

Design, implementation and performance study of programmable automatic voltage regulator

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Abstract:

The design and implementation of a Programmable Automatic Voltage Regulator (PAVR) with improved precision, suitable hysteresis, and anomaly protection are proposed in this study. The local systems currently in use are imprecise and have the issue of cycling between two output voltages, which results in surges at the output that can harm expensive devices. They need to be avoided, therefore power-voltage stabilisation, output wave rate minimization, and constant power-voltage to the instruments are required while the load fluctuates. It necessitates the preservation of constant voltage and quick response to abrupt changes in input voltage and load. This paper defines the shortcomings and introduces a new system in the tolerable and substantial stable of 220V with $\pm 4.5\%$ output accuracy for any deviation of input supply voltage within 100V-340V. To control the whole system automatically a microcontroller is used with some protection devices where to detect fault and the circuit implementation in this system are simple and flexible than conventional analog control circuitry. A simulation for both circuit and program has been accomplished for establishing better performance.

Keywords: Programmable Automatic Voltage Regulator (PAVR), Hysteresis, Microcontroller, Protection, Simulation.

Introduction

AC power supply by Power Development Board (PDB) in Bangladesh is subjected to variation from time to time. Moreover in rural areas supply voltage remains lower than specified most of the times. This poses a considerable threat to the sophisticated electronic devices. For that reason, many important electric machine or electric equipments may destroy. Power quality related problems, in particular voltage sags [1-3], surge [4] and brownouts have a major negative impact on industrial productivity. This appears to be true for both industrialized as well as developing nations. 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. In order to save these we need to use the Automatic Voltage Regulator [1,5,6]. An AVR is an electronic device that automatically regulates a variation of input voltage at a certain desired level to load [1,5,7]. The voltage of main power supply may be affected by various troubling physical factors [1,3], so that special regulating equipment is required to keep the voltage steady. In replace of AVR, Programmable AVR is more flexible, easy to modify and the best for good precision and hysteresis [5,8-11].

The existing systems like servo-stabilizers [12], CVTs [13], Ferro resonant regulators [14], thyristor ac regulators [15], tap changers [16-19] and the electronic regulators [5,6,20,21] are the available means for voltage regulator. Here the performances of existing commercially available technologies are compared by this system regarding response, faults handling, precision, efficiency and other important parameters.

It is essential that the supply ac voltage is needed to operate automatically [7-10] due to the interconnections among the systems in modern age. The electronic control circuit [7-10] may be utilized to get the desired output which is very simple, flexible, reliable and cost effective.

AVR mainly functions to measure and regulate the input voltage for producing the stable output and to provide the Protection against sag, surge, spike, impulse, notch, brown out, over voltage, under voltage, over current and hysteresis to the sophisticated equipments and machineries. In this system, the whole operations are implemented by a microcontroller [22]. Microcontroller here performs all actions in accordance with the program maintaining proper precision and hysteresis as we desire and the undesired input transitions are handled by the AC protection devices. The whole proposed design is illustrated in the following block diagram (Figure-1).

