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Research Article

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Comparison of Over Current Relay Characteristics in Electric Power Protection Systems: A Comparison of Theory and Practice

Alex Sandria Jaya Wardhana[1,*], Eko Swi Damarwan[1], Muhammad Al Azis Bachrun[2] and Muhammad Luthfi Hakim[1]

[1]*Electrical Engineering Education Dept., Universitas Negeri Yogyakarta, Indonesia*
[2]*North Carolina State University, North Carolina, United States*

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Abstract

One of the most important protection elements in the power system is the Over Current Relay (OCR). This study aims to determine the differences in the characteristics of OCR in terms of theoretical based on the IEC 60255 standard compared to the results of practical trials using Relay SEPAM 1000+ T20. When the results of practical trials, current injection is carried out in the circuit. OCR characteristics that will be compared are standard inverse time, very inverse time, long inverse time, and extremely inverse time. The results showed that the average percentage difference between the calculation and theories on each OCR characteristic is less than 5%. The percentage difference in the standard inverse characteristic is 1.83%, Very inverse is 3.67%, Long time inverse is 1.57%, and extremely inverse is 4.47%. It can be concluded that there is no significant difference in OCR characteristics theoretically and practically.

Keywords: Comparison of Characteristics, Over Current relay, Inverse Time, Protection System

1. Introduction

The electric power system is a system consisting of various components that work together to generate, transmit, and distribute electrical energy from resources to end consumers. A protection system is needed to maintain the power system's reliability. The current Relay (OCR) is one of the most important protection elements in the power system. Its main function is to detect overcurrents that occur due to disturbances such as short circuits or overloads and then instruct the circuit breaker to disconnect the electricity to protect the equipment and prevent further damage. OCR characteristics greatly affect the performance and reliability of the protection system [1-3]. In the context of theory, OCR characteristics are designed based on basic electrical and mathematical principles that govern the relationship between current and disconnection time. There are several commonly used OCR characteristic curves, such as the standard inverse-time, inverse-time, and instantaneous-time curves. These curves determine how quickly the relay responds to overcurrent, considering various system parameters such as nominal current, safety factor, and other operating conditions [4,5].

However, in practice, OCR implementation does not always match the theory. Various factors such as field conditions, component quality, equipment calibration, and environmental influences can cause differences between the theoretical and actual performance of OCR. In addition, technological modernization and developments in digital engineering and programming have introduced more advanced OCR with automatic adjustment capabilities and real-time data analysis, which adds complexity to the comparison between theory and practice [6,7].

Although the theoretical OCR settings are well established based on the IEC 60255 standard, in practice, various factors such as component calibration, environmental conditions, and hardware limitations may cause measurable deviations [8,9]. These practical challenges call for relay calibration and optimization based on real-world performance rather than relying solely on theoretical values. Therefore, a comparative study between the theoretical and practical characteristics of OCR is important to identify the differences and gaps, while finding solutions to minimize these deviations [3], [10]. By understanding the dynamics of OCR in power systems more deeply, this research is expected to make a significant contribution in improving the reliability and efficiency of protection systems, so that the entire power system can operate more optimally and in accordance with actual conditions in the field.

This research will discuss various aspects of OCR characteristics, both in terms of theory and practice. In the first part, the basic concepts and theories underlying OCR operations will be reviewed, including the types of characteristic curves that are commonly used. Furthermore, this research will compare empirical data from OCR implementation in the field with the existing theory, using case studies and field data analysis. In this research, the OCR characteristics used are the IEC 60255 standard. Finally, this research will offer recommendations to address the gap between theory and practice, as well as consider the latest technological developments in power protection systems. In this study, the SEPAM 1000+ T20 relay that is given a current injection is used.

*E-mail address: alexwardhana@uny.ac.id

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2. Methods

The method used in this research uses a comparison between OCR characteristics. The first step is to conduct a literature study related to OCR characteristics. The second step is to formulate the type of OCR characteristics that will be compared. Next, determine the reference standard, namely IEC. Next determine the parameters of fault current and TMS value. Then perform theoretical calculations. Conducting OCR trials SEPAM 1000 + T20. The next step compares the results between the theoretical calculations with the test results. Calculate the percentage difference between theoretical results and practice. In detail, this research method is shown in Figure 1. To ensure accuracy in testing, the experiment was conducted with attention to potential sources of deviation such as environmental temperature, hardware response delay, and calibration inconsistencies. Future tests are recommended to be carried out in climate-controlled laboratories using certified measurement devices and automatic data loggers to minimize human and instrument errors [11].

