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Three Phase Automatic Voltage Regulator Using Microcontroller

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The AVR (automatic voltage regulator) is a device which maintains a constant output voltage irrespective of the change in input voltage over time. Generally the AVR retains the system voltage constant to a particular value from rising or falling from the specified value. In power system, generators are connected in parallel with the system bus. The change in system voltage due to the variation of the system load and fault hamper the system stability. The system frequency as well as the power factor of the interconnected system is also affected due to the variation of the system voltage. In order to restore system voltage within permissible limit in power system, the variation of voltage can be controlled from generation side by using voltage regulator. The voltage regulator controls the system voltage by increasing or decreasing the excitation of the generator according to the system requirement. However in large power system, the reactive power compensator pre-dominates the voltage regulator in case of compensation of system voltage. Therefore in large system both the reactive power compensator and voltage regulator are used for compensation of system voltage. In this paper, the design and operation of three phase AVR is discussed. In this design, TRIAC (triode for alternating current) is used as a bidirectional switch for changing the tap position of the transformer according to the system requirement which feeds voltage to the excitation system of the generator. The ATmega8 microcontroller is used for controlling the switching of TRIACs. The triggering of a particular TRIAC is determined by the microcontroller after making comparison between system and reference voltages. In order to keep isolation between the system voltage and TRIAC, optocoupler is used. The use of microcontroller eases the controlling of the three phase AVR for changing various tap positions of the transformer according to the system requirement. The Proteus 7.8 is used for simulation of the designed circuit. The designed AVR provides about 70% voltage regulation and fast response time in comparison to conventional AVRs.

Introduction

The variation in system voltage is a common phenomenon in electrical system. Since the electrical power system in an interconnected electrical network therefore the change in system voltage causes effect not only at generation side but also at consumer premises [1], [2]. Therefore the quality transfer of electrical power to the consumers is hampered. Generally electricity with constant standard voltage and frequency is termed as quality power where there is no fluctuation of voltage and frequency [3]. In case of interconnected electrical power system, the system stability greatly depends on constant terminal voltage of synchronous generators connected in parallel irrespective of effect of system fault and variation of system load [3]. The effect of faults and variation of load cause effect not only on system voltage but also on speed and frequency of alternators as well as the real and reactive power of the overall power system get affected [2,3]. Moreover the hunting of alternators occur which also hampers the system stability. The damper winding of generator prevents the short time hunting but long persisting hunting cannot be prevented by damper winding. The governor of generator controls the fuel intake according to the output power requirement of the generator whose function also hampers due to long persisting hunting [4]. In order to restore system balance, the voltage regulator is used along with the reactive power compensator. The excitation of generators must be continuously regulated to match the reactive power demand of the system; otherwise the voltages of various system buses may go beyond the prescribed limits [4,5]. At the consumer premises, the three phase consumers like manufacturing units and industries are greatly affected by the fluctuation of system voltage and frequency. Most electrical and electronic equipments at the consumer end are run by voltage stabilizers which keeps the output voltage constant irrespective of the variation of input voltage. Even some electronic devices have inbuilt voltage stabilizer in order to prevent voltage fluctuation. In electrical power stations, voltage regulators are used for generators in order to keep the generated voltage within the permissible limit [2]. The controlling of system voltage from the generation side is better option than that from the consumer side therefore the importance of voltage regulator is more than voltage stabilizer in power system[3].