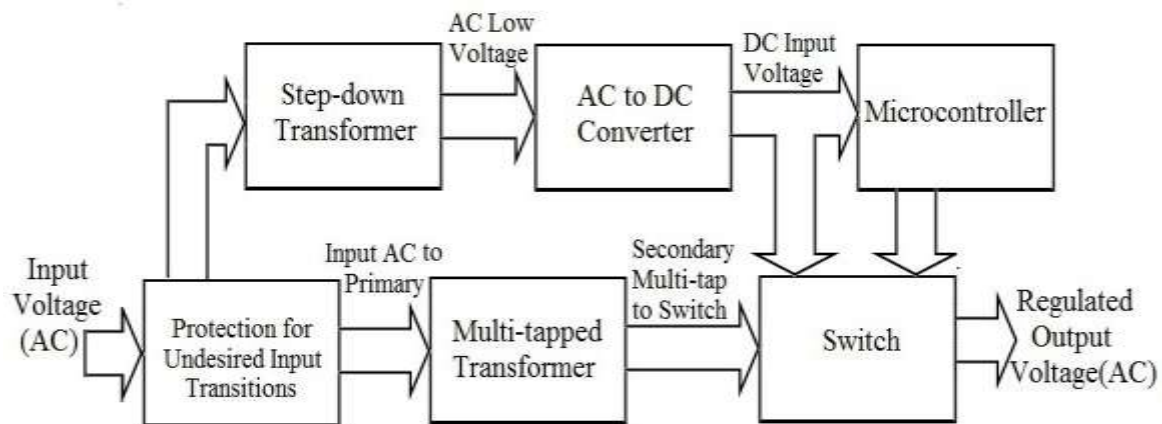


Figure-1: Block diagram of PAVR

A multi-tapped transformer [7,16-19] with input supply and switches connected in primary and in secondary respectively to obtain regulated and stabilized output voltage at the load side is used. Here microcontroller 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. This system also provides the protection against surge, spike, lightning, overvoltage and excess current [1,3-5] by adding AC breaker (MCB) [23,24], Automatic Voltage Switcher (AVS) [25] in the Input line. In the upcoming sections the designing procedure with simulations, programming, the control operation of microcontroller and performance analysis will be discussed.

1. Designing Procedure and Discussion

Description of Circuit Design

As the designing commitment which is to stabilize automatically a large range (100V-340V) variation of input voltage at a normal prescribed level output voltage (Table-1) with a great precision. 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 value. To achieve this, a microcontroller has been programmed in such a way that when the dc input to microcontroller varies in accordance with the variation of input voltage, microcontroller will operate the suitable switch to get a regulated output from desired transformer tap. Table-1 represents the designing configuration of the multi-tapped transformer.

Firstly, the microcontroller compares a converted variable DC voltage which is found by stepped down the ac supply voltage with the range, which is shown in Table-2 and is set

in the memory of the microcontroller. The voltage range for the program has been chosen in such different manner for letting switches functioned to select the different taps for getting desired output of around 220V AC (Table-2). Thus the stable output voltage occurs at the output of this designed regulation system for any short of variation of input voltage automatically. The whole schematic of the PAVR is shown in Figure-2 and Figure-3.

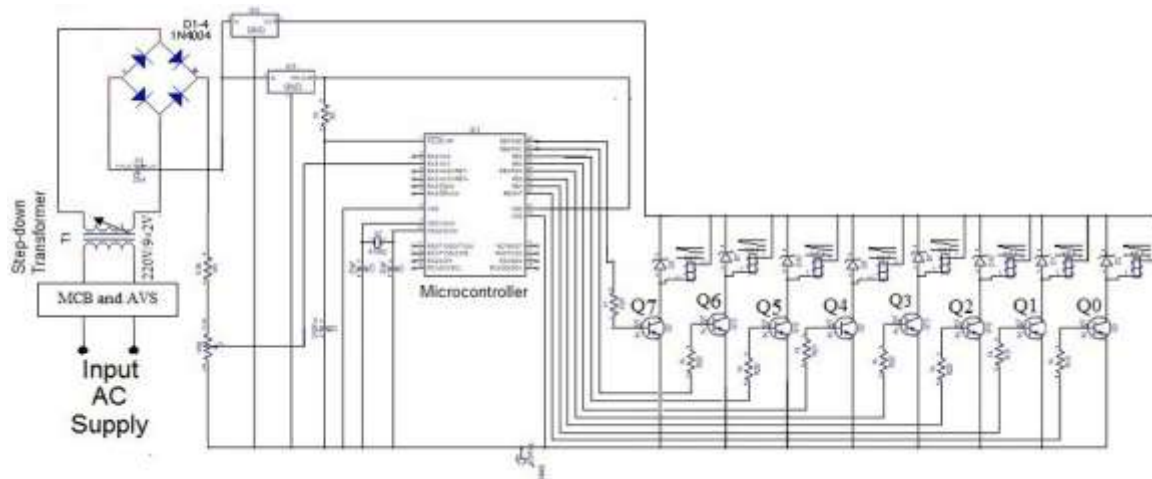


Figure-2: Schematic diagram of PAVR (Part-1)

