International Journal of Electrical, Energy and Power System Engineering
Vol. 07, No. 02, June 2024
e-ISSN: 2654-4644

The Evaluation of Over Current Relay and Ground Fault Relay Settings on Power Transformers

Fikri Fatwa Ulhuda[1*], Azriyenni Azhari Zakri[2], Umair Ali[3]
[1,2] Dept. of Electrical Engineering, Faculty of Engineering Universitas Riau, Pekanbaru, Indonesia
[3]Dept. of Electrical Engineering, CECOS University of IT and Emerging Science, Peshawar, Pakistan
[1]fikri.fatwa3859@student.unri.ac.id, [2]azriyenni@eng.unri.ac.id, [3]engg.aliumair@gmail.com

[*]Correspondence Author: fikri.fatwa3859@student.unri.ac.id

Abstract — Power transformer is an important component of the substation and has an important role in the electric power distribution system. During operation the power transformer can't be isolated from distribution system when abnormal conditions or faults occur. A fault in the power transformer will have huge impact on the power transformer itself. The substation has an installed capacity of 60 MVA of power transformers, and during operation there is a possibility of relay failure, which may interrupt the power distribution process to the load. To avoid this failure, it is necessary to analyse the settings of Over Current Relay (OCR) and Ground Fault Relay (GFR) on the 60 MVA transformers. The analysis was carried out by simulating short circuit faults of the electrical system in the ETAP software application, and then configure the setting of the relay by referring to the magnitude of the short circuit current value for phase to phase and phase to ground. The results of this analysis are used as a reference to determine the OCR and GFR relay values in the power transformer. The results obtained show that the recommended value for OCR setting on 150 kV power transformers is 0.92 second while for GFR is 0.96 second, and for the 20 KVA power transformers the OCR and GFR setting values are 0.40 and 0.20 seconds respectively. Comparison based on the results of the setup data and the analysis data has carried out, there is difference in the working time of the relay, with a difference of 5%, where the value of the analysis results is not much different from the conditions in the field.

Keywords: *Ground Fault Relay, Over Current Relay, Power Transformer, Settings Relay.*

INTRODUCTION

Based on data obtained from the central statistics agency of Riau Province sourced from Electrical Power Company, electricity consumers have experienced significant growth over the past few periods. In 2018 the electrical consumers was 129,818, then in 2019 there were 142,777 consumers, and in 2020 the electricity consumers increased by 156,672 [1]. Given the increasing demand for electrical energy, the quality and quantity of electricity supply are things that need attention. One effort to compensate for the increase in the number of consumers can be made by increasing power capacity, i.e. by adding new power transformers to the substations [2]. The addition of this power transformer is used to increase the installed capacity of the substation, where earlier the installed capacity at that substation was 40 MVA. According to NFPA [3], it is recommended that at least short-circuit current study analysis be

Received: December 24, 2023, Revised: February 11, 2024, Accepted: March 30, 2024
https://doi.org/10.31258/ijeepse.7.2.100-110

conducted once at every five years or whenever a major modification occurs in an electrical system. Power transformer protection systems protect or isolate high-voltage or extra-high-voltage power transformers from transient interruptions and long-term interruptions that occur in power transformers [4]. There are two parts of the power transformer protection system, primary protection and backup protection [5]. Backup protection in power transformers often uses ground fault relays and overcurrent relays, while primary protection usually uses a differential relay system [6]. A short circuit fault is a fault that occurs due to a fault between the voltage parts, which can cause a high current [7]. Short-circuit faults can result in damage to electrical equipment, especially around the fault point [8]. The functions of power transformer protection system are that to secure or isolate high-voltage or extra-high-voltage power transformers from temporary disturbances and permanent interruptions that occur in the power transformer [9]. The power transformer protection system itself is divided into two parts, namely main protection and backup protection [10]. The main protection on power transformers usually uses a differential relay system, while backup protection uses overcurrent relay and ground fault relay [11]. An overcurrent relay is a relay that works against overcurrent. The relay will work when the current flowing exceeds the value of relay setting, either caused by a short circuit fault or overload, and then give trip orders to PMT according to the character of the time [12]. The backup protection is needed in the power transformer system because this protection is important to maintain the reliability of the electrical system. Substation equipment maintenance is an important part of power generation and transmission [13][15]. The maintenance of network equipment plays an important role in improving the health of devices and ensuring the safety of the power grid [16] [17]. The purpose of maintenance is to achieve equipment reliability by improving equipment operation and reducing maintenance costs. The maintenance model is very important because it can provide a better understanding of different maintenance methods by determining the most effective inspection in terms of cost and frequency of maintenance. The basic goal of such maintenance is to achieve an optimal balance between resources and maintenance benefits [18]. The research was used to analyse whether the protection system installed on the Batu 60 MVA power transformer is working according to the standards used by Electrical Power Company.

