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Andalas Journal of Electrical and Electronic Engineering Technology

ISSN 2777-0079

Research Article

Design of Protection Relay Coordination Settings and Connecting to PLC Siemens S7-1500 For Load Shedding and HMI Display at PT. Semen Padang

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ARTICLE INFORMATION

Received: October 17, 2022
Revised: November 4, 2022
Available online: November 25, 2022

KEYWORDS

Electric Power System, Control System, PLC Siemens S7-1500, HMI, OCR dan Load Shedding.

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A B S T R A C T

There are some vital loads and must not extinguished on the production activities of PT. Semen Padang cause the operational costs to rerun are very large. To solve this problem, it is necessary to evaluate the coordination settings of protection relays and automatic control systems to supporting the production process of PT. Semen Padang so production efficiency can be maintained. The relay settings to be evaluated are inverse time and instantaneous overcurrent relays by coordinating the main relay, backup relay 1 and backup relay 2 from downstream to upstream load feeder. The designed control system is an automatic load shedding and HMI display that can visualizing the system in real time using the PLC Siemens S7-1500 with simulating on the PLCSimulator of the TIA Portal 15.1 software. Based on the calculations carried out, there are significant differences in the relay settings from the calculation results with the existing state. the relays installed in the system do not coordinate properly in the existing state, while after the calculation of the coordination relays the relays coordinate well. From the design of the control system, an automatic load shedding program and the display of the HMI system in real time were produced.

INTRODUCTION

In production activities at PT Semen Padang, there are several operating loads such as kiln areas, mines, raw mills, coal mills, cement mills, housing areas, pocketing, and factory lighting. Of these loads, there is a very vital load that should not be allowed to trip because the operational costs for re-running are very large such as the kiln area and priority loads related to K3 PT. Semen Padang employees such as housing area, head office, and factory lighting. Therefore, it is necessary to pay more attention so that the supply of electrical energy can be distributed to the maximum load and can minimize losses due to disturbances that may occur in the electric power distribution system [1].

In maintaining the effectiveness and efficiency of pt. Semen Padang needs periodic evaluation in the alignment of the existing protection system. existing protection system in the development substation system of PT. Semen Padang has several weaknesses that can interfere with production activities, especially in the current setting in the overcurrent relay (OCR) which does not coordinate with each other. Hence, an evaluation of the proper relay coordination settings is needed by looking at some requirements regarding the selectivity, sensitivity, reliability, and speed of work of the relay [2].

When there is an under-voltage, in the existing state that exists in the development substation system of PT. Semen Padang will be protected using an under-voltage relay (UVR) with a voltage setting of 90% of the nominal system voltage and a delay time of 1s on each feeder. This will also affect the effectiveness of production because with a decrease in the voltage value by 10%, the amount of current will increase by 10%. So that the lifetime of the equipment will be shorter [3].

In this study, an evaluation will be carried out on the protection system settings, especially in the overcurrent (OCR) relay. After that, an automatic load-shedding control system will be designed using Siemens S7-1500 PLC in protecting under-voltage interference in the PT development substation system. Semen Padang and an HMI display of the system that includes a real-time picture of the system, real-time data, and data records on the system.

https://doi.org/10.25077/ajeeet.v2i2.24

LITERATURE REVIEW

Overcurrent Relay

An overcurrent relay (OCR) is a relay that works with an increase in current that exceeds the setting value within a certain period of time. So that overcurrent relays can be used to secure overload and short circuit disturbances. The overcurrent relay operates when the current flowing in the system exceeds the setting limit on the relay. The application of overcurrent relays in industrial electrical systems should be adjusted based on relay coordination. So that this relay can be workers quickly and actually in case of disruption to the system [4].

Instantaneous overcurrent relay

Overcurrent relays that work directly or without delay time based on differences in fault current levels at different locations. This relay works will instantly the current flowing exceeds its setting value. Although theoretically the working time of the relay is equal to zero but in the work area close to the setting there is still a delay time of several milliseconds. The relay period from ¬pick-up until the completion of the relay work is very short which is 20 to 100 ms [4]–[6]. The characteristic curve of the instantaneous over current relay in Figure 1.

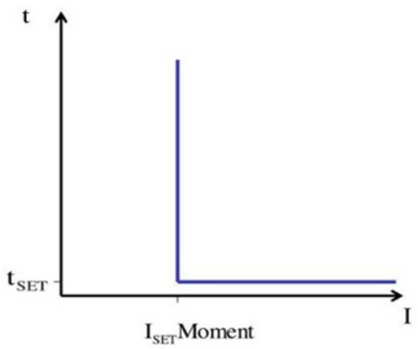

Figure 1. Instantaneous Over Current Relay Characteristic Curve

Definite time overcurrent relay

This definite time overcurrent relay works when the fault current exceeds the amount of current that has been set on the relay and will instruct the PMT to trip when the delay time setting has been reached. In other words, the overcurrent relay will not work until the delay time of the relay has not been reached even though the magnitude of the fault current continues to grow. The characteristic curve of the definite time over current relay in Figure 2.

