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Design and Implementation of a 3-Phase Automatic Power Change-over Switch

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ABSTRACT : *In this research, a "3-Phase Automatic Power Change Over switch" has been designed and implemented using three voltage Comparators (LM741 AH1883), 3-input-AND gate (4073), two BC 108 transistors and 12V, 30mA relay as well as some biasing resistors. The voltage Comparators (LM741 AH1883) were biased to sense the unregulated voltage - one for each of the three phases (Rø, Yø, Bø) and then couple the analogue outputs to the 3-input-AND gate (4073). The AND gate produces an output of '0' (OFF) when all the three phase input voltages are all within the normal (preset) range, else it produces an output of '1' (ON) implying a voltage drop or phase failure in at least one of the compared phases. The output of the gate when coupled to the base of switching transistors (BC 108) determines their states (OFF or ON). Since the transistors are configured in a Darlington pair arrangement, the second is ON only when the first is OFF. This then triggers the public power supply ON due to normal phase voltage. On the contrary, when the first transistor is ON, the 12V battery produces a potential which triggers ON the alternative power source (Generator) via the 12V, 30mA relays hence breaking contact from the public power supply to the Generator side. The switch is tested to have function optimally within ±5% nominal voltage of 220 or 415V supply at the point of changing over to an alternative power source. Hence this device can be of Industrial or domestic use where 3-phase power supply is available with a stand-by power source.*

KEYWORDS*: Alternative power, Change over Switch, Generator, Relay*

I. INTRODUCTION

Power supply instability in developing countries creates a need for automation of electrical power generation or alternative sources of power to back up the utility supply. This automation becomes necessary as the rate of power outage becomes predominantly high. Most industries and commercial processes are partly dependent on generators and public power supply which is epileptic especially in tropical African countries where Nigeria forms a part. Therefore, if the processes of power change-over between these two power-supplying sources are manual, human error during change-over connections may occur; leading to machine damage, electric shock/electrocution as well as increased down time consequently introducing massive losses [1].

However, if the starting of the generator is automatically done by a relay which switches the battery voltage to ignition coil of the generator while the main power relay switches the load to either public supply or generator, the down time would greatly be reduce thereby maintaining the tempo of production in such industries. A manual change-over switch consists of a manual change over switch box, switch gear box and cut-out fuse or the connector fuse [2].

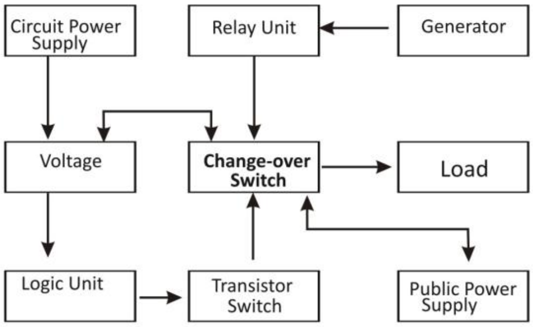

Figure 1: The block diagram of the system

The approach used in this work is the modular approach where the overall design is first broken into functional blocks as shown in the above block diagram. The 3-phase automatic change-over switch has been divided into eight (8) blocks as shown in Fig. 1. Each of these blocks carries out a specific function in the entire system as shown by the interconnections between the blocks.

II. DESIGN EQUATIONS, ANALYSES AND CALCULATIONS

The following design equations have been used in analysing various stages of the Automatic Change-over Switch.

$$C = \frac{5i}{Vpf} \quad (1)$$

where, C is capacitor value, $V_p$is peak voltage (Bridge output max voltage), f is frequency of the a.c supply and $i$is the load current [4].

$$V_R = \frac{R_2}{R_1+R_2}V^+ \quad (3)$$

where, V_R is voltage drop across R , V^+ is supply unregulated and rectified voltage from a single phase

$$V_{out} = A_o V_{in} \quad (4)$$

where$A_o$is open loop voltage gain which usually not less than 20,000 [3].

$$V_{in} = V^+ - V^- \quad (5)$$

$$V^+ = I_c R_C + V_{CE} \quad (6)$$

$$V_{IN} = I_B R_B + V_{BE} \quad (7)$$

$$hfe = \frac{I_C}{I_B} \quad (8)$$

where, I_C is collector current, I_B is base current, V_{IN} is input voltage, V^+ is supply voltage, V_{CE} is the collector-emitter voltage, hfe is current gain [4].

$$\text{Relay coil current} = \frac{\text{supply voltage}}{\text{coil resistance}} \quad [2] \quad (9)$$

III. MATERIALS

Three voltage Comparators (LM741 AH1883), 3-input-AND gate (4073), two BC 108 transistors, two 12V; 30mA relays, biasing resistors, 240/12V; 500mA transformer, bridge rectifier (1N4002), two voltage regulators (LM7812 and LM7805), variac, Multimeter plus some other components.

