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Evaluation of Transformer Protection System Coordination at ULTG Jeneponto

Nur Ahmad Basri[1,a], Bakhtiar[2,b], Muhammad Thahir[3,c], Andarini Asri[4,d]
[1, 2, 3, 4] Department of Electrical Engineering, State Polytechnic of Ujung Pandang
[a] nurahmadbasri972@gmail.com, [b] bakhtiar.poltekup@gmail.com, [c] muh.thahir@poliupg.ac.id, [d] andariniasri@poliupg.ac.id

***Abstract*—Power transformers are essential components in electrical power systems as they transform electrical quantities. In practical terms, electrical power systems may experience disturbances such as short-circuit faults, either between phases or to ground. One type of relay used to accommodate these faults is the Over Current Relay (OCR) for phase-to-phase faults and the Ground Fault Relay (GFR) for ground faults. This research evaluates the coordination settings of transformer protection systems at PT PLN (Persero) ULTG Jeneponto by analyzing the characteristics plot of each transformer unit. The evaluation results reveal intersecting characteristics on the high voltage (HV) and medium voltage (MV) sides of Transformers #3 Tallasa and #3 Bulukumba. By implementing recommended settings for these two transformer units, anomalies can be addressed, and the protection system can coordinate effectively.**

***Keywords*—Protection system; Short-circuit; Transformer; OCR/ GFR**

I. Introduction

Electrical power systems often face disturbances, causing interruptions in power distribution. Short-circuit faults are among the common disturbances, leading to significant current flows. If not promptly addressed, these currents can damage equipment [1]. Hence, a protection system is necessary to detect faults, isolate fault zones, and safeguard electrical components with minimal impact. Short-circuit faults can occur in various forms, including three-phase, phase-to-phase, or phase-to-ground faults. Protection equipment such as OCR and GFR relays are typically used to mitigate short-circuit faults [2]. The reliability of the protection system depends on the reliability of relay equipment, as anomalies in relays can compromise system protection.

A. Protection System

The protection system is one part of the electricity system that is crucial. It functions to keep either the generation, system network and distribution parts from interference so that service to consumers can be reliable. Protection system equipment must meet criteria such as sensitivity, selectivity, speed and reliability of operation. Each part of the electricity system has its own protection system with a function to secure electrical equipment. Power system protection equipment must be able to isolate the location of a disturbance in an electricity system in order to minimize blackouts and the impact of damage that spreads to a wide area.

B. Protection System

A short-circuit fault is a condition in the power system where the current conductor is connected to another conductor or to the ground. Short circuit faults can cause currents that are much larger than the normal conditions. If a short circuit fault is allowed to last for a long time on an electric power system, it will have an undesirable effect that can occur [3]:

1. Reduced stability limits for the power system of a power system
2. Damage to equipment located close to the fault is caused by unbalanced currents, or low voltage caused by short circuits.
3. Explosions may occur in equipment containing insulating oil during a short circuit, which may cause a fire that can endanger people who handle and damage other equipment.
4. The rupture of the entire service area of the electric power system was due to a series of safety measures taken by different security systems. This event is known as cascading.

The types of fault are divided depending on the point of impact.

1. Three-phase short-circuit fault (raises the positive sequence).
2. Two-phase short-circuit fault (creates positive & negative sequences)
3. Single-phase ground short-circuit fault (gives rise to positive, negative & zero sequences).

These sequences are forms of impedance that arise as a result of a fault.

$$Z_f\ 3\varphi = Z1 \quad (1)$$

$$Z_f\ 2\varphi = Z1 + Z2 \quad (2)$$

$$Zf\ \varphi \text{ to ground} = Z1 + Z2 + Z0 \quad (3)$$

Calculation of short-circuit fault current is an analysis of an electric power system to obtain the value of electrical quantities generated as a result of the short-circuit fault [4]. Calculation of short circuit fault current is done with several stages of calculation as follows.

