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Embedded Based Control of AC Automatic Voltage Regulator

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ABSTRACT— In recent years, the scale of power systems has been expanding, and with that expansion stable power supply and smooth power system operation is becoming increasingly important. One measure for increasing stability is to improve the main circuits by raising the voltage in power transmission lines, which makes use of AVR (automatic voltage regulator), is attracting attention because of its inherent cost advantage. An AVR is configured by an input inductor, an output filter, a small – capacitance dc capacitor, and a four-arm power converter. This four-arm power converter acts as an ac buck converter when the utility voltage is higher than the specified voltage. On the contrary, this four-arm power converter acts as an ac boost converter when the utility voltage is lower than the specified voltage. The capacitance of the dc capacitor in the four – arm power converter is very small. Hence, the size and cost can be reduced, while the reliability and power efficiency can be increased.

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***Keywords*— AVR, Power Converter**

I. INTRODUCTION

Computer-related precision equipment has been widely used in many fields, and it requires a high-quality power source in maintaining normal operation. Voltage regulation is an important issue in the field of power quality improvement. Conventionally, a tap-changer autotransformer is a popular solution to the problems of under- and over-voltages. The tap-changer autotransformer connects the utility and a load, and it provides the load with a stable voltage by adjusting the tap of the transformer. However, voltage regulation of the tap changer autotransformer has some disadvantages including step regulation of the supply voltage, large installation volume, and inability to improve the voltage distortion.

II. FOUR ARM AUTOMATIC VOLTAGE REGULATOR

A. Conventional system

The conventional Three arm AVR is shown in Fig. 1.1. The conventional three-arm AVR acts as an ac boost converter when the utility voltage is lower than the specified voltage, and it acts as an ac buck converter when the utility voltage is higher than the specified voltage.

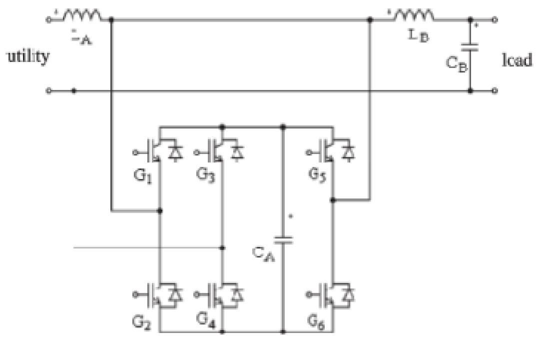


Fig. 1.1 Conventional Three -arm AVR.

Hence, the output voltage of the AVR can be maintained at the specified voltage. The power demanded by the load is directly supplied by the conversion results of the power converter (ac to ac). Moreover, the power electronic switches in only one arm of the three-arm power converter are switched in high frequency, while those of the other arms are switched in low frequency. The switching power loss is reduced, and no transformer is required. The dc bus voltage of the proposed three-arm AVR is a full-wave rectified voltage. Hence, the use of a large dc capacitor in sustaining a Constant dc voltage is avoided, and only a small dc capacitor is employed to act as a Snubber and filter circuit. The disadvantages of the conventional method is one among the 3 arm is shared by converter & inverter so current rating is high. To avoid this the proposed method is implemented by using four arm.

B. Proposed System

This project proposes a novel Four -arm AVR. The proposed Four -arm AVR acts as an ac boost converter when the utility voltage is lower than the specified voltage and it acts as an ac buck converter when the utility voltage is higher than the specified voltage. Hence, the output voltage of the AVR can be maintained at the specified voltage. The power demanded by the load is directly supplied by the conversion results of the power converter (ac to ac). In comparison with the conventional Four arm power converter which requires double conversion (ac to dc and dc to ac), the proposed Four -arm AVR requires only a single conversion. Moreover, the power electronic switches in only one arm of the Four -arm power converter are switched in high frequency, while those of the other arms are switched in low frequency. The switching power loss is reduced, and no transformer is required. In comparison with the conventional three -arm AVR with a constant dc bus voltage, the dc bus voltage of the proposed Four -arm AVR is a full-wave rectified voltage. Hence, the use of a large dc capacitor in sustaining a constant dc voltage is avoided, and only a small dc capacitor is employed to act as a snubber and filter circuit. Consequently, the proposed Four -arm AVR has the advantages of reduced installation cost and volume, as well as increased reliability and power efficiency.

