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Analysis of Fuse Failure in a 6 kV 5-Cubicle Circuit Breaker Based on Motor Starting Current Characteristics in a Steam Turbine Of Block II at PT PLN Indonesia Power UBP Grati

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ABSTRACT

The reliability of a power plant electrical system is essential to ensure continuous operation, particularly in the 6 kV distribution system supplying auxiliary equipment such as the Circulating Water Pump (CWP) motor. A problem was identified in Cubicle 5 at PT PLN Indonesia Power UBP Grati, where a 250 A fuse frequently failed during motor operation, raising concerns about its suitability. This study aims to analyze the cause of the fuse failure and evaluate the protection system using a descriptive method based on field data, including motor specifications, fuse ratings, and operating conditions such as starting current. The analysis shows that the motor starting current reaches approximately 325 A, exceeding the fuse rating and causing thermal stress due to I^2t energy accumulation from repeated operations. As a result, the fuse operates near its limit and eventually fails under normal conditions. It can be concluded that the failure is caused by a mismatch between the fuse characteristics and the motor starting profile, as well as improper protection coordination, thus requiring reevaluation of fuse selection and protection settings to ensure reliable and selective system operation.

1. Introduction

The power system at a power plant plays a critical role in ensuring the continuity and reliability of the electricity generation process. One key component of this system is the 6 kV medium-voltage distribution network, which supplies power to various auxiliary equipment, such as pump motors, compressors, and steam turbine support systems. The reliability of this distribution system heavily depends on the performance of protective devices capable of safeguarding equipment against overcurrent faults and short circuits [1,2]

In the 6 kV distribution system, High Rupturing Capacity (HRC) fuses are used as one of the primary protective devices. Fuses operate by melting the conductive element when the current exceeds a certain limit, thereby breaking the circuit and preventing equipment damage [3,4]. Fuse rating selection must be tailored to load characteristics, particularly for medium-voltage induction

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motors with significant starting currents [5]. Inappropriate fuse ratings can result in frequent fuse blowouts or, conversely, fail to provide optimal equipment protection [6].

At PT PLN Indonesia Power UBP Grati, in Switchgear Bay 5 supplying the Circulating Water Pump (CWP) motor, an issue was identified involving a 250 A fuse that frequently blew. The motor in question has specifications of 6.3 kV, a power rating of 830 kW, and a nominal current of 88 A. This situation raises questions regarding the suitability of the fuse rating relative to the motor's characteristics and on-site operational conditions. There is also the possibility of replacing the fuse with a 300 A however, further analysis is required to ensure that the rating change still complies with safety principles and protection coordination [4,6].

Furthermore, the reliability of the Circulating Water Pump (CWP) motor significantly impacts the condenser cooling process and the overall operational stability of the steam turbine. A failure of this motor due to a blown fuse not only causes a temporary shutdown of auxiliary equipment but also has the potential to reduce the power plant unit's performance and even trigger derating if not addressed immediately [7]. Therefore, an analysis of the cause of the fuse failure and an evaluation of the suitability of the protection rating are essential to ensure the 6 kV distribution system operates safely, selectively, and reliably.

Table 1
Summary of previous studies on fuse protection and motor systems in medium-voltage networks

Reference	Approach / Method	Research Focus	Main Findings
[8]	Standard-based analysis	Protection coordination in power system buses	Proper coordination ensures selective operation of protection devices and system reliability
[9]	Case study and fault current analysis	Fuse failure in distribution systems	Fuse failure is often caused by overcurrent conditions exceeding design limits
[10]	Time-Current Characteristic (TCC) simulation	Protection coordination using TCC curves	TCC curves are essential for determining operating time and coordination between devices
[11]	Analytical and simulation approach	Induction motor protection in MV systems	High starting current (5–7 × nominal) can affect protection performance
[12]	Experimental and TCC evaluation	Performance of HRC fuse in MV systems	HRC fuse effectively interrupts high fault current but must be properly rated

