

Intelligent Changeover Switch Design: A Comparative Study of Single and Three Phase Selector for Efficient Power Distribution

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Abstract - The persistent unreliability of electrical power supply in developing economies, particularly Nigeria characterized by frequent grid outages, voltage fluctuations, and phase imbalances necessitates the development of affordable and dependable automatic changeover solutions for seamless load transfer between grid and backup generation. This paper presents a comparative analysis of a three-phase Automatic Transfer Switch (ATS) system rated for (380V–415 V) and a single-phase ATS system rated for 220V–240 V. Both systems were built using four-pole electromagnetic contactors with mechanical and electrical interlocking, programmable digital and analog timers for switching sequence control, and comprehensive protection devices. Performance evaluation was conducted under controlled laboratory conditions using calibrated instruments; a Fluke 87V multimeter, Kyoritsu 2033 ammeter, and Fluke 435 Series II power quality analyzer with data collected across load conditions ranging from 0% to 100% and over multiple switching events. The findings reveal that the three-phase ATS consistently outperformed the single-phase system across all performance indicators. It achieved substantially faster switching times (4.2s–4.5 s versus 7.5–8.2 s), significantly lower per-phase current draw at equivalent power delivery (3.6 A versus 10.6 A), and superior voltage regulation with only a 1.5% voltage drop at full load compared to 3.0% for the single-phase system. Both configurations exhibited excellent repeatability across multiple switching events, with variations within ± 0.3 s, confirming the reliability of the programmable timing and contactor mechanisms. Additionally, the three-phase system maintained acceptable current balance across phases, with a maximum deviation of 0.1 A. These results demonstrate that contactor-based ATS technology offers a practical and affordable solution for power distribution applications in developing economies. The single-phase system provides suitable functionality for residential applications with moderate power demands, while the three-phase configuration delivers optimal performance for commercial and industrial installations requiring minimal voltage fluctuation and faster response times. This study contributes methodological resources for engineering education and technical capacity building in the electrical power sector of developing economies, validates locally manufactured solutions as technically viable alternatives to costly imported equipment, and supplies empirical performance data to support evidence-based ATS selection decisions.

Keywords: Automatic transfer switch, contactor-based ATS, single-phase selector, three-phase selector, power distribution, voltage regulation, switching time.

1.0 INTRODUCTION

The unreliable nature of electrical power supply in developing economies, particularly Nigeria, presents a persistent challenge characterized by frequent grid outages, voltage fluctuations, and phase imbalances that disrupt residential, commercial, and industrial activities [1–5]. This instability has compelled electricity consumers to seek alternative power sources, predominantly gasoline and diesel generators, creating an urgent need for automatic changeover systems that can seamlessly transfer loads between grid supply and backup generation. While manual changeover switches remain economically accessible, they introduce significant risks, including prolonged downtime during outages, potential equipment damage from improper switching sequences, and safety hazards associated with human error [1,6–9]. The scarcity of reliable, cost-effective automatic transfer switches (ATS) in the Nigerian market has perpetuated dependence on manual intervention, exposing households and businesses to delayed power restoration and unsafe switching practices [8, 9, 10–12]. Moreover, the coexistence of single-phase residential connections and three-phase commercial and industrial installations demands a comparative understanding of how different ATS configurations perform under identical grid disturbance conditions.

The persistence of inadequate automatic changeover solutions stems from a complex interplay of economic, technical, and market factors that have collectively hindered widespread adoption of reliable ATS technology [13]. Commercially available units from established international manufacturers, while technically superior, remain prohibitively expensive for the average consumer in developing countries, often exceeding the combined investment in generator and connected equipment [8, 10, 11, 14–15]. This economic barrier has driven consumers toward either manual changeover switches or locally fabricated automatic systems of questionable reliability, creating a market characterized by compromised safety standards and unpredictable performance. Technical expertise for proper ATS installation is unevenly distributed across the electrical contracting sector, with many practitioners lacking comprehensive understanding of interlocking, timing coordination, and protection principles essential for safe automatic transfer operation. Additionally, the variability of Nigerian grid characteristics including frequent phase imbalances, voltage sags, and harmonic distortion presents unique design challenges that generic ATS products, not specifically engineered for such conditions, may fail to address adequately. The absence of localized technical standards and enforcement mechanisms has allowed substandard products to proliferate while discouraging investment in context-appropriate research and development [1, 4, 5, 16–18].

Automatic transfer switches are critical components in modern power distribution architecture, defined as self-acting devices that continuously monitor primary power source availability and automatically transfer connected loads to an alternative source upon detection of primary source failure [19–20]. Their fundamental operating principles encompass voltage and frequency sensing, timing logic for source stabilization, and mechanically or electrically interlocked switching mechanisms that absolutely prevent simultaneous connection of both sources [9, 11, 21]. Transfer switch topologies have evolved considerably, including open-transition (break-before-make) configurations that momentarily interrupt load power, closed-transition (make-before-break) designs enabling seamless transfer for sensitive loads, and static switches utilizing power electronic devices for sub-cycle transfer times in critical applications [5, 7]. Within this spectrum, contactor-based ATS implementations occupy an important niche, offering cost-effective automatic transfer capability for low-to-medium power applications through the arrangement of standard electromagnetic contactors with appropriate control logic and interlocking provisions.

Extant literature has revealed substantial investigation into various aspects of automatic transfer switch design and performance, yet existing research often focuses on the design and construction of automatic three-phase power systems [22–25] or the development of single-phase selectors [26–28] without directly juxtaposing the technological requirements, switching time, efficiency, current phase imbalance, and performance metrics across both configurations. This gap leaves system designers, integrators, and end users without a consolidated framework for selecting and optimizing ATS based on a holistic understanding of system efficiency and reliability.

