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Design and Implementation of an Automatic High-Performance Voltage Stabilizer

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Abstract: *This research aims at the design and implementation of an automatic high-performance voltage stabilizer which helps to detect inappropriate voltage levels and correct them to produce a reasonably stable output. The system consists of five dependent architectural designs which involve the power supply, delay switching circuit, monitoring circuit and load changeover circuit using 555 ic which produces the required signal when switched on by a relay to activate the alarm. The system uses a relay to charge the batteries and automatically switches on this supply to supply the loads. It is composed of switching transistors and relay to control the power provided to ac loads, and it has LEDs for indicating the state of the system, 240-220vac/120-110vac switch, voltmeter displaying load voltage, heatsink, and fans for cooling the system. The system protects electrical equipment and machine against voltage surge.*

Keyword: Automatic Voltage Stabilizer, Delay Switching Circuit, Inverters, Load Changeover Circuit, Monitoring Circuit, Power Supply.

1. INTRODUCTION

Given the problems faced by mainly in industries and electrical networks, the importance of the project sets out the development and study a voltage stabilizer. Therefore, voltage stabilizer maintains good quality power to equipment. In practice, stabilizing voltage can be obtained using existing voltage stabilizers like relay voltage stabilizers being the first developed stabilizers and servo type at the latest. Now the new implemented design has been designed to emulate the current devices due to its numerous advantages. Among the natural ways to stabilize power is conditioning it at the input from source before supplied to loads. (Jimmy.S. kan, G., Denny, T.cony sturat, V., 'power migitation' cof ut. 2016).

With the improvement in technology, the implemented device has been integrated with an alternative power source (DC Batteries) to avoid power inconveniences during power outages furthermore an alarm system has been combined with the invention to notify the user on the power outage

This project is useful; it provides solutions for the existing power problem happening in real life since the required components were available at reasonable costs, researchers implemented the device with the latest technology which is to replace the current methods. The method is cheap compared to the present invention.

Voltage stabilizer using servomotor for three phase was designed, but the project was not energy efficient. It had control circuit based microcontroller integrated with a servo to achieve the control, but due to the cascading energy used, recommended the use of solid state to replace the servo motor. (Salihu, Nasir and omega 2015)

Pak sote, dong Yee wu (2016) designed and implemented an automatic voltage stabilizer using the embedded system and servo motor. It incorporated an autotransformer which was very operating in both single phase and three phases. A servo motor is right on voltage stabilization but the weakness found was preventive maintenance on the carbon brushes.

2. MATERIALS AND METHODS

The system uses five dependent architectural designs which involve the power supply, delay switching circuit, monitoring circuit and load changeover circuit. The system comprises diagrammatic illustrations showing the components arrangement and the power flow from one component to another. The new system has less complicated architecture, easily operated, cheap and additionally reduces on power problems.

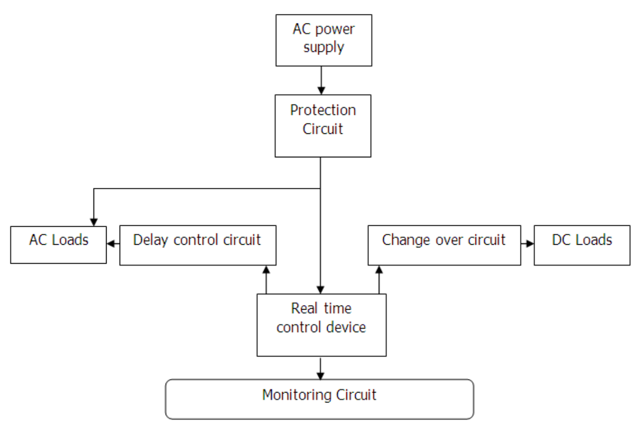

Figure 1: Show Block Diagram Of The New System

Components description

The design and implementation of the fundamental circuit units and how the program was implemented to control the layout and perform the required functionality.

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The steps involved in the designing this project includes:

- Power Supply
- Protection
- Alarm Circuit
- Automatic Change Over Circuit
- Delay Switching Circuit,
- Monitoring Circuit
- Load Change Over Circuit.

The device powers AC loads like lights, motors, pumps, fun and among others. Primarily the loads use (240-110) VAC as described earlier thus stabilizes single-phase voltage as above and in any power outage, automatically provides stabilized DC power

Required to supply 240VAC such that our relay used receives 5VDC.

