

Novel 9-Steps Automatic Voltage Regulator based on Two Step-Down Transformers

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ABSTRACT

A novel design and simulation results of 9-steps automatic AC voltage regulator based on one step-down transformer is presented in this paper. Avoiding the problem of surge at the AC load during controlling jump steps is done through the proposed design. Accurate and smooth controlling function is achieved as well. Instead of the necessity of increasing the number of taps of the used multi tap transformer for wide controlling range of fluctuated AC supply voltage, the proposed design adopts using only two step down transformers with 10 Vrms, and 30 Vrms secondary voltages respectively. Through the controlling of the proposed design of AV voltage regulator, the resultant load voltage is equal the AC supply voltage as well as the suitable voltage step which may one of the following voltages; +40V, +30V, +20V, +10V, 0V, -10V, -20V, -30V, -40V. The electronic design is done Multisim software while the electrical circuit connection of step down transformers and relays contacts that is made by using PSIM software for power circuit design.

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1. INTRODUCTION

The unregulated usage of the AC utility during day and night hours as well as the unarranged connection and disconnection of the electrical and electronic equipment that leads to have fluctuation in the AC supply voltage. Because of the equipment are manufacturing to work with stable AC supply voltage within acceptable range $220\text{Vrms} > V_{in} > 235\text{Vrms}$, the voltage regulator is required device that to manipulate the voltage fluctuation before delivering to the AC loads. In this field of AC voltage regulation, many research works proposed a lot of electrical/electronic designs and solutions that to overcome the state of voltage fluctuation. This fluctuation effects negatively on the connected loads like electronic equipment such as television, computer, microwave and electrical equipment such heaters, and refrigerator respectively. The state of voltage oscillation during the motion between each two steps through the controlling function that to avoid the power spike at the connected AC loads. The negative effect of the generated power spike or voltage surge may damage the connected AC loads.

A microcontroller based system is designed and implemented in [1] to provide a suitable programmable automatic control that to manipulate the state voltage oscillation through a multi taps transformers in the power side of the voltage regulator. A tolerable range of 215-237 volt regulation through multi taps transformer is presented in [2]. The voltage oscillation is manipulated by adopting a suitable hysteresis in the voltage levels comparisons. However, the research works in [1], and [2] have demerit that represented by the step of voltage during controlling in high level of voltage, in other meaning, the relays

contacts which used in voltage controlling in power side of regulator works on connect and disconnect high level of voltage to the load. For example, during one jump of voltage controlling let from 240 V to 230 V, this means the relay contacts will connect firstly 240 V then for a short period which during jumping motion there is no voltage from supply to the load i.e. 0 V then connect 230 V to the AC load. This is the main reason which leads to generate a voltage surge at the connected load. Additional demerit within multi-tap transformer in AC voltage regulation that is represented by only one tap of all the included taps of the designed transformer is used in one time. In other word, the remaining not used taps of multi-taps transformer become useless terminals.

A different commercially available for domestic applications types of 1kVA Automatic Voltage Stabilizers brands are demonstrated in [3]. The study in [4] is focused on the electrical hazards within a certain types of voltage stabilizers which depend on the servo method. the main demerit with this type that is represented by the slowly reaction with respect to the fluctuation speed of the AC supply voltage, the response of this type is compared to other type that fully electronics controlling function, the results of comparison demonstrate the slowly response in voltage fluctuation manipulating.

Sinusoidal Pulse Width Modulation (SPWM) technique is also adopted as an active technique in the field AC voltage regulation as shown in [5], [6]. A microcontroller unit based AC voltage regulator is presented in [5] using SPWM technique. The proposed regulator works as an AC/DC/AC stabilizer. The presented design is started by rectifier part for the unstable input AC voltage and followed by a PWM inverter that to have a pure sine wave at the output terminals of the regulator. The complexity and the highly cost are represented as main challenges of this type of AC voltage regulators. SPWM technique is also adopted through PWM inverter in [6]. The inverter is designed to regulate the unregulated voltage of a wind turbine. Due a variable speed wind, the output AC voltage of wind turbine is unregulated. The inverter works on stabilizing the voltage fluctuation through controlling the modulation index of inverter output voltage. However, the fact of high level of complexity and cost is reflect the challenge of this type of voltage manipulation

A 3-phase AC-voltage regulator with a novel design of a trigger circuitry of SCR in presented in [7]. The controlling function is done in this work through an unit of microcontroller. Because of broadly used SCRs in industrial field, a thyristors are designed in the implemented 3-ph AC voltage regulator. However, the resultant harmonics in the load current that represents a main challenge due the negative on the design complexity which come from the necessity of harmonics manipulation.