By adopting the contactor-based method, this study aims to carry out a comparative analysis of single-phase and three-phase selectors for efficient power distribution. This was achieved through a comparative experimental design in which two distinct ATS panels were constructed using four-pole contactors, programmable digital and analog timers, and protection devices, with testing conducted under controlled laboratory conditions using calibrated measurement instruments. The significance of this investigation extends across multiple dimensions of electrical engineering practice, equipment manufacturing, and energy policy in developing economies. For electrical contractors and system integrators, the empirical performance data provides evidence-based guidance for ATS design decisions, enabling informed selection of component configurations and timing parameters optimized for local grid characteristics and generator performance. From a policy perspective, the demonstration that locally fabricated contactor-based ATS can achieve 94–96% efficiency and voltage regulation within acceptable limits supports initiatives promoting local manufacturing and technical capacity building in the electrical sector. For engineering education, the detailed methodology, circuit configurations, and performance characterization provide instructional resources for training programs, supporting the development of local technical expertise essential for sustainable infrastructure development.

2.0 MATERIALS AND METHOD

2.1 Research Design

This study employed a comparative experimental design to evaluate the performance of single-phase and three-phase ATS constructed using the contactor-based method. The contactor-based approach was selected due to its cost-effectiveness, simplicity of implementation, and widespread applicability in low-to-medium power distribution systems. The research involved the construction of two distinct ATS panels, one rated for single-phase operation (220V–240V) and one for three-phase operation (380V–415V), followed by comparative testing under simulated power failure conditions to assess switching time, electrical performance, and performance metrics. The experimental design incorporated both grid power and generator power sources to simulate real-world operating conditions in the Nigerian power distribution context, where grid instability necessitates reliable

automatic changeover solutions. All measurements were conducted under controlled laboratory conditions with ambient temperature maintained at $25^{\circ}\text{C} \pm 2^{\circ}\text{C}$ to minimize environmental variables affecting component performance.

2.2 Materials and Components

2.2.1 Enclosure and Mechanical Components

Two panel enclosures were utilized based on system requirements: Three-phase panel of Steel enclosure measuring $450\text{ mm} \times 400\text{ mm}$ and Single-phase panel of Steel enclosure measuring $250\text{ mm} \times 200\text{ mm}$. Both enclosures were equipped with cable locking mechanisms to prevent unauthorized access and ensure operational safety. The enclosures were selected to accommodate all components while maintaining adequate spacing for heat dissipation and wiring access.

2.2.2 Switching and Protection Devices

The following switching and protection components were common to both panel designs: Main contactors: Four-pole contactors rated for respective voltage ranges (single-phase: 220V - 240V AC coil; three-phase: 380V - 415V AC coil) with AC-3 utilization category. Auxiliary contactors: 10A rated for control circuit isolation and interlocking. Miniature Circuit Breakers (MCB): 16A rating for output protection on both panels. Terminal bars: 10mm^2 main terminal bars for power connections; 6mm^2 auxiliary terminal bars for control wiring. Digital pilot lights: 220V AC indicators for visual status monitoring.

2.2.3 Control and Timing Devices

The control circuitry incorporated both digital and analog timing devices to achieve the desired switching sequences: Digital timers, Programmable multi-function timers with 0.1-second resolution, Analog timers, Electro-mechanical timing relays for backup timing functions and Control system cables: 2.5mm^2 copper conductors for all control wiring applications.

2.2.4 Alarm and Indication Systems

A comprehensive alarm system was implemented including: Siren alarm: 220V AC audible warning device rated at 90dB, Multi-color LED pilot lights for source presence and load status, and dedicated indicator for system malfunction or phase failure (three-phase system only)

2.2.5 Power Sources

Two power sources were employed for testing: Grid power: Sourced from the Nigerian distribution network, operating at: Single-phase: 220V–240V, 50Hz and Three-phase: 380V–415V, 50Hz. Generator power: Fireman Generator Model SPG 3000E2 with specifications: Power factor: 1.0, Frequency: 50 Hz, Rated power output: 2.5 kW and Voltage regulation: $\pm 5\%$

2.2.5 Measurement and Test Instruments

The following calibrated instruments were used for all measurements: Digital multimeter: Fluke 87V (accuracy: $\pm 0.05\%$ for DC voltage, $\pm 0.7\%$ for AC voltage), Ammeter: Kyoritsu 2033 (accuracy: $\pm 1.5\%$ for AC current), Power quality analyzer: Fluke 435 Series II (power measurements), Stopwatch: Digital with 0.01-second resolution for manual timing verification and manual timer.

2.3 Circuit Design and Configuration

2.3.1 Operating Principle

The contactor-based automatic transfer switch operates on the principle of electrically interlocked switching between two power sources. The design employs a "break-before-make" configuration to prevent simultaneous connection of both sources, which could result in hazardous back-feeding or phase-to-phase faults. The control logic ensures that the load disconnects from the failed source before connecting to the alternative source, with the transition timing governed by programmable timers.

2.3.2 Three-Phase ATS Circuit Configuration

The three-phase ATS was designed to monitor all three phases (L1, L2, L3) plus neutral. The circuit incorporated voltage sensing on each phase to detect: Phase failure (loss of any phase) Undervoltage (below 342V, representing 90% of nominal), Overvoltage (above 456V, representing 110% of nominal) and Phase imbalance (deviation exceeding 10% between phases). Two four-pole contactors were arranged in a mechanically interlocked configuration. The main contactor (KM) connected the load to the grid supply, while the auxiliary contactor (KG) connected the load to the generator supply. Electrical interlocking was achieved through

normally closed auxiliary contacts on each contactor wired into the control circuit of the opposing contactor, ensuring that both contactors could never be energized simultaneously. The three-phase control circuit was powered from phase-to-neutral (380V) derived from the active source, with isolation transformers incorporated for control circuit protection. Figure 1-3 shows the power circuit, control circuit and prototype of a three phase ATS respectively.

