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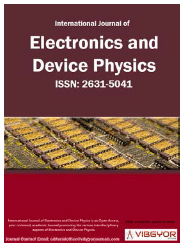

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Design and Investigation the Characteristics of the Components of a DC Regulated Power Supply Using Multisim 14.2 Simulator

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Abstract

In an ordinary (unregulated) power supply the voltage regulation is poor (i.e. the DC output voltage also changes due to variations in the input AC voltage). These variations in DC voltage may cause unreliable operation of electronic circuits; Therefore, regulated DC power supply is the only solution in such situations. In this paper, the V-I characteristics of a PN junction diode in both forward and reverse directions was investigated using Multisim 14.2, simulator and graphically discusses, the V-I characteristics of a Zener diode in both forward and reverse bias conditions and used it as voltage regulator was determined and discusses graphically, the effect of load resistance and filter capacitor on ripple factor of half wave was determined and discusses graphically, the effect of load resistance and filter capacitor on ripple factor full wave rectifiers was also determined and discusses graphically, finally a complete circuit of 8V DC regulated power supply with constant output voltage `irrespective of load variations was design using Zener diode as voltage regulator and simulated.

Keywords

DC Power, Investigation, Multisim 14.2 simulator, Regulation

Introduction

Design is to create, fashion, execute or construct according to plan [1]. Simulation is the process of using computer based modeling of a system to understand its behavior and predict the effect of changes [2]. Simulation represents a powerful method for analyzing, designing, operating complex systems and allows the designer to determine the correctness and efficiency of a design before the system is actually constructed [3]. Design and simulation helps manufacturers to verify and validate the intended function of a product under development, as well as the manufacturability of the product [4]. It provides an important method of analysis which is easily verified, communicated, and understood [5]. Across industries and disciplines, simulation modeling provides valuable solutions by giving clear insights into complex systems. The underlying purpose of simulation is to shed light on the underlying mechanisms that control the behavior

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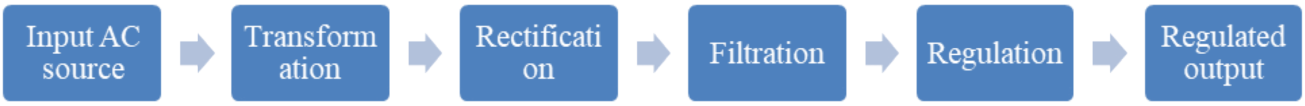

Figure 1: Block diagram of regulated DC power supply.

of a system. More practically, simulation can be used to predict (forecast) the future behavior of a system, determine what can influence that future behavior. A power supply is an electrical device that supplies electric power to an electrical load. There are two types of power supplies, AC and DC power supply, DC power supply which maintains the output voltage constant irrespective of AC mains fluctuations or load variations is known as regulated DC power supply and DC power supply in which output voltage changes due to variation in the input AC voltage is knows as an ordinary or unregulated DC power supply, an unregulated DC power supply is unreliable to the operation of electronic circuits therefore need to be regulated. Many authors have carried out different researches on investigation the characteristics of different electrical components using different simulators softwares some of they are: Bonkoungou, *et al*. [6] carried out research on Modelling and Simulation of photovoltaic module considering single diode equivalent circuit model in MATLAB, [7] carried out a research on new mixed mode full-wave rectifier realization with current differencing transconductance amplifier using LTSPICE simulations with 0.18 µm CMOS model obtained through TMSC are included to verify the workability of the proposed circuit and Jang, *et al*. [8] carried out research on investigated a tunneling field effect transistors (TFETs) model for simulation program with integrated circuit emphasis (SPICE) simulation that can identify ambipolar characteristics using a Berkeley short channel IGFET model 3 (BSIM3) model. However some have difficulties for beginners, in that case Proteus or Multisim can be used. Multisim software combines SPICE simulation and circuit design into an environment optimized to simplify common design tasks, which helps to improve performance, minimize errors, and shorten time to prototype. The paper is mainly aimed at the design of 8V regulated DC power supply; this involves the study of the behaviors and characteristics of the component of regulated DC power supply using Zener as voltage regulator with Multisim 14.2 simulator.

Methodology

Design and simulation

Design: The DC regulated power supply under goes the following process represented in form of block diagram as shown Figure 1 [9].

Input AC source: An electrical supply or simply, “a source” is a device that supplies electrical power to a circuit in the form of a voltage source or a current source. AC stands for 'alternating current' which means the current constantly changes direction. The sources of power may come from the electric power grid, such as an electrical outlet, energy storage devices such as batteries or fuel cells, generators or alternators, solar power converters, or another power sources [10]. Universal power source input range is within AC 85~264 Volt and capable of operating at 50 and 60 Hz [11]. This AC is needed to be either step down or step up for equipments uses the process of stepping it down or up is called transformation.

Transformation

A transformer is a device for changing the voltage (step-down or step-up) of an AC supply with a transformation ratio expressed as

$$\frac{\mathrm{Secondary}\ e.m.f}{\mathrm{Primary}\ e.m,f} = \frac{Number\ of\ turns\ in\ the\ \mathrm{Secondary}\ coil}{Number\ of\ turns\ in\ the\ primary\ coil}$$

In symbols, $$\frac{E_s}{E_p} = \frac{N_s}{N_P} \qquad (1)$$

If $N_P > N_s$ so that $E_s < E_p$, then the transformer is a step-down transformer,

If $N_P < N_s$ so that $E_s > E_p$, then the transformer is a step-up transformer.

To design a step-down transformer in which 240V is applied at the primary coil, at 50 Hz and 12V available at the secondary coil, the ratio of the secondary turns to the primary turns is

$$\frac{E_s}{E_p} = \frac{N_s}{N_P},\ \frac{12}{240} = \frac{N_s}{N_P} = \frac{1}{20}$$

∴ Ratio of the secondary turns to the primary turns is 20:1

Digital devices require constant voltages, thus to get those constant voltage levels (DC levels) there is need to convert AC into DC using Rectifiers.

Rectification

Rectification is the process of converting alternating current (AC) which reverses its direction periodically to direct current (DC) which flows only in one direction. There are four common types of rectification: Half-wave rectification, Full-wave rectification, Full wave bridge rectification and Voltage multipliers rectification (Mehta &Mehta, 2008). A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC). The three basic types of rectifiers are half-wave rectifier, full-wave center-tapped rectifier and full-wave bridge rectifier [9]. The ratio of DC power output to the applied input AC power is known as rectifier efficiency is given by

$$\mathrm{Re}\,ctifier\ effiency, \eta = \frac{DC\ power\ output}{Input\ AC\ power}$$

For a half-wave rectified is given as

$$\mathrm{Re}\,ctifier\ effiency\ = \frac{\left(I_m/\pi\right)^2 \times R_L}{\left(I_m/2\right)^2\left(r_f + R_L\right)} \tag{2}$$

The efficiency will be maximum if *rf* is negligible as compared to *RL*. Max. Rectifier efficiency = 40.6%.

This shows that in half-wave rectification, a maximum of 40.6% of AC power is converted into DC power. Full-wave rectification efficiency is given by

$$\eta = \frac{\left(2I_m/\pi\right)^2 \times R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2\left(r_f + R_L\right)} \tag{3}$$

The efficiency will be maximum if *rf* is negligible as compared to *RL*. Maximum efficiency = 81.2%.

This is double the efficiency due to half-wave rectifier. Therefore, a full-wave rectifier is twice as effective as a half-wave rectifier [9]. It follows, that a pulsating output of a rectifier contains a DC component and an AC component also known as ripple.

Ripple factor: The ratio of r.m.s value of AC component to the DC component in the rectifier output is known as ripple factor is given by

$$Ripple\ factor = \frac{r.m.s.value\ of\ AC\ component}{value\ of\ DC\ component} = \frac{I_{ac}}{I_{dc}}$$

$$\therefore\ Ripple\ factor\ = \frac{I}{I_{dc}}\sqrt{I_{rms}^2 - I_{dc}^2} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

In half-wave rectification,

$$Ripple\ factor\ = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = 1.21 \tag{4}$$

It is clear that AC component exceeds the DC component in the output of a half-wave rectifier; therefore, half wave rectifier is ineffective for conversion of AC into DC.