V1= 240VAC, 13A, 50Hz,

T1= 240VAC, 13A, 50Hz to 12 VAC, 1 A.

f=100Hz since after converting 50Hz AC into DCV, through full wave bridge. As the negative part of the pulse is converted into positive, one pulse is count twice. So

T = 1/100 = 10ms.

V= peak voltage, the i.e. voltage given to voltage regulator IC (2 more than rated). Using 12-0-12 the rms value of transformer Vpeak is;

Vrms*√2

12*√2 = 16.968V.

1.4V is dropped on diodes (using 1N4007, have high PIV = 1000V datasheet ref datasheet) when forward biased.

So 16.968V-1.4 = 15.568. For more information, refer to datasheet of 7806. (I_o = 500mA-1A, Vi = 8.0V-21V, V_o = 5.70-6.3V). Efficiency of regulator = V_o/Vin. 6/12 = 0.5%

Capacitor must supply voltage regulator Voltage >= 6V. Thus capacitor voltage (2+7.568 where 2 is standard voltage drop across voltage regulator),

ΔV =15.568- 6 =9.568.

C1 = I*T/ΔV. C = 1*10ms/9.568 = 1045.2µf.

using a relay of 5V (nominal voltage VDC 5V, pick up voltage VDC max 3.5, drop out voltage VDC 0.5, Nominal current 72mA, nominal operating power 360mw, coil resistance 69.4Ω.

Battery of 6V at 720mA

Practical, suitable component values used are

Capacitor 25V at 2200µf and Others remained.

Calculation on IC 555.

From the datasheet, Rvr1 max = (Vcc-V capacitor)/I threshold, I threshold = 0.25µA, bypass capacitor 0.01µf be placed across pin 5 to Gnd. This will increase the noise immunity of the timmer to avoid causing timing errors.

Vcapacitor = 2/3vcc for monostable circuit of 555. Output pin 3 gives max 200mA when sourcing, for VCC 9V, v_o= 2.75V minimum, reset current of 0.25µA, pulse width (T) = 1.1VR1*C4.

Using B1 = 9V at 750mA. Vcap = 2/3*Vcc, 2/3*9 = 6V

Rvrl max = Vcc-Vcap/Ith, Rvrl max = (9-6)/0.25µA = 12mΩ.

Control voltage at pin 5, Cv= 2/3*Vcc, 2/3*9=6V.

Assuming required T = 10seconds. Then C4= 10/1.1Rvrl max, 10/1.1*12MΩ = 0.7575µf.

Load at pin 3. From chart, low level output voltage at 5mA = 0.05V min and 0.35V max. High level output voltage at 200mA = 3V min and 13V max. Therefore, any load parameters within those operating range work.

Since input voltage is small, transistor Q1 is switching transistor BC 547, (IC =10mA, Ib = 0.5mA, VBE(sat) = 0.7, VCE= 5V).

R3 = Vcc/IC, R3 =Vcc-Vce/Ic, R3 = 9-5/10mA, =400Ω,

R1 = Vcc-0.7/Ib, R1 = 9-0.7/0.5 mA = 16.6KΩ,

Since the minimum voltage is 5V at pin 2, then R2 = Vcc-Vtrig/Itrig, [min trigger current (Itrig) = 0.5µA and min voltage trigger (Vtrig) =1.45] R2 = 9-1.45/0.5µA, = 15.1mΩ.

C5 = I*T/V, C = 0.5µA*10/1.45 = 3.45µf.

R6 = Vcc- 0.7/Imax, R6 = 9-0.7/20mA, = 415Ω.

R4 = Vin RL1-0.7/Iin, R4 = 6-0.7/20mA, = 265Ω

Practical suitable components used are.

NE 555P Z9CXY8A

Vr1 + R= 100kΩ+90KΩ. R is used in the final design. Tmr = 1.1*C4*(Vr1+R) =1.1*190e3*100e-6 = 21seconds.

C3 recommended from chart = 0.1µf. C4 = 100µf 16V, C1 = 2200µf.

R3 = 15KΩ. R2 = 15KΩ. R6 = 1KΩ.

D1-D4 =1N4007, RL1 = 5V

Rechargeable battery (8.4V-250mAh). Standard charge for 14-16hrs at 25mA and quick charge for 5hrs at 75mA.