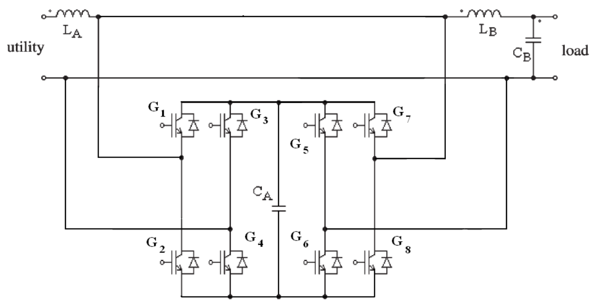


Fig. 1.2 Circuit configuration of the proposed Four -arm AVR.

C. System Configuration and Operation Theory

The circuit configuration of the proposed Four -arm AVR is shown in Fig. 1.2 This AVR comprises a Four -arm power converter, an input inductor, a small dc capacitor, and an output filter. The Four -arm power converter of the proposed AVR acts as an ac boost converter when the utility voltage is lower than the specified voltage, and it acts as an ac buck converter when the utility voltage is higher than the specified voltage. Hence, the output voltage of the AVR can be maintained at the specified voltage. Since the power converter operates as an ac boost converter or an ac buck converter, the dc bus voltage of the power converter is a rectified utility voltage where the amplitude can be controlled. The dc bus voltage of the proposed Four -arm AVR with a full-wave rectified voltage is different from that of the conventional three -arm AVRs with a constant dc voltage. Hence, there is no need to use a large dc capacitor of several thousands of microfarads in sustaining a constant dc voltage, and only a small dc capacitor of several tens of microfarads is applied to act as a snubber and filter circuit.

AC Boost Mode

When the utility voltage is lower than the specified load voltage, the Four -arm power converter operates as an ac boost converter. In this situation, the first and third arms are controlled by a square signal with the fundamental frequency of utility, and the second arm is controlled by a high-frequency pulse width modulation (PWM) signal. Fig. 1.3 shows the operating circuit of the proposed AVR under the ac boost mode. The inductor *LA* is applied as the energy storage element when the Four -arm power converter operates as an ac boost converter. Fig. 1.3(a) shows the operating circuit of the ac boost converter when the utility voltage is in the positive half-cycle. As shown in Fig. 1.3(a), *G*1 and *G*6 are always on, and *G*2 and *G*5 are always on off. When *G*3 is on and *G*4 is off, the inductor *LA* is energized through the utility, *G*1 and *G*3. In this duration, the inductor voltage (*v*LA) is given by

$$V_{LA}=V_s \qquad (1)$$

where *vs* is the utility voltage. The current of the inductor *LA* is increased. The energy stored in the inductor *LA* will be released through *G*1 and *G*4 to the dc capacitor of the Four -arm power converter when *G*3 is off and *G*4 is on, and the inductor voltage becomes

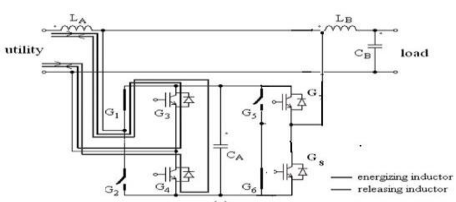
$$V_{LA} = V_s - V_c \qquad (2)$$

where *vc* is the dc bus voltage of the Four -arm power converter. Since the dc bus voltage of the Four -arm power converter will be higher than the utility voltage under the ac boost mode, the current passing through the inductor *LA* is decreased. When the current passing through the inductor *LA* is continuous, by applying Faraday's law, the voltage-second balance can be represented as

$$V_sDT + (V_s - V_c)(1\text{-}D)T = 0 \qquad (3)$$

where *D* and *T* are the duty ratio and the switching period of *G*3, respectively. From (3), the amplifier gain can be derived as

$$M_v = V_c/V_s = 1/(1-D) \qquad (4)$$



(a)

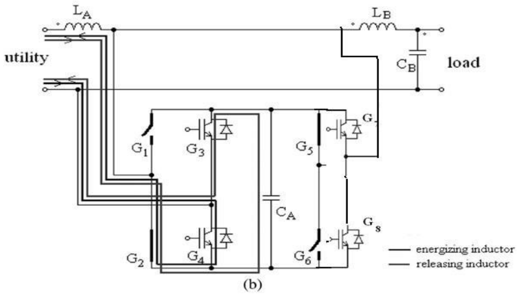


Fig. 1.3Operating circuit of the proposed AVR under the ac boost mode.

