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ELECTRICAL POWER ENGINEERING

Design of Excitation Control Based on PIC Microcontroller in Generator Operation

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Abstract- **In recent year, the synchronous generators have moved almost completely from analogue control to digital control. It is necessary to develop the digital control for the machine. The Automatic Voltage Regulator (AVR) is widely used in electrical power field to obtain the stability and good regulation of the electric system. This paper approaches the design and construction of excitation control or Automatic Voltage Regulator (AVR) for the synchronous generator. The characteristics of alternator output required are constant voltage and constant current. To get the constant output, alternator field excitation is controlled by Automatic Voltage Regulator (AVR).The Automatic Voltage Regulator maintains the constant voltage up to certain level of load current independently generator speed and load. Our approach is based on design and construction of microcontroller based excitation control for synchronous generator that introduces the digital excitation control technology. In this paper, we modify the AVR with PIC microcontroller technology to improve the overall effectiveness of the synchronous generator. This includes a more accurate measurement of voltage and current, as well as improving the response time and system stability.**

Keywords: **Automatic Voltage Regulator, Excitation Control, Microcontroller, Current Detector**

I. INTRODUCTION

Constant voltage at the generator terminals is essential for satisfactory main power supply. The terminal voltage can be affected by various disturbing factors (speed, load, power factor, and temperature rise), so that special regulating equipment is required to keep the voltage constant, even when affected by these disturbing factors [2]. Power system operation considered so far was under condition of steady load. However, both active and reactive power demands are never steady and they continually change with the rising or falling trend. Therefore, steam input to turbo generators (or water input to hydro-generators) must be continuously regulated to match the active power demand, failing which the machine speed will vary with consequent change in frequency which may be highly undesirable. Also excitation of generators must be continuously regulated to match the reactive power demand with reactive generation, otherwise the voltages of various system buses may go beyond the prescribed limits [3]. 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. In manual control, the output voltage is sensed with a voltmeter connected at the output; decision and correcting operation is made by a human being. The manual control may not be feasible always due to various factors and the accuracy, which can be obtained, depends on the degree of instrument and give much better performance so far as stability[4]. In modern large interconnected system, manual regulation is not feasible and automatic generation and voltage regulation equipment is installed on each generator. Automatic Voltage Regulator (AVR) may be discontinuous or continuous type. The discontinuous control type is simpler than the continuous type but it has a dead zone where no single is given. Its response time is longer and less accurate. Modern static continuous type automatic voltage regulator have advantage of providing extremely fast response times and high field ceiling voltages for forcing rapid changes in the generator terminal voltage during system faults. Rapid terminal voltage forcing is necessary to maintain transient stability of power system during and immediately after system faults. Response time variation can cause the AVR to degrade the system stability [4]. Microcontrollers are found in multitude of applications in the automotive, consumer, communications, office automation and industrial control.

The advantages of using microcontrollers are that the system cost is decreased and system reliability and design flexibility are increased. The main contribution is to design the Automatic Voltage Regulator (AVR) for generator operation. In this AVR, PIC microcontroller is used as a sensing device and produces the required signal to drive control unit. The control unit regulates the signal to give a correcting voltage for exciter. The source code of PIC is written in assembly language and it is simulated in software using MPLAB IDE. The remainder of the paper is organized as follows. Section 2 provides design specification of automatic voltage regulator. Design and calculation of automatic voltage regulator is presented in section 3. Performance testing and results of PIC-based AVR are explained in section 4. Section 5 describes performance testing and results of PIC-based AVR. Concluding remarks and future work are provided in section 5.

II. DESIGN SPECIFICATION OF AUTOMATIC VOLTAGE REGULATOR

An automatic voltage regulator can be designed, and it is necessary to know certain factors about the input and the required accuracy of the output voltage, together with, certain information on the load.

A. Supply-type Automatic Voltage Regulator

In the supply-type automatic voltage regulator, it is necessary to state the type of input, whether direct or alternating, its nominal voltage and, if alternating, its nominal frequency. Most automatic voltage regulators are operated over a limited range of input voltage. If the frequency of input is likely to vary, the range of variation of the frequency may have a considerable influence.

The output voltage is to be variable; the range of variation must be stated. The maximum output current must be known and also the range of variation of output current over which the regulator is to operate. When the output is alternating it is necessary to specify the power factor of the load, as certain designs will only operate over a small range of power factor, around unity. In three phase regulators it may be necessary to maintain the three phase voltage at 120 degrees to each other, as well as maintaining them constant in magnitude. Certain information may also be specified concerning the maintenance, operation and reliability.

