An Optimal Fuzzy Logic-based PI Controller for the Speed Control of an Induction Motor using the V/F Method

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Abstract-The Induction Motor (IM) is popular because of its low price, higher efficiency, and low maintenance cost. A comparative analysis of IM speed controllers using Voltage/Frequency (V/F) control or Scalar Control (SC) is presented in this paper. SC is commonly used due to its ease of implementation, simplicity, and low cost. To decrease the difficulty and cost of hardware implementation, this paper proposes an optimal Fuzzy Proportional Integral (Fuzzy-PI) controller. Firstly, the speed of IM using the V/F control technique is discussed. Then, speed control of IM using a conventional PI controller is performed. Finally, a simplified-rules Fuzzy-PI controller is developed in MATLAB/SIMULINK and its performance is compared with that of open-loop SC and the traditional PI controller. The performance of the simplified-rules Fuzzy-PI controller is superior to that of an open-loop constant V/F control and a conventional PI controller.

Keywords-induction motor; constant V/F control; PI controller; optimal fuzzy PI controller

I. INTRODUCTION

Its low cost, simple structure, reliability, and good robustness have made the Induction Motor (IM) a most attractive choice [1, 2] for industry applications. To change the speed of IMs, frequency and voltage can be varied. In Voltage/Frequency (V/F) control, only their magnitudes are controlled. V/F control is easy to implement, it requires a small number of components, and can be employed in several applications such as variable speed pumps, fans, blowers, etc. [3]. Normally, a Proportional Integral (PI) controller is employed for IM speed control for most applications [4, 5]. But, the conventional PI controller has some disadvantages: Its accuracy depends on the mathematical model, the system suffers fromnon-linearity, and it is very sensitive to parameter and temperature variations and to load disturbances [6, 7].

A Fuzzy Logic-based Controller (FLC) can overcome these disadvantages [8-10]. The FLC does not need the model of the plant, can handle non-linearity, it is less sensitive to load disturbances, it produces human logic linguistic rules, and is robust [11-13]. Authors in [14] suggested a 3-phase IM speed control technique using constant V/F control. A simplified fuzzy rule-based FLC can be easily implemented in hardware and performs better in comparison with the standard 25-rule FLC [15]. D. Asija proposed a standard 25-rule Fuzzy-PI controller for IM speed control using SC and concluded that the Fuzzy-PI controller outperforms the traditional PI controller [16]. B. N. Kar and K. B. Mohanty presented a standard 49-rule FLC for IM speed control by Indirect Vector Control (IVC) and concluded that compared with the conventional PI controller, the proposed FLC performs better with regard to change in load, settling time, and overshoot [17]. Authors in [18] proposed a standard 49-rule FLC based IM speed control by IVC and concluded that FLC performs better than the traditional PI controller with regard to load disturbances and changing reference speed. Authors in [19] proposed and implemented a 3-phase IM using V/F control.

II. PROPOSED FRAMEWORK

A simplified-rule Fuzzy-PI controller using the V/F control technique is presented in this paper. Various researchers proposed FLC-based IM speed control using standard 49 fuzzy rules, standard 25 rules, standard 9 rules, and simplified fuzzy rules [20-25]. In this paper, the standard 9 rules are simplified into 5 rules for the first time and the simplified-rule Fuzzy-PI controller is developed and implemented for the speed control of a 3-phase IM using constant V/F control. The rule base is selected using the trial and error technique. The proposed simplified Fuzzy-PI controller reduces complexity and computational load, it is easily implemented, it is simple, and has better performance. Figure 1 exhibits the diagram of the proposed framework. The DC supply voltage is converted into variable voltage and variable frequency by a Metal Oxide Semiconductor Field Effect Transistor (MOSFET) inverter. The optimal Fuzzy-PI controller gets feedback signals from an IM. The method of speed control used here is the popular constant V/F control. The SVPWM generator produces firing pulses to the inverter. The MOSFET converts the DC supply voltage into variable AC by the SVPWM method.