2. Methodology

2.1 Research Methods and Analysis Steps

This study employs a structured workflow to analyze fuse failures in a 6 kV distribution system supplying a Circulating Water Pump (CWP) motor. The initial phase involved a literature review to establish the theoretical foundation regarding HRC fuses, motor starting current, and protection coordination. Next, field data was collected, including motor specifications, fuse data, and operating conditions, particularly the starting current. This data was then used to calculate key parameters such as rated current, starting current, and thermal energy (I^2t).The next phase involved analysis using Time-Current Characteristic (TCC) curves to compare the fuse characteristics with the motor starting current, as well as evaluating the protection coordination between the fuse and the relay. The final phase involved interpreting the results to determine the primary cause of frequent fuse blowouts and providing appropriate technical recommendations to ensure the protection system operates more optimally and prevents recurring outages [13].

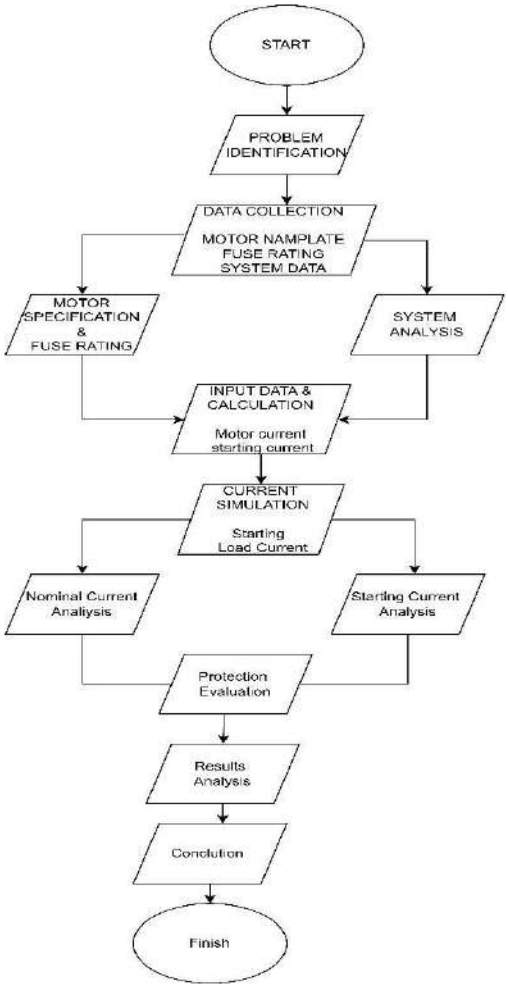

Fig. 1. Flowchart of the research stages for the analysis of fuse protection coordination

2.2 6 kV Switchgear System at the Grati Combined Cycle Power Plant, Block II

The medium-voltage distribution system at the Grati Block II Combined Cycle Power Plant uses a 6 kV network to supply electrical power to various auxiliary plant equipment. One of the pieces of equipment connected to this system is the Circulating Water Pump (CWP), which plays a role in the cooling water circulation process within the power generation system. The motor driving this pump is a medium-voltage electric motor operated via a 6 kV switchgear panel, thus requiring a reliable protection system to ensure equipment safety during operation.

In this study, the object of analysis is Switchgear Panel 5, which is connected to the Circulating Water Pump B (CWP B) motor. This switchgear panel is equipped with protective devices such as circuit breakers and fuses that function to protect the motor from overcurrent faults and short circuits. The fuses in this switchgear are a critical component of the protection system, particularly during motor startup, which can cause significant current surges. Therefore, a detailed analysis of the fuse conditions and current characteristics within the 6 kV switchgear system is necessary to determine the cause of fuse failure [14].

In a three-phase system, the relationship between power, voltage, and current can be expressed by the following equation:

$$P = \sqrt{3}.V.I.cos\ \phi \qquad (1)$$

Thus, the nominal current of the motor can be calculated as:

$$I = \frac{P}{\sqrt{3}.\ V\ .coscos\ \phi} \tag{2}$$

where *P* is the motor power (W), V is the line voltage (V), I is the current (A), and cos ϕ is the power factor. This equation is used to verify the suitability of the motor's nominal current with the protection system installed. The calculated current becomes a fundamental parameter in determining the appropriate fuse rating, ensuring that the fuse does not operate under normal conditions but can still provide protection during fault conditions.