1. Calculating the impedance value
   a. Source impedance

   The source impedance of either the generator or the power grid is obtained by the formula:

$$Xs = \frac{kV^2}{MVA} \quad (4)$$

Where:

Xs : Source impedance (Ω)

kV : Nominal voltage (kV)

MVA : Generated power (MVA)

b. Transformer impedance

For transformer impedance values, it can be seen on the transformer nameplate with a comparison to PU, its positive, negative and zero sequence impedance.

c. Conductor impedance

The amount of impedance is represented by [5]:

$$R + jX \quad (5)$$

In calculating the conductor impedance, the calculation depends on the impedance per unit distance to be calculated.

d. Equivalent impedance

The calculation that will be done here is the calculation of the equivalent impedance value of the sequence that appears when a disturbance occurs from the source to the point of interference.

2. Calculating the short circuit value

The equivalent impedance entered into the basic formula is the type of three-phase, two-phase, or single-phase short-circuit fault on the ground. So the formulas used for every kind of fault are different.

a. Three-phase short circuit current

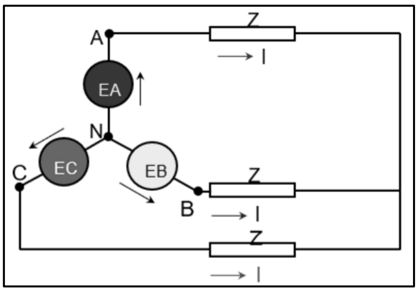

Figure 1. 3-phase short circuit diagram

The three-phase short circuit fault current can be calculated using the formula:

$$I_{3\varphi} = \frac{V_{ph}}{Z_{eq}} \quad (6)$$

Where:

I3φ : 3-Phase short circuit (A)

Vph : Voltage Ph-N (V)

Zeq : Equivalent impedance (Ω)

b. Two-phase short circuit current

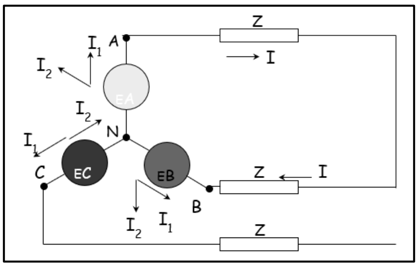

Figure 2. 2-phase short circuit diagram

The two-phase short circuit fault current can be calculated using the formula:

$$I_{2\varphi} = \frac{V_{ph\text{-}ph}}{Z_{1eq} + Z_{2eq}} \quad (7)$$

If the value of Z1eq = Z2eq, then:

$$I_{2\varphi} = \frac{V_{ph\text{-}ph}}{2 \times Z_{1eq}} \quad (8)$$

If this were the case, the value of I2phase to I3phase would be:

$$I_{3\varphi} = \frac{\sqrt{3} \times V_{ph}}{2 \times Z_{1eq}} = \frac{\sqrt{3}}{2} I_{3\varphi} \quad (9)$$

c. One-phase to ground short circuit current

Single-phase short circuit current to ground can be calculated using the formula:

$$I_{1\varphi} = \frac{3 \times V_{ph}}{Z_{1eq} + Z_{2eq} + Z_{0eq}} \quad (10)$$

C. Overcurrent Relay (OCR)

OCR is equipment that signals the presence of over current, either caused by a short circuit fault or overload that can damage power system equipment within its protection area [6]. The following types of relays are based on time characteristics.

- Instantaneous over current relay
- Definite over current relay
- Inverse over current relay

D. Overcurrent Relay Settings Parameter

The following describes the coordination of relay settings in accordance with the standards of PT PLN (Persero) P3B Sumatera Bidang Transmisi Sub Bidang Proteksi Scadatel Padang, 2008 OCR setting rules include technical considerations in OCR settings [7].