METHODOLOGY

A flowchart is used to show an overview of the steps that need to be taken in the research process with the aim of getting optimal results. Data obtained during observation and data collection, both the power transformer data and substation data will be used as a reference for designing and modelling single-line diagrams. The modelling of single-line diagrams is carried out and adjusted to the original conditions in the field. Single line daigram also includes the value and data of components in the form of 60 MVA power transformers, relays, Circuit Breaker (CB) specifications and the values of OCR and GFR that have been installed. The Bagan Batu substation has been interconnected with the DR substation and the KP substation. BB substation, commissioned in 2020, has a capacity of 40 MVA. In 2021, the installed capacity of the Bagan Batu substation upgraded to 100MVA. The 100MVA consists of three power transformers, each with a capacity of 20MVA, 20MVA, and 60MVA. With the increase in installed capacity at the Bagan Batu substation, it is 100% of the load required for most of RR district. The 60MVA power transformer at the BB substation consists of two voltage level, namely; 1) The 150kV voltage, appeared at the BB Substation, which is interconnected at the DR Substation and the PC Substation is step down to 20 KV. 2) The 20kV voltage, located on the load side of the 60MVA power transformer, which will be distributed to both medium-voltage customers and low-voltage customers.

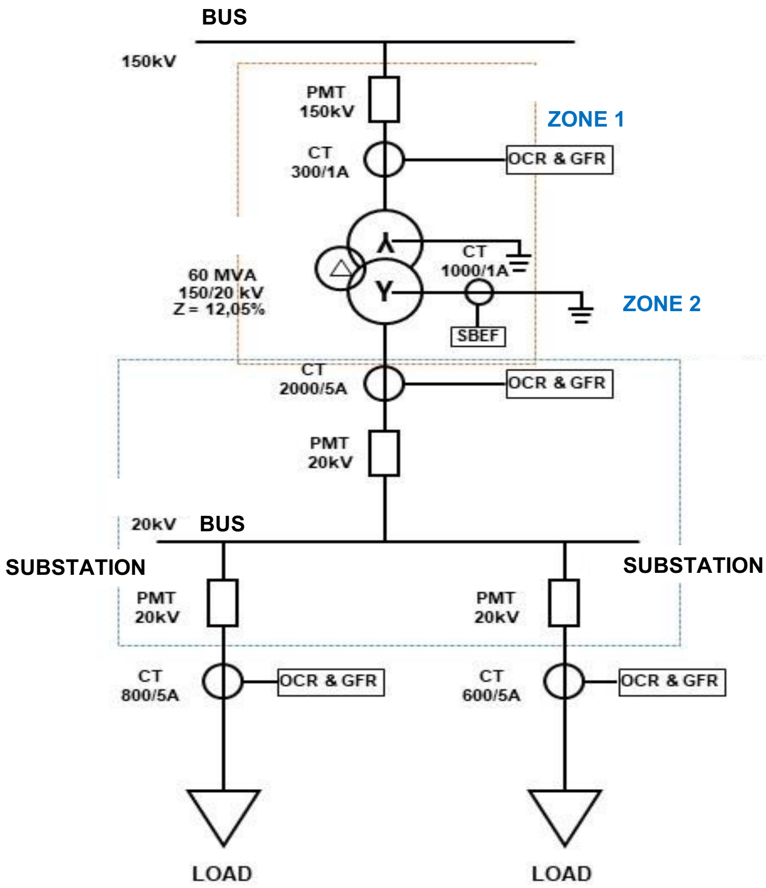

Figure 1. OCR & GFR Protection Zone Power Transformer 60 MVA of BB Substation

In this study, OCR and GFR analysis will be carried out on the 60 MVA BB power transformer. After observation at BB substation, the data and specifications of the transformer are as follows in Table 1.

