A Sliding Mode Controller for a Three Phase Induction Motor

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ABSTRACT
In this paper, a sliding mode controller (SMC) is designed to control the speed of an induction motor fed by three phase voltage source inverter based on space vector pulse width modulation (SVPWM) technique. The sliding mode controller is a nonlinear controller. The space vector pulse width modulation technique is advanced pulse width modulation (PWM) technique. The proposed scheme enables us to adjust the speed of the motor by controlling the frequency and amplitude of the stator voltage; the ratio of the stator voltage to the frequency should be kept constant. Simulation results show the validation of the proposed scheme.

Keywords
Sliding mode controller, induction motor, space vector pulse width modulation

1. INTRODUCTION
Induction motors are used in many applications such as motion control, robotics, and automotive control. [1, 2]. The squirrel-cage induction motor has been widely used in many control systems. It has many advantages, such as simple and rugged structure and low cost. However, induction motors also have speed control problems [1].

Many control methods have been used for the induction motor [3-10]. The space vector pulse width modulation (SVPWM) method is an advanced PWM method for variable frequency drive applications [11]. Space vector modulation is based on the representation of three phase voltages as space vectors. [12, 13].

Classical control systems like PI (proportional-integral) control have been used for the speed control of induction machines. The main drawbacks of classical PI controllers are their large overshoot and excessive settling time. To face these problems, sliding mode control has recently been applied to the control of electrical drive systems. A sliding mode controller (SMC) is a nonlinear, high speed switching, feedback control strategy that provides an effective and robust approach for controlling nonlinear plants [14-16]. However, the SMC easily produces a chattering phenomenon due to its discontinuous switching control.

In this paper, a sliding mode controller is designed to control the speed of an induction motor fed by three phase voltage source inverter based on space vector pulse width modulation technique. Simulation results show the validation of the proposed scheme.

The paper is organized as follows: Section 2, presents the space vector pulse width modulation and the sliding mode controller. The sliding mode controller based design is shown in Section 3. In section 4, simulation results are given to validate the proposed approach. Section 5 gives a comparative study. This paper is concluded in Section 6.

2. SLIDING MODE CONTROLLER
The motor speed ω_r should track a specific reference speed ω_r^* in the presence of load torque and noise. The system is controlled in such a way that the error $e = \omega_r^* - \omega_r$ and its rate of change $\dot{e}$ always move towards a sliding surface. The sliding surface is defined in the state space by the equation [18]:

$$s(e, \dot{e}, t) = 0 \qquad (1)$$

where: the sliding variable s is:

$$s = \dot{e} + \lambda e \qquad (2)$$

where: λ is a positive constant that depends on the bandwidth of the system.

The problem is to remain on the sliding surface for all the time, and the sliding variable s is kept at zero. The condition of sliding mode is :

$$\frac{1}{2}\frac{d}{dt}s^2 = s\dot{s} \le -\eta|s| \qquad (3)$$

where: η is a positive constant.

3. PROPOSED SLIDING MODE CONTROLLER SCHEME
The flow chart of the sliding mode control process is represented in Figure 1. It illustrates that the sliding mode control is performed by reading the value of actual speed and comparing it to the reference speed to generate an error signal. This error signal and the derivative of error are used to determine the switching surface and the state of the system must remain on the sliding surface. The controller then generates the 6 PWM signals for inverter and compares the error value e to a set value ε_0. If the error is less than this value, the error value is printed and the control process stops, otherwise the process is repeated to an acceptable error value.

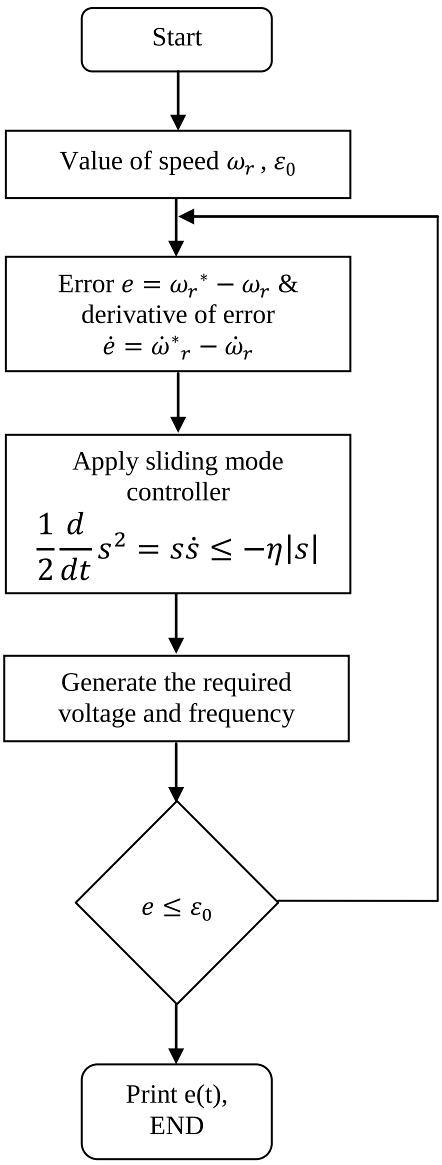

Fig. 1: Flow chart of the sliding mode control process.

