Design and Implementation of an Automatic Transfer Switch for a Single-Phase Load, from a 3–phase Supply with Standby Generator.

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Abstract- *The reliability of electrical power supply is a critical requirement for residential, commercial, and industrial consumers, particularly in regions where power interruptions and phase outages are common. In many three-phase distribution systems, single-phase loads are connected to one of the available phases, making them vulnerable to supply interruptions if that phase fails, even when other phases remain healthy. This study presents the design and implementation of a microcontroller-based Automatic Transfer Switch (ATS) for a single-phase system capable of automatically transferring the load among the available phases of a three-phase utility supply and, when necessary, to a standby generator. The system continuously monitors the voltage status of the three utility phases and automatically selects the highest-priority healthy phase to supply the load. In the event of a phase failure, the microcontroller initiates an automatic transfer of the load to another available phase without human intervention. When all utility phases become unavailable, the system automatically starts a standby generator, verifies its operating conditions, and transfers the load to the generator. Upon restoration of utility power, the ATS reconnects the load to the preferred utility phase and safely shuts down the generator after a programmed delay. The study adopted Positivist research philosophy and quantitative research approach. Experimental testing demonstrated that the system effectively detected phase failures, executed automatic phase-to-phase load transfers, successfully started the standby generator during complete utility outages, and restored utility supply when available. The results confirmed improved power continuity, reduced generator operating time, enhanced equipment protection, and minimized dependence on manual intervention.*

Keywords: Automatic Transfer Switch (ATS), Single-Phase Power System, Generator Protection, Load Transfer, Microcontroller.

1. INTRODUCTION

A consistent and uninterrupted electric power supply is critical for industrial, commercial, and residential operations [1]. However, in several developing countries, like Nigeria, electricity supply from the national grid is frequently disrupted by unpredictable interruptions, voltage fluctuations, and outages [2]. These problems reduce productivity, destroy electrical appliances, and adversely affect daily operations [3, 4]. Consequently, the adoption of an alternative source of power, like standby generators, is now increasingly common [5]. Traditionally, the process of transferring load between the utility supply and a standby generator is done manually. This manual technique is not only cumbersome but also susceptible to human error, delays, and safety hazards, particularly in important applications that require a continuous power supply [6]. Furthermore, incorrect switching can cause electrical problems like back-feeding, posing major risks to both personnel and equipment.

To solve these problems, the Automatic Transfer Switch (ATS) was designed as an innovative approach for power source management. An ATS is intended to monitor the status of the primary source of power supply automatically and seamlessly shift the load to an alternate source if a failure is detected. When the main supply is restored, the system reverts the load and shuts down the standby generator safely. This automation minimises interruption, enhances safety, and increases operational efficiency.

An Automatic Transfer Switch (ATS) is an electrical device that is designed to automatically transfer electrical loads between two power sources, which are the primary source and the secondary (backup) source [7, 8]. Automatic transfer switching has currently eliminated the anomalies in the manual switching mechanism, which include interrupted power supply, device damage (electronics) due to frequent commutations, fire outbreaks due to sparks in the switching mechanism, wear and tear of mechanical parts [9, 10]. Over the years, many researchers have done work on ATS; some have improved on the designs of others [11–13]. This work includes the use of a pre-integrated digital power switching system design of ATS for residential and small industrial loads. Some designed ATS that constitute both hardware and software modules. Others are designed for a single-phase household generator, with a digital multimeter (DMM) incorporated using a microcontroller and alternating current and voltage. Values are displayed on the liquid crystal display LCD screen. There are so many other ways to design an ATS, for instance, the use of EMR (Electromagnetic relay), which is gradually being replaced by solid-state relay [14]. According to William [15], the selection of a suitable ATS depends on certain requirements, as shown in Figure 1.