Table 1. Range Setting of Transformers OCR

	Feeder	MV Side	HV Side
Curve	SI	SI	SI
I_{set}	(1.0-1.2 × In) or (1.0-1.2) × ccc) *	(1.0-1.2 × In) or (1.0-1.2) × ccc) **	(1.0 -1.2 × In)
t_{op}	0.2 - 0.4 s	0.8 – 1.0 s	1.2 – 1.6 s

*) Choose the smaller value

**) Not smaller than the Ifault on the nearest distribution transformer

1. Current Setting OCR (Iset)

   To calculate the value of the over current setting can be done in accordance with Pedoman dan Petunjuk Sistem Proteksi Transmisi dan Gardu Induk Jawa Bali as follows [8].

   Setting value of 20 kV feeder relay

$$I_{set} = (1.0\text{-}1.2) \times I_{load} \quad (11)$$

   The set value is the primary value. To get the secondary setting value that can be set on the Overcurrent Relay (OCR), it is calculated using the current transformer ratio data installed in the feeder, are as shown below:

$$I_{set}\ (\text{sec.}) = I_{set} \times \frac{1}{CT} \quad (12)$$

2. Time Setting OCR (TMS)

   The results of the short-circuit fault current calculation are then used to obtain a Time Multiple Set (TMS). TMS use to determine the delay time for a protection device to work when it senses a fault.

Table 2. Time Operation Characteristics of Inverse Relay Type

Curve	Time Multiple Set
Standard Inverse	$\frac{\left[\frac{I_f}{I_{set}}\right]^{0,02} - 1}{0,14} \times t$
Very Inverse	$\frac{\left[\frac{I_f}{I_{set}}\right] - 1}{13,5} \times t$
Extremely Inverse	$\frac{\left[\frac{I_f}{I_{set}}\right]^{2} - 1}{80} \times t$
Long Time Inverse	$\frac{\left[\frac{I_f}{I_{set}}\right] - 1}{120} \times t$

E. Ground Fault Relay

1. Current Setting GFR (Iset)

   Determination of GFR settings considers 2 (two) things, which are the number of transformer windings and the transformer grounding system. The availability of the third winding (delta) will affect the GFR setting value of the high-voltage side (HV side) of the transformer.

   a. With delta winding

$$\text{Iset GFR HV} = 0.2 \times \text{In} \quad (13)$$

   b. Without delta winding

$$\text{Iset GFR HV} = (0.5 - 0.8) \times \text{In} \quad (14)$$

2. Time Setting GFR (TMS)

   The setting value of GFR for each typical based on the neutral grounding resistor resistance value can be seen in the table below.

Table 3. Range Setting of Transformers OCR

NGR	Setting Value GFR at MV side	
	Iset	TMS
500 Ω	-	-
62 Ω	(0.3 -0.4) × In	1 s (SI) sc at MV
40 Ω	(0.2 -0.4) × In	1 s (SI) sc at MV
Solid	(0.2 -0.4) × In	1 s (SI) sc at MV
	3 × In (highest)	0.5 s (definite)

II. Research Methodology

The location of research and data collection is in the work area of PT PLN (Persero) Unit Layanan Transmisi & Gardu Induk (ULTG Jeneponto). Located in Kalumpang Loe, Arungkeke, Jeneponto Regency. The research will be conducted at each substasion under ULTG Jeneponto. The research started in January 2022 and is planned until June 2022. ULTG Jeneponto has 7 (seven) substations under supervision. These substations are under the supervision of ULTG Jeneponto along with the number of transformer units:

1. Tallasa substation (three units)
2. Punagaya substation (one unit)
3. Jeneponto substation (two units)
4. Bantaeng New Substation (one unit)
5. Bantaeng Smelter Substation (without transformer)
6. Bantaeng Switch Substation (without transformer)
7. Bulukumba substation (three units)

The author collects the necessary data such as existing relay settings, transformer component parameters, circuit breakers, CT & VT ratio. The data is then entered into the ETAP 19 electrical power system simulator application. From the simulation results, the characteristics of a particular relay are produced and analyzed. As well as the calculation of the recommendations set and re-simulation is carried out which can later be compared as evaluation.

III. Results and Discussion

A. Transformers Parameter

Here are the parameter specifications of each transformer.