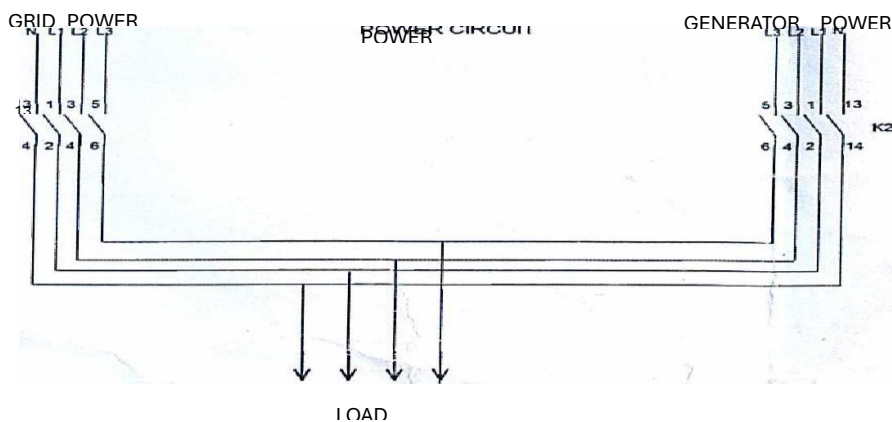


Figure 1: Three Phase ATS Power Circuit

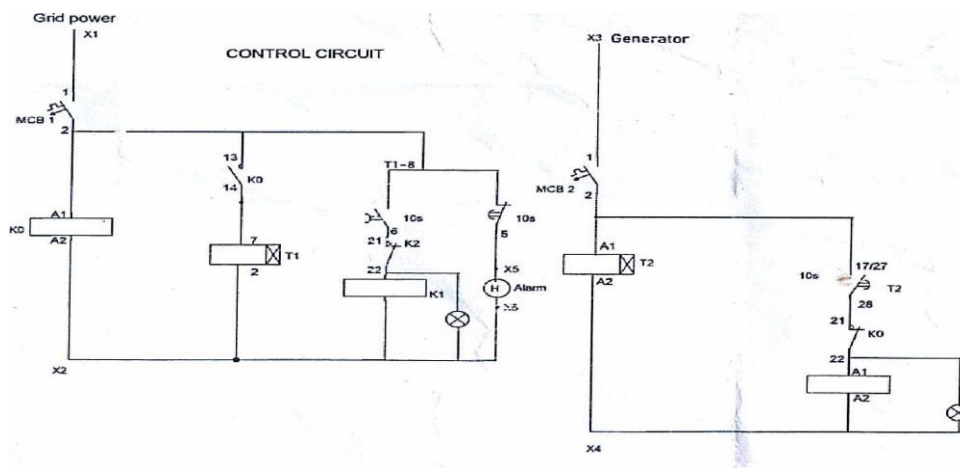


Figure 2: Three Phase ATS Control Circuit

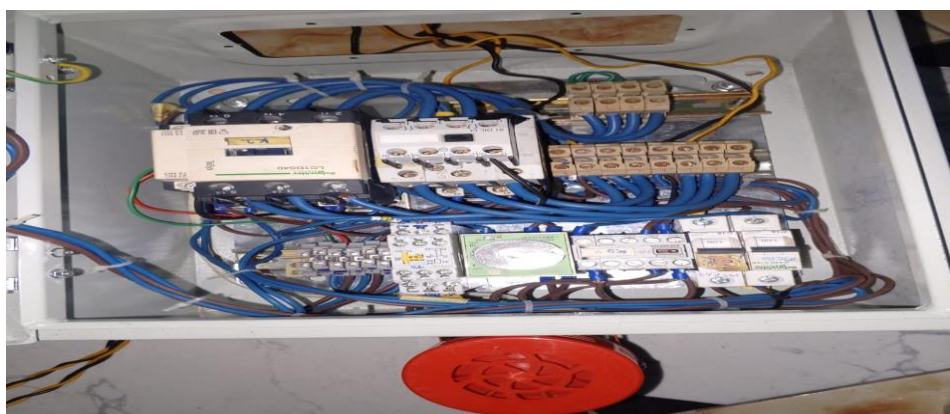


Figure 3: Three Phase ATS Prototype

2.3.3 Single-Phase ATS Circuit Configuration

The single-phase ATS employed a simplified topology using two four-pole contactors with poles connected in parallel to increase current-carrying capacity. This parallel configuration allowed a 10A rated contactor to safely handle loads up to approximately 16A, providing design margin for