The accuracy of maintenance of the output voltage may be divided into two general classes; (1) short period accuracy, this is, the accuracy over a period of minutes, due to changes of input or load and (2) long-period accuracy- this is the accuracy over a period of hours or days, due to changes in ambient temperature, ageing of components, vibration instability of components.

There are two other factors connected with the output voltage that may be important.

(1) Response time: All regulators take a finite time to effect a change in the supply voltage or load. This time is referred to as the time constant of the regulator, but in most cases it is termed as response time. In some cases, the response time is depending on the magnitude of the change of output voltage, but the rate of change remains constant. The maximum allowable response time depends upon the type of application. It is always desirable to make the response time as small as possible to reduce the transients in the output voltage.

(2) Waveform distortion: It is important in AC voltage regulators and the ripple voltage in DC voltage regulators. Care should be taken to reduce the distortion as much as possible. The distortion is expressed as the total percentage of harmonics relative to the pure sine wave [4].

B. Generator-type Automatic Voltage Regulator

It is a control device which automatically regulates the voltage at the exciter of an alternator, to hold the output voltage constant within specified limits. Probably due to the fact that this part of the equipment is often of different manufacture from the generator.

One can only express the performance in terms of the whole equipment as this is determined by the characteristics of the generator (and exciter, if used). When referring to the performance which is used by the term automatic voltage regulators will imply the whole equipment and not just that part which controls the field current. It will be seen that all generator type automatic voltage regulators are type C regulators. In the specification for an automatic voltage regulator of this type it is necessary to bring in the characteristics of the machine. The design of the regulator will depend on;

- The characteristics of the driving source since changes in speed cause variations of voltage
- The maximum and minimum load on the generator
- In the case of alternating current, the power factor of the load, since this, in conjunction with (2), will determine the range of field current required
- The regulation of the generator
- The magnetization curve of the generator
- The characteristics of the exciter (if used).

In the case of small machines most of this information may be given by stating the field current at minimum speed and maximum load, and the field current at maximum speed and minimum load. When a regulator is being designed for a large machine (e.g. an alternator in a large power station) more information is required, and the designer of the machine and of the regulator must work in closed harmony if a successful result is to be achieved. The short period accuracy of the output voltage is usually specified as the percentage change of load, speed and power factor. The long period accuracy may not be so important [4].

III. PROPOSED SYSTEM

A. Design and Calculation of Automatic Voltage Regulator

The voltage regulator is of complete static design. Principal particulars of the voltage regulator are 13 V DC for nominal output voltage, 11~14 V DC for adjustable output voltage and 15 A for maximum field current.

The characteristics of alternator output required are constant-voltage and constant-current. It maintains the constant-voltage up to a certain level of load current independently of alternator speed and load. And when it exceeds the certain level, the characteristic prevents the alternator current to become excessive by sudden drop in output voltage. To satisfy these two characteristics, the voltage regulator controls the alternator field current.

<u>Rating of Voltage Transformer</u>

The voltage ratio of voltage transformer is 380:12.

The turn ratio, $$\frac{N_1}{N_2} = \frac{V_1}{V_2} \quad (1)$$

Therefore $$\frac{N_1}{N_2} = \frac{380}{12} = 31:1$$

<u>Rating of Current Transformer</u>

The current ratio of current transformer is 100A:0.2A.

The turn ratio, $$\frac{N_1}{N_2} = \frac{I_2}{I_1} \quad (2)$$

Therefore $$\frac{N_1}{N_2} = \frac{I_2}{I_1} = \frac{0.2}{100} = 1:500$$

The resistor is selected and connected across the secondary terminal to change the current source to voltage source.

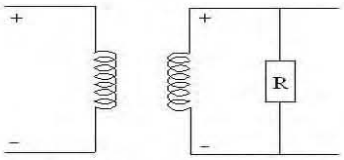

Fig. 1 Change of Current Source to Voltage Source

The voltage at the secondary terminal is

$$V = IR$$

$$V = 0.2 \times 70$$

$$= 14V$$

<u>Design Calculation of Voltage Regular (TL 431)</u>

The output voltage of TL 431 can be set to any value between Vref (approximately 2.5 V) and 36 V with two external resistors in the Figure 2.