In full-wave rectification,

$$Ripple\ factor = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} = 0.48 \quad (5)$$

This shows that in the output of a full wave rectifier, the DC component is more than the AC component. Consequently, the pulsations in the output will be less than in half-wave rectifier [9]. For this reason, full-wave rectification is invariably used for conversion of AC into DC. However, the AC component is undesirable and must be kept away from the load, to do so, a filter circuit is used.

Filtration

The process of removing the AC component and allows only the DC component to reach the load is known as filtration and device which can do this work is called filter circuit. The most commonly used filter circuits are capacitor filter, choke input filter and capacitor input filter or π-filter [9]. It can be proved that output DC voltage from the filter circuit is given by:

For full-wave rectification,

$$V_{dc} = V_{p(in)}\left(1 - \frac{1}{4f_{in}R_L c}\right) \quad (6)$$

Here $V_{p(in)}$ = Peak rectified full wave voltage applied to the filter.

f_{in} = Output frequency from for full-wave rectification into filter circuit [9], this DC voltage is unregulated and is needed to be regulated.

Regulation

Voltage regulation is a measure of change in the voltage magnitude between the sending and receiving end of a component. It is commonly used in power engineering to describe the percentage voltage difference between no load and full load voltages distribution lines, transmission lines, and transformers.

Load regulation it indicates how much the load voltage varies when the load current changes. Quantitatively, it is defined as:

$$Load\ regulation = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%. \quad (7)$$

Where, V_{NL} = load voltage with no load current V_{FL} = load voltage with full load current [9]. The smaller the regulation, the better is the power supply. Line regulation it indicates the change in output voltage due to the change in input voltage. Quantitatively, it is defined as:

$$Line\ regulation = \frac{V_{HL} - V_{LL}}{V_{LL}} \times 100\%. \quad (8)$$

Where, V_{HL} = load voltage with high input line voltage, and V_{LL} = load voltage with low input line voltage, the smaller the regulation the better is the power supply [9].

Regulated output

A DC power supply which maintains the output voltage constant irrespective of AC mains fluctuations or load variations is known as regulated DC power supply [9]. A voltage regulator generates a fixed output voltage of a preset magnitude that remains constant regardless of changes to its input voltage or load conditions. Basically, there are two types of Voltage regulators: Linear voltage regulator and switching voltage regulator. There are two types of linear voltage regulators: Series and Shunt. There are three types of switching voltage regulators: Step up, Step down, and Inverter voltage regulators [9]. The complete circuit of a regulated power supply using Zener diode as a voltage regulating device is a combination of three circuits, (i) Bridge rectifier or Center tapped rectifier (ii) A capacitor filter and (iii) Zener voltage regulator as shown in Figure 2.

Simulation

In order to find the properties of the components of complete circuit of a regulated DC power supply the following investigation were carried out:

I. Investigations of V-I characteristics of a PN junction diode in both forward and reverse directions.

II. Determination the V-I characteristics of a Zener diode in both forward and reverse bias conditions.

III. Zener diode as voltage regulator.

IV. Effect of load resistance and filter capacitor on ripple factor of half wave rectifier.

V. Effect of load resistance and filter capacitor on ripple factor of full wave rectifier.

VI. Complete design of DC regulated power supply.

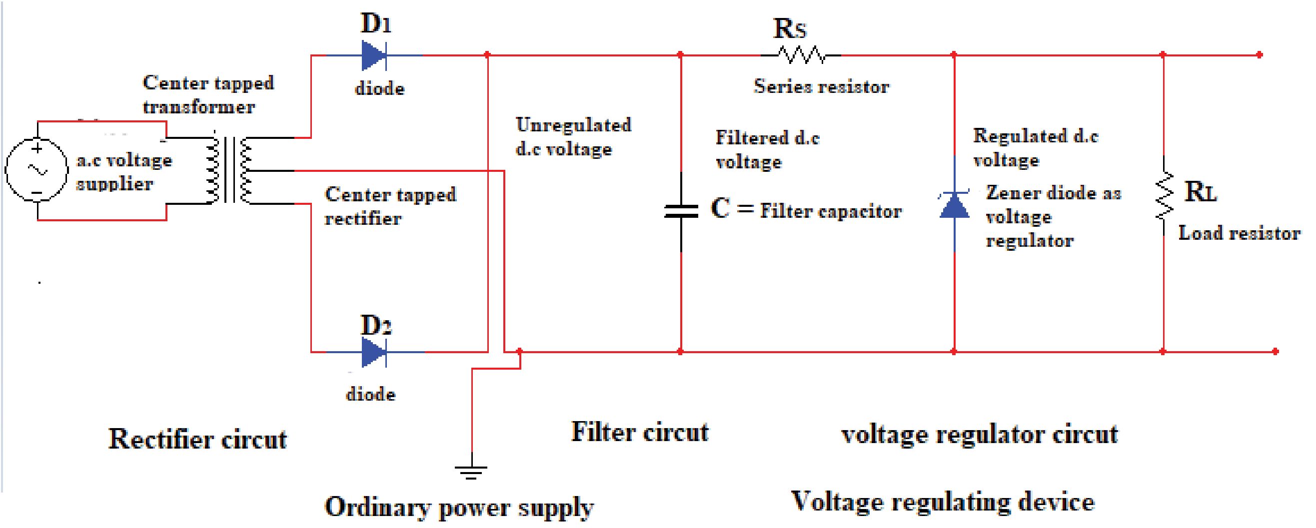

Figure 2: Complete circuit of a regulated DC power supply.

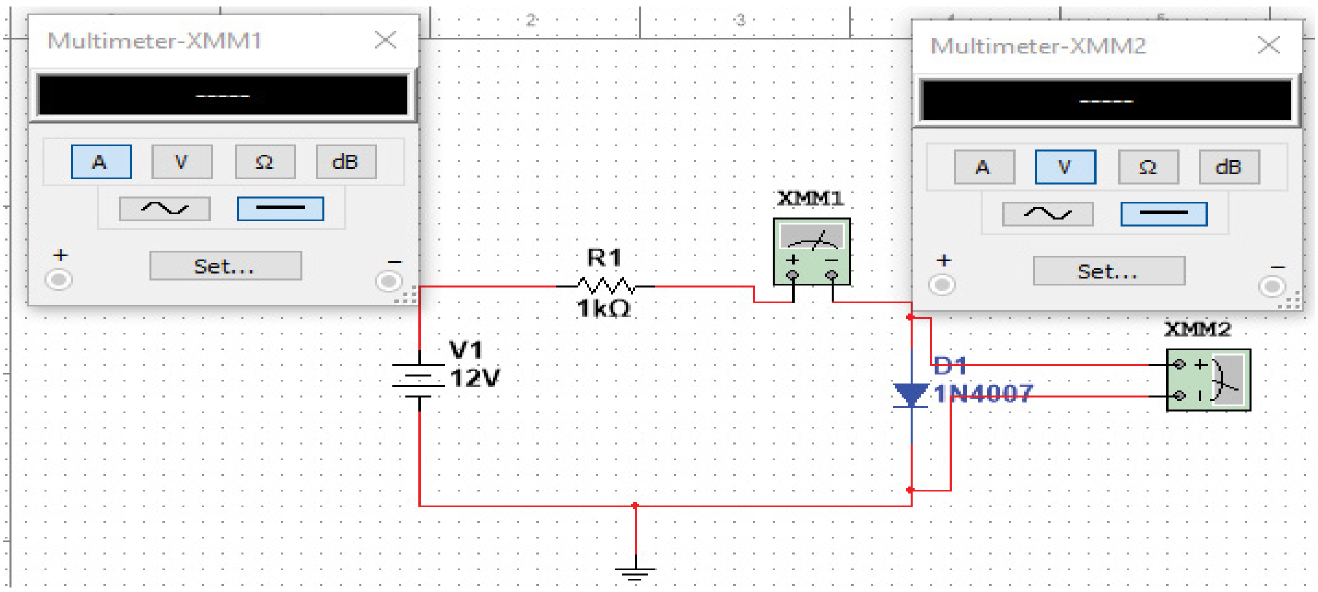

Figure 3a: Shown the simulation circuit diagram of PN junction diode connected in forward direction.

Investigations of V-I characteristics of a PN junction diode in both forward and reverse direction

Both the forward voltage, current and reverse bias voltage, current were measured based on the applied input voltage, the proposed simulation circuit diagram of a PN junction diode in both forward and reverse direction are shown in Figure 3a and Figure 3b.