IV. IMPLEMENTATION

4.1 Power Supply

This section is represented in the diagram with two blocks (Public Power Supply and Circuit Power Supply) for the sake of clarity. The Public Power Supply has a nominal three phase or phase-to-phase voltage level of 415 a.c voltage under normal system condition, while the single phase-to-neutral nominal voltage is 240V. The Circuit Power Supply is tapped from the public power Supply and rectified to power the circuitry. The main function of the circuit power supply is to convert *a.c – d.c.* The first stage makes full wave rectification from the a.c signal by employing a bridge rectifier. The rectified d.c voltage is then filtered by using filtering capacitor to smoothen the resulting d.c signal. Finally, appropriate voltage regulators (LM78XX) are then selected to keep the d.c signal within specified ranges.

4.1.1. Transformer Rating

The transformer requirements:

Input voltage = 240Vk
Output voltage = 12V
The maximum output current 500mA = 0.5A
Therefore, power (VA) required = 15 x 0.5= 7.5VA

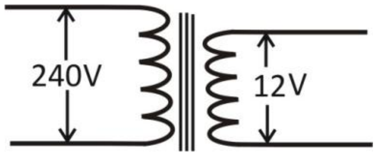

Figure 2: The transformer

4.1.2 Bridge Rectifier

This is achieved using half-wave bridge rectification. Two diodes (1N4002) were chosen due to their low voltage drop (≈0.7V) [2] and ruggedness.

4.1.3 Filtering capacitor:

To calculate filtering capacitance; C, the equation (1) is applied for 10% ripple voltage.

$$C = \frac{5i}{Vpf}$$

Transformer secondary voltage = 12V,
Ripple voltage = 10% of 12V = 1.2
Bridge rectifier = 1.4V
The expected voltage after rectification = 12 + 1.2+1.4 = 14.6V
V_p= peak voltage = 15V (peak-to-peak, bridge output max voltage)
i= load current = 0.5A
f = frequency of the AC supply = 50Hz;
Therefore; designing of +12V @ 0.5A, the filtering capacitance is:

$$C = \frac{5i}{Vpf} = \frac{5 \times 0.5}{15 \times 50} = 3333.3333\ \mu F; \quad (2)$$

Preferred value = 3300µF.

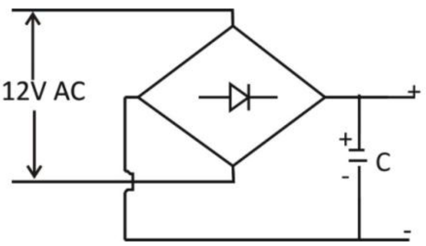

Figure 3: The bridge rectifier

4.1.4 Voltage Regulator

In this design, 7812 and 7805 regulators are used, which can provide up to 2A (guaranteed) with only 1.3V drop-out voltage. Input voltage must be around 15V, otherwise the regulator temperature will increase as input voltage increases [3].

1 = input, 2 = common, 3 = output

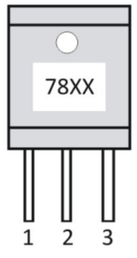

Figure 4: 78 Series regulator

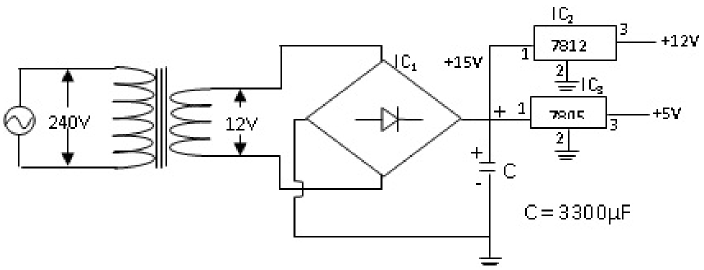

Figure 5: Power supply

4.1.5 Voltage Sensor

The comparator/voltage sensor compares two voltages, one voltage sampled from the unregulated voltage while the other is the regulated +5V voltage from the device power supply. If the two voltage levels are equal, there will be no output from the sensor but if a reasonable discrepancy is experienced, an output will be obtained from the sensor. The comparator stage is used to sense when the public power supply voltage has dropped below a certain preset level. The input public power supply voltage is converted to d.c (rectification) in the power supply stage and is regulated to 12V and 5V for power supply needed in the circuit. The unregulated voltage varies as the public supply input varies.