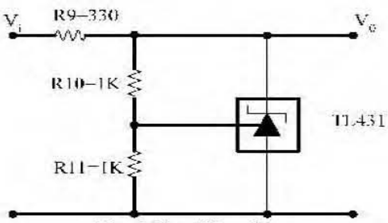

Fig. 2 Shunt Regulator

From data sheet (TL431)

$$V_{ref} = 2.495V \quad (\text{At } T_A = 25°C)$$

$$V_O = (1 + \frac{R_1}{R_2}) V_{ref} \quad \text{Volt} \qquad (3)$$

$$V_O = (1 + \frac{1K}{1K})\, 2.495 = 4.99\ V \approx 5V$$

According to the above calculation, the resistor (R_{10}=1K and R_{11}=1K) are suitable to get the output voltage of TL 431 is 5V.

<u>Design Calculation of Over Voltage Protection</u>

The over voltage protection circuit of this Automatic Voltage Regulator circuit is as shown in Fig. 3.

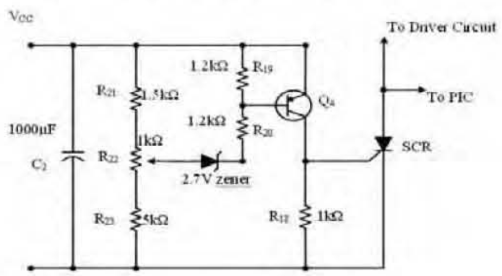

Fig. 3 Over Voltage Protection Circuit

In over voltage protection circuit, transistor acts as a switch. Normal operation voltage is 11V to 14V. The variable resistor (R22=1K) is adjusted to get 700Ω to 300Ω. By applying the voltage division method,

Zener diode voltage at anode terminal (V_{ZA}),

$$V_{ZA} = 13 \times \frac{(5K+300)}{(1.5K+700+5K+300)} = 9.187V$$

Zener diode voltage at cathode terminal (V_{ZK}),

$$V_{ZK} = V_{ZA} + V_D = 9.187 + 2.7V = 11.887V$$

The voltage across R19 and R20,

$$V_1 = V_{CC} - V_{ZK} = 13 - 11.887 = 1.113V$$

For transistor, voltage at base with respect to emitter (V_{BE}). By applying the voltage division method

$$V_{BE} = V_1 \times \frac{R_{19}}{(R_{20} + R_{19})} = 1.113 \times \frac{1K}{(1K + 1K)}$$

$$= 0.557V$$

The typical barrier potential is 0.7V for silicon. Therefore, the transistor is in cut off region.

Over voltage is up to 14 V. By applying the voltage division method,

Zener diode voltage at anode terminal (V_{ZA}),

$$V_{ZA} = 14 \times \frac{(5K+300)}{(1.5K+700+5K+300)} = 9.893V$$

Zener diode voltage at cathode terminal (V_{ZK}),

$$V_{ZK} = V_{ZA} + V_D = 9.893 + 2.7 = 12.593V$$

The voltage across R19 and R20,

$$V_1 = V_{CC} - V_{ZK} = 14 - 12.593 = 1.407V$$

For transistor, voltage at base with respect to emitter (V_{BE}). By applying the voltage division method

$$V_{BE} = V_1 \times \frac{R_{19}}{(R_{20} + R_{19})}$$

$$= 1.407 \times \frac{1K}{(1K + 1K)} = 0.703V$$

The typical barrier potential is 0.7V for silicon. Therefore, the transistor is in saturation region. From above calculation R_{21}=1.5KΩ, R_{22}=1KΩ and R_{23}= 5KΩ and zener diode (2.7V) are in suitable for this control circuit. If the control circuit has over voltage, transistor (Q4) is ON and the silicon controlled rectifier (SCR) is ON therefore the SCR is grounded.

C. Flow Chart for AVR Circuit

Flow chart for AVR circuit is as shown in Figure 5. The flow chart can be divided into four parts. They are:

(1) Initialization,
(2)Detecting signals
(4) Producing output and
(5) Interrupt handling.

D. Electronic Circuit Representation of Automatic Voltage Regulator

Fig. 5 (a), (b), (c), and (d) show the schematic diagram of AVR circuit. The TL431 regulator IC is used as a voltage regulating device and has been designed to produce +5 V for supply power to PIC 16F628A and it gives the reference voltage.