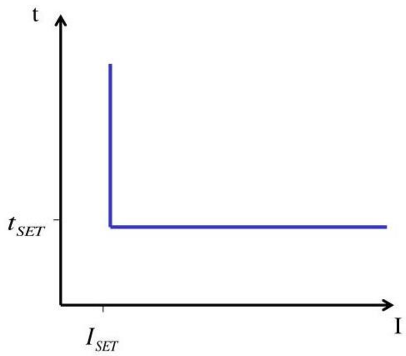

Figure 2. Definite Time Over Current Relay Characteristic Curve

Inverse time overcurrent relay

Relays with this characteristic of inverse time will work with a delay time that depends on the magnitude of the current in reverse (inverse time), the greater the current, the smaller the delay time will be. Inverse time overcurrent relays are grouped based on their delay time steepness characteristics namely normal inverse, very inverse, long inverse and definite time [7]–[9]. The characteristic curve of the inverse time over current relay in Figure 3.

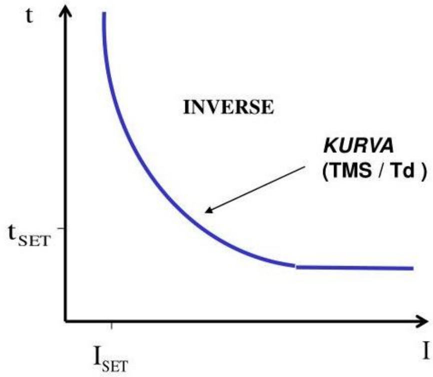

Figure 3. Characteristic Curve of Inverse Time Over Current Relay

Overcurrent Relay Settings

The current setting must be greater than the maximum load current. According to British BS standards 142-1983 [10]–[12], the setting limit is between 1.05–1.3 I_{set}. Referring to these standards and also how the state of the electrical system of the PT. Semen Padang, in this study was considered safer if using the constant 1.2 I_{set}. That way the current setting on the relay can be seen in the following equation.

$$I_{set} = 1.2 \text{ nominal} \quad (1)$$

$$I_s = \frac{I_{set}}{CT \text{ ratio}} \quad (2)$$

In the inverse time overcurrent relay setting, the working time is set based on the fault current felt by the relay. The greater the fault current, the faster the relay working time. The operation time on the inverse relay is calculated using the following equation.

$$t_{op} = \frac{0.14 \times TMS}{PSM^{0.02} - 1} \quad (3)$$

$$PSM = \frac{I_{fault}}{I_{pickup}} \quad (4)$$

Programmable Logic Controller (PLC)

Programmable logic controllers (PLCs) are electronic devices for controlling equipment used in real-time and are usually widely operated in industrial automation [13]–[16]. PLC has many input and output lines, so it can work with extreme conditions such as high temperatures, has immunity to electrical noise, and is resistant to vibration. The application of PLC aims to replace conventional control system control [17]–[19].

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Principle of PLC is that PLC will receive inputs coming from various sensors from the system and other signals. Such input signals are processed by PLC based on logic in the form of a specific programming language. Then the PLC will output in the form of a signal to control the equipment to be controlled. The output signal can be a signal that can turn on, off, mathematical operations, and various logical functions contained in the PLC. In general, the working principle of PLC can be seen in Figure 4.

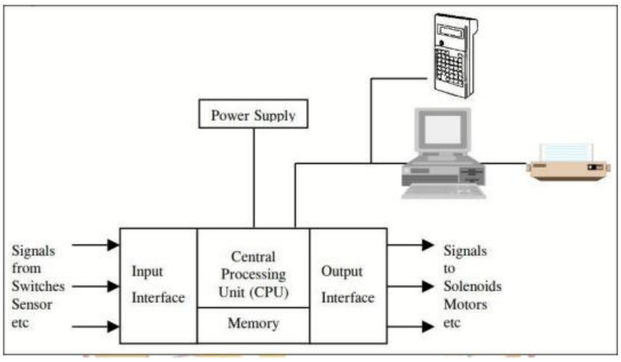

Figure 4. Working Principle of PLC

Human Machine Interface (HMI)

A system equipped with a Human machine interface (HMI) allows operators to see visualizations of processes that are happening in real time. Operators can also use HMI to change set points, quickly determine critical conditions, and analyze and display trend data.

METHOD

Single Line Diagram Modelling

In modeling a single line diagram in the ETAP 12.6 software, researchers adjusted the single line diagram modeled with a single line diagram from PT. Semen Padang. The data used in this modeling was also obtained from taking data directly at PT. Semen Padang. So that the results of the protection system design can be utilized in the substation system for the development of PT. Semen Padang. Modeling a single line diagram can be seen in Figure 5.