2.3 Specifications Motor Circulating Water Pump (CWP)

The drive motor for the Circulating Water Pump (CWP) in the Grati Block II Combined Cycle Power Plant system is a three-phase induction motor used to drive the cooling water circulation pump in the power generation system. This motor is manufactured by Siemens, model LOHER ATRA-710LP-14N, and is designed to operate on a 6.3 kV medium-voltage system. An induction motor was selected due to its simple construction, high reliability, and ability to operate continuously to support the power plant's operational needs.

The technical specifications of the Circulating Water Pump motor are shown in Table 2.1, derived from the motor's nameplate data. Based on this data, the motor has a power rating of 1180 kW, an operating voltage of 6300 V, and a rated current of 200 A at a frequency of 50 Hz and a power factor of 0.70. This motor has a rotational speed of 426 rpm and an insulation class of 155/130 (Class F/B) with an IP65 protection rating. These specifications indicate that the motor operates on a medium-voltage system with high power capacity; consequently, during the starting process, a significant current surge may occur, potentially affecting the performance of the fuse protection system in the 6 kV switchgear [10].

In induction motors, the starting current is typically much higher than the nominal current due to low initial impedance. The magnitude of the starting current can be approximated by the following equation:

$$I_{Start} = k\ x\ I_{nom} \tag{3}$$

Where I_{Start} is the starting current, I_{nom} is the nominal current, and k (typically 5–7 for DOL starting) is a constant thus, the starting current can be several times higher than 200 A, producing a high but short duration surge.

Furthermore, the thermal impact of the starting current on the fuse can be evaluated using the I^2t concept:

$$I^2\,t = I^2\ x\ t \tag{4}$$

This indicates that the energy generated during starting depends on both the magnitude of the current and its duration. If the resulting I^2t value approaches or exceeds the fuse's withstand capability, the fuse may operate even under normal starting conditions.

Table 2
Specifications motor circulating water pump

Parameter	Spesifikasi
Manufacturer	Siemens
Motor Type	LOHER ATRA-710LP-14N
Motor Class	Motor Induksi 3 Fasa
Motor Power	1180 kW
Rated Voltage	6300 V
Rated Current	200 A
Frequency	50 Hz
Power Factor	0,70
RPM	426 rpm
Insulation Class	155 / 130 (Class F/B)
Protection Rating	IP65
Motor Weight	21500 kg

2.4 Fuse Specifications for a 6 kV Switchgear

Fuses are one of the protective devices used in medium-voltage distribution systems to protect electrical equipment from overcurrent faults and short circuits. In the 6 kV switchgear system at the Grati Block II Combined Cycle Power Plant, fuses are installed as part of the protection system to safeguard the Circulating Water Pump (CWP) motor and other electrical equipment. The fuses used in this system are High Rupturing Capacity (HRC) fuses, which have the ability to interrupt large fault currents relatively quickly, thereby preventing further damage to the equipment [15].

The specifications of the fuses used in the 6 kV switchgear are shown in Table 2.2. Based on the data printed on the fuse body, the protection device used is a High Voltage HRC Fuse manufactured by SIBA with a nominal voltage of 7.2 kV and a nominal current of 250 A [16]. This fuse is also equipped with a striker mechanism that provides a mechanical indication when the fuse operates or trips due to overcurrent. These specifications indicate that the fuse is designed to operate in medium-voltage systems and is capable of protecting electrical equipment from current disturbances that exceed the permitted operating limits. The fuse's operating characteristics are determined by the Time-Current Characteristic (TCC) curve, which illustrates the relationship between current magnitude and fuse trip time; therefore, fuse rating selection must be tailored to the load characteristics and motor starting current.

