IJAM: International Journal of Advanced Multidisciplinary
GREENATION PUBLISHER
+62 812 1046 7572 http://greenpub.org greenation.info@gmail.com
DOI: https://doi.org/10.38035/ijam.v5i2

Improving Network Fault Protection at 20/0.4 kV for General Hospital Operations through ETAP Simulation-Based Protection Relay Re-Setting

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Abstract: Fires caused by electrical disturbances are a major cause of material loss and safety risk in hospital buildings, particularly from short-circuit faults that are not selectively isolated by the existing protection system. This study evaluates the performance of the 20/0.4 kV distribution network protection system in a type-B general hospital and formulates a re-setting of the Over Current Relay (OCR) and Ground Fault Relay (GFR) to satisfy the principles of selectivity, sensitivity, reliability, and speed. A quantitative method with an ETAP 19.0.1 simulation approach was used, supported by field observation and historical fault data. The results show that the existing protection coordination has a grading margin of less than 0.2 seconds between relay levels, resulting in non-selective operation, consistent with a laboratory fire incident that was not isolated quickly. After re-setting based on short-circuit simulation and Time Current Characteristic (TCC) curve analysis, the protection coordination becomes selective, with a total clearance time on the priority feeder below 1.5 seconds and a considerably narrower outage area. This study recommends implementing the new settings together with primary injection testing and standardized documentation procedures for the hospital's electrical team.

Keywords: Protection Relay, OCR-GFR, Protection Coordination, ETAP, Hospital Electrical Safety

INTRODUCTION

Hospitals are critical facilities that depend heavily on the reliability of the electrical distribution system, particularly for medical equipment supporting diagnosis and emergency procedures. Electrical disturbances such as overcurrent, ground faults, leakage current, overvoltage, and undervoltage can damage medical devices and delay patient care, as emphasized in Minister of Health Regulation No. 40 of 2022 on the technical requirements for hospital buildings (Arifianto & Irfani, 2025).

A field study at a type-B regional general hospital in Kediri City shows that most electrical disturbances in the radiology room during the 2023-2024 period were caused by overcurrent resulting from power surges during the starting of supporting equipment such as air conditioning, lighting, and high-power radiology equipment (CT-Scan, MRI, Fluoroscopy). The Over Current Relay (OCR) functions to interrupt current at values of up to 125% of the nominal current within a range of 0.1-2 seconds to prevent overheating, while the Ground Fault Relay (GFR) detects ground leakage current above 30 mA that could potentially cause fire or electric shock.

A fire incident in the hospital's laboratory installation in 2019 indicated that the installed protection system did not operate selectively and quickly enough to isolate the short-circuit fault, allowing the fire to spread before it could be extinguished. The absence of complete technical documentation on the protection equipment configuration, setting values, and Time Current Characteristic (TCC) curves made it difficult to evaluate the exact cause of the incident. Meanwhile, the hospital is undergoing a service transformation, adding cardiovascular intervention diagnostic installations and constructing a new building, which changes the load characteristics and configuration of the existing distribution network.

Based on these conditions, this study aims to conduct a comprehensive evaluation of the 20/0.4 kV distribution network protection system and to formulate a re-setting of the OCR and GFR based on ETAP 19.0.1 simulation, covering the modeling of the existing system, short-circuit current analysis at various fault points, evaluation of existing protection performance, development of TCC curves, determination of new settings, and comparison of system performance before and after re-setting. The research questions addressed include: (1) how the re-setting of protection relays and their coordination can improve network reliability; (2) what the existing condition of the relay settings is and how an accurate network model can be developed using ETAP; and (3) what optimal re-setting values are required to achieve full selectivity and a real impact on hospital operations.

Theoretically, overcurrent protection coordination refers to the principle of time grading, namely the minimum operating time difference between relay levels (grading margin), which is typically set at around 0.3-0.4 seconds so that the downstream relay has time to complete its clearance before the upstream relay also operates. Relay characteristic curves generally follow the IEC 60255 standard, with standard inverse, very inverse, or extremely inverse types selected based on the fault current characteristics and coordination with the upstream and downstream protective devices. Mismatches in curve type or time dial setting values between protection levels are generally the main cause of selectivity failure in hospital distribution networks, as found in various case studies of other healthcare facilities (Marchese et al., 2015; Regoli et al., 2015).