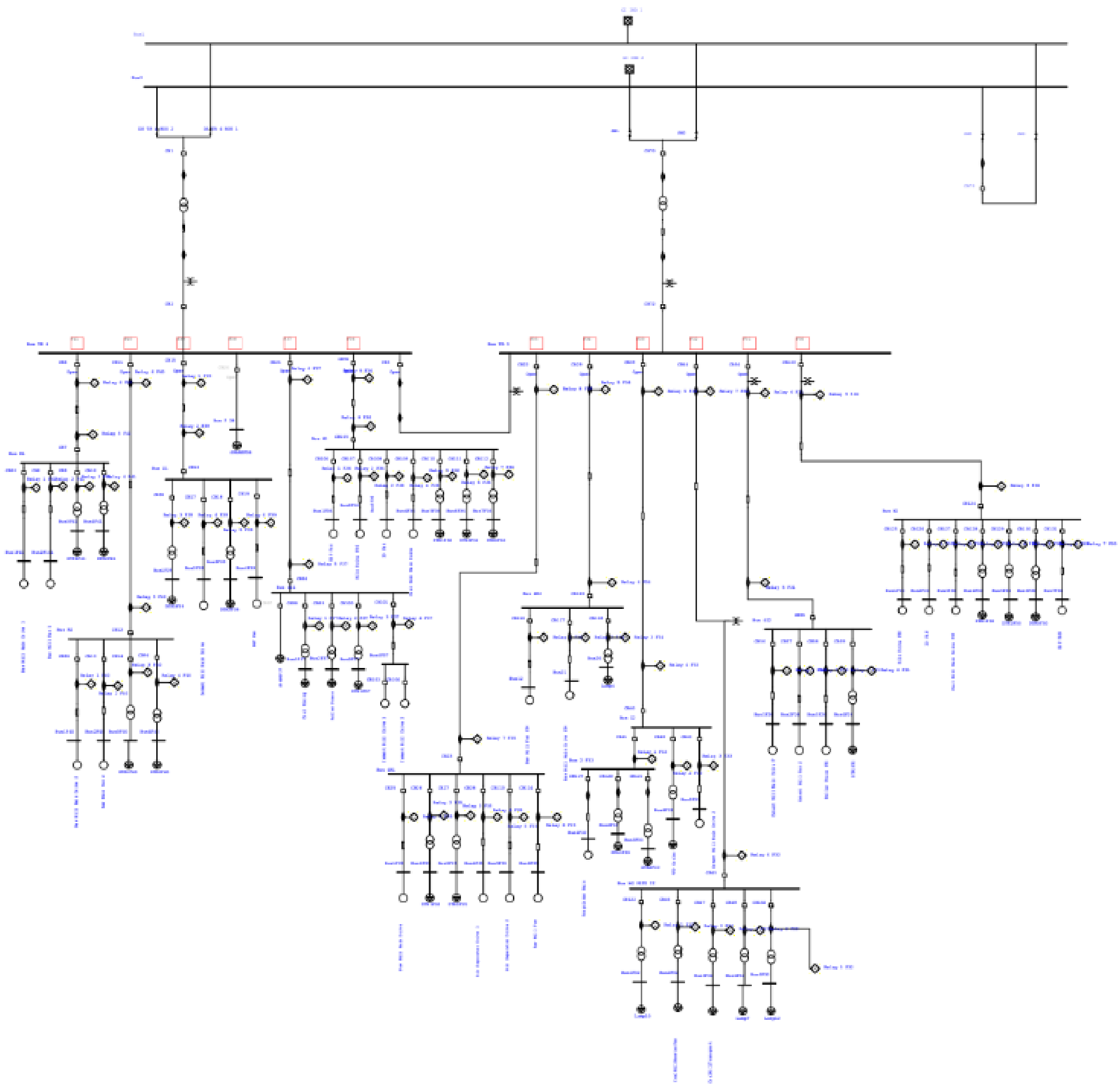

Figure 5. Single Line Diagram Modeling in ETAP 12.6 Software

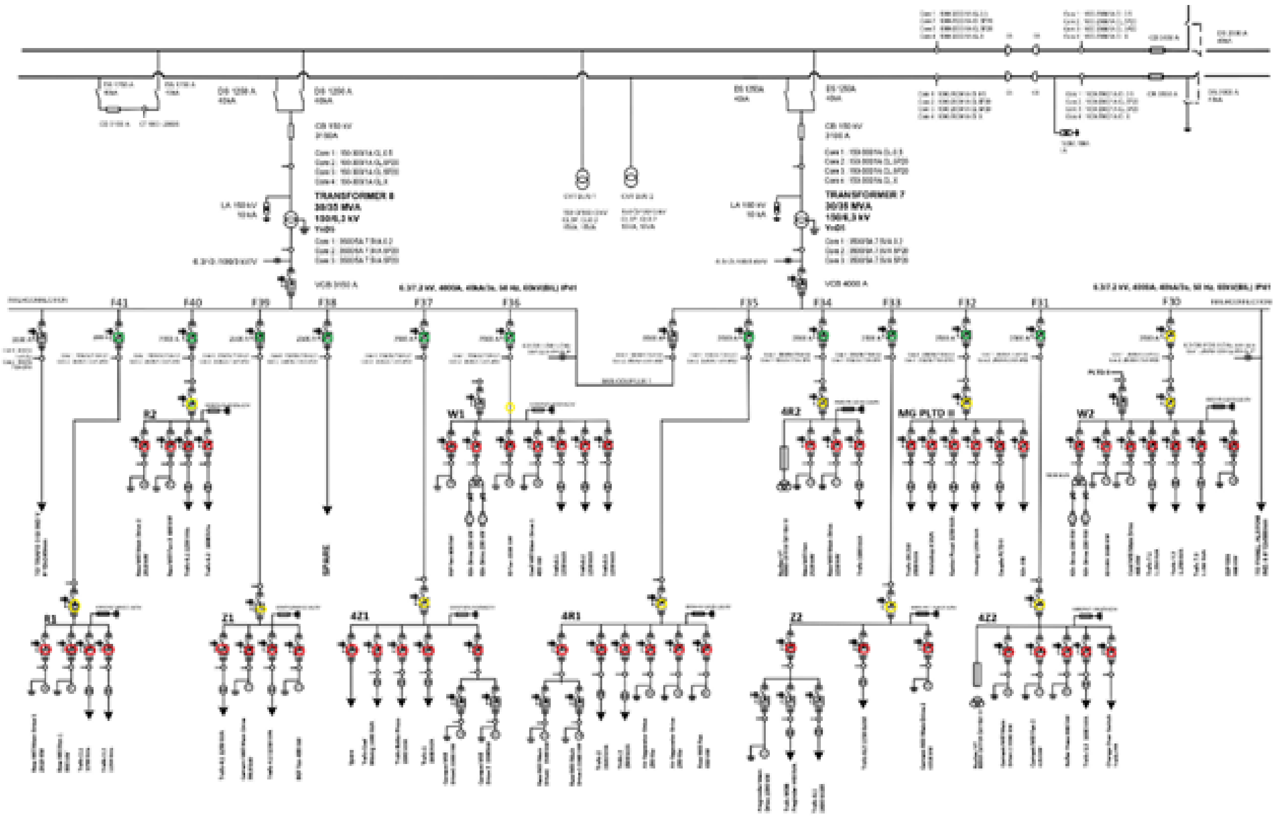

Figure 6. Relay Installation

Simulation and Coordination Analysis of Overcurrent Relay Protection Systems

In this study, a simulation of disturbances in the main bus in the development substation system was carried out in knowing how to coordinate the installation of overcurrent relays in each feeder. If the coordination of the protection relay is not as expected, it will be recalculated in determining the setting of the overcurrent relay.

Programming Methods

The programming carried out is in the form of PLC programming for automatic load shedding systems in protecting undervoltage disturbances and programming for the display of HMI data records and real-time data of the PT. Semen Padang. In this study, the PLC programming language used was the function block diagram language. The method of creating an automatic load shedding system program uses setpoint according to the nominal voltage of the system and also the voltage setpoint for each of the load shedding steps, where in this load shedding the author divides into four steps of load shedding. Furthermore, the HMI display of the load shedding program is modeled according to the single line diagram of the system used. After modeling the HMI display, the load shedding program is connected to the HMI by synchronizing the TAG on the load shedding program and the HMI.

The HMI program in displaying data records and real-time data of the system is designed by utilizing the IEC61580 communication protocol to retrieve the parameters that will be displayed on the HMI. The parameter data from the MVDB panel of each system feeder is mapped, then the data bits are input into the block function. The data bits that have been inputted are changed in data type to word so that they can be displayed on the HMI.

Program Testing

In testing the load shedding program, it was carried out by simulating the PLCSimulator feature in the TIA Portal V15.1 software. The simulation is carried out by entering the value of the system voltage at the setpoint the nominal voltage. The voltage value entered in the nominal voltage setpoint is the value of the load discharge voltage at each step to find out how the control system runs when an undervoltage fault occurs. The HMI data record display program and real time data were tested by directly running the program in the Center Control Room of the PT substation. Semen Padang. Then the data of these electrical parameters are recorded within a week.

RESULTS AND DISCUSSION

Overcurrent Relay Location

Overcurrent relays are used to secure short-circuit faults on each channel installed at the base of each channel. For the installation of relays divided into three, namely, the main relay is located on the incoming on each load, the backup relay 1 is located on the outgoing of the feeder close to the load bus and the backup relay 2 is located on the incoming of each feeder. The installation location of the relay can be seen in Figure 6.

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Comparison of Protection Relay Settings Based on Calculations and Existing Condition

This is because there are differences in the data used. There is a comparison of inverse time type overcurrent relay settings and instantaneous types of normal state and existing state In Tables 1 and 2.