Q1 = BC547. F1 = 240V, 10A. SW1 = Normally open (NO).

Below shows the power supply, protection and alarm circuits

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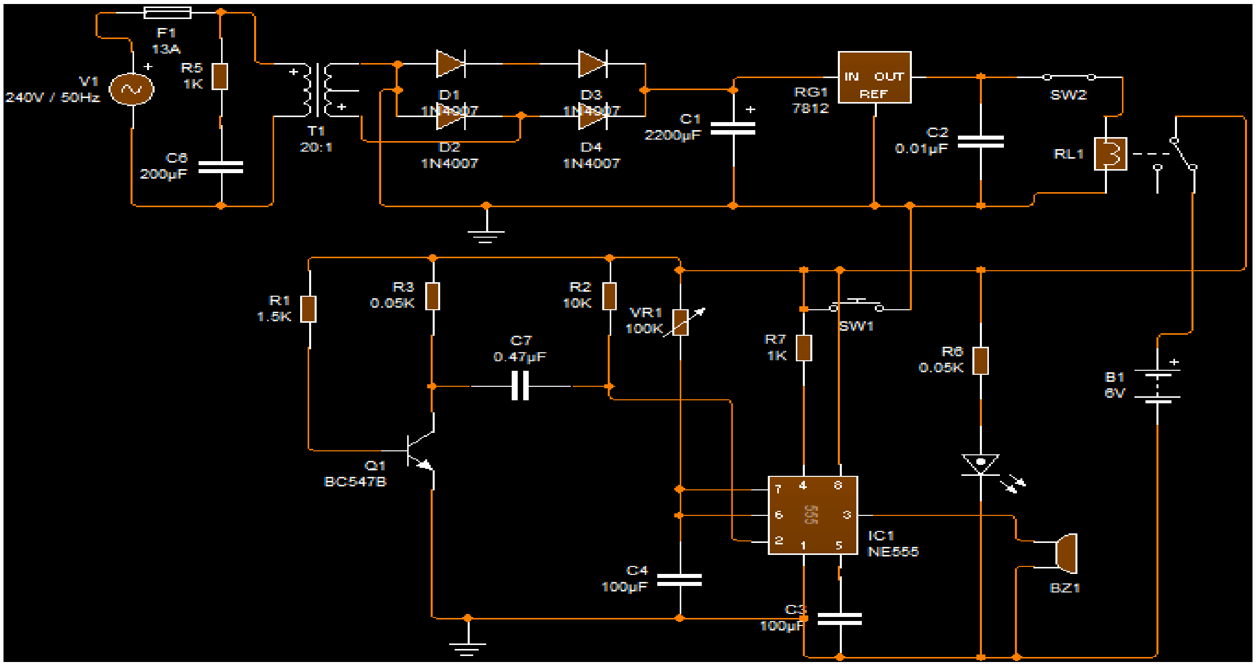


Figure 2: Power supply, protection and alarm circuits

Power supply

In the above circuit diagram AC from V1 through an overload protection fuse F1, snubber circuit R5, C6, step-down by a transformer T1 to bridge rectifier (D1, D2, D3, and D4) for rectification. Then through filter capacitor C1 and fed to voltage regulator RG1 and finally to relay RL1. AC power from the source directly powers AC loads controlled by the relay RL1 as in fig 4. DC power operates the relay RL1. (Briefly about C-R. By using a ceramic capacitor and carbon film resistor, when the source reduces in the sourcing current, the capacitor sources enough current so that the di/dt rate of current fall through the inductor is not fast also R-C damps out the ringing if the component value is selected. Finally, reduce spikes by dropping the voltage across the resistor, capacitor charges and discharges then discharge allowing energy with fewer spikes to inductor).

Alarm circuit

It operates on DC power supply from the rechargeable battery which charges through RL2 of fig 4 ready to power the monitoring system in the absence of power. The oscillatory connection of (R2, R3, C7, and Q1) helps to generate a pulse at a frequency determined by period T of the 555 IC connected in mono-stable mode. Therefore, the value of R2 and C7 should be of small amounts. Transistor Q1 is connected in a common-emitter configuration to Vcc through R1 on base for limiting the current and R3 collector for C7 discharge. A signal sent to IC 555 from that oscillatory circuit enables the IC 555 to produce a message for the period T which is assigned to activate the load connected to output pin 3. D6 is powered directly from the battery to give out a continuous light and also controlled through switch SW3. During normal operation, the monitoring system is in off state waiting for activation from the relay RL1; if it is not activated, no signal is produced, load and D6 are off. SW1 for resetting the timer to enable it and reproduce the signal is used. It is pressed to find the state of the system thus helpful in case of fault finding in the system.