Table 4. Transformers specification at ULTG Jeneponto

Transformer	**Vector Group**	**Ratio**	**Z**	**NGR**
		kV	**%**	**Ω**
Tallasa#2	YNyn0(d11)	150/20	12.5	40
Tallasa#1	YNyn0(d5)	150/20	12.724	40
Tallasa#3	YNyn0+d	150/20	12.05	40
Punagaya#1	YNyn0+d	150/20	12.542	40
Jeneponto#1	YNyn0+d11	150/20	12.35	40
Jeneponto#2	YNyn0+d5	150/20	12.31	40
Bantaeng New#1	YNyn0+d	150/20	12.474	40
Bulukumba#1	YNyn0d11	150/20	12.77	40
Bulukumba#2	YNyn0d	150/20	13.29	40
Bulkukumba#3	YNyn0+d	150/20	12.6	40

The specifications of the parameters of each CT on the high-voltage side and the medium-voltage side of the transformer bay are as shown below.

Table 5. CT Ratio at primer and secondary side of transformers

Transformer	**CT HV**		**CT MV**	
	Prim.	**Sec.**	**Prim.**	**Sec.**
Tallasa#1	150	5	1200	5
Tallasa#2	150	5	600	5
Tallasa#3	150	5	2000	5
Punagaya#1	150	5	1000	5
Jeneponto#1	150	5	600	5
Jeneponto#2	150	5	1200	5
Bantaeng New#1	300	5	1000	5
Bulukumba#1	150	5	600	5
Bulukumba#2	150	5	1200	5
Bulukumba#3	300	5	2000	5

B. Short Circuit Rating

The table below shows the values or parameters used in the source impedance (grid as an equivalent substitute at each substation) for determining the equivalent impedance in the calculations of short circuit currents.

Table 6. Shot circuit rating of each substations

Transformer	**MVAsc**			**Isc**	
	3φ	**φ-gnd**	**2φ**	**3φ**	**φ-gnd**
Tallasa	4446.79	1335.05	1201.06	17.12	15.42
Punagaya	5864.39	2353.50	1528.89	22.57	27.18
Jeneponto	3115.56	811.95	862.95	11.99	9.375
Bantaeng New	2003.43	490.17	564.22	7.711	5.66
Bantaeng Switching	2115.11	511.45	595.74	8.141	5.905
Bantaeng Smelter	2080.67	502.73	586.26	8.009	5.805
Bulukumba	2032.18	486.72	573.25	7.822	5.62

C. Simulation of Existing Transformer Protection Coordination (OCR/GFR)

From the overall simulation of the settings of each transformer unit carried out, in the simulator there are 2 (two) transformers sections that are suspected of having anomalies. The anomalies are transformers 60 MVA Tallasa#3 and 60 MVA Bulukumba#3. For anomalous conditions, there are protection characteristics that intersect each other.