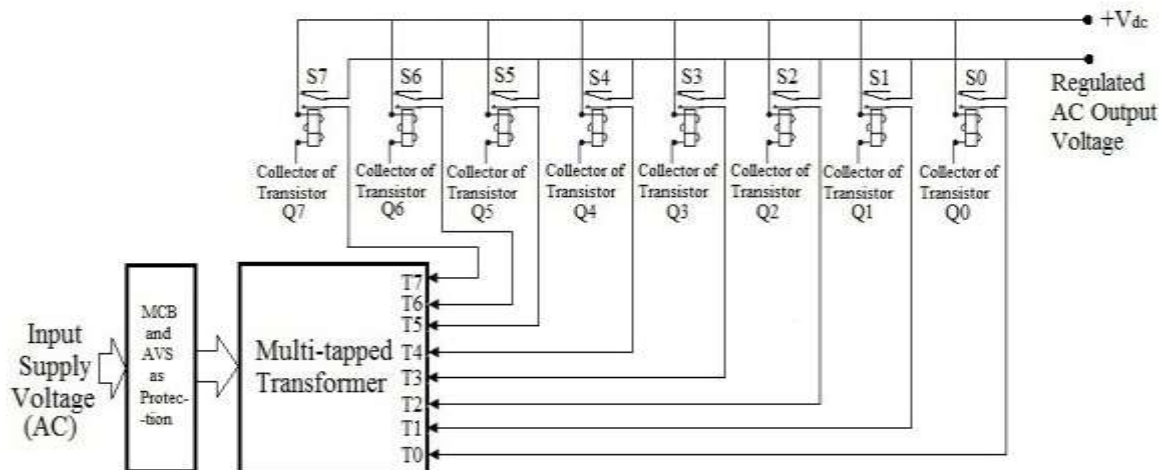


Figure-3: Schematic diagram of PAVR (Part-2)

Simulation Procedure

To determine the accurate level of voltage for designing of switching and making the microcontroller program this circuit has been simulated using PSPICE Simulator [26,27]. The operation of switching of PAVR at different level of input voltage is observed as well. Here, for input supply voltage of 130V, the switching operation is shown graphically in Figure-4 where the switch under PB0 and Q0 is “ON”. At any input voltage within 100V-340V, one and only one switch is activated at a time as defined in the program.

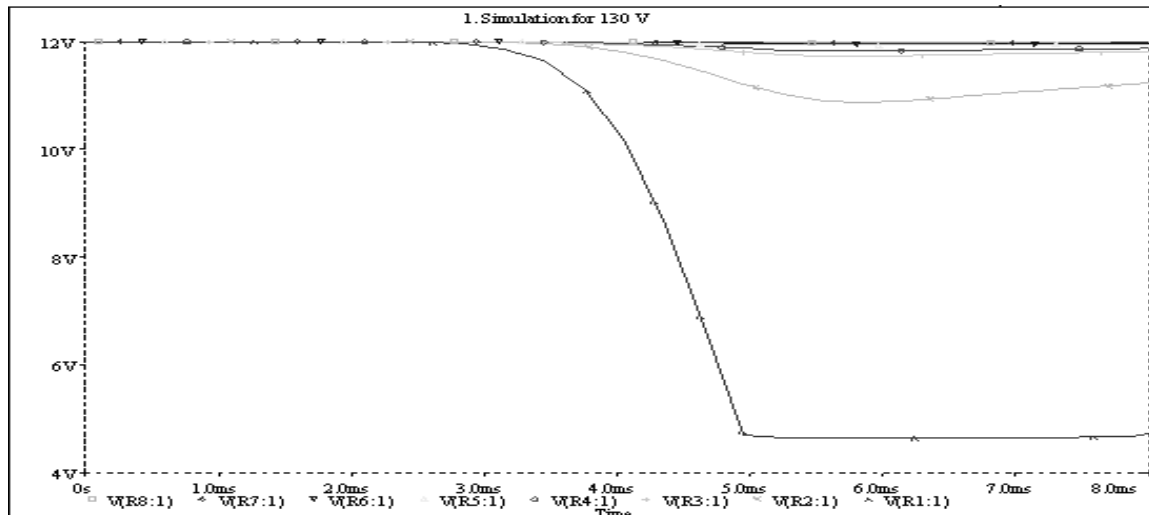


Figure-4: Simulation for 130V Input [26]

