Development of a Three-Way Automatic Mains Failure for an Electric Recoil Petrol Generator

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***Abstract*— A "Three-way automatic mains failure (AMF)" for a single-phase electric recoil petrol generator has been designed and implemented to enable the automatic switching of power supply between the public utility and a power generator. The AMF is a functional system that is capable of sensing the availability or unavailability of mains power source. It is capable of starting the generator immediately when there's power outage; it monitors the incoming AC (alternating current) supply. The method employed in designing this AMF involves the use of delay timers, electro-mechanical relays, contactors and breakers. Incorporated in the AMF are under-voltage/overvoltage protections. Digital volt-meter using Arduino Uno and LCD (liquid crystal display), electronic key circuit (making it usable with an electric recoil petrol generator), IR (infra-red) transmitter and IR receiver circuits for remote start, push-button start and stop.**

***Index Terms*— Automatic Mains Failure (AMF), Automatic Switching, under-voltage and overvoltage protections, Digital voltmeter with Arduino, IR (infra-red) transmitter and receiver**

I. Introduction

IN this modern time, uninterrupted electrical power supply has been termed inevitable in developed countries, but in developing nations like Nigeria, the issue of uninterrupted or unreliable electrical power supply has been a major issue. This is largely due to the vulnerability of electrical power systems to large scale failure. This deplorable state of power delivery, results in slow development at the private and public sectors of developing nations. The cost of setting up, and running businesses or industries despite the available large market, for various goods and services becomes an issue of concern to prospective investors. In today's world, electrical power supply plays a critical role in almost every activity that surrounds our life. For some equipment, an uninterrupted reliable power supply free of disturbance, is a necessity.

Therefore, when there is a fault on the power supply at critical areas such as communications systems, hospital apparatus, security systems, banking computers, water and gas distribution devices, data centers and many other critical areas, it may lead to serious issues with consequences that can be disastrous. These areas can be identified as "critical power applications."

It therefore requires the automation and innovation of alternative sources for electrical power generation to back up the public utility supply or public grid. In a bid to curb this situation and ensure high level of reliability, the use of backup generators, inverters and other alternative energy sources is now being implemented in electrical designs for various buildings. Hence, there's a need for a change-over switch between the public utility supply and the backup generator or alternative power source.

One of the major functions of the related generator is the mains power switching when the main power source fails. They are capable of switching between power sources. This function is maintained with a change-over switching device according to IEC 60947-6-1 norm. A change-over generator works in a break before make transfer mode. It is like handling a three position circuit breaker, with utility power on one side, the generator on the other, and "off" position in the middle. Before making any connection, it is necessary to pass through the "off" position. That is, the load will be isolated from its initial power source (public utility supply) to another supply, such as a generator.

Changeover panels vary in size and in current rating. The major factor in sizing a changeover panel, is its ampere rating. Changeover switches can be categorized as:

- Manual changeover
- Automatic changeover

However, installation of a backup generator doesn't offer a sufficient solution, as manual starting of a generator takes some time which may cause problem in sectors or industries where constant power supply is mandatory, such as: Data-center, hospital, banks etc.

However, solving this problem requires the use of an automatic change-over system. Hence, the need of an AMF (automatic mains failure), which has the ability to switch between mains power supply and generator supply becomes imperative. If the method of change-over is automatic, it will reduce the down time of operation, thereby maintaining the tempo of production in such industries.

II. Methodology

The monitoring of the mains AC voltage was designed using an UNDER VOLTAGE/OVERVOLTAGE PROTECTION CIRCUIT, such that if the ac voltage is not within a specified range (195V-245V), the mains contactor would remain de-energized.

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The switching between generator supply and mains supply was achieved by using a control circuitry comprising electromechanical relays, contactors and timers which were electrically interlocked. When the control unit detects a failed condition (i.e. there is no mains supply), it performs a switching operation that switches on the generator. The load does not switch to the generator supply immediately so as to prevent powering the load with voltage levels and frequencies different from nominal values. This is done with the aid of an on-delay timer. After stabilization, power is transferred from the generator to the load. The load is powered by the generator until the mains supply returns within appropriate AC voltage limits. At this point, the control unit sends a signal to switch the load back to the mains supply, but this switching process is delayed by a few seconds, so as to prevent feedback signal to the generator. This is achieved with the aid of an on-delay timer. The generator goes off a few seconds after the switching process and this is achieved with the use of an off-delay timer.

The AMF panel could also be controlled by an indoor unit, which allows the user to choose between the following operations: remote start and stop (using infra-red remote), push button start and stop (using push buttons).

The function of the generator key would be replicated using an electrical key starter circuitry which consists of several relays and a timer.

