International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 14, No. 2, June 2023, pp. 719~726
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v14.i2.pp719-726

Simulation model for pulse width modulation-voltage source inverter of three-phase induction motor

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Article Info

Article history:

Received Sep 14, 2022
Revised Dec 30, 2022
Accepted Jan 13, 2023

Keywords:

Pulse-width modulation
Speed
Three-phase induction motor
Torque
Voltage source inverter

ABSTRACT

Induction motor has been widely applied in many sectors, as it has the advantages of simplicity, toughness and can withstand hard environment conditions. The working of such motor in constant voltage/frequency (V/F) speed control method has been popular since the introduction of the power electronic devices, which consequently make the implementation of this method simpler and effectives. The V/F speed control is dominated choice for many applications, especially open loop control and also for closed loop control when the accuracy is not a crucial issue. This study deals with two cases of controlling open and close of the electronic switches. The first with equal intervals by placing regular pulses at the opening and closing periods, and the second using three-phase pulse width generator, through which the control of different periods is carried out according to the required control. Four models have been simulated in this study including, three-phase induction motor at constant torque (constant load) as well as at variable torque (variable load), modeling of PWM-VSI for three-phase induction motor at constant torque (constant load) as well as at variable torque (variable load). The results have shown that speed profile of the IM can be improved by controlling the invertor using PWM technique.

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1. INTRODUCTION

Three-phase induction motors (3ϕ IMs) have been utilized in both constant and variable speed applications. Since they are distinguished by having reliable and robust rotor configurations with no commutators, which consequently eliminate the commutating problem that is the main drawback of conventional direct current motors (DCMs). In fact, the 3ϕ IMs, particularly, squirrel cage types have the following merits over the conventional DCMs: i) less cost, ii) lighter weight and less volume, iii) need less maintenance, iv) deliver higher efficiency, v) more reliable and rigidness, and vi) more withstanding to hard environments.

For the prementioned advantages of the 3ϕ IMs, they have been utilized in many industrial applications and they have been known as the workhorses of the industrial sectors [1]. Previously, when the 3ϕ IMs were introduced, the conventional direct current motors were the dominated candidates for the variable speed applications, while the 3ϕ IMs were used with the constant speed applications. This is because at that time the existing speed control methods of the 3ϕ IMs were either too excessive cost or incompetent, which led to limit the applications of the 3ϕ IMs for only constant speed. Thanks to the development of power electronic devices, which open new trend in the electrical motors' drives [2]. Hence, the controlling of the 3ϕ IMs have become more efficient, more reliable and less costly compared with the conventional counterpart, consequenttly make such motors promising candidates for variable speed applications.

Variable speed controller of the 3ϕ IM has been considered in many literatures, since the introducing of the power electronic devices. Variable speed controller is a device, which is designed to adjust the speed and the torque of the AC motor. It basically consists of controllable power electronic device, i.e., inverter or convertor with adjustable frequency and amplitude output voltage [3]–[5].The variable speed controller can be classified into scalar and vector types. Although there are three methods to achieve the scalar methods including constant voltage/frequency (V/F) ratio, constant slip, and constant air-gap magnetic field. On the other hand, vector control method is recommended for applications in which precise speed and high torque are crucial requirements. This method can be achieved by direct torque control or field-oriented control [6]–[9].

