Design and Implementation of an Automatic Voltage Regulator with a Great Precision and Proper Hysteresis

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Abstract

This research aims at the designing and implementation of an Automatic Voltage Regulator (AVR) with higher precision and hysteresis. AC power supplied by PDB (Power development board) in Bangladesh is subjected to variation from time to time. Moreover in rural areas supplied voltage remains lower than specified. This causes a considerable threat to the sophisticated electronic devices like computer, refrigerator, television etc. So ensuring the input voltage to remain in a tolerable pre-specified limit has become a necessity in rural as well as some urban areas. Current systems available locally lacks precision and suffers the problem of oscillating between two output voltage and hence creating surge at the output which can damage valuable electronics. This research handled both shortcomings and introduced in the tolerable range of 215-237 volt using several taps. Hysteresis has been introduced while changing from one level to other and thus preventing oscillation.

Keywords: Automatic Voltage Regulator (AVR), precision, hysteresis, auto transformer, comparator circuit, relay, PDB (Power development board)

1. Introduction

In our practical life voltage may be high or low for purpose of electricity supply system or for the weakness of supply system or for other causes. For that reason, many important electric machine or electric equipment may destroy. In order to save these we need to use the voltage regulator.

The voltage regulator may be manually or automatically controlled. The voltage can be regulated manually by tap-changing switches, a variable auto transformer, and an induction regulator [1]. In manual control, the output voltage is sensed with a voltmeter connected at the output; the decision and correcting operation is made by a human being [2]. The manual control may not always be feasible due to various factors and the accuracy, which can be obtained, depending on the degree of instrument and giving much better performance so far as stability [2]. In modern large interconnected system, manual regulation is not feasible and therefore automatic voltage regulation equipment is installed on each generator [1].

Power quality problems commonly faced by industrial operations include transients, sags, swells, surges, outages, harmonics, and impulses that vary in quantity or magnitude of the voltage [3, 4]. Of these, voltage sags and extended under voltages have the largest negative impact on industrial productivity, and could be the most significant type of power quality variation for many industrial and commercial customers [3–9]. AVR is a suitable choice to control the output voltage through field excitation in variable speed application [10].
2. Specifications

Based on the above initial design decisions, the final parameters/specifications:

- Input voltage: 150V to 273V
- Output voltage: 215V to 237V for all input lying between 150V and 273V
- Input and output frequency are the same
- High cut feature at 274V
- Low cut feature at 145V
- 8 relays are used
- The auto-transformer has a 0V/neutral connection and 8 additional tapping’s: 315V, 285V, 257V, 233V, 212V, 190V, 172V, 156V

3. Related Work

In existing market, a traditional voltage regulator [11, 12, 14] normally designed is only suitable at synchronous speed of the primer mover [10] and it may cause easy burn out of the power electronic components if hunting and speed change occurs.

In the earlier research, 100V-340V (PAVR) [13], 120V-350V (AVR) [14] regulates the actual input voltage variation with an imprecise output voltage and improper hysteresis.

4. Overview of the Proposed Design

By the following block diagram the whole system can be recognized easily.

![Block Diagram of the AVR Design](image)

Figure 1. Block Diagram of the AVR Design

Input supply and switches connected with a multi-tapped transformer in primary and in secondary respectively to obtain regulated and stabilized output voltage at the load side is used [13]. Here comparator circuit plays the important role to decide and hence to control...
the switches through which secondary tap carries the power from input to load with a steady voltage.

It is necessary to introduce two units, one to prevent hunting known as anti-hunting unit and another to maintain hysteresis known as hysteresis circuit [14, 15, 16-18]. Hunting is continuous fluctuation or oscillation of the voltage regulator and hysteresis is a change of the voltage from the one comparator to another and vice-versa [14]. The poor hysteresis means the less difference of the input voltages while changing the comparator stages [14].

5. Circuit Description

A. 12 volt Power Supply

![Figure 2. 12 volt Power Supply]

This circuit is design for getting 12 volt dc stable power supply; here we use IC 7812 which give the fixed 12v dc. It is use as reference voltage of comparator circuit and for the biasing of LM324.

B. 5 volt Power Supply

![Figure 3. 5 volt Power Supply]

This circuit is design for getting 5 volt dc stable power supply; here we use IC 7805 which give the fixed 5v dc. It is use to drive the inverter circuit and logic circuit.
C. Input Voltage Circuit

![Input Voltage Circuit Diagram]

**Figure 4. Input Voltage Circuit**

The input voltage is generated by a step down transformer and fed to the inverting terminal of the op-amp as Vin.

D. Comparator Circuit

![Comparator Circuit Diagram]

**Figure 5. Comparator Circuit**

LM324 are used for the comparator circuit which compares a variable dc voltage which is found by step down voltage (220vac-12vdc) of the PDB supply voltage with the reference voltage (12v dc).

The reference voltage is chosen in different manner to the comparators to compare the variable input voltage for energizing the relays.

