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Contactor-Based Simulation Design of an Automatic Transfer Switch and Mains Failure Panel for Power Continuity Systems

I Wayan Sukadana[1*], Ida Ayu Dwi Giriantari[2], Ida Bagus Alit Swamardika[2], Wayan Gede Ariastina[2], I Putu Aswin Anandam[1], I Wayan Sugara Yasa[1]

[1]Electrical Engineering Study Program, Universitas Pendidikan Nasional Denpasar, Indonesia

[2]Electrical Engineering Study Program, Universitas Udayana Denpasar, Indonesia

*sukadana@undiknas.ac.id

Abstract. Reliable electrical power supply is crucial for industrial, commercial, and essential facilities, as mains failures can cause significant operational losses and equipment damage. To address this, Automatic Transfer Switches (ATS) integrated with Mains Failure (AMF) panels are employed to ensure continuous power supply by automatically transferring loads to backup sources such as generators. This study aims to design and simulate a contactor-based ATS-AMF system to evaluate its performance, stability, and monitoring capabilities prior to physical implementation. The methodology involved system design, specification of components, simulation modeling, and performance testing, including input and output voltage verification at Miniature Circuit Breakers (MCBs) and contactors, measurement of current and frequency, and evaluation of operational modes (manual, automatic, and repair). Results indicate that both the PLN main supply and the generator maintain stable single-phase and three-phase voltages within nominal limits, with minimal voltage drop across contactors, confirming proper power transmission. Current measurements under no-load conditions were zero, while frequency remained constant at 50 Hz, meeting operational standards. These findings demonstrate that the contactor-based ATS-AMF system can reliably manage automatic load transfers, ensure uninterrupted and stable power delivery, and provide accurate monitoring, offering an effective and safe solution for backup power systems.

Keywords: Automatic transfer switch, mains failure panel, contactor simulation, power continuity, voltage stability, backup power

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1. Introduction

The reliability of electrical power supply is a critical aspect in industrial, commercial, and essential facilities such as hospitals, data centers, and telecommunication infrastructures. In many cases, a mains failure can result in significant losses, equipment damage, or data loss if the system is not equipped with an automatic power recovery mechanism [1]. To ensure continuity of power supply, systems such as Automatic Transfer Switches (ATS) and Mains Failure panels are employed. An ATS monitors the condition of the primary power source and automatically transfers the load to a backup source, such as a generator or UPS, in the event of a mains failure. However, developing an effective ATS requires proper control design, fast response capability, and reliable integration between the contactor mechanism, voltage sensors, and control logic. This is where contactor-based simulation design becomes crucial. [2–5]

The increasing reliance on electricity in daily life, particularly in industrial, commercial, and public service sectors, underscores the critical need for uninterrupted power supply. While backup generators are commonly employed in facilities such as industries, hotels, and tourist destinations, their effectiveness depends on proper integration with advanced control mechanisms. For instance, Villa Asli Tibubeneng utilizes an Automatic Transfer Switch (ATS) to manage load transfers during power outages, yet it lacks an Automatic Mains Failure (AMF) system capable of detecting disturbances such as generator malfunctions, overheating, or fuel shortages [6]. The integration of ATS and AMF systems offers an optimal solution for ensuring continuous, stable, and automatic electricity supply without the need for operator intervention.

Previous research stated that the purpose of the study was to analyze the economic value and utilization of Automatic Transfer Switches (ATS) for various electricity-saving concepts over a certain period using project management analysis, in order to evaluate the feasibility of project implementation. The method involved calculating economic feasibility by determining the Internal Rate of Return (IRR), Net Present Value (NPV), and Payback Period using Microsoft Excel, alongside project risk analysis. The results indicated an IRR of 6.51%, exceeding the interest rate of 5.75%, an NPV of IDR 572,252, and a payback period of 12 years. Based on these results, the project was declared feasible to proceed. This study provides a foundation demonstrating that the implementation of ATS, especially when integrated with an Automatic Mains Failure (AMF) system, not only ensures continuous power supply but also offers significant long-term economic and operational benefits. [7,8]