Automatic change over circuit

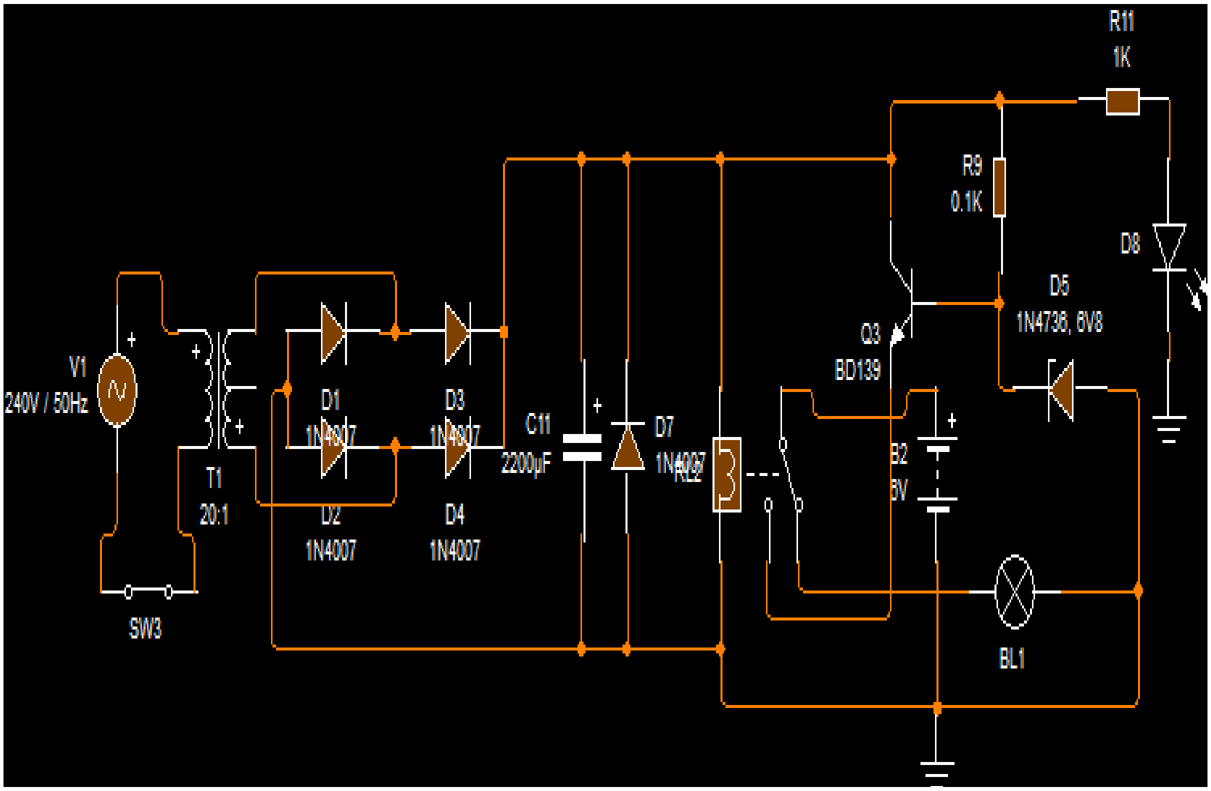


Figure 3: shows automatic change over circuit

From the circuit above, the AC from V1 is step-down by transformer T1, rectified by D1, D2, D3 and D4 to DC pulsating power, filtered to DC voltage by capacitor C11, fed to a relay RL2. Power transistor Q3 provides the DC power to charge the batteries B1 and B2. Zener diode D5 divert the charging current to ground in case the batteries are 100% charged. When the power goes off, the relay RL2 is de-energized and moving contact turned off in normally closed position (NC), this automatically connects and power the DC loads with power from batteries. LED D8 indicates the state of the system

V1 =240VAC.

T1= 240VAC at 13A to 12VAC at 1A.

f =100Hz, T = 1/100 = 10ms,

V= Vrms*√2, 12*√2 = 16.968V.