On the other side, AC and DC voltage controlling field is partially covered, as well as voltage regulation and supplying to the connected loads that are done with/without PWM technique based on discrete components electronics designs all through the studies in [8-16], while studies in [17-19] proposed electronic solutions through a certain microcontroller or digital signal processing units.

A novel 3-steps AC voltage regulator based on one step down transformer is presented in [20]. Simplicity and low cost are an important specifications of the proposed design because of one transformer is designed in the proposal. A binary weighted 7-steps voltage regulator based on two step-down transformers is done in [21] to have more smoothing AC voltage control performance.

This paper presents design and simulation results of a new AC voltage regulator with 9-steps of controlling based on using two step down transformers. The presented regulator offers more steps of low voltage levels that for more flexible AC voltage controlling range and to remove the case of high voltage level 220V through jumping between voltage steps. Additional merit of this proposal is avoiding the necessity of multi-taps transformer. Section 2 of this paper explains the proposed voltage regulator. Section 3 illustrate and discuss the simulation results while the summary of findings and the effectiveness of presented regulator will be concluding in section 4.

2. RESEARCH METHOD

A new AC voltage regulator is proposed based on two step-down transformers. The proposed design is capable to do controlling function that to manipulate the fluctuation of AC supply voltage through a suitable motion among voltage steps. The step voltage is delivered from the secondary winding of the step-down transformers which connect in serial connection between AC supply and related AC load. This serial connection leads to increase or decrease load voltage depends on the direction of the connected secondary winding. Through a new logic solution, only two low voltages 10 V, and 30 V of secondary windings of two additional transformers are enough to have 9-steps of voltage particularly; +40V, +30V, +20V, +10V, 0V, -10V, -20V, -30V, -40V. The voltages specification of the designed two step down transformers are 220V/30V, and 220V/10V. To obtain 9-voltage steps, controlling the polarity of the primary windings of the two transformers is necessary. In other word, the controlling function delivers value of total additional serial voltage in one instant one of the mentioned values of steps.

Continuous measuring the instantaneous root mean square value of the AC supply and comparing with a suitable designed limits, and the logic solution will decide the suitable voltage step that need to be selected. So, the controlling function determines the required directions of the primary windings of the two transformers with AC supply that means in phase or out of phase AC supply. The voltage step of 0V will be selected in case the input voltage of AC within acceptable range ($225V < V_{in} < 235V$). In this case of normal range of supply voltage, the two transformers will disconnect from the connection that to let the input supply connect to the load without any voltage increment or decrement.

Figure 1 represents main block diagram of the proposed 9-steps AC voltage regulator. Multisim software of electronic circuit design is used to do the blocks that represented by electronic circuit included in the proposed regulator, so, the blocks of sensing circuit, analog comparators array, and logic circuit and relays driver all are designed through Multisim software. On the other hand, PSIM software for power electric circuit design is used to do the power part design of the two step-down transformers and load connections.

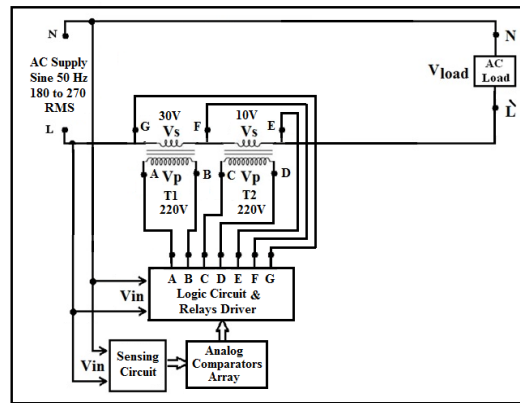


Figure 1. Block diagram of the proposed 9-steps AC voltage regulator

2.1. Sensing Circuit

Sensing circuit is designed to sense the instantaneous rms value of AC supply voltage. A certain calculated voltage divider is added to this circuit to produce a correct level of DC voltage related linearly to the root mean square value of input supply voltage Figure 2 illustrates sensing circuit and simulation result of an one of supply voltage, as shown in Figure 2, the output DC voltage is 2.589 V that indicates the input AC voltage 258.8 V. In other word the numbering minimization rate is approximately 1%.