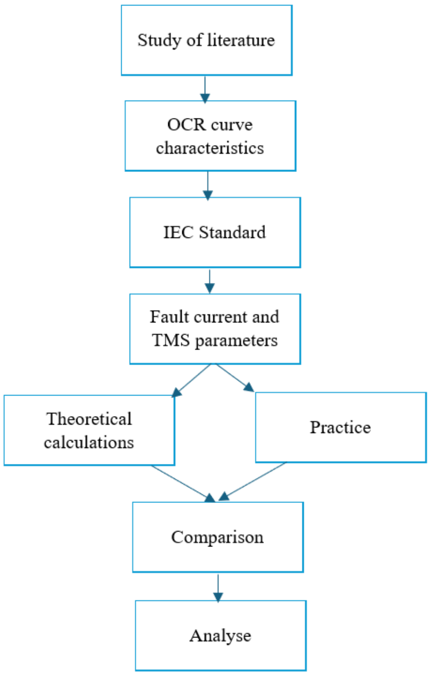

Fig. 1. Research method

In this research, the selected OCR curve characteristics are standard inverse time, very inverse time, long inverse time, and extremely inverse time. The OCR circuit configuration is shown in Figure 2 below.

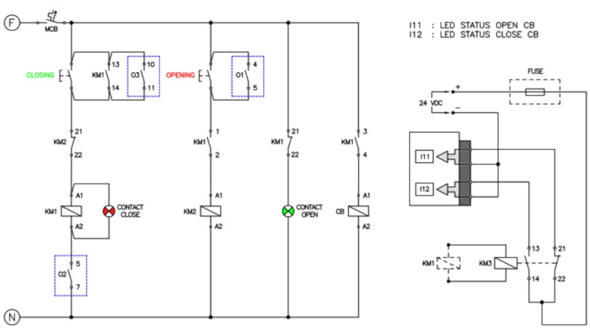

Fig. 2. The OCR circuit configuration

3. Result and Discussion

This study did not previously elaborate comparisons with other experimental findings. For example, [8] reported deviations between 3–7% depending on load conditions and current injection methods. Similarly, [12] observed that OCRs in microgrid networks exhibited theoretical-practical deviations due to local load fluctuations and distributed generation interaction. Compared to these, the <5% deviation in our results shows competitive performance and alignment with recent literature.

Although the average percentage deviation between theoretical and practical results is below 5%, it is essential to analyze the possible sources of deviation to improve experimental data validity. Environmental temperature variation during testing may significantly impact system impedance and relay thermal performance, affecting relay operation time. Additionally, inaccurate calibration of the SEPAM 1000+ T20 relay may shift pickup current and TMS settings. Even with modern digital relays, tolerances in time and current measurements remain. Measurement tools such as external ammeters or timers may also contribute to errors, especially at high currents where resolution is critical. To enhance accuracy, future experiments should be conducted in temperature and humidity-controlled laboratories using certified instruments and automated data loggers to reduce human error.

The results are consistent with prior studies. For instance, [13] reported performance differences across relay manufacturers even when identical TMS and Ir values were used. These variations stem from internal firmware and algorithmic differences, highlighting the need for platform-specific relay coordination planning.

The SEPAM 1000+ relay used in this research is a digital device based on IEC standards. However, other manufacturers such as Siemens (SIPROTEC), ABB (REF615), and GE (Multilin) incorporate different internal algorithms and thermal compensations. [18] showed that Siemens SIPROTEC relays operated 8–12% faster under extremely inverse characteristics than MiCOM relays, despite both complying with IEC. Additionally, AI and fuzzy-logic-based relays have emerged, demonstrating deviation reduction below 2%. Expanding this study to include multiple relay types would provide broader insights into OCR behavior in practical systems.

These findings have significant implications for OCR deployment in real-world power systems, particularly in medium-voltage distribution and industrial grids. The small deviation between theoretical and practical results enables these findings to serve as preliminary references for field relay settings prior to fine-tuning during commissioning. In utility systems, using theoretical settings as initial estimates can accelerate installation and reduce engineering costs. Nguyen et al., reported a 20% reduction in commissioning time when practical settings closely matched initial configurations [14].

Relay coordination is a critical aspect of protection systems. The low deviation in this study indicates that theoretical IEC 60255-based coordination schemes remain effective, especially in conventional systems. However, for more complex networks with high DG penetration, the adoption of dual-setting or adaptive relays is recommended to maintain selectivity and prevent maloperation. These results support IEC standard usage while highlighting the future need for smarter and more flexible protection systems.