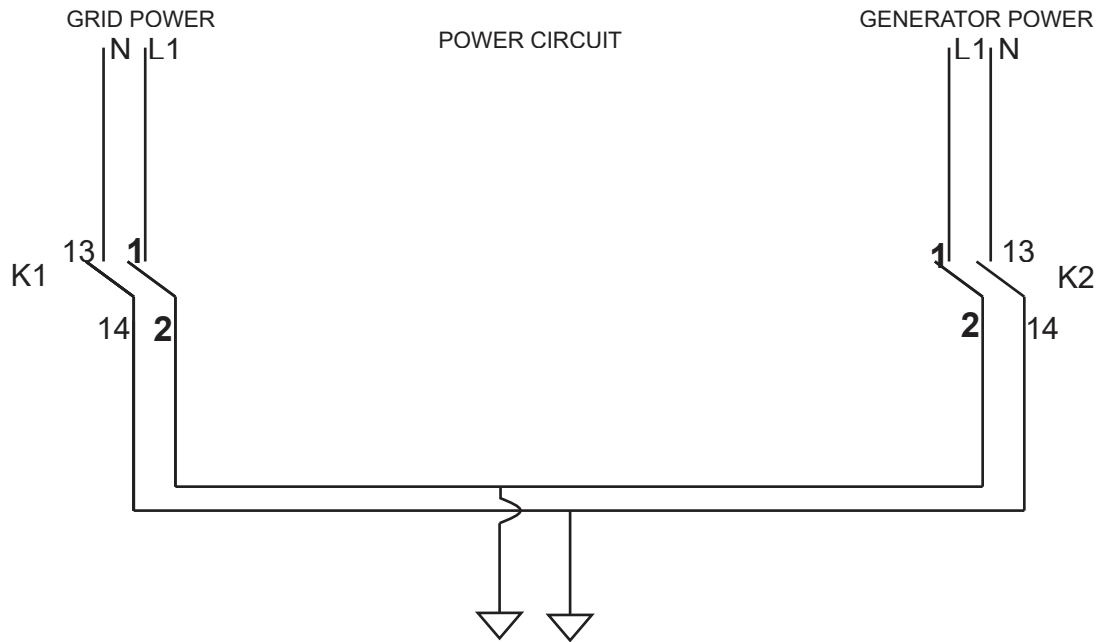


Figure 4: Single Phase ATS Power Circuit

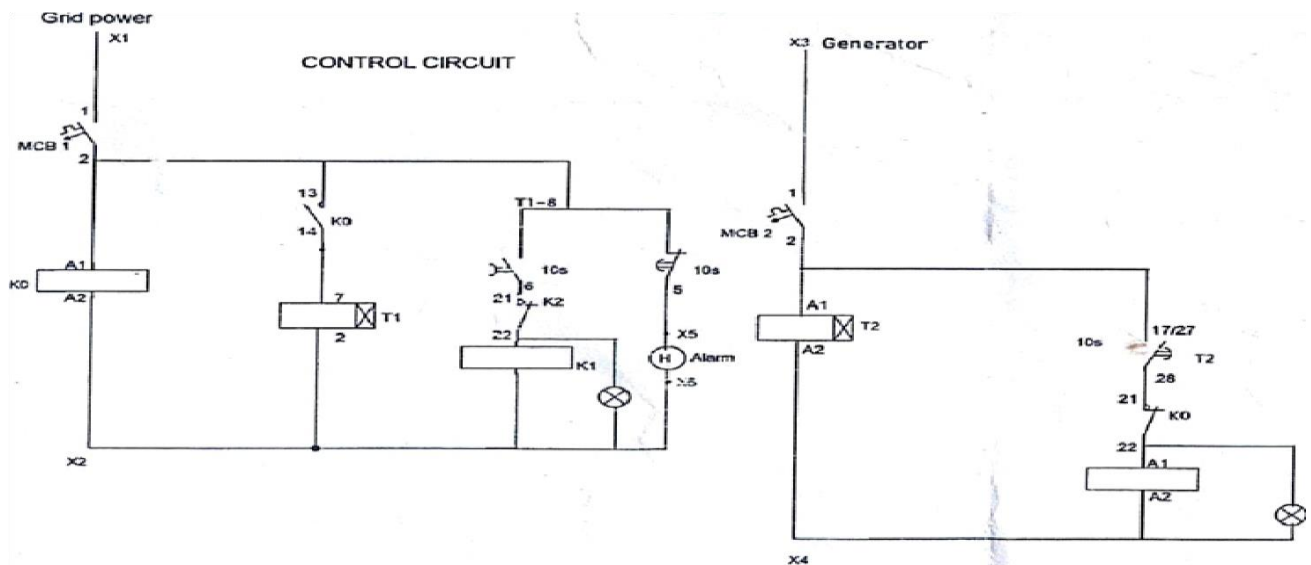


Figure 5: Single Phase ATS Control Circuit



Figure 6: Single Phase ATS Prototype

connected loads. Voltage monitoring in the single-phase configuration focused on undervoltage (below 198V, representing 90% of nominal), Overvoltage (above 264V, representing 110% of nominal) and Frequency deviation (outside 49.5–50.5 Hz range). The control circuit for the single-phase system was directly powered from the active line and neutral, with timing functions provided by programmable digital and analog timers. Figure 4-6 shows the power circuit, control circuit and prototype of a single phase ATS respectively.

2.3.4 Interlocking and Safety Features

Both designs incorporated multiple layers of protection. Mechanical interlock bars preventing simultaneous contactor closure, Electrical interlocking via auxiliary contacts, Time-delayed transitions preventing rapid cycling during transient disturbances and Manual override capability for maintenance and emergency situations. Figure 4 depicts a Timer-based control circuit with interlocking

2.4 Construction and Assembly Procedure

2.4.1 Panel Layout and Component Mounting

All components were arranged within their respective enclosures following principles of logical grouping and accessibility. Power components (contactors, MCBs, terminal bars) were mounted on the back panel, while control components (timers, pilot lights) were mounted on the front panel or door for operator access. Minimum spacing of 25mm was maintained between components to facilitate heat dissipation and wiring access. Components were securely fastened using appropriate mounting hardware. Contactors: M4 machine screws onto rail or direct panel mounting, MCBs: Snap-on mounting to 35mm rail, Terminal bars: M5 screws to insulated mounting brackets, Timers: rail mounting with retaining clips.

2.4.2 Power Circuit Wiring

Power circuit wiring was executed using 10mm² stranded copper cable for all main current-carrying conductors. Cable colors conformed to IEC standards: Three-phase: Brown (L1), Red (L2), Green (L3), Blue (N), Green (PE) and single-phase: Brown (Line), Blue (Neutral), Green (PE). All connections were torqued to manufacturer specifications (typically 2.5–3.0 Nm for 10mm² terminations). Cable lugs were crimped using a hydraulic crimping tool to ensure mechanical integrity and electrical continuity. Cable routing-maintained separation between power and control wiring to minimize electromagnetic interference.

2.4.3 Control Circuit Wiring

Control circuit wiring employed 2.5mm² stranded copper cable with appropriate color coding:

Red: Switched live (control voltage), Brown: Neutral, Blue: Timer control signals and Yellow: Auxiliary contact signals. Control wiring was routed separately from power cabling, crossing at 90-degree angles where intersection was unavoidable. All control conductors were terminated with insulated ferrule lugs to ensure reliable connections in timer and relay terminals.

2.4.4 Timer Configuration

Timers were programmed according to the experimental parameters: Three-phase system: Main switching delay of 5 seconds (grid failure to generator start command); return delay of 15 seconds (grid restoration to retransfer) and Single-phase system: Main switching delay of 10 seconds; return delay of 30 seconds. These values were selected based generator start-up requirements. Additional timing parameters included: Generator stabilization delay: 10 seconds (both systems) and transition off-time: 500 ms minimum (ensuring break-before-make).