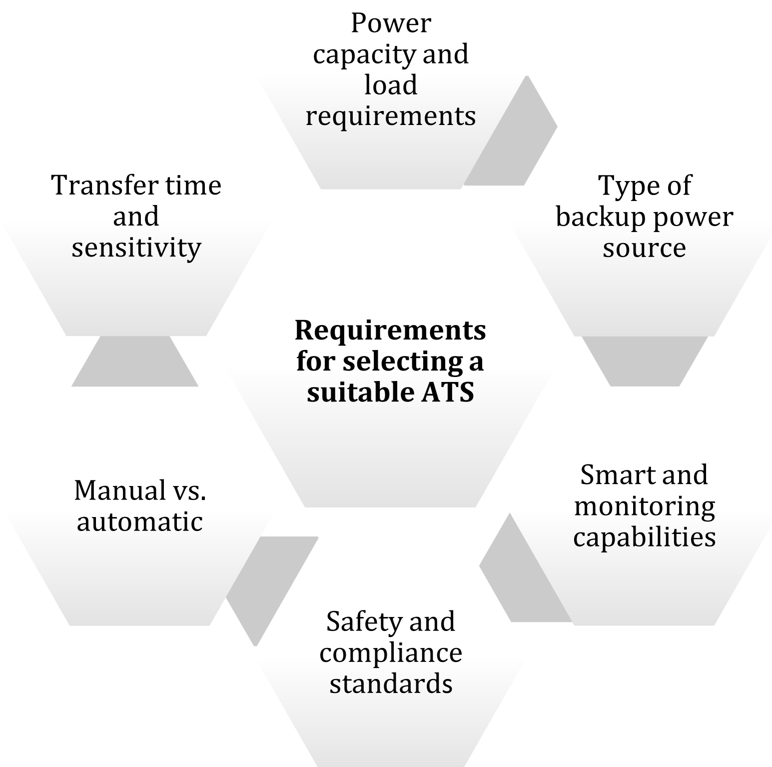

Figure 1. Requirements for selecting a suitable ATS

The Automatic Transfer Switch (ATS) can be in Single-phase or three-phase [16], but our focus in this study is on single-phase. This device maintains a constant power supply to the load by automatically activating the load when there is a need. In medical facilities, stable power is important in life-saving equipment; power outage can lead to data loss and financial downtime [17]. The design and implementation of an ATS involves different components, including sensors to detect power status, Voltage Monitoring System (VMS), contactors, breakers, indicators, and relays for optimal switching operation. The system is designed to monitor the quality of the main power supply, initiate generator startup, and maintain the transfer of power load between both power sources [18, 19].

This study focuses on the design and implementation of an Automatic Transfer Switch for a single-phase system with integrated generator protection, which is commonly utilised in residential buildings and small business facilities. The system aims to offer a reliable, cost-effective, and efficient solution that lowers the need for manual intervention while maintaining smooth and safe load transfer across sources.

2. REVIEW OF RELATED LITERATURE

Oyefusi and Akinwunmi [16] (p. 1), designed and constructed an "automatic transfer switch" by utilising a "programmable logic controller". This system transfers the load seamlessly to the available backup source of power as soon as it senses a power failure from its source. The outcome of the study demonstrated high scalability and efficiency via rigorous simulations carried out between the three sources of power and hardware implementation. Akinola et al. [20] (p. 161), made an effort to tackle erratic and unstable power supply by designing “an automatic changeover selection switch” using a three-phase microcontroller. The system disconnects the load from a failed phase and transfers it to another phase that meets the required condition automatically, instead of the conventional manual switching done from one phase to another in a 3-phase supply system. The study outcome reveals that the application is suitable for residential and industrial buildings where a three-phase power supply is adopted alongside a stand-by source of power. Supardi and Binava [21] (p. 1), designed an "automatic transfer switch" with an "Internet of Things (IoT)" monitoring system. The process begins with selecting and designing the necessary equipment. To guarantee that the equipment works properly, it is tested under three different conditions. Condition one is PLN, which occurs when the primary source goes on and distributes electricity to the consumers. Condition two is that the primary source is turned off and the power is shifted to the generator set. Condition three is that the main source is switched on again, while the generator serves as a backup power source. The outcome of the study demonstrates that the equipment is functional. If the main source is switched off, the equipment switches the connections and turns on the generator automatically. If the main source is turned back on, the device will immediately cut off the generator and restore the connection to the main source. Marhatang et al. [22], developed an optimum ATS technology that enables a fast transition with minimal voltage dips. The design and testing findings showed that the ATS performed optimally throughout the transition from the Solar energy system to the grid. The tests found that the shortest transmission time was 29 ms and the longest one was 32 ms. In addition, visual examinations of the switching process of the ATS revealed no visible voltage dips in the lighting load and no restarts of the computer. This quick switching mechanism with no voltage dips guarantees the safety of connected devices. Adesina et al. [23] (p. 15), developed "an Automatic Phase Selector” for customers of the Nigerian grid power using a three-phase power supply from a distribution company. From the three-phase power system's supply lines, the device will choose one available phase automatically. This involves circuit design for the automatic phase selector, the design circuit simulation, the development of the microcontroller programming code in C language, building the circuit designed, as well as, testing the completed work. The outcome of the test carried out "with an unbalanced three-phase system supply displayed an efficient and flawless performance. Zainuri et al. [24] (p. 95), designed a “Synchronous Automatic Transfer Switch for an On-Grid Solar System” using a triggered grid tie inverter and a synchronous ATS. The study aimed to ensure that the on-grid solar system continues to operate in the case of a grid failure. The outcome of the study indicates that the grid tie system and the ATS can operate effectively to promote the availability of renewable energy.

