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Design of a Low-Cost Back-to-Back MOSFET based Automatic Transfer Switch for Single- Phase Residential and BusinessLoads

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Abstract
Power interruptions are frequent in many developing countries, adversely affecting residences and small businesses alike. Design of a Low-Cost Back-to-Back MOSFET-Based Automatic Transfer Switch for Single-Phase Residential and Business Loads is to mitigate these interruptions, but many existing designs are expensive or rely on mechanical switching devices with relatively slow response. This paper addresses lack of affordable ATS for single-phase residential users, and limited solutions optimized for mixed residential-business loads. A low-cost microcontroller-controlled ATS using back-to-back MOSFETs for automatic switching is proposed. Experimental results indicate transfer times under 50µs, negligible voltage sag, and stable operation up to 90% of rated load.

I. Introduction
Power reliability is critical in households and small business environments, particularly where sensitive electronics are used. Conventional ATS units are mostly mechanical relay or contactor based, which results in switching times on the order of **100–300ms** [1] [2]. This delay may reset or damage sensitive loads. Semiconductor switches such as **MOSFETS connected back-to-back offer faster response, silent operation, and higher durability** [3] [4]. This study proposes a design of back-to-back MOSFET based Automatic Transfer Switch (ATS), designed for affordable single-phase use, with built-in load prioritization for mixed residential-business applications.

II. Related Work
[1] Developed a low-cost ATS using ATmega8 and relays but achieved switching delays >200ms. [2] also used electromechanical switching with delays of ~250ms. IoT-based systems [3] improved monitoring but still relied on contactors. Recent research highlights the growing use of MOSFETs and IGBTs in transfer and inverter switching applications due to their high efficiency and microsecond-scale response [4] [5].

III. Methods
A. System Overview
The proposed automatic transfer switch using MOSFET back-to-back function in the order of input power stage which provide actual AC voltage mains and the back-up supply (inverter), these voltages go into the voltage sensors from the sensors to the microcontroller to gate drive to MOSFET pair and finally to load. The complete system has afive stages which are the DC power supply, Voltage sensing, Microcontroller, Gate Driver, and MOSFET pair connected Back-to-Back.

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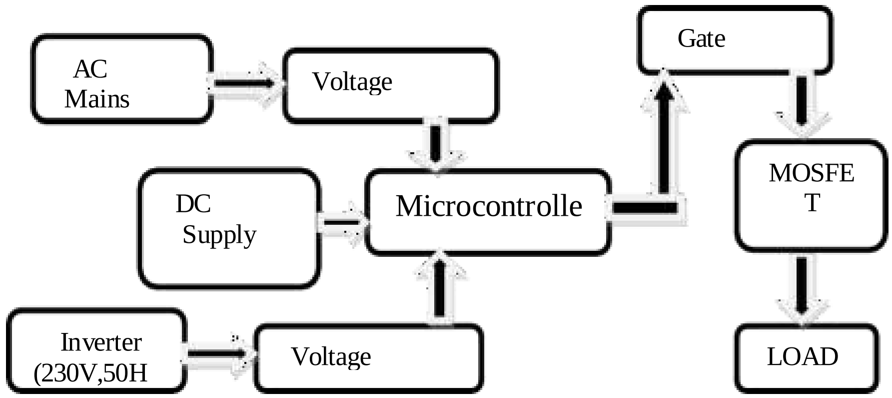

Fig. 1 Block diagram of system

1. **Power Supply Unit (PSU)** – Provides regulated DC voltage for the control circuitry. This power supply consist of a step-down transformer (230-12V), a bridge rectifier, filter capacitor, voltage regulator (LM7805) and another filter capacitor before the output (5Vdc)

2. **Voltage Sensing Circuit –** The voltage sensor (ZMPT101B) module is a compact single-phase AC voltage sensor module based on the minuscule 2mA/2mA precision voltage, which measured the supply voltage to a desired level
for the microcontroller. The ZMPT101B module, can handle AC voltages up to 250V (50Hz/60Hz). Its secondary circuitry, centered on the LM358 dual op-amp chip, also allows tweaking the isolated analog output via an onboard multi-turn trimpot (Trimmer Potentiometer). The recommended operating voltage of the module is 5VDC.