The ac voltage level would be displayed using a digital voltmeter, comprising an Arduino which reads the ac voltage (analogue input) and converts it into digital form using its Atmel Atmega 328 microcontroller inbuilt ADC(analogue to digital converter), such that it can be displayed using a LCD (liquid crystal display).

III. Design Stages

A. Contactor Selection

The size of the contactor is dependent on the following:

- Generator rating
- Consumer load rating.

Generator rating = 6.6 kVA

Operating voltage = 220V

∴Generator rated current = $\frac{6,600}{220} = 30A$

∴The contactors selected for this AMF are each rated at 30A.

B. AMF Section:

This section controls the switching between the generator supply and the mains supply. Two major circuits in the design of the AMF are the:

-Power circuit; and

-Control circuit.

In the power circuit, the major goal is to interconnect all the power components that are responsible for making or breaking the circuit. This power design stage entails terminating the power cables in the panel in such a way that when certain conditions are met, electrical power would flow from the selected source to the load. To control this processes, the need for a control circuit arises.

The control circuit is responsible for the automatic switching of the contactors, which require the use of relays, timers, etc.

The control circuit is further divided into DC and AC sections.

The AC section entails controlling the flow of AC in the panel. Cable 1 and cable 4 are the life and neutral cables respectively. Under normal operating condition, when the mains relay is energized by cables 3 and 4, its NO (normally open) contact will close thus energizing the mains timer. The NO of the mains timer will close after the preset time has exhausted, current will then pass through the NC (normally closed) contact of the generator contactor, to the mains contactor thus energizing the mains contactor (The load will be powered by the mains supply.). The NO contact of the mains contactor will close, thus switching on the mains ON indicator lamp.

If there is a high voltage supply from the mains power source, the red indicator lamp will come "ON" and power supply will switch from the mains supply to generator supply. "Override condition" occurs when the electrical power supply isn't within the preset limits and the user decides to bypass it by turning the rotary switch to the override position, thus putting the load at risk.

When the generator is turned "ON", by the DC circuitry, current will flow through cables 10 and 12 (life and neutral) respectively. Current will flow through the "NC" contact of the mains-timer, which then flows to the positive side of the generator timer, thus energizing it. The "NO" terminal of the generator timer will close after a preset time (It is an off-delay timer) after which current will flow through the "NC" contact of the mains contactor to the positive terminal of the generator contactor, thus energizing it. Thus, the generator starts supplying the load. The "NO" contact of the generator contactor then closes, switching the "ON" indicator lamp of the generator.

The aim of the DC circuit in this section is primarily to start and stop the generator automatically. There are three sub-modes in this circuit. These are:

Control start/ Auto start;

Remote start/ comp start; and

Button start/ Elect or Auto start.

These modes can be selected by using the selector switch. The comp start mode wasn't used, it is for expansion purposes.

C. Generator off Delay Timer or GTR

This is an OFF delay timer. Its main function is to keep the generator on for a few seconds after the mains power has been restored, before the generator finally goes off.

Once the switch is open, the capacitor begins to discharge, thus keeping the transistor in the active region, thereby energizing the relay. The relay will retain its initial state provided the capacitor is still discharging. The time delay can be varied by adjusting the 10-kΩ variable resistor.

D. Under-Voltage/Over-Voltage Protection Circuit:

The function of this circuit is to isolate the load from under-voltage and over-voltage conditions by controlling a relay coil. The transformer steps down 220V AC to 12V AC. The input ac voltage is rectified using center-tap full

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wave rectifier. LED D3 is to indicate that power is being supplied to the circuit. Capacitor c1 is a filtering capacitor. A voltage divider exists between R3 and RV1. Zener diode. D4 ensures that no voltage less than 5V is across the base terminals of the transistor. If there is an overvoltage supply, transistor Q1 will come on, hence switching Q2 off (The base of Q2 will be grounded) thus, switching the relay off.

If the voltage input is normal (210V – 230V), transistor Q2 will be on, and if the input voltage is low Q2 will go off. The 555 timer is for creating an 11-second delay before switching the panel on, and also the buzzer is powered on during the delay.

E. IR Remote Circuit

The major function of this circuit is to generate infrared signals at a frequency ranging between 35 kHz and 38khz.This was achieved by using a multivibrator, such as 555 timer to generate the much needed frequency for the infrared LED to transmit. The 100-uf capacitor C1 reduces ripples in the input voltage. Pin 1 and pin 8 are used to supply power to GND and Vcc respectively. Pin 4 is the reset pin, which is active low input. Hence, it is connected to Vcc. Pin 5 is the control voltage pin which is not being used. Hence, it is grounded via a capacitor to prevent high frequency noises through the pin. Capacitor C2, resistors R1and R2 determine the period of oscillation, while the 555 timer was connected in an astable mode.