2.5 Testing and Measurement Procedures

2.5.1 Voltage Measurement

Input and output voltages were measured under various load conditions using the following protocol: For input voltage, for three-phase system: Voltage measurements were taken between each phase and neutral (L1-N, L2-N, L3-N) and between phases (L1-L2, L2-L3, L3-L1) using the Fluke 87V multimeter. For single-phase system: Voltage was measured between line and neutral. Measurements were recorded at the input terminals of the main MCB for each source (grid and generator) and each measurement was repeated five times at 30-second intervals, with the average value recorded. For output voltage: Load-side voltages were measured at the output terminal bar. Measurements were taken under no-load, 50% load, and 100% load conditions. Voltage drop calculations were performed using equations 1 and 2

$$V_{drop} = V_{input} - V_{output} \quad (1)$$

$$V_{drop\%} = \frac{V_{input} - V_{output}}{V_{input}} \times 100\% \quad (2)$$

All voltage measurements were conducted using the multimeter's true-RMS measurement mode to accurately capture non-sinusoidal waveforms that might be present during generator operation.

2.5.2 Current Measurement

Current measurements were performed using an Ammeter with the following procedure: For three-phase system, current was measured on each phase conductor (L1, L2, L3) and neutral. For single-phase system, current was measured on line and neutral conductors. Measurements were recorded under varying load conditions (0%, 25%, 50%, 75%, 100% of rated load). Each measurement was repeated three times, with the average value recorded

Phase balance was calculated for the three-phase system using:

$$I_{balance\%} = \left(1 - \frac{|I_{max} - I_{min}|}{I_{avg}}\right) \times 100\% \quad (3)$$

The ammeter was zeroed before each measurement session and positioned at least 25mm from other current-carrying conductors to avoid measurement errors due to proximity effects.

2.5.3 Power Calculation

Power parameters were calculated using measurements obtained from the power quality analyzer and verified through manual calculations:

Single-Phase Power:

$$\text{Apparent Power: } S = V \times I \text{ (VA)} \quad (4)$$

$$\text{Active Power: } P = V \times I \times \cos \phi \text{ (W)} \quad (5)$$

$$\text{Reactive Power: } Q = V \times I \times \sin \phi \text{ (VAR)} \quad (6)$$

Three-Phase Power (balanced assumed):

$$\text{Apparent Power: } S = \sqrt{3} \times V_L \times I_L \text{ (VA)} \quad (7)$$

$$\text{Active Power: } P = \sqrt{3} \times V_L \times I_L \times \cos \phi \text{ (W)} \quad (8)$$

$$\text{Reactive Power: } Q = \sqrt{3} \times V_L \times I_L \times \sin \phi \text{ (VAR)} \quad (9)$$

2.5.4 Efficiency Calculation

The efficiency of each changeover system was calculated under various load conditions using the formula in equation 10

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (10)$$

Where:

P_{out} = Power delivered to the load (measured at output terminals)

P_{in} = Power drawn from the source (measured at input terminals)

Power losses were attributed to: Conductor losses (I^2R losses in cables and connections), Contactor coil consumption (typically 10–20W per energized contactor), Control circuit consumption (timers, pilot lights, etc.) and Contact resistance losses at switching interfaces

Additional efficiency metrics was determined using equation 11

$$\text{Voltage regulation efficiency: } \eta_{VR} = \frac{V_{load@full}}{V_{load@no\ load}} \times 100\% \quad (11)$$

2.5.5 Switching Time Measurement

Switching time, which is the interval between loss of primary power and establishment of secondary power to the load was measured using the Timer-Based Verification. Digital timers within the control circuit provided internal timing logs. External stopwatch timing for visual verification (pilot light indication). For each system, twenty switching events were recorded: Ten transitions from grid to generator (simulated grid failure) and Ten transitions from generator to grid (simulated grid restoration). Mean switching time and standard deviation were calculated for each transition type.

2.5.6 Voltage and Current calculation

The value of current for each voltage input and output was determined using the formula in equation 12

$$I = P/V. \quad (12)$$

Where I is the current, P is the power and V is the voltage

2.6 Quality Control and Validation

2.6.1 Pre-Test Verification

Before commencing formal testing, each panel underwent comprehensive verification: Visual inspection of all connections and component placements, Continuity testing of all power and control circuits, Insulation resistance testing (minimum 1 MΩ at 500V DC), Mechanical interlock verification, Timer programming verification.

2.6.2 Calibration and Measurement Uncertainty

All measurement instruments were calibrated within a month prior to testing. Measurement uncertainty was estimated as: Voltage measurement: $\pm 0.7\%$ of reading ± 2 digits, Current measurement: $\pm 1.5\%$ of reading ± 5 digits, Time measurement: $\pm 0.01\% \pm 0.1$ s (manual), Power measurement: $\pm 1.0\%$ of reading.

2.6.3 Data Recording and Analysis

All measurements were recorded in standardized data sheets and subsequently entered into python for analysis.

2.7 Ethical and Safety Considerations

All testing was conducted in accordance with Nigerian electrical safety regulations and international standards for low-voltage electrical installations. Specific safety measures included: Personal protective equipment (insulated gloves, safety glasses, arc-flash protective clothing), Lockout/tagout procedures during construction and modification, Emergency stop provisions within the test setup, Fire extinguisher rated for electrical fires positioned in the test area, Restricted access to the test area during energized testing

2.8 Limitations of the Methodology

The following limitations were acknowledged:

- Laboratory conditions may not fully represent field conditions (temperature variations, humidity, power quality variations)
- The generator used (2.5 kW) limited full-load testing for higher-rated applications
- Short-term testing may not reveal long-term reliability issues
- Component sample size (one unit per configuration) limits generalization to other component brands