Flowchart description

The microcontroller program [22] of the PAVR is designed and functioned, as the following flowchart (Figure-5), to measure the received DC voltage and then to compare with the prescribed range stored in the microcontroller memory and finally to obtain a decision for the output. In the flowchart, it is also shown that when the received DC input is out of the range (i.e. above 5V and below 1V), microcontroller will operate “No Operation (NOP)”. That means, the PAVR will remain “OFF” during excess high and low voltage AC supply to protect the devices and equipments from damaging. Here the increasing and decreasing of DC input voltage are given orderly to maintain the hysteresis properly.

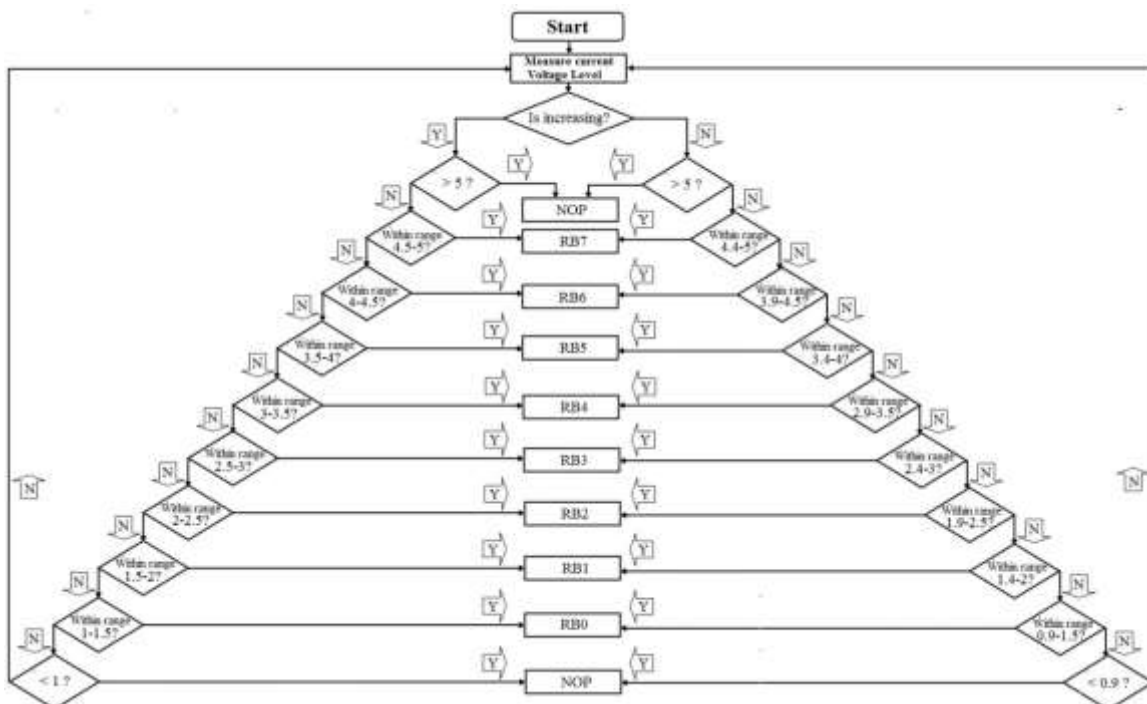


Figure-5: Flowchart for the program of microcontroller operation

Description of Program Operation

The program that was designed for the PAVR has been simulated using PIC Simulator IDE software [28]. PIC Simulator IDE is a basic compiler, assembler, disassembler and debugger for microchip family PICmicro. Firstly, the microcontroller has to be selected to load the program. Then the simulation has to be run. The sequences of operation have to be executed as follows.