3. **Microcontroller Unit (MCU)** – The technical specifications of the Arduino UNO board is that, it uses a microcontroller ATmegaa328, with operating voltage 5v, input voltage 6-20v, 14 digital IO(Input and Output) pins of which 6 provide PWM output, 8 Analog input pins, flash memory 32kb

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4. while 2kb used by boot loader, 2kb SRAM, 1kb

5. EEPROM, 16MHz clock speed and 0.73‖ x 1.70‖ dimensions. The Arduino UNO can be powered via the Mini-B USB

6. connection of which the sketches from the IDE are uploaded also, 6-20v unregulated external power supply (pin30), or 5v regulated external power supply (pin 27). The control logic, sensed and processes the supply voltage sent by voltage sensor and compares it with the required threshold and then initiates switching effect of either mains supply or back-up supply.

7. MOSFET Pair Connected Back- To-Back

A back to back MOSFET is a pair of MOSFET connected in a way that allows for bidirectional blocking of current, preventing flow in both directions when turned off. When the MOSFETs are turned on, they conduct current in both directions, acting as a single switch that can handle high currents with low on-resistance, a significant improvement over traditional diodes. The MOSFET has an interview intrinsic body diode inside which conduct current automatically in reverse direction (source to drain), even when the MOSFET is off. Which means using a only one

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MOSFET to switch AC mains or bidirectional current, the body diode will always allow half of the current (during one polarity of the AC cycle) to pass even when the device is supposed to be off. To overcome that, two MOSFET are been connected back to back with common source connection, where the drains become input and output terminals of the switch.

V_{rms} = 230V, f= 50Hz, Upload = 40A

Voltage rating

V_p = 230V X √2 = 325.3v

Using margin of ~1.5 to 2

Therefore, V_{DS} = 1.5 X V_p = 1.5 X 325.3 = 488V

600V was select as standard

Current rating

For 40A, Id=

Margin/de-rating ~ 1.5 to 2 Id= 2 X 40 = 80A

8. Gate Driver

While the gate are driven together by the same gate driver signal. When the gate are off both MOSFET block current in both directions because their body diode are oriented in an opposite to each other. The MOSFET connected back to back basically works on ensuring it use a get driver to turn ON one MOSFET pair while the other pair remains OFF and a short dead time (2-5s) ensure both pairs are ON simultaneously preventing shorting

Output Voltage V_{out} = 5V Input Voltage V_{in} = 240V

The rated I_{rms} of the secondary winding is 500mA

So, $I_d = \frac{2 \times I_{rms} \times \sqrt{2}}{\pi}$

$$= \frac{2 \times 500 \times 10^{-3} \times \sqrt{2}}{\pi}$$

= 450mA

$$Vdc = \sqrt{2} \times V$$

$$= \sqrt{2} \times 5 = 7.07V$$

between the mains and back -up supply. When all are off it blocks current flow in both directions and when ON, one pair allows bidirectional conduction of full AC line to load.

B. Power Supply Design

Design of DC Power Unit

The power unit converts AC supply available at the mains to DC supply for the electronic circuits. The transformer is one of the elements in the DC power supply unit. It steps down the voltage to a suitable level for the circuits; it also provides electrical ground insulation of the device from the power line to reduce potential shock hazards. The rectifier follows the transformer and it converts the alternating wave form to a unidirectional but non constant supply. Silicon rectifiers are popular because of its low cost and high reliability. A capacitor is used to both smoothen out ripples and convert to dual power supply giving a positive terminal, negative terminal and ground, then a regulator is used to provide a 5v regulated supply to the circuit.

Transformer Selection

The AC supply is rated 220-240V, 50Hz. Since the circuit operate with a DC voltage range of 9-12V a step down transformer is used. Assuming unity power factor (ideal situation),

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Selection of a Rectifiers (Bridge)

The peak Inverse Voltage (PIV) of a diode is the maximum reverse voltage a diode can tolerate before it breaks down. Since the output voltage of the transformer is 12.73V, diodes of PIV above 12.73 that can handle 450mA is selected. For this work, a bridge rectifier using four IN4002 diodes encapsulated in a chip is used.