Now 1.4V will be dropped on diodes (use 1N4007, have high PIV = 1000V datasheet) when forward biased. So 16.968V-1.4V = 15.568.

C = I*T/ΔV. C = 1*10ms/9, C = 1111.1µf.

For more information, refer to datasheet of Relay 9V (nominal voltage VDC 9V, pick up voltage VDC max 6.3, drop out voltage VDC 0.9, Nominal current 40mA, nominal operating power 360mw, coil resistance 225Ω

For zener to be activated, the voltage at its node has to be higher than its reverse bias voltage such that it diverts current to ground therefore at the base of power transistor Q3 except 6.8V for a 6V zener to operate well.

Voltage drop across resistor R9 = 15.568-6.8 = 8.768V.

R9 = V drop/Iin; 8.768/0.041A = 213.85Ω.

Remember the design is 6V, 0.66A.

Q3 (Vo) = Vb-0.7, Vb = 6.8, Vo = (6.8-0.7) V = 6.1V.

IB2, IE =Ic - Ib; 0.7A-0.041mA = 659mA.

Value of R11 = Vdrop R11-Vdrop D8. Iin = 59mA (blue/green data sheet forward current 30mA, peak forward current 100mA, power dissipation 120mw).

R11 = 14.168-0.7/59mA =228.27Ω. Having got 6.1V, 0.659A, the load has to be within those operating parameters.

Practical, suitable components used all except;

Capacitor 25V, 2200µf

R9 = 200KΩ. It's because the smaller values tested burnt.

Q3 = BD139

Rechargeable battery sized 8.4V at 240mAh (standard charge 14-16hrs at 25mA and quick charge for 5hrs at 75mA.

Delay circuit

The circuit below shows AC from V1 is step-down by T1, rectified by D1, D2, D3 and D4 to DC power, smoothened by capacitor C1 to through VR1, R1 and resistor R2 making a voltage divider biasing C2 which delays to charge and power the switching transistors Q1 and Q2 connected in such a way to increase current gain which drives the relay RL1 to power and control the AC Load BL1. Additionally, the circuit has LED D6 for showing the state of the circuit.