Determination the V-I characteristics of a Zener diode in both forward and reverse bias conditions

Both the forward voltage, current and reverse bias voltage, current were measured based on the applied input voltage, the proposed simulation circuit diagram of a Zener diode in both forward and reverse direction are shown in Figure 4a and Figure 4b.

Zener diode as voltage regulator

The regulation and percentage regulation of a Zener diode at constant load resistance $R_L = 15k$ vary input voltage and at input voltage $V_{in} = 15V$ vary load resistances were determined, the proposed simulation circuit diagram shown in Figure 5.

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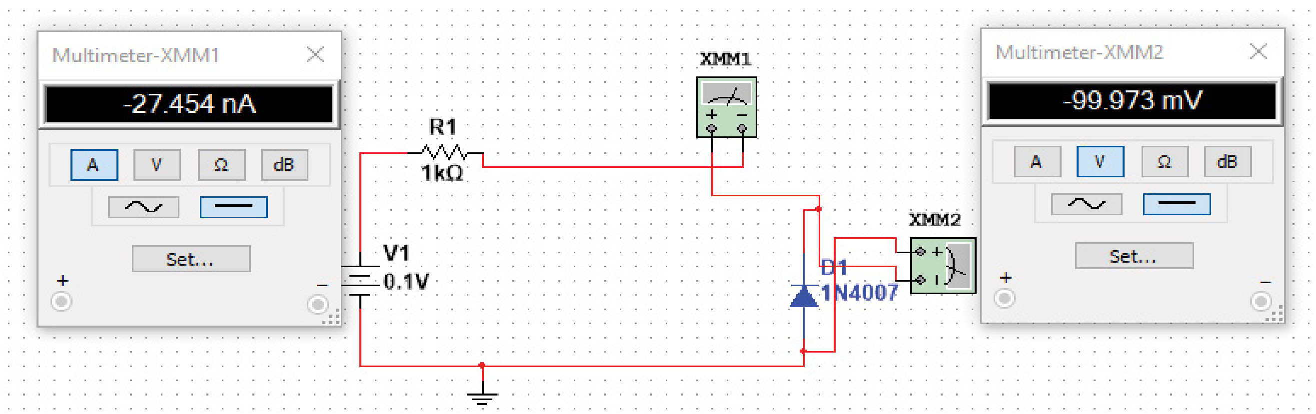

Figure 3b: Shown the simulation circuit diagram of PN junction diode connected in reverse direction.

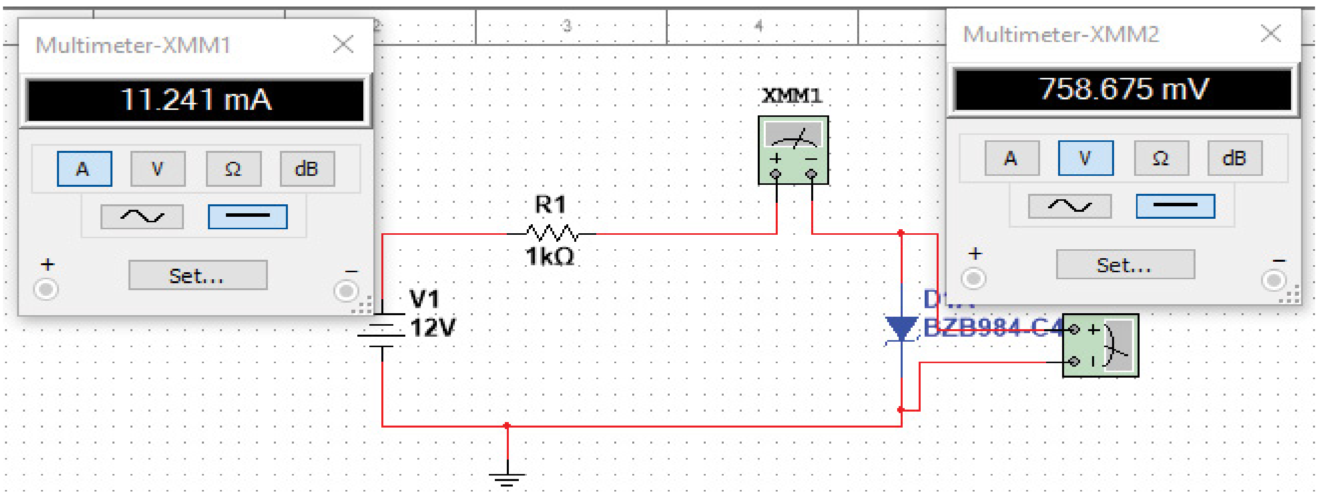

Figure 4a: Shown the circuit diagram of Zener diode connected in forward bias condition.

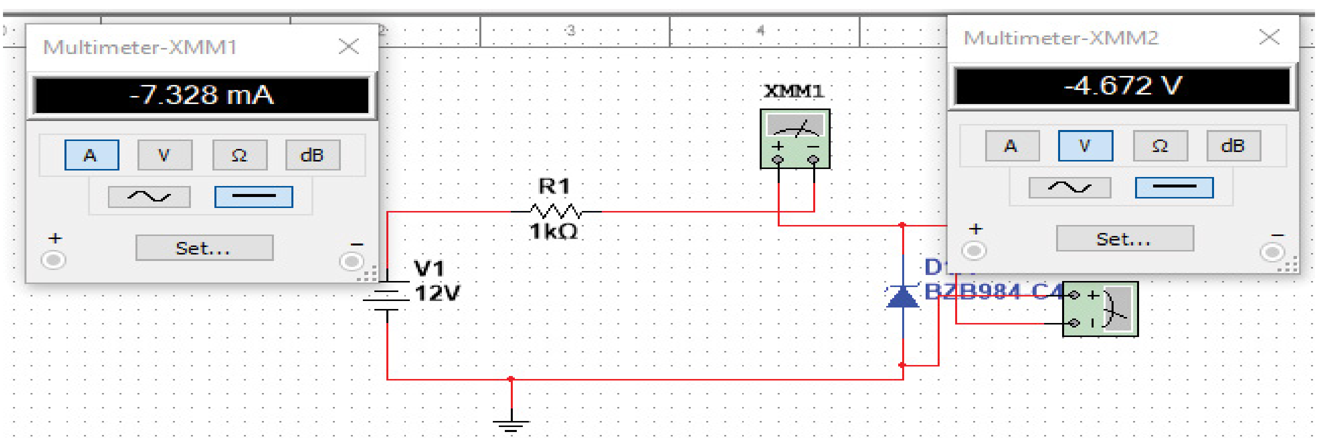

Figure 4b: Shown the circuit diagram of Zener diode connected in reverse bias condition.

Effect of load resistance and filter capacitor on ripple factor of half wave rectifier

The effect of load resistance on ripple factor with and without filter of half wave rectifier, at constant AC voltage of 240 V_{rms} at frequency of 50 Hz from the AC power source and 12V input voltage peak (V_m) from the stepped down transformer was determined, the proposed simulation circuit diagram is shown in Figure 6.

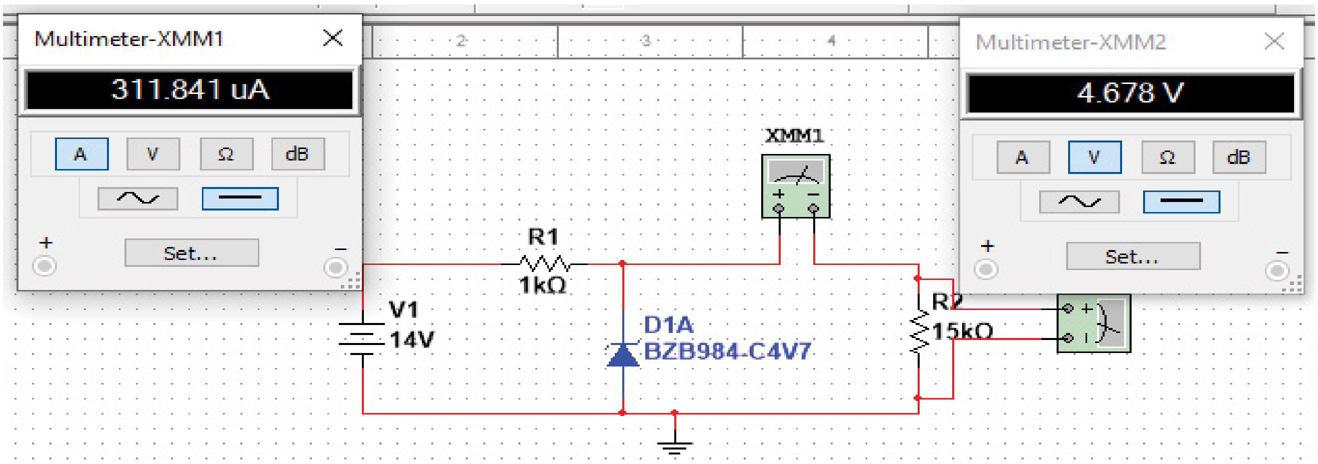

Figure 5: Shown the circuit diagram of Zener diode as voltage regulator at constant load resistance R_L = 15k vary input voltage.