The constant V/F ratio speed control method can be fulfilled by changing either the voltage or the frequency of the supply and keeping the V/F ratio constant. It is worth mentioning that such method is the most preferable choice for open loop control applications. This is because it offers smooth output speed with wide ranges, suitable to all IMs types and high efficiency [10]. Therefore, its speed control method has gained considerable attention through the literatures. A digital controller named DSPIC30F2010 was used to implement a close loop constant (voltage/frequency) speed control of 3ϕ IM. It was revealed that the line- to-line voltage of the inverter was steady, and about 98% accuracy of the speed controller was obtained [11]. In addition, in [12] an open loop speed controller of 3ϕ IM was implemnetedusing a DSPACE DS1104 Controller. The motor was fed by an inverter, which was controlled by a SVPWM.Different ranges of speed were obtained by varying the duty cycles. Similarly, [13] used dcPIC30F2010 controller to achieve constant V/F ratio for different speed ranges. It was proved that the controller delivered precise speed control. Moreover, [14] showed that harmonics contents and starting current reductions with good motor efficiency was delivered by microcontroller based 3 ϕ space vector pulse width modulation technique, which was introduced in this study to obtain constant V/F ratio. A comparison between tow pulse width modulation techniques including sinusoidal and space vector techniques was conductedin [15]. It was shown that the space vector pulse width modulation has better performance than the sinusoidal counterpart. Also, in the same study modifications on these techniques have been made by applying controllable boost voltage with modified reference commands method. It was revealed that bad performance of sinusoidal pulse width modulation, particularly at low frequency would be overcome by such modification. Considering the impact of slip regulation a V/F speed control method has been introduced in [16]. Simulation results of the suggested control method were experimentally validated and both results ensured the effectiveness of the control method and well regulation was delivered. In this paper electronic variable speed drive for 3ϕ IM is designed and implemented by MATLAB/Simulink environment. It is proposed to improve the performance of electronic transformers. The proposed electronic transformer is a full -phase wave transformer.

Pulse width modulation (PWM) control techniquehas been adopted to control the inverter switches that are fed from DC source. The DC source can be battery, solar energy or it can be obtained from DC source after converting the alternating current to DC using the integrator. The three-frame inverter has six electronic switches. Operating periods of these switches are controlled by the PWMin order to suit the required output of the inverter. It should be noted that four cases with constant and variable load with PWM and without PWM have been simulated and their results were compared in order to evaluate the proposed controller.

2. INDUCTION MOTOR SPEED CONTROLLER

The date back of the induction motor was in 1924, when Nicola Tesla first introduced such motor and it was received considerable attention since it can be designed as a single phase and three-phase [17]. The 3ϕ IMs can be considered as the predominating candidates for industry field, as they can be directly connected to the AC sources. Although supplying these motors by constant frequency, leads to limit the operating speed ranges of the motors close to their rated speeds, and this consequently results in wasting on the energy. This is because many applications do not require the operating of the motor at full speed all the time. Hence, speed controller is required to vary the motor according to the need of the applications. The speed (υ) of these motors is directly proportional to the supplied source frequency (F),which is given in (1).

$$\upsilon = \frac{120*F}{P} \tag{1}$$

Where: (P) is number of the motor poles.

According to the (1), the speed of the IM (υ) can be varied (over or less the rated speed) by increasing or decreasing the source frequency (F), respectively. It should be mentioned that earlier, using the IM in variable speed applications was not widespread, since the available method for changing the source frequency was bulky and expensive (required a DC motor and an alternative generator). However, changing the power supply frequency became an easy and simple task since the introduction of the power electronic devices. Hence, voltage with required frequency can be obtained by a power electronic device known as inverter, the output voltage of the inverter may have variable or fix amplitude and frequencybased on switching used method [18].

3. SIMULATION AND MODELING

3.1. Modeling of the motor

The first task in designing speed controller system for any electrical motor is driving its dynamic model. The dynamic model of the current motor is adapted from [19]. Using the Park transformation, the (2)-(12) represent the dynamic model of the 3ϕ IM in form of differential equations.

$$V_{ds} = R_s I_{ds} + \frac{d\varphi_{ds}}{dt} - \omega_e \varphi_{qs} \quad (2)$$

$$V_{qs} = R_s I_{qs} + \frac{d\varphi_{qs}}{dt} + \omega_e \varphi_{ds} \quad (3)$$

$$V_{dr} = R_r I_{dr} + \frac{d\varphi_{dr}}{dt} - (\omega_e - \omega_r)\varphi_{qr} \quad (4)$$

$$V_{qr} = R_r I_{qr} + \frac{d\varphi_{qr}}{dt} + (\omega_e - \omega_r)\varphi_{dr} \quad (5)$$