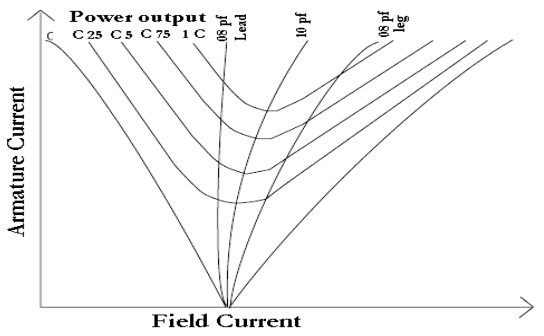

Fig. 1 V curve of alternator

In this paper, the design and operation of three phase automatic voltage regulator (AVR) is discussed which can be used for voltage regulation of alternator. Most AVRS are discontinuous type which are simpler than the continuous type but have longer response time and less accuracy. These types of AVRs are not feasible for large interconnected power system with many alternators is in synchronism with bus bars where voltage fluctuation needs to remove within short time [5]. The designed AVR is of static continuous type which has fast response time and high field ceiling voltage for forcing rapid changes in the generator terminal voltage during fault and variation of load. The microcontroller is used for controlling the overall operation of the designed AVR which helps in fast response in accordance with the fluctuations in voltage of the alternator. Like conventional AVR, it controls the field excitation voltage of the alternator for adjusting the generated voltage.

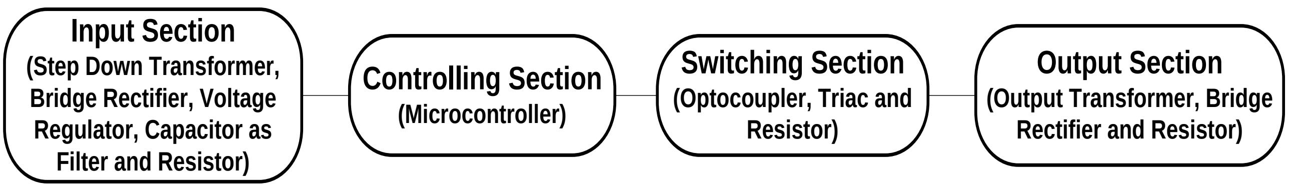

Fig. 2 Block diagram of the AVR

AVR and Its Classification

An automatic voltage regulator is an electronic device which is capable of delivering relatively constant output voltage irrespective of change in input voltage and load current over time [1]. Generally the automatic voltage regulator retains the system voltage constant to a particular value from rising or falling from the specified value.

When a generator is connected to bus running in parallel with many other generators, the system voltage needs to remain same for all the generators which are connected in parallel [3]. The system frequency of the interconnected system is also affected due to the variation of system voltage which may cause problem in overall system. Due to complex nature of power system the overall system voltage, the variation of system of voltage can be controlled from generation side by using voltage regulator [6]. The voltage regulator controls the system voltage by increasing or decreasing the excitation of the generator according to the system requirement. However for large power system, the voltage regulator has less effect in system voltage compensation than that of the var compensator [2]. Since the variation of power factor and reactive power is also related with the variation of system voltage which can only be compensated by var compensator [7]. Therefore in large system both the var compensator and voltage regulator are used for compensation of system voltage.

The variation of load causes unbalance in electrical power system which also affects the terminal voltage of the generator. Moreover the system fault also hampers the terminal voltage of the parallel connected generators which are in synchronism with the overall electrical network [3]. By controlling the field excitation, the generator induced voltage can be controlled. The automatic voltage regulator works on the principle of error detection. The output voltage of the alternator which is sensed by a potential transformer is compared with a reference [1]. The difference between the actual and reference voltage is the voltage error. The voltage error is amplified through an amplifier (rotary, magnetic or static) and fed to the field circuit of main exciter or pilot exciter. Thus the amplified error signal controls the excitation of the main exciter or pilot exciter through a buck or boost action [5]. A control of exciter output leads to a control of the main alternator voltage. There are various modes of controlling the voltage of the alternator which are discussed below.

Excitation Control

The rotor excitation can be provided through slip rings and brushes by means of DC generators mounted on the same shaft as the rotor of the synchronous generator. However, modern excitation systems comprises of rotating rectifiers which is also known as brush-less excitation [8]. There is a direct relationship between the generator terminal voltage and the quantity of current flowing in the field windings [4]. It provides a means for regulating the terminal voltage of the generator to match a desired set point and to provide damping for power system oscillations. The variation in field excitation of generator is also helpful for reactive power compensation and improvement of power factor of the overall system [2].