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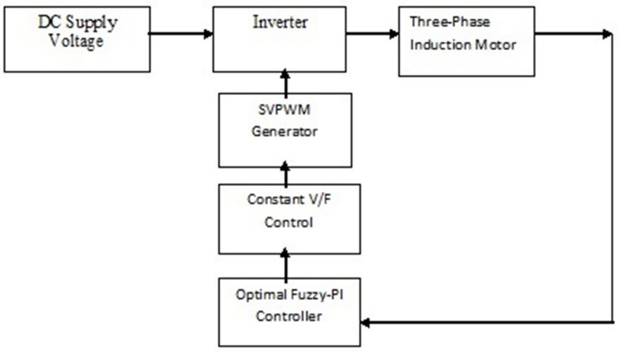

Fig. 1. The proposed framework.

III. CONSTANT V/F CONTROL

With the recent developments in power electronics, variable voltage variable frequency IMs are increasingly employed in a variety of industrial applications. The circuit diagram of V/F control is shown in Figure 2. Speed control of IM is achieved using a 3-phase inverter. The frequency and applied voltage must be varied to maintain constant air-gap flux and to evade saturation of the IM. The stator voltage and frequency are changed at the same time to keep V/F ratio constant.

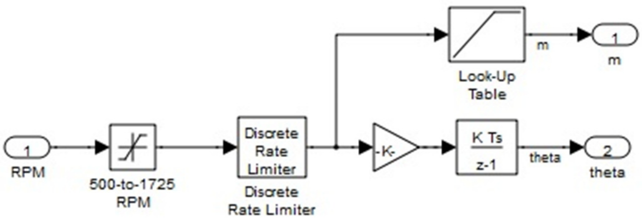

Fig. 2. Constant V/F control.

IV. THE FUZZY LOGIC CONTROLLER

The FLC is an intelligent controller that is very similar to human reasoning. It accepts crisp input, performs calculations, and then gives an output value [26]. The structural diagram of the FLC is shown in Figure 3. There are four steps for the implementation of an FLC: Fuzzification, inference engine, rule base, and de-fuzzification. The FLC inputs are characterized by triangular Membership Functions (MFs) and 3 triangular MFs are used for output control. There are 9 rules out of which 5 are executed by the Fuzzy Inference System (FIS). The triangular MFs for the FLC system are shown in a Figure 4. The MFs for two inputs and a single output are: Positive (P), Zero (Z), and Negative (N).

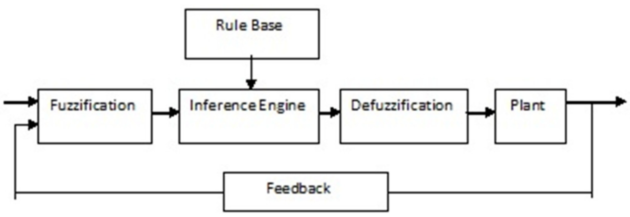

Fig. 3. The FLC structural block diagram.