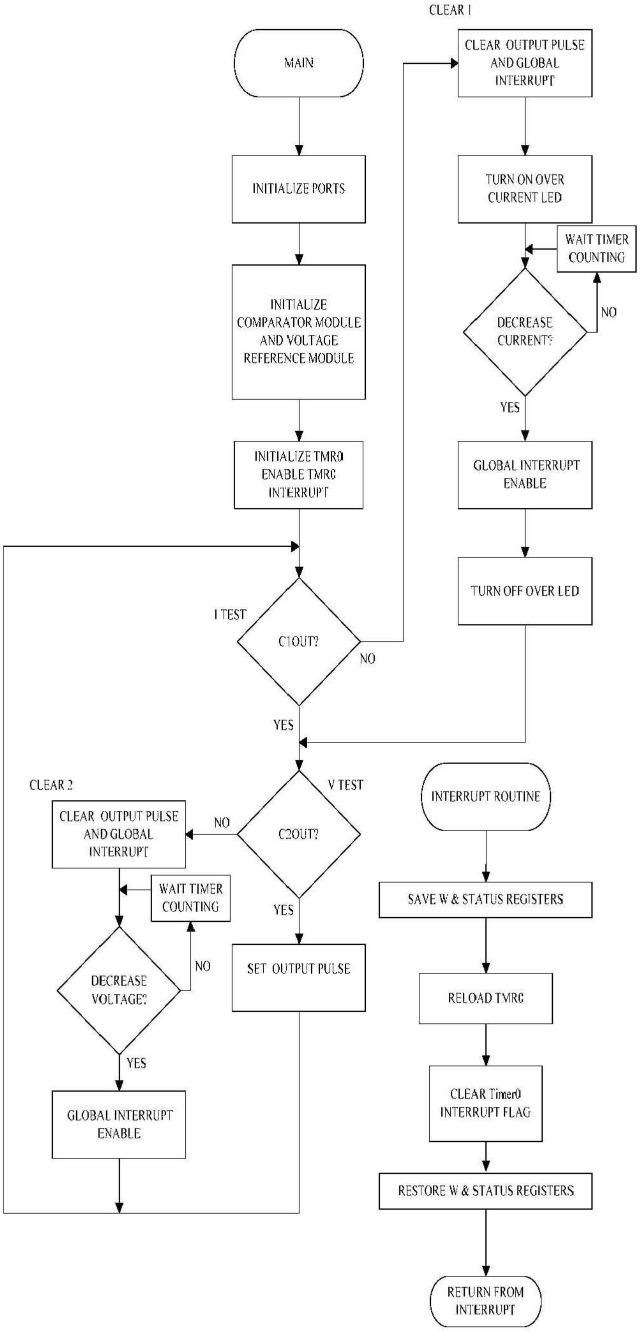

Fig. 4 Flow Chart for Automatic Voltage Regulator

The two 1 kΩ resistors (R_{10} and R_{11}) are used as voltage divider to give the reference voltage for PIC 16F628A. The input voltage and current is connected to RA1/AN1 and RA0/AN0. The RA4 pin is used as an output pin. In voltage control mode, the voltage is rectified by diodes (Rf4~9) of alternator output is applied to the resistor (Rf1~3). The divided and smoothed voltage is compared with the setting voltage by the comparator (CP2) inside the PIC 16F628A and it produces a low or high signal from RA4 pin. In current control mode, the current detector takes alternator current through current transformer (C.T), and converts into the smoothed voltage by resistor (R_{24}), bridge diodes and capacitor filter. This voltage is divided by resistors R_1, R_2, R_3 and R_4. This divided voltage is compared with the reference voltage by the comparator (CP1) and RA4 pin produces a signal.

When the alternator output and current is lower than the reference values, RA4 pin is high and Q_3 turns on, Q_2 turns off, and then Q_1 turns on respectively. So, field current gradually increases and alternator output voltage rises until input voltage is greater than setting voltage. If the alternator output voltage or current overcomes the set values, RA4 pin gets low level and Q_3 turns off, Q_2 turns on, then the base current of Q_1 is by-pass through Q_2 and at the same time Q_1 keeps off conduction. Field current decreases gradually by the aid of field inductance and freewheeling diode. So, alternator output voltage gradually decreases. Thus, these two actions occur alternately.