Power Factor and Armature Current Control

The armature current as well as the generated power of a synchronous generator can be controlled by adjusting its field excitation. The relationship between armature current and field current at constant terminal voltage and power is shown in Figure 1. This curve is called V curve which represents generator's characteristics [4]. The output power of a synchronous generator is,

$$P_{3\phi} = R[3VI^{*}\alpha] = 3|V|\,|Ia| \cos\theta$$

The developed power at fixed values of V, Ia and cos θ must be constant and α is firing angle. In case of reduction of excitation, the angle of the current phasor (as well as the power factor) goes from lagging to leading. Any reduction in excitation below the stability limit for a particular load will cause the rotor to pull out of synchronism. Therefore excitation plays a significant role in generator's operation.

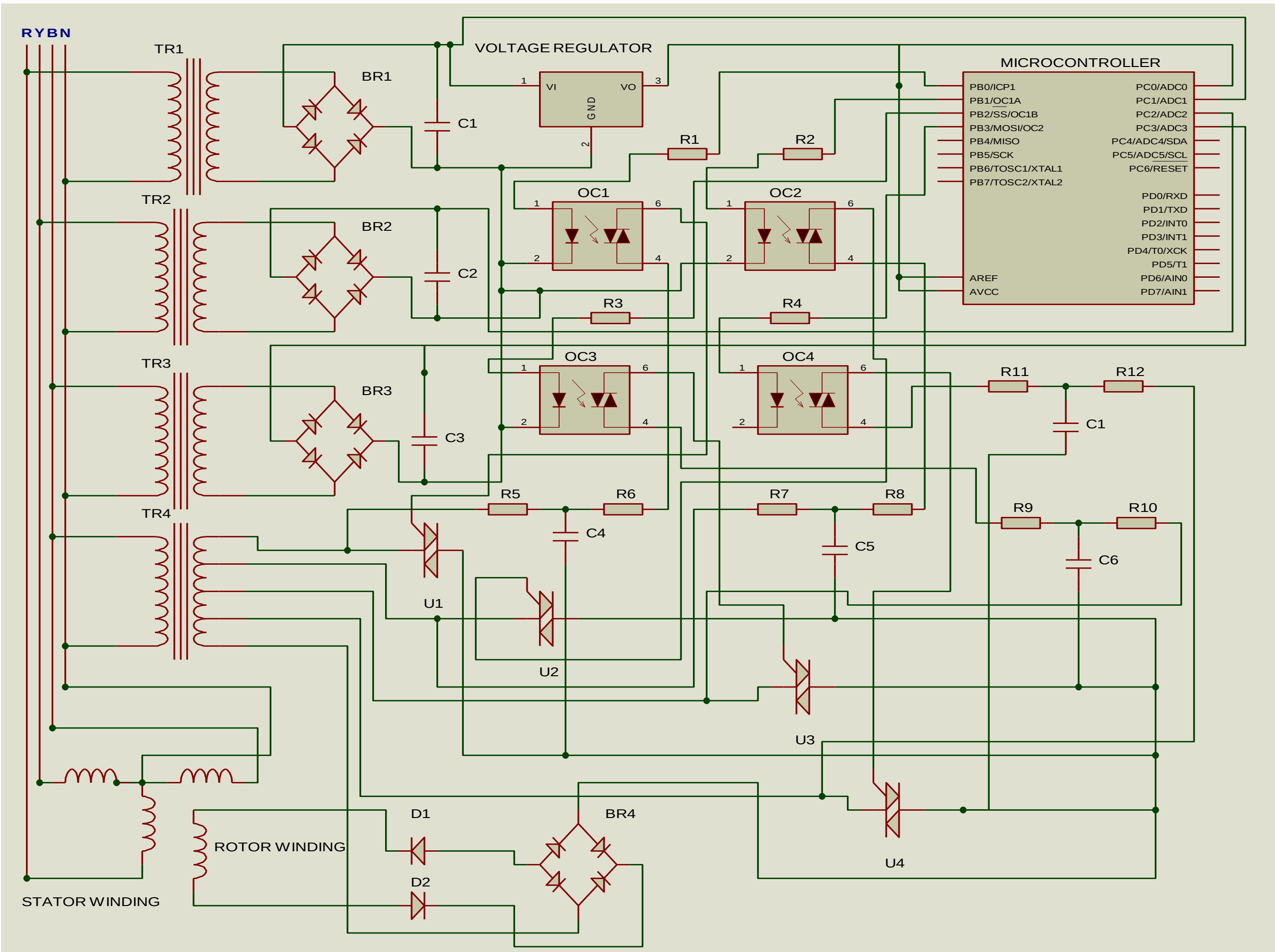

Fig. 3 Complete circuit diagram of AVR

Design of Three-Phase AVR

Design Considerations of AVR

The variation of system voltage, current and frequency has considerable influence in case of design of voltage regulator [7,9]. The accuracy of operation and response time are important considerations in design. Moreover the distortion in output waveform should also be considered for design [8, 10]. The AVR used for alternators generally regulates the field voltage as well as field current in order to keep the generator voltage within the permissible limit. The design of the AVR for alternator depends on the voltage and speed regulation of the alternator, the maximum and minimum load on the generator, the power factor of the load, the magnetization curve of the generator and the characteristics of the exciter [1-6]. .

Block Diagram of the Designed AVR