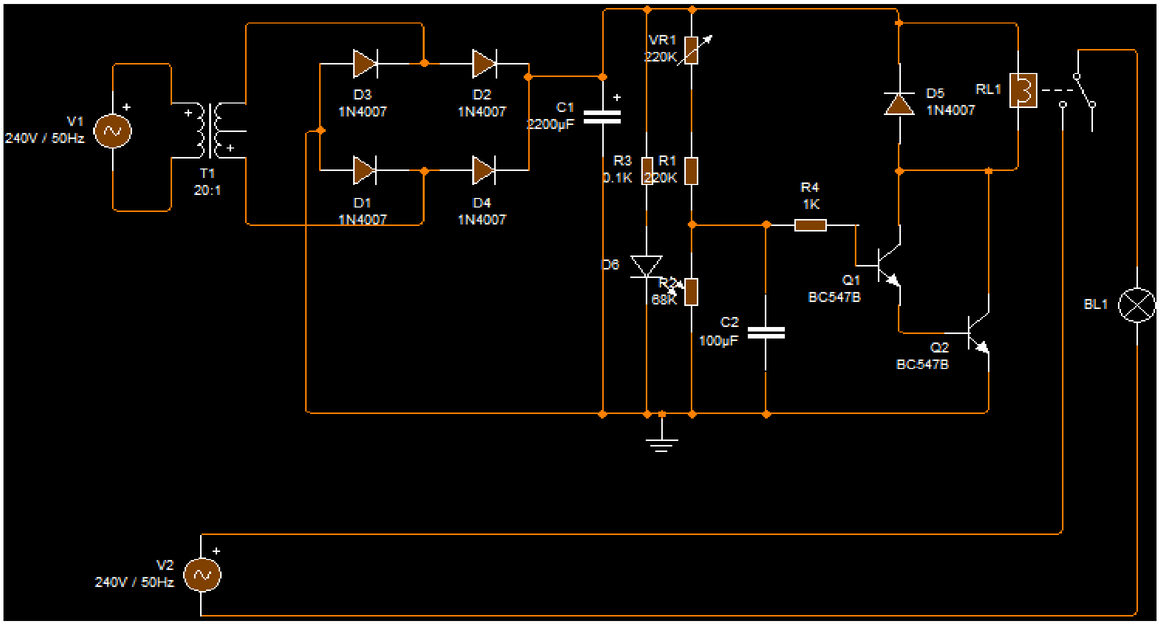


Figure 4: shows delay circuit

V1 = 240VAC.
T1= 240VAC at 13A to 12 VAC at 1 A.
f=100Hz, T = 1/100 = 10ms.
V= Vrms*√2, 12*√2 = 16.968V.
1.4V droped on diodes (use 1N4007, have high PIV = 1000V datasheet) when forward biased.
So 16.968V-1.4V = 15.568V. V = 15.568-9.568 = 6V.
C = I*T/ΔV; C = 1*10ms/6V = 1666.7µf.
using a relay of 6V (nominal voltage VDC 6V, pick up voltage VDC max 4.2, drop out voltage VDC 0.6, Nominal current 60mA, nominal operating power 360mw, coil resistance 100Ω).
Using switching transistor (BC547) Q1 and Q2 to increase the current gain. This Darlington configuration use specifications of the datasheet where IC = 1Adc, VCE = 4.0Vdc, Ib = 16mA, hfe = 500min and 15000max).
1.4 Drops across the two transistors.
R4 = (Vin Q1-1.4)/Iin*Q1hfe.
R4 = (4-1.4)/0.016*22.5, R4 = 7.2Ω.
Iin= IRL1+Iin potential divider.
Iin potential divider =0.5A. Iin C2 = Ib = 16mA.
Required 1.4V to set Configuration in saturation, then taking it as the same voltage for biasing capacitor. Therefore, relay takes 0.5A.
Charging resistor VR1 = 15.568-1.4/0.5, R1 = 28.336Ω.
Discharging resistor R2 = 14.168-0/0.5= 28.336Ω.
C2 = 1*T/V, C = 16mA*10ms/1.4 = 114.3µf.
When VR1 increases resistance, C2 takes long to charge and bias configuration thus providing the delay. The more the capacitance value of C2 the longer it takes to charge.
Practical suitable component values used.
VR1 +(R1+R2) = 100KΩ+4.7KΩ.
R2 = 4.7KΩ.
C2 = 25V 200µf
R4 = 1KΩ.
Q1 &Q2 = BC 547.
BL1 = 240VAC, 0.09A

Designed circuit of the automatic high-performance voltage stabilizer.