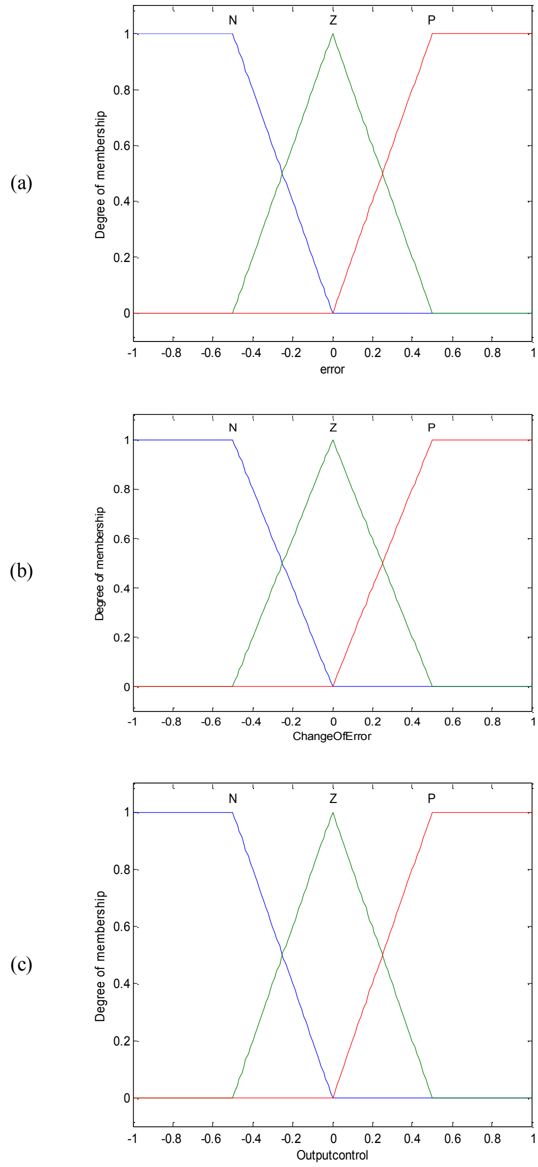

Fig. 4. The triangular membership functions: (a) error (e), (b) change of error (Δe), (c) Output control (Δu).

Table I shows the simplified rule base for the FLC. For this application the Mamdani type FIS is chosen. The fuzzy logic process which is based on if-then rules is represented as follows: If N and P denote the error and change of error respectively then the output control will be denoted by Z.

TABLE I. THE SIMPLIFIED FUZZY RULES FOR THE FLC

e	Δe N	Δe Z	Δe P	**Simplified Rules**
P	Z	P	P	1. If e is N and Δe is Z then Δu is N 2. If e is Z and Δe is P then Δu is P
Z	N	Z	P	3. If e is Z and Δe is Z then Δu is Z
N	N	N	Z	4. If e is Z and Δe is N then Δu is N 5. If e is P and Δe is N then Δu is Z