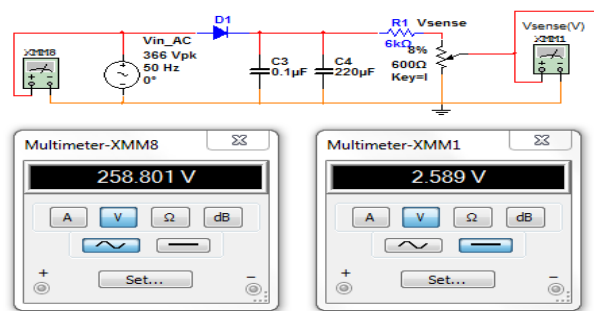


Figure 2. Sensing circuit of RMS Value of AC supply voltage

2.2. Analog Comparators Array

Eight operational amplifiers (Op-Amps) are designed to use as analog comparators in second block. The op-amps are compare the sensing circuit output voltage separately with eight fixed DC voltage levels particularly; 1.95V, 2.05V, 2.15V, 2.25V, 2.35V, 2.45V, 2.55V and 2.65V. These DC voltage levels reflect

indication of the grid voltage levels respectively; 195V, 205V, 215V, 225V, 235V, 245V, 255V, and 265V. Electronic design of the comparator array is shown in Figure 3 while Table I shows the array behavior regarding to the all probabilities of the input supply voltage level.

From Table 1 details, the states of supply voltage of low range of need to increase supply voltage by connecting in phase secondary windings voltages of the two transformers in series with the supply voltage. For the high range AC supply voltage state, the controlling need to reduce supply voltage by the windings voltage through out of phase connection. Same principle is used to the other different increment or decrement voltage based on the RMS value of supply voltage.

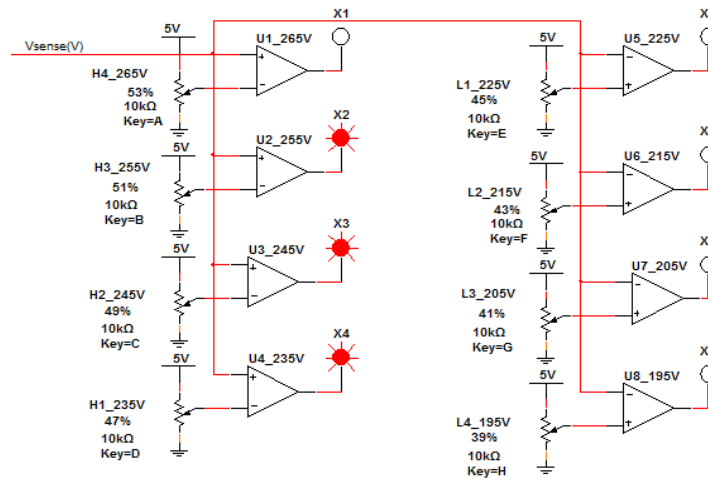


Figure 3. Analog comparators array

Table 1. Op-Amps comparators outputs for different values of input AC supply voltage

AC Supply Vrms	Vo of Sensing Circuit	Vo_X1 H4 265 V	Vo_X2 H3 255 V	Vo_X3 H2 245 V	Vo_X4 H1 235 V	Vo_X5 L1 225 V	Vo_X6 L2 215 V	Vo_X7 L3 205 V	Vo_X8 L4 195 V
171.1	1.71	0	0	0	0	1	1	1	1
180.3	1.80	0	0	0	0	1	1	1	1
189.5	1.89	0	0	0	0	1	1	1	1
200.8	2.01	0	0	0	0	1	1	1	0
210.7	2.11	0	0	0	0	1	1	0	0
221.3	2.21	0	0	0	0	1	0	0	0
231.2	2.31	0	0	0	0	0	0	0	0
240.4	2.40	0	0	0	1	0	0	0	0
250.3	2.50	0	0	1	1	0	0	0	0
260.2	2.60	0	1	1	1	0	0	0	0
270.8	2.71	1	1	1	1	0	0	0	0
280.7	2.81	1	1	1	1	0	0	0	0
289.9	2.91	1	1	1	1	0	0	0	0