For a typical example comparators’ input voltage combinations are shown in the following table:
Table 1. Comparator Selection

<table>
<thead>
<tr>
<th>Input $V_{AC}$ (volt)</th>
<th>$V_{ref}$ (Volt DC)</th>
<th>$V_{in}$ (volt DC)</th>
<th>Output of Comparator</th>
</tr>
</thead>
<tbody>
<tr>
<td>145</td>
<td>3.60</td>
<td>3.71</td>
<td>A</td>
</tr>
<tr>
<td>150</td>
<td>3.75</td>
<td>3.83</td>
<td>B</td>
</tr>
<tr>
<td>166</td>
<td>4.10</td>
<td>4.24</td>
<td>C</td>
</tr>
<tr>
<td>184</td>
<td>4.50</td>
<td>4.70</td>
<td>D</td>
</tr>
<tr>
<td>203</td>
<td>4.90</td>
<td>5.19</td>
<td>E</td>
</tr>
<tr>
<td>224</td>
<td>5.55</td>
<td>5.73</td>
<td>F</td>
</tr>
<tr>
<td>248</td>
<td>6.10</td>
<td>6.34</td>
<td>G</td>
</tr>
<tr>
<td>274</td>
<td>6.85</td>
<td>7.01</td>
<td>H</td>
</tr>
</tbody>
</table>

Here, Input $V_{AC}$ (volt) defines input voltage for AVR

$V_{ref}$ (Volt DC) defines non-inverting input for comparator

$V_{in}$ (volt DC) defines inverting input for comparator

E. Inverter Circuit

![Figure 6. Inverter Circuit](image)

The output of the comparator circuit is connected to the base of the transistor. When $V_{in}$ is less than $V_{ref}$ then output is zero & when $V_{in}$ is greater than $V_{ref}$ then output from collector is 5V.

F. Logic Circuit

![Figure 7. Logic Circuit](image)
The output of the inverter circuit is fed to the logic circuit which acts as a decoder. We find the output of the logic circuit by the following truth table:

Table 2. Relay Selection

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>O/P</th>
<th>Relay</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>OFF</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>AB</td>
<td>R1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>BC</td>
<td>R2</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>CD</td>
<td>R3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>DF</td>
<td>R4</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>EF</td>
<td>R5</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>FG</td>
<td>R6</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>GH</td>
<td>R7</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>GH</td>
<td>R8</td>
</tr>
</tbody>
</table>

G. Relay Driver Circuit

![Figure 8. Relay Driver Circuit](image)

Output of the logic circuit select relays for getting stable output voltage. The transformer is a simple autotransformer with the turn ratio 315V: 285V: 257V: 233V: 212V: 190V: 172V: 156V along with an auxiliary winding for powering the circuitry.

6. Procedure towards Design

As our designing commitment which is to stabilize automatically a large range (150V-273V) variation of input voltage at a normal prescribed level output voltage with a great precision and proper hysteresis. For this the voltage regulation of input supply is designed which is regulated automatically in such a way that when the input voltage varies the output voltage will remain stable at a constant level [14, 15, 19, 20]. To attain the variation of the large range input voltage, a mechanism is defined to stabilize a large
range *i.e.*, 150V-273V of the input by using the measuring circuit which drives multi-tapped transformer to select the appropriate tap [14, 20] and also the way that is inserted to make the system for the precision of output, is the selection of a transformer of a many number of taps in the secondary winding side maintaining a small turn difference between two successive taps [14, 20]. To maintain a good hysteresis a feedback is formed in the comparator circuit with a variable resistance [14, 16, 21]. Here the variable resistance provides a differential value to the input of comparator during the changing of the comparator stages and also adjusts the hysteresis condition.

In this design a transformer of eight taps has been chosen from lowest tap to highest *i.e.*, T2, T3, T4, T5, T6, and T7 in the secondary side those are selected by the relays/switches R2, R3, R4, R5, R6, and R7 respectively. Here the relays are controlled by a measuring unit consisting of comparators [14, 16, 21] (A, B, C, D, E, F, G, and H) The comparator compares a dc input with a reference level where the dc input voltage varies in accordance with the variation of supply input voltage and it selects the appropriate tap. Hence the stable output is found from the secondary side of transformer. This design is depicted in the following practical circuit diagram (Figure 9).
The stable output voltage occurs in the output of our designed regulated system for any short of variation of input voltage automatically. It is cleared to us from the following table:

<table>
<thead>
<tr>
<th>Input ( V_{AC} ) (volt)</th>
<th>Voltage for Tap Selection</th>
<th>Tap no.</th>
<th>Switch Selection</th>
<th>Stabilized Output Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>145</td>
<td>--</td>
<td>--</td>
<td>R1</td>
<td>0 V</td>
</tr>
<tr>
<td>150</td>
<td>315</td>
<td>T2</td>
<td>R2</td>
<td>214.77≈215</td>
</tr>
<tr>
<td>166</td>
<td>285</td>
<td>T3</td>
<td>R3</td>
<td>215.0</td>
</tr>
<tr>
<td>184</td>
<td>257</td>
<td>T4</td>
<td>R4</td>
<td>214.94≈215</td>
</tr>
<tr>
<td>203</td>
<td>233</td>
<td>T5</td>
<td>R5</td>
<td>214.99≈215</td>
</tr>
<tr>
<td>224</td>
<td>212</td>
<td>T6</td>
<td>R6</td>
<td>215.85≈215</td>
</tr>
<tr>
<td>248</td>
<td>190</td>
<td>T7</td>
<td>R7</td>
<td>214.18≈215</td>
</tr>
<tr>
<td>274</td>
<td>--</td>
<td>--</td>
<td>R8</td>
<td>0V</td>
</tr>
</tbody>
</table>