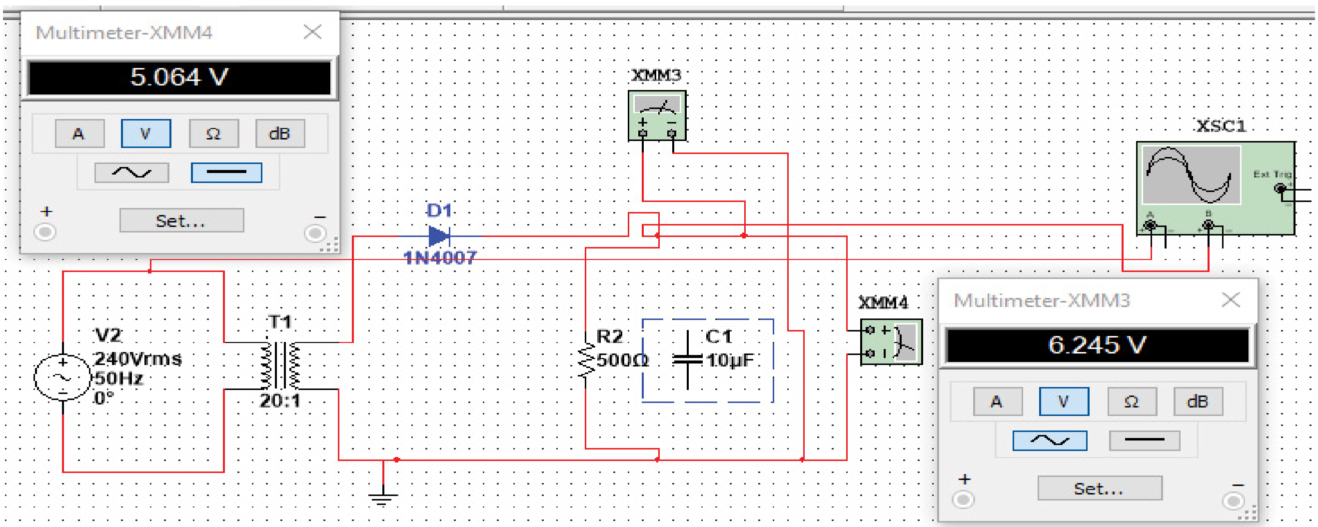

Figure 6: Shown simulation circuit diagram of half wave rectifier without capacitor connected.

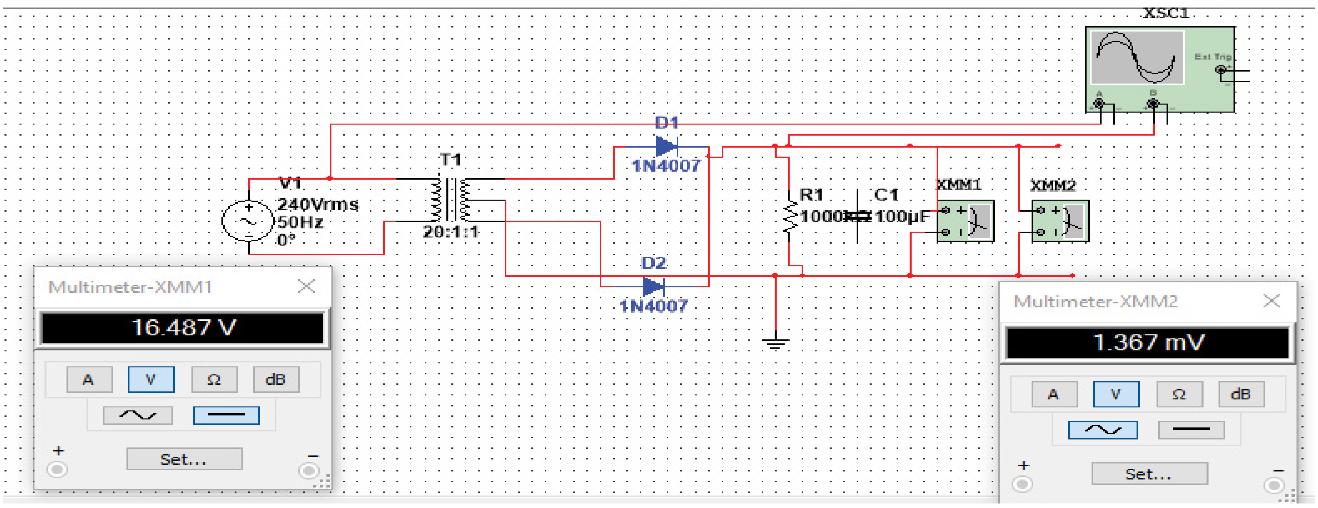

Figure 7: Shown simulated circuit diagram of full wave rectifier without capacitor connected.

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Effect of load resistance and filter capacitor on ripple factor of full wave rectifier

The effect of load resistance on ripple factor with and without filter of full wave rectifier at constant AC voltage of 240 V_{rms} frequency of 50 Hz from the AC power source and 12V input voltage peak (V_m) from the stepped down transformer was determined, the proposed simulation circuit diagram is shown in Figure 7.

Complete design of DC regulated power supply

The proposed simulation circuit diagram of 8V regulated DC power supplying with 240V and 50Hz applied to step-down center tapped transformer with turns ration of secondary coil to primary coil, 20:1 in which 12V (V_m) is the peak voltage value available at the secondary coil, for full wave center tapped rectifier was determined as shown in Figure 8.

Results and Discussions

Results and discussion of the results of simulated PN junction diode in both forward and reverse directions in order to determined it is V-I characteristics

Vary the supply voltage from DC power source in steps the corresponding values of forward voltages and forward currents was noted down and the V-I characteristics of PN junction diode in forward direction was determined graphically as shown in Figure 9a.

Looking at the first data point from the right to the left of horizontal axis of the graph of Figure 9a, it indicate that increases in forward voltage lead to the increases in forward current due to the reducing in potential barrier of the diode across the junction and from 0.622647V the diode is

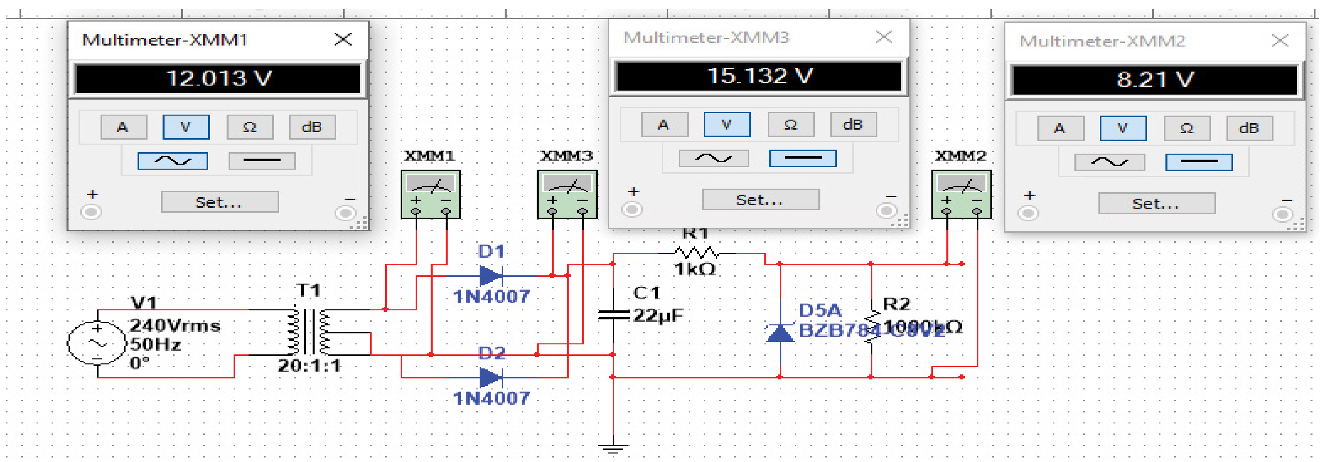

Figure 8: Shown the complete circuit diagram of DC power supplier with filter capacitor connected.