This research has yet to explore how relay settings can be optimized to enhance protective performance. Optimization involves improving selectivity, sensitivity, and response time. For instance, adjusting the pickup current (Ir) based on dynamic load profiles can minimize nuisance tripping without sacrificing protection. According to [6] demonstrated that load-adaptive Ir adjustments reduce false trips. Moreover, Time Multiplier Setting (TMS) optimization is vital for coordination between main and backup relays. According to [12] found that evolutionary TMS optimization reduced response time by 12% and improved selectivity by 20%. Using this study's deviation data, TMS and Ir values can be reassessed and fine-tuned through system simulations.

This study focused on theoretical vs. practical comparison but did not explicitly discuss hardware or firmware constraints in SEPAM 1000+ T20 relays. Relay hardware may introduce timing inaccuracies due to analog-to-digital conversion delays, especially in older digital relay generations. Firmware plays a vital role in interpreting IEC curve characteristics. Some relays simplify inverse-time algorithms for processing efficiency, leading to subtle deviations from standards. Based on a study [15] found that fuzzy-logic-based firmware yielded more accurate and adaptive responses than conventional static lookup tables. SEPAM 1000+ limitations in signal processing and firmware versioning could contribute to deviations, even within acceptable tolerance.

Relay type and manufacturer significantly affect experimental outcomes due to differing implementations of inverse-time curves and internal algorithms. For instance, Siemens SIPROTEC uses polynomial interpolation for curve fitting, while Schneider's MiCOM applies linear segmentation. Despite identical TMS and Ir, this results in varying response times. According to [13] found SIPROTEC relays operated 8–10% faster than ABB's REF615 under extremely inverse settings. Thus, while this study's findings are valid for SEPAM 1000+, generalizing to broader protection schemes requires further investigation using various relay platforms.

This section will explain the comparison between theoretic calculations and practical results of OCR characteristics, namely standard inverse time, very inverse time, long inverse time, and extremely inverse time. The calculation standard used is the IEC 60255 standard. Furthermore, a comparison is also made on the four OCR characteristics in practice. Activities during data collection are shown in Figure 3 below.

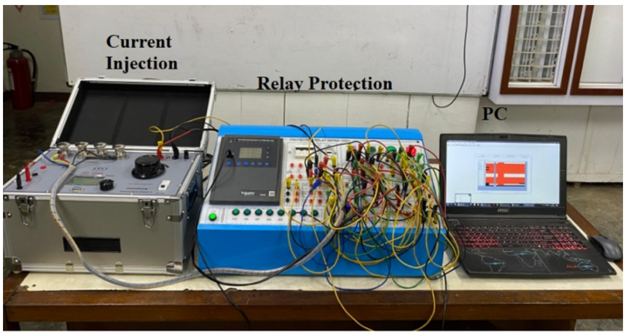

Fig. 3. Data collection process

3.1. Comparison of standard inverse time

Standard Inverse Time (SIT) in overcurrent relays is a characteristic where the relay disconnection time is inversely proportional to the magnitude of the detected overcurrent. That is, the greater the current that exceeds the pickup current setting, the faster the relay will break the circuit. This helps protect the power system from damage caused by overcurrent, such as in short circuit or overload conditions [8] [16-18]. According to the IEC standard, the determination of the disconnection time (t) is determined by the following equation 1.

$$t = TMS \times \frac{0{,}14}{Ir^{\,0{,}02} - 1} \qquad (1)$$

In the above formula, TMS is the time multiple setting (in this experiment, it is set at a value of 1) and Ir is the overcurrent set on the OCR. Comparison between theoretical calculations and practical trial results on the standard inverse time characteristics are shown in Table 1 below.

Table 1. Comparison of standard inverse time

Ihs/ Is	Fault Current (A)	Calculation T (s)	Practice T (s)	Differences (%)
1,5	3	17,1942	16,6630	3,09
2	4	10,0290	10,1550	1,26
3	6	6,3019	6,4613	2,53
4	8	4,9798	4,9320	0,96
5	10	4,2797	4,4067	2,97
7	14	3,5277	3,5225	0,15
8	16	3,2968	3,3949	2,98
9	18	3,1163	3,1390	0,73
10	20	2,9706	3,0275	1,92
11	22	2,8498	2,9075	2,03
12	24	2,7476	2,7015	1,68
		Average differences		**1,84**