Option>Select Microcontroller
 Tools>Assembler
 File>open/PAVR.asm
 Tools>Assemble & Load
 Simulation>Start
 Tools>Microcontroller View
 Tools>8xLED Board

The overview of simulation is presented by Figure-6 with PIC Simulator IDE interface. In this figure, the PORTB0 is displayed as ON when the input voltage is in the range of 1.0V-1.5V (2Ch-0Fh).

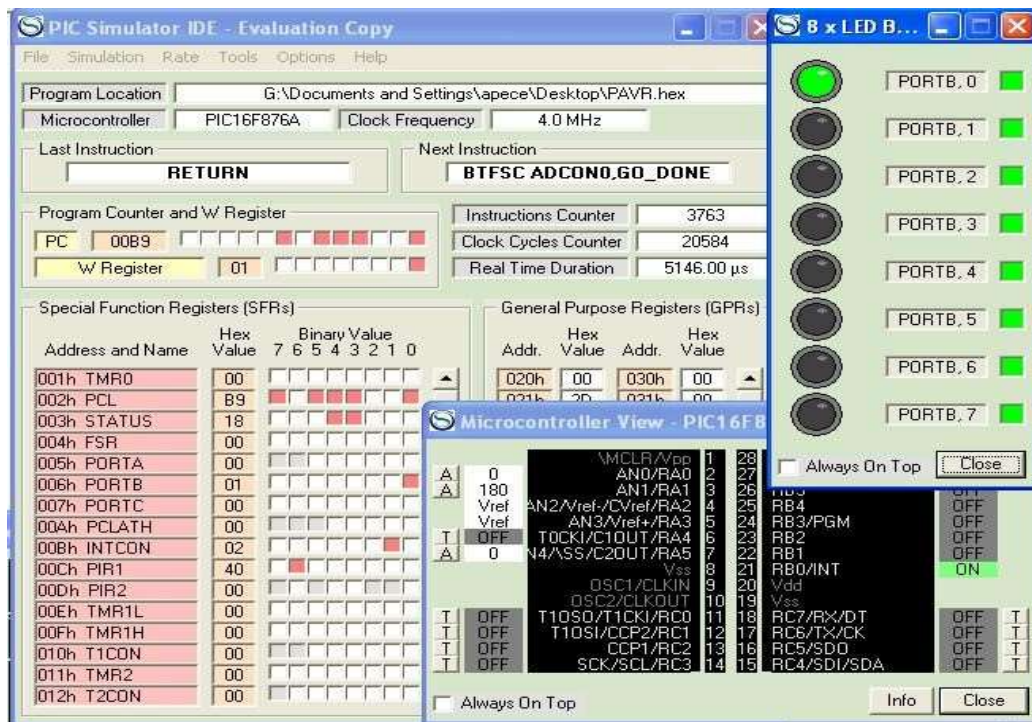


Figure-6: The simulation interface of PIC Simulator IDE with output Display [28]

Description of Microcontroller Operation

A PIC16F876A CMOS FLASH-based 8-bit microcontroller [22] (Figure-7) is used to control the whole system which is more reliable, simple and flexible than conventional analog control circuitry. It features especially Self-reprogrammable under software control, 2 I/O pins & 3 I/O ports, 256 bytes of EEPROM data memory, 2 Comparators, 5 channels of 10-bit Analog-to-Digital (A/D) converter, Programmable code protection, Power-saving Sleep mode, Selectable oscillator options and In-Circuit Debug via two pins.