Ghosh et al. [25] (p. 1), designed and implemented an "Automatic phase changeover switch" using cloud integration and an Arduino Uno relay. The outcome shows that when an active phase becomes available, it switches automatically to it; otherwise, no power is given out. Using programmed logic, the microcontroller changes to the available phase. Yakubu and Dahiru [26] (p. 93), designed and implemented a “microcontroller-based multiple source power pickers with a priority selector”. Priority selector enables sources to be selected for usage based on their cost or uninterruptibility. When the selection is carried out based on cost, mains power is preferred over generators, and when none is at hand, generators are selected last. When priority is given to uninterruptible power (UP), the higher-quality supply is selected. Each one of the three different "sources is rectified, sampled, and stepped down" with a transformer. The programming of the ATmega328 microcontroller was carried out to choose the outcome on the basis of cost or availability. The system simulation was performed with the "Proteus simulation environment." The simulation results show that, notwithstanding the performance situation, the source that supplies the output relies on the priority mode selected.

3. MATERIALS AND METHODS

This section embraces the system overview and design requirements, Source Priority (Selection Logic), components of the block diagram, operating sequence of the Automatic Transfer Switch (ATS), component design, and the working principle of an Automatic Transfer Switch (ATS) for Single-Phase. The operation of the automatic transfer switch adopts the pattern given in Figure 2.

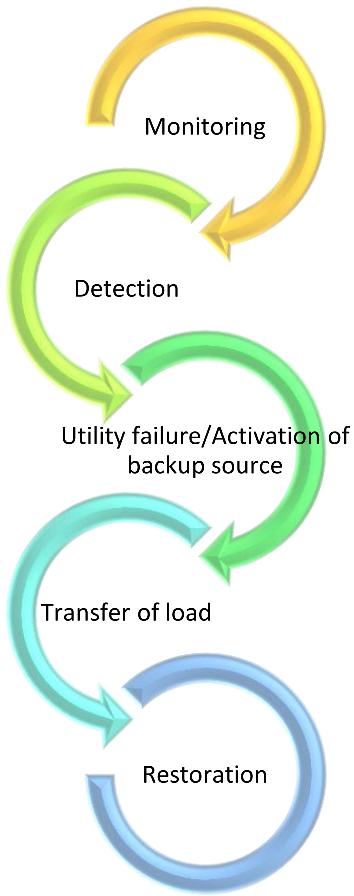

Figure 2. Pattern of operation of the ATS.

The working principle of an automatic transfer switch (ATS) is to switch electrical energy between both primary and secondary sources automatically without human interference. The ATS is an essential component in an Emergency Power Supply System (EPSS) [27].

3.1 System Overview and Design Requirements

This Automatic Transfer Switch (ATS) supplies a single-phase load from the highest priority available source among the three utility phases (R, Y, B). If all utility phases fail, the system automatically starts a standby generator and transfers the load to the generator. When Utility power is restored, the system returns the load to the highest priority healthy phase and stops the generator.

The design requirements embrace the following

- Automatic monitoring of 3-phase supply
- Automatic phase-to-phase transfer
- Automatic return to utility power
- Source prioritization (R > Y > B > Generator)
- Protection: Overvoltage, Undervoltage, Overload
- Electrical and mechanical interlocking
- Generator start/stop with delays
- Indication of source status and alarms

3.2 Source Priority (Selection Logic), and the Adopted Microcontroller

The source priority adopted for this study is given in Table 1

Table 1. Source Priority (Selection Logic)

Priority	Source
1	R phase
2	Y phase
3	B phase
4	Generator

Conversely, the microcontroller adopted in this study is Arduino UNO, and it carries out several tasks as given below

- Voltage sensing: this is carried out such that each phase is stepped down using a resistor divider and isolated using an opto-coupler for protection
- Contactor driving: This requires Transistor (2N2222) with a flyback diode to drive relays/coils for contactors K1 – K4.
- Power Switching: This requires 4-pole contactors (R, Y, B, Generator) with an electrical interlock to ensure only one (1) source is connected to the load
- Generator Control: It starts and stops relays with time delays
- Protection Circuits:

Over/Under detection using comparator (LM3S8 LED/Alarm)
Overload detection using current transformer and comparator
Generator failure (low voltage/low frequency) detection

- Indicators: This includes LEDs/Buzzers/LCD for source status and alarms.
- Power Supply: 5V for logic, 12V for relays and contactor coils