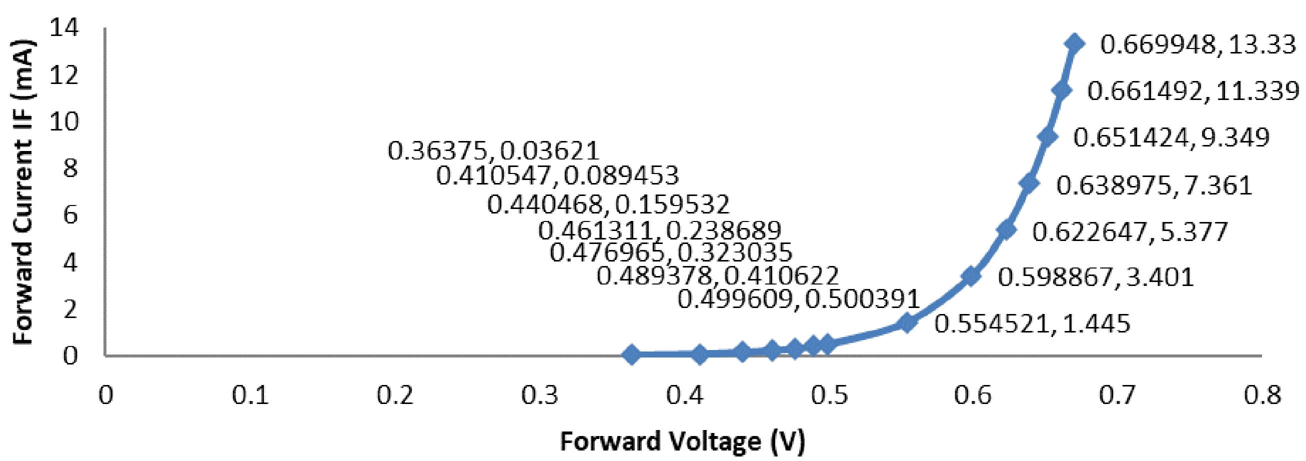

Figure 9a: Shown the graph of forward current against forward voltage.

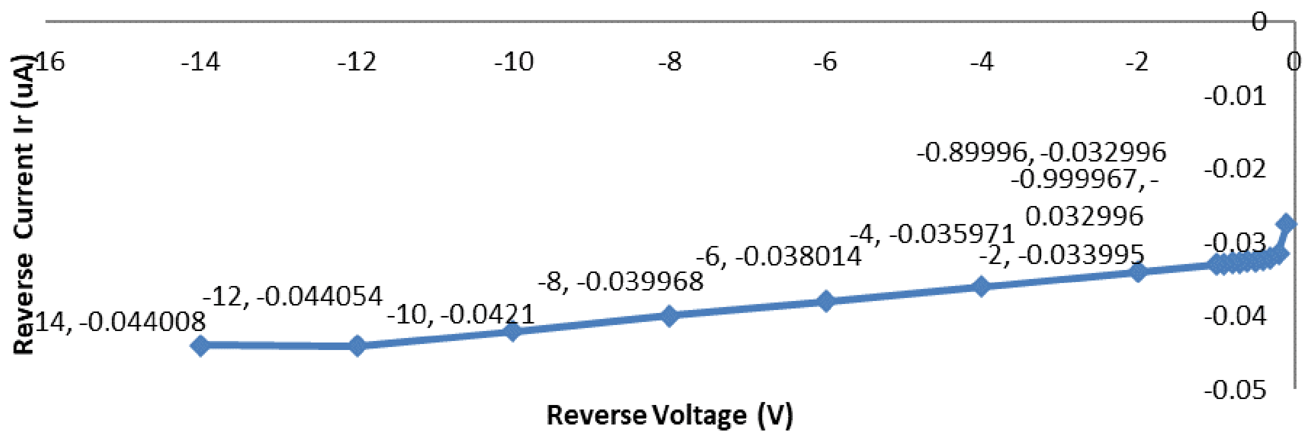

Figure 9b: Shown the graph of reverse bias current against reverse bias voltage.

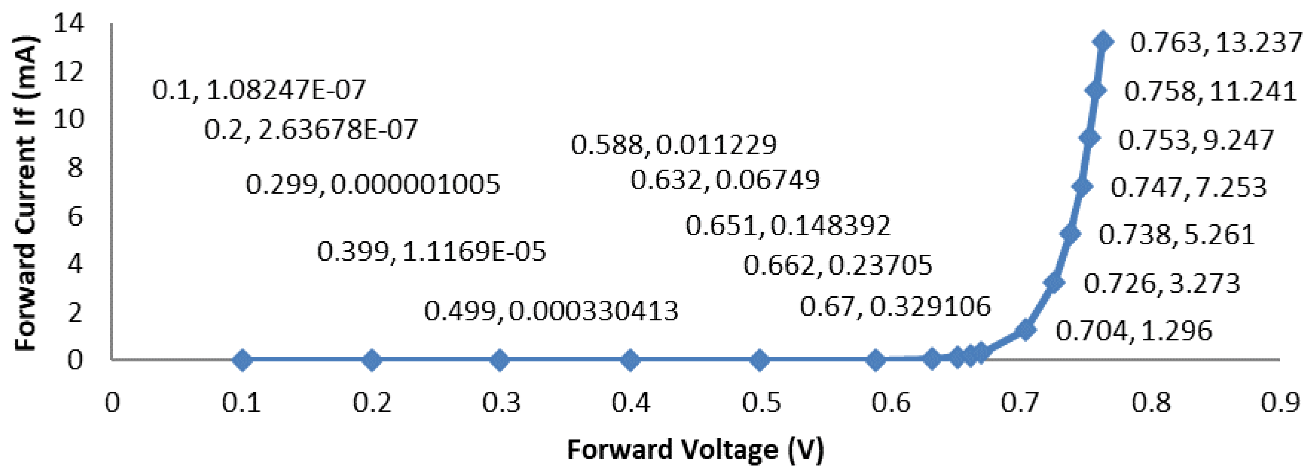

Figure 10a: Shown the graph of forward bias current against forward bias voltage of Zener diode.

regulating, said to be in ON state, this indicated a silicon diode, however at 0.669V the potential barrier overall eliminated as a result of that larger current starts flowing through the diode this shows the characteristics of PN junction diode connected in forward bias for its operation also a graphical V-I characteristics of the diode in the forward biased condition are curve between voltage across the diode, current through the diode and in the circuit. A PN junction diode can also be connected in reverse bias in order to investigate its characteristics.

Vary the supply voltage from DC power source in steps the corresponding values of reverse bias voltages and reverse currents was noted down and the V-I characteristics of PN junction diode in reverse direction was determined graphically as shown in Figure 9b.

Looking at the first data point from the left to right of horizontal axis of the graph it indicate that increases in reverse voltage causes very small current to flows in the circuit with high voltage due to increases in potential barrier across the junction, also the reverse bias current is as a result of minority charge carriers, this shows that PN junction diode is not design to operate in reverse bias condition.

Results and discussion of the results of simulated a Zener diode in both forward and reverse directions in order to determined it is V-I characteristics

Vary the supply voltage in steps the corresponding values of forward voltages and forward currents were noted down through ammeter and the V-I characteristics of Zener diode in forward direction was determined graphically as shown in Figure 10a.

Looking at the first data point from the right to the left of the horizontal axis of graph of Figure 10a, it indicate that increases in forward voltage lead to the increases in forward current due to the reducing in potential barrier of the diode across the junction and from 0.704V the diode is regulating, said to be in ON state, this indicated a silicon diode, however at 0.763V the potential barrier overall eliminated as a result of that larger current starts flowing through the diode also a graphical V-I characteristics of the diode in the forward biased condition are curve between voltage across the diode, current through the diode and in the circuit. A Zener diode can also be connected in reverse bias in order to investigate its characteristics.