The block diagram of the designed circuit of the three phases AVR is shown in Figure 2. The whole circuit can be divided into four blocks according to its operation. The first block is the input section which is used for conversion of phase voltages of generator into dc voltages in order to compare with a reference voltage. The phase voltages of the three phase alternators are stepped down to 5 V and then converted to 5 V DC by using bridge rectifier. Three transformers are used for stepping down the voltage whereas bridge rectifiers are used for conversion to DC voltage. In order to compare the generated voltages with the reference voltage, a fixed reference voltage of 5 V DC is generated by using voltage regulator IC. These DC voltages are used for controlling the overall circuit operation. The second block is the controlling section which consists of microcontroller. The microcontroller compares the phase voltages of the generator with the reference voltage and generates corresponding output according to the operational logic which is defined in its program. The third section is the switching section which has optocoupler and triac as switching device. The optocoupler provides an electrical isolation between input and output section of the circuit which helps in avoiding electromagnetic interference between two sections [10]. This increases the possibility of getting desired output. The output from the controlling section of the microcontroller is used to trigger the corresponding triac according to the control logic. The optocoupler optically transfers the output signal of microcontroller to the gate of the triac for its switching operation [7]. The final section is the output section where different tap positions of the output transformer are changed according to the operational sequence of the traics of the switching section. When one particular tap position is selected then that corresponding AC voltage is converted to DC voltage by the bridge rectifier. The pulsating DC is then fed to the rotor field winding for excitation. In order to avoid feedback of power from rotor circuit to the AVR, blocking diode is used.