Table 1. Specifications of Transformer

Power Transformer	
Brand/Type	Unindo
Rated Power	60 MVA
Standard	IEC-60076
Frequency Hertz	50 Hz
Phases	3
Vector Group	Ynd1
Primary Voltage	150 kV
Secondary Voltage	20 kV
Impedance	12,05%
Rn	10 ohms

For this study, the relay setting data used was 150 kV and 20 kV incoming. The following relay setting data used in BB substation was obtained during observation and data collection in Table 2.

Table 2. OCR of Power Transformer

Relay	$I_{setting}$ (A)	Characteristic curves	Tms(s)
NR PCS-9611	230,94	IEC SI	0,26
Siemens Reyrolle 7SR21	1880	IEC SI	0,21

Table 3. GFR of Power Transformer

Relay	$I_{setting}$ (A)	Characteristic curves	Tms(s)
NR PCS-9611	93	IEC SI	0.56
Siemens Reyrolle 7SR21	100	IEC SI	0.25

RESULT AND DISCUSSION

After carried out the observation and data collection process at the BB Substation, the short circuit current value I_{sc} at 150 kV of the BB Substation was obtained at 19.69 kA. The short circuit current value of the substation will be used to determine the MVA_{sc} value of 150 kV of the BB Substation. This MVA_{sc} value can be determined using calculations that refer to the equation where the MVA_{sc} value for 150 kV on the BB Substation is 1550 MVA. The MVA_{sc} value obtained can be used to determine the source impedance value from 150 kV of the Substation. This source impedance value later will be used for analysis of the short-circuit current that occurred. After obtaining the MVASC value at 150 kV of the transformer, the source impedance value is Z_{s1} = j0.019568 pu and Z_{s0} = j0.05855 pu. The next impedance component to note is the impedance value of the power transformer to be analysed, namely the 60MVA power transformer at BB substation. The impedance value of the power transformer can be determined by looking at the impedance presentation on the data or the power transformer specification itself. The characteristic value of the impedance of the 60 MVA power transformer of substation, which has the SPLN standard, has a transformer impedance value of 12.05%. This impedance value needs to be calculating by adjusting to the new system per unit, the Base value is 100 MVA and the kV_{base} is 150 kV. So, the impedance value of the negative and positive sequence transformers is Z_{t1} = j0.20083 pu and Z_0 = j0.602499 pu.

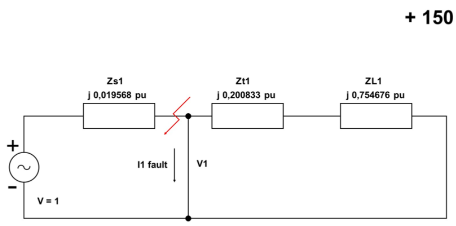

Figure 2. Equivalent Impedance Circuit of Positive Sequence at 150 kV

The values of source impedance, transformer impedance, and load impedance will be summed according to their respective sequences, where the equivalent impedance of positive, negative, and zero sequence will be obtained. In conducting a short circuit fault current analysis, equivalent components of each sequence are needed. This aims to facilitate the calculation of the short circuit current that occurs. Figure 2 is a series of positive sequence equivalents in the Bagan Batu substation, impedance and reactance values were obtained in the previous calculation so that the equivalent impedance value of the positive sequence can be analysed. The assumption of a fault that occurs at 150 kV of the transformer or just before the 60 MVA power transformer of BB substation is that when there is a short circuit fault. The current will only go through the source impedance and will not go through the transformer impedance or the refiner impedance, so that the calculation of Z1eq, Z2eq, and Z0eq at 150 kV. If the equivalent impedance value has been obtained, then the next step is to calculate the fault current that occurs at 150kV of the power transformer.