In addition, the study previous stated that the use of a D1 R32 microcontroller and a PZEM-004T sensor enabled the measurement of voltage and current from two sources: the state electricity provider (PLN) and a generator. The measurement data were displayed in real-time through the Blynk application and stored in the cloud. Testing was conducted over a 14-day period at one-hour intervals, covering both automatic and manual switching conditions. The results demonstrated that the Blynk application could display the power supply switching status with a fast response and accurately log voltage data. This indicates the effectiveness of Blynk as a cloud-based monitoring and data logging tool in an IoT-based ATS-AMF system. [9,10]

The study involved experiments on the ATS-AMF control panel and IoT-based control, using a NodeMCU-ESP8266 microcontroller as the input-output control center and a PZEM-004T sensor to measure and display parameters including current, voltage, power, energy, frequency, and power factor. Comparison of the PZEM-004T sensor results with a KWS AC301 power meter under PLN and generator supply with five active loads showed the following: voltage error rate of 0.8% (accuracy 99.2%), current error rate of 0.65% (accuracy 99.35%), power parameter error of 0.08% (accuracy 99.18%), power factor error of 0.4% (accuracy 99.6%), frequency error of 0.6% (accuracy 99.4%), and energy parameter error of 8.5% (accuracy 91.04%). These results indicate that the system is highly accurate and can serve as a recommendation for more efficient load management, potentially reducing operational costs. [11]

Although previous studies have demonstrated the effectiveness of IoT-based ATS-AMF systems in monitoring and controlling power supply, there remains a research gap in the integration of contactor-based simulation to test system responses in real-time prior to physical implementation, as well as limited analysis of switching stability and efficiency between power sources. The novelty of this research lies in the development of a contactor-based ATS-AMF simulation design, enabling the virtual testing of load transfer logic, response time, and data logging, thereby minimizing the risk of failure in actual systems. Based on this, the objective of the study is to design and simulate a contactor-based ATS-AMF panel that ensures continuous power supply, enhances system stability, and provides accurate monitoring data to support the implementation of a reliable backup power system.

2. Methods

This research focuses on engineering design and simulation, rather than purely qualitative approaches. The study was conducted through system design, component specification, simulation modeling, and performance validation to ensure reproducibility and technical accuracy. Data collection was based on technical documentation, manufacturer manuals, and verified electrical component specifications. The working principle of the designed ATS-AMF system is as follows: under normal conditions, the electrical load is supplied by the main source, PLN. In the event of a blackout or disturbance, the Automatic Mains Failure (AMF) system detects potential generator faults, such as excessive engine temperature, low lubricant (oil) levels, or insufficient fuel. If a fault is detected, the AMF system disconnects the start/stop circuit to prevent the generator from starting and causing further damage. If no faults are detected, the generator automatically starts and supplies the load, remaining on standby to ensure continuous power supply. When the PLN supply returns and remains stable for the preset delay time, the system switches the load back to PLN, and the generator shuts down automatically. For inductive loads, a dead-bus delay of 2–5 seconds is applied after PLN disconnection to prevent residual voltage from causing phase differences, high inrush currents, or protection trips. Operational standards require the ATS to switch to the generator within a maximum of 10 seconds after main source failure. The system also supports a maintenance mode, where the generator runs periodically (e.g., one hour per month) to lubricate internal components and remove moisture, as well as a repair mode, in which all generator control circuits are disabled for technician safety during major repairs. In repair mode, the load can only be supplied by PLN, provided that the supply is available and stable.

3. Results and Discussion

Testing is carried out to find out and ensure that the designed circuit is planned and can function according to the expected work description. Therefore, it is necessary to test the tools that have been made. The testing process is carried out on the following aspects:

3.1 Testing the Input Voltage on the MCB

This test aims to determine and ensure the flow of voltage from the power source to the MCB input so that it can be ensured that the system receives the electricity supply as planned. The technique or test method for the input voltage on the MCB can be seen in Figure 1 below and the test results can be seen in Table 1.