The output period of the timer can be calculated as:

$T=0.693*(R1+2R2)*C2$

If R1=1kΩ; R2=20kΩ; C2=0.01uf, then

$T= 0.693\times (1k\Omega+2(20k\Omega)) \times 0.001\mu f$

$T=2.8413\times 10^{(-5)}$

$F= T^{(-1)}$

F=35,195.16 Hz (which is within the range of operation of the TSOP).

In this circuit, the TSOP 1738 output pin is always high, so when it senses an infrared signal with a frequency of 38khz, it goes low, hence the pnp-transistor (BC548, BC558) starts conducting, thereby grounding pin 2 of the NE555, and causes pin 3 of the 555 timer to give out an output signal to the decade counter, and also causing pin 14 of the CD4017 to sense the flow of current which triggers the counter, and pin 2 goes high then triggers D2 to come "ON", and the BC547 NPN transistor to start conducting, and then amplifies the voltage to switch on the relay. The 555 timer is connected in a monostable-mode. The period of the output pulse signal from the 555 timer can be calculated as:

$T=1.1*R*C$

where T=period; R=220kohm; C=22μf

$T=1.1*220kohm*22\mu f$

T=5.324sec

LED D1 is "ON" when pin 3 of the 555 timer goes high.

Pin 15(reset pin) and pin 4(Decoded output "2") of the CD4017 are connected together to reset the **IC** to its initial state when pin 14 goes high again. On the CD4017, pin 3 equally goes high when pin 2 goes high, thus triggering the LED D2 "ON".

F. Electronic Key Circuit

This replicates the role which a manual key would play in starting a petrol generator. It has several modes. These include:

In the off mode relays, A and C are normally closed (The terminals controlled by these relays are closed), while relay B is normally closed (The terminals controlled by this relay are open). The three relays are not energized in this mode.

The 555 timer is acting as a delay-on timer, it is in monostable mode. When the mains power supply is unavailable, it comes on automatically. The timer's timing can be varied by adjusting the variable resistor. This timer only works when the panel is in auto mode.

In the ON- mode, the three relays are in the NO position (The terminals and the relays control are open), thereby opening the circuits which they are controlling. Relays A and C are energized, relay B remains de-energized.

In the start mode, relay B becomes energized and it switches to normally closed. This mode lasts for a few seconds, and it can also be activated by pressing the start button in manual mode, or when the MTR (mains timer relay) is closed.

This circuit also powers the linear solenoid actuator used for controlling the generator choke, its positive wire is connected to terminal port 27, and its neutral wire is connected to terminal port 2.

G. Voltmeter Circuit

This section is responsible for displaying the output voltage across the load. The major component is the Atmega 328 micro controller in the arduino.

The mains voltage is stepped down to 5V ac by the use of a transformer. The stepped down ac voltage is rectified to dc by using a bridge rectifier.

Since most micro controllers operate within the range of 5V, a variable resistor, and a 5-V Zener are used to ensure that the input voltage does not exceed 5V. The input voltage is applied across the ADC port of the Arduino. The circuit also includes a liquid crystal display, which displays the voltage readings.

IV. Results

The project underwent various tests. These tests are relay switching time test (to ascertain the time taken to switch from the generator to the mains supply and vice-versa, this took about 7seconds), also Voltage variation test, (to ensure the output voltage was within the permissible limits between 195V and 245V).

The three starting modes were tested and they worked according to specification.

V. Conclusion

A conclusion section is not compulsory. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