- 150 kV

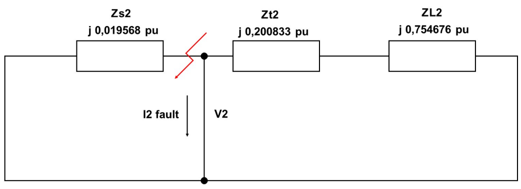

Figure 3. Equivalent Impedance Circuit of Negative Sequence at 150 kV

0 150 kV

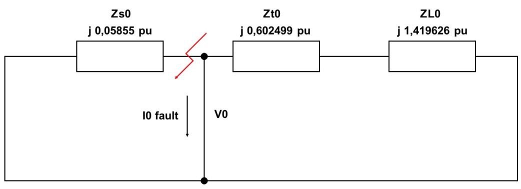

Figure 4. Zero Sequence Equivalent Impedance Circuit Fault at 150 kV

To determine the value of OCR at 150 kV, data is needed in the form of short circuit current value, setting current, and CT ratio. The results of data collection in the field showed that the magnitude of the current at 150 kV equal to 230.94 A, while the CT value used with a ratio of 300/1. To determine the value of OCR settings used two-phase short circuit fault current and the obtained short circuit current at 150 kV equal to 17,033A. Primary and secondary I_{set} values and TMS will be used in the simulation of disturbances that will be filled in the relay data in accordance with the type of relay used, namely NR PCS-9611 relay with SI (non-directional) characteristics. The working current of the relay at 150 kV in accordance with SPLN guidelines using a cascade pattern used a working time of 1.5 seconds. The same procedure can also be done to determine the GFR value at 150 kV. A single-phase short-circuit fault value to the ground is needed. Based on the analysis of the magnitude of the single-phase short-circuit current to the ground, which is obtained at 6,813.54 A. The CT ratio used is 300/1, and the working time of the relay used according to SPLN is 1.5 seconds or it can be 0.5 times greater than the setting current at the incoming working time of the power transformer. The simulation results of a single-phase short circuit to ground at 150 kV can be seen in Figure 5. The magnitude of the current simulated using ETAP was obtained at 6.611 Ampere and the magnitude of the short-circuit current from the calculation was obtained at 6.813 Ampere.

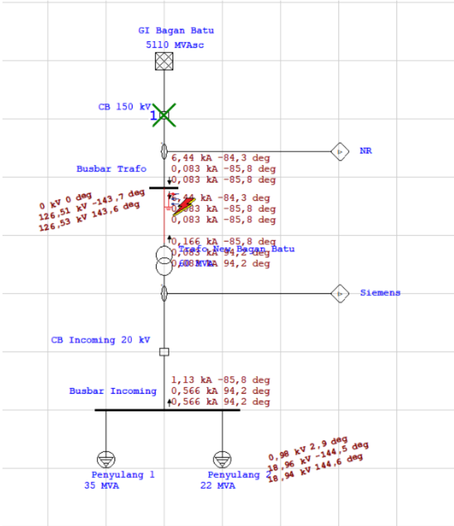

Figure 5. Simulation of a Single-Phase to Ground Short Circuit at 150kV

The simulation results of a two-phase short circuit at 150 kV can be seen in Figure 6. The value of the simulated current using ETAP is obtained at 17,706 Ampere, while the short-circuit current from the calculation is obtained at 17,033 Ampere.