$$\varphi_{ds} = L_{ls} I_{ds} + L_m (I_{ds} + I_{dr}) \quad (6)$$

$$\varphi_{dr} = L_{lr} I_{dr} + L_m (I_{ds} + I_{dr}) \quad (7)$$

$$\varphi_{qs} = L_{ls} I_{ds} + L_m (I_{qs} + I_{qr}) \quad (8)$$

$$\varphi_{qr} = L_{lr} I_{dr} + L_m (I_{qs} + I_{qr}) \quad (9)$$

$$\varphi_{dm} = L_m (I_{ds} + I_{dr}) \quad (10)$$

$$\varphi_{qm} = L_m (I_{qs} + I_{qr}) \quad (11)$$

Where V_{ds}, V_{qs}, I_{ds}, I_{qs}, φ_{ds} and φ_{qs} are stator voltages, currents and flux linkages in d- and q-axes, respectively, while V_{dr}, V_{qr}, I_{dr}, I_{qr}, φ_{dr} and φ_{qr} are rotor voltages, currents and flux linkages in d- and q-axes. R_s, R_r represent stator and rotor windings resistances, respectively. ω_e and ω_r are the angular synchronous and rotor speeds, respectively. Moreover, L_{ls} and L_{lr} are stator and rotor self-inductions, respectively. Furthermore, L_m is mutual inductance. The developed torque equation is (12).

$$\tau_e = \frac{3}{2}\frac{P}{2}(\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds}) \quad (12)$$

The specificationsof the understuding induction motor, are: 15 KW, 400 V, 1460 R, 50 Hz. Moreover, the spectifictions of the current supply source are V_{in} is 380 V. Rotor resistance and indcutance are 0.2205 ohm, and 0.000991 H, respectively. On the other hand, those for the stator are 0.2147 ohm and 0.000991 H, respectively. Mechanical power equals 1.492e+006 W, Inertia=0.102-J (kg.m^2), Friction=0.009541-F (N.m.s).

3.2. Three-phase inverter

A device, which converts the DC input voltage to symmetrical three-phase AC output voltage is known as three-phase inverter. Based on the inverter design the both magnitude of the output voltage can be constant or changeable at constant or changeable frequency. Variable output voltage would be obtained by either changing the input DC voltage and keeping the inverter gain constant, or keeping the input DC voltage constant and changing the inverter gain. Pulse width modulation technique can be utilized within the inverter in order to accomplish these tasks. It should be noted that the ratio of the output (AC voltage) to the input (DC voltage) is known as the inverter gain.

3.3. Pulse width modulation technique

Achievement in the power electronics and integrated circuit field has played important rule in the electrical machines drives. It enables the enhancement of dynamic as well as steady state performances of the electrical motors. due to the such achievement, the IMs have been applicable in variable speed applications. In fact, the interest IM with variable speed controller has been grown, since the introduced of the power electronic devices [20]. One of the most popular application of power electronic in driving the IM is variable speed with pulse width modulation (PWM) technique. Such technique is preferable for controlling power electronic devices, this is because its merits including less power consuming, simple construction, no change due to the temperature and it is appropriate with microprocessor and semiconductor technologies [21]. In IM, inverter based PWM drive makes the amplitude as well as the frequency of the supplied voltage and controllable. Such drive offers better performance in terms of efficiency and speed ranges compared to fixed frequency counterpart. Usually, controlling the inverter output voltage using the PWM results in reduction the harmonic contents of the signal [22], [23]. Through the literature various PWM techniques have been introduced to achieve variable voltage as well as frequency for controlling the torque and the speed of the IMs. The most popular among them are sinusoidal, space vector, and hysteresis-band PWM [24]–[26].

In this paper the PWM technique as shown in Figure 1 will be used to control the inverter, that feedsa 3ϕ IM, in order to control the voltage electronic transformers to convert electrical power according to the required type or amount of power. Simulation was carried out using MATLAB/Simulink to design a controllerthat contllorsthe inverteroutput, the bandwidth and frequencies of the electronic switches. In order to assess the suggested controller, 3ϕ IM models without and with the contorller at both constant and varible load conditions models have been discussed. Two models are for 3ϕ IM without contoller for constant and variable loads conditions, as shown in Figures 2 and 3 respectively. In addtions, two models are for 3ϕ IM with the suggested contoller for constant and variable loads conditions, as shown in Figures 4 and 5 respectively .