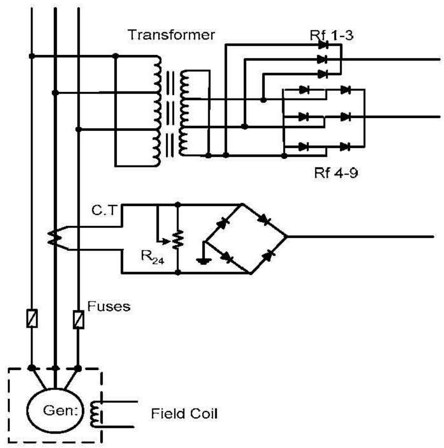

Fig. 5(a). Detecting Circuit

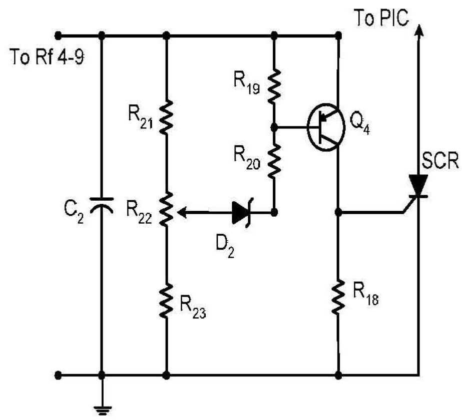

Fig. 5(b) Over Voltage Protection Circuit

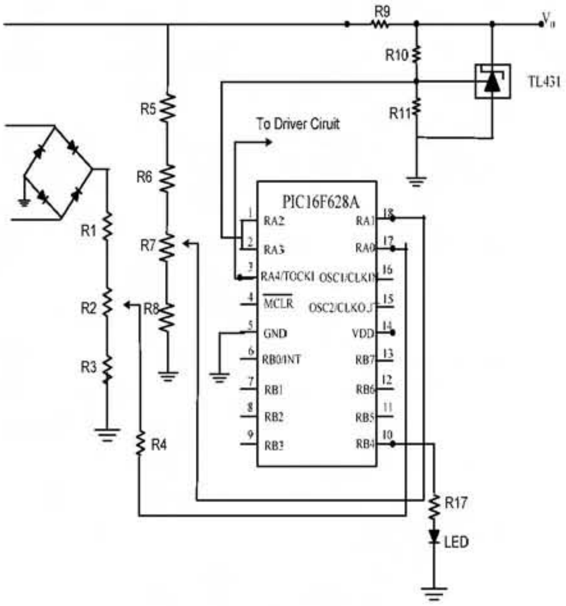

Fig. 5(c) Voltage Regulator Circuit

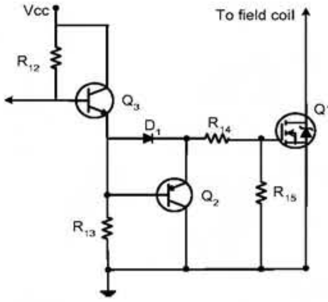

Fig. 5(d) Exciter Driver Circuit

D. Simulation in Software Using MPLAB IDE

The source code of PIC 16F628A is written in assembly language and it is simulated in software using MPLAB IDE. Fig. 6 is as shown program which is running at MPLAB. According to the Fig. 7, assembly source files are successful to assemble.