The operating principle of an HRC fuse is based on the thermal effect caused by overcurrent, where the fuse element melts when the generated heat exceeds its capability. The relationship between current and melting time can be generally expressed as:

$$t = \frac{K}{I^n} \tag{5}$$

where t is the operating time (s), I *is* the current (A), and K and n are constants determined by the fuse characteristics. In addition, the fuse performance is also evaluated using the energy concept:

$$I^2 t_{fuse} \geq I^2 t_{system} \tag{6}$$

which indicates that the fuse must withstand the energy generated during normal conditions such as motor starting, while still being able to operate under fault conditions. The fuse's operating characteristics are represented by the Time-Current Characteristic (TCC) curve, which shows the inverse relationship between current magnitude and operating time. Therefore, the selection of fuse rating must consider both the load characteristics and the motor starting current to ensure proper protection coordination and prevent nuisance tripping.

Table 3
Specifications fuse cubicle 6 kV

Parameter	Spesifikasi
Fuse Type	High Voltage HRC Fuse
Manufacturer	SIBA
Rated Voltage	7.2 kV
Rated Current	250 A
Fuse Type	Striker Fitted Fuse
Standard	DIN
Application	Motor protection in a 6 kV cubicle

2.5 Kurva Time Current Characteristic (TCC)

The Time-Current Characteristic (TCC) curve is a graph that illustrates the relationship between current magnitude and the operating time of a protective device [17]. This curve is used to determine the tripping characteristics of a fuse when an overcurrent or short-circuit fault occurs in an electrical power system. The higher the current flowing, the shorter the time required for the fuse to trip [18]. Therefore, the TCC curve is used to ensure protection coordination so that the fuse operates only under fault conditions and does not trip during normal operation. In induction motor systems, the current flowing during the starting process is generally higher than the motor's rated current.

Based on measurements taken on the Circulating Water Pump (CWP) system in cubicle 5, it was found that the current during motor starting reached approximately 325 A. This current value is greater than the nominal current of the fuse used, which is 250 A; therefore, it needs to be analyzed using the TCC curve to determine whether the starting current is still within the safe zone or has already entered the fuse's operating range. Please summarize the paragraph above.

2.6 Analysis of Motor Starting Current

High starting current is a common characteristic of induction motors, particularly in high-power motors used in industrial systems or power plants. When the motor is first started, this condition causes the motor's impedance to become very low, resulting in a current flowing from the power source that is significantly higher than the motor's rated current [19].

High starting current can also be influenced by the motor starting method used. If the motor uses the Direct On Line (DOL) method, the motor immediately receives full voltage from the system, so the current flowing during startup can reach several times the motor's rated current. In high-power motors such as Circulating Water Pumps (CWP), this condition can cause a significant current surge in the electrical system. Other factors that can affect the magnitude of the starting current include the mechanical load on the motor and the condition of the electrical system. A high initial load on the pump, stable system voltage, and motor characteristics can cause the starting current to increase significantly before the motor reaches its rated speed.

2.7 Protection Coordination

Protection coordination is the process of setting and adjusting the operating characteristics of protection devices within an electrical power system so that they can operate selectively, quickly, and reliably to protect equipment from faults. The main principle of protection coordination is to ensure that the protection device closest to the fault location operates first, while other protection devices remain on standby as backup protection. Thus, the fault can be isolated locally without causing an outage in a wider part of the system.

In medium-voltage distribution systems, protection coordination generally involves protection relays, circuit breakers, and fuses [19]. The coordination process is carried out by analyzing the time-current characteristic (TCC) curve of each protection device. These curves illustrate the relationship between the magnitude of the fault current and the operating time of the protective devices. Through this analysis, the sequence of protection operation can be determined to prevent mal-operations, such as a fuse tripping before a relay or vice versa.

Medium-voltage motor protection systems, protection coordination is particularly critical because induction motors have high starting currents, which can reach several times the rated current. Therefore, protection settings must account for the motor's starting current characteristics and acceleration time to ensure protection devices do not trip under normal operating conditions. In practice, the motor protection relay serves as the primary protection, continuously monitoring the motor's operating condition, while the fuse acts as a backup protection that trips during a large short-circuit fault.