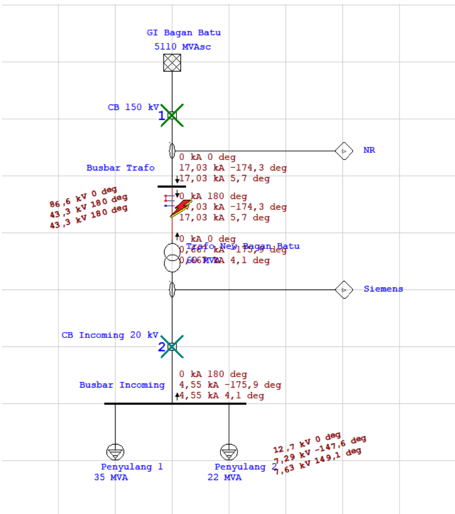

Figure 6. Simulation of Two-Phase Short Circuit at 150 kV

After setting values of each component, it is necessary to analyse the load flow to obtain the amount of current flowing in the system that has been designed. After obtaining the TMS and pickup values, run a relay coordination simulation during a fault using the STAR Protective Device Coordination simulation in ETAP, which aims to test the performance of each OCR relay according to the zone that has been set for current and working time. The simulation results of a single-phase short circuit to the ground at 22 kV, the magnitude of the simulation current using ETAP is obtained at 1,028 Ampere, while the magnitude of the short circuit current obtained from the calculation is 1,584 Ampere. The results of the two-phase short circuit simulation at 22 kV. The magnitude of the simulated current using ETAP is obtained at 18,145 Ampere, while the magnitude of the short-circuit current from the calculation is obtained at 18,043 Ampere. To ensure that the results of the settings determined are correct, it must be simulated for disturbances that occur on the primary and secondary sides of the power transformer, in the form of two-phase and one-phase disturbances to the ground. This is done to prove that the relay will work in the event of a short-circuit fault within the protection zone and not work in the event of a fault outside the protection zone. When a two-phase short circuit fault occurs at a 150 kV power transformer, all the current will go to the fault point. The disturbance that occurs will order the breaker to work. It can be seen in Figure 9 that when a fault occurs, the NR PCS-9611 relay will read the amount of fault current that occurs, which will then order the 150kV CB to work. The fault current in the simulation is 17.03 kA with a relay working time of 1.83 second, which will then cause the breaker command to trip. Meanwhile, the Siemens 7SR21 relay will be the backup relay to secure the 22 kV.

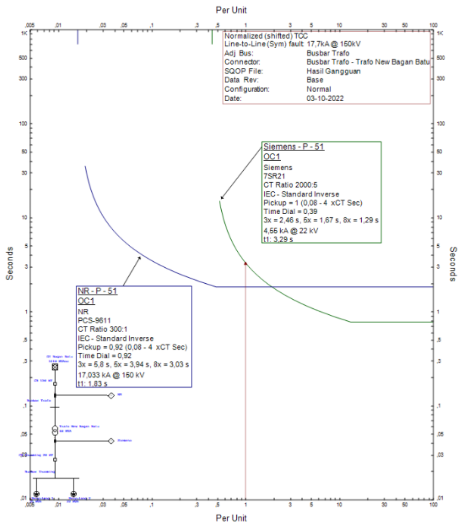

Figure 7. 150kV Two-Phase Fault OCR Coordination Curve

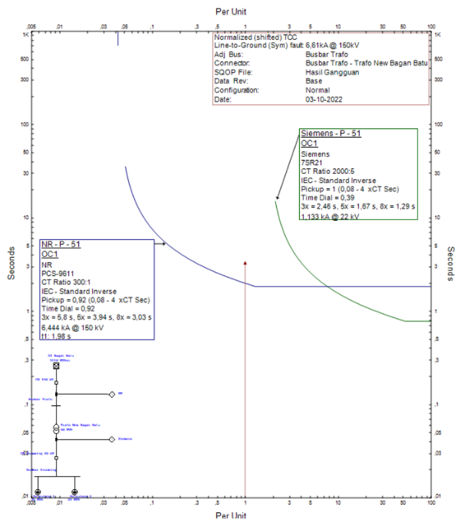

Figure 8. 150kV Single Phase to Ground Fault OCR Coordination Curve

Figure 8 is the GFR coordination curve when a single-phase ground fault occurs at 150 kV of the power transformer. The short-circuit fault current value is 6.44 kA. The value of the fault current that occurs will affect how quickly the relay orders the breaker to trip. Based on the coordination of OCR and GFR at 150 kV obtained from the results of the analysis using ETAP, it can be seen that if a short circuit fault occurs at 150kV power transformer, the relay that will work and order a trip is the NR PCS-9611 relay. This is in accordance with the IEC 242 standard, where the fault division zone and relay working time are appropriate. In this case, the TMS value of the relay setting plays an important role in determining the relay working time. In GFR coordination curve a single-phase fault occurs at a 22kV power transformer can be seen in Figure 9. The short circuit fault current value is 1.06kA with a relay working time of 2.72 seconds. The magnitude of the fault current that occurs will decide that how fast the relay will command the breaker to trip.