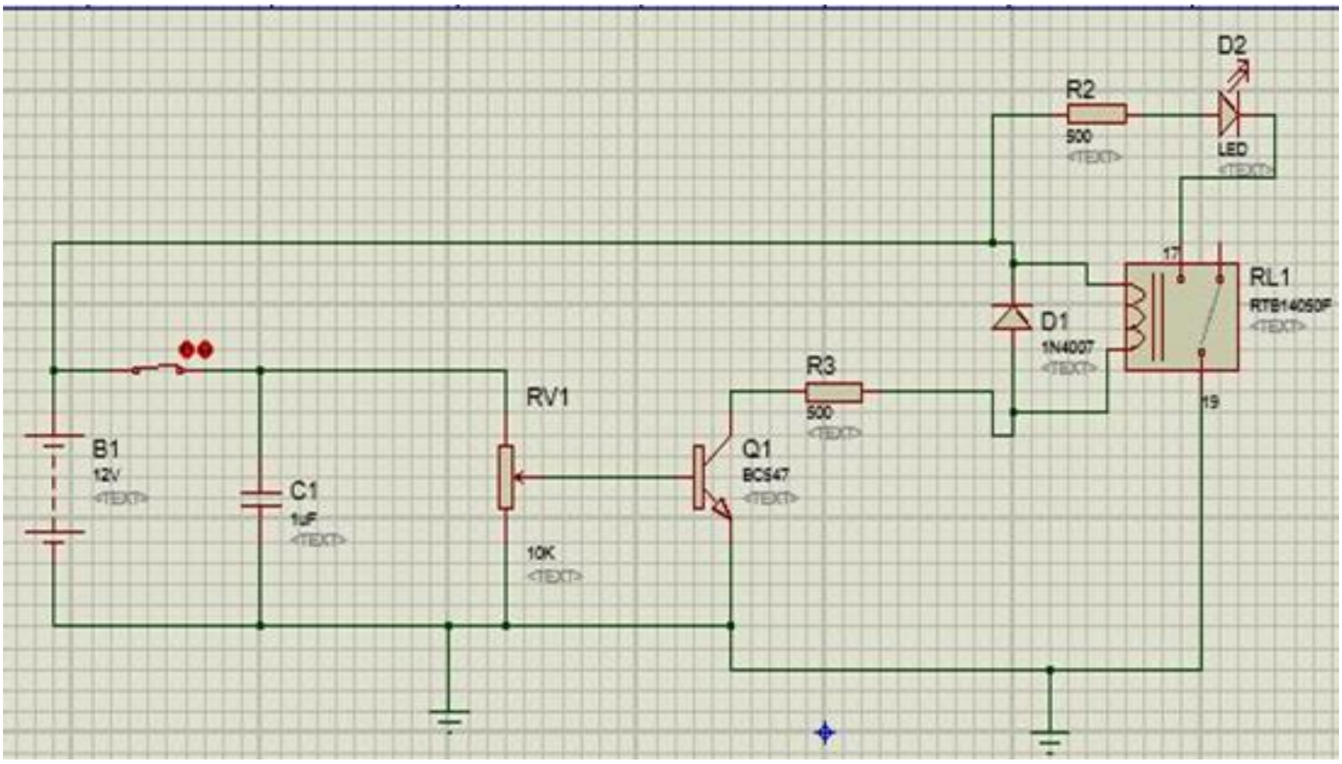

Figure 1. Off Delay Timer Circuit

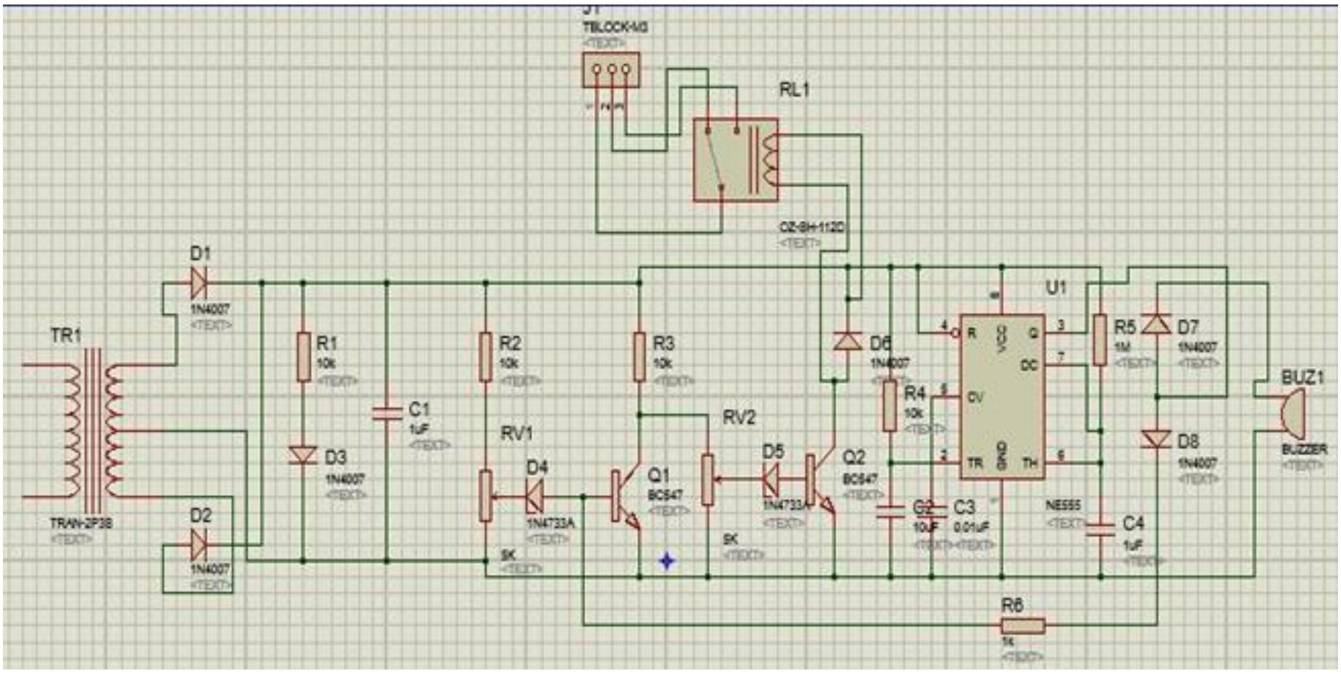

Figure 2. Under-Voltage/ Over-voltage Protection Circuit