Unlike most previous studies that limit their analysis to short-circuit simulation and OCR/GFR coordination alone, this study offers novelty by integrating three elements simultaneously: ETAP-based fault simulation, evaluation of harmonic distortion caused by non-linear medical loads, and validation against actual field fault incidents as empirical evidence. This integration is particularly important for regional referral hospitals with complete critical loads, because a failure of protection selectivity can directly affect patient safety, not merely result in material loss.

METHOD

This study employs a quantitative method with a power system simulation approach (quantitative simulation approach) using a quasi-experimental before-after design, comparing the existing protection setting conditions with the proposed re-setting results. This approach was chosen because the primary data are measurable (short-circuit current, relay operating time, setting values, and characteristic curves) and allow for replication in other hospital case studies. To complement the understanding of real conditions, this study also includes a limited qualitative component in the form of field observations at the 20/0.4 kV distribution substation and brief interviews with the hospital's electrical technicians.

The population of this study consists of all medium-voltage (20 kV) and low-voltage (0.4 kV) electrical distribution systems operating in general hospitals in Indonesia, along with all installed protection devices, covering the 20 kV distribution network (feeders, cables, and primary-side protection), 20/0.4 kV transformers, the 0.4 kV distribution network (main panel, sub-distribution panels, and feeders to critical and non-critical loads), protection devices (OCR, GFR, MCCB, ACB, fuse), and the hospital's electrical loads, both critical (anesthesia equipment, ventilators, CT-Scan, MRI, incubators) and supporting (lighting, air conditioning, elevators, pumps). Because it is not feasible to study every general hospital in Indonesia, the research sample was determined purposively at one type-B regional general hospital considered representative of the general characteristics of a hospital electrical distribution system with high critical loads, two supply sources (the state utility PLN and a generator set), and a UPS for priority loads.

Primary data collection includes the development of a single line diagram of the 20/0.4 kV network, transformer specifications, power cables, critical medical loads, and the existing setting data of the protection devices (OCR, GFR, and circuit breakers). Secondary data in the form of network fault history over the past one to two years were also collected as material for model validation.

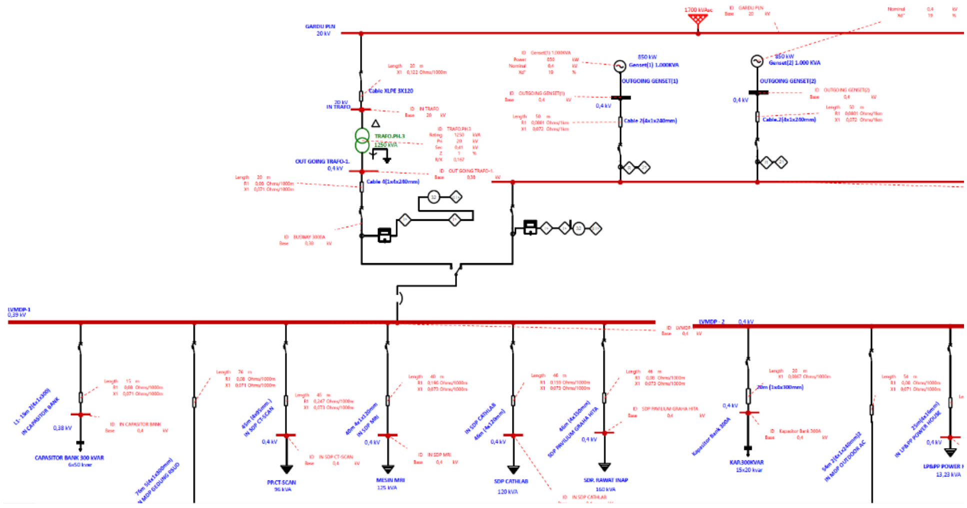
The system was modeled in ETAP 19.0.1 software by entering source impedance parameters, transformer capacity, cable length and type, load characteristics, and the TCC curves of the protection devices. Short-circuit analysis was carried out with reference to IEC 60909 through simulation of three-phase, two-phase, and single-phase-to-ground faults at various strategic points in the network, on both the 20 kV and 0.4 kV sides, to obtain the maximum and minimum fault current values as the basis for determining protection sensitivity and selectivity.