Table-2: Selection of output pins, Switches and Transformer Taps for the prescribed input DC voltage range corresponding to input AC supply voltage range.

| Input Supply AC Voltage Range | Reference Input DC Voltage Range for increasing | Reference Input DC Voltage Range for decreasing | Output Pin Selection | Switch Selection | Transformer Tap Selection |
|--------------------------------------|--|--|-----------------------------|-------------------------|----------------------------------|
| 100V-130V | 1.0V-1.5V | 0.9V-1.5V | RB0 | S0 | T0 |
| 131V-160V | 1.5V-2.0V | 1.4V-2.0V | RB1 | S1 | T1 |
| 161V-190V | 2.0V-2.5V | 1.9V-2.5V | RB2 | S2 | T2 |
| 191V-220V | 2.5V-3.0V | 2.4V-3.0V | RB3 | S3 | T3 |
| 221V-250V | 3.0V-3.5V | 2.9V-3.5V | RB4 | S4 | T4 |
| 251V-280V | 3.5V-4.0V | 3.4V-4.0V | RB5 | S5 | T5 |
| 281V-310V | 4.0V-4.5V | 3.9V-4.5V | RB6 | S6 | T6 |
| 311V-340V | 4.5V-5.0V | 4.4V-5.0V | RB7 | S7 | T7 |

Table-3: Hexadecimal Value of digital code equivalent to prescribed DC voltage range corresponding to AC input and PAVR output voltage.

| Tap No. | Input (Volt AC) | PAVR Output (Volt AC) | Equivalent DC Level for Microcontroller (ADC) | Hexadecimal Value (Initiating range) | Hexadecimal Value (Tolerance range) |
|----------------|------------------------|------------------------------|--|---|--|
| T0 | 100V-130V | 210V-230V | 1.0V-1.5V | 2Ch-0Fh | 31h-0Ah |
| T1 | 131V-160V | 210V-230V | 1.5V-2.0V | 49h-2Ch | 4Eh-27h |
| T2 | 161V-190V | 210V-230V | 2.0V-2.5V | 66h-49h | 6Bh-44h |
| T3 | 191V-220V | 210V-230V | 2.5V-3.0V | 83h-66h | 88h-61h |
| T4 | 221V-250V | 210V-230V | 3.0V-3.5V | A0h-83h | A5h-7Eh |
| T5 | 251V-280V | 210V-230V | 3.5V-4.0V | BDh-A0h | C3h-9Bh |
| T6 | 281V-310V | 210V-230V | 4.0V-4.5V | DAh-BDh | DFh-B8h |
| T7 | 311V-340V | 210V-230V | 4.5V-5.0V | F8h-DAh | FDh-F5h |

Table-4: Experimented Analog DC input for ADC of Microcontroller and Regulated AC Output Voltage for typical AC Input Supply

| Typical AC Input Voltage Supply | Vin DC to RA1 | Output at | Output for Normal Input (220V) at different tap | Desired Regulated Output | Practical Regulated AC Output |
|--|----------------------|------------------|--|---------------------------------|--------------------------------------|
| 115V | 1.326923V | RB0 | 420.86V \approx 420V(T7) | 220V | 219.55V |
| 145V | 1.8125V | RB1 | 333.74V \approx 335V(T6) | 220V | 220.80V |
| 175V | 2.302632V | RB2 | 276.54V \approx 275V(T5) | 220V | 218.75V |
| 205V | 2.795455V | RB3 | 236.06V \approx 235V(T4) | 220V | 218.98V |
| 235V | 3.29V | RB4 | 205.92V \approx 205V(T3) | 220V | 218.98V |
| 265V | 3.785714V | RB5 | 182.60V \approx 185V(T2) | 220V | 222.84V |

| | | | | | |
|-------------|-----------|-----|----------------------------|------|---------|
| 295V | 4.282258V | RB6 | 164.12V \approx 165V(T1) | 220V | 221.25V |
| 325V | 4.779412V | RB7 | 148.94V \approx 150V(T0) | 220V | 221.59V |

2. Performance Analysis

This system has been experimented practically after designing. Here for some typical AC input voltage supply, the regulated output approximate to desired level is found that is shown in Table-4. From this table, it is clearly revealed that this PAVR is able to regulate any variation of input voltage of a system within 100V-340V at a stable range of 210V-230V and also to defend the system from damage due to extreme decrease and increase in AC supply voltage which is out of the range of 100V-340V. In Figures below present some performance curves of PAVR. Figure-8 shows the desired response curve of PAVR which is produced from the desired output voltage (210V-230V) for any input supply voltage within range of 100V-340V. In Figure-9, a typical input-output voltage characteristics curve of PAVR is put on view of the regulated output voltage that is near about 220V AC (Data in Table-4).

