    | SC level (kA) | Feeder | Ground Fault Set (Non-directional) |
|--------|---------------|--------|-----------------------------------|
|        | 3 p | 1 p | I > | TMS | KURV | I >> | t | KURV |
| Toboali| 5.023| 1.34| 20 | 0.1 | SIT | 60 | 0.05 | DEF |
|        |      |     | 20 | 0.1 | SIT | 80 | 0.05 | DEF |
|        |      |     | 20 | 0.07| SIT | 80 | 0.1 | DEF |
|        |      |     | 20 | 0.1 | SIT | 30 | 0.05 | DEF |
|        |      |     | 20 | 0.1 | SIT | 40 | 0.05 | DEF |
|        |      |     | 40 | 0.12| SIT | 60 | 0.05 | DEF |
| Pengarem| 1.494| 0.3| Tukak | 20 | 0.1 | SIT | 160 | 0.2 | DEF |
|        |      |     | 20 | 0.12| SIT | 160 | 0.2 | DEF |
|        |      |     | 20 | 0.1 | SIT | 160 | 0.2 | DEF |

Single line diagram of Toboali system shown in Figure 1.

Figure 1. In this system configuration, it describes that the Feeder Tukak and Feeder Sadai are synchronous at 20 kV. Operating systems such as this are very vulnerable to blackouts because if there is a ground fault in other feeders (ex. Feeder Kota) then Tukak and Sadai can feel the disturbance too. If the synchronizes feeder trip, the Toboali bus, and the Pengarem bus are separated, the separation of these two bus synchronization results in a "load > supply" condition on the Toboali bus and a "load < supply" condition on the Pengarem bus.

Single line diagram of the Toboali system after the operating of the substation shown in Figure 2.

Figure 2. In this system configuration, it describes that the Feeder Tiram and Feeder Tugu Nanas are synchronous at 20 kV. Also, Feeder Keposang and Feeder Puput are synchronous at 20 kV. This operating system is good enough. But it needs improvement on the protection side and the addition of a set of directions makes the protection system work more selectively also the whole system can work more reliably.
3.2. Data of Toboali system (after the operating of substation)

The configuration after the operating of the substation system is shown in table 2.

| Bus          | SC level (kA) | Feeder | Ground Fault Set (Non-directional) | I | TMS | KURV | I >> | t | KURV |
|--------------|---------------|--------|-----------------------------------|---|-----|------|------|---|------|
| Toboali      | 5.023         | Kota   | 20                                | 0.1| SIT | 60   | 0.05 | DEF|
|              |               | Rindik | 20                                | 0.1| SIT | 80   | 0.05 | DEF|
|              |               | Bikang | 20                                | 0.07| SIT | 80   | 0.1  | DEF|
|              |               | Sadai  | 20                                | 0.1| SIT | 30   | 0.05 | DEF|
|              |               | Sukadamai | 20                            | 0.1| SIT | 40   | 0.05 | DEF|
|              |               | Tiram  | 40                                | 0.12| SIT | 60   | 0.05 | DEF|
| Pengarem     | 1.494         | Tukak  | 20                                | 0.1| SIT | 160  | 0.2  | DEF|
|              |               | Puput  | 20                                | 0.12| SIT | 160  | 0.2  | DEF|
|              |               | Tj Labu | 20                            | 0.1| SIT | 160  | 0.2  | DEF|
| Substation   |               | Tg Nanas | 30                        | 0.12| SIT | 100  | 0.09 | DEF|
|              |               | Parit 7 | 30                            | 0.12| SIT | 100  | 0.1  | DEF|
|              |               | Keposang | 30                        | 0.12| SIT | 100  | 0.09 | DEF|