3.3. Components of the Block Diagram

The block diagram of the automatic control switch is given in Figure 3

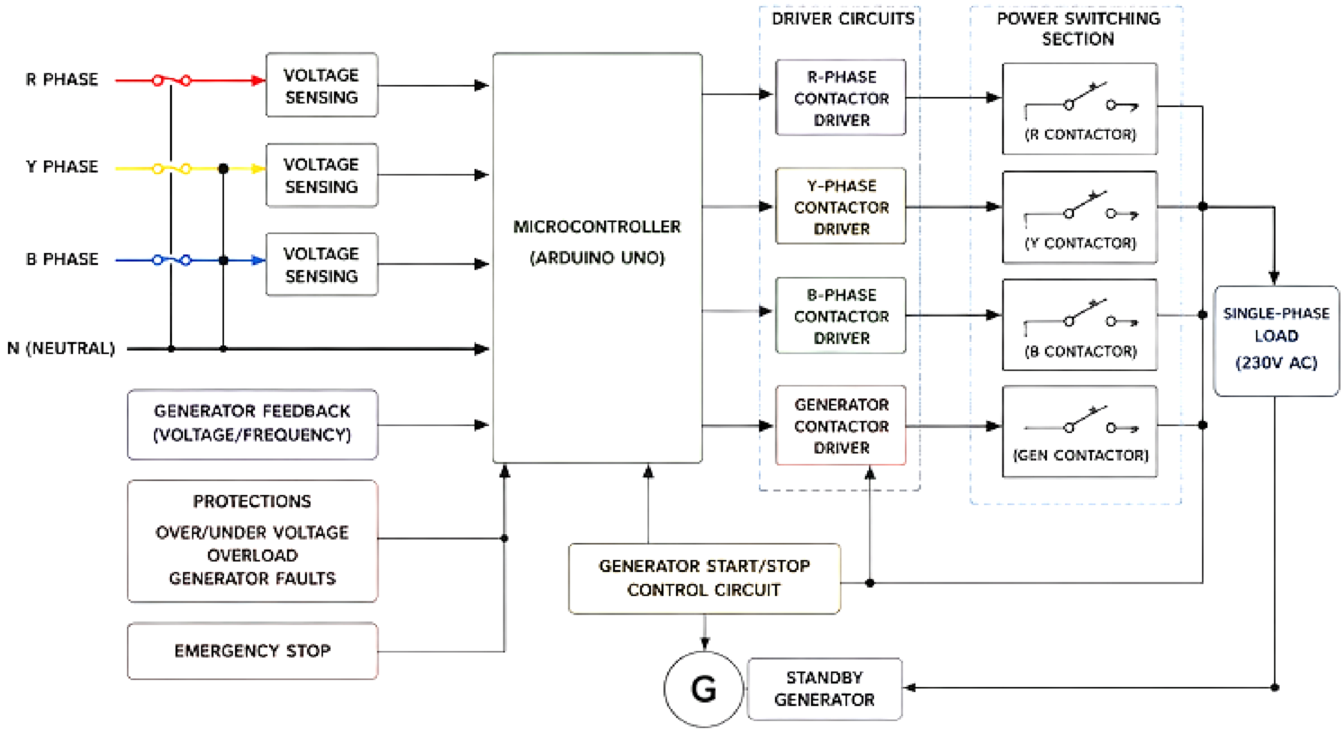

Figure 3. Block Diagram of the Automatic Control Switch (ATS)

Three-Phase Utility Supply

The utility source is power supply from Power Holding Company of Nigeria (PHCN) and consists of R (Red) Phase, Y (Yellow) Phase, B (Blue) Phase, and Neutral. Although the incoming supply is three-phase, the connected load is single-phase.

a) Voltage Sensing Unit

The voltage-sensing circuit continuously monitors the availability of the R-phase, the availability of the Y-phase, the availability of the B-phase, and voltage quality (overvoltage and undervoltage). The sensed information is transmitted to the microcontroller.

b) Microcontroller Unit

This is the brain of the system, and its functions include

- Monitoring all three phases.
- Determining the healthiest available source.
- Implementing phase-priority logic.
- Controlling contactors.
- Starting and stopping the generator.
- Executing protection algorithms.

c) Phase Contactors

This involves three (3) independent contactors, and these are the R-phase contactor, the Y-phase contactor, and the B-phase contactor, but only one contactor is allowed to close at any time.

d) Source Selection and Interlocking Circuit

This part of the block diagram prevents:
- Simultaneous connection of multiple phases.
- Back-feeding between sources.
- Dangerous switching conditions.

The circuit ensures that only one source supplies the load at any given moment.

e) Standby Generator

The standby Generator finds its usefulness when all utility phases become unavailable:
- The microcontroller sends a start signal.
- The generator starts automatically.
- The load is transferred to the generator after stabilization.

f) Generator Start/Stop Control Circuit

This circuit performs several tasks, as mentioned below
- It cranks the generator during a utility failure.
- It helps to stop the generator after utility restoration.
- It also helps to control generator operating sequences.

g) Generator Protection Unit

This part of the block diagram protects against:
- Overload
- Overvoltage
- Undervoltage
- Frequency abnormalities
- Failed starting attempts

h) Single-Phase Load

The load receives power from:
1. R-phase (highest priority),
2. Y-phase (second priority),
3. B-phase (third priority), or
4. Standby generator (last priority),

All of these depend on source availability.