4. SIMULATION RESULTS AND ANALYSIS

The speed is a step function with initial value of 500 rpm and final value of 1200 rpm. There is no load torque.

4.1 Using PI Controller

For the speed shown in **Fig. 2**, the rise time is 1.2526 sec and the settling time is 1.405 sec. The maximum overshoot is 21 rpm. The peak time is 0.935 sec, and the delay time is 1.06 sec. For the torque shown in **Fig. 3**, the ratio of ripples varies as follows:

- From 0 sec to 0.25 sec: the ratio is 34%.
- From 0.25 sec to 1 sec: the ratio is 35%.
- From 1 sec to 1.4 sec: the ratio is 27%.
- From 1.4 sec to 3 sec: the ratio is 20%.

So, when using PI controller, the speed and torque have some ripples.

4.3 Using sliding mode Controller

For the speed shown in figure 5.8, the rise time is 1.2539 sec and the settling time is 1.389 sec. The maximum overshoot is 6 rpm which is very small and less than 2%. The peak time is 0.283 sec, and the delay time is 1.055 sec. For the torque shown in figure 5.9, the ratio of ripples varies as follows:

- From 0 sec to 0.25 sec: the ratio is 30%.
- From 0.25 sec to 1 sec: the ratio is 40%.
- From 1 sec to 1.4 sec: the ratio is 32%.
- From 1.4 sec to 3 sec: the ratio is 40%.

So, when using sliding mode controller, the speed has some ripples with magnitude less than the PI controller, but the torque ripples are still high. These results are summarized in **Table 1** and **Table 2**.

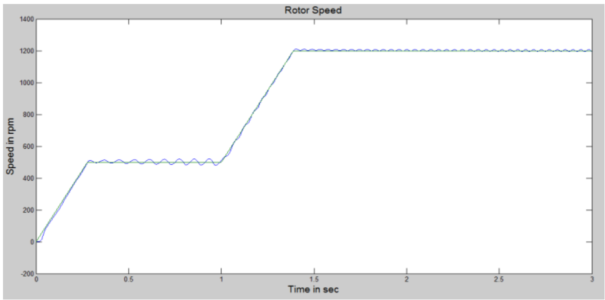

Fig. 2: Reference vs. actual speed using PI controller.

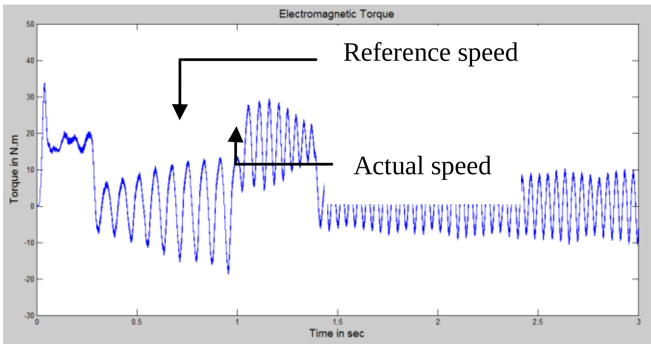

Fig. 3: Electromagnetic torque using PI controller.

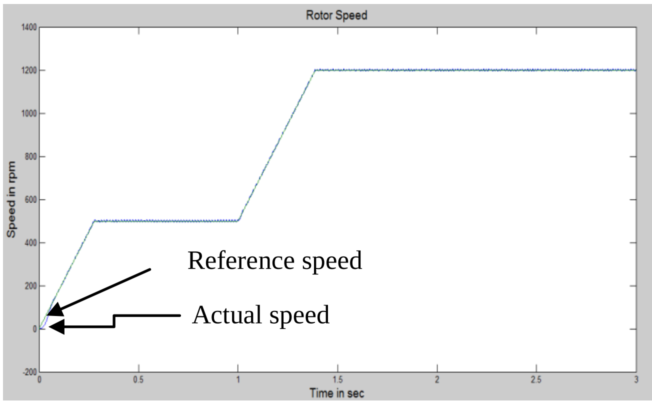

Fig. 4: Reference vs. actual speed using SMC.

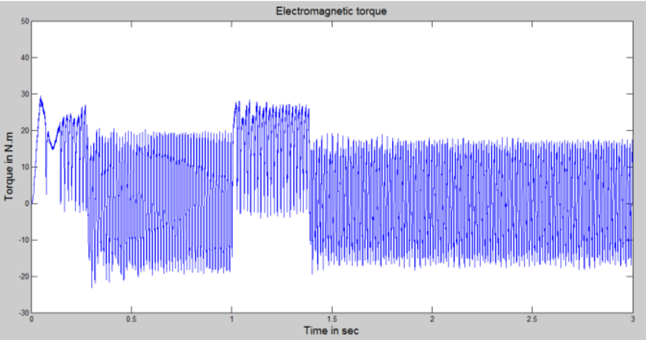

Fig. 5: Electromagnetic torque using SMC.