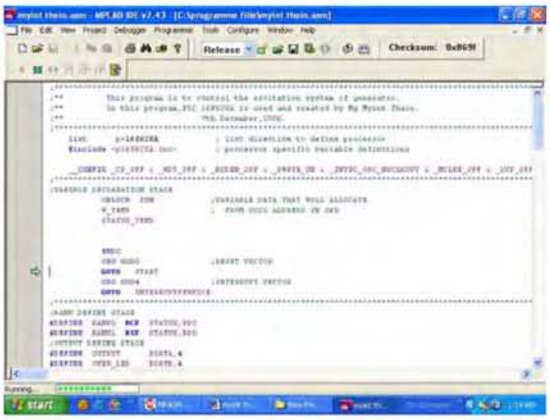

Fig. 6 Running Program at MPLAB

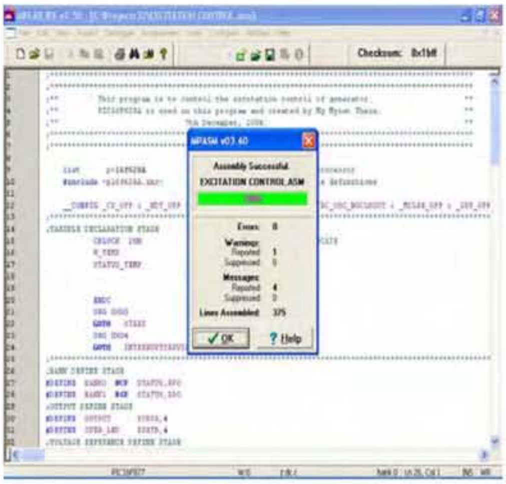

Fig. 7 Message Window

IV. PERFORMANCE TESTING AND RESULT OF AUTOMATIC VOLTAGE REGUALTOR

The main test points for this automatic voltage regulator circuit are comparator1 input (RAO/ANO), comparator2 input (RA1/AN1), comparator output (RA4/TOCK) and reference pin (RA2/RA3). The test results of automatic voltage regulator are shown in Table I to Table IV. The field control modes of automatic voltage regulator are shown in Table V.

TABLE I
TESTING WITH SUPPLY VOLTAGE 11V

NO.	Test Points		Voltages(V)
	Pin	**Description**	
1	RA2/RA3	Reference voltage	2.491
2	RA0/AN0	Detecting output voltage	1.719
3	RA1/AN1	Detecting output current	1.731
4	RA4/TOCK	Comparator output voltage	5.000

In this condition RA4 output is HIGH; Q_3 ON, Q_2 OFF and Q_1 ON, so the field current is increase.

TABLE II
TESTING WITH SUPPLY VOLTAGE 12V

NO.	Test Points		Voltages(V)
	Pin	**Description**	
1	RA2/RA3	Reference voltage	2.504
2	RA0/AN0	Detecting output voltage	2.026
3	RA1/AN1	Detecting output current	2.194
4	RA4/TOCK	Comparator output voltage	5.001

In this condition RA4 output is HIGH; Q_3 ON, Q_2 OFF and Q_1 ON, so the field current is increase.

TABLE III
TESTING WITH SUPPLY VOLTAGE 13V

NO.	Test Points		Voltages(V)
	Pin	Description	
1	RA2/RA3	Reference voltage	2.511
2	RA0/AN0	Detecting output voltage	2.351
3	RA1/AN1	Detecting output current	2.400
4	RA4/TOCK	Comparator output voltage	5.107

In this condition RA4 output is HIGH; Q_3 ON, Q_2 OFF and Q_1 ON, so the field current is increase.

TABLE IV
TESTING WITH SUPPLY VOLTAGE 14 V

NO.	Test Points		Voltages(V)
	Pin	Description	
1	RA_2/RA_3	Reference voltage	2.519
2	RA0/AN0	Detecting output voltage	2.701
3	RA1/AN1	Detecting output current	2.723
4	RA4/TOCK	Comparator output voltage	0.000

In this condition RA4 output is LOW; Q_3 OFF, Q_2 ON and Q_1 OFF, so the field current is decrease.

TABLE V
FIELD CONTROL MODES OF AUTOMATIC VOLTAGE REGULATOR

CMCOM register C1 Out	CMCON register C2 Out	RA4/T0CK1 (controlled by software)	Transistor			Field Current
			Q_3	Q_2	Q_1	
Low	Low	High	ON	OFF	ON	Increase
Low	High	Low	OFF	ON	OFF	Decrease
High	Low	Low	OFF	ON	OFF	Decrease
High	High	Low	OFF	ON	OFF	Decrease

V. CONCLUSION AND FUTURE WORK

In this paper, it proposed design and implementation of excitation control in generator operation. The Automatic Voltage Regulator (AVR) is designed by using the latest technology of PIC Microcontroller and the components available in local. In this project, PIC 16F628A is used as a sensing device and it has 2 kbytes of Program Memory. In the AVR circuit, the user can change the over voltage setting by adjusting the variable resistors or by changing the voltage reference setting in the application software. So, these AVR circuit card is upgraded with PIC microcontroller technology and used the components available in local. The principal particulars of the Automatic Voltage Regulator are 13 V DC for nominal output voltage, 11~14 V DC for the adjustable output voltage and 15 A for maximum field current. The over voltage setting 14 V is suitable for this running condition. The advantages of this AVR card is that the system cost is decreased and system reliability and design flexibility are increased. This AVR card is well suited to the high production requirements of mass production. If this AVR card is produced in the nation, it can give the benefit for the technical support and economy.

In this paper, it has proposed excitation control theory, design and calculation of automatic voltage regulator, assembly source file for AVR circuit. And it also highlights the important role of automatic voltage regulator for generator.

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