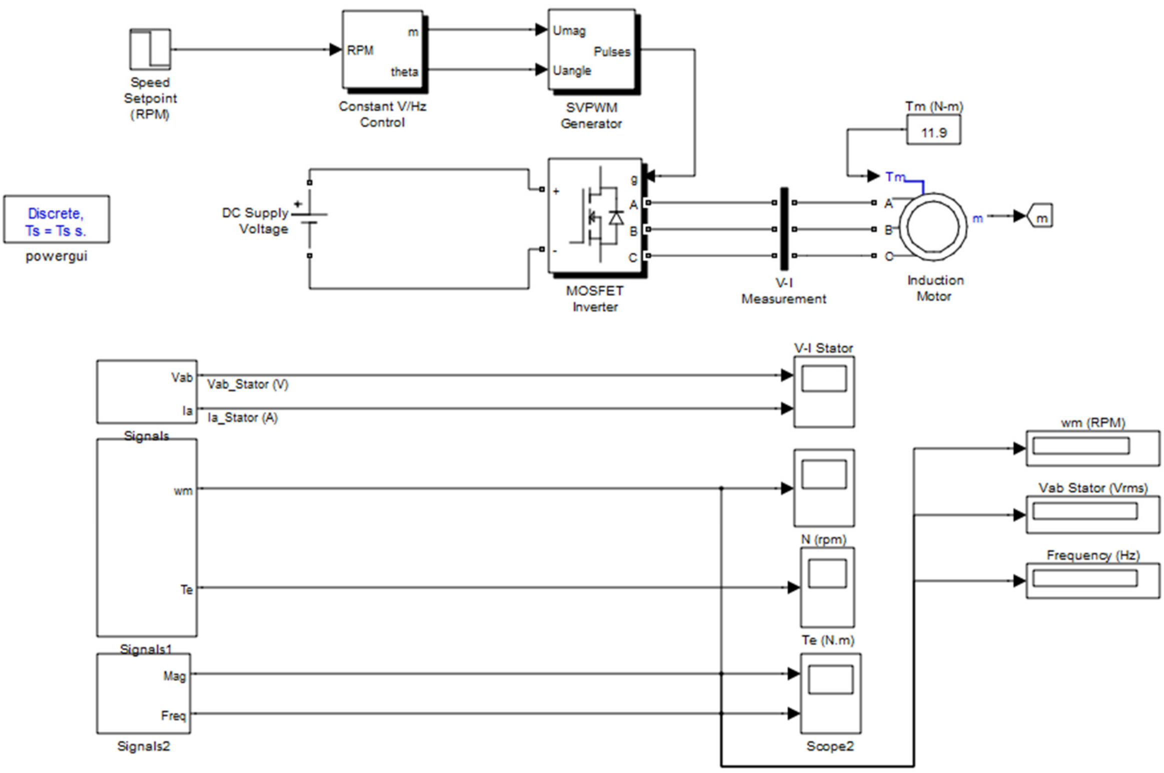

Fig. 5. The SIMULINK diagram of the open loop V/F control-based IM speed control.

(a)

(b)

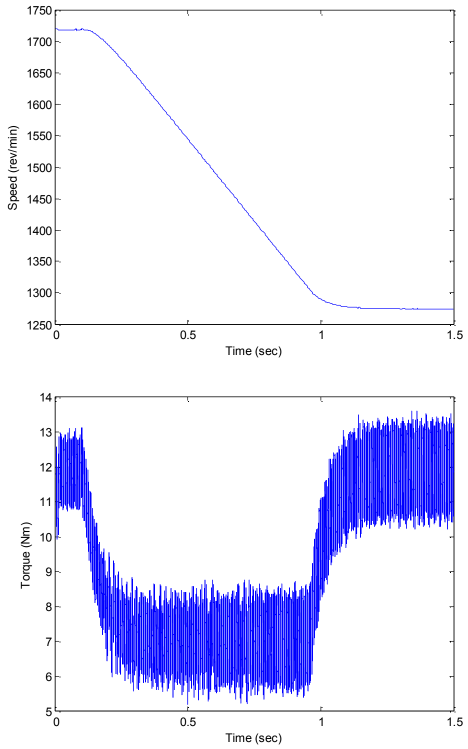

Fig. 6. The open loop IM speed control: (a) rotor speed, (b) electromagnetic torque.

V. RESULTS AND DISCUSSION

Figure 5 depicts the SIMULINK diagram of the open loop IM speed control using the SVPWM technique. A 3-phase IM is fed from an inverter and is connected with a DC voltage source. A MOSFET inverter is modeled by a universal block and the IM by an asynchronous machine block. A constant value of 11.9Nm load torque is applied to the IM shaft. A speed set point in rpm is applied to the V/Hz block. The initially reference speed is 1725rpm and the final speed value is 1300rpm. The induction motor reaches a speed of 1275rpm. In this application, IM does not reach the final speed of 1300rpm which is the required final value. The simulation results for open loop scalar control are shown in a Figure 6.

The SIMULINK diagram of the traditional PI controller based IM closed loop speed control using SVPWM technique is shown in Figure 7. The Zeigler-Nichols method is used in this paper for tuning the PI controller. To study the performance of the 3-phase IM, two performance indices, i.e. rotor speed and electromagnetic torque are used. In order to achieve the actual IM speed, feedback is used and it is compared to the IM reference speed. The error is produced by the obtained difference of the two and the error is processed in a conventional PI controller which reduces it. The same reference step speed and load torque is used for the traditional PI controller. The SIMULINK diagram of the simplified Fuzzy-PI controller using SC is given in Figure 9. The error signal and the change of error are the input of an intelligent controller. The Fuzzy-PI controller produces the controlled output signal and provides it to the V/F control.