5. COMPARATIVE ANALYSIS

In this section, a comparison with A R. Arulmozhiyaly and K. Baskaran [17] using different speeds and load torques is performed**. Figure 6** shows the speed using the proposed sliding mode controller at speed 1000 rpm and no load. **Figure 7** shows the speed using the proposed sliding mode controller at reference speed of 1000 rpm and load of 5 N.m. **Figure 8** shows the speed using the proposed sliding mode controller at reference speed of 1200 rpm and no load. **Figure 9** shows the speed using the proposed sliding mode controller at reference speed of 1200 rpm and load of 5 N.m.

From the results shown in the last figures, it is clear that the sliding mode controller gives better response and lower overshoot than PI and fuzzy PI controllers. **Table 3** shows the settling time using the proposed sliding mode controller and fuzzy PI controllers. The results are approximately the same.

Table 1: Comparison of speed between PI, PID, and SMC

Speed	PI	Sliding mode
Rise time (s)	1.2526	1.2539
Settling time (s)	1.405	1.389
Maximum overshoot (rpm)	21	6
Peak time (s)	0.935	0.283
Delay time (s)	1.06	1.055

Table 2: Comparison of torque between PI, PID, and SMC

Torque		PI	Sliding Mode
Ratio of ripples %	0 - 0.25	34	30
	0.25 - 1	35	40
	1 – 1.4	27	32
	1.4 – 3	20	40

Table 3: Comparison of settling time in sec between fuzzy PI and SMC.

Load Condition	Fuzzy PI [17]	Sliding mode
1000 rpm with no load	0.7	0.71
1000 rpm with load	0.79	0.71
1200 rpm with no load	0.79	0.858
1200 rpm with load	0.85	0.85

6. CONCLUSION

This paper proposed a sliding mode controller design to control the speed of an induction motor fed by three phase voltage source inverter based on space vector pulse width modulation technique. The proposed scheme enabled us to adjust the speed of the motor by controlling the frequency and amplitude of the stator voltage; the ratio of the stator voltage to the frequency should be kept constant. It is introduced to maintain a constant speed to when the load varies. Simulation results showed the validation of the proposed scheme. As a conclusion, the sliding mode controller gives lower overshoot than PI and fuzzy PI controllers. As a future work, more analysis is needed to face the sliding mode controller torque ripples which are not completely eliminated.

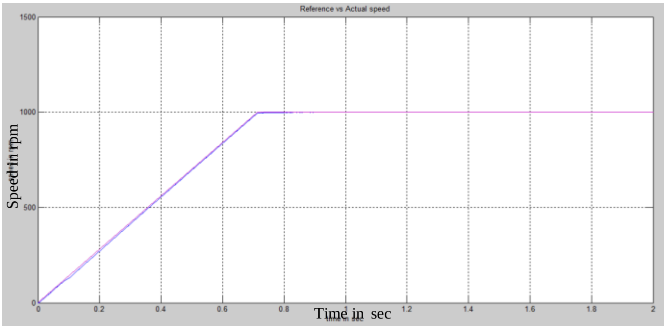

Fig. 6: Reference vs. actual speed using SMC at speed 1000 rpm and no load.

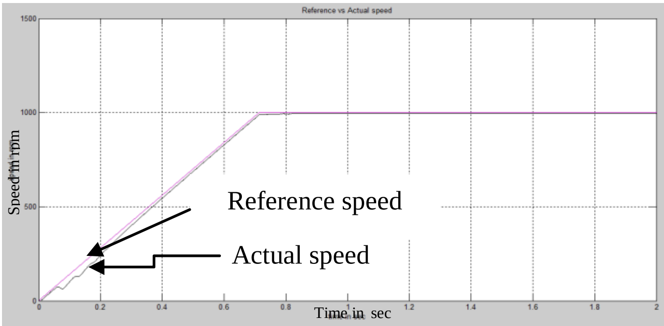

Fig. 7: Reference vs. actual speed using SMC at Speed of 1000 rpm with load of 5 N.m.

Fig. 8: Reference vs. actual speed using SMC at Speed of 1200 rpm with no load.

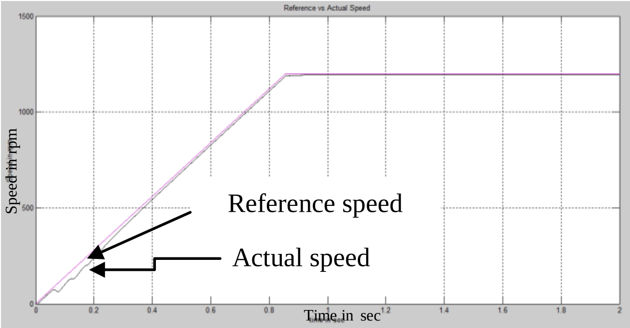

Fig. 9: Reference vs. actual speed using SMC at Speed of 1200 rpm with load of 5 N.m.

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