(a) Positive half-cycle. (b) Negative half-cycle.

The operation of the Four -arm power converter is similar to the dc/dc boost converter during the positive half-cycle. Fig. 1.3(b) shows the operating circuit while the utility voltage is in the negative half-cycle. As shown in Fig. 1.3(b), *G*2 and *G*5 are always on, and *G*1 and *G*6 are always off. The inductor *LA* is energized from the utility through *G*2 and *G*4 when *G*4 is on and *G*3 is off, and the energy stored in the inductor *LA* will be released to the dc capacitor of the Four -arm power converter through *G*2 and *G*3 when *G*4 is off and *G*3 is on. The operation of the Four -arm power converter is also similar to that of the dc/dc boost converter under the negative half cycle, and the amplifier gain is also the same as (4). As shown in (4), the dc bus voltage of the Four -arm power converter is a rectified ac voltage which is higher than the utility voltage when serving as an ac boost converter, and the amplifier gain is determined by the duty ratio *D*. The dc bus voltage of the Four arm power converter is inverted by the third arm, and then, it passes through the output filter so as to supply a load voltage higher than the utility voltage. Hence, the proposed AVR can sustain the load voltage at the specified voltage under the sag of the utility voltage. The efficiency of the dc/dc boost converter is dependent on the duty ratio. Hence, the efficiency of the proposed AVR is also dependent on the amplifier gain shown in (4). The higher the amplifier gain is, the lower the efficiency of the proposed AVR will be. Since the voltage across the inductor *LA* is smaller than that of the conventional Four -arm AVR, the inductance of the inductor *LA* in the proposed AVR can be reduced. The ripple of the input current can be derived as

$$\Delta I_{LA} = V_s D / L_A f \qquad (5)$$

where *f* is the switching frequency. As shown in (5), the ripple of the input current is dependent on the duty ratio, switching frequency *f*, and inductor *LA*. In the continuous conduction mode, the minimum product of *LA* and *f* can be derived as

$$(L_A f)_{min} = D(1-D)^2 Z/2 \qquad (6)$$

where *Z* is the load. Hence, the inductor *LA* can be determined by the switching frequency, specified ripple current, range of the duty ratio, and load. As shown in Fig.1.3, the dc capacitor *CA* and output filter (*LB*, *CB*) form as a third-order low-pass filter to filter out the switching harmonic in the output voltage. Hence, a lower capacitance dc capacitor *CA* of several tens of microfarads can be selected.

AC Buck Mode

When the utility voltage is higher than the specified load voltage, the Four -arm power converter operates as an ac buck converter. In this situation, the first and second arms are controlled by a square signal with the fundamental frequency of utility, and the third arm is controlled by a high-frequency PWM signal. The inductor *LB* serves as the energy storage element when the Four -arm power converter operates as an ac buck converter. Fig. 1.4(a) shows the operating circuit of the ac buck converter when the utility voltage is in the positive half-cycle. As shown in Fig. 1.4(a), *G*1 and *G*4 are always on, while *G*2 and *G*3 are always off. The utility voltage is rectified through the first and second arms of the Four -arm power converter; thus, a rectified utility voltage appears at the dc bus of the Four -arm power converter. Both the input inductor *LA* and the dc capacitor *CA* performed as a low-pass filter. When *G*5 is on and *G*6 is off, the inductor *LB* is energized from the rectified utility voltage through *G*4 and *G*5. In this duration, the inductor voltage (*v*LB) can be represented as