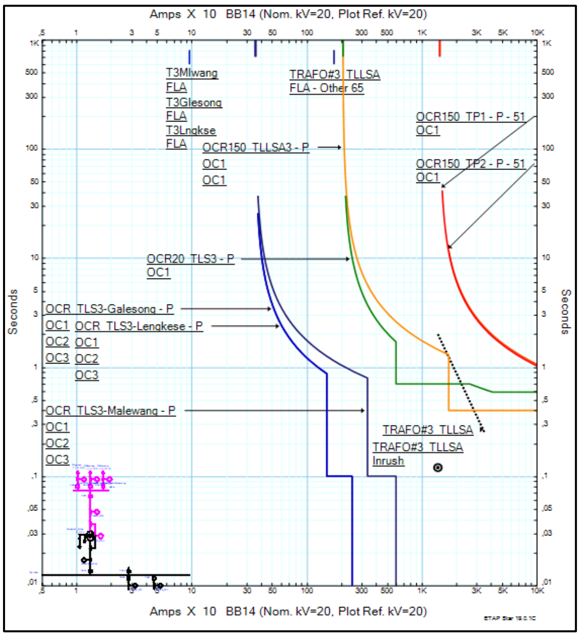

Figure 3. Plot of existing settings OCR Tallasa #3

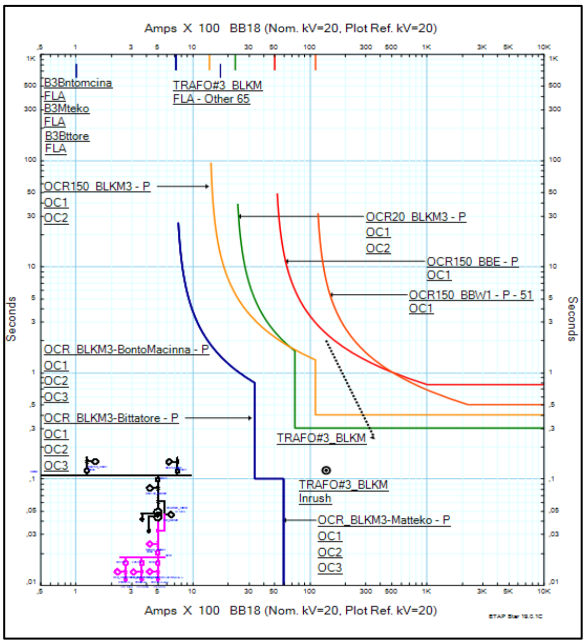

Figure 4. Plot of existing settings OCR Bulukumba#3

D. Recommendation Settings of Transformer Protection

The results of the evaluation of the transformer protection system settings show anomalies in the characteristics. Recommendations from the evaluation results intended for transformer protection settings, seeing from the anomalies obtained are in the form of changes in the setting value of Time Multiple Set (TMS) at a certain protection level or the addition of the protection level of relay characteristics in order to form new characteristics that coordinate with each other.

As for the first anomaly, which is the type of OCR relay protection of transformer #3 60 MVA Tallasa, the MV side OCR setting intersects with the HV side OCR setting. The existing OCR setting is as shown below.

Table 7. Existing settings OCR Tallasa #3

Section	OCR Settings							
	Ip>	Is>	Curve	TMS	Ip >>	Is >>	Curve	t
HV	276	4.6	SI	0.4	2298	38.3	DT	0.4
MV	2080	1.04	NI	0.26	6000	3	DT	0.7

By adding a level 3 (three) protection level on the MV side with the Iset setting of 5 (five) times the nominal MV current (1732.102 A) and the type of DT (definite time) work curve with a lower working time than the HV side protection time setting, the recommendation settings is as shown below.

Table 8. Recommendation settings OCR Tallasa #3

Section	Recommendation Setting			
	Ip>>>	Is>>>	Curve	t
HV	-	-	-	-
MV	8660	4.33	DT	0.3

If the recommendation settings are inputted in the simulator application, it will generate the the results of the characteristic plot as shown below.

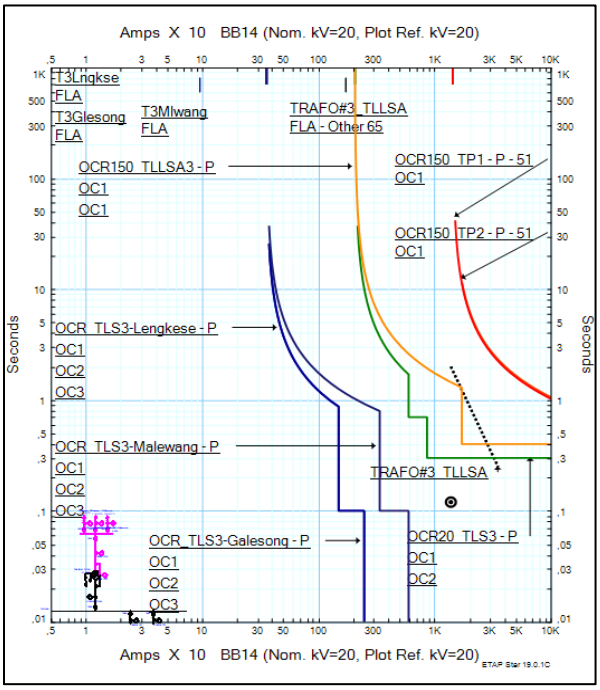

Figure 5. Plot of recommendations settings OCR Tallasa #3

The second anomaly is in the protection system of transformer #3 60 MVA Bulukumba, in the same case as transformer #3 60 MVA Tallasa, the protection system of the MV side OCR type that intersects with the HV OCR type protection system. The existing setting data for transformer #3 60 MVA Bulukumba is in the table as shown below.

