

Research Article

A Binary Weighted 7-steps Automatic Voltage Regulator

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Abstract: In domestic and industrial applications, the automatic AC voltage regulator is an important device especially during AC voltage fluctuations. Multi tap transformer based solutions are presented in many studies, however the smoothness and performance quality are depends on the number of taps of transformer in this solution the steps of voltage controlling equal to the number of taps of transformer, that means, the AC voltage connection is for 220 volt levels through controlling function as well as only one tap used in one time while other taps did not use. The AC load which connected to the regulator output terminals suffer and effect negatively from this spikes during steps of controlling jumps among high voltage levels. This study presents a novel design and simulation results of an automatic 7-steps AC voltage regulator that to avoid the problem of voltage surge at relay contacts. On the other hand, the proposed design offers removing the necessity of increasing taps number as what happened in the multi tap transformer that for smooth voltage for. This study proposes a novel design based on two binary weighted step down transformers that to delivers 7- steps AC voltage controlling function through jumping among low voltage levels. Multisim software for electronic design and PSIM software for power circuit design are used to do the proposed design and simulation results.

Keywords: Automatic voltage regulator, binary weighted voltage, step down transformer

INTRODUCTION

The electrical and electronic equipment for home and/or industrial applications that are made for working via a stable AC supply with voltage range around 220-230Vrms, however the unbalance connected loads and the continuous changing in loads currents that lead to the AC supply suffers from voltage fluctuation. This fluctuation leads to the necessity of using a suitable AC voltage regulator. For this matter, many solutions based on different methodologies are proposed.

Explanation of a twelve types of 1kVA Automatic Voltage Stabilizers brands which are commercially available for domestic applications that are illustrated in Ponnle (2015). The studies in Alamgir and Dev (2015) and Hoque (2014) are focus on using a multi taps transformers as a power part in the AC voltage regulation that to overcome the instantaneous fluctuations of supply voltage. Unstable supply voltage reflects negatively on the connected loads such as electronic and electrical equipment like television, computer, microwave heaters and refrigerator. These studies manipulate voltage oscillation through controlling function to avoid the voltage surge at the connected AC loads that may damage these loads. The work in Alamgir and Dev (2015) introduces tolerable range of 215-237 V through using a several taps.

Hysteresis has been introduced to avoid the voltage oscillation. However, in this study, still the step of voltage in high level ($220 V \pm \Delta V$) where ΔV is the voltage change between each two successive steps, in other word the designed controlling function works on connect and disconnect high level of voltage to the load. This procedure of controlling reflects negatively on the connected loads because jumping among steps creating surge at the output terminals of the regulator. Other demerit in the proposed design in Alamgir and Dev (2015) that the necessity of using multi tapes transformer. In Hoque (2014) the design and implementation is based on a certain type of microcontroller that to introduce a programmable automatic control to cover the problem voltage oscillation.

In Tarchanidis *et al.* (2013) and Nawaz and Arbab (2013), a sinusoidal pulse width modulation (SPWM) technique is presented for regulating the unstable input AC voltage. This study of Tarchanidis *et al.* (2013), proposed technique based on microcontroller unit controls an AC/DC/AC stabilizer. The controlling function is made through rectify the unstable input AC voltage and then a PWM inverter; the regulated voltage is produced through a filter that to have pure sinusoidal AC voltage. The challenge of the system is represented by the complexity and the highly cost.

The unregulated output voltage of a standalone wind turbine is regulated through a PWM inverter based on SPWM technique in Nawaz and Arbab (2013). The variable speed wind leads to out unregulated AC voltage, the regulator is designed to regulate the fluctuation in the output voltage of wind turbine. In Tarchanidis *et al.* (2013), the system in Nawaz and Arbab (2013) is characterized by the complexity and the highly cost that because of it includes many stages such as battery storage stage, inverter stage, filter and load connection. other demerit in this design; the difficulty of controlling when wind turbine voltage is less than the threshold value due to low level of wind speed.