3.4 Operating Sequence of the Automatic Transfer Switch (ATS)

a) The system continuously monitors R, Y, and B phases, and then connects loads to the highest priority healthy phase.
b) If the active phase fails, the load is transferred to the next available phase.
c) If all the phases fail, it starts the generator and transfers the load.
d) When the utility power supply is restored. It returns to the highest priority phase and stops the generator after a cooling delay

The mode of operation of the automatic transfer switch is given in Table 2

Table 2. Mode of Operation of the Automatic Transfer Switch

Mode	Condition	Action
1	R available	Supply load from R phase (K1 is ON)
2	R fail, Y available	Supply load from Y phase (K2 is ON)
3	R & Y fail, B available	Supply load from B phase (K3 is ON)
4	All phases fail	Start generator (K4 is ON)
5	Utility restored	Return to the highest priority phase, stop the generator

The main power section of the automatic Transfer switch is given in Figure 4

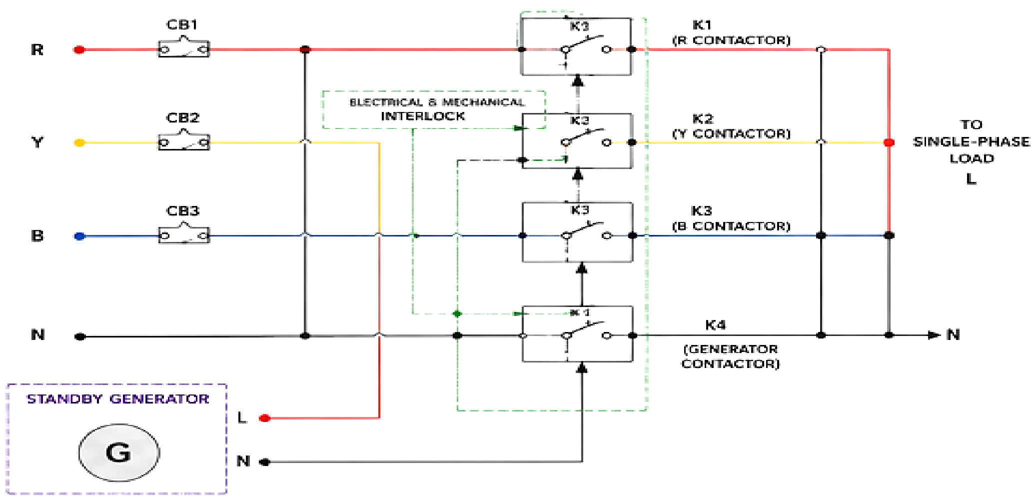

Figure 4. Main power section of the automatic control switch

Conversely, the flow chart showing the sequence of operation of the automatic transfer switch is given in Figure 5

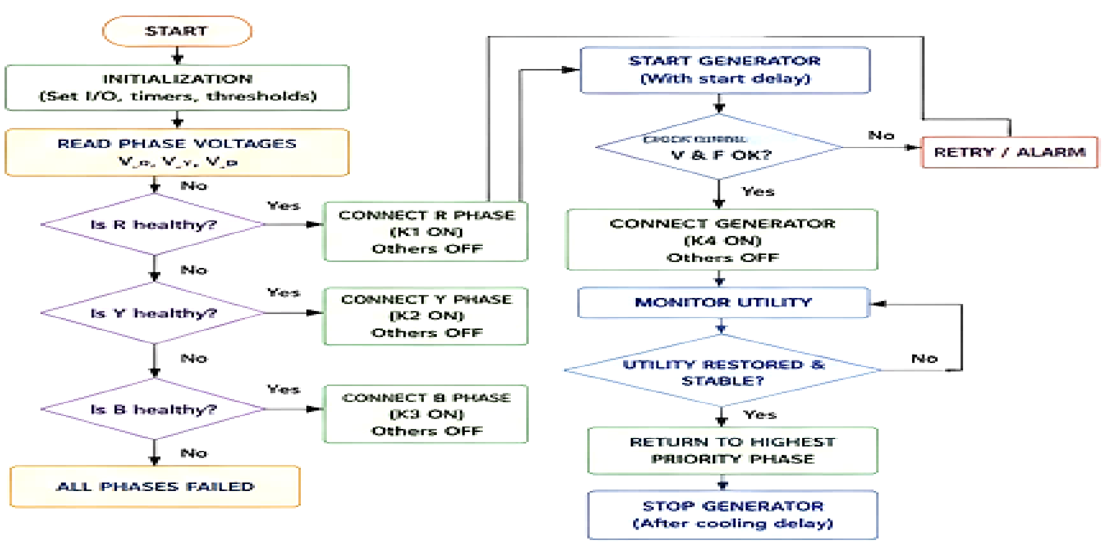

Figure 5. Flow chart of the Automatic Transfer Switch (ATS)

3.5 Component Design

If the transfer switch is to be applied on 400V/230V, 12KVA generator operating at 50Hz, and a power factor of about 0.8. The automatic transfer switch (ATS) was designed using the specifications in Table 3