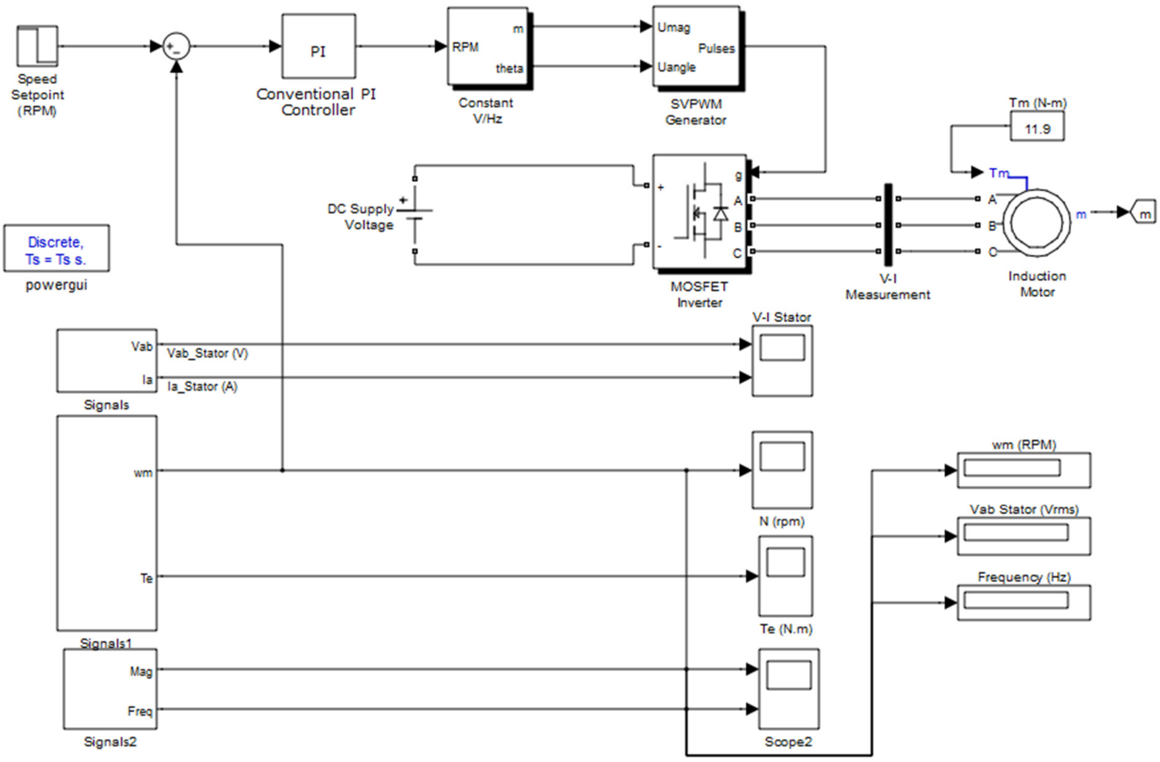

Fig. 7. The SIMULINK model of the conventional PI controller based IM speed control.

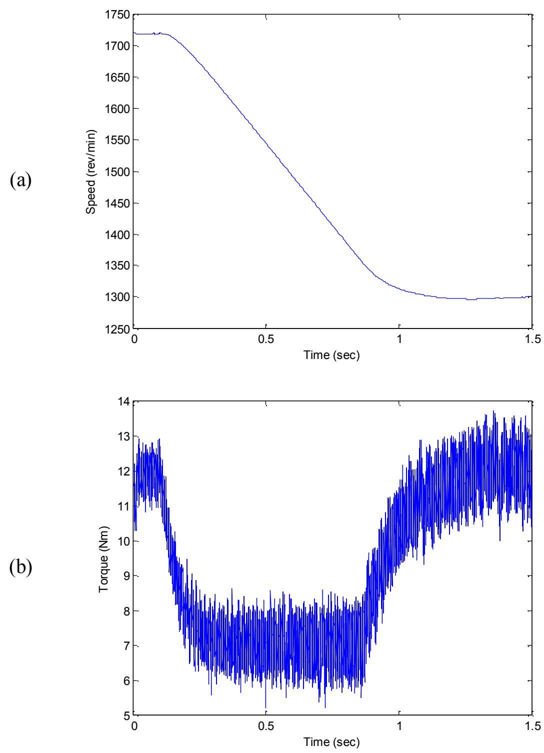

Fig. 8. The simulation results for conventional PI controller based IM speed control: (a) rotor speed, (b) electromagnetic torque.