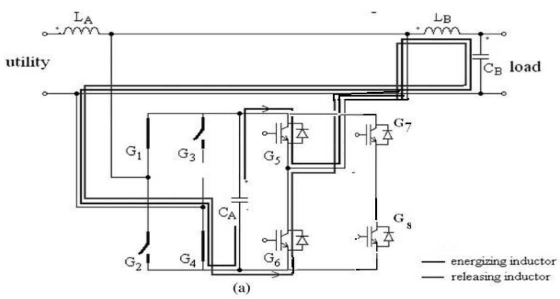
$$V_{LB} = V_c - V_o \qquad (7)$$

where *vo* is the load voltage. Since the rectified utility voltage is higher than the load voltage, the current passing through the inductor *LB* will be increased, and it stores energy in this duration. The energy stored in the inductor *LB* will be released to the load through *G*4 and *G*6 when *G*5 is off and *G*6 is on, and the inductor voltage is

$$V_{LB} = - V_o \qquad (8)$$

Hence, the current passing through the inductor *LB* will be decreased. When the current passing through the inductor *LB* is continuous and the Faraday's law for the inductor *LB* is used, the voltage-second balance can be represented as

$$(V_c-V_o)DT + (-V_o)(1-D)T = 0 \qquad (9)$$



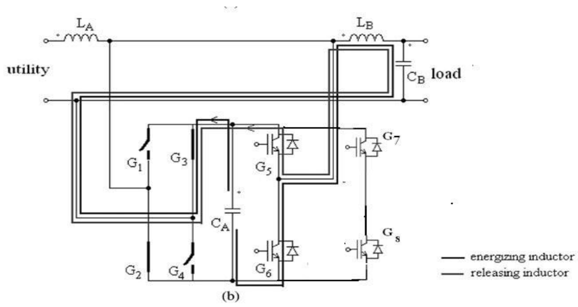


Fig. 1.4 Operating circuit of the proposed AVR under the ac buck mode.
(a) Positive half-cycle. (b) Negative half-cycle.

where *D* and *T* are the duty ratio and switching period of *G*6, respectively. From (9), the dropped gain can be derived as

$$M_v = V_o/V_c = D \qquad (10)$$

Since the input inductor *LA* and the dc capacitor *CA* form a low-pass filter, the rectified voltage of the Four -arm power converter is close to the absolute utility voltage. Hence, the operation of the Four -arm power converter is similar to the dc/dc buck converter under the positive half-cycle. Fig. 1.4(b) shows the operating circuit when the utility voltage is in the negative half-cycle. As shown in Fig. 1.4(b), *G*2 and *G*3 are always on, while *G*1 and *G*4 are always off. The utility voltage is rectified through the first and second arms of the Four -arm power converter; thus, the dc bus voltage of the Four -arm power converter is the negative utility voltage. The inductor *LB* is energized by the rectified utility voltage through *G*3 and *G*6 when *G*5 is off and *G*6 is on, and the energy stored in the inductor *LB* will be released to the load through *G*3 and *G*5 when *G*5 is on and *G*6 is off. The operation of the Four -arm power converter is also similar to the dc/dc buck converter under the negative half-cycle, and the dropped gain is the same as that in (10). As shown in (10), the load voltage is lower than the dc bus voltage of the Four -arm power converter. The dc bus voltage of the Four -arm power converter is close to the absolute utility voltage. Hence, the relationship between the utility voltage and the load voltage is close to (10) when serving as an ac buck converter. The dropped gain is determined by the duty ratio *D*. Hence, the proposed AVR can sustain the load voltage at a specified voltage under the swell utility voltage.

Mode	Cycle	G1	G2	G3	G4	G5	G6	G7	G8
Boost Mode	Positive	ON	OFF	OFF	ON	ON	ON	ON	OFF
		ON	OFF	OFF	ON	OFF	OFF	ON	OFF
	Negative	OFF	ON	ON	OFF	OFF	OFF	OFF	ON
		OFF	ON	ON	OFF	ON	ON	OFF	ON
Buck Mode	Positive	OFF	ON	ON	ON	ON	OFF	OFF	ON
		OFF	ON	OFF	OFF	ON	OFF	OFF	ON
	Negative	ON	OFF	OFF	OFF	OFF	ON	ON	OFF
		ON	OFF	ON	ON	OFF	ON	ON	OFF

Table 1.1 Mode of operation of the proposed AVR under the ac buck and boost mode.

