

Short-Circuit Disturbance and Distribution Network Protection Electric Power System in Human Resources Development Center for Oil and Gas

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Abstract

The power system is a very vital part of the industry, serving as the source of electrical energy up to the distribution of electric power, which must be protected against various types of disturbances that may affect the equipment in use. Power system protection is the protection provided to electrical equipment installed in a system against abnormal operating conditions of the system itself. These abnormal conditions include short-circuit faults, overload faults, and overvoltage disturbances. Breaking capacity, or the maximum interrupting capacity, is the highest short-circuit current value that a circuit breaker can withstand without sustaining damage.

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Keywords:

Power system; electric power distribution; power system protection; short-circuit faults; circuit breaker

Article History:

Received: October 1st, 2025

Revised: October 28th, 2025

Accepted: October 29th, 2025

Published: October 31st, 2025

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1. Introduction

The electric power system is a fundamental backbone of industrial operations, serving not only as the primary source of electrical energy but also as the infrastructure that ensures its reliable transmission and distribution to end-users. Given its critical role, the power system must be provided with robust protection schemes to guard against disturbances that may threaten equipment integrity, operational reliability, and personnel safety. Disturbances in power systems, such as short circuits, overloads, and overvoltage conditions, can cause severe damage to electrical equipment, interrupt industrial processes, and even lead to large-scale system instability if not addressed promptly. Therefore, protection systems are not optional but are indispensable elements in modern electrical networks, designed to isolate faults, minimize damage, and maintain service continuity. Among the most essential analyses in power system protection is the short-circuit current study.

A short circuit introduces a low-resistance path that allows fault currents to escalate rapidly to values many times higher than the normal operating current. Such high fault currents, if not interrupted quickly, can cause overheating, mechanical stress, insulation failure, and catastrophic equipment damage. Short-circuit studies provide engineers with critical data for planning, designing, and expanding power systems. Specifically, these studies are used to determine protective relay settings, verify system coordination, and establish the required interrupting capacity of circuit breakers. Without accurate short-circuit analysis, it is impossible to ensure that protective devices will operate reliably under fault conditions. Circuit breakers, as primary protective devices, must be carefully selected not only based on their normal current-carrying capacity but also with respect to their ability to withstand and interrupt maximum fault currents. The concept of breaking capacity—also known as rupturing capacity—is central to this process. Breaking capacity defines the highest short-circuit current a breaker can safely interrupt at its rated system voltage without sustaining permanent damage. Choosing breakers with insufficient breaking capacity may result in catastrophic failures during fault conditions, while appropriately rated breakers ensure system safety, reliability, and stability. For this reason, standards and guidelines emphasize the importance of selecting protective devices that correspond to the maximum prospective fault currents at their installation points.

Protection systems must also be designed to operate selectively and reliably. Selectivity ensures that only the protective device closest to the fault operates, isolating the affected section while allowing the remainder of the system to continue functioning. This principle minimizes service disruption and enhances overall system reliability. In practice, protection can be achieved using devices such as fuses or circuit breakers. While fuses are simple and cost-effective, circuit breakers are generally preferred in industrial power systems due to their higher

fault-handling capacity, coordination capabilities with protective relays, and ability to be reused after operation. Importantly, protective devices must be capable of eliminating disturbances without damaging themselves during the process, which underscores the necessity of selecting equipment rated for the expected short-circuit conditions.

2. Method

The reliability and continuity of an electric power system in delivering electricity to consumers is strongly determined by the protection system that is implemented. A reliable power system is not only expected to meet the growing demand for electrical energy but also to ensure that supply is maintained safely and with minimal disruption. For this reason, the design of a protection system requires careful attention to potential disturbances and fault conditions that may arise within the network. These considerations are addressed through fault analysis, which serves as the foundation for planning protection schemes, selecting switchgear, and determining the specifications of essential equipment such as circuit breakers (CBs) and protective relays. The results obtained from a fault analysis are used to establish critical parameters, including the relay settings that dictate how and when relays will operate under abnormal conditions. Furthermore, the analysis ensures that the ratings of circuit breakers are appropriate for the maximum fault current levels expected in the system. Faults may occur in different parts of the power system, including generators, power transformers, transmission networks, and busbars, each of which requires a tailored protection strategy.

A. Power System and Distribution Protection

Delivering electricity to consumers involves a relatively complex process that spans from generation at the power plant to transmission through high-voltage lines, and finally to distribution networks before reaching end-users. The last stage, distribution, is especially critical, as it directly impacts the reliability and quality of supply received by consumers. Distribution system protection refers to the protective measures and equipment installed along the distribution network to ensure that electricity is safely transferred from the power generation station through substations and finally to households, industries, and commercial consumers. Without proper protection, disturbances within the distribution network could result in widespread outages, equipment damage, or even hazards to human safety. Effective protection ensures that disturbances are isolated promptly, allowing electricity to be supplied reliably, safely, and at the required quality standards [2].

B. Power System Protection

In general, power system protection can be defined as the coordinated application of protective devices to safeguard electrical equipment and maintain system stability under abnormal operating conditions. This includes protection of generators, power transformers, transmission and distribution lines, and other essential components of the power system. Abnormal operating conditions may take several forms, including:

1. **Short-circuit faults** (line-to-line, line-to-ground, or three-phase faults)
2. **Overload conditions** caused by demand exceeding equipment capacity
3. **Overvoltage disturbances** due to switching surges, lightning strikes, or system instability

Among these, short-circuit faults are particularly significant. When a short circuit occurs, it creates a very low impedance path that allows extremely high currents to flow through the system. These currents may be several times higher than the normal operating current, posing serious threats to equipment and system stability. Short-circuit faults can be classified as either permanent or temporary. Permanent faults typically occur due to insulation failure, equipment breakdown, or mechanical damage, and include three-phase short circuits, double-phase-to-ground faults, interphase faults, and single-phase-to-ground faults. On the other hand, temporary faults are often caused by environmental conditions such as flashovers between conductors and ground, between conductors and poles, or between conductors and grounding wires. Temporary faults may clear themselves once the disturbance is removed, but protective systems must still respond quickly to prevent damage [2].

C. Short-Circuit Current and Breaking Capacity

The magnitude of the maximum short-circuit current is a critical parameter in power system protection. This current value is compared against the breaking capacity (or interrupting capacity) of protection equipment such as circuit breakers to ensure that the equipment can safely operate under fault conditions. According to the ANSI C37.010-1999 standard, the instantaneous fault current I_m for systems with voltage levels above 1.5 kV can be calculated as:

$$I_m = 1.6 \times I_{SC}$$

For systems operating at voltage levels below 0.6 kV, the equation is:

$$I_m = 1.5 \times I_{SC}$$

where I_{SC} is the symmetrical short-circuit current.

The instantaneous power capacity of a circuit breaker can be determined by:

$$S_m = \sqrt{3} V_p \times I_m$$

where V_p is the system's phase-to-phase voltage. These equations provide the basis for evaluating whether a circuit breaker is adequately rated to handle the worst-case fault scenarios. Using underrated breakers could result in catastrophic equipment failure, while properly rated breakers ensure safe interruption of fault currents and protect the stability of the entire power system [3].

D. The Function of Protection

Understanding the magnitude and characteristics of fault currents at different points in the system is essential for designing an effective protection system. Since fault currents can reach dangerously high values in a very short time, the protection system must be capable of detecting and isolating them almost instantaneously. This requires the use of detection devices, such as protective relays, that continuously monitor system conditions. When an abnormal condition is detected, the relay issues a trip signal to the appropriate circuit breaker. The circuit breaker, in turn, disconnects the faulty section from the rest of the system, thereby preventing damage and maintaining stability. A circuit breaker is defined as a mechanical switching device capable of making, carrying, and breaking currents under normal operating conditions. Additionally, it must also be capable of making, carrying for a specified duration, and interrupting currents under abnormal conditions, such as those caused by short circuits [4].

The primary functions of power system protection can be summarized as follows [2]:

1. Prevent or minimize equipment damage caused by abnormal operating conditions. The faster the protective devices respond, the smaller the potential for equipment failure.
2. Localize faults to the smallest possible area, ensuring that unaffected parts of the system continue to operate normally.
3. Maintain service reliability and power quality, ensuring uninterrupted electricity delivery to consumers.
4. Protect human safety by preventing exposure to dangerous electrical conditions.

3. Result and Discussion

Pusat Pengembangan Sumber Daya Manusia Minyak dan Gas Bumi or Human Resources Development Center for Oil and Gas (PPSDM MIGAS) is a Central Government Agency under the Human Resources

Development Agency for Energy and Mineral Resources, Ministry of Energy and Mineral Resources [5]. The majority of the load at PPSDM Migas consists of induction motor units used in crude oil processing within refinery and utility units. In addition, the power plant also supplies loads for lighting systems. The installed load data at PPSDM Migas are presented as follows:

Table 1. Total Operating Load of Refinery and Utility Units

Load Unit	Maximum Operating Load (kW)
Power Plant Unit	38.55
Water Treatment	145
Boiler Unit	5.9
Refinery Unit	323.03
Total Load	512.48

The protective equipment used at PPSDM Migas includes fuses, Oil Circuit Breakers (OCB), Disconnecting Switches (DS), Load Break Switches (LBS), relays, and grounding systems. Following the processing of field study data on the existing conditions of the PPSDM Migas power system, a Single Line Diagram (SLD) model was developed using ETAP 16.0 software. ETAP was used to analyze power flow and short-circuit disturbances with high accuracy. Figure 1 shows the single line diagram of the PPSDM Migas power system developed using ETAP Power Station 16.0 based on the collected data. When Generator 2 operates, the power flow distribution at each bus bar is as follows:

Table 2. Power Distribution on Bus Bars

Bus ID	kV	Load (%)	MW Loading	Amp (A)
Bus 1	0.4	100	0.692	1134
Bus Dist. Boiler	0.38	99.72	0.0076	13.27
Bus Dist. Kilang	0.38	98.19	0.373	642.8
Bus Dist. P.Plant	0.38	99.36	0.0438	71.43
Bus Dist. Water Treatment	0.38	97.24	0.159	285.5
Bus T.Kilang	6.1	98.35	0.473	50.9
Bus T.Utilitas	6.1	98.35	0.216	23.48
Bus T8	6.1	98.3	0.465	50.05
Bus T9	6.1	98.35	0	0
Bus T10	6.1	98.35	0.0076	0.843
Bus T13	6.1	98.34	0.172	18.98
Bus T14	6.1	98.35	0.044	4.535
Main Bus	6.1	98.35	0.689	74.37

The maximum short-circuit current was obtained from a three-phase short-circuit simulation with 4 cycles, while the minimum short-circuit current was obtained from a two-phase short-circuit simulation with 30 cycles. The short-circuit current values at each bus bar supplied by Generator 2 are shown in Table 3.

Table 3. Short-Circuit Current Magnitudes

Bus ID	3-Phase (kA)	L-G (kA)	L-L (kA)	L-L-G (kA)
Bus 1	10.529	14.824	9.309	14.999
Bus Dist. Boiler	2.056	1.883	1.783	2.04
Bus Dist. Kilang	4.151	0.975	3.591	3.688
Bus Dist. P.Plant	3.516	3.328	3.061	3.551
Bus Dist. W. Treatment	3.641	3.065	3.155	3.702
Bus T.Kilang	0.62	0	0.546	0.546
Bus T.Utilitas	0.62	0	0.546	0.546
Bus T8	0.619	0	0.545	0.545
Bus T9	0.618	0	0.544	0.544
Bus T10	0.618	0	0.544	0.544
Bus T13	0.619	0	0.545	0.545
Bus T14	0.62	0	0.545	0.545
Main Bus	0.62	0	0.546	0.546

Simulation results using ETAP 16.0 under full-load operating conditions show that the largest fault is a Line-to-Line-to-Ground (L-L-G) fault at Bus 1, producing a short-circuit current of 14.299 kA. The fault current values at the load distribution buses are larger than those in the distribution lines, because as more loads operate, the positive- and negative-sequence impedances decrease, resulting in higher short-circuit currents. On the other hand, zero-sequence impedance is not affected by the number of loads in operation [3]. The Breaking Capacity (or maximum interrupting capacity) of a circuit breaker is the highest short-circuit current that the device can interrupt without damage. Circuit breaker performance is rated by two key parameters: interrupting duty (the ability to break fault current) and momentary duty (the ability to withstand the first half-cycle fault current surge) [6].

Table 4. Circuit Breaker Breaking Capacity during Short-Circuit Conditions

Bus ID	kV	SCmax (kA)	Im CB (kA)	Sm (kVA)
Bus 1	0.4	14.999	239.984	16626.5
Bus Dist. Boiler	0.38	2.04	3.264	2148.29
Bus Dist. Kilang	0.38	3.688	59.008	3883.78
Bus Dist. P.Plant	0.38	3.551	56.816	3739.51
Bus Dist. Water Treatment	0.38	3.702	59.232	3898.52
Bus T.Kilang	0.38	0.546	0.8736	574.98
Bus T.Utilitas	0.38	0.546	0.8736	574.98
Bus T8	6.1	0.545	0.872	9213.12
Bus T9	6.1	0.544	0.8704	9196.21
Bus T10	6.1	0.544	0.8704	9196.21
Bus T13	6.1	0.545	0.872	9213.12
Bus T14	6.1	0.545	0.872	9213.12
Main Bus	6.1	0.546	0.8736	9230.02

From the short-circuit simulation, the maximum fault current in the distribution system was found to be 9.938 kA. The largest fault current occurred during an L-L-G fault, which was then used to calculate the momentary current duty—the maximum current that may flow through a circuit breaker in the first half cycle after a fault. Once the short-circuit currents and nominal load currents were obtained from ETAP simulations, they were compared with the ratings of the existing circuit breakers at PPSDM Migas. The comparison included maximum short-circuit current (IM), nominal current (IN) from load flow analysis, and the existing CB rating and breaking capacity (ICU).

Table 5. Existing Circuit Breakers, Nominal Currents, and Short-Circuit Currents

Bus ID	Nearest CB	Im CB (kA)	IN (A)	Existing CB Rating (A)	ICU (kA)
Bus 1 (ACB 2)	ACB 2	239.984	1134	2000	65
Bus 1 (ACB 6)	ACB 6	239.984	1134	1600	65
Bus Dist. Boiler	CB Ts10	3.264	13.27	400	36
Bus Dist. Kilang	CB Ts8	59.008	642.8	400	36
Bus Dist. P.Plant	CB Ts14	56.816	71.43	400	36
Bus Dist. Water Treatment	CB Ts13	59.232	285.5	400	36
Bus T.Kilang	OCB 3	0.8736	50.9	630	30
Bus T.Utilitas	OCB 4	0.8736	23.48	630	30
Bus T8	CB T8	0.872	50.05	630	30
Bus T9	CB T9	0.8704	0	630	30
Bus T10	CB T10	0.8704	0.843	630	30
Bus T13	CB T13	0.872	18.98	630	30
Bus T14	CB T14	0.872	4.535	630	30
Main Bus	OCB 1	0.8736	74.37	630	30

The comparison results indicate that most circuit breakers are appropriately rated and are capable of protecting against short-circuit faults in the system. However, it was found that the circuit breaker in the refinery distribution unit requires replacement with a minimum rating of 800 A, since the existing 400 A breaker is inadequate to withstand the fault current under full-load conditions. The overload towards the refinery distribution occurs due to load transfer from Transformer 10 (Boiler Unit) to Transformer 8 (Refinery Unit), which increases the current beyond the rating of the existing circuit breaker.

4. Conclusion

The distribution network at PPSDM Migas uses a radial distribution system, which makes the power system less reliable when disturbances occur. However, the generation system is relatively quick in meeting the electricity demand of the refinery and utility units. The transfer of load from Transformer 10 to Transformer 8 has resulted in a nominal current exceeding the circuit breaker rating under full-load conditions (when all loads are operating). Therefore, it is necessary to replace the circuit breaker from a 400 A rating to an 800 A rating.

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