3.3. Evaluation Feeder Tiram – Feeder Tugu Nanas

The feeder Tiram and the feeder Tugu Nanas are in a synchronous condition without load, facing each other in a system, and the conductor distance is not too far (about 4 km). Accordingly, the value of the ground fault setting determine in the feeder Tiram is the same as the feeder Tugu Nanas. Noteworthy is the phase angle to activate the directional function so that the relay is supposed to work more selectively only at the predetermined phase angle. In this case, it is necessary to measure the right phase angle beforehand under normal conditions and ground fault conditions. In this study, the reference angle phase is formed from VR and IR, depends on the relay brand used. Each relay brand has different characteristics to determine the phase angle of ground disturbance. From the historical data of ground fault that has occurred in the Toboali system, it describes that the characteristics of ground fault occur in the work area of phase angle $0^\circ$ to $-45^\circ$ (quadrant IV). From the historical data, the directional function determined “forward” is $-45^\circ$ with phase angle tolerance $+90^\circ$. 
For reliability and protection coordination of the bus Toboali and bus substation, the value of Feeder Tugu Nanas ground fault set must be greater than all feeders on Toboali buses. At least it has a delta t of 0.3 seconds by the recommended coordination of protection in Indonesia.

The coordination of ground fault protection shown in Figure 4.

3.4. Evaluation Feeder Keposang – Feeder Puput
The feeder Keposang and the feeder Puput are in a synchronous condition without load and facing each other in a system. From the historical data, the directional function determined “forward” is $-45^\circ$ with phase angle tolerance $+ 90^\circ$. The ground fault set value in the feeder on the Pengarem bus needs to be adjusted to the bus Toboali and the bus substation. Because the position and function are the same as the bus Toboali, the ground fault value can be determined to adjust to the bus Toboali value so that it can be coordinated with the bus substation.
The new ground fault set value after evaluation shown in Table 3

| Bus     | SC level (kA) | Feeder | Ground Fault Set (Dir = forward, -45°, tol = ±90°) | I > | TMS | KURV | I >> | t | KURV |
|---------|---------------|--------|--------------------------------------------------|-----|-----|------|------|---|------|
| Tobaali | 5.023         | Kota   | 20 0.1  SIT 60 0.05 DEF                           |     |     |      |      |   |      |
|         |               | Rindik | 20 0.1  SIT 80 0.05 DEF                           |     |     |      |      |   |      |
|         |               | Bikang | 20 0.07  SIT 80 0.1 DEF                            |     |     |      |      |   |      |
|         |               | Sadai  | 20 0.1  SIT 30 0.05 DEF                            |     |     |      |      |   |      |
|         |               | Sukadamai | 20 0.1  SIT 40 0.05 DEF                         |     |     |      |      |   |      |
|         |               | Tiram  | 30 0.12  SIT 60 0.05 DEF                           |     |     |      |      |   |      |
|         | 1.494         | Pengarem | Tukak | 20 0.1  SIT 60 0.1 DEF                             |     |     |      |      |   |      |
|         |               | Puput  | 20 0.12  SIT 60 0.1 DEF                            |     |     |      |      |   |      |
|         |               | Tj Labu | 20 0.1  SIT 60 0.1 DEF                            |     |     |      |      |   |      |
|         | 30.12         | Susbstation | Tg Nanas | 20 0.12  SIT 100 0.09 DEF |     |     |      |      |   |      |
|         | 30.12         |        | Parit 7 | 30 0.12  SIT 100 0.1 DEF                           |     |     |      |      |   |      |
|         | 30.12         |        | Keposang | 30 0.12  SIT 100 0.09 DEF                           |     |     |      |      |   |      |

3.5. Energy Not Supplied

After set value adjustment the sympathetic trip does not occur again. With the formula \( P = \sqrt{3} \times V \times I \times \cos \delta \), Power can be calculated. As known the total load of Tobaali system estimated 180 amperes. So the estimated power of Tobaali system were 9 megawatt. So with this numbers, the energy not supplied shown in table below:

| Year | Down (Time) | ENS(MWh) |
|------|-------------|----------|
| 2019 | 26          | 51.261   |
| 2020 | 10          | 21.17    |

4. Conclusions

The optimizing of directional ground relay can reduce the symphatetic trip. This condition also reduce the energy not supplied at Tobaali system from 51.261 MWh (2019) become 21.17 MWh (2020).

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