A novel design of a 3-phase AC-voltage regulator with trigger circuitry of SCR based on a certain microcontroller unit is proposed in Zhou *et al.* (2014), the proposed design adopts Silicon Controlled Rectifier (SCR) as a power parts which broadly applied in industrial field. However, in the thyristors included regulation system, the main challenge is the resultant harmonics in the load current and the effect this on the design complexity.

The electrical hazards, types of voltage stabilizers including servo voltage stabilizers that are illustrated in Venkatesh and Muthiah (2011), the study focuses on the electrical hazards, types of stabilizers, servo voltage stabilizers, how the need for servo stabilizers is rising rapidly. Although of the objectives of Venkatesh and Muthiah (2011), the research feedback records reflect that the response of the servo voltage stabilizers is slow compared to the other proposals of fully electronic control systems.

Other studies focus on AC and DC voltage controlling system based on fully electronics design are proposed in Attia *et al.* (2014a, 2014b, 2015), Al-Mashhadany and Attia (2014), Getu and Attia (2015)

and Attia and Getu (2015). These studies illustrate different methods of AC and/or DC voltage regulation and supplying loads with/without PWM technique.

The work in Attia (2015) proposes a new three steps AC voltage regulator based on one step down transformer, this study is characterized by simplicity and low cost because of the dependence on one transformer. Other merit that the design is done via general purpose discrete components.

Comparing to the above proposals, this study presents a novel design of seven - steps of AC voltage regulator, the design adopts binary weighted principle of a two step down transformers that to remove high voltage jumping between steps during controlling function. In addition, the presented design avoids the necessity of using multi-taps transformer.

The remaining sections are including the proposal of a novel regulator design which illustrated in section II. The simulation and simulated results as well as the effectiveness prove are shown in section III. The conclusion points and the merits of the presented work are discussed in section IV.

MATERIALS AND METHODS

Adopting two step-down transformers in the proposed 7- steps AC voltage regulator is done and will be explained in this section. Two binary weighted step down transformer 220/15V and 220/30V are designed for binary weighted principle. Control the connection direction leads to control the polarity of the input AC voltage to the primary windings of the transformers. This way of controlling offers capability of increase or decrease the input AC supply voltage. The steps of voltage controlling function are designed in the following values; +45, +30, +15V, 0, -15, -30, -45V, respectively depending upon the instantaneous root

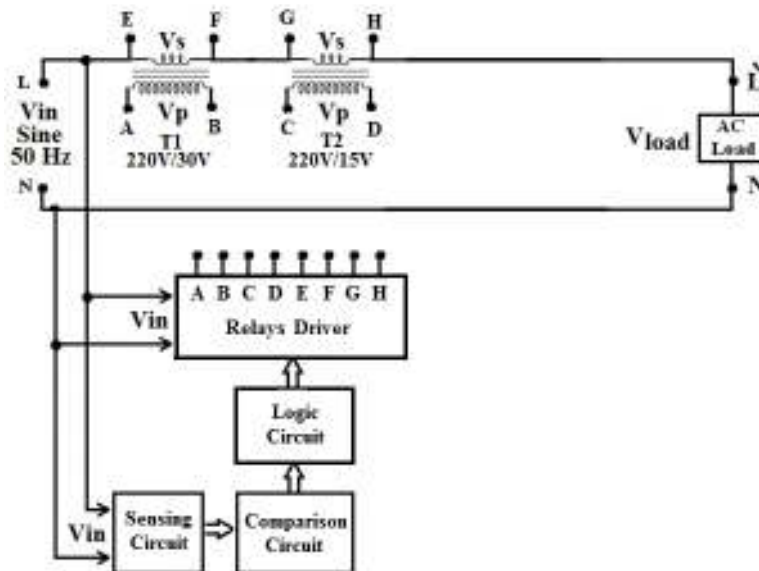


Fig. 1: Block diagram of the proposed binary weighted 7-steps AC voltage regulator