Vary the supply voltage in steps the corresponding values of reverse bias voltages and reverse bias currents were noted down and the V-I characteristics of Zener diode in reverse bias direction was determined graphically as shown in Figure 10b.

Looking at the first data point from the right to the left of horizontal axis of the graph it indicated that increases in reverse voltage causes very small current to flows in the circuit with high voltage due to increases in potential barrier across the junction, also the reverse bias current is as a result of minority charge carriers, therefore the diode is said to be in OFF state, but at a particular voltage 4.627V it starts conducting heavily is said to be ON state, this voltage is called break down voltage, a Zener diode specially made to operate in the break down region, a PN junction diode normally does not conduct when reverse biased, for this reasons Zener diode can be connected reverse bias as voltage regulator.

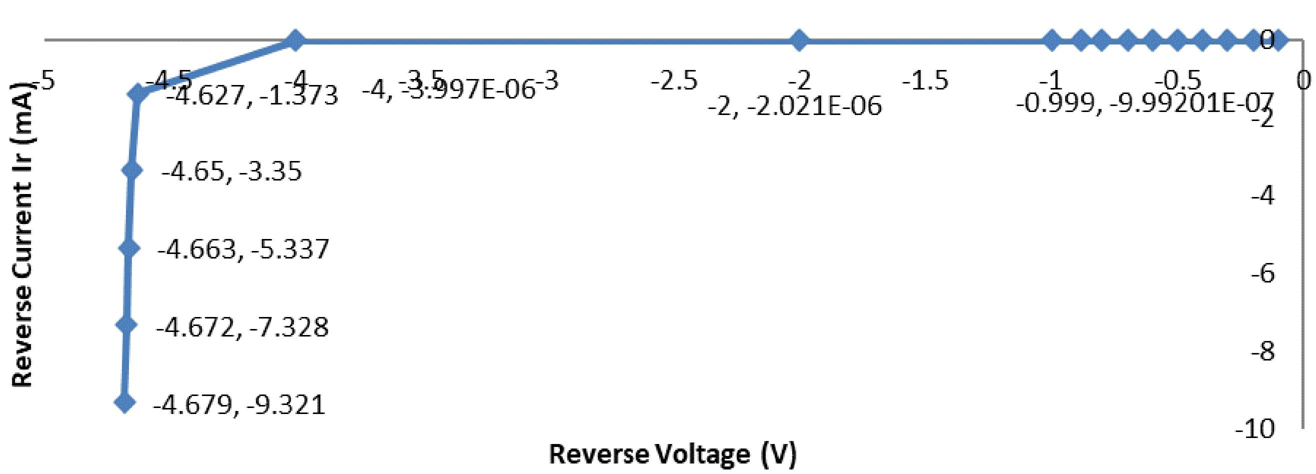

Figure 10b: Shown the graph of reverse bias current against reverse bias voltage of Zener diode.

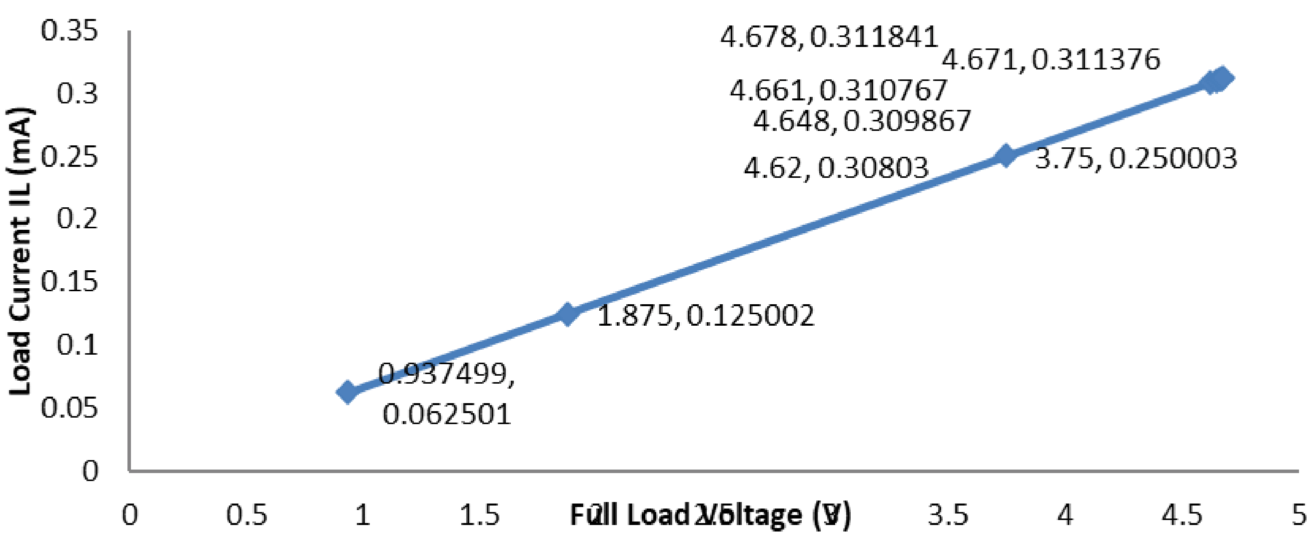

Figure 11a: Shown the graph of load current against full load voltage.

Results and discussion of the results of simulated Zener diode as voltage regulator

At constant load resistance $V_{in} = 15V$ vary the supply input voltage in steps the corresponding values of full load voltages and load currents were noted down and the graph of load current I_L against full load voltage was plotted as shown in Figure 11a.

looking at the first data point from the graph changes in input voltage causes changes in both load current and full load voltage, however at last data points when the diode is ON both load current and full load voltage are regulated, this shown the regulating points of the Zener diode uses as voltage regulator.

Also At constant input voltage $V_{in} = 15V$ vary the load resistance in steps the corresponding values of full load voltages and load currents were noted down and the graph of load resistance R_L against % regulation was plotted as shown in Figure 11b.

Looking at the first horizontal data point from the right of vertical axis of the graph indicated that increases in load resistance causes decreases in percentage regulation but the smaller in percentage regulation, the better power supply, therefore the last point on the horizontal axis has better power supply.

Results and discussion of the results of simulated effect of load resistance and filter capacitor on ripple factor of half wave rectifier

Adjusting the load resistance and noting down the DC and AC voltage reading after passing through a single diode, the ripple factor was calculated and effect of load resistance on ripple factor without filter capacitor was determined graphically as

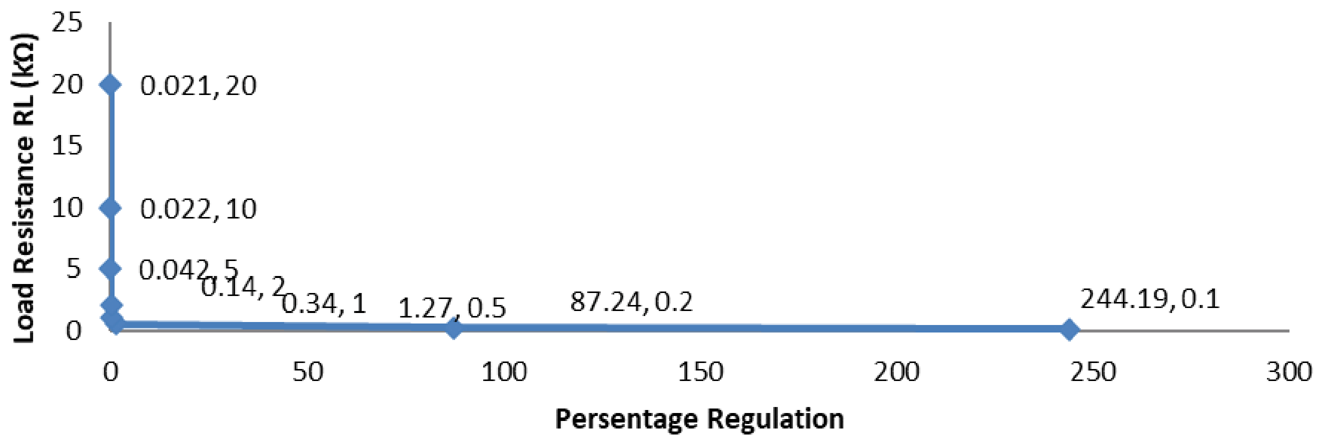

Figure 11b: Shown the graph of load resistance against full percentage regulation.