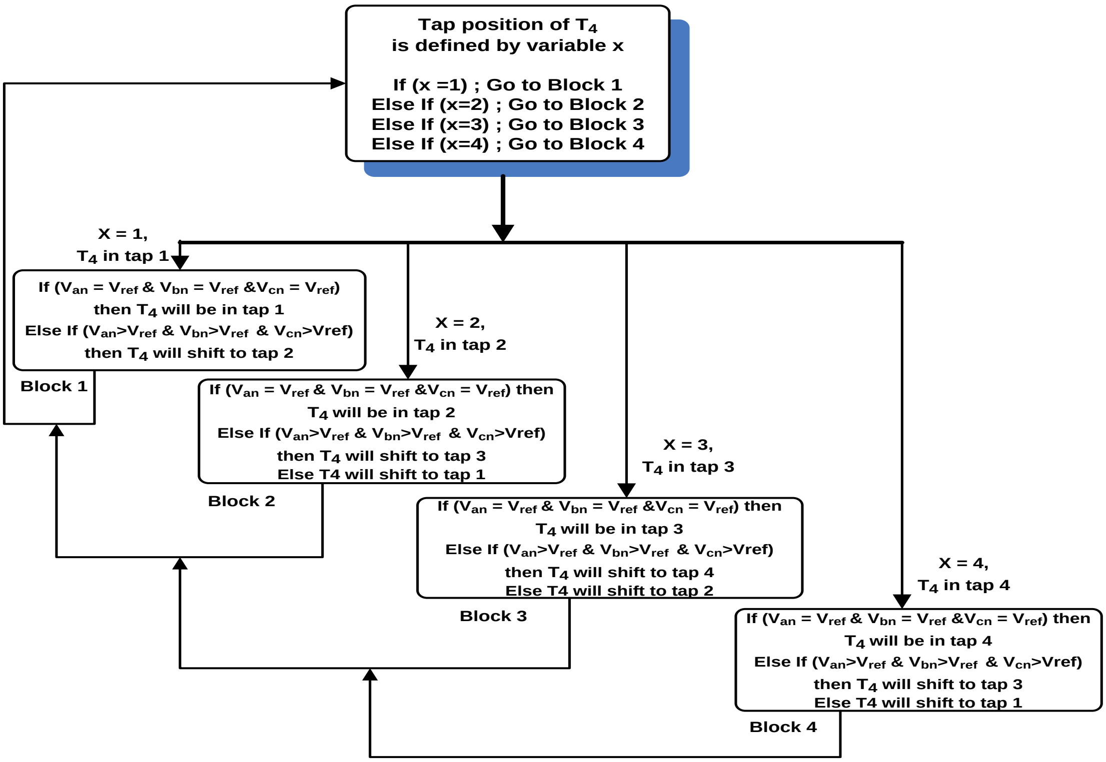

Fig. 4 Operational logical diagram of AVR

Designed Circuit and Its Operation

The complete circuit diagram is shown in the Figure 3. The generated phase voltages of the altenator are stepped down from 415 V to 5V by using transformers TR1, TR2 and TR3. Then these voltages are converted to 5V DC by using bridge rectifiers (BR1, BR2 and BR3) and capacitors. The bridge rectifiers are GBPC35005 type which has maximum current capacity of 35 A. The voltage rating of each transformer TR1, TR2 and TR3 is 415V/5 V. In order to get constant reference voltage of 5V, IC 7805 is used which acts as voltage regulator. The microcontroller, ATmega8 is used for controlling the overall operation of the AVR. Three generated voltages of the alternator are converted to DC voltages and then compared with the reference voltage in the microcontroller. These voltages are connected to pins PC0 –PC3 of the Atmega8 [11]. The AVR continuously check the alternator’s generated voltages with the reference voltage and increase or decrease the excitation voltage in the rotor winding accordingly. The microcontroller gives outputs in pins PB0 – PB3 according to the controlling logic in its program [11]. The operational logical diagram of the microcontroller is shown in Figure 4.

The outputs of the microcontroller drive four optocouplers (OC1-OC4). The MOC3021 type optocouplers are used for this design. The non zero crossing optocouplers ensure high isolation between input and output. They provide trigger pluses to triacs, U1–U4 according to the operational control logic. The Q 6010N4 type triac is used for the design which has maximum voltage and current handling capacity of 600 V and 10 A respectively. For this design, four probable tap positions are considered for the output transformer TR4 and it is possible increase the number of tap positions according to the system requirement. TR4 is a 1:1 ratio transformer whose input and output voltages remain 220V. In order to avoid short circuit in the output transformer in case of changing tap position, the natural commutation is used for tuning off the triacs so that two triacs cannot be turned on at the same time. When a particular triac is truned on, it delivers voltage from a particular tap position of transformer, TR4 to the rotor winding through a bride rectifier BR4. The bridge rectifier provides pulsating DC to the rotor widning. The diodes D1 and D2 are used to block feedback of power from rotor circuit to the AVR. The excitation voltage can easily be changed by varying the tap position in accordance with the change in generated voltage of the alternator.

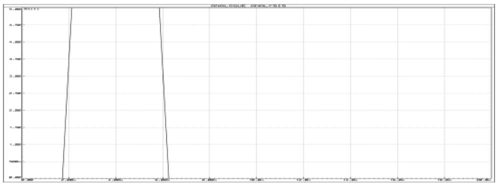

Fig. 5 Generated trigger pulse for triac.