The Figure-10 exhibits a practical input-output voltage characteristics of PAVR for random supply. In this response curve, it confirms the design requisition of a stable output in range of 210V-230V as the regulation of any change in AC supply voltage within 100V-340V, and the protection any system from spoiling due to low voltage i.e. below 100V and high voltage i.e. above 340V. A hysteresis curve, given in Figure-11, shows the hysteresis behavior of PAVR during the operation of switches at the transition of different ranges of input supply voltage. It is needed to maintain properly to prevent the frequent vacillation of switching between “ON” and “OFF”.

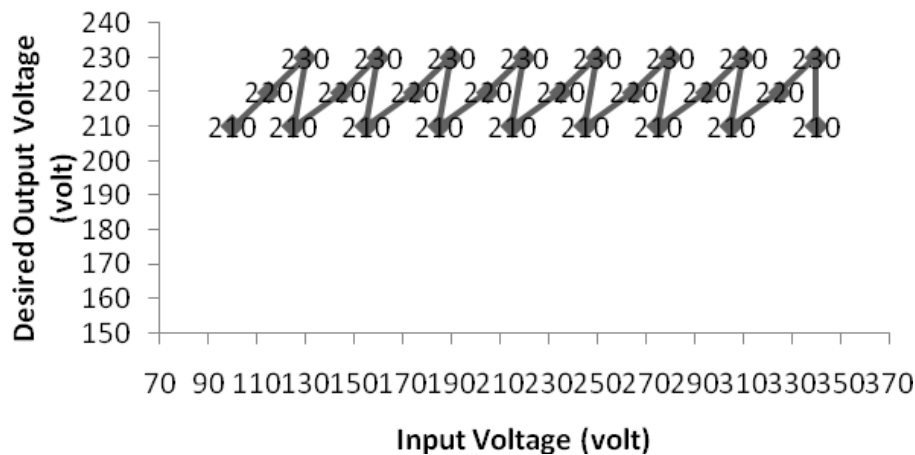


Figure-8: Desired Response Curve of PAVR

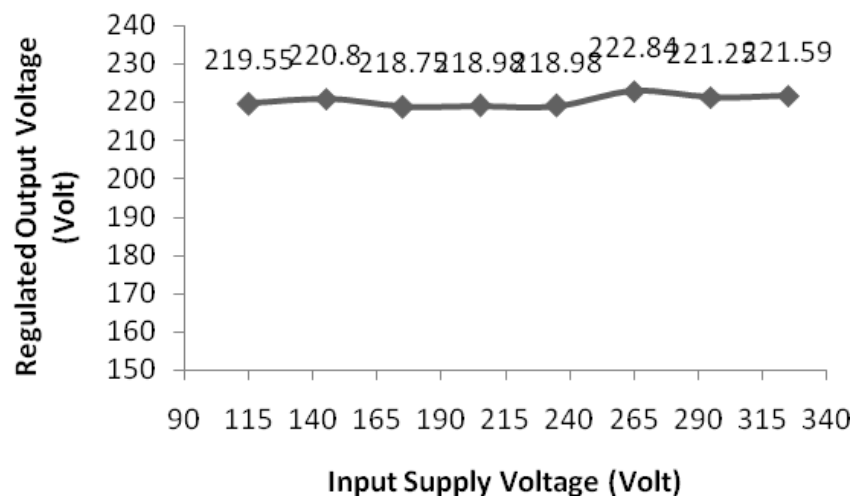


Figure-9: Typical Input-Output Voltage Characteristics of PAVR

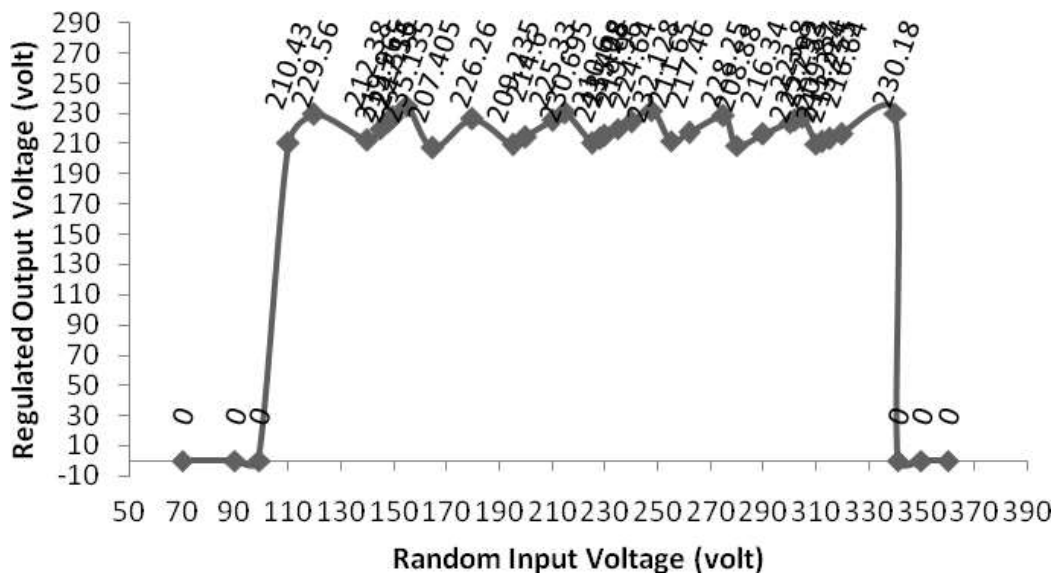


Figure-10: Practical Input-Output Voltage Characteristics of PAVR for Random Supply

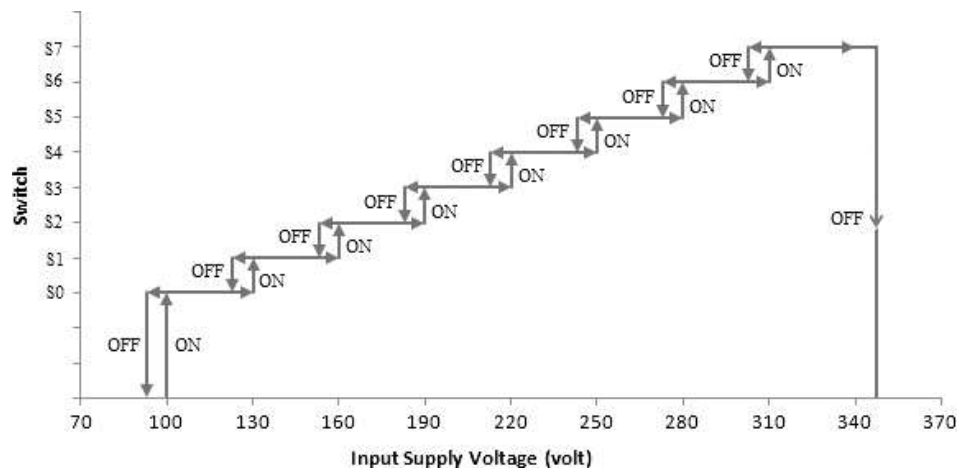


Figure-11: Hyteresis Curve [5]

3. Conclusion

It is evident from the architecture and discussion above and the comparison of my proposed proprietary PAVR with some other popular current AVR systems in Table 5 that it outperforms all other systems. It can be designed to maintain suitable precision and adequate hysteresis throughout a wide range of input variation because it is primarily programmable. Here, it is confirmed that there is protection against excessively high and low voltage and current, which is essential for highly advanced electrical and electronic equipment. It should be noted that the PAVR is significantly less expensive than other systems because it uses a microcontroller instead of discrete electronic components and straightforward protection mechanisms. Therefore, the circuit design and implementation are very much easy, flexible and the efficiency of this system is good enough as well. According to market comparison study, the commercially available AVR [29] 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 precised. For this reason in my research the way has been adopted 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. PAVR is applied to all electrical and electronics equipments especially in communications and precision instruments of manufactories.

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