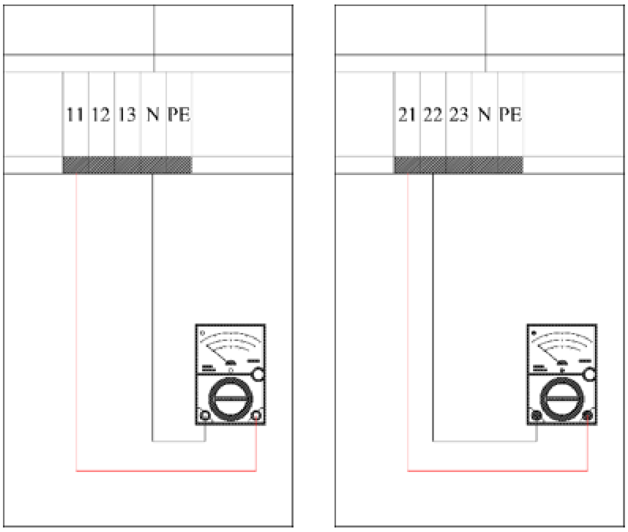

Figure 1. Testing the Input Voltage on the MCB

This test was conducted to verify and ensure the proper flow of voltage from the power source to the MCB (Miniature Circuit Breaker) input, confirming that the system receives electricity as intended. The testing procedure involves measuring the input voltage at the MCB terminals, as illustrated in Figure 1, to check continuity and correct voltage levels. The results of this measurement, summarized in Table 1, demonstrate whether the system is correctly supplied with power and can safely operate under normal conditions. This step is essential to validate the integrity of the electrical input circuit before further system operation or testing.

Several previous studies also support the importance of verifying the input voltage in electrical systems before full system operation. Research by Kostic et al., (2025) highlights that preliminary testing of the electrical supply line, including voltage measurement and circuit continuity checks, is a fundamental step to ensure that electrical protection devices receive power according to their operational specifications. Such verification helps confirm that the power distribution path from the source to the protection component functions properly and safely. [12]

Similarly, studies in power system installation and protection that measuring voltage at the input terminals of protection devices, such as a Miniature Circuit Breaker (MCB), is an essential diagnostic procedure. This process ensures that electrical energy flows correctly from the power source to the distribution system and allows early identification of installation errors, supply irregularities, or abnormal voltage conditions that could affect system performance. Therefore, verifying the input voltage at the MCB terminals prior to further operation is considered a crucial step in maintaining the reliability and safety of electrical systems. [9]

Before presenting the measurement results, voltage testing was carried out on both the single-phase and three-phase inputs connected to the MCB to ensure that the electrical supply from the main source and the generator operates within acceptable limits. This procedure aims to verify that the voltage delivered to the protection device is stable and close to the rated voltage required for safe system operation. Measurements were taken at the input terminals of the MCB for each phase combination, including line-to-neutral for single-phase testing and line-to-line for three-phase testing. The results obtained from these measurements are summarized in Table 1.

Table 1. Testing Results of I-Phase and 3-Phase Input to MBC

Description	1 Phase Voltage		3 Phase Voltage	
	Input	Rated Voltage (V)	Input	Rated Voltage (V)
PLN Power MCB (MCB14)	R-N	227	R-S	401
	S-N	231	S-T	406
	T-N	229	T-R	398
Generator Power MCB (MCB16)	R-N	219	R-S	384
	S-N	221	S-T	384
	T-N	222	T-R	381

Table 1 presents the results of voltage measurements conducted on the input terminals of the MCB for both the PLN power source and the generator set. The measurement results show that the single-phase voltages (R–N, S–N, and T–N) for the PLN supply range between 227 V and 231 V, with an average value of approximately 229 V, which is close to the nominal single-phase voltage standard. Meanwhile, the three-phase voltages (R–S, S–T, and T–R) recorded values of 401 V, 406 V, and 398 V respectively, with an average of 401.6 V. These values indicate that the PLN power supply is operating within a normal voltage range and can provide stable electrical energy to the system through the MCB input.

Similarly, the generator power supply also demonstrates stable voltage conditions based on the measurement results. The phase-to-neutral voltages measured at the generator MCB input range from 219 V to 222 V, with an average value of 220.6 V, while the inter-phase voltages range from 381 V to 384 V, with an average of approximately 383 V. These values remain within the acceptable operational limits for three-phase electrical systems. In addition, the voltage measured at the PLN Control MCB input is 227 V, which is supplied from phase R of the PLN Power MCB, while the Genset Control MCB input shows a voltage of 219 V supplied from phase R of the Genset Power MCB. These results confirm that both the main power supply and the generator source are able to deliver stable voltage to the control and distribution systems, ensuring safe and reliable operation for subsequent system processes and testing.