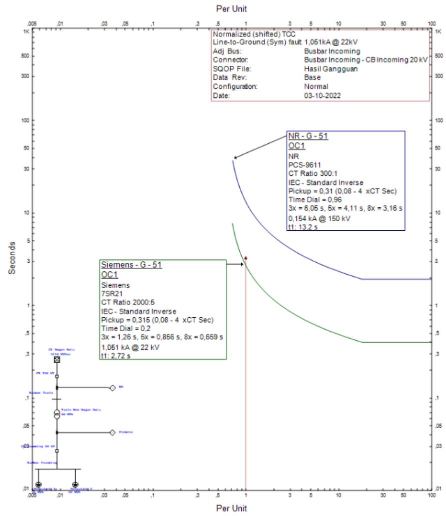

Figure 9. GFR Coordination Curve for a Single-Phase Ground Fault 22kV

The OCR coordination curve when a two-phase fault occurs at 22 kV of the power transformer can be seen in Figure 10. The value of the fault current that occurs is 11.5 kA. With a relay working time of 1.53 second, which will then give the breaker command to trip.

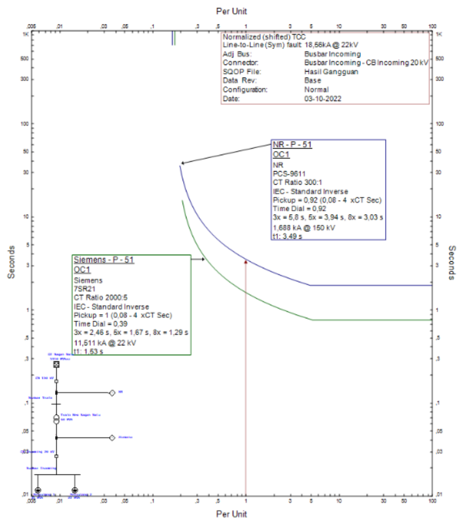

Figure 10. 22kV Two-Phase Fault OCR Coordination Curve

Based on the coordination of OCR and GFR at 150 kV, obtained from the results of the analysis using ETAP, if there is a short circuit fault at a 22 kV power transformer, the relay that will work and order a trip is the Siemens 7SR21 relay. This is in accordance with the IEC 242 standard, where the fault division zone and relay working time are appropriate. In this case, the TMS value of the relay setting plays an important role in determining the relay working time. The results of the analysis that has been carried out have revealed a significant difference in the value of the setting current, pickup current and TMS value from the data obtained in the field. This difference can be seen in Table 4.

Table 4. The Comparison of OCR and GFR Settings

Relay Name	OCR settings		GFR settings	
	Field Data	ETAP	Field Data	ETAP
NR PCS978	I_{set} = 276 A I_{pickup} = 0.92 A TMS = 0.26 s	I_{set} = 277.13 A I_{pickup} = 0.92 A TMS = 0.92 s	I_{set} = 93 A I_{pickup} = 0.3 A TMS = 0.56 s	I_{set} = 92 A I_{pickup} = 0.31 A TMS = 0.96 s
Siemens Reyrolle 7SR21	I_{set} = 1.880 A I_{pickup} = 4.7 A TMS = 21 s	I_{set} = 1.889 A I_{pickup} = 4.72 A TMS = 0.4 s	I_{set} = 100 A I_{pickup} = 0.25 A TMS = 0.25 s	I_{set} = 630 A I_{pickup} = 1.57 A TMS = 0.22 s

Table 4 explains the differences in the results of the adjustment values with the analysis performed. The TMS value in the OCR relay of the NR PCS978 relay has a time difference of 0.66 seconds. This is affected by the magnitude of the short circuit fault current obtained. The difference in the TMS value in the GFR relay of the PCS978 NR Relay with the conditions in the field and analysis also has a difference in working time. The difference in TMS value is 0.3 seconds because the TMS value determination system is based on the amount of short fault current that occurs when the system experiences a one-phase short circuit to the ground. For the TMS value, the Siemens Reyrolle relay at OCR has a TMS difference of 0.19 seconds. As for the GFR Relay at Siemens, Reyrolle has a TMS time difference of 0.05 seconds. This difference occurs because the analysis is carried out using a different system from those in the field. The difference between field data and the results of the analysis can be seen from the TMS value. The difference in TMS value is caused by the assumption of fault currents that occur both for two-phase disturbances for OCR and one-phase for GFR.