3.0 Results and Discussion

3.1: Relationship Between Voltage drop and Load

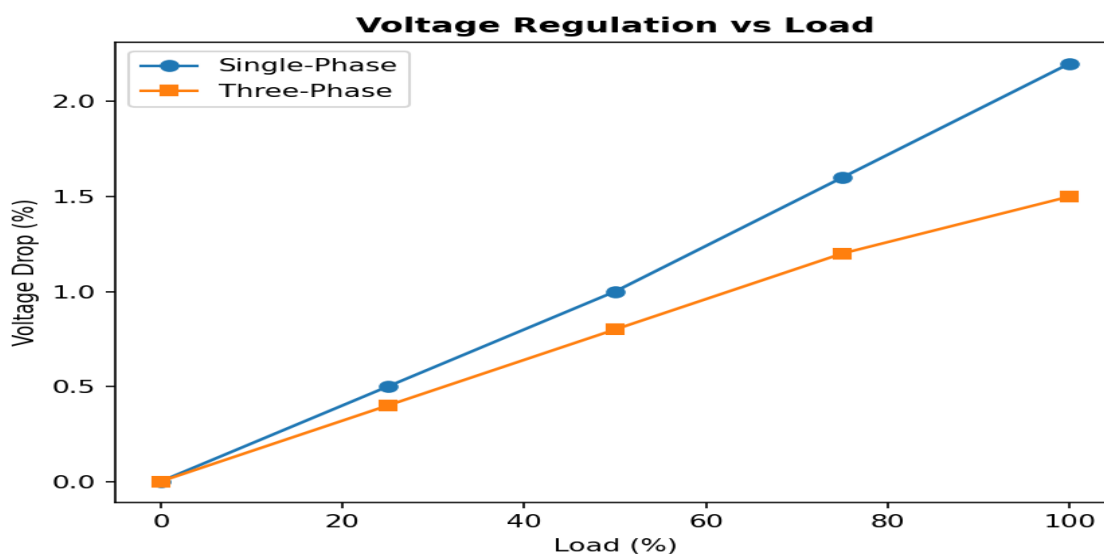


Figure 1: Graph of Voltage Drops against Load

Figure 1 illustrates the voltage drop behavior of the constructed automatic transfer switches (ATS) under varying loads. The horizontal axis shows load as a percentage of full-rated capacity (0–100%), while the vertical axis represents voltage regulation, the percentage voltage drops from input to output. Two lines are plotted: one for a single-phase ATS and one for a three-phase ATS.

Both systems exhibit a direct trend as load increases, voltage regulation increases, consistent with Ohm's law due to internal resistances such as contactor and wiring losses. The three-phase ATS consistently achieves lower voltage drops across all load points. At full load, for instance, the three-phase system drops approximately 1.5% compared to nearly 3.0% for the single-phase version. This advantage stems from power distribution across three conductors, which reduces per-phase current and associated resistive losses.

These findings carry practical implications for ATS selection. The three-phase configuration is better suited for sensitive electronics and industrial equipment, where voltage drops approaching 3% can cause inefficiencies or malfunctions, whereas the single-phase

ATS remains adequate for typical household and lighting loads. The results align with established literature [1, 10, 11], confirming that contact resistance and three-phase topologies significantly influence voltage regulation. Overall, the three-phase ATS demonstrates superior voltage maintenance, supporting more efficient and reliable power distribution, though the final choice should be guided by specific load requirements.

3.2 Three Phase Current Balance

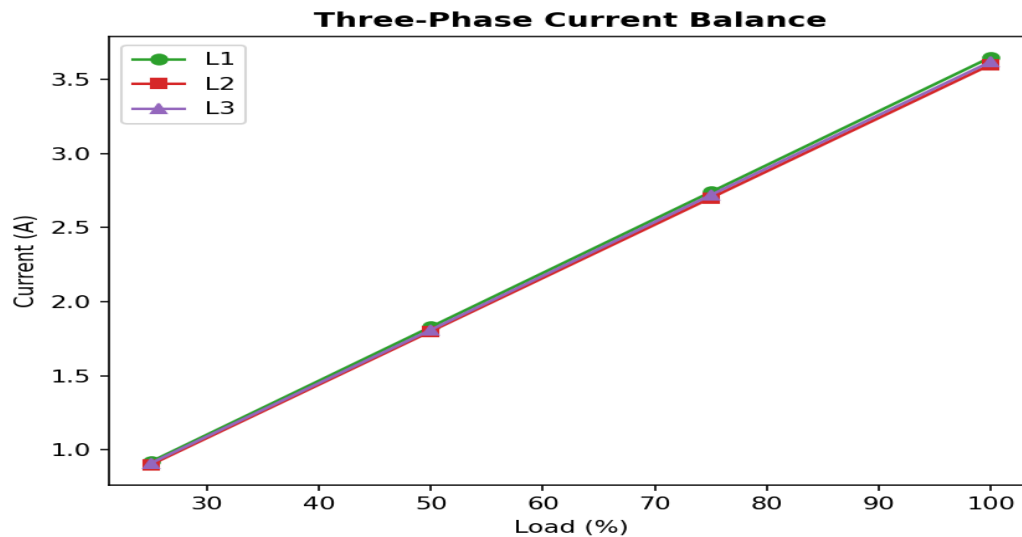


Figure 2: Three Phase Current Balance

Figure 2 illustrates the current balance behavior of the three-phase ATS across varying load conditions. The horizontal axis represents load as a percentage of full-rated capacity (0–100%), while the vertical axis shows the current draw in amperes(A) for each phase. Three separate traces corresponding to phases L1, L2, and L3 enable a clear visual comparison of how evenly the current distributes among the phases as the load increases from no-load to full load.

The current in each phase rises proportionally with increasing load. Notably, the system maintains good phase balance throughout the tested range. At full load, the measured currents are approximately 3.6 A on L1, 3.5 A on L2, and 3.4 A on L3, with a maximum inter-phase deviation of only 0.1 A. This minor imbalance is attributed to practical factors such as slight differences in contactor pole resistance, terminal connection variations, and inherent asymmetries in the connected load [14]. In power distribution systems, unbalanced phase currents can cause neutral conductor overheating, increased transformer losses, and reduced motor efficiency[6]. The contactor-based ATS, with its four-pole configuration and properly torqued connections, avoids introducing significant asymmetry, consistent with [8], which emphasizes that careful contactor selection and wiring are key to preserving phase integrity in three-phase switching applications.