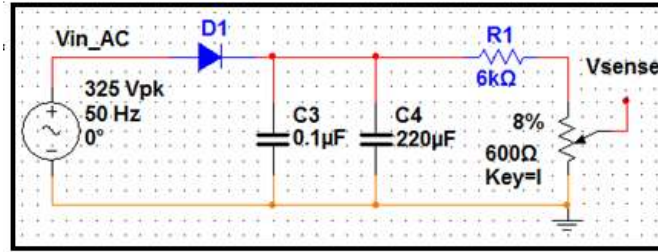


Fig. 2: Sensing circuit of AC supply voltage (Attia, 2015)

Table 1: Response of the comparison circuit with respect to the different input AC voltage values

AC Vin(V) Vrms	DC Vo Sensing Circuit	Vo X1 U1 265V	Vo X2 U2 250V	Vo X3 U3 235V	Vo X4 U4 220V	Vo X5 U5 205V	Vo X6 U6 190 V
169.7	1.696	0	0	0	1	1	1
180.3	1.802	0	0	0	1	1	1
191.6	1.916	0	0	0	1	1	0
200.1	2.001	0	0	0	1	1	0
210.7	2.107	0	0	0	1	0	0
220.9	2.209	0	0	0	0	0	0
230.2	2.302	0	0	0	0	0	0
240.4	2.405	0	0	1	0	0	0
251.6	2.517	0	1	1	0	0	0
260.2	2.603	0	1	1	0	0	0
270.8	2.710	1	1	1	0	0	0
280.7	2.809	1	1	1	0	0	0

Table 2: Truth table of the increment voltage steps

X6	X5	X4	$\Delta V(+30V) R_{AB}$	$\Delta V(+15V) R_{CD}$
0	0	0	0	0
0	0	1	0	1
0	1	X	1	0
1	X	X	1	1

X: don't care

mean square value of the AC supply. The controlling function works on determine the direction of connected AC supply voltage to the primary windings of the two transformers that connection can be in same phase of or out of phase of the input AC voltage. When the input voltage within acceptable range ($223V < V_{in} < 238V$) of AC supply, the two transformers will disconnect from load line that to allow to pass the input voltage without any increment or decrement.

The block diagram of the proposed electronic design of AC voltage regulator is represented in Fig. 1. The specifications of the step down transformers are designed at 15 V and 30 V secondary windings voltages.

Many circuits are included in the block diagram that represented by sensing circuit, comparison circuit, logic circuit and relay driver. The electronic designs of the included circuits are done using NI-Multisim software of electronic circuit design. The power part and the load connections are done using PSIM software for power electric circuit design. Sensing and conditioning function is done to sense the instantaneous rms value of the grid voltage and to produce DC level linear proportional with rms value of the grid voltage. Figure 2 shows full design of the circuit. The linear step down rate of 100V to 1 V is selected to indicate the actual range, so the output voltage of sensing circuit

equals 1.8 V if the actual grid voltage equals 180 Vrms and equals 2.6V for grid voltage 260 V.

The output voltage of sensing circuit enters the analog comparison circuit which designed to cover the comparison of all voltage levels. The comparisons are done for following voltage levels are 1.9, 2.05, 2.2, 2.35, 2.5 and 2.65V, respectively that to represent the grid voltage levels 190, 205, 220, 235, 250 and 265V respectively. Figure 3 shows full electronic design of the comparison circuit and Table 1 includes all of the probabilities of the outputs of operational amplifiers.

The next stage is represented by the logic circuit which receives all of the logic levels X, X, X, X, X and X6, respectively. Based on Table 1 data and based on the value of step down transformers 220/30 V and 220/15 V, the binary weighted additional voltages will depend on the sensing voltage. In other word the proposed AC voltage regulator adopts add one of +15 V, +30 V and +45 V, or works on reduce the AC supply voltage by one of the following voltage steps -15 V, -30 V and -45 V. Based on Table 1, a suitable truth table for binary weighted voltage step increments is explained in Table 2.