As verification of the simulation results, a manual calculation of the short-circuit current was also carried out using the per-unit value approach. The base current (I_base) was calculated from the system's base power (S_base) and base voltage (V_base) using the equation I_base = S_base / (V_base x square root of 3), while the transformer impedance in per-unit was obtained from Z_pu = %Z / 100. As an illustration, a transformer with a capacity of 1.6 MVA, a voltage of 20/0.4 kV, and an impedance of 6% produces an I_base of 2,309 A and a Z_pu of 0.06, so that the short-circuit current in per-unit (1/Z_pu) is 16.67 pu, or equivalent to 38.5 kA on the secondary side. This value was used as a comparison against the ETAP simulation output to ensure the validity of the model before it was used in the re-setting stage.

Evaluation of the existing protection performance was carried out by simulating the response of the protection devices to faults at several feeder locations to identify coordination weaknesses. Based on the results of this evaluation, the protection parameters (pickup current, time dial setting, and curve type) were re-set using ETAP's Star Protective Device Coordination feature, with criteria for fulfilling the principles of selectivity, sensitivity, reliability, and speed. The system performance before and after re-setting was then compared quantitatively to assess the effectiveness of the proposed improvement.

RESULTS AND DISCUSSION

The object of this study is a type-B regional general hospital that functions as a regional referral hospital with critical loads at the central surgery installation, laboratory, and intensive care unit, making the continuity of the electrical supply a key factor in patient safety. Modeling of the electrical system in ETAP 19.0.1 produced a single line diagram as shown in Figure 1, covering the incoming network from the 20 kV PLN substation, the 20/0.4 kV step-down transformer, the backup generator, and the sub-distribution panels serving critical loads such as CT-Scan, MRI, and inpatient wards.



Source: ETAP 19.0.1 Modeling Results

Figure 1. Single Line Diagram of the 20/0.4 kV Electrical System of the Study Object

The technical data of the system on the LB Substation side used as the basis for the simulation is presented in Table 1. The main transformer, with an installed capacity of 1.6 MVA, a voltage of 20/0.4 kV, and a delta-star connection, produces a three-phase short-circuit current of 3.313 kA and a single-phase-to-ground short-circuit current of 3.997 kA at the LB Substation point.

Table 1. Technical Data of the 20 kV LB Substation System

Parameter	Specification
Transformer Type	3 Phase Transformer
Installed / Used Capacity	115 MVA (1.6 MVA used)
Primary/Secondary Voltage	20/0.4 kV
Frequency	50-60 Hz
Connection	Delta/Star
Three-Phase Short-Circuit Current (Isc)	3.313 kA
Single-Phase-to-Ground Short-Circuit Current	3.997 kA

Source: Research data processing results

Evaluation of the existing condition found that the current-time characteristic (TCC) curves between relay levels have a grading margin of less than 0.2 seconds, indicating non-selective protection coordination. This condition is consistent with the fire incident at the laboratory installation caused by an electrical short circuit, in which the short-circuit fault was not quickly isolated by the panel-level protection, allowing the fire to spread before it could be extinguished. In addition, the addition of power-electronics-based medical equipment such as CT-Scan, MRI, and ventilators increases voltage harmonic distortion (THDv) to as much as 7.8%, exceeding the 5% limit required by IEEE 519-2014, potentially disrupting relay performance through nuisance tripping or, conversely, failure to trip.

Based on the short-circuit current simulation results and the TCC curve analysis, the pickup current, time dial setting, and curve type (normal inverse time) values of the OCR and GFR were re-set at every protection level, from the 20 kV incoming side to the 0.4 kV outgoing side of the priority loads. A comparison of the conditions before and after re-setting is presented in Table 2.

Table 2. Comparison of Protection Performance Before and After Re-Setting

Aspect	Existing Condition	After Re-Setting
Grading margin between relays	< 0.2 seconds (non-selective)	Meets full selectivity standard
Outage coverage during a fault	Potentially extends to the entire hospital system	Limited to a single affected room/area
Total clearance time on the priority feeder	Not standardized	< 1.5 seconds
Voltage harmonic distortion (THDv)	7.8% (exceeding the IEEE 519-2014 limit)	Accommodated in the re-development of the TCC curve

Source: ETAP 19.0.1 analysis and simulation results

These results show that ETAP simulation-based re-setting can significantly improve the selectivity of coordination between protection levels, narrow the area affected by outages, and accelerate service recovery time, since only the circuit breaker on the branch nearest to the fault operates (trips), while the upstream protective devices remain functional as backup. These findings are consistent with previous studies highlighting the issue of non-selective protection in existing healthcare facility systems (Sihombing et al., 2019; Hassan et al., 2022) as well as the effect of non-linear loads on power quality in hospitals (Utami et al., 2026).