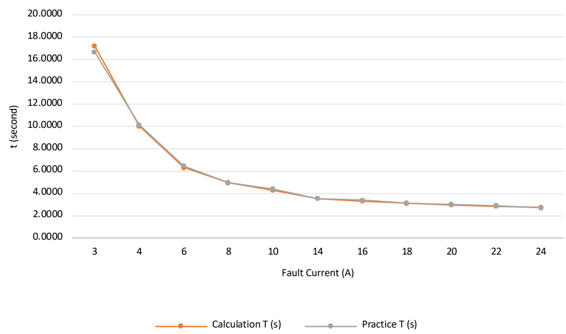

Fig. 4. Time inverse standard curve

Based on Table 1 above, it can be explained that the fault current used ranges from 3 A to 24 A. At a fault current of 3 A, a calculation T of 17, 1942 seconds is obtained while during practice a T value of 16.6630 seconds is obtained. The percentage difference between theory and practice is obtained by 3.09%. At a fault current of 24 A, the calculation T is 2.7476 seconds while the practice obtained a T value of 2.7015 seconds. The percentage difference between theory and practice is 1.68%. In the standard inverse time an average difference t of 1.84%. A comparison picture of the standard inverse time curve is shown in Figure 4.

3.2. Comparison at very inverse time

Very Inverse Time (VIT) is one of the time characteristics of over current relays used in power protection systems. In relays with very inverse time characteristics, the relay disconnection time has a steeper relationship to overcurrent compared to standard inverse time relays. This means that the relay will react faster at higher overcurrents, providing a higher level of protection for severe fault conditions [15], [19-22]. According to the IEC standard, the determination of the disconnection time (t) is determined by the following equation 2.

$$t = TMS \times \frac{13{,}5}{I_r - 1} \tag{2}$$

In the above formula TMS is the time multiple setting which is set at a value of 1 and Ir is the overcurrent set on the OCR. Comparison between theoretical calculations and practical trial results on very inverse time characteristics is shown in Table 2.

Table 2. Comparison on very inverse time

Ihs/ Is	Fault Current (A)	Calculation T (s)	Practice T (s)	Differences (%)
1,5	3	27,0000	26,1800	3,04
2	4	13,5000	13,4520	0,36
3	6	6,7500	7,0234	4,05
4	8	4,5000	4,4178	1,83
5	10	3,3750	3,2008	5,16
7	14	2,2500	2,2441	0,26
8	16	1,9286	2,0157	4,52
9	18	1,6875	1,7670	4,71
10	20	1,5000	1,5944	6,29
11	22	1,3500	1,4230	5,41
12	24	1,2273	1,2860	4,79
		Average differences		**3,67**

Based on Table 2 above, it can be explained that the fault current used ranges from 3 A to 24 A. At a fault current of 3 A, a calculation T of 27 seconds is obtained while during practice a T value of 26.1800 seconds is obtained. The percentage difference between theory and practice is obtained by 3.04%. At a fault current of 24 A, the calculation T is obtained at 1.2273 seconds while the practice obtained a T value of 1.2860 seconds. The percentage difference between theory and practice is 4.79%. At the inverse time obtained an average difference t of 3.67%. A comparison picture of the very inverse time curve is shown in Figure 5.

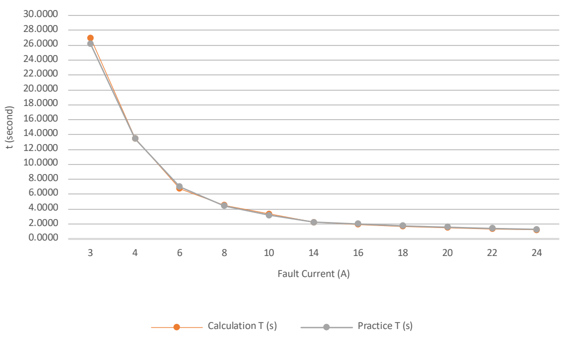

Fig. 5. Very inverse time curve

3.3. Long time inverse comparison

Long Time Inverse (LTI) is one of the time characteristics in over current relays used in electrical power protection systems. This characteristic is designed to provide a longer disconnection time at low overcurrents, but still operate faster at higher overcurrents. Long Time Inverse relays are usually used to protect against overload conditions that last for a relatively long time, as can occur in power distribution systems [23-25]**.** According to the IEC standard, the determination of the disconnection time (t) is determined by the following Equation 3.

$$t = TMS \times \frac{80}{Ir^2 - 1} \tag{3}$$

In the above formula TMS is the time multiple setting which is set at a value of 1 and Ir is the overcurrent set on the OCR. Comparison between theoretical calculations and practical test results on long time inverse characteristics is shown in Table 3.