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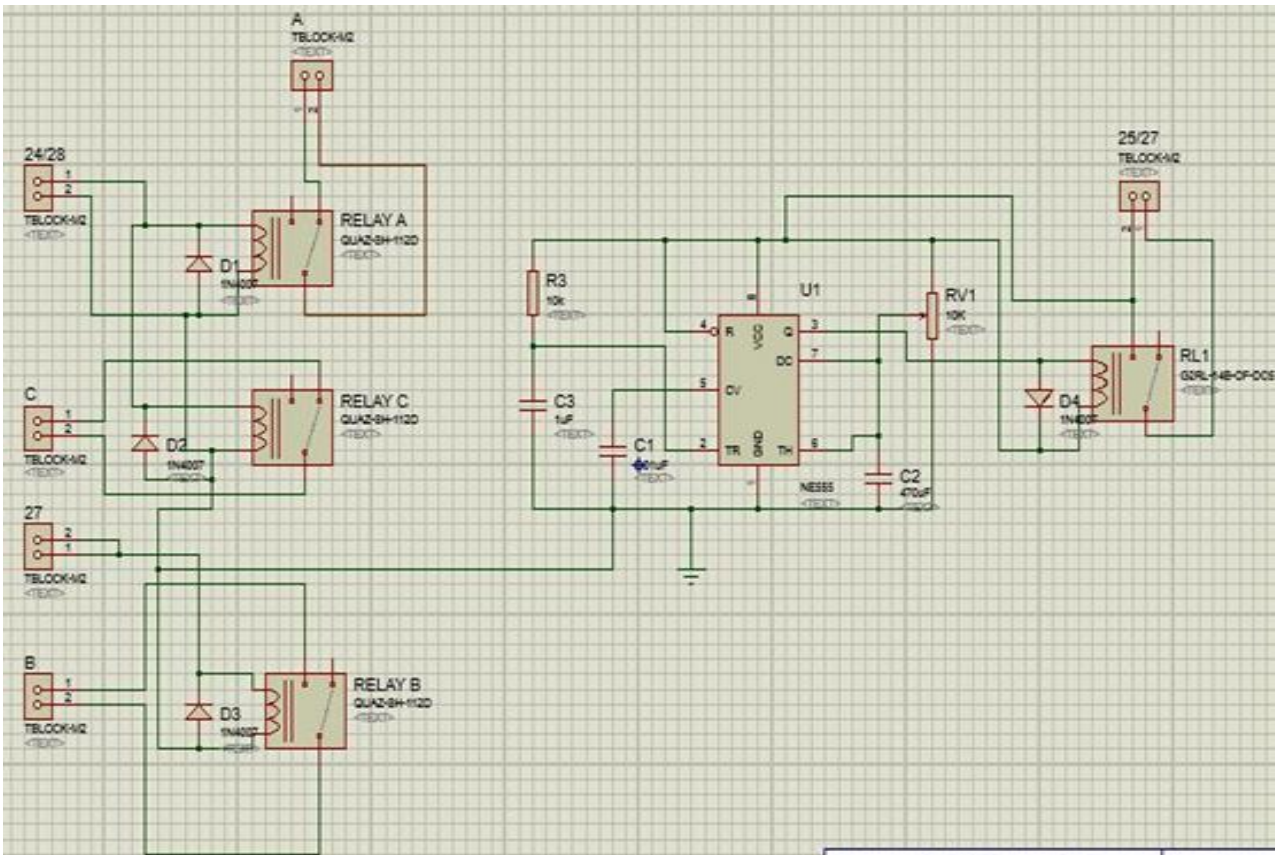

Figure 3. Electronic Key Circuit

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