Since the voltage across the inductor *LA* is smaller than that of the conventional Four -arm AVR, the inductance of the inductor *LB* in the proposed AVR can be reduced. The ripple of the input current can be derived as

$$\Delta I_{LA} = (V_c - V_o)D / L_B f \quad (11)$$

In the continuous conduction mode, the minimum product of *LB* and *f* can be derived as

$$(L_B f)_{min} = (1-D)Z/2 \quad (12)$$

Hence, the inductance of the inductor *LB* can be determined by the switching frequency, specified ripple current, range of the duty ratio, and load. The ripple of the output voltage can be derived as

$$\Delta V_o = V_o (1-D) / 8 L_B C_B f^2. \quad (13)$$

The capacitor *CB* can be determined for a specified output ripple voltage. As shown in Fig. 1.4, the input inductor *LA* and the dc capacitor *CA* form a low-pass filter to filter out the switching harmonic in the input current.

The amplifier gain *Mv* shown in (4) and (10) is derived from the continuous conduction mode of the inductor current. If the inductor current is discontinuous, the duty ratio must be decreased slightly in obtaining the same amplifier gain. However, this problem can be solved effectively by a close-loop control of the output voltage. The output voltage will deviate from its desired value when the inductor current is discontinuous, and the controller of the output voltage can correct the duty ratio to trace the desired value. As discussed earlier, the conventional Four -arm AVR utilizes a high-capacitance dc capacitor to provide a constant dc voltage, and at least four power electronic switches of the conventional AVR are switched in high frequency. In accordance with the proposed AVR, either the second or the third arm is controlled via high frequency switching. As a result, the power electronic switches of only one arm are switched in high frequency, while those of the other arms are switched in the fundamental frequency of the utility voltage. Hence, the switching loss can be reduced effectively. Moreover, the high-capacitance dc capacitor and high-inductance inductors employed in the conventional Four arm AVR are replaced by a small-capacitance dc capacitor and small-inductance inductors in the proposed AVR. The present design achieves lower cost and smaller volume for installation as well as lower switching loss.

D. Comparison between existing and proposed system

System	Existing System		Proposed System			
	Boost mode	Buck mode	Open loop		Closed loop	
			Boost	Buck	Boost(set value= 400v)	Buck (set value =100 v)
Input voltage	143V	160V	143V	160V	143V	160V
Output voltage	220V	120V	500V	50V	400V	100V
Output current	7.5A	11A	0.6A	2A	0.5A	7A

Table 1.2 Comparison between conventional and proposed system

E. Hard ware Model

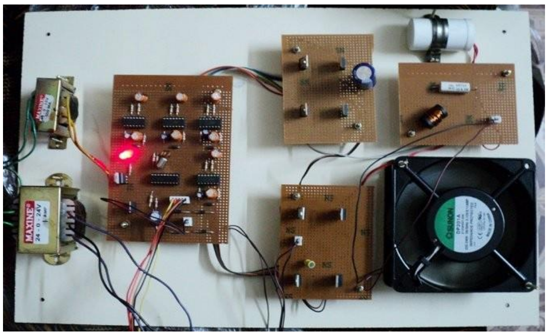


Fig 1.5 Hardware model for proposed system

Figure 1.5 shows the hardware model for proposed system. It includes the power supply unit , Driver Unit and Power Circuit unit . The output is depend on the firing angle of PIC microcontroller such as if the input of 24V is given in the power circuit the output is 20V or less.

III. CONCLUSION

This project has presented an AVR configured by a Four -arm power converter has been proposed in this project. The proposed AVR is operated as an ac boost under over-voltage of the utility, and it is operated as an ac buck when the utility is under-voltage. Moreover, there is no need to use a large dc capacitor in sustaining a constant dc voltage. Hence, the size can be decreased, the cost can be reduced, and the life of the power converter can be extended. A prototype is developed and tested to verify the performance of this AVR. The experimental results verify that the performance of the proposed AVR is as expected.

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