Table 1. Comparison of Protection Inverse Time Relay Settings Based on Calculations and Existing Condition

Feeder Incoming	OCR Inverse Time			
	Calculation		Existing	
	Current Setting(I)	TMS	Current Setting (I)	TMS
R1	658.08	0.524	575	0.975
R2	624.00	0.532	575	0.975
Z1	730.56	0.489	650	1.015
4Z1	787.80	0.493	675	0.965
W1	685.20	0.506	550	1.005
4R1	768.60	0.500	625	0.945
4R2	720.84	0.508	625	0.945
Z2	953.88	0.459	650	1.015
MG PLTD II	673.56	0.514	-	-
4Z2	729.36	0.495	675	0.965
W2	730.08	0.496	550	1.005

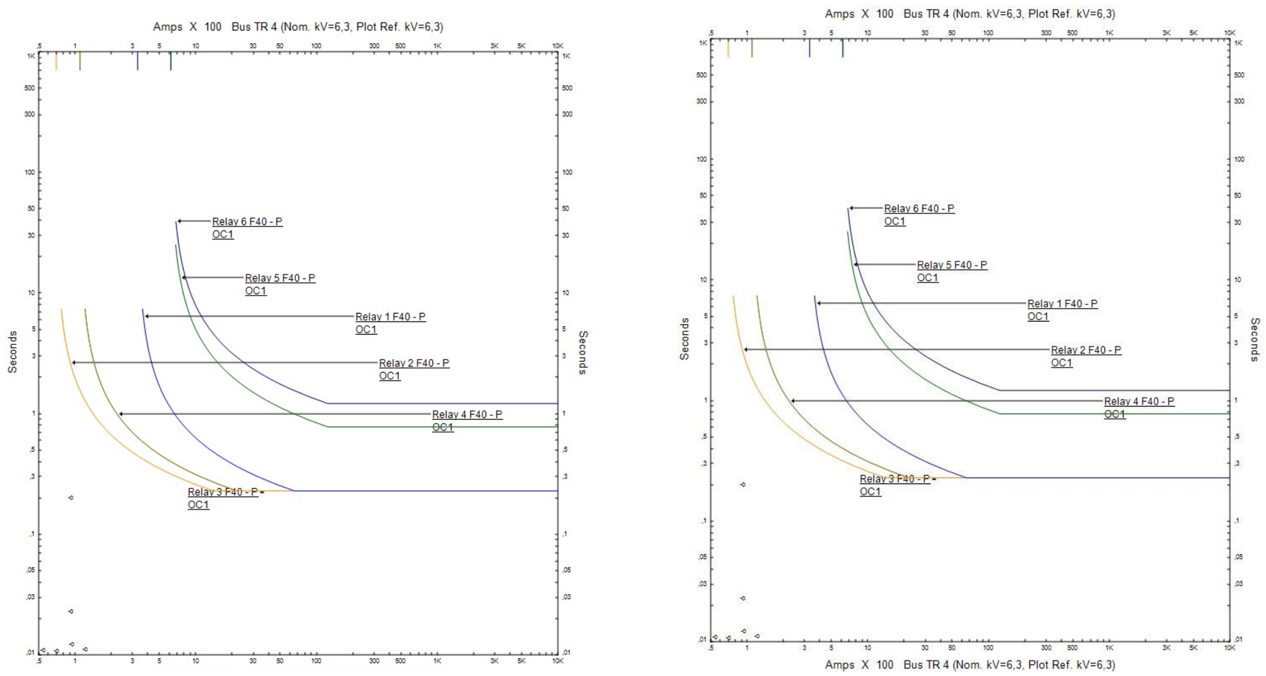
Table 2. Comparison of Protection Instantaneous Relay Settings Based on Calculations and Existing Condition

Feeder Incoming	OCR Instantaneous	
	Calculation	Existing
	Current Setting (I)	Current Setting(I)
R1	2193.6	1825
R2	2080.0	1825
Z1	2448.4	2100
4Z1	2636.0	2125
W1	2284.0	2000
4R1	2562.0	1950
4R2	2402.8	1950
Z2	3179.6	2100
MG PLTD II	2245.2	-
4Z2	2431.2	2125
W2	2433.6	2000

From the data that has been obtained through the calculation of the protection system and existing data applied in the substation system for the development of PT. Semen Padang, there is a very significant difference. The current setting of the current relay is more inverse time type and instantaneous type, the data obtained is very much different. Judging from the I_{pickup} of the inverse time overcurrent relay, calculations are carried out with the existing conditions in the field differing on average as far as ±100 A. This also applies to instantaneous type overcurrent relays where the I_{pickup} in the calculation with the existing state is also very much different. This difference occurs due to differences in $I_{nominal}$ data for setting up the relay used. In this study, the $I_{nominal}$ used was obtained from a power flow simulation using ETAP 12.6 software with full load conditions with an 80% load factor on the system. In this study, the $I_{nominal}$ used was obtained from a power flow simulation using ETAP 12.6 software with full load conditions with an 80% load factor on the system. Meanwhile, the existing $I_{nominal}$ state is used based on data on the full load current that occurs in the field. This difference in current settings greatly impacts the use of loads on the system. The use of $I_{nominal}$ is intended for the relay current setting to be used, it is recommended to use $I_{nominal}$ where the load current is full when all loads are alive with a loading factor of 80%. This is intended, when the current setting on the relay uses data based on the full load operated per month then when all the loads on each feeder are detected to be live, the relay will perceive this as a fault and will break the system. This incident will have an impact on the company's efficiency in operating because the load attached to the system cannot be operated optimally.