Simplified logic expression of $\Delta V(+30V)$ is equal $R_{AB} = X5 + X6$, while the expression of $\Delta V(+15V)$ equals $R_{CD} = (X4 \cdot \bar{X}5) + X6$. The requirements in Table 1 are obtained based on same process of simplification regarding decrement voltage steps, the logic expressions are as follow;

$$\Delta V (AB \text{ for } +30V) = \Delta_{AB} = R_{AB} = X5 + X6 \quad (1)$$

$$\Delta V (CD \text{ for } +15V) = \Delta_{CD} = R_{CD} = (X4 \cdot \bar{X}5) + X6 \quad (2)$$

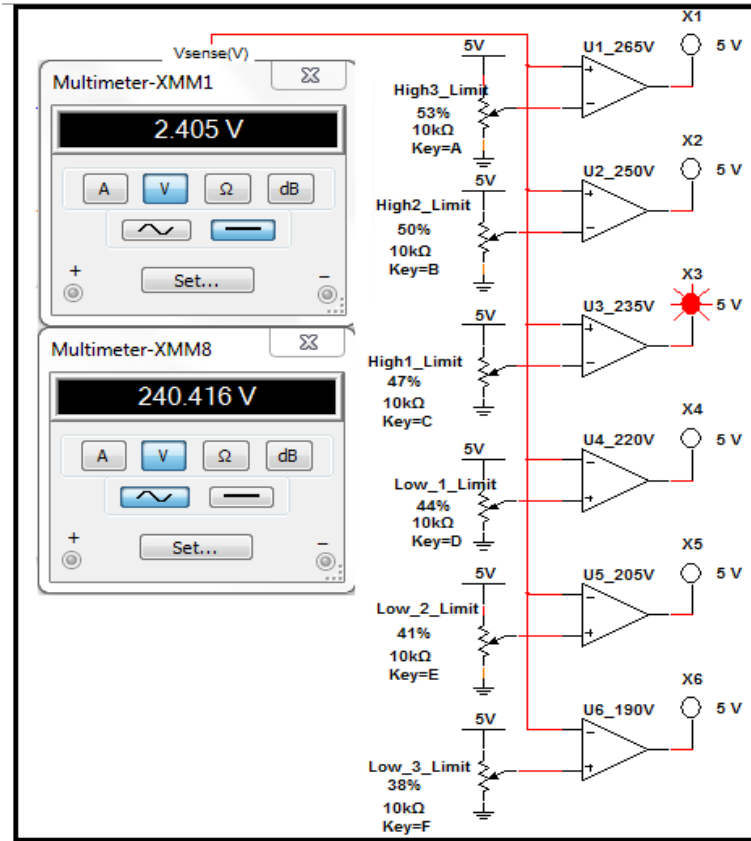


Fig. 3: Comparison circuit

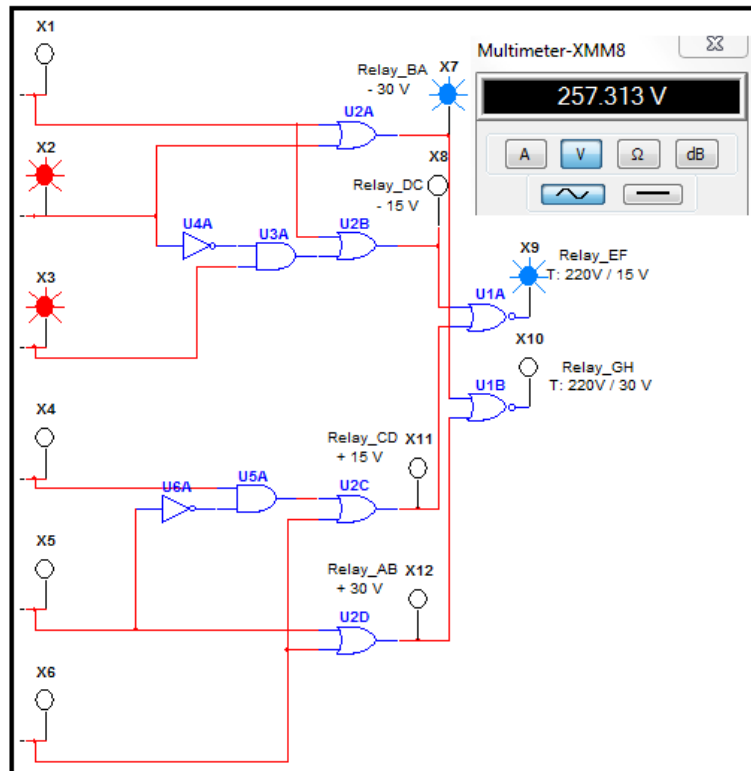


Fig. 4: Logic circuit

$$\Delta V (BA \text{ for } -30V) = \Delta_{BA} = R_{BA} = X1+X2 \quad (3)$$

$$\Delta V (DC \text{ for } +15V) = \Delta_{DC} = R_{DC} = X1+(X2 \cdot X3) \quad (4)$$

In case of AC supply voltage in acceptable voltage range $220 < V_{in} < 235$, the two step down transformers will be disconnected that to avoid any drop voltage across transformers windings. The logic expressions are designed to make the two relays (Relay REF and Relay RGH) working on disconnect transformers based on the following two expressions;

$$\text{Relay (EF to disconnect T1: 30V)} = R_{EF} = \text{NOT} (R_{AB}+R_{BA}) \quad (5)$$

$$\text{Relay (GH to disconnect T2: 15V)} = R_{GH} = \text{NOT} (R_{CD}+R_{DC}) \quad (6)$$

The electronic design of the logic circuit with simulation records are illustrated in Fig. 4.

Relays drive circuit in Fig. 5 is designed to control the direction of the input AC supply terminals (L, N) that to provide a suitable increment or decrement voltage step.

RESULTS AND DISCUSSION

The simulation process and results demonstrate a big range of input AC voltage that to illustrate the automatic controlling function through providing a suitable voltage step.

Figure 6 shows AC source sinusoidal waveforms, secondary winding voltages and load voltage for different levels of the supply voltage. The waveforms clearly illustrate the effectiveness of the proposed design through taking into account the transformer connection in phase or out of phase that to increase or decrease respectively the value of supply voltage.

Figure 7 illustrates the response of the proposed regulator through covering a big range of the input AC