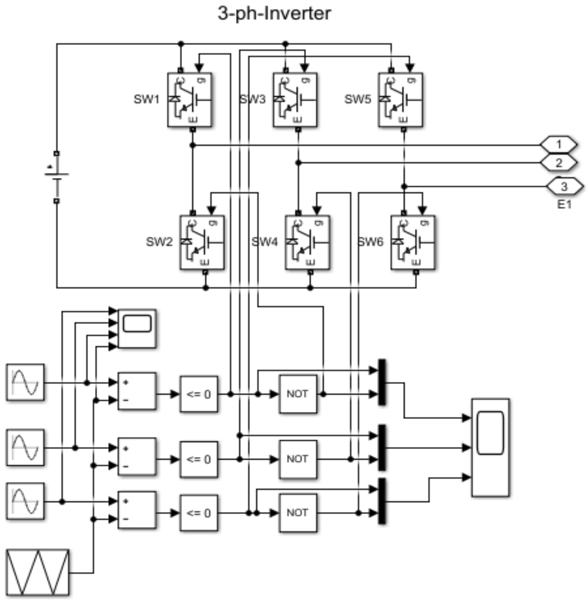

Figure 1. Simulation model of PWM-VSI

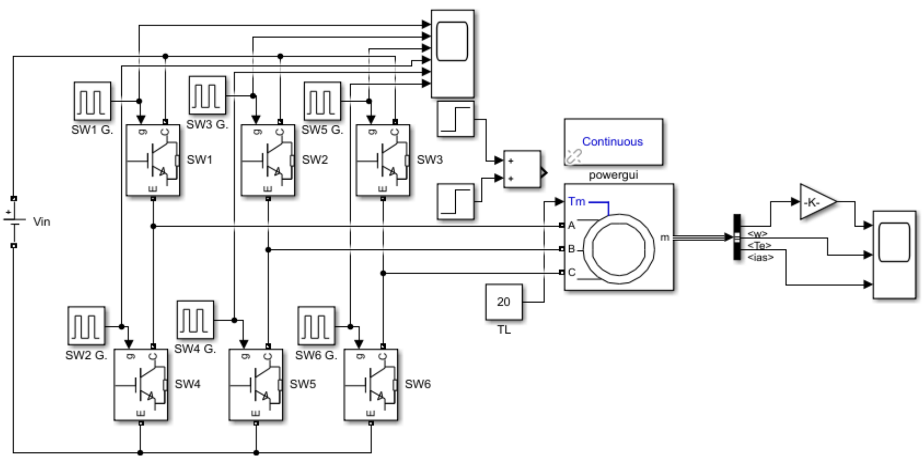

Figure 2. Simulation model of three-phase induction motor at constant load

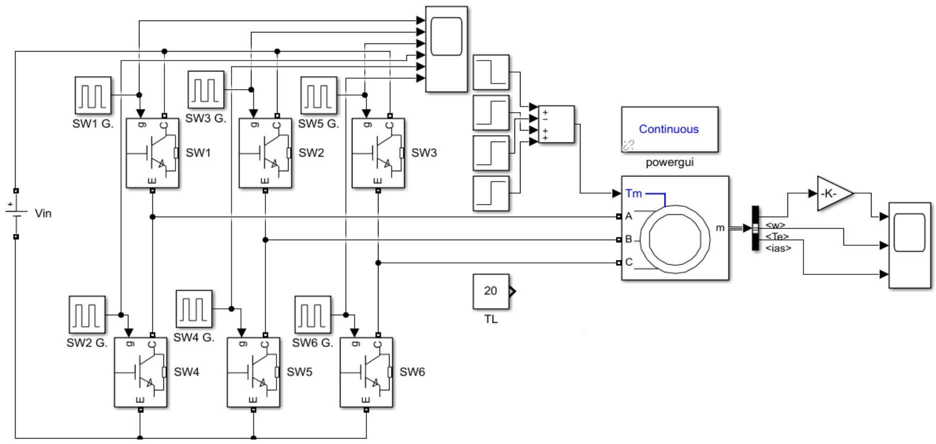

Figure 3. Simulation model of three-phase induction motor at a variable load

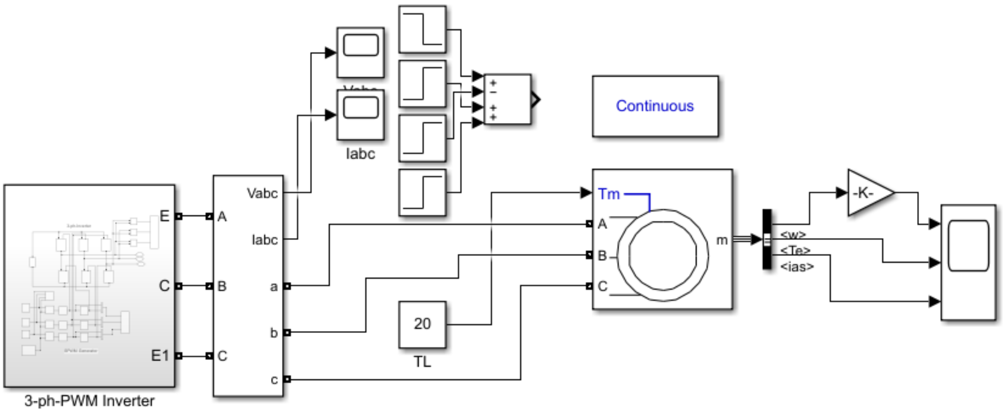

Figure 4. Simulation model of PWM-VSI for three-phase induction motor at constant load

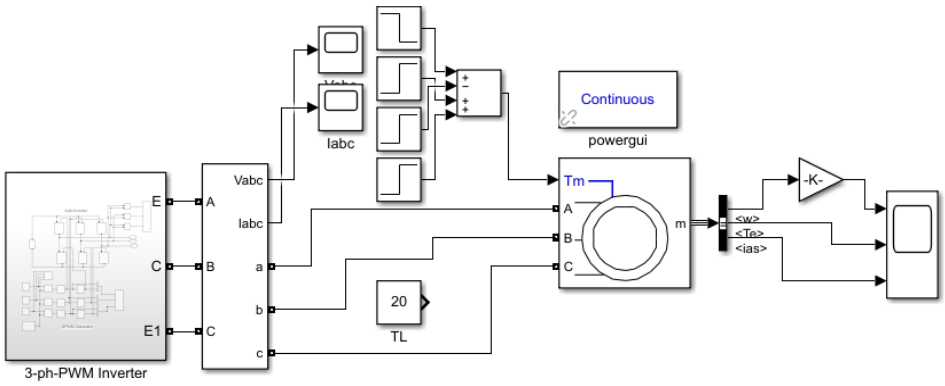

Figure 5. Simulation model of PWM-VSI for three-phase induction motor at a variable load

4. SIMULATION RESULTS

In this section, simulation results including speed, torque and current will be displyed for the four mentioned cases. Figures 6-8 illustrate the speed, torque and current responces of the 3ϕ IM at constant and variable loads, the PWM-VSI 3ϕ IM at a constant and variable loads, resprctively. It can be seen that for the first case, i.e. the 3ϕ IM at constant loadthe steady state of velocity response occurs after the lower and upper peaks are exceeded, Figure 6. Similarly,the steady state of the velocity response occurs after the lower and upper peaks are exceeded in case of 3ϕ IM with variable load as shown in Figure 7. It can also be observed that there is a change in the engine speed when the load changes per second in an inverse relationship. Moreover, it can be noted that using the PWM-VSI to control the speed of the motor has improved the speed profile at both constant and variable load conditions. The speed reaches the static state without exceeding the upper and lower peaks, Figures 8 and 9.