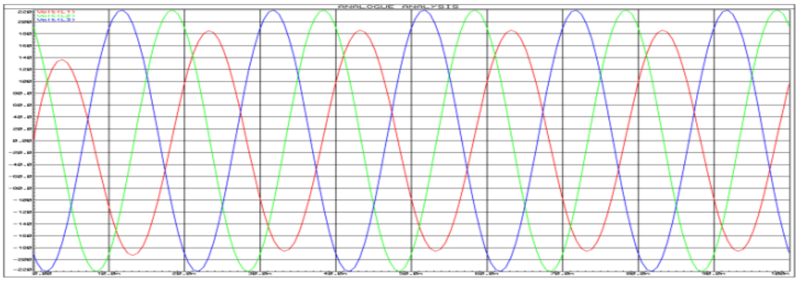

Fig. 6 Variation of excitation voltage with generated voltage. Red line represents variation of excitation voltage.

Logical Operation of AVR

For proper logical operation of microcontroller it is required to define the initial tap position of the output transformer TR4. The ATmeaga8 checks the tap position at the beginning of logical operation and performs this task in close loop. After initialization of tap position, four different blocks of logical comparison has set. In each block, the microcontroller compares the generated phase voltages of the alternator with the reference voltage. If the generated voltages are equal to the reference voltage then the corresponding triac of the initial tap position remains on and thereby the tap position of the transformer doesn't change. When any generated phase voltages of the alternator becomes greater than the reference voltage then the corresponding triac of the lower tap position is turned on and thereby the transformer TR4 moves to lower tap position from its initial tap position. In this way the alternator's rotor winding gets lower excitation voltage since the generated voltage becomes higher than the rated value. Similarly when any generated phase voltages of the alternator becomes lower than the reference voltage then the corresponding triac of the higher tap position is turned on and thereby the transformer T4 moves to higher tap position from its initial tap position. So the alternator's rotor winding gets higher excitation voltage because the generated voltage becomes lower than the rated value.

Table 1 Change in excitation voltage with the generated voltage.

Generated phase voltage of three phase alternator (V)			Difference in Voltage from reference voltage (V)	Rotor Excitation Voltage (V)	Rotor current (A)
R-N	Y-N	B-N			
415	415	415	0	180	19
415	415	400	15	200	18
405	400	400	10	190	18.5
410	415	415	5	185	17.9
390	390	415	25	210	17.5
420	415	415	-5	212	17.2
415	415	425	-10	215	17
415	430	415	-15	220	16.5

Tests and Results

The AVR is designed and simulated by using Proteus 7.8. software. Later in order to verify the performance of the designed three phase AVR, it is used for controlling excitation of a 3 phase, 5 kW diesel generator. From the test results it is observed that the response time of the AVR is very fast (in millisecond) with the change in alternator voltage. Moreover smooth and accurate switching of the triacs increases the reliability of the AVR's operation at different load and power factor of the alternator. The gate trigger pulse for traic and the change in variation of excitation voltage are shown in Figures 5 and 6 respectively.

Table 1 shows the test results of the change in excitation voltage with the variation of generated voltage of the diesel alternator. It can be inferred from the test results that the designed three phase AVR can regulate the alternator voltage up to 70% of the rated value.

Conclusions

Three phase AVR is widely used for voltage regulation of alternators. The main consideration of this work is to design cost effective AVR which has better voltage regulation and fast response time in case of change in generated voltage from rated value. The designed AVR can be used for up to 10 kVA rated alternator. The use of microcontroller not only eases the controlling but also provides reliable operation of the overall circuit. Due to directional switching capability, triac is used for switching device. The optocoupler provides isolation between input and output section of the designed circuit which is essential for any electronic circuit. The designed AVR can provide up to 70% voltage regulation for alternator which is higher than that of the conventional AVRs which provide up to 60% voltage regulation. The excitation current varies within the range of 1 to 15A whereas excitation voltage varies from 180 to 220 V. However for smooth operation and better voltage regulation the number of taps in transformer TR4 can be increased. The IGBT or MOSFET can be used in place of triac for better switching performance.

Notes and References

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