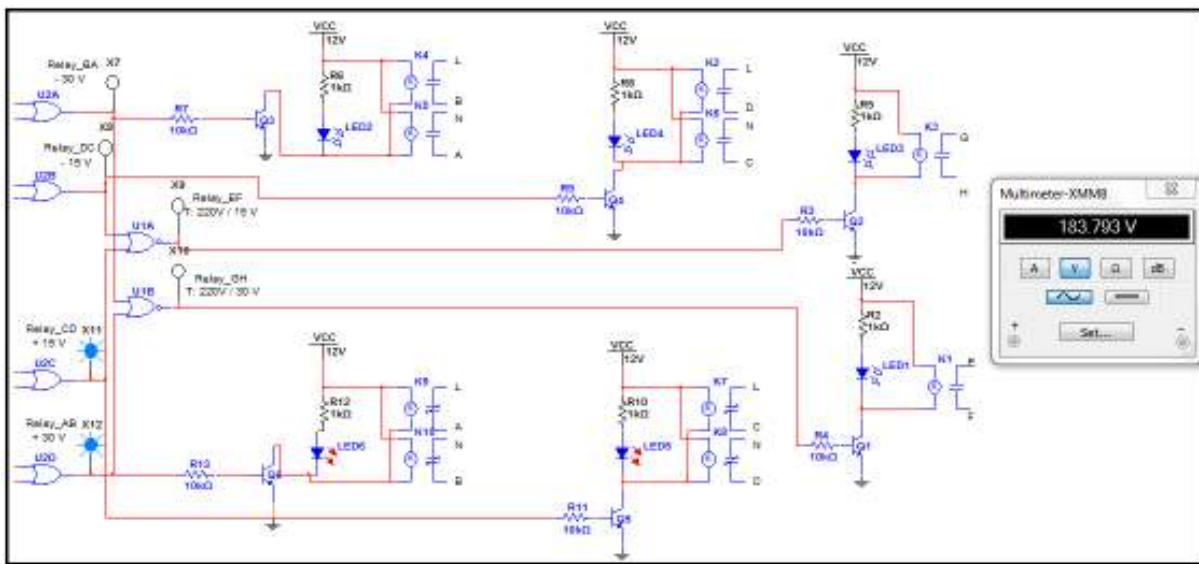
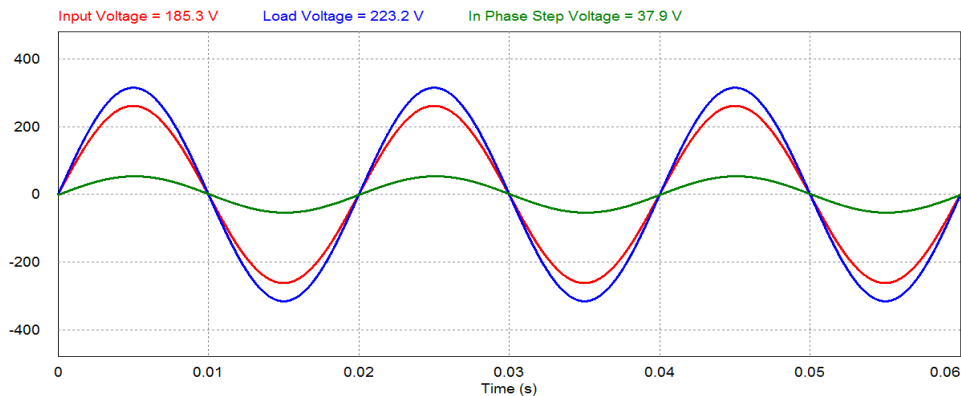
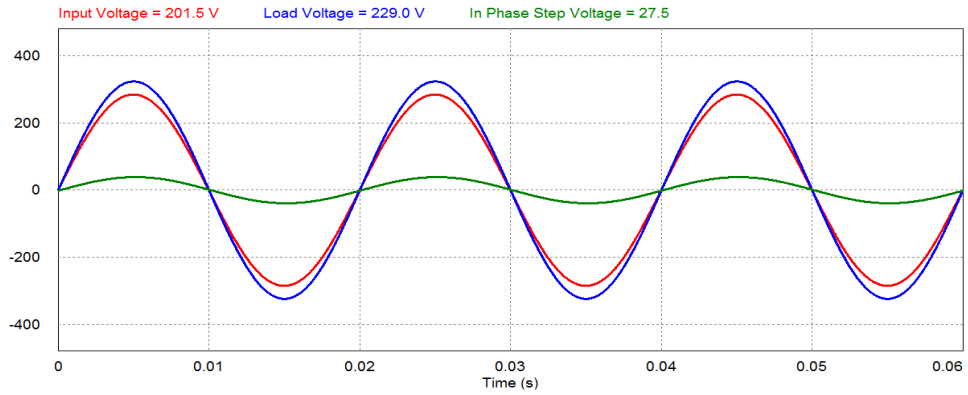