Table 9. Existing settings OCR Bulukumba #3 (level 1 & 2)

Section	OCR Settings							
	Ip>	Is>	Curve	TMS	Ip>>	Is>>	Curve	t
HV	186	3.1	SI	0.4	1497	24.95	DT	0.4
MV	2320	5.8	SI	0.27	7660	19.15	DT	0.7

Table 10. Existing settings OCR Bulukumba #3 (level 3)

Section	OCR Settings			
	Ip>>>	Is>>>	Curve	t
HV	-	-	-	-
MV	10000	25	DT	0.3

Inasmuch as the anomalous characteristic plot located at the intersection of the pickup settings of both the HV and MV sides, the recommendation method for evaluation at level 1 protection is to take the results from the calculation of the transformer's Iset (current setting) pickup protection system that has been calculated previously, and to determine the protection level 2 & 3 keep following the existing settings.

Table 11. Recommendation settings OCR Bulukumba #3 (level 1)

Section	Recommendation Setting			
	Ip>	Is>	Curve	TMS
HV	277.136	4.619	SI	0.673
MV	2078.52	5.1963	SI	0.413

If the recommendation settings are inputted in the simulator application, it will generate the the results of the characteristic plot as shown below.

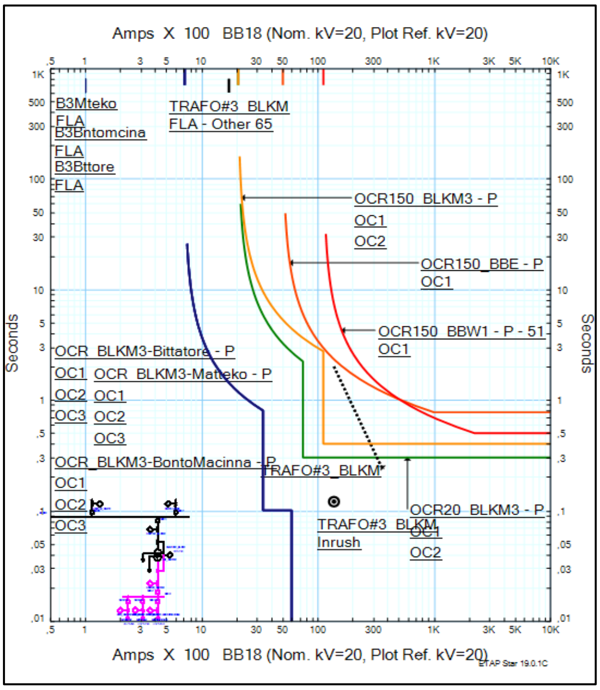

Figure 6. Plot of recommendations settings OCR Bulukumba#3

IV. Conclusion

1. The simulation results in the form of characteristic plots found that there were 2 (two) transformer units suspected of anomalies that could cause the protection system to not coordinate properly. The anomalies mentioned are in the OCR type protection system on the HV and MV sides of transformer #3 Tallasa as well as in transformer unit #3 Bulukumba.
2. Each anomaly has characteristics that overlap or intersect between the HV and MV protection systems. The action of the evaluation results was carried out by adding a protection level to the OCR of Transformer#3 Tallasa. And for OCR of Transformer#3 Bulukumba, the recommended setting was applied as a result of the calculation of the relay setting for level 1 protection. With the action of the evaluation results, the anomaly can be overcome.

Acknowledgement

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