Here, the frequency varying device is the SVPWM generator which uses the SVPWM technique to produce firing pulses to the inverter and hence the frequency of the supply is changed w.r.t the voltage of the IM. Using the SVPWM method, the MOSFET inverter converts the DC supply voltage into variable AC. From Figure 8, it is clear that the conventional PI controller reaches the final speed of 1300rpm. From Figure 10, it is clear that the optimal Fuzzy-PI controller also achieves the final speed of 1300rpm but with less settling time and without overshoot compared with a conventional PI controller and also better electromagnetic torque response is obtained. When compared with the existing literature, the proposed simplified Fuzzy-PI controller uses the least number of fuzzy rules. The proposed intelligent controller employs a trial and error approach to minimize the fuzzy rules while achieving better IM speed control performance. Figure 11 depicts the speed response of the IM with step speed reference with both controllers and constant V/F control. The performance analysis of both controllers and without any controller at a constant reference speed is given in Table II.

TABLE II. PERFORMANCE ANALYSIS

	Settling time (sec)	**Overshoot (%)**	**Load (Nm)**
Conventional PI controller	1.440	0.307	
Optimal Fuzzy-PI controller	0.980	0	11.9
Without controller	Does not settle	----	

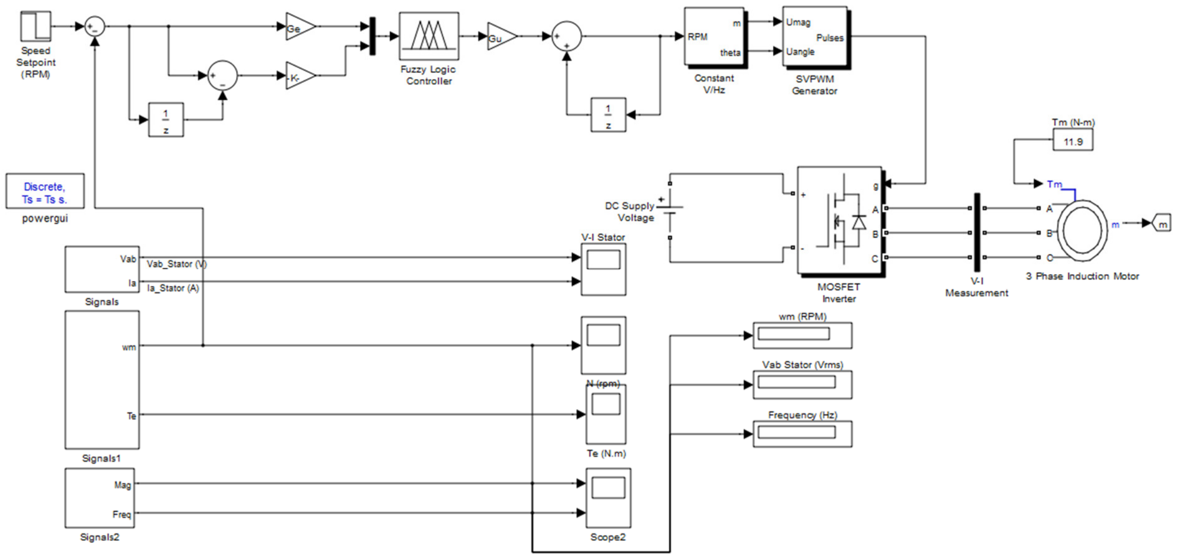

Fig. 9. The SIMULINK diagram of the optimal Fuzzy-PI controller based IM speed control.