The time setting of the inverse time relay also has a considerable difference. Where the difference between TMS from the calculation results in this study and the existing conditions in the field is an average of ±0.5. This is due to the fact that the fault current values used are different. In this study, the fault current used was data obtained through short circuit simulation using ETAP 12.6 software. While in the existing condition the fault current used is 2 x $I_{nominal}$ in the system. This difference in TMS value also affects the speed of work of the relay, where it should be the expected relay speed of work when there is a fast interruption, but in fact, there is a long delay time which will harm the system.

In figure 7, it can be seen the difference in how the relay coordination is contained in the PT. Semen Padang. Where before the calculation of the existing state in the system, the coordination of the overcurrent relay was not as expected. When there is a disturbance, backup relay 2 is on the main outgoing feeder trip before backup relay 1 which is on the incoming feeder load. Meanwhile, after calculating the setting of the current relay, the coordination of each relay is as expected, namely the main relay on each load feeder that first trips, then backup relay 1 on the incoming load feeder, and the last backup relay 2 on the main outgoing feeder.



(a) (b)

(b)

Figure 7. (a) F40 Relay Work Graph Calculation (b) Existing State F40 Relay Work Graph

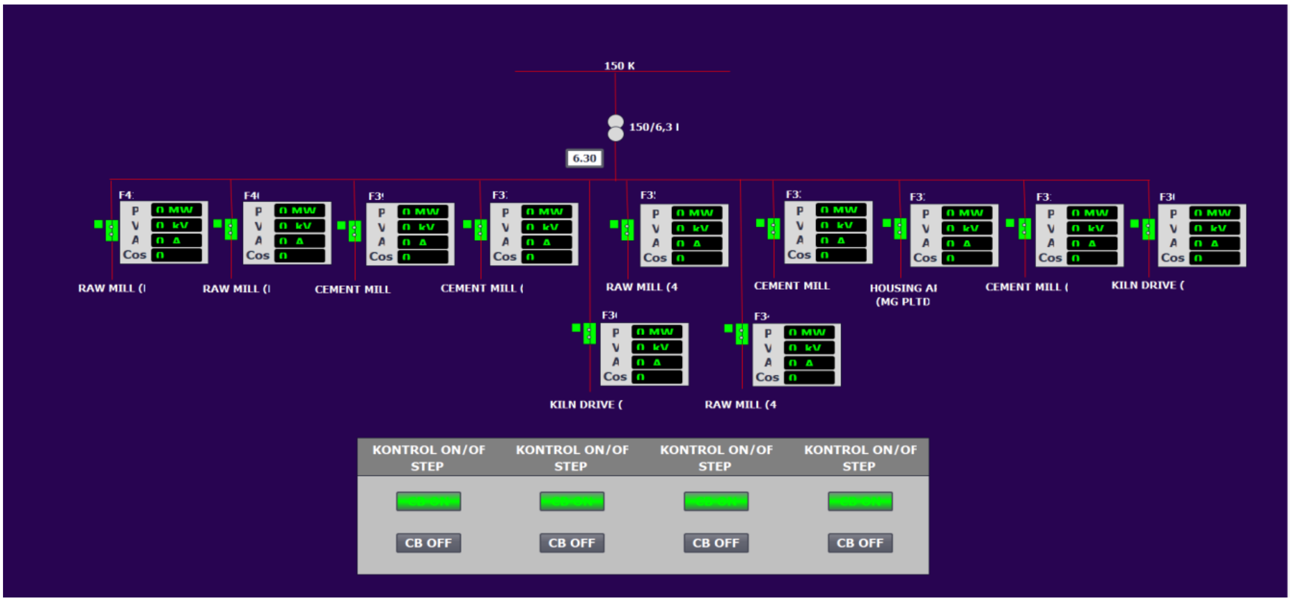


Figure 8. Display of the System under Normal Voltage State of 6.3 kV

Test Results of Load Shadding Program Simulation

This study was designed an automatic load shedding program that aims to protect the system when an undervoltage disturbance occurs. This automatic load shedding is controlled by using the Siemens S7-1500 PLC. A load shedding program is automatically created based on the system voltage setpoint. To setpoint this load-shedding program, researchers divide into four steps as shown in Table 3 [20].

In testing this load shedding program, researchers used the PLCSimulator feature in the TIA Portal 15.1 software. By modeling a single line diagram of the PT development substation system. Semen Padang on HMI is parallel in displaying how the system is doing when there is a voltage drop. The results of the load shedding simulation can be seen in Figure 8.