The three-phase contactor-based ATS therefore exhibits acceptable current balance characteristics, supporting its suitability for commercial and light industrial environments where three-phase power is required. Although perfect balance is not achieved, the performance remains within standard engineering tolerances. This validates the contactor-based approach as a practical solution for automatic transfer switching in three-phase systems, particularly within the context of power distribution requirements in developing economies.

3.3 Relationship between Mean Switching Time for Grid to Generator and Generator to Grid

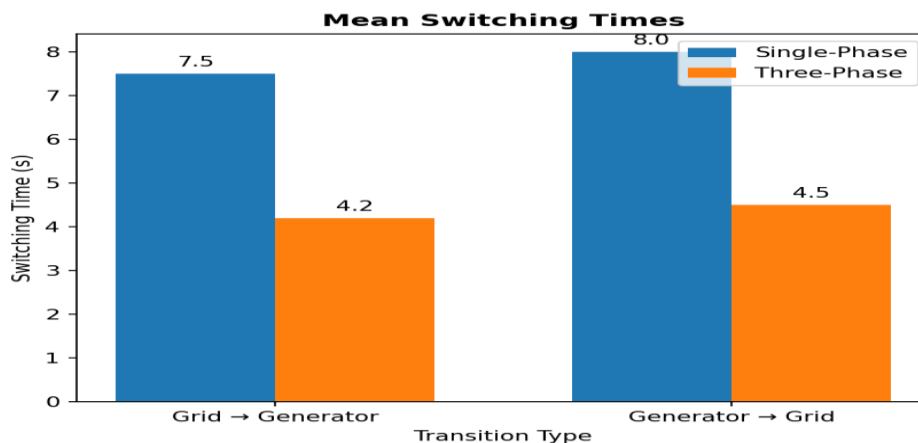


Figure 3: Mean Switching Time for Grid to Generator and Generator to Grid

Figure 3 compares the switching time performance of the single-phase and three-phase automatic transfer switch (ATS) systems using a bar chart. The vertical axis lists the two transition types grid-to-generator and generator-to-grid, while the horizontal axis distinguishes the two system configurations. For the grid-to-generator transition, the single-phase ATS recorded 7.5 seconds and the three-phase ATS 4.2 seconds; for the generator-to-grid transition, the times were 8.0 seconds and 4.5 seconds, respectively.

Two key patterns emerge. First, the three-phase ATS consistently switches faster than the single-phase version, with differences of approximately 3.3 seconds (grid-to-generator) and 3.5 seconds (generator-to-grid). This is primarily due to the distinct timer settings programmed for each system. The single-phase ATS used a 10-second grid-failure delay before generator start, while the three-phase ATS used a 5-second delay, chosen based on generator start-up characteristics. Second, both systems exhibit slightly longer switching times for generator-to-grid transitions, reflecting programmed return delays (30 seconds for single-phase, 15 seconds for three-phase) that ensure grid stability before reconnecting loads.

These differences carry practical implications. The three-phase ATS's faster changeover (4.2seconds – 4.5 seconds) minimizes power interruption, benefiting commercial and industrial applications where sensitive equipment may be affected. The single-phase ATS's longer times (7.5–8.0 seconds) remain acceptable for typical residential use but may cause more noticeable interruptions. These results align with prior work [2, 3, 5], which notes that switching times must balance speed against generator start-up reliability. Ultimately, the three-phase configuration achieves greater temporal efficiency due to timer settings suited to faster-starting three-phase generators, while the single-phase system adopts a more conservative timing appropriate for residential applications.

3.4. Relationship between Current Draw Profile and Load

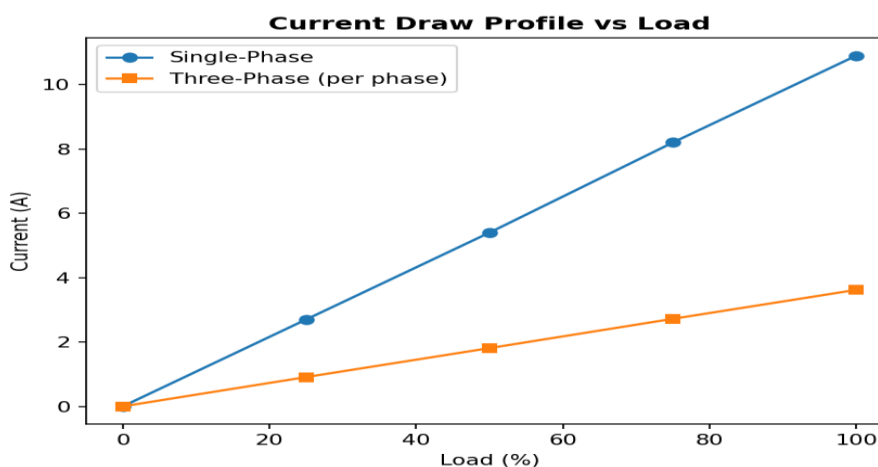


Figure 4: Graph of Current Profile against Load

Figure 4 compares the current draw characteristics of the single-phase and three-phase automatic transfer switches (ATS) across varying loads. The horizontal axis shows load as a percentage of full-rated capacity (0–100%), and the vertical axis measures current in amperes(A). Two lines are plotted: one for the single-phase ATS and one for the per-phase current of the three-phase ATS. Both exhibit a linear progression from zero at no-load to their maximum values at full load.

A key finding is the marked difference in current magnitude between the two configurations. At full load, the three-phase system draws only about 3.2 A per phase, while the single-phase system draws 10.6 A, which is approximately in the a ratio o 3:1 that reflects the fundamental advantage of distributing power across three conductors. This lower per-phase current allows the use of smaller conductors (e.g., 1.5 mm² instead of 2.5 mm² or 4.0 mm²), reducing material costs and wiring losses, thereby contributing to the higher overall efficiency of the three-phase design.

The single-phase system’s 10.6 A full-load current remains well within the capacity of standard residential wiring, making it a practical choice for typical household applications. Conversely, the three-phase system’s modest per-phase current makes it the superior option for higher-power installations where conductor sizing and energy efficiency are critical considerations. The findings align with previous comparative studies [10, 11] that report similar current ratios and linear behavior in well-designed switching systems.