Table 3. Comparison of long time inverse

Ihs/ Is	Fault Current (A)	Calculation T (s)	Practice T (s)	Differences (%)
1,5	3	223,2000	219,4600	1,68
2	4	111,6000	110,0000	1,43
3	6	55,8000	54,2370	2,80
4	8	37,2000	36,1000	2,96
5	10	27,9000	28,2210	1,15
7	14	18,6000	18,1560	2,39
8	16	15,9429	16,2360	1,84
9	18	13,9500	13,8510	0,71
10	20	12,4000	12,1860	1,73
11	22	11,1600	11,2020	0,38
12	24	10,1455	10,1250	0,20
		Average differences		**1,57**

Based on table 3 above, it can be explained that the fault current used ranges from 3 A to 24 A. At a fault current of 3 A, a calculation T of 223.2 seconds is obtained, while during practice a T value of 219.4600 seconds is obtained. The percentage difference between theory and practice is 1.68%. At a fault current of 24 A, the calculation T is obtained at 10.1455 seconds while the practice obtained a T value of 10.1250 seconds. The percentage difference between theory and practice is 0.20%. In he long time inverse obtained average diffences t of 1.57%. A comparison picture of the long time inverse curve is shown in Figure 6.

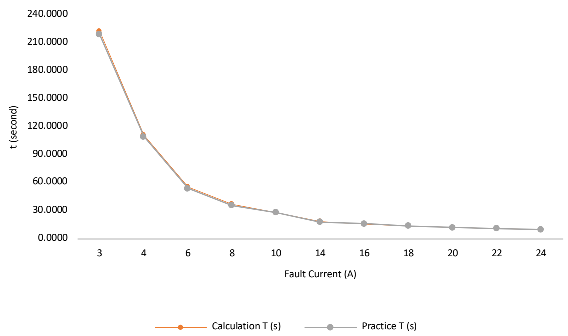

Fig. 6. Long tme inverse curve

3.4. Comparison on Extremely inverse time

Extremely Inverse Time (EIT) is one of the time characteristics on over current relays used in electric power protection systems. Relays with extremely inverse time characteristics are designed to provide a very fast response to high overcurrents, while providing a longer disconnection time at lower overcurrents [11], [13,14]. This makes this relay very effective in protecting the system from severe disturbances [26, 27]. According to the IEC standard, the determination of the disconnection time (t) is determined by the following Equation 4.

$$t = TMS \times \frac{120}{I_r - 1} \tag{4}$$

In the above formula, TMS is the time multiple setting which is set at a value of 1 and Ir is the overcurrent set on the OCR. A comparison between theoretical calculations and practical trial results on Extremely inverse time characteristics is shown in Table 4.

Table 4. Comparison of Extremely inverse time

Ihs/ Is	Fault Current (A)	Calculation T (s)	Practice T (s)	Differences (%)
1,5	3	64,1584	61,0710	4,81
2	4	26,7327	25,8940	3,14
3	6	10,0248	10,5810	5,55
4	8	5,3465	5,2901	1,06
5	10	3,3416	3,6035	7,84
7	14	1,6708	1,6780	0,43
8	16	1,2730	1,2356	2,94
9	18	1,0025	0,9185	8,38
10	20	0,8101	0,8353	3,11
11	22	0,6683	0,6957	4,10
12	24	0,5608	0,6049	7,86
		Average differences		**4,47**

Based on Table 4 above, it can be explained that the fault current used ranges from 3 A to 24 A. At a fault current of 3 A, a calculation T of 64.1584 seconds is obtained while during practice a T value of 61.0710 seconds is obtained. The percentage difference between theory and practice is obtained by 4.81%. At a fault current of 24 A, the calculation T is obtained at 0.5608 seconds while the practice obtained a T value of 0.6049 seconds. The percentage difference between theory and practice is 7.86%. At Extremely inverse time obtained average diffences t of 4.47%. The comparison picture of the extremely inverse time curve is shown in Figure 7.

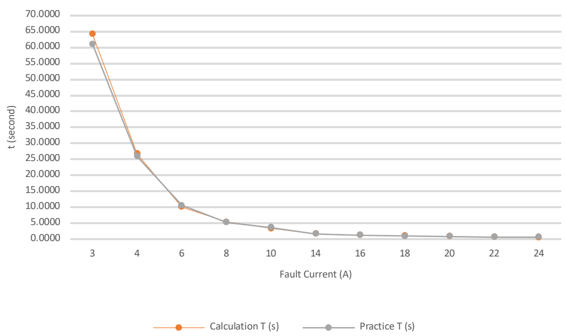

Fig. 7. Kurva Extremely inverse time

Based on the four types of characteristics of OCR, the average difference value between the theoretical and practical calculations is below 5%. This means that there is no significant difference between the theoretical calculation and the practical test results. In detail, the percentage difference between the theoretical calculation and the results of the practical test on each characteristic of OCR is shown in Figure 8.