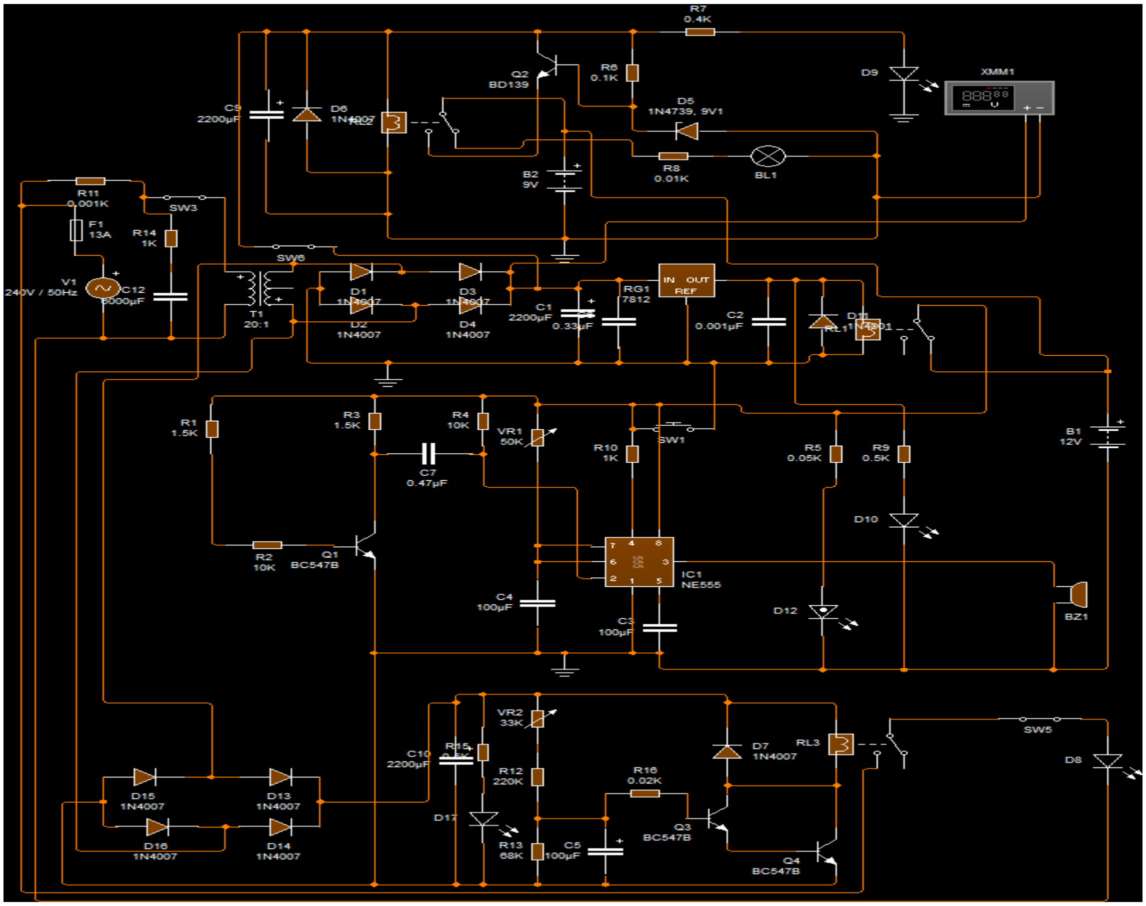
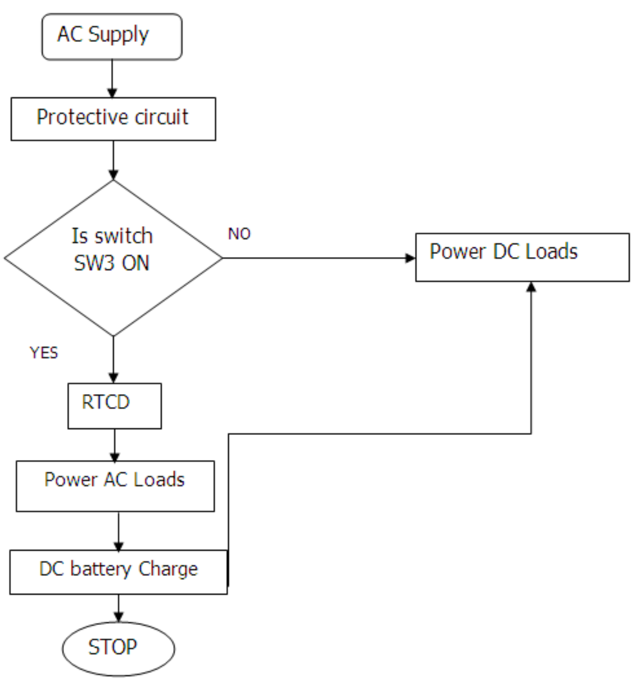


Figure 5: shows the complete designed circuit of the voltage stabilizer.

Flow diagram of the automatic high-performance voltage stabilizer.



AC is supplied from a source, through protection circuit to activate Real-time control device. Now if SW3 is ON, AC loads are power and batteries charge or else power DC loads from batteries.

3. TESTING AND RESULT

The design has five circuits integrated together to form the system. During testing different components were used, design tested to determine the accurate value and any variation in the output.
The testing involved use of multi-meter and comparison made with the simulated design to obtain variations and suitable components. From the calculated values of the design, a table and graph were obtained, and conclusions reached as below.
Different resistor values were plotted against capacitor charging time and results tabulated in mat lab after which a graph was drawn and system response for the delay circuit determined as shown in figure 6. The first row is resistor values in ohms while a second row is time values in seconds as simplified below. These are practical values used, however, the time values were 1.0, 6.3 and 12.4s. Mat lab was not tabulating the required table when using values with points thus were removed, and stable values used.

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Table 1: Mat lab tabulated results of resistor values with capacitor charging time.

Resistor values (Ω)	Capacitor charging time (seconds)
4700	1
54700	6
104700	12

Three circuits involved used relays of different ratings. According to design, 240VAC 13A at 50Hz supplied was stepped down to 12VAC 1A, rectified, smoothed and regulated and circuit proceeded to finish. During testing, all relays (5V, 6V, 9V) used gave positive results because relay ratings were within operating range.
Rectification diodes used were 1N4007 because have high PIV as in the data chart, but even 1N4006 were used and output was the same.