Design of the Filter Capacitor

The output of the bridge rectifier has ripples, whose voltage is calculated, $V_R = V_{PP} - V_{rms}$

Where V_{PP} = peak to peak voltage of the secondary

Also $V_R = \frac{I_{dc}}{2f}$

Where f = frequency of the power supply in Hz

C = capacitance in Farad

Equating the two V_R equations

$$V_{PP} - V_{rms} = \frac{I_{dc}}{2fC}$$

$$\text{Therefore, } C = \frac{I_{dc}}{2f(V_{pp} - V_{rms})}$$

Since I_{dc} = 450mA, f = 50Hz, V_{pp} = 7.07V, V_{rms} = 5V

Therefore C = 2174µF

For good filtering, the capacitor used must not be less than 2174µF. For this work, 2200µF capacitor was used. Because capacitors with higher values filter better than capacitors with lower values

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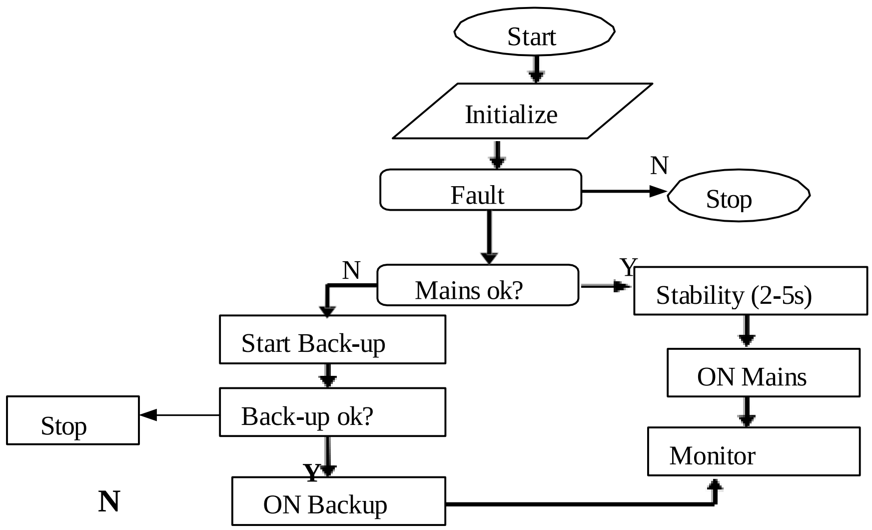

The Fig. 2 shows flowchart of the system

iv. Result and Discussion

The propose Low-Cost Automatic Transfer Switch (ATS) using MOSFET back-to-back was evaluated and the performance and parameter obtained was compared with others transfer switch, the MOSFET back-to-back based when place side by side with electromechanical relay ATS and the following parameters are put into consideration like transfer time, voltage sag during transfer, load regulation and power efficiency.

Table. 1 shows metric Performance of ATS MOSFET Back-to-Back

Parameters	**Mechanical ATS**	**Proposed MOSFET ATS**	**Improvement**
Transfer time	**20ms**	***<50μs***	**faster with 99.8%**
Voltage sag	**10**	**1.8**	**Reduce to 82%**
Load stability	**80**	**90**	**12.5%**
Power efficiency	**93**	**97.5**	**4.5%**

The proposed prototyped was tested under the following load conditions of 90,75,50 and 25 all are in percentage of the rated load. The two single phases where used to show the functionality and performance of the system, both sync. to a nominal v oltage of 230V, 50Hz. The microcontroller (Arduino UNO) used as the control unit, while the back-to-back N-channel MOSFET serve as the switching element.

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v. Conclusion

The proposed MOSFET back-to-back ATS using microcontroller has be designed and tested successfully and the system achieves a very good and fast transfer time of (<50µs) and maintain a voltage sag that's below 2% during supply switching. After been compared sided by side with mechanical relay ATS. The MOSFET back-to-back adoption shows how mechanical ATS are becoming obsolete due to its wearing; arching and the MOSFET based enhance reliability and lifespan. The proposed system design makes it ideal for single-phase residential and small business installations, particularly in region affected by power interruptions. I recommend future work should incorporate synchronization of algorithms and integrating IoT-based monitoring for remote control and predictive maintenance.

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