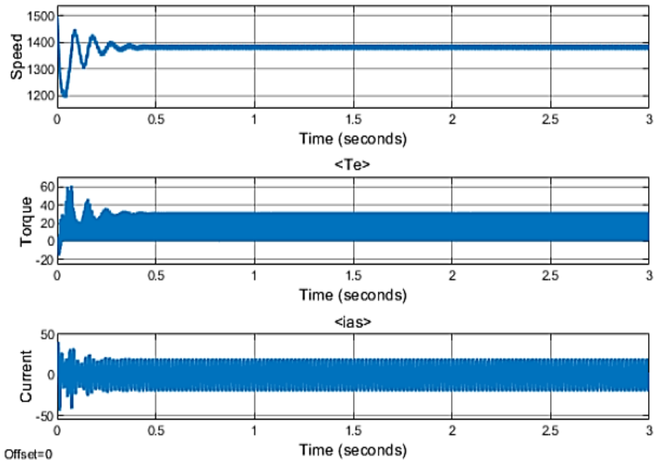

Figure 6. Simulation results of three-phase induction motor at constant load

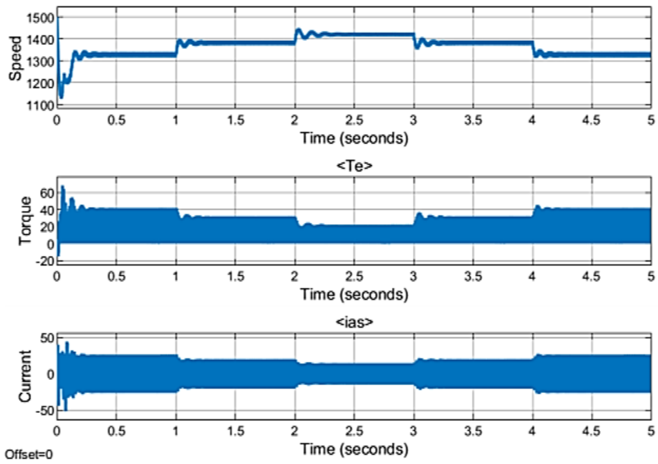

Figure 7. Simulation results of three-phase induction motor at variable load

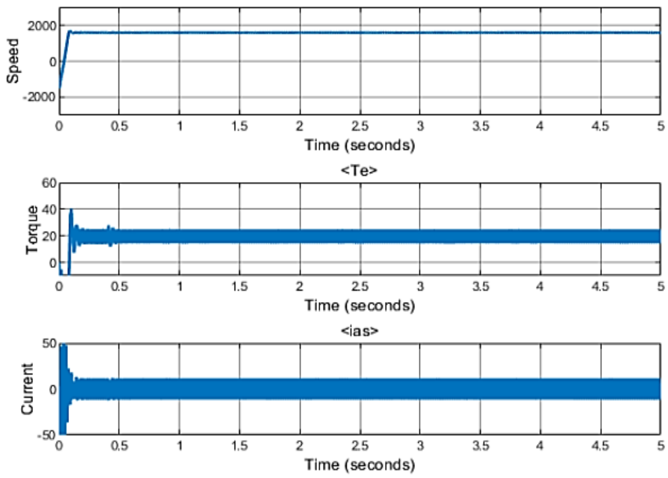

Figure 8. Simulation results of PWM-VSI three-phase induction motor at constant load

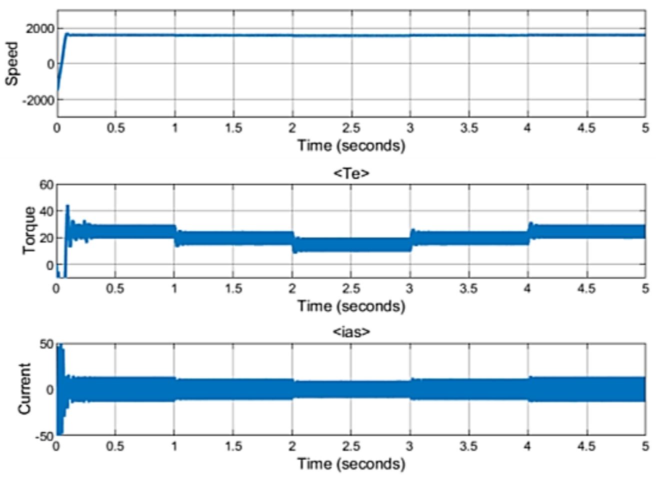

Figure 9. Simulation results of PWM-VSI three-phase induction motor at variable load

5. CONCLUSION

Three-phase induction motors have been wieldy used in many applications. Reliable and fast response controllers for such motors have been of interesting of many literatures. In this study using MATLAB/Simulink,a speed contoller of 3ϕ IM based on PWM have been designed for both constant and variable load conditions. In order to evalute the perfromnace of the suggested controller, speed controller of 3ϕ IM without PWM technology for both constant and variable load conditons were simulated. The results showed that the speed response of the suggested controller was enhanced, where the steady state was reached without exceeding the upper and lower peaks. Undoubtedly, despite the advantage of the suggested controller, it is not without complexity in the control mechanism that requires work and mastery to control the process of switching between the set of electronic switches. Therefore, steps should be taken to reduce the complexity of the suggested controller.

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