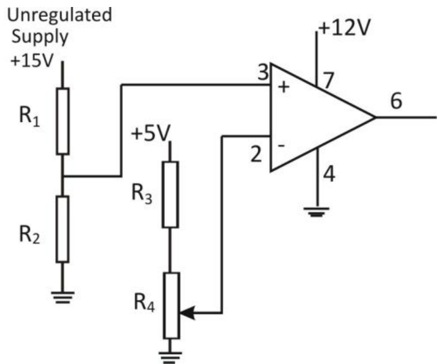

Figure 6: Voltage Sensing Circuit

From Fig. 6, R_1 and R_2 form a potential divider to reduce the unregulated voltage to a low voltage of less than 5V at 180V a.c input. Remember, 180V a.c is sampled single phase voltage to be rectified and compared with the regulated +5V d.c at pin 2 of the comparator. It is being taken as dangerously low voltage for appliances meant to operate with a nominal voltage of 240V a.c single-phase supply. At the 3-phase power supply (415V a.c), it will be as low as 340V a.c.

From equation (3), let V_{R1} = 1.45V = voltage drop across R_1.

But $V_{R2} = \frac{R_2}{R_1+R_2}V^+$ = voltage drop across R_2

From Table 1; at an input voltage of 180V (a.c), the sampled unregulated and rectified voltage from a single phase; V^+ equals 11.6V d.c.

Now, let R_1 = 100kΩ;

i.e. 1.45 = $\frac{R_2 \text{ x } 11.6}{100+R_2}$

R_2 = 14.2kΩ but 15kΩ is to be taken as the preferred value So, R_1 = 100kΩ while R_2 = 15.0kΩ.

Looking at Fig. 2, R_3 and R_4 are forming another potential divider for the reference voltage. Assuming a maximum adjustable reference voltage of 2.5V while setting R_3 = 2.2kΩ,

$V_{R_4} = \frac{R_4 \text{ x } 5v}{R_4 \text{ x } 2.2}$

where V_{R4} = 2.5V, R_3 = 2.2kΩ and V^+ = 5V.

i.e2.5 = $\frac{R_4 \text{ x } 5v}{R_4 \text{ x } 2.2}$,

Therefore, $R_3 = R_4$ = 2.2kΩ.

Table 1: Variation of D.C Voltage against Input Supply Voltage (Calculated)

AC Input Voltage	Unregulated (DC) Voltage	V_{R2} (DC) Voltage
220	13.60	1.77
210	13.10	1.71
200	12.60	1.64
190	12.10	1.56
180	**11.60**	**1.51**
170	11.10	1.45
160	10.60	1.38
150	10.10	1.32

4.2 The Comparator

From equations (4) and (3), $V_{out} = A_o V_{in}$

whereA_o= open loop voltage gain = 20,000 (chosen from datasheet)
and from equation (5), $V_{in} = V^+ - V^-$
V_{out} will drop to V^+ for the slightest positive difference in voltage since $A_o$is very large (order of 20000). As the Public Power Supply input drops below 1.45V reference voltage, the output of the comparator goes LOW to changeover the relay. As the output goes above 1.45V, the comparator output goes HIGH to switch the Public Power Supply to the load.

4.3 Logic Control Stage

A 3-input AND gate was used to implement the logic control stage. The logic circuit compares the input voltages across A, B, C corresponding to three phases from a public power supply and then gives an output of ‘1’ (ON) when all of A, B and C = 1 (ON) or ‘0’ (OFF) when any of A, B or C is zero.