Table 3. Specifications of the ATS

Parameters	Values
Utility Supply	400/230 V, 50 Hz, Three-Phase
Load Supply	230 V AC Single Phase
Generator Supply	230 V AC Single Phase
Rated Load	3KW
Frequency	50Hz
Control Voltage	5V DC
Relay Coil Voltage	12V DC
Power Factor	0.8
Microcontroller	Arduino UNO (ATmega328P)

Load estimation

Assume the connected load consists of the devices given in Table 4

Table 4. Load Estimation

Appliances	Quantity	Power Rating (W)	Total Power Rating (W)
Lighting	10	15	150
Ceiling Fan	4	75	300
Television	2	150	300
Refrigerator	1	400	400
Water Pump	1	750	750
Computer	4	200	800
Miscellaneous	1	300	300
Total			**3000**

Load Current Calculation

From Table 4, the total connected load is 3KW.
The single-phase current is given by: $I = P/(V \times PF)$
Where:

$P = 3000W$
$V = 230V$
$PF = 0.8$

Therefore,

Design Load Current = 16.3 A
Applying a 25% design margin:
Selected Design Current = 20 A

Generator Capacity

The apparent power required from the generator is calculated using: S = P/PF
Where:

S= Apparent power (VA)
P= Active power (W)
PF= Power factor

Given:

Active power, P = 3000 W
Power factor, PF = 0.8

Substituting these values:

$$S = \frac{3000}{0.8} = 3750 \text{ VA} = 3.75 \text{ kVA}$$

Therefore, the minimum apparent power required is 3.75 kVA.
Many household and commercial loads, such as refrigerators, pumps, and air conditioners, draw a starting current that is significantly higher than their normal running current. In addition, it is good engineering practice to provide spare capacity for future load growth and to avoid operating the generator continuously at full load.
A design margin of 20–30% is therefore added.
Using a 20% safety margin:
Generator Capacity = 3.75 × 1.20 = 4.50 kVA
Since generators are manufactured in standard ratings, the next higher standard size is selected
Based on the calculated demand, the selected standby generator has the following specifications as given in Table 5.

Table 5. Generator specifications

Parameter	Selected Value
Generator Type	Single-phase Petrol/Diesel Generator
Rated Output	5kVA
Rated Voltage	230V AC
Frequency	50 Hz
Power Factor	0.8
Rated Current	Approximately 21.7 A
Starting Method	Electric Starter
Control Mode	Automatic Start/Stop

The rated output current of the selected generator is calculated as:

$$I = \frac{5000}{230 \times 1} = 21.74 \text{ A}$$

where the 5 kVA rating is treated as the apparent power available from the generator. This current exceeds the design load current of approximately 20 A, confirming that the selected generator has sufficient capacity to supply the connected load safely.

Contactor Selection

Contactors are the primary switching devices used in the Automatic Transfer Switch (ATS) to connect the single-phase load to the appropriate power source. In the proposed system, four contactors are employed: three for the utility phases (R, Y, and B) and one for the standby generator. The microcontroller energizes the appropriate contactor through relay driver circuits based on the availability and quality of the power sources.

Proper selection of the contactors is essential to ensure reliable operation, prevent overheating, and guarantee safe switching under normal and fault conditions. The contactors in the ATS perform the following functions:

- Connect the load to the selected healthy utility phase.
- Disconnect the failed utility phase before connecting another source.
- Connect the standby generator to the load when all utility phases are unavailable.
- Electrically isolate all other sources during load transfer.
- Prevent back-feeding between the utility supply and the standby generator.

The contactors operate according to the programmed priority sequence:

1. R Phase (Highest Priority)
2. Y Phase
3. B Phase
4. Standby Generator (Last Priority)

Only one contactor is permitted to close at any given time.
The contactor current rating is selected based on the load's maximum design current, with an additional safety margin.
The design load current calculated in Section 3.5 is:

$$I_{Load} = 20\ A$$

To ensure reliable operation and accommodate transient current surges, a safety factor of 1.25 is applied. The required contactor current rating is therefore 25A. Hence, each contactor adopted a minimum current rating of 25 A.
The contactor must be capable of safely switching the supply voltage.

Utility Supply Voltage:

- Phase-to-Neutral = 230 V AC

Generator Output Voltage:

- 230 V AC

Therefore, the selected contactors have:

- Rated operating voltage: 230 V AC
- Frequency: 50 Hz

Since the microcontroller operates at 5 V DC, it cannot directly energize the contactor coils. Therefore, transistor-based driver circuits are used to switch 12 V DC contactor coils supplied from the control power supply.
Selected coil voltage:

- 12 V DC

Advantages of using 12 V DC coils include:

- Easy interfacing with transistor drivers.
- Improved safety compared with AC-operated coils.
- Reduced switching noise.
- Better compatibility with battery-backed control circuits.