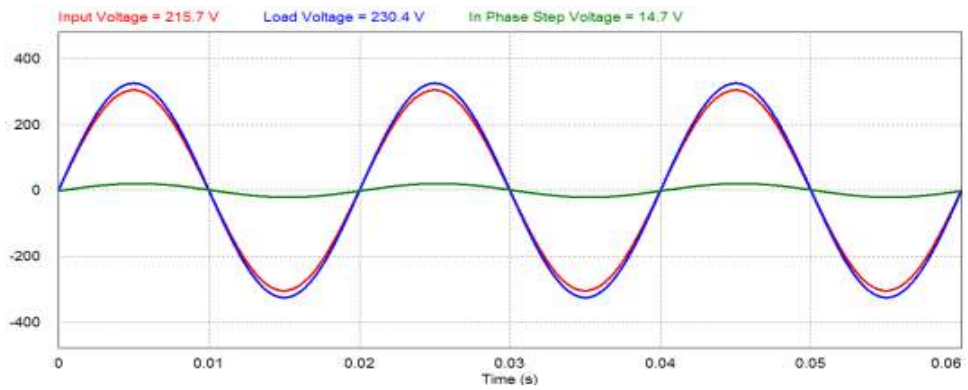
Fig. 5: Relays driver circuit



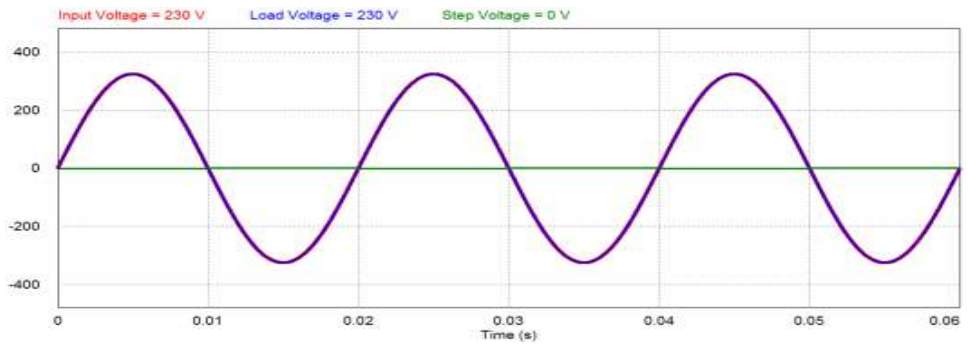
(a)