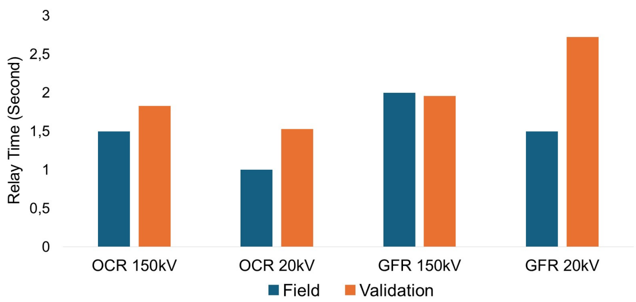

Figure 11. Comparison of Relay Working Time

Based on the Electrical Power Company transformer protection and control maintenance manual, the working time of the OCR relay at 150 kV transformer is a maximum of 1.5 seconds, while for incoming 22 kV the maximum time is one second, while the working time of the GFR relay at 150 kV transformer is two seconds, according to the type of transformer used, and for incoming 22 kV the working time of the relay is 15.5 seconds. Figure 11 for OCR 150 kV works with a working time of 1.83 seconds with a fault current of 17 kA, while OCR of 22 kV with a relay working time of 1.63 seconds with a fault current that occurs is 11.51 kA. For GFR 150 kV the working time is 1.92 seconds with a fault current of 6.4 kA, while for GFR 22 kV it works with a time of 2.72 seconds with a fault current that occurs of 1061 Ampere.

CONCLUSION

The protection system that has been installed, it can be connected and distributed to customers. OCR and GFR adjustment values on the 60 MVA power transformer of the BB Substation is already working according to SPLN standards. The TMS value in the OCR relay of the PCS978 NR relay has a time difference of 0.66 seconds, this is influenced by the magnitude of the short circuit fault current obtained. The difference in the TMS value in the GFR relay of the PCS978 NR Relay with the conditions in the field and analysis also has a difference in working time, the difference in TMS value is 0.3 seconds because the TMS value determination system is based on the amount of short fault current that occurs when the system experiences a one-phase short circuit to the ground. For the TMS value, the Siemens Reyrolle relay at OCR has a TMS difference of 0.19 seconds and for the GFR Relay at Siemens, Reyrolle has a TMS time difference of 0.05 seconds.

ACKNOWLEDGMENT

The authors gratefully thanks to God and would like to convey a great appreciation to PT. PLN (Persero) and also Department of Electrical Engineering, Faculty of Engineering, Universitas Riau, Indonesia for supporting this research.