Table 3. Load Shedding Step

Load Shedding Step	Load Shadding Voltage (kV)	Detachable Feeder	Time Delay
1	6.05	F34 and F35	5
2	5.90	F33, F40 and F41	3
3	5.75	F31, F37 and F39	2
4	5.67	F30, F32 and F36	0

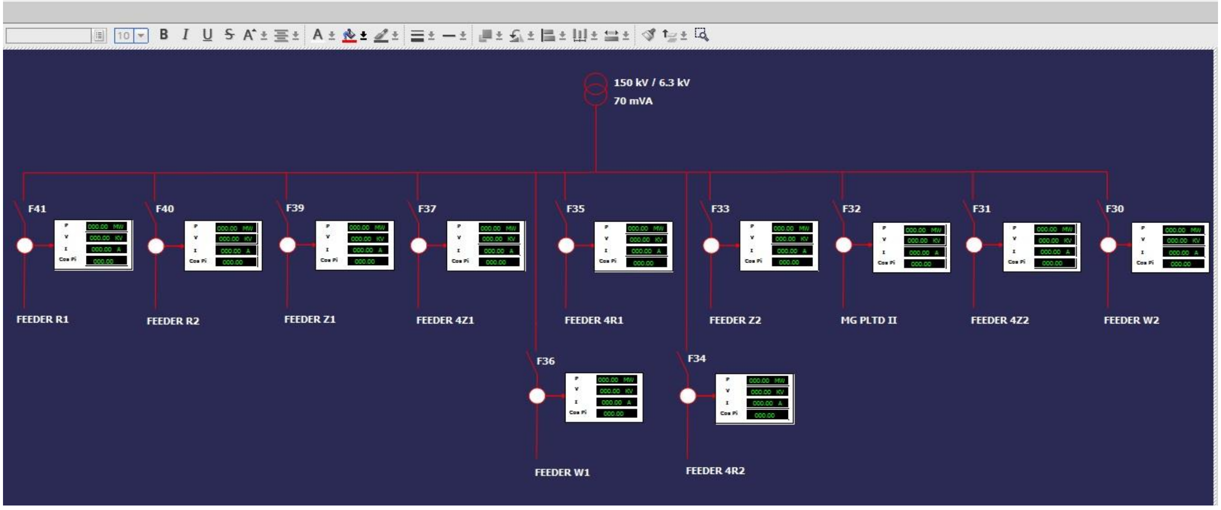


Figure 10. HMI Data Record And Realtime Data Designed View

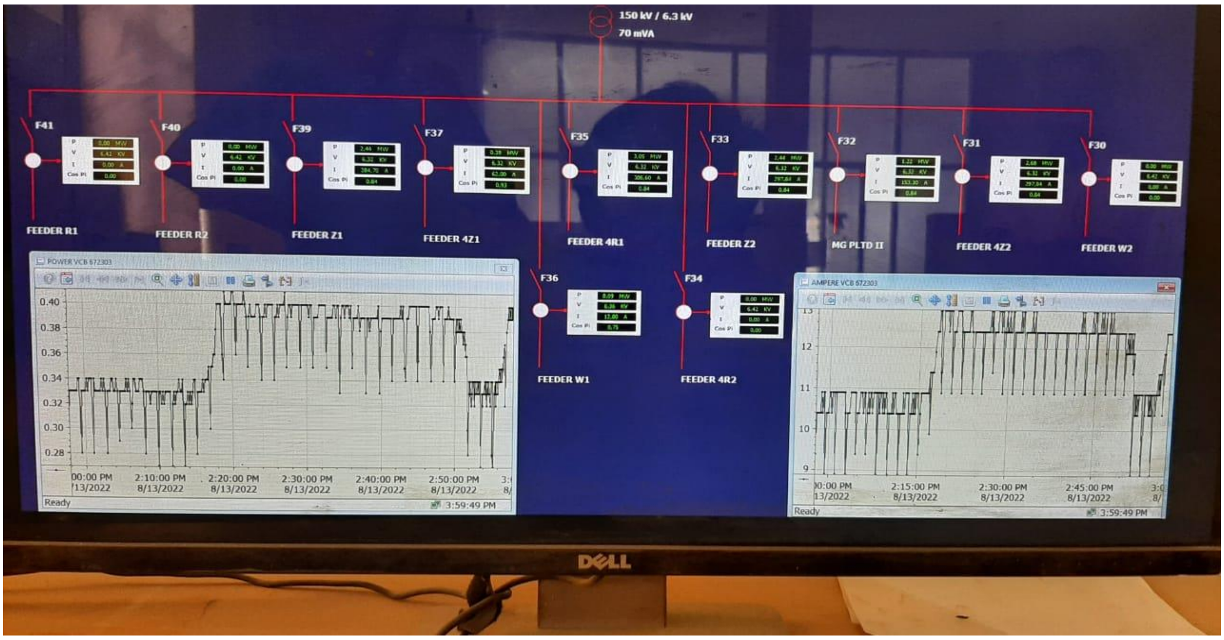


Figure 11. Running HMI Data Record and Realtime Data Designed View

Design of HMI Data Record and Realtime Data Substation System Development of PT. Semen Padang

The HMI data record and real-time data designed are HMI that can be displayed on the Center Control Room (CCR) screen on the PT substation system. Semen Padang. This real-time data and data retrieval utilize the IEC61580 communication module which will communicate between the Siemens S7-1500 PLC and the ACB panel of each feeder in the system. The HMI program displaying data records and real-time data is designed by taking bits of data from the ACB on each feeder and inputting it into the PLC and then displaying it through the HMI. The designed HMI display can be seen in Figure 9.