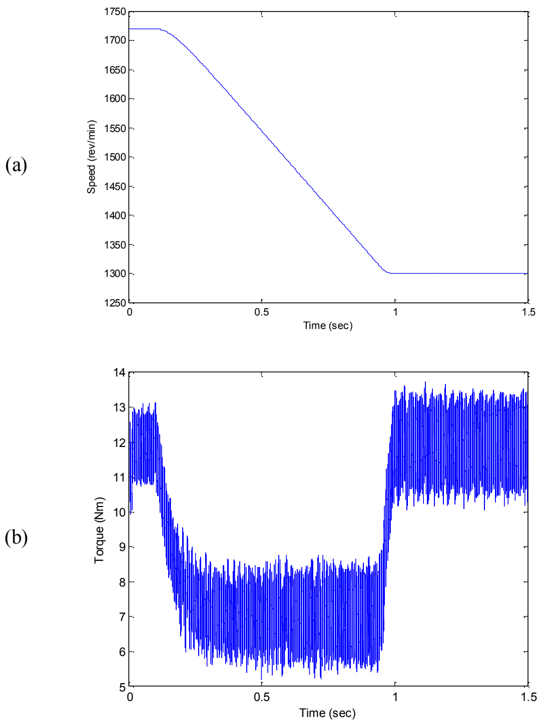

Fig. 10. The simulation results for the optimal Fuzzy-PI controller based IM speed control: (a) rotor speed, (b) electromagnetic torque.

VI. Conclusion

To reduce the computation load, the need of memory space, and to enable more easy hardware implementation an optimal Fuzzy-PI controller using SC is successfully developed and simulated in this paper. The proposed optimal Fuzzy-PI controller uses a minimum number of fuzzy rules. The simulation results show that the performance and speed response of the simplified-rule set Fuzzy-PI controller surpass the ones of the open loop constant V/F control and the traditional PI controller. The optimal Fuzzy-PI controller fully eradicates the overshoot of the conventional PI controller and the settling time is much smaller than that of the traditional PI controller.

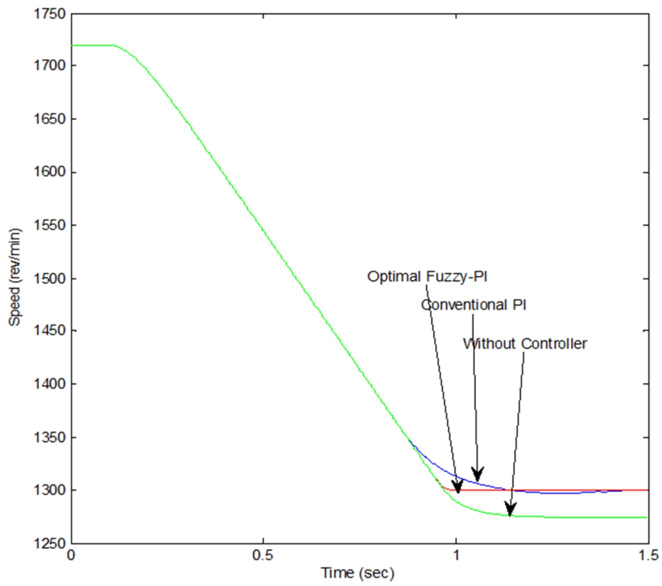

Fig. 11. Speed response of the 3-phase IM with step speed reference with an initial value of 1725rpm and final speed reference of 1300rpm at 0.1s and 11.9Nm load with optimal Fuzzy-PI controller, conventional PI controller, and without controller.

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APPENDIX

IM ELECTRICAL PARAMETERS

Power = 3hp , Voltage = 220V, Poles = 4, Frequency = 60Hz
$R_S = 0.435\Omega$, $R_r = 0.815\Omega$
$L_S = 2*2.0mH$, $L_r = 2.0mH$
$L_m = 69.31mH$
$J = 0.089\ Kg.m^2$

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