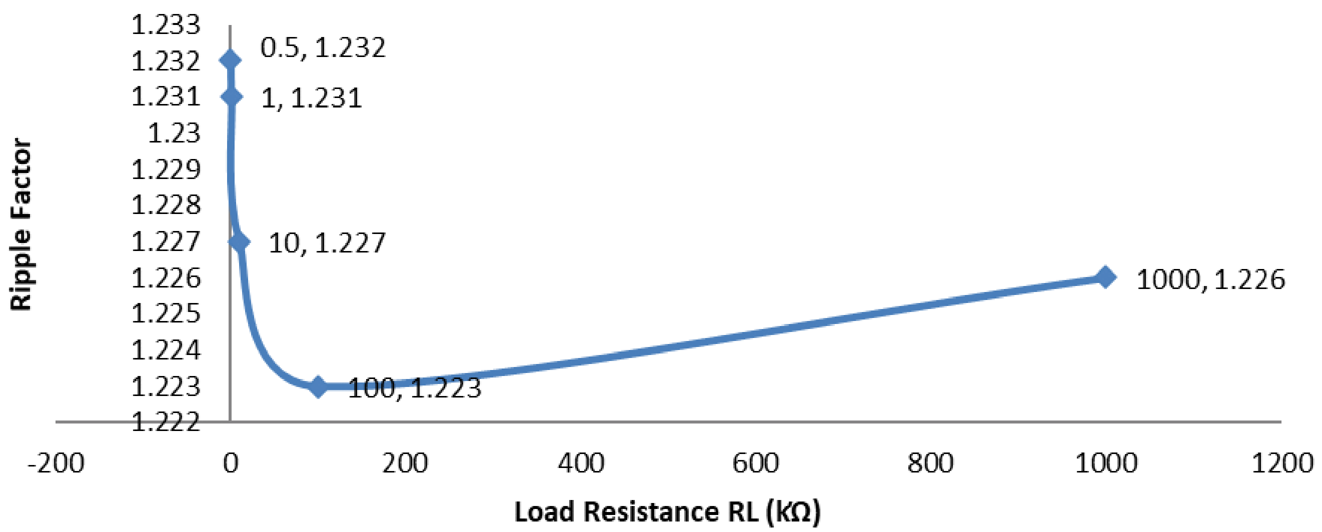

Figure 12a: Shown the graph of ripple factor against load resistance without filter capacitor.

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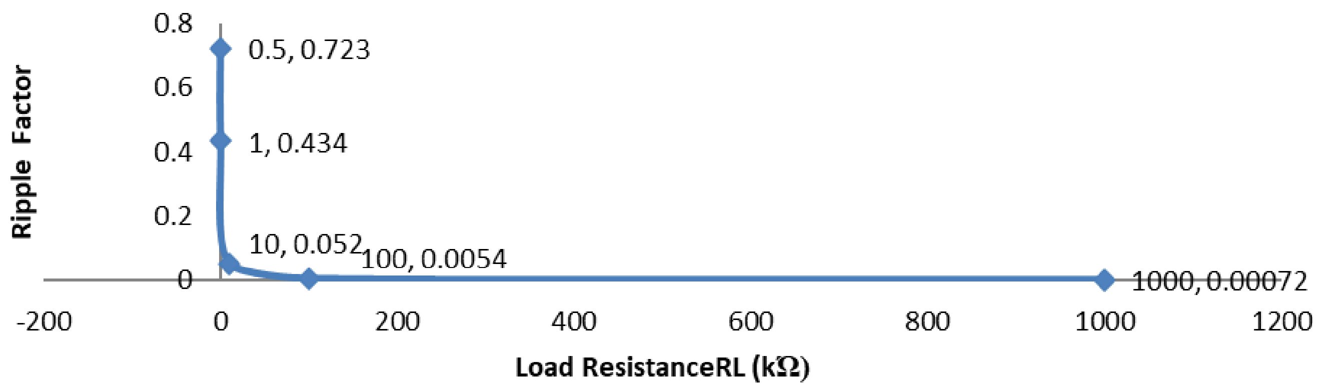

Figure 12b: Shown the graph of ripple factor against load resistance with filter capacitor of half wave rectifier.

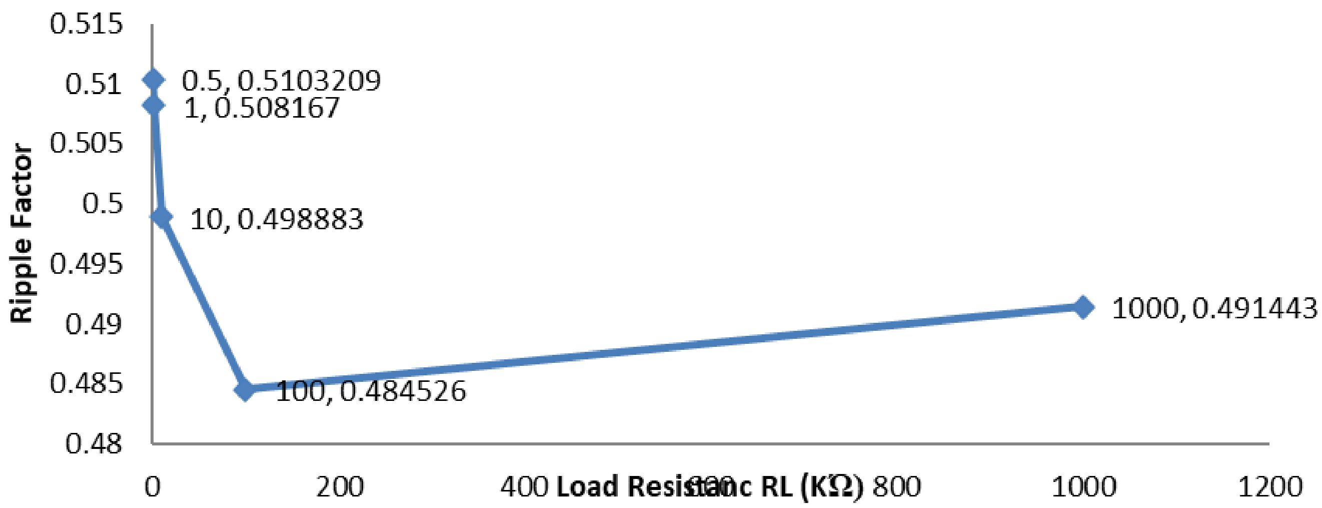

Figure 13: Shown the graph ripple factor against load resistance of full wave rectifier without filter capacitor connected.

shown in Figure 12a.

Looking at first data point from the top of vertical axis of the graph it shows that increases in values of load resistance causes decreasing in ripple factor, therefore load resistance have an effect on ripple factor of half wave rectifier without filter capacitor.

After connecting the filter capacitor of 10 µf in varying the load resistances the reading of DC and AC voltages were noted down and effect of load resistance on ripple factor was determined graphically as shown in Figure 12b.

Looking at the first data point from the top of vertical axis of the graph increases in load resistance causes decreases in ripple factor of half wave rectifier with filter capacitor but smoothing the graph, therefore load resistance have an effect on ripple factor with or without filter capacitor.

Results and discussion of the results of simulated effect of load resistance (R_L) and filter capacitor (c) on ripple factor (r) of full wave rectifier

Adjusting the load resistance the reading of DC and AC voltages were noted down after passing through two diodes which are connected to the center tapped transformer, the ripple factor was calculated and the effect of load resistance on ripple factor of full wave rectifier without filter capacitor was determined graphically as shown in the Figure 13.

Looking at the first data point from the top of vertical axis of the graph it indicated that changes in load resistance causes decreases in ripple factor, therefore load resistance have an effect on ripple factor of full wave rectifier without filter capacitor.