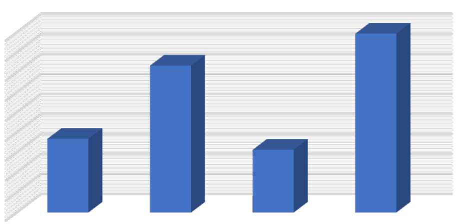

Fig. 8. Percentage difference between theory and practice

Of the four characteristics of OCR, each has its own characteristics and uses [9]. The Inverse time standard on over current relays is a characteristic where the relay disconnection time is inversely proportional to the magnitude of the detected overcurrent. That is, the greater the current that exceeds the pickup current setting, the faster the relay will break the circuit. In relays with very inverse time characteristics, the relay disconnection time has a steeper relationship to the overcurrent compared to standard inverse time relays. This means that the relay will react faster at higher overcurrents, providing a higher level of protection for severe fault conditions. Long Time Inverse characteristics are designed to provide longer disconnection times at low overcurrents, but still operate faster at higher overcurrents. Long Time Inverse relays are usually used to provide protection against overload conditions that last for a relatively long time. Meanwhile, relays with extremely inverse time characteristics are designed to provide a very fast response to high overcurrents, while providing a longer disconnection time at lower overcurrents. A picture of the disconnection time curve for the four characteristics according to IEC standards is shown in Figure 9.

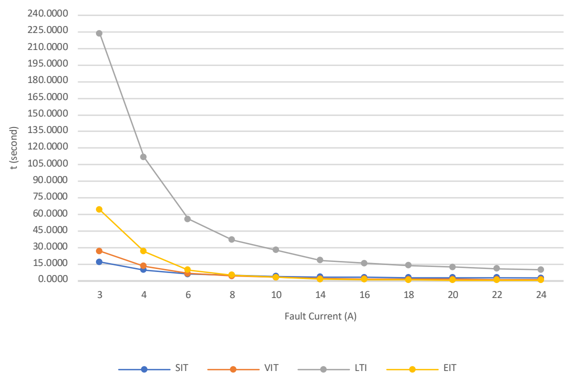

Fig. 9. Comparison of OCR characteristics

4. Conclusions

One of the most important protection elements in the power system is the Over Current relay (OCR). Its main function is to detect overcurrents that occur due to disturbances such as short circuit or overload, and then command the circuit breaker to cut off the flow of electricity to protect the equipment. OCR has several types and characteristics. In this research, the OCR characteristics that will be compared are standard inverse time, very inverse time, long inverse time, extremely inverse time. The standard used is IEC 60255. The standard inverse time characteristic is a characteristic in which the relay disconnection time is inversely proportional to the magnitude of the detected overcurrent. That is, the greater the current that exceeds the pickup current setting, the faster the relay will break the circuit. The very inverse time characteristic, the relay disconnection time has a steeper relationship to the overcurrent compared to the standard inverse time relay. The relay will react faster at higher overcurrents, providing a higher level of protection for severe fault conditions. Long Time Inverse characteristics are designed to provide longer disconnection times at low overcurrents, but still operate faster at higher overcurrents. Long Time Inverse relays are usually used to provide protection against overload conditions that last for a relatively long time. The extremely inverse time characteristic is designed to provide a very fast response to high overcurrents, while providing a longer disconnection time at lower overcurrents. The results of this study show that the average percentage difference between calculations and theory on each OCR characteristic is less than 5%. The percentage difference in the standard inverse characteristic is 1.83%, Very inverse is 3.67%, Long time inverse is 1.57% and extremely inverse is 4.47%. It can be concluded that there is no significant difference in OCR characteristics theoretically and practically. Despite the minimal deviation found in this study, it is important to recognize that relay optimization through adaptive settings (e.g., dynamic TMS and Ir adjustments) could enhance system protection, particularly in modern grids with renewable penetration. Leveraging algorithms like fuzzy logic, as shown by [15], can further improve relay responsiveness and reliability.

References

[1] H. C. Kiliçkiran, İ. Şengör, H. Akdemir, B. Kekezoğlu, O. Erdinç, and N. G. Paterakis, "Power system protection with digital overcurrent relays: A review of non-standard characteristics," *Elect. Power Sys. Res.*, vol. 164, pp. 89–102, Nov. 2018, doi: 10.1016/j.epsr.2018.07.008.