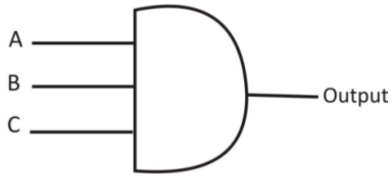

Figure7. 3-input AND Gate (4073)

4.4 Transistor Switching Stage

The switching transistor switches the relay, which selects between the generator and public power supply. A base resistor; R_B is required to ensure perfect switching of the transistor in saturation [4]. Applying equation (9),

$$R_B = \frac{V_{IN} - V_{BE}}{I_B}$$

V_{BE} = 0.6V (silicon); (0.3V-germanium) [4]
The input voltage; V_{IN} = 5V, hfe = 300 (from datasheet for BC 108)
The base current; I_B is therefore calculated from current gain; $hfe = \frac{I_C}{I_B}$

I_B = 100A
The collector current; I_C= 30mA from equation (6)

$$V^+ = I_c R_C + V_{CE}$$

The supply voltage; V^+ = 12V, collector resistor; R_C = 400Ω (chosen with regard to the resistance of the relay coil, used in this work and the collector-emitter voltage V_{CE} = 0V (when transistor is ON).
Therefore, R_B = 44K = 47K (preferred value)

4.5 Change-Over/Electrical Relay Isolation Stage

i.Physical size and pin arrangement: A relay is chose based on the existing PCB to ensure that its dimensions and pin arrangement are suitable for the designed project.
ii. Coil Voltage: The relay coil voltage rating and resistance were taken into consideration.
iii. Coil Resistance: The circuit must be able to supply the current required by the relay coil.
From Ohm’s law (equation 9), Relay coil current = $\frac{\text{supply voltage}}{\text{coil resistance}}$

Relay coil current = $\frac{V}{400\Omega} = \frac{12}{400}$ = 30mA

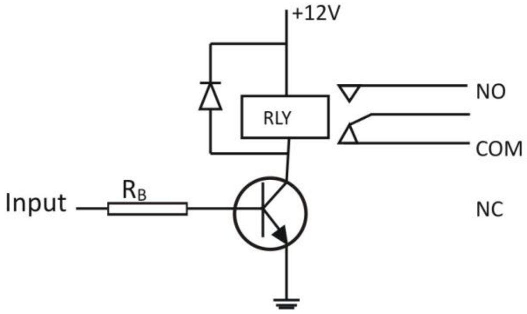

Figure 8: Changeover switch

V. TEST AND RESULTS

After the construction of the automatic voltage change-over system, a variac was used to carry out the measurement and the results in Table 2 were obtained and compared with the calculated values (Table 1). Also, the logic stage implemented in section 4.3 was also tested with a digital multimeter and results presented in Table 3.0.

Table 2: Measured and Calculated and Parameters

Ac Input Voltage (V)	Unreg. (dc) (Measured)(V)	V_{R1}(V) (Measured)	V_{R2}(V) (Measured)	V_{R2}(V) (Calculated)	Dif. Between V_{R2}(V)
220	12.60	10.90	1.68	1.77	0.09
210	12.10	10.49	1.60	1.71	0.10
200	11.40	9.82	1.54	1.64	0.10
190	10.65	9.22	1.48	1.56	0.08
180	**10.20**	**8.72**	**1.46**	**1.51**	**0.05**
170	9.72	8.26	1.44	1.45	0.01
160	9.20	7.80	1.35	1.38	0.03
150	8.46	7.10	1.30	1.32	0.02

Key:
A.C Input voltage: This is an a.c voltage sampled from one of the three phases and injected into the circuit.
Unreg. (dc) volt measured: It is the measured value of the sampled a.c voltage, now rectified and reduced to the desired level.
V_{R1} Measured: Measured DC voltage across resistor R_1.
V_{R2} Measured: Measured DC voltage across resistor R_2.
V_{R2} Calculated: Calculated DC voltage across resistor R_2.

Table 3: Truth Table for 3-input AND gate (4073)

Input C	Input B	Input A	Out put
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

VI. DISCUSSION

From Table 2, the sampled unregulated voltage reduces alongside with the a.c input voltage; also the comparing voltage (V_{R2}) in pin 3 of the comparator follows the same trend. The result clearly shows the relationship between the input, regulated and the unregulated voltage levels. The result in Table 2 shows a deviation between the practical and calculated values. This is attributed to losses and stray capacitances in the implemented circuit. However, these losses do not affect the performance of the switch.

Table 3 shows the switching sequence of the compared voltages for 3-input AND gate (4073). The sequence (1,1,1) produces an output of '1'. This when coupled to the BC 108 transistors turns them 'ON' thus initiating a switch via the relay. All other sequences from the table are those at which the compared voltages has no or negligible difference. When these sequences with '0' or 'OFF' are coupled to the transistors, no changeover is initiated thus the circuit only monitors.