2.3. Logic Circuit & Relay Driver

This block includes logic circuit and relays driver; logic circuit is designed to do the logic manipulation to the all probabilities of the AC supply voltage level that to have suitable voltage range for load delivering. Logic circuit receives the outputs of all analog comparators and based on designed logic function of this circuit. The logic function is determining the suitable increment or decrement voltage step (ΔV) that is needed for monitored supply voltage. Table 2 shows the required voltage step as well as the suitable secondary windings voltages connection (in phase or out of phase) for different values of supply voltage along wide voltage fluctuation range. The state of AC supply voltage within suitable range ($235 > V_{in} > 225$) leads to disconnect the primary windings of the two transformers and making short connection on the points of secondary windings by activation the two relays R_{FG} and R_{EF} as shown in Table 2.

Table 2. Logic circuit outputs based on Op-Amps outputs for a different AC supply voltages

AC Supply Vrms	X1	X2	X3	X4	X5	X6	X7	X8	ΔV	R _{AB} +30V	R _{BA} - 30 V	R _{FG} T1	R _{CD} +10V	R _{DC} - 10 V	R _{EF} T2
189.5	0	0	0	0	1	1	1	1	+40	1:on	0:off	0:off	1:on	0:off	0:off
200.8	0	0	0	0	1	1	1	0	+30	1	0	0	0	0	1
210.7	0	0	0	0	1	1	0	0	+20	1	0	0	0	1	0
221.3	0	0	0	0	1	0	0	0	+10	0	0	1	1	0	0
231.2	0	0	0	0	0	0	0	0	0V	0	0	1	0	0	1
240.4	0	0	0	1	0	0	0	0	-10	0	0	1	0	1	0
250.3	0	0	1	1	0	0	0	0	-20	0	1	0	1	0	0
260.2	0	1	1	1	0	0	0	0	-30	0	1	0	0	0	1
270.8	1	1	1	1	0	0	0	0	-40	0	1	0	0	1	0

Based on the above details; to activate the correct relay regarding suitable voltage step and direction, should be determine logic expressions of the relays; R_{AB}, R_{BA}, R_{CD}, R_{DC}, R_{FG}, and R_E :

$$\begin{aligned}
 R_{AB} &= X_5 \cdot X_6 \cdot X_7 \cdot X_8 + X_5 \cdot X_6 \cdot X_7 \cdot X_8^{\setminus} + X_5 \cdot X_6 \cdot X_7^{\setminus} \cdot X_8^{\setminus} \\
 R_{AB} &= X_5 \cdot X_6 \cdot X_7 (X_8 + X_8^{\setminus}) + X_5 \cdot X_6 \cdot X_7^{\setminus} \cdot X_8^{\setminus} \\
 R_{AB} &= X_5 \cdot X_6 \cdot X_7 + X_5 \cdot X_6 \cdot X_7^{\setminus} \cdot X_8^{\setminus} \\
 R_{AB} &= X_5 \cdot X_6 (X_7 + X_7^{\setminus} \cdot X_8^{\setminus}) \quad ; \text{ through Boolean algebra} \\
 R_{AB} &= X_5 \cdot X_6 (X_7 + X_8^{\setminus}) \quad ; \text{ so} \\
 R_{AB} &= X_5 \cdot X_6 \cdot X_7 + X_5 \cdot X_6 \cdot X_8^{\setminus} \quad (1)
 \end{aligned}$$

Using same procedure to find R_{BA}, R_{CD}, R_{DC}, R_{EF}, and R_{FG}

$$R_{BA} = X_1^{\setminus} \cdot X_3 \cdot X_4 + X_2 \cdot X_3 \cdot X_4 \quad (2)$$

$$R_{FG} = (R_{AB} + R_{BA})^{\setminus} \quad (3)$$

$$R_{CD} = X_5 \cdot X_6 \cdot X_7 \cdot X_8 + X_5 \cdot X_6^{\setminus} \cdot X_7^{\setminus} \cdot X_8^{\setminus} + X_1^{\setminus} \cdot X_2^{\setminus} \cdot X_3 \cdot X_4 \quad (4)$$

$$R_{DC} = X_5 \cdot X_6 \cdot X_7^{\setminus} \cdot X_8^{\setminus} + X_1 \cdot X_2 \cdot X_3 \cdot X_4 + X_1^{\setminus} \cdot X_2^{\setminus} \cdot X_3^{\setminus} \cdot X_4 \quad (5)$$

$$R_{EF} = (R_{CD} + R_{DC})^{\setminus} \quad (6)$$

Six relays are used as shown in Figure 4 to control the direction of input AC voltage to the primary windings of the two transformers that for doing increment or decrement voltage step.