At constant filter capacitor (C = 10 µf) varying

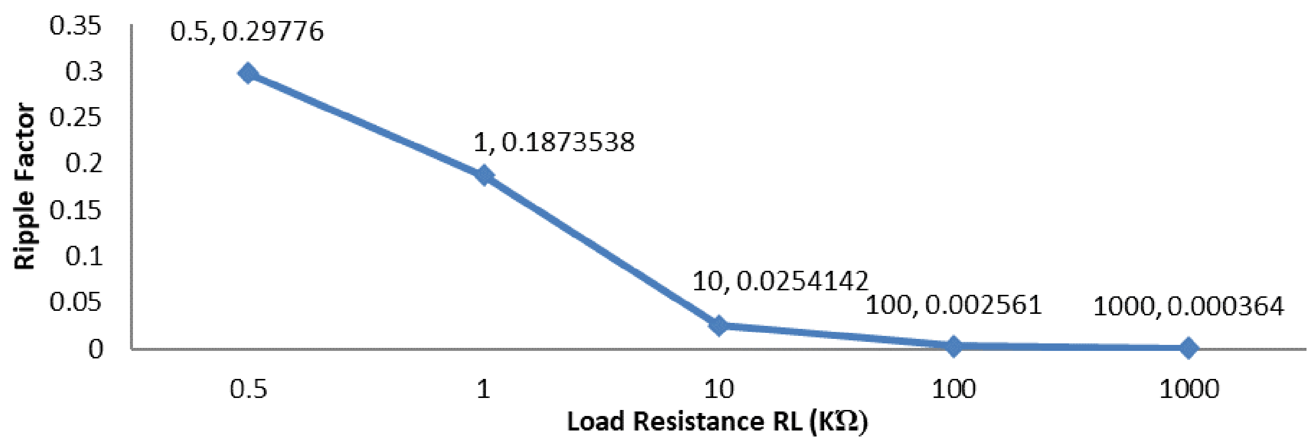

Figure 14: Shown the graph of ripple factor against load resistance of full wave rectifier with 10 µf constant filter capacitor.

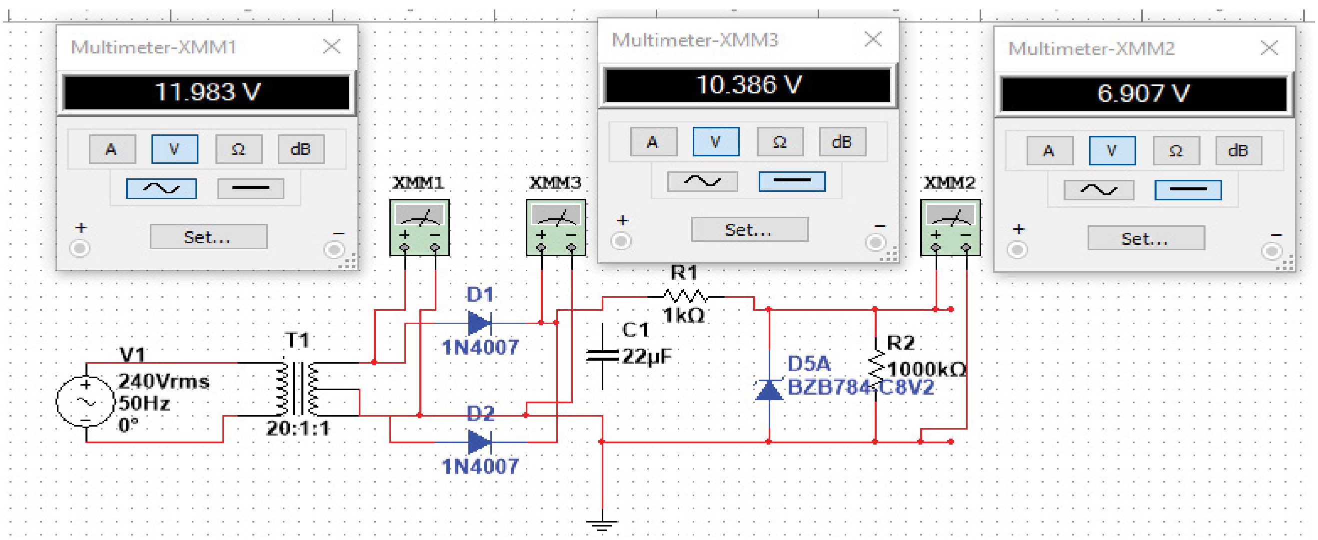

Figure 15a: Shown the complete circuit diagram of DC power supplier without filter capacitor connected.

load resistance **(R_L)** in steps the corresponding values DC and AC voltages were noted down, the ripple factor was calculated and the effect of load resistance on ripple factor of full wave rectifier was determined graphically as shown in Figure 14.

Looking at the first data point from the top of the vertical axis of the graph it shows that increases in load resistance causes decreases in ripple factor but smoothing the graph therefore load resistance have an effect on ripple factor of full wave rectifier with constant filter capacitor.

Results and discussion of the results of simulated Complete design of D.C regulated power supply

With a 240V applied AC voltages at 50 Hz to step down center tapped transformer, turns ration of secondary coil to primary coil 20:1 in which 12V (V_m) was the peak voltage value available at the secondary coil, the rectified output voltages 10.386V was obtained without filter capacitor connected as shown in Figure 15a.

With connected filter capacitor of 22 µf and a Zener diode of 8.2 break down region, the rectified output voltages increases to 15.132V, the output voltages remain constant 8.2V irrespective of load variations as shown in Figure 15b.

Conclusion

From the simulation result of the proposed compantent circuits of DC power supply, the V-I characteristics of a PN junction diode and zener

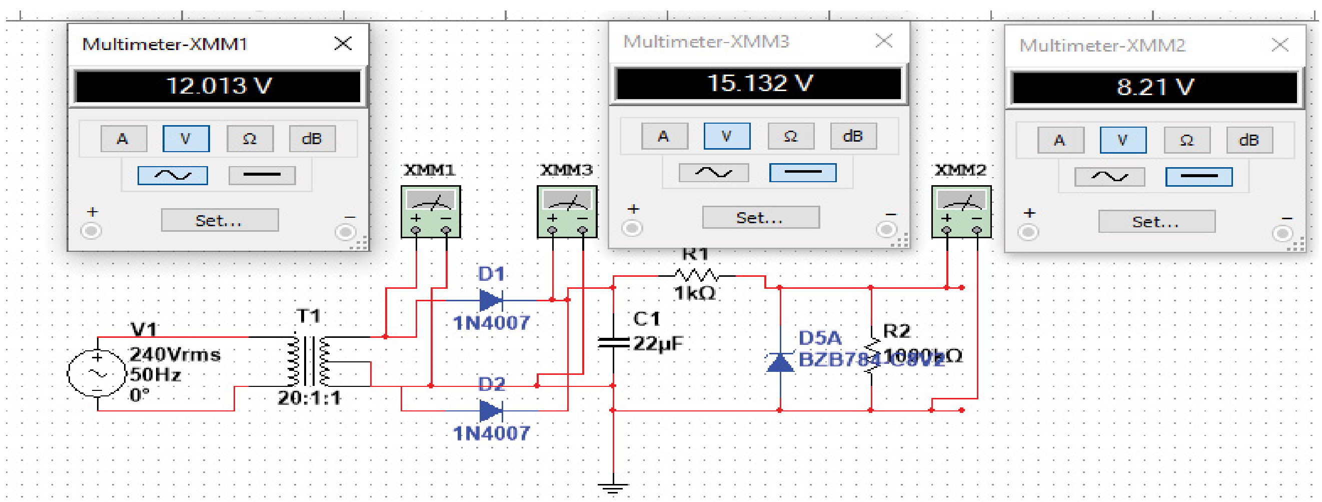

Figure 15b: Shown the complete circuit diagram of DC power supplier with filter capacitor connected.

diode in both forward and reverse directions was determined and investigated graphically, the result shows that a Zener diode specially made to operate in reverse biased while a PN junction diode normally does not conduct when reverse biased, the regulation and percentage regulation of a Zener diode at constant load resistance $R_L = 15k$ vary input voltage and at input voltage $V_{in} = 15V$ vary load resistances was determined graphically, results shows the regulating poins of the Zener diode uses as voltage regulator where both load current and full load voltage are regulated and the smaller in percentage regulation, the better power supply, therefore the highest on the vertical axis has better power supply, effect of load resistance *(R_L)* and filter capacitor (c) On ripple factor (r) Of both half wave and full wave rectifiers was determined graphically, the results shows that load resistance without or with constant filter capacitor have an effect on ripple factor of half wave or full wave rectifiers and filter capacitor without or with constant load resistance also have an effect on ripple factor of half wave or full wave rectifiers, finally complete circuit of 8V DC regulated power supply irrespective of load variations was design and simulated, the result shown the regulating of 8.2V using Multisim 14.2 simulator with Zener diode as voltage regulator.

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