VII. CONCLUSION

After the implementation of the design, various tests were carried out and the results obtained demonstrated that the 3-phase automatic change over switch achieved its design and construction purpose. The system worked according to specification by monitoring phase failure and under-voltage thereby changing over to the alternative power supply. This automatic electronic system operates without human intervention hence the sluggishness of manual operation is eliminated and production downtime reduced to the barest minimum thereby reducing production losses and costs.

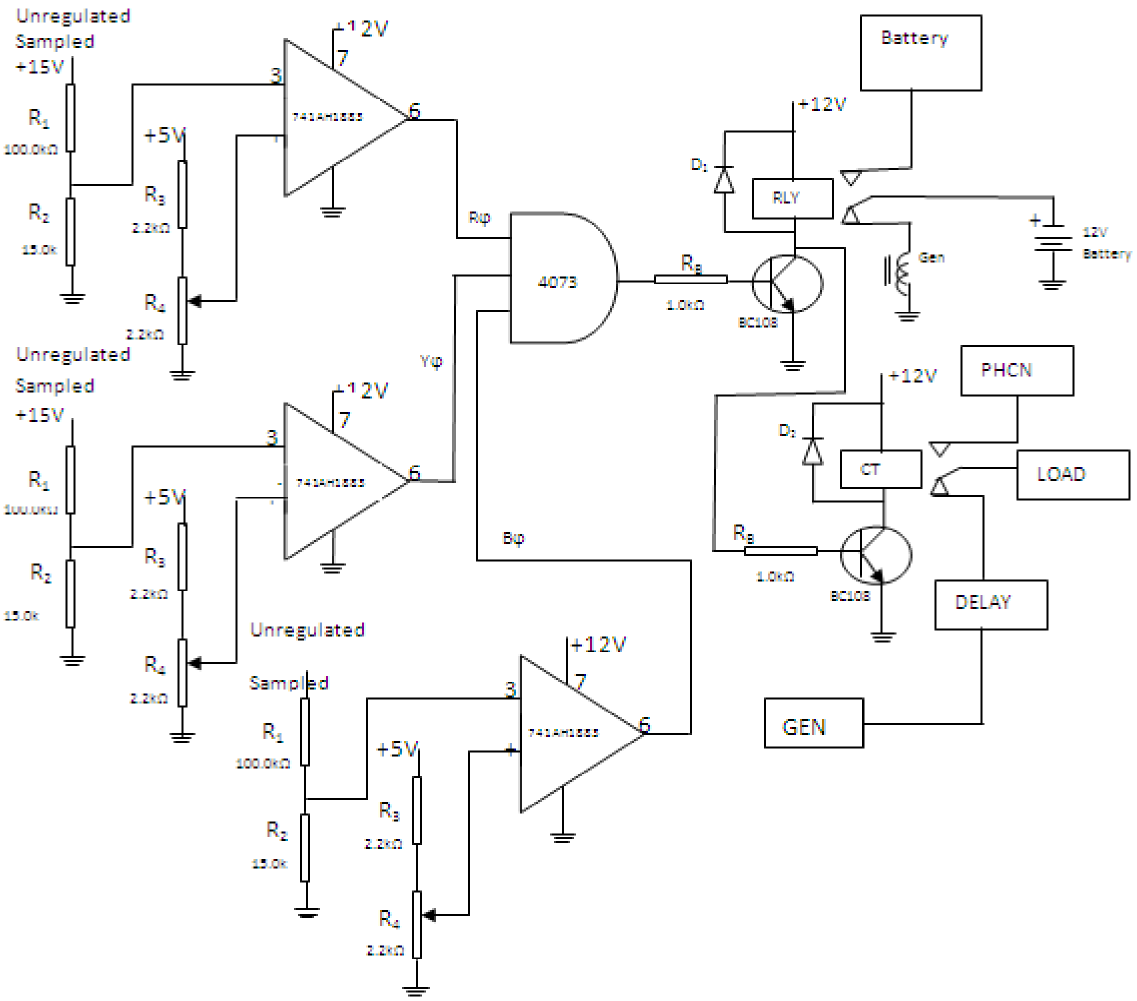

Figure 9: The designed circuit for the automatic power change-over switch

Key:

$D_1 = D_2$: IN4002 │ RLY = 12V Relay │ CT: Contactor (Load Dependent)

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