Several previous studies have also reported similar findings regarding the importance of verifying voltage stability at the input of protection devices in electrical distribution systems. Voltage measurements at circuit breaker inputs are commonly used to ensure that the electrical supply operates within acceptable tolerance limits before the system is activated [13]. The study highlights that stable phase-to-neutral and phase-to-phase voltages indicate that the power source and distribution network are functioning properly. When the measured voltage values are close to their nominal ratings, it confirms that the electrical system can operate safely without risking damage to equipment or protection components. [14]

In addition, studies in power system operation and distribution show that voltage verification on both utility power sources and backup generators is a standard procedure in electrical system commissioning. Their work shows that comparing inter-phase and phase-to-neutral voltage values can help determine whether the supply system is balanced and operating within normal parameters [15]. If the measured voltages fall within the expected range, it indicates that both the main power source and the backup generator can supply stable electrical power to the distribution panel and protection devices such as MCBs, thereby supporting reliable and continuous system operation. [16]

3.2 Output Voltage Testing on Contactors

Testing the output voltage on the contactor aims to determine and ensure the flow of electric current from the contactor output terminal after the contactor is active or operating. This test is important to ensure that the contractor works according to its function in delivering power to the load. The technique or way of testing the output voltage on the contactor can be seen in Figure 2 below and the test results can be seen in Table 2.

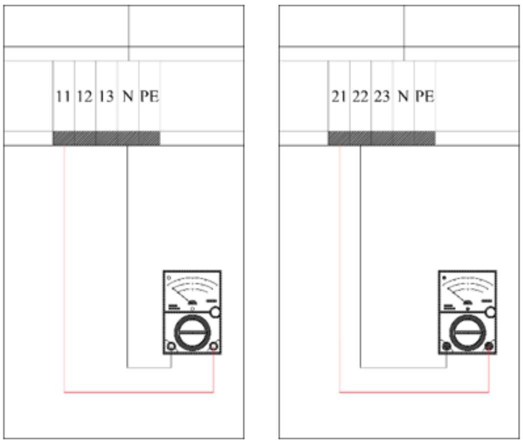

Figure 2. Testing the output voltage on contactors

Based on Figure 2, the output voltage testing on the contactors was carried out by measuring the voltage at the output terminals of the contactor using a measuring instrument (multimeter). This test aims to ensure that the electrical voltage from the power source can be properly transmitted through the contactor to the load circuit when the contactor is in the active condition. The measurement results indicate that voltage is detected at the contactor output terminals and corresponds to the input voltage supplied to the contactor, which shows that the contactor operates properly and can distribute electrical power normally. Therefore, the control and power distribution circuit through the contactor can function stably and is ready for further system operation.

Similar findings have been reported in previous studies. According to research discussed by Panda et al., contactors play a critical role in industrial power control systems by enabling reliable switching and ensuring stable voltage transmission from the supply to the load [17]. Furthermore, studies in electrical power distribution systems explain that voltage testing at the output terminals of switching devices such as contactors is an important diagnostic step to verify that the control components are functioning correctly and that electrical energy is delivered efficiently to the connected system. These findings support the results of the current test, which confirm that the contactor can properly conduct voltage and maintain stable system operation. [18]

Testing of the output voltage on the contactors was conducted to verify that the contactor is capable of properly transmitting electrical power from the input side to the output terminals. This test is important to ensure that the switching mechanism of the contactor operates correctly when energized and that the voltage delivered to the load remains within the acceptable operating range. Measurements were carried out using a multimeter at the output terminals of the PLN control contactor (K28) and the genset control contactor (K22) for both single-phase (line-to-neutral) and three-phase (line-to-line) configurations. The results of these measurements are summarized in Table 2.