The ATS utilized four (4) contactors, each assigned to a specific source, as shown in Table 6

Table 6. Contactor Functions and ratings

Contactor	Function	Rating
K1	Connects R Phase to Load	25 A, 230 V AC
K2	Connects Y Phase to Load	25 A, 230 V AC
K3	Connects B Phase to Load	25 A, 230 V AC
K4	Connects Generator to Load	25 A, 230 V AC

Interlocking Requirement

To prevent hazardous operating conditions, the contactors are electrically and mechanically interlocked. The interlocking arrangement ensures that:

- Only one contactor can be energized at any instant.
- Two power sources cannot be connected simultaneously.
- Back-feeding between utility phases and the generator is prevented.
- Switching occurs in a controlled sequence.

For example:

- If K1 (R Phase) is energized, K2, K3, and K4 remain de-energized.
- If K2 (Y Phase) is energized, K1, K3, and K4 remain de-energized.
- If K3 (B Phase) is energized, K1, K2, and K4 remain de-energized.
- If K4 (Generator) is energized, K1, K2, and K3 remain de-energized.

This interlocking arrangement improves operational safety and protects the utility network, generator, and connected loads. The complete schematics of the automatic transfer switch (ATS) is given in Figure 6.

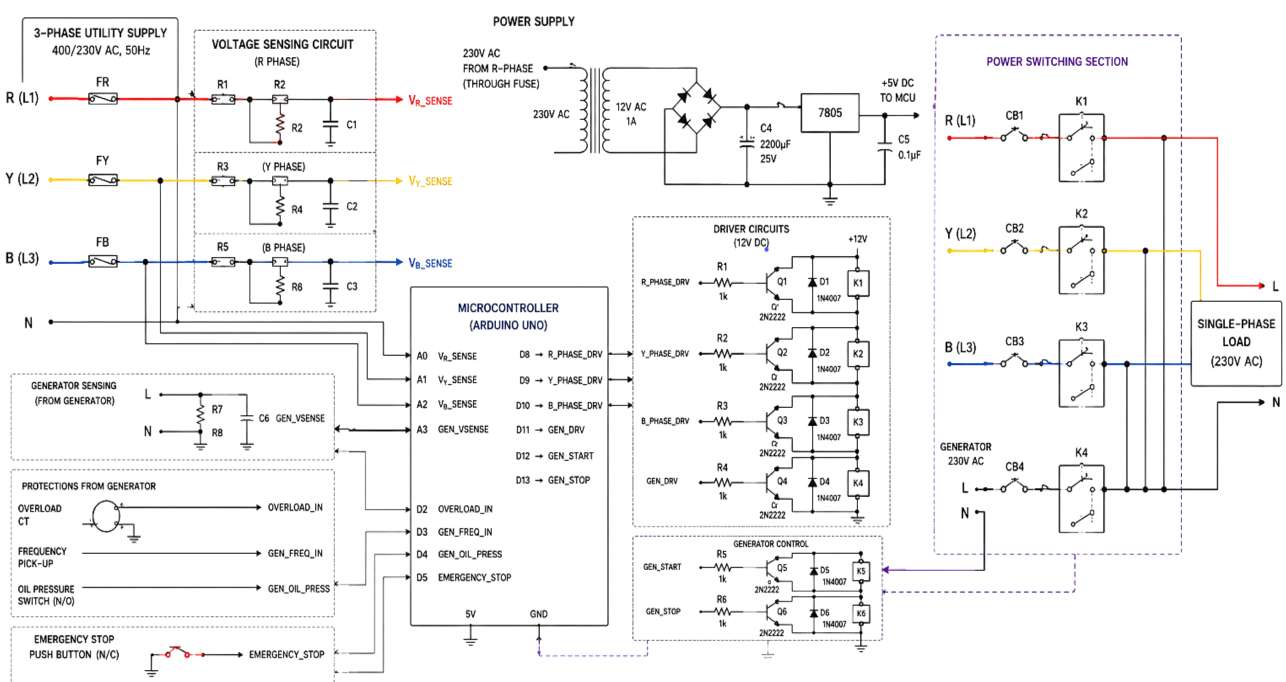

Figure 6. Complete Schematic Diagram of the Automatic Transfer Switch

3.6 Working Principle of an Automatic Transfer Switch (ATS) for Single-Phase

Load Transfer between Phases with Generator Backup

The proposed system uses a microcontroller to continuously monitor the status of the three utility phases and the standby generator, ensuring an uninterrupted power supply to the connected single-phase load. The system consists of three utility phases (R, Y, and B phases), a single-phase load, a standby generator, voltage-sensing circuits, a microcontroller, relays/contactors, a generator start/stop unit, and protection circuits. The load is connected to only one source at a time through electrically interlocked contactors.

The microcontroller continuously monitors:

- R-phase voltage
- Y-phase voltage
- B-phase voltage
- Generator voltage and frequency

The controller prioritizes utility phases according to a predetermined sequence (for example: R → Y → B → Generator).