3. RESULTS AND ANALYSIS

The automatic controlling function is proved and illustrated in this section of simulation results. The suitable step of increment or decrement voltage is done through activation to one or two relays that for controlling the direction of relays contacts.

Figure 5 shows different probabilities of input AC supply voltage, as well as the load voltage for each case. Figure 5 demonstrates clearly the controlling of voltage step value and the direction of secondary winding voltage. In the case of AC supply voltage within an acceptable voltage level, the load voltage is equal supply voltage without any increment or decrement voltage step. The effectiveness of the presented design is proved compared to designs based on multi tap transformer that through the fact in this paper of the jumping during the controlling process is done among low voltage levels that leads to no big voltage spikes.

The response of the proposed 9-step AC voltage regulator through covering a big range of supply voltage is shown in Figure 6. The effectiveness of adopting 9-steps of voltage controlling is illustrated through the load voltages in acceptable range while the input AC supply voltage included big fluctuation range.

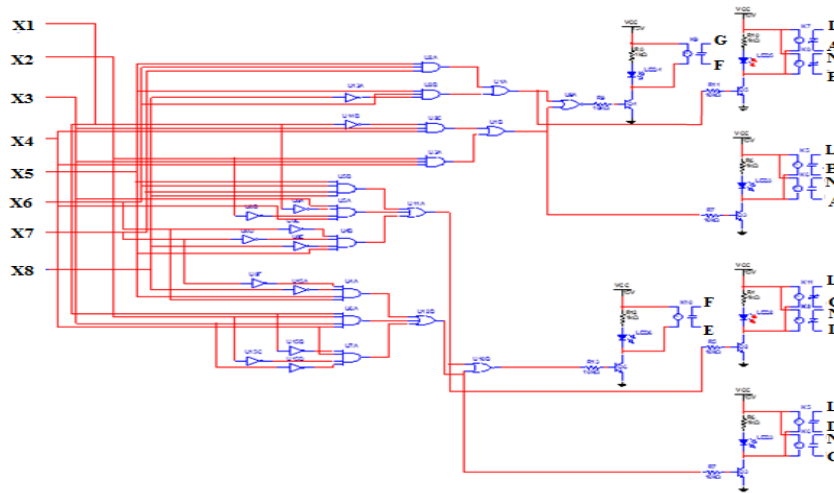


Figure 4. Logic Circuit and Relays Driver

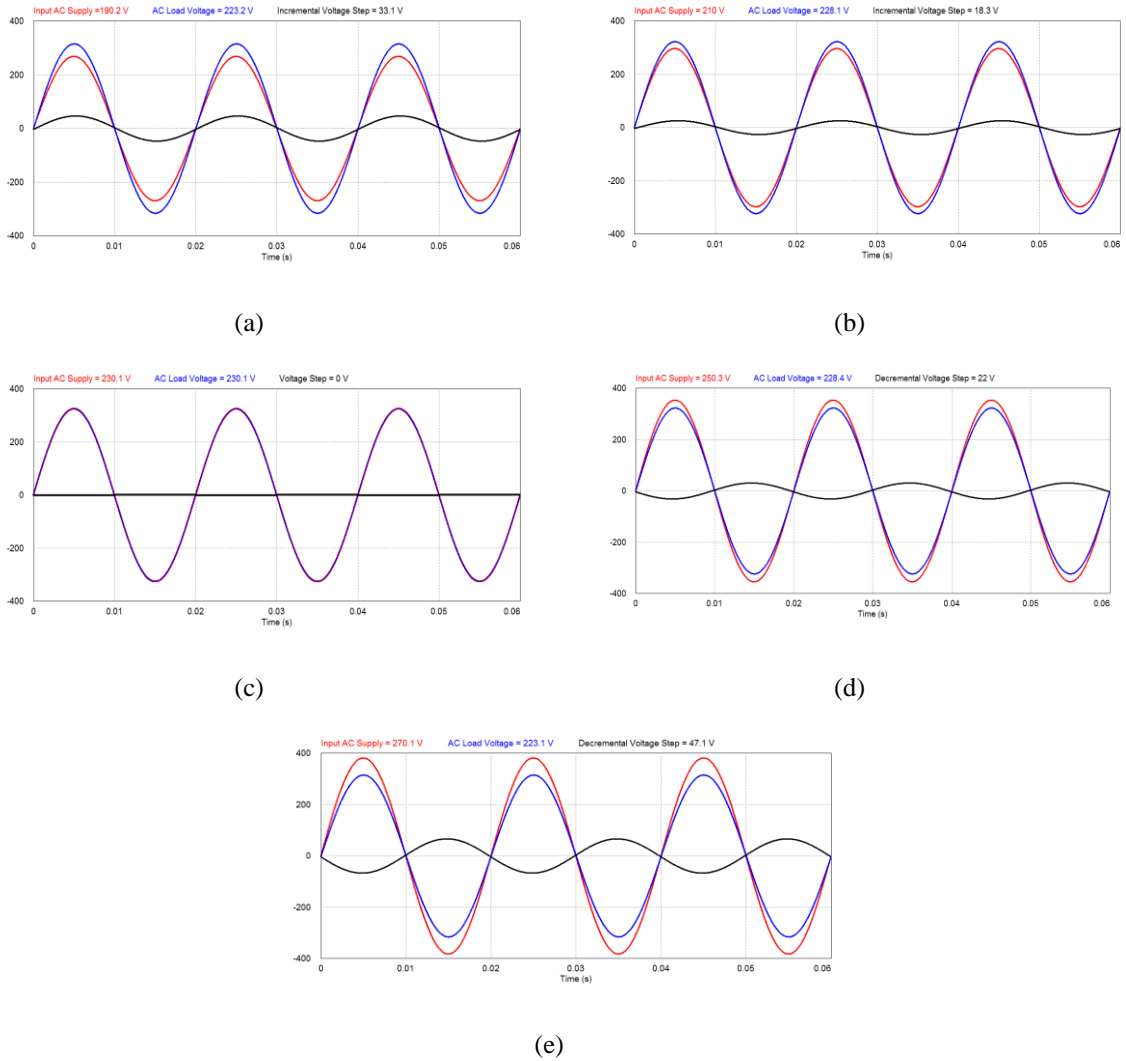


Figure 5. Different cases of input AC supply voltage, load voltage, and incremental / decremental voltage step

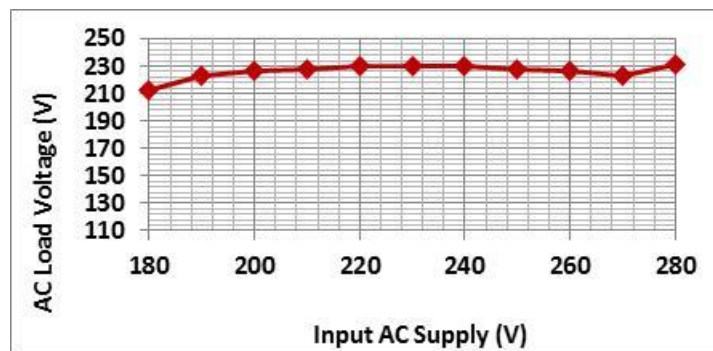


Figure 6. Proposed automatic 9- steps AC voltage regulator response

4. CONCLUSION

A full design and simulation results of a novel 9-steps automatic AC voltage regulator are presented in this paper based on two step-down transformers. A big range of fluctuated AC supply voltage is covered through the proposed regulator that to deliver the connected load with acceptable range of AC voltage. High voltage spike during jump among voltage steps of multi tap transformer that is avoided through the presented design due a low voltage step (10 V) between each successive two steps. The controlling function controls value and direction of the suitable voltage step through controlling relays contacts based on special logic solution. The effectiveness of the proposed AC voltage regulator is proved by testing different values of voltage levels of AC supply while the produced load voltage in acceptable levels. Selection of two step down transformers 220V/30V, and 220V/10V that leads to have ability of providing 9-steps of incremental or decremental voltage, particularly, the voltage steps are; +40V, +30V, +20V, +10V, 0V, -10V, -20V, -30V, -40V. Figure 6 demonstrates a big range of fluctuated AC supply voltage is covered with high accuracy manipulation through the proposed regulator. Additional merit is offered in the design due using only discrete components in the electronic design of the proposed regulator. Discrete components based design offers low cost, easy maintenance merits.

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