[2] A. Darabi, M. Bagheri, and G. B. Gharehpetian, "Highly sensitive microgrid protection using overcurrent relays with a novel relay characteristic," *IET Renew. Power Gen.*, vol. 14, no. 7, pp. 1201–1209, May 2020, doi: 10.1049/iet-rpg.2019.0793.

[3] M. Y. Suliman and M. Ghazal, "Design and Implementation of Overcurrent Protection Relay," *J. Electr. Eng. Technol.*, vol. 15, no. 4, pp. 1595–1605, Jul. 2020, doi: 10.1007/s42835-020-00447-0.

[4] R. Hemmati and H. Mehrjerdi, "Non-standard characteristic of overcurrent relay for minimum operating time and maximum protection level," *Simul. Model. Pract. Theory*, vol. 97, Dec. 2019, Art. no. 101953, doi: 10.1016/j.simpat.2019.101953.

[5] M. H. Hussain, S. R. A. Rahim, and I. Musirin, "Optimal Overcurrent Relay Coordination: A Review," *Procedia Engineer.*, vol. 53, pp. 332–336, Nov. 2013, doi: 10.1016/j.proeng.2013.02.043.

[6] S. D. Saldarriaga-Zuluaga, J. M. López-Lezama, and N. Muñoz-Galeano, "Optimal coordination of over-current relays in microgrids considering multiple characteristic curves," *Alexandria Engin. J.*, vol. 60, no. 2, pp. 2093–2113, Apr. 2021, doi: 10.1016/j.aej.2020.12.012.

[7] A. R. Al-Roomi and M. E. El-Hawary, "Optimal coordination of directional overcurrent relays using hybrid BBO-LP algorithm with the best extracted time-current characteristic curve," in *2017 IEEE 30th Canadian Conf. Electr. Comput. Engin. (CCECE)*, Windsor, ON: IEEE, Apr. 2017, pp. 1–6. doi: 10.1109/CCECE.2017.7946625.

[8] F. Alasali *et al.*, "The recent development of protection coordination schemes based on inverse of AC microgrid: A review," *IET Generation Trans. Dist.*, vol. 18, no. 1, pp. 1–23, Jan. 2024, doi: 10.1049/gtd2.13074.

[9] R. Tiwari, R. K. Singh, and N. K. Choudhary, "Coordination of dual setting overcurrent relays in microgrid with optimally determined relay characteristics for dual operating modes," *Prot. Control Mod. Power Sys.*, vol. 7, no. 1, Dec. 2022, Art. no. 6., doi: 10.1186/s41601-022-00226-1.

[10] H. Prasetijo and D. T. Nugroho, "Overcurrent relays coordination : comparison characteristics standar inverse, very inverse and extremly inverse," *J. Phys.: Conf. Ser.*, vol. 1367, no. 1, Nov. 2019, Art. no. 012051, doi: 10.1088/1742-6596/1367/1/012051.

[11] M.-S. Kim, G.-J. Cho, C.-H. Kim, and J.-S. Chai, "New protective relay modeling scheme and analysis for AC electric railway feeding systems with Scott transformer," *Int. J. Electr. Power Ener.Sys.*, vol. 123, Dec. 2020, Art. no. 106226, doi: 10.1016/j.ijepes.2020.106226.

[12] M. F. Kotb, M. El-Saadawi, and E. H. El-Desouky, "Over Current Protection Relay using Arduino Uno for Future Renewable Electric Energy Delivery and Management (FREEDM) System," *European J. Electr. Engin. Comp. Sci.*, vol. 2, no. 5, Aug. 2018, doi: 10.24018/ejece.2018.2.5.39.

[13] R. Jalilzadeh Hamidi, A. Ahmadian, R. Patil, and A. Asadinejad, "Optimal time-current graded coordination of multistage inverse-time overcurrent relays in distribution networks," *Int Trans Electr Energ Syst*, vol. 29, no. 5, May 2019, Art. no. e2841, doi: 10.1002/2050-7038.2841.

[14] A. V. Nguyen, L. B. Nguyen, and A. Hoang, "A Numerical Relay Implementation for Overcurrent Protection Based on ARM Cortex – M4 Microprocessor," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 752, no. 1, Jan. 2020, Art. no. 012005, doi: 10.1088/1757-899X/752/1/012005.