Compared with previous studies that generally focus solely on short-circuit simulation and OCR/GFR coordination (Irwanto et al., 2021; Yuliza et al., 2023), this study broadens the scope of analysis by integrating an evaluation of harmonic distortion and validation against actual field fault incidents as empirical evidence of the urgency of re-setting. An approach that links simulation results with historical data on real faults provides a stronger justification for hospital management in deciding on the implementation of new settings, in line with the principle of protection reliability for healthcare facilities emphasized in NFPA 99 and IEEE Std 602 (NFPA, 2018; IEEE, 2021). The position of this study relative to the existing literature is summarized in Table 3.

Table 3. Comparison of This Study's Position with Previous Research

Aspect	Previous Research	This Study
Study object	General 20 kV distribution or hospitals with a limited focus	Type-B regional referral hospital with full critical loads
Analytical approach	Short-circuit simulation and OCR/GFR coordination	Short-circuit, harmonics, and integrated hospital-standard evaluation
Data validation	Pure simulation or limited data	Historical fault data and actual field observation
Reference standard	PUIL 2011 or IEEE 242	PUIL 2020, NFPA 99, IEEE 519-2014, and IEEE 602

Source: Synthesis of literature review and research findings

In practical terms, the application of these re-setting results can reduce the risk of damage to high-value medical equipment and reduce the potential losses caused by disruptions to patient services, since selective clearance limits the affected area to only the part of the network experiencing the fault. Theoretically, this study enriches the methodology of protection coordination in the distribution networks of healthcare facilities with critical loads through an approach that combines quantitative simulation with real-incident validation. From a policy perspective, these findings support the need for periodic evaluation and re-setting of hospital electrical protection systems as part of healthcare facility risk management, particularly for hospitals undergoing load additions or building expansion.

Before being implemented permanently, the new setting values produced by this simulation need to be verified through field testing, including a secondary injection test to ensure the relay operates according to the new pickup and time dial values, and a primary injection test limited to critical points to confirm the agreement between the simulation results and the actual condition of the network. The recommended implementation stages include a final simulation, approval from hospital management, coordination with PLN for setting changes on the 20 kV side, and the execution of setting changes during scheduled downtime to minimize disruption to patient services.

In addition to the time-current coordination aspect, voltage harmonic distortion exceeding the IEEE 519-2014 limit also needs attention in the redesign of the protection system, as it can cause current-reading errors in both electromechanical and digital relays, triggering nuisance tripping or, conversely, failure to trip. Mitigation measures that can be considered include the use of passive harmonic filters on buses serving dominant non-linear loads (CT-Scan, MRI, and other power electronics equipment), the selection of digital relays with true RMS sensing features that are more resistant to waveform distortion, and the re-adjustment of the time dial with an additional margin under peak load conditions. These steps complement the OCR and GFR re-setting results so that protection reliability is maintained even as the hospital's load characteristics continue to change with the addition of modern medical equipment.

This study has limitations, including the fact that the available historical fault data is limited to the past one to two years, and that field validation has not yet included comprehensive primary injection testing at every protection point, due to considerations for maintaining hospital operational continuity. Therefore, the proposed re-setting results should be regarded as an initial simulation-based recommendation that requires follow-up in the form of field testing before being permanently implemented in the operating protection system.

CONCLUSION

This study concludes that the existing condition of the 20/0.4 kV distribution network protection system at the study object does not yet meet the principle of selectivity, with a grading margin between relays of less than 0.2 seconds, as reinforced by the laboratory installation fire incident that was not isolated quickly. System modeling using ETAP 19.0.1 successfully represented the network condition accurately based on source impedance data, transformer specifications, cables, and actual loads, so that it can be used as the basis for re-setting simulation without the risk of an outage on the operating system. Re-setting the pickup current, time dial, and curve type values of the OCR and GFR proved capable of producing selective protection coordination, with a total clearance time on the priority feeder of below 1.5 seconds and an outage coverage significantly narrower than the existing condition. Thus, protection relay re-setting based on ETAP simulation can improve hospital operational reliability while reducing the risk of fire caused by electrical disturbances. Further research is recommended to validate the simulation results through direct primary injection testing in the field, expand the scope of the study to the hospital's entire electrical system, and develop a documented standard operating procedure for protection setting changes for the hospital's electrical team.

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