REFERENCES

[1] BPS, Pertumbuhan Pelanggan Listrik Wilayah Riau. Pekanbaru, Badan Pusat Statistik, 2021.
[2] PLN, Buku Pedoman Pemeliharaan Proteksi dan Kontrol Transformator. Jakarta, Perusahaan Listrik Negara, 2014.
[3] NPFA, "Life Safety Code," 2018. https://up.codes/code/nfpa-101-life-safety-code-2018 (accessed October 20, 2023).
[4] Zulkarnain and Sepriadi, "Over Current Relay Coordination Analysis at the Indarung III Cement Mill PT. Semen Padang," Rang Tek. J., vol. 4, no. 1, pp. 42–51, 2021.
[5] H. Saadat, Power System Analysis. New York: McGraw-Hill, 1999.
[6] R. H. M. Noor, "Analysis of Over Current Relay Coordination for Phase and Ground Disturbances at PT. KPC," Institut Teknologi Nasional, 2017.
[7] A. S. Sampeallo, N. Nursalim, and P. J. Fischer, "Analysis of Short Circuit Faults in the Own Use Network of PLTU Bolok PT. SMSE (IPP) Unit 3 and Unit 4 Using Etap 12.6.0 Software," J. Media Elektro, vol. 8, no. 1, pp. 76–85, Apr. 2019.
[8] T. A. Al qoyyimi, O. Penangsang, and N. K. Aryani, "Determining the Location of Short Circuit Faults in the 20 kV Distribution Network Tegalsari Surabaya Feeder Using the GIS Based Impedance Method," J. Tek. ITS, vol. 6, no. 1, Mar. 2017.
[9] J. H. Harlow, Electrical Power Transformer Engineering, 3rd ed. New York, Taylor & Francis Group, 2012.
[10] Karyana, Sistem Proteksi Transmisi dan Gardu Induk Jawa Bali Edisi Pertama. Jakarta: PT. PLN (Persero), 2013.
[11] M. Madani, T. Suheta, and T. Odinanto, "Analysis of Over Current Relay (OCR) and Ground Fault Relay (GFR) Settings on 60 MVA Transformers in 150 KV GIS," Semin. Nas. Sains dan Teknol. Terap. VII 2019, pp. 683–690, 2019.
[12] I. K. W. Iswara, G. D. Arjana, and W. A. Wijaya, "Analysis of Safety Relay Settings Due to Reconfiguration at the Blahbatuh Feeder," J. Spektrum, vol. 2, no. 2, pp. 74–79, 2015.

[13] I. Gunawan, W. Rinas, and I. G. N. Janardana, "Analysis of Resetting Over Current Relay and Ground Fault Relay on 60 MVA 150/20 kV Transformer 20 KV Feeder Padang Sambian Main Substation", SPEKTRUM, vol. 5, no. 2, pp. 246–252, 2018.

[14] H. Y. Kustanto, M. Suyanto, and S. Hani, "Analysis of Over Current Relays and Ground Fault Relays on 60 MVA Power Transformers at Bantul 150 kV Substation Using the Etap Program," J. Elektro, vol. 1, no. 1, pp. 58–68, 2014.

[15] I. Abdullah, June Tyastuti, and S. Handoko, "Evaluation of OCR, GFR and Recloser Relay Settings After Distribution Network Reconfiguration at Transformer 2 of Srondol Semarang Substation Using Etap 12.6.0," TRANSIENT, vol. 5, no. 3, pp. 329–337, 2016.

[16] C. Fang, W. Yan, X. Zhiwei, and Y. Zili, "A Survey of Disconnecting Circuit Breaker's Application" in 2018 International Conference on Smart Grid and Electrical Automation (ICSGA), June. 2018, pp. 80–84.

[17] J. P. Barret, P. Bornard, and B. Mayer, Power System Simulation. London: Chapman & Hall, 1997.

[18] D. C. Idoniboyeobu, B. A. Wokoma, and V. C. Ibanibo, "Preventive Maintenance for Substation with Aging Equipment Using Weibull Distribution," Am. J. Eng. Res, vol. 7, no. 4, pp. 106–112, 2018.

BIOGRAPHIES OF AUTHORS

FIKRI FATWA ULHUDA received a bachelor's degree in the Department of Electrical Engineering from Universitas Riau, Pekanbaru, Indonesia, in 2023. His research interests include Power System Analysis, Software Engineering, and Intelligent Techniques.

AZRIYENNI AZHARI ZAKRI received her bachelor's degree from Universitas Bung Hatta (UBH), Padang, Indonesia. Her Master and Ph.D degree from Universitas Teknologi Malaysia (UTM), Johor Bahru, Malaysia, respectively. Since 1999 until now, she is Professor in the Electrical Department, Universitas Riau, Pekanbaru Indonesia. Her research interests include Energy Conservation, Power System Protection, PMU Measurement, Smart Grid, Distributed Generation, Intelligent Technique, and Energy Storage.

UMAIR ALI received his bachelor degree (BE) from NED University of Engineering and Technology Karachi, Pakistan and Master Degree from CECOS University of IT and Emerging Sciences Peshawar, Pakistan. Since December 2015 working as Electrical Engineering in different private organisations. Research interests are Renewable Energy resources and Energy storage, Power Systems protections and Smart Grid.