[15] A. E. C. Momesso, W. M. S. Bernardes, and E. N. Asada, "Fuzzy adaptive setting for time-current-voltage based overcurrent relays in distribution systems," *Int. J. Electr. Power Ener. Sys.*, vol. 108, pp. 135–144, Jun. 2019, doi: 10.1016/j.ijepes.2018.12.035.

[16] A. Tyagi, Y. Bhandari, K. Verma, and V. Gulati, "Inverse Time Overcurrent Relaying Decision for Protection of Three Phase Transmission Line," in *2022 IEEE 10th Power India Int. Conf. (PIICON)*, New Delhi, India: IEEE, Nov. 2022, pp. 1–5. doi: 10.1109/PIICON56320.2022.10045238.

[17] W. Wahyono, "Reverse Time During Current Relay Performance to Support the Protection System Practicum," *Eksergi: J. Tekn.Ener.*, vol. 18, no. 2, pp. 142–147, May 2022.

[18] S. Syukriyadin, I. D. Sara, and F. Mashuri, "Design of a Digital Standard Inverse Overcurrent Relay Using Arduino Uno as a Microcontroller," in *2018 Int. Conf. Electr. Engin. Inform. (ICELTICs)(44501)*, Banda Aceh: IEEE, Sep. 2018, pp. 45–50. doi: 10.1109/ICELTICS.2018.8548835.

[19] T. Soleymani Aghdam, H. Kazemi Karegar, and H. H. Zeineldin, "Optimal Coordination of Double-Inverse Overcurrent Relays for Stable Operation of DGs," *IEEE Trans. Ind. Inf.*, vol. 15, no. 1, pp. 183–192, Jan. 2019, doi: 10.1109/TII.2018.2808264.

[20] S.-H. Lim and S.-T. Lim, "Analysis on Coordination of Over-Current Relay Using Voltage Component in a Power Distribution System With a SFCL," *IEEE Trans. Appl. Supercond.*, vol. 29, no. 5, pp. 1–5, Aug. 2019, doi: 10.1109/TASC.2019.2904668.

[21] N. Emmanuel, H. N. Amadi, and D. J. Horsfall, "Enhancing Electrical System Reliability Through Advanced Relay Coordination Techniques: A Focus on Indorama Fertilizer and Chemicals Limited," *Int. J. Eng. Modern Techn.*, vol. 10, no 7, pp. 127–139, Jul. 2024.

[22] A. Kakilli and U. Kesen, "Examination of Electromechanical Over-Current Relay Characteristics By Using Experimental and ANN Methods," *Int. J. Eng. Res. Applic.*, vol. 8, no. 2, pp. 1–6, Feb. 2018.

[23] E. S. Nasution, F. I. Pasaribu, and M. H. Hidayat, "Studi Proteksi Sistem Tenaga Listrik Pada Trafo 1600 kVA Menggunakan Current Relay IWU 2-3," *J. Mesil*, vol. 2, no. 2, pp. 28–39, Dec. 2021, doi: 10.53695/jm.v2i2.562.

[24] M. A. Bayu, N. Arif, and H. Nirwana, "Analisa Penggunaan Recloser 3 Phasa 20 Kv Penyulang Pajalau Untuk Pengaman Arus Lebih Pt. Pln (Persero) Ulp Kalebajeng," *J. Multidisiplin Saintek*, vol. 1, no. 3, pp. 1–20, Mar. 2023.

[25] R. Putri, E. Juliadi, M. Jannah, T. Zubaidah, D. R. Ramji, and W. K. A. Al-Ani, "Study Coordination Design of Over Current Relay on The Kiln Area Electrical System," *J. Renew Energ. Electric. Comp Eng*, vol. 1, no. 2, Sep. 2021, Art. no. 94, doi: 10.29103/jreece.v1i2.5570.

[26] D. K. Ibrahim, H. M. Sharaf, E. E.-D. A. El-Zahab, and H. H. Zeineldin, "Directional Inverse Time Overcurrent Relay for Meshed Distribution Systems with Distributed Generation with Additional Continuous Relay Settings," in *12th IET Int. Conf. Developm. Power Sys. Prot. (DPSP 2014)*, Copenhagen, Denmark: Institution of Engineering and Technology, 2014, p. 12.19-12.19. doi: 10.1049/cp.2014.0101.

[27] N. H. Hussin *et al.*, "Modeling and simulation of inverse time overcurrent relay using Matlab/Simulink," in *2016 IEEE Int. Conf. Automatic Control Intell. Sys, (I2CACIS)*, Selangor, Malaysia: IEEE, Oct. 2016, pp. 40–44. doi: 10.1109/I2CACIS.2016.7885286.