Table 2. Testing Results of 1-Phase and 3-Phase Output Voltage at the Contractor

Description	1 Phase Voltage		3 Phase Voltage	
	Input	Rated Voltage (V)	Input	Rated Voltage (V)
K28 PLN control contactor	R-N	227	R-S	405
	S-N	231	S-T	403
	T-N	229	T-R	400
K22 Genset control contactor	R-N	220	R-S	381
	S-N	221	S-T	387
	T-N	222	T-R	382

Table 2 shows that the measured output voltages from both contactors are close to the expected nominal values. For the PLN control contactor (K28), the single-phase voltages range from 227 V to 231 V, with an average phase-to-neutral voltage of approximately 229 V. Meanwhile, the three-phase voltages measured between phases (R–S, S–T, and T–R) range from 400 V to 405 V, with an average inter-phase voltage of about 402.6 V. These values indicate that the PLN contactor is capable of transmitting electrical power from the PLN source to the system without significant deviation from the nominal voltage. Similarly, the genset control contactor (K22) also shows stable voltage results, with single-phase voltages between 220 V and 222 V and an average phase-to-neutral voltage of around 221 V. The inter-phase voltages measured range from 381 V to 387 V, resulting in an average value of approximately 383.3 V, which is still within the acceptable operational range for a three-phase power system.

When compared with the results of the voltage measurements at the MCB input, both the single-phase and three-phase voltage values at the input and output sides appear relatively stable and do not show a significant voltage drop. This condition indicates that the contactor components are functioning properly in transmitting electrical energy from the source to the distribution system. The observed results are consistent with the provisions stated in PUIL 2011 paragraph 2.2.3, which specifies that the allowable voltage drop in an electrical installation should not exceed 4% of the nominal voltage. The small difference between the measured input and output voltages is most likely caused by the measurement tolerance of the testing instruments used during the experiment. Overall, the testing results confirm that the electrical system operates according to the designed specifications and can deliver stable voltage through the contactor to the connected load.

The findings of this test are consistent with previous studies conducted by Pongoh who states that contactors used in electrical control systems are designed to deliver electrical voltage from the power source to the load efficiently with only minimal losses during normal operation. When the measured voltage values at the input and output terminals remain relatively stable, it indicates that the switching device operates properly and that the power distribution process runs effectively [19]. Furthermore, research by Dimitrov also explains that slight variations between input and output voltage measurements are common in electrical systems. These differences are typically influenced by measurement accuracy or small internal resistance within the components, and as long as the voltage drop remains within the permitted tolerance range, the system can still be considered to function safely and according to its operational design. [20]

3.3 Tool Work Description Testing

The work description testing is conducted to verify that the designed system functions according to the planned operational scenarios and system design. This testing process involves three main operating conditions: manual mode, automatic mode, and repair mode. Each mode is evaluated to determine how the system responds to changes in the availability or status of the power source and to ensure that the switching mechanism operates correctly. The tests are performed at the generator set location to observe the system's ability to manage the transition of the power supply between sources based on the selected operating mode. Through this testing process, the reliability, responsiveness, and operational readiness of the system in handling power supply switching can be effectively assessed.

3.4 Testing measuring instruments

Testing measuring instruments aims to determine the value of the desired electrical quantities such as current, frequency, and voltage between phases. In addition, testing measuring instruments also aims to ensure that measuring instruments can function normally. As for the measurement results obtained are as follows;

Table 3. Current and Frequency Measurement Results

Voltage Source	Current (A)			Frequency
	R	S	T	(Hz)
PLN	0	0	0	50
Genset	0	0	0	50

Table 3 presents the results of current and frequency measurements for both power sources, namely PLN and the generator set. The data show that the current values in phases R, S, and T are 0 Ampere for both sources. This condition occurs because no electrical load was connected to the system at the time the measurements were conducted, resulting in no current flowing through the circuit. Meanwhile, the measured frequency from both PLN and the generator is 50 Hz, which complies with the standard electrical frequency used in Indonesia. These results indicate that although no load current is present in the system during testing, both power sources are capable of maintaining a stable and appropriate frequency level according to the operational standards of the national power system.