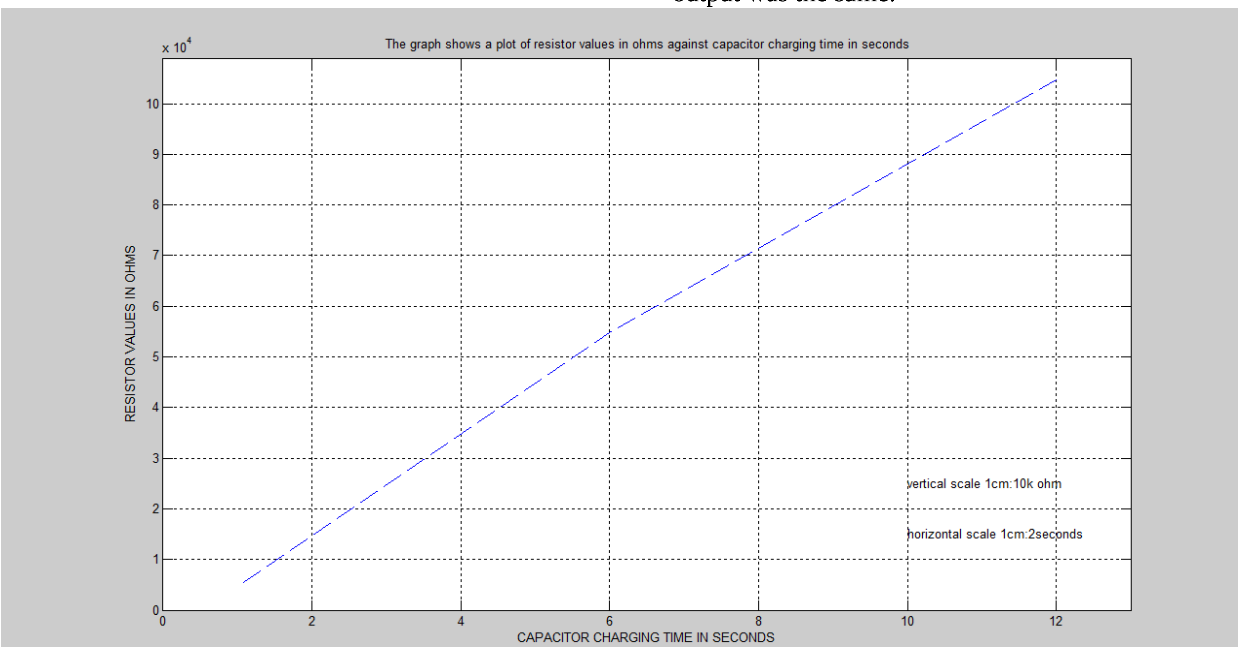

Figure 6: The graph shows a plot of resistor values against capacitor charging time in seconds.

From the graph, resistor values were proportional to capacitor charging time implying that the larger the resistor values, the more the capacitor charging period.
Operating capacitor voltages used for testing were 25V, 16V and 10V. The best choice was only 25V at (1000-2200) µf in smoothening application because 16V and 10V capacitors blew due to high voltage peaks.
240VAC 13A 50Hz - 12V-0-12V 1A transformer was used and tested giving different values like (10.4-13.1) VAC. This was due to varying AC voltage supplied and stepped down.
The system design shall be capable of operation at an input frequency range of-+0.5 of nominal 50Hz and 60Hz, without cleaning protective devices or causing component failure within the stabilizer.
Percentage voltage unbalance defined by IEEE/ANSI as 100times the deviation of the line voltage from the average over by the average voltage. The standard measured voltages are 220V, 230V, and 240V, the average is 230V, and the deviation is 10%
The % unbalance is given by (10V*100/230V) = 4.3%. The 1% voltage unbalance increases the motor losses by 5% thus the designed device reduces it to 2%.

4. CONCLUSION

There has been an increasing trend of power problems due to power transients, yet loads need a quality supply of power. The power needs to be stabilized before supplied to the loads.
To overcome the above problem automatic high-performance voltage stabilizer was designed using circuit wizard and mat lab soft-wares, the principle of operation understood and integrated on Printed Circuit Board.
In a nutshell, the design can be practically implemented in future based on the design achieved and is a user-friendly system; it can easily be operated. With few modifications, like integrating it with an inverter can give instant AC power supply.

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