7. Shortcomings Recovery

The main goal of our research is to recovery of the shortcomings of the existing automatic voltage regulating system. In this portion these are described by the followings:

7.1. To get the Stabilized Output for a Large Variation of Input Voltage

Automatic voltage regulator has an enormous uses in human daily life where it is able to regulate a small range variation of input voltage that makes an obstacle of human life from the power because of not stabilizing the low and high voltage values. To recover that situation our research defines the mechanism to stabilize a large range of input voltage from lowest value to highest value by considering such measuring circuit which drives transformer of multiple times step up secondary side from the primary side.

7.2. To get the Precision Output

The commercially available automatic voltage regulator has a three to four step stabilization of the input variable voltage where the output becomes a big changing stable value within a prescribed range that is not an absolute design to get an output précised. For this reason in our research the way has been adopt to make the system for getting the precision output within in a large variation of input is the design of the main transformer having a many number of taps in the secondary winding side of the transformer maintaining a small turn difference between two adjacent taps.

7.3. To get a Regulated Output with a Proper Hysteresis

Hysteresis can be defined in such a way that a change in the value of the voltage when it reaches the level for the upper comparator and back to the previous position. The poor value of hysteresis means the less difference of the voltage values for changing and backing from the comparator stage. It is the general problem in our daily used AVR that causes a rapid alternation in the switching. In our research this problem is removed by employing a technique to maintain a good hysteresis which is a feedback connection in the comparator from output to inverting input with a variable resistance that shown in below.
8. Performance Analysis

We implemented this design practically for getting a clear performance after the completion of the design. We affirm with proof that the AVR turned on and stabilized any variable input voltage within our prescribed range (150V ~ 273V) to the tolerable range of 215-237 volt AC output which is in the following table:

<table>
<thead>
<tr>
<th>AVR INPUT</th>
<th>RATIO</th>
<th>AVR OUTPUT</th>
<th>AVR OUTPUT DUE TO HYSTERESIS</th>
<th>Relay</th>
</tr>
</thead>
<tbody>
<tr>
<td>150~165</td>
<td>1.4334</td>
<td>215.01~236.511 (≈237)</td>
<td>209.2764~230.7774</td>
<td>R2</td>
</tr>
<tr>
<td>166~183</td>
<td>1.2952</td>
<td>215.0032~237.0216 (≈237)</td>
<td>209.8224~230.5456</td>
<td>R3</td>
</tr>
<tr>
<td>184~202</td>
<td>1.1685</td>
<td>215.004~236.037 (≈237)</td>
<td>209.1615~230.1945</td>
<td>R4</td>
</tr>
<tr>
<td>203~223</td>
<td>1.0592</td>
<td>215.0176~236.2016 (≈237)</td>
<td>209.7216~229.8464</td>
<td>R5</td>
</tr>
<tr>
<td>224~247</td>
<td>0.9599</td>
<td>215.0176~237.0953 (≈237)</td>
<td>209.2582~231.3359</td>
<td>R6</td>
</tr>
<tr>
<td>248~273</td>
<td>0.867</td>
<td>215.016~236.691 (≈237)</td>
<td>209.814~236.691</td>
<td>R7</td>
</tr>
</tbody>
</table>

Here it is cleared to us that the output voltage within a stable range from our design has been found for any input voltage variation with a smooth and linear response that is shown in below:

Figure 11. Response Curve; Output Voltage vs. Input Voltage
It is also maintaining a proper hysteresis with a desired level variation of voltage in switching ON and OFF. Form this ‘ON-OFF features of Switch with Input Voltage’ graph (Figure12) the hysteresis is evidently defined whenever any switch becomes to switch ON or back to switch OFF [14].

**Figure 12. ON-OFF Features of Switch with Input Voltage (Hysteresis Curve)**

9. Conclusion

We have used a custom designed transformer and it was costly but other circuit component was cheap enough that the total system costs low or inexpensive. Although, this regulating system is not wide-spread in our country we hope if it becomes available, the customers will appreciate it. So the proper steps should be taken to encourage the owner of industries to produce this type of regulator system and deliver to the customer at a reasonable price. Here this design ensures to regulate 150V-273V AC variation of input to the tolerable range of 215-237 volt AC output. By adding many taps at the secondary side of the auto transformer and relays we can make a new automatic voltage regulator which can regulates input voltage range of 80VAC-350VAC to a stable 220VAC output voltage.

References