3. Results

3.1 Operating Conditions of the Circulating Water Pump

The Circulating Water Pump (CWP) motor is a critical component of the cooling system at the Grati Block II Combined Cycle Power Plant, serving to circulate cooling water during the power generation process. This motor is driven by a three-phase induction motor with a power rating of 1180 kW and an operating voltage of 6300 V. According to the nameplate data, the motor has a rated current of 200 A, which is used as a reference for determining the motor's normal operating conditions [20].

Based on measurement data from the monitoring system, the motor current under normal operating conditions was recorded at approximately 217.7 A. This current value is slightly higher than the rated current but remains within the permitted operating limits. Furthermore, this current value is also below the fuse rating used in the system, which is 250 A; thus, under normal operating conditions, the fuse does not trip, and the system can continue to operate stably.

This measurement data indicates that the Circulating Water Pump motor operates normally during normal operating conditions. However, during the motor starting process, a higher current surge occurs before the current stabilizes again under normal operating conditions [21].

3.2 Analysis of Motor Starting Current

Based on the starting current graph of the CWP motor, it can be seen that the current rises sharply from the initial state until it peaks at around 325 A at the 1-second mark, then gradually decreases until it stabilizes in the range of 217–220 A after a few seconds [19]. This pattern demonstrates the inrush current characteristic of an induction motor, which is a high current surge for a brief period during the starting process. When compared to the motor's rated current of 200 A, the starting current reaches approximately 1.6 times the rated current. Furthermore, this value also exceeds the fuse rating of 250 A; thus, the graph shows that the starting condition exceeds the fuse's rated capacity, even if only for a brief moment.

Thus, the graph shows that the fuse operates near its capacity limit during motor starting. Although this does not immediately cause the fuse to blow, this condition has the potential to reduce fuse reliability if it occurs repeatedly, so it requires attention in the evaluation of the protection system in the 6 kV switchgear.

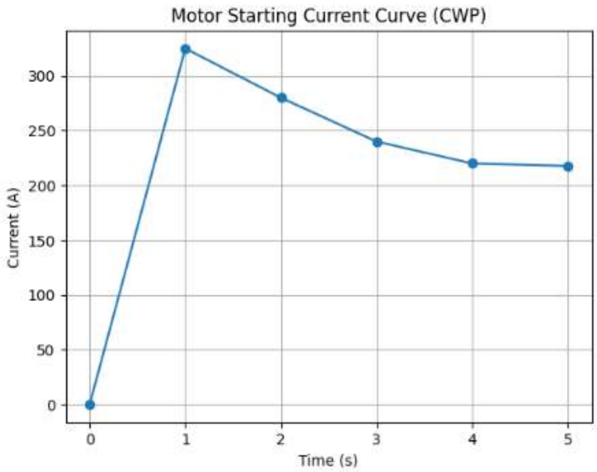

Fig. 2. Starting current curve of 6 kV induction motor for Circulating Water Pump (CWP)

3.3 Analysis of Fuse Characteristics

Fuse characteristics are analyzed using a Time-Current Characteristic (TCC) curve, which is a graphical representation that shows the relationship between current magnitude and the operating time of a protective device. This curve is used to determine how fast a fuse will respond under overcurrent or short-circuit conditions. Based on this curve, the higher the current flowing, the faster the fuse will trip, ensuring that the fuse can protect equipment without interfering with normal operating conditions.

When compared to the motor starting current graph, it is observed that the current reaches approximately 325 A in less than 1 second. This value exceeds the fuse's rated current of 250 A; however, it remains within the very short operating time range on the TCC curve. Consequently, the fuse does not trip immediately during motor startup because the current is still within its characteristic tolerance limits [17].However, the starting current's position near the TCC curve indicates that the fuse is operating at the limit of its capacity. This condition has the potential to cause heating of the fuse element if it occurs repeatedly, thereby reducing the fuse's reliability and increasing the risk of unwanted tripping in the 6 kV switchgear system [22].