The results of this test are consistent with findings reported in previous studies on electrical power systems and generator operation. Research by Fernandez explains that when no load is connected to an electrical system, the current flowing through each phase will approach zero because there is no electrical demand from the load side [21]. Under this condition, the power source still maintains its nominal voltage and frequency, but current does not flow significantly through the circuit. This phenomenon is commonly observed during no-load testing of power systems and is often used to verify the basic operational condition of electrical equipment before applying a load [22]. In addition, studies on power generation and distribution systems by Stephen J. Chapman also state that generators and utility power systems are designed to maintain a stable frequency even when operating without load. Maintaining a constant frequency is essential because it reflects the stability of the generator speed and the synchronization of the electrical system. [23]

Table 4. Voltage Measurement Results on the Measuring Device

Voltage Source	1 phase voltage		3 phase voltage	
	Output	Rated Voltage (V)	Output	Rated Voltage (V)
PLN	R – N	221	R - S	385
	S – N	221	S - T	385
	T – N	221	T - R	385
Genset	R – N	230	R - S	400
	S – N	230	S - T	400
	T – N	230	T - R	400

Table 4 presents the voltage measurement results obtained from the analog measuring instrument installed on the panel door for both PLN and generator power sources. The data show that the single-phase voltages from the PLN source (R–N, S–N, and T–N) are measured at 221 V for each phase, while the three-phase voltages (R–S, S–T, and T–R) are recorded at 385 V. Meanwhile, the generator source shows single-phase voltages of 230 V for each phase-to-neutral measurement and three-phase voltages of 400 V for the phase-to-phase measurements. These values indicate that the voltage supplied by both power sources remains within the normal operating range and is relatively close to the expected nominal voltage levels for single-phase and three-phase electrical systems. In general, the measured voltage values obtained from the analog measuring device are consistent with the input voltage supplied to the system from both PLN and the generator. The slight differences between the input voltage values and the readings displayed on the measuring instrument are most likely caused by the limited precision and stability of analog measurement devices during the reading process. Fluctuations in the needle movement of analog instruments may lead to small variations in the observed values, which can affect the accuracy of the measurement results. Nevertheless, the overall results indicate that the electrical system is capable of delivering voltage from both power sources properly and within acceptable operational limits.

The results of this measurement are supported by previous studies related to voltage monitoring in electrical distribution panels. Voltage measurements obtained from panel-mounted analog instruments generally show values close to the actual system voltage, although slight deviations may occur due to the mechanical characteristics and reading limitations of analog meters. These deviations are considered normal as long as the measured voltage remains within the allowable tolerance range of the electrical system, indicating that the power supply and measurement devices are still operating properly [24]. In addition, analog measuring devices may experience minor fluctuations during the measurement process because their readings depend on pointer movement and human observation. As a result, small differences between the actual input voltage and the value displayed on the analog instrument are commonly observed in practical measurements [25]. Nevertheless, if the measured values remain close to the nominal voltage level, it confirms that the electrical system and the monitoring instruments are functioning effectively in indicating the operating condition of the power supply.

4. Conclusion

This study successfully verified the design of a contactor-based Automatic Transfer Switch (ATS) and Mains Failure panel for power continuity systems, focusing on tests of MCB input voltage, contactor output voltage, system operation modes, and measurements of current and frequency. Measurement results showed that voltages from both the main PLN supply and the generator were within normal limits for single-phase and three-phase configurations, with minimal differences between input and output values, indicating that the contactors functioned according to specifications and could reliably deliver stable power to the load. Testing of the system’s operation modes manual, automatic, and maintenance demonstrated its capability to manage power source switching responsively and reliably. Instrument measurements showed zero current under no-load conditions and a stable frequency of 50 Hz, confirming that both power sources maintained nominal operating conditions. Overall, the tested ATS and Mains Failure panel provided safe, stable, and reliable power distribution as designed, and the measurement results were consistent with previous studies on voltage verification, contactor performance, and frequency stability in electrical systems.

Declaration of AI and AI assisted technologies in the writing process

During the development of this manuscript, the author(s) utilized ChatGPT solely as a supporting tool to improve academic language, enhance sentence flow, correct grammatical issues, and strengthen overall readability. All AI-assisted suggestions were subsequently evaluated, revised, and verified by the author(s) to ensure that the scientific meaning and accuracy of the manuscript remained unchanged. The author(s) retain full responsibility for the final content of the article.

Declaration of Competing Interest

The authors confirm that there are no financial, professional, institutional, or personal interests that could have improperly influenced the research, interpretation of the findings, or preparation of this manuscript.

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