Figure 9 is the result of the HMI design where there is a real-time data display of power, voltage, current and cos φ from each feeder in the PT development substation system. Semen Padang. This designed HMI can also show a graph view of the data record at any time. The running HMI display connected to the system can be seen in Figure 10.

Figure 10 shows the running HMI data record and real-time data from the PT. Semen Padang on CCR screen. In the display, you can see the real-time value and also a graph of the data record of the operating system. Data records from the system can also be exported to excel. Example of a chart of the data record of one of the feeders within one week from August 8, 2022 – August 14, 2022 on the F31 feeder.

CONCLUSIONS

In the inverse time (OCR) type, in the existing state of the development substation system, there is not good coordination between the relays on the load feeders, this is shown in the backup relay 2 located on the main outgoing feeder, so that when there is a disturbance, the relay that should be a backup experience the trip first. In this study, this problem can be overcome with the right calculations in the settings where if a disturbance occurs, the relay works according to the work flow that is in accordance with the system. From the results of the simulation program that has been carried out in this study, the results obtained are indicators of the actual status of the feeder and the quantities in the form of current, voltage, power and cos can be displayed by connecting the protection relay with the HMI via PLC, and the simulation results of the load shading program show system selectivity in protecting undervoltage disturbances is guaranteed. This can be a reference so that if there is a priority load disturbance on the development substation system, there is no need for actions that can hamper production.

REFERENCES

[1] P. P. Bedekar, S. R. Bhide, and V. S. Kale, "Optimum Time Coordination of Overcurrent Relays in Distribution System Using Big-M (Penalty) Method," *WSEAS Trans. Power Syst.*, vol. 4, no. 11, pp. 341–3350, 2009.

[2] H. M. Yudha, *Rele Proteksi: Prinsip dan Aplikasi*. Palembang: Jurusan Teknik Elektro Fakultas Teknik Universitas Sriwijaya, 2008.

[3] PT. Semen Padang, "SP Jajaki Kerjasama dengan PT Bukit Asam," 2014. https://www.semenpadang.co.id/?mod=berita&kat=&id=1033.

[4] A. Azrul, "Over Current Ralay Standart Invers Berbasis Arduino Uno," Universitas Diponegoro, 2014.

[5] F. A. Rahmadani, "Analisis Pelepasan Beban (Load Shedding) Menggunakan Under Frequency Relay (UFR) pada Sistem Tenaga Listrik Gardu Induk Pauh Limo Padang 150/20 KV," Universitas Andalas, 2016.

[6] J. P. Ardy, "Perancangan Human Machine Interface Dan Sistem Kendali Side Reclaimer Menggunakan PLC Siemens S7-300," Universitas Andalas, 2017.

[7] Ariyati, "Evaluasi Setting Proteksi Relai Arus Lebih untuk Memperbaiki Koordinasi Relai di Pabrik Indarung V PT.Semen Padang," Universitas Andalas, 2017.

[8] G. Johannsen, "Cooperative human-machine interfaces for plant-wide control and communication," *Annu. Rev. Control*, vol. 21, pp. 159–170, Jan. 1997, doi: 10.1016/S1367-5788(97)00022-9.

[9] W. D. Stevenson, *Analisis Sistem Tenaga Listrik*, 4th Editio. Jakarta: Erlangga, 1983.

[10] IEC 60255-6, "Electrical relays - Part 6: Measuring relays and protection equipment," 1988.

[11] M. Nasir, *Diklat Kuliah Sistem Proteksi*. Padang: Teknik Elektro Universitas Andalas, 2003.

[12] Pusdiklat PT. PLN (Persero), *Materi 2: Dasar-Dasar Sistem Proteksi Tegangan Tinggi*. 2009.

[13] A. Moallim, J.-M. Lee, and D.-S. Kim, "Wireless control and monitoring using Programmable Logic Controller (PLC)," in *2017 17th International Conference on Control, Automation and Systems (ICCAS)*, Oct. 2017, pp. 1763–1767, doi: 10.23919/ICCAS.2017.8204259.

[14] U. Ziqri, "Perancangan Sistem Kendali Coal Transport Menggunakan PLC Siemens S7-300 dan Intouch Wonderware di CCMS PT. Semen Padang," Universitas Andalas, 2017.

[15] H. Wicaksono, *Programmable Logic Controller: Teori, Pemrograman dan Aplikasinya dalam Otomasi Sistem*. Yogyakarta: Graha Ilmu, 2009.

[16] L. A. Bryan, *Programmable Controllers: Theory and Implementation*, 2nd editio. Atlanta: Industrial Text Co., 1997.

[17] V. R. Segovia and A. Theorin, "History of Control: History of PLC and DCS," Lund University, 2012.

[18] W. Bolton, *Programmable Logic Controllers*, 4th Editio. Newnes, 2006.

[19] W. Bolton, "Ladder and Functional Block Programming," in *Programmable Logic Controllers*, 4th Editio., Newnes, 2006, pp. 453–482.

[20] N. Netri, "Aplikasi Wonderware Intouch 10.1 & Interkoneksi dengan PLC Siemens S7," Padang, 2015.