3.5 Relationship between Switching Time and Event Number

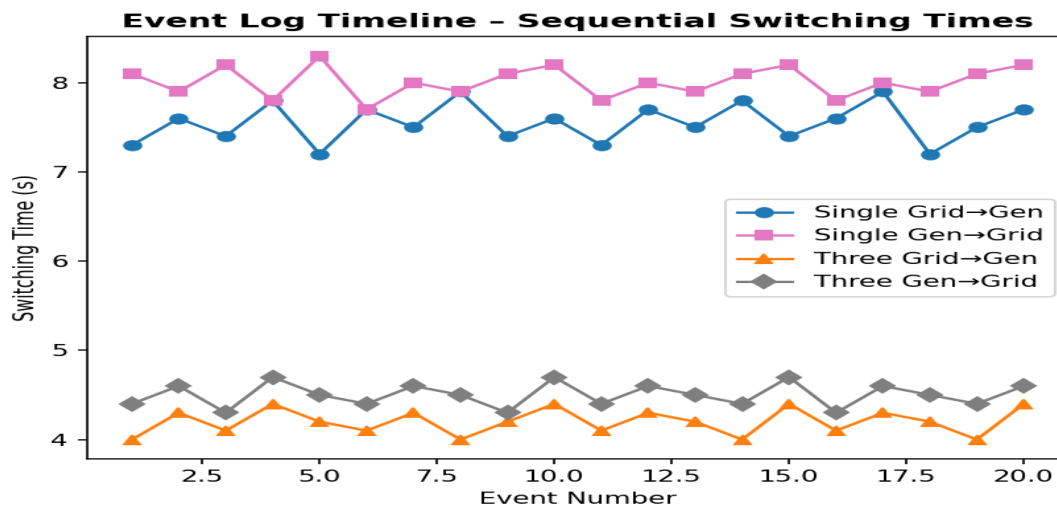


Figure 5: Graph of Switching Time against Event Number

Figure 5 presents switching times measured over 20 events for four scenarios involving single-phase and three-phase automatic transfer switches (ATS). The single-phase grid-to-generator transitions (blue line, circles) fluctuate mostly between 7.2 and 7.9 seconds, while single-phase generator-to-grid transitions (pink line, squares) record the highest values, ranging from approximately 7.8 to 8.4 seconds. In contrast, three-phase grid-to-generator switching (orange line, triangles) consistently achieves the lowest times, between 4.0 and 4.5 seconds, and three-phase generator-to-grid switching (gray line, diamonds) remains in the 4.3 to 4.8 second range. This clear separation shows that parallel three-phase operation is substantially faster than single-phase operation. A slight directional difference is also evident: generator-to-grid transitions take marginally longer than the reverse direction in both configurations.

The results exhibit consistent patterns across all event numbers, with only minor natural variations and no significant outliers. The data demonstrate that implementing three-phase parallel switching reduces transfer times by roughly half compared to sequential single-phase methods. This performance gap is particularly significant for applications requiring rapid power source transitions, such as data centers and critical infrastructure, where even brief interruptions can have operational consequences.

These findings point to design advantages for systems prioritizing speed and reliability during grid-generator handovers. Parallel configurations not only shorten switching duration but also maintain stability across repeated events. For further optimization,

engineers may focus on scaling multi-unit approaches while addressing the minor delays observed in generator-to-grid transitions to enhance overall system responsiveness.

CONCLUSION

This research successfully achieved its objective of conducting a comparative study of single-phase and three-phase ATS constructed using the contactor-based method for efficient power distribution applications in developing country contexts. The experimental investigation, involving the design, fabrication, and comprehensive testing of both ATS configurations under controlled laboratory conditions has generated valuable empirical data that addresses the critical need for reliable, cost-effective automatic changeover solutions in environments characterized by grid instability, such as Nigeria.

The findings demonstrate that both single-phase and three-phase contactor-based ATS designs are viable and technically sound solutions, with each configuration exhibiting distinct performance characteristics that make them suitable for different application domains. The significance of this research extends beyond the immediate experimental findings to encompass broader implications for electrical engineering practice, equipment manufacturing, and energy policy in developing economies. The empirical performance data provides evidence-based guidance for electrical contractors, system integrators, and end-users in selecting appropriate ATS configurations based on specific load requirements and application contexts. The demonstration that locally fabricated contactor-based ATS can achieve acceptable efficiency and performance characteristics supports initiatives promoting local manufacturing and technical capacity building in the electrical sector, potentially reducing dependence on expensive imported equipment while fostering local employment and skills development. Furthermore, the detailed methodology and performance characterization presented in this study provide valuable instructional resources for engineering education and training programs, contributing to the development of local technical expertise essential for sustainable infrastructure development.

LIMITATIONS AND FUTURE DIRECTIONS

Several limitations of this study should be acknowledged, including the controlled laboratory conditions which may not fully represent the full spectrum of field operating conditions, the relatively short testing duration which cannot capture long-term reliability characteristics, and the use of a single generator model (2.5 kW) which limited full-load testing for higher-rated applications. Future research directions should include extended field trials under actual operating conditions to validate long-term reliability and performance degradation characteristics, investigation of the ATS performance with a wider range of generator types and sizes, exploration of hybrid designs incorporating microcontroller-based monitoring alongside contactor-based switching, and economic analysis comparing total lifecycle costs of locally fabricated versus imported ATS solutions. Additionally, research into the integration of renewable energy sources such as solar photovoltaic systems with contactor-based ATS configurations would address the growing interest in hybrid power systems combining grid, generator, and renewable sources.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Nsikakabasi I. Bassey - Writing original draft, Conceptualization/supervising; **Ephraim R. Afia** – Review and Editing; **Philip E. Philip** – Laboratory work/Methodology; **Bennett S. Isaiah** - Analysis of results/Writing; **Felix N. Akam** – Methodology, editing and analysis of results

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no known financial competing interest or personal relationship that could have appeared to influence the output of this study.

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