Whenever the currently connected phase fails, the controller automatically transfers the load to the next available healthy phase. If no utility phase is available, the controller starts the standby generator and transfers the load to the generator.

Assuming the R-phase is the preferred phase. The microcontroller detects healthy voltage on the R-phase, the R-phase contactor is energized, load is supplied from the R-phase. While the Y-phase and B-phase contactors remain open. The generator remains off. Should the R-phase fail. The voltage sensor detects loss of R-phase, and sends a signal sent to the microcontroller. The microcontroller verifies failure for a short delay (2–5 seconds). The R-phase contactor opens, and the controller checks the Y-phase. If the Y-phase is healthy, the Y-phase contactor closes, and the load is transferred to the Y-phase. The load continues receiving power supply without starting the generator.

When the R-phase and Y-phase fail. The microcontroller detects loss of R-phase and checks Y-phase. Since the Y-phase is unavailable, it proceeds to check the B-phase. Since the B-phase is healthy, the load is transferred to the B-phase. The load remains powered through another utility phase. Furthermore, when R, Y, and B phases fail, the microcontroller confirms total utility outage and issues a generator start signal. The generator cranks and starts; its voltage stabilizes, the generator contactor closes, and the load is transferred to the generator. At this point, the generator supplies the load automatically.

Should the utility power returns while the generator is running. The microcontroller detects restoration of utility phases, waits for a stabilization period (10–30 seconds), and checks phase priority. Assuming the R-phase is restored, the generator contactor opens, and the R-phase contactor closes. The load reconnects to the utility supply, and the generator shuts down automatically.

The standby generator serves as the last source of power when all utility phases are unavailable. This approach significantly improves supply reliability, reduces generator operating time and fuel consumption, and ensures continuous power delivery to the connected single-phase load.

4. RESULTS AND DISCUSSION

This section presents the results from the design, implementation, and testing of a microcontroller-based Automatic Transfer Switch (ATS) for a single-phase load connected to a three-phase utility supply with a standby generator. The developed system automatically transfers the load among the available utility phases (R, Y, and B phases) and switches to a standby generator when all utility phases fail. The system performance was evaluated under various operating conditions to determine its **effectiveness,** which includes phase detection test, load transfer performance, etc. The ATS continuously selected the highest-priority healthy source.

A phase detection test was carried out during the study. The purpose of this test was to verify the system's ability to detect the availability of each utility phase. The outcomes of the phase detection test are given in Table 7.

Table 7. Phase detection test result

Test condition	R-Phase	Y-Phase	B-Phase	Detection Status
Test 1	Available	Available	Available	Correct
Test 2	Failed	Available	Available	Correct
Test 3	Failed	Failed	Available	Correct
Test 4	Failed	Failed	Failed	Correct

The voltage sensing unit accurately detected the condition of each utility phase. The microcontroller correctly identified healthy and failed phases in all test scenarios, providing reliable information for source selection. Automatic phase transfer tests were also carried out. This test evaluated the ATS's ability to transfer the load from a failed phase to another healthy phase. The outcomes of the tests are given in Table 8.

Table 8. Load transfer performance.

Initial source	Fault introduced	New source selected	Transfer successful
R-Phase	R Failure	Y-Phase	Yes
Y-Phase	Y Failure	B-Phase	Yes
B-Phase	B Failure	Generator	Yes
R-Phase	R and Y Failure	B-phase	Yes

The ATS successfully transferred the load to the next available phase whenever the active phase failed. This functionality significantly improves supply continuity by utilizing healthy phases before resorting to generator operation.

5. CONCLUSION

This study successfully achieved the design and implementation of a microcontroller-based Automatic Transfer Switch (ATS) for a single-phase system capable of automatically transferring a load among the available phases of a three-phase utility supply and, when necessary, to a standby generator. The study was motivated by the need to improve power supply reliability in environments where phase outages frequently occur, causing interruptions to single-phase loads despite the availability of other healthy utility phases. The developed system continuously monitored the status of the three utility phases and intelligently selected the highest-priority healthy phase for load connection. In the event of a phase failure, the ATS automatically transferred the load to another available phase without requiring human intervention. When all utility phases became unavailable, the system successfully initiated the startup of the standby generator and transferred the load to the generator after verifying stable operating conditions. Upon restoration of utility power, the ATS automatically reconnected the load to the preferred utility phase and safely shut down the generator after a programmed delay period. Experimental testing demonstrated that the system responded effectively to various operating conditions, achieved successful phase-to-phase transfers, provided reliable generator backup operation, and maintained stable performance throughout repeated operating cycles. The results obtained indicate that the ATS significantly reduces power interruptions, minimizes generator running time and fuel consumption, improves operational efficiency, and eliminates the need for manual source selection. Furthermore, by prioritizing the use of healthy utility phases before engaging the generator, the system provides a more economical and energy-efficient solution than conventional automatic changeover systems.

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