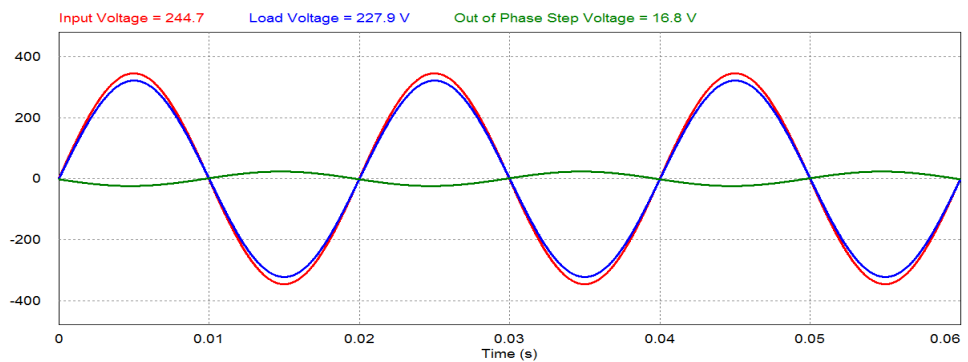
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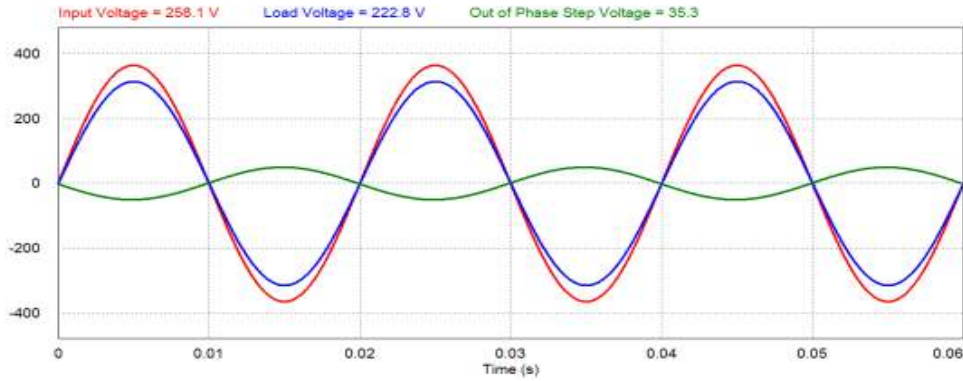
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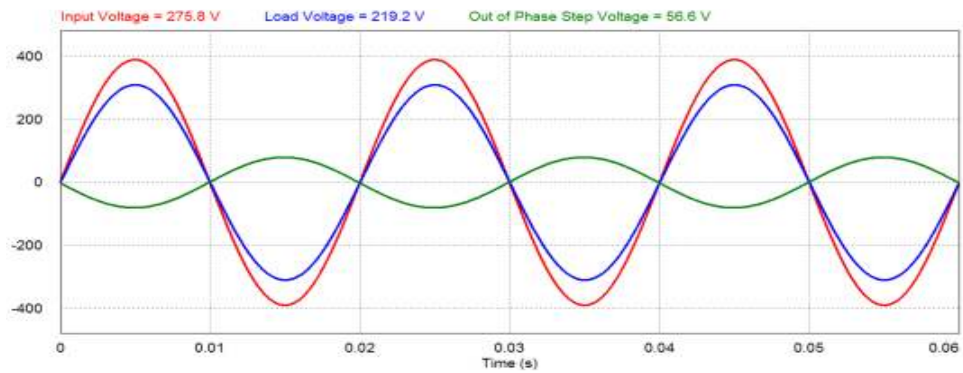
(d)



(e)



(f)



(g)

Fig. 6: Sinusoidal waveforms of AC supply, load voltage and additional step voltage for different values of input voltages

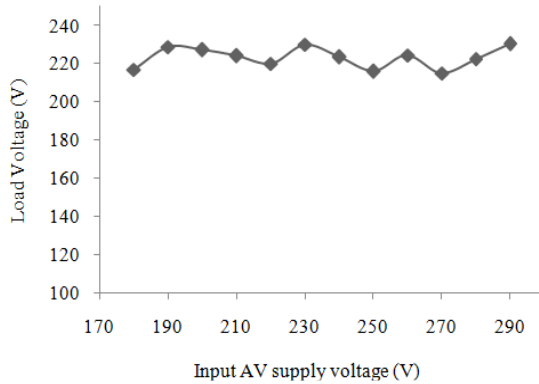


Fig. 7: Response of the proposed regulator

supply voltage. Figure 7 reflects the effectiveness of the presented regulator through adopting only two step down transformers.

CONCLUSION

The presented paper proposes a new electronic design of 7-steps automatic voltage regulator based on binary weighted of voltage steps. The regulator works on controlling a big range of voltage fluctuating of AC supply. Simulation results prove the effectiveness of the

presented design which offers many controlling steps by using only two step down transformers. Through the offered voltage steps +45, +30, +15, 0, -15, -30, -45V, respectively a wide controlling range is obtained with ability of covering a big fluctuation voltage range 175 V to 275 V of AC supply voltage. Discrete components are selected in the full electronic design of this study and these components offer low manufacturing cost and easy maintenance. The additional advantage of the presented design is avoiding voltage spike during the controlling jump of relay contacts that what is happen in the case of multi tap transformer. This study controls voltage steps with low voltage range (15 V and 30 V) that leads to highly mitigate voltage spike during controlling jumps.

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