RESEARCH ARTICLE

Soft Computing Techniques based Digital Adoptive Controllers with Intelligent System for Switched Reluctance Motor

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ABSTRACT: Nowadays GA based H -Infinity control technique applied for speed control applications for switched reluctance motor drive. H infinity control is an external