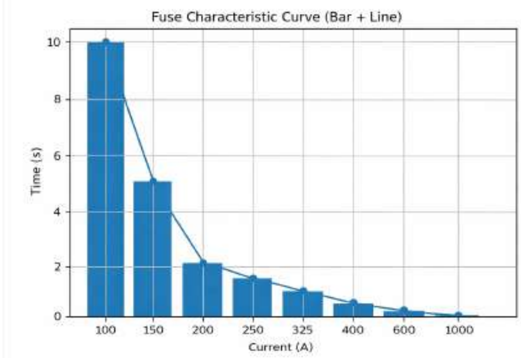

Fig. 3. Time-Current Characteristic (TCC) curve of fuses in a 6 kV CWP motor system

3.4 Analysis of the Causes of Fuse Failure

Fuse failure in the 6 kV switchgear is caused by transient overcurrent during motor startup, which reaches approximately 325 A—exceeding the fuse's 250 A rating [23]. Theoretically, fuses operate based on the thermal energy principle (I^2t), where the element melts due to heat accumulation from the flowing current. Although the starting current is brief (< 1 second), its value is close to the Time Current Characteristic (TCC) curve, causing the fuse to operate at the limit of its capacity.

Under repeated conditions, high starting currents cause thermal energy accumulation (thermal aging) in the fuse element. This results in a reduction in current-carrying capacity, changes in melting characteristics, and accelerates failure. Additionally, the Direct On Line (DOL) starting method and the pump's high initial load increase the inrush current, thereby increasing thermal and mechanical stress on the fuse. Thus, the primary cause of fuse failure is a combination of starting currents exceeding the rating, the cumulative I^2t effect, and repeated operating cycles, which cause degradation of the fuse element until eventual tripping occurs even in the absence of a short-circuit fault.

3.5 Recommendations for Improving the Protection System

Based on an analysis of the Time-Current Characteristic (TCC) curve, the fuse used in the 6 kV switchgear system must be matched to the current characteristics of the Circulating Water Pump (CWP) motor. A 250 A fuse is considered unsuitable because it is too close to the motor's starting current, which reaches approximately 325 A, potentially causing thermal stress due to the accumulation of I^2t energy. Therefore, the use of a 315 A fuse is more recommended as it provides a safer margin against the starting current, ensuring the fuse does not trip under normal conditions while still providing effective protection against faults, and thereby enhancing the fuse's reliability and service life within the system [24].

Additionally, the use of better starting methods such as soft starters or Variable Frequency Drives (VFDs) can serve as a solution to reduce initial current surges. By reducing the starting current, the thermal load on the fuse is also reduced, thereby extending the fuse's service life and improving the reliability of the protection system. Furthermore, protection coordination between the fuse and relays must be established to ensure the protection system operates selectively. Relay settings, such as those for overcurrent relays and thermal overloads, must be adjusted to match the characteristics of the motor and fuse to provide optimal protection without disrupting normal operation.

Thus, the combination of proper fuse selection, appropriate starting methods, and good protection coordination is a critical step in preventing fuse damage and improving the reliability of the electrical system in 6 kV switchgear.

4. Conclusions

Based on the analysis conducted on the 6 kV switchgear system supplying the Circulating Water Pump (CWP) motor at PT PLN Indonesia Power UBP Grati, it can be concluded that the primary cause of fuse failure is the mismatch between the fuse rating and the motor starting current characteristics. The motor starting current, which reaches approximately 325 A, exceeds the installed fuse rating of 250 A, causing the fuse to operate near its Time-Current Characteristic (TCC) limit.

Although the fuse does not immediately trip during motor startup, repeated exposure to high inrush currents results in thermal energy accumulation (I^2t), leading to thermal aging and degradation of the fuse element. This condition significantly reduces the reliability of the protection system and increases the risk of unexpected fuse operation during normal conditions.

The impact of this issue includes reduced system reliability, potential disruption to the cooling system, and decreased overall performance of the power plant unit. Therefore, proper selection of fuse rating, improvement of motor starting methods, and optimal protection coordination are essential to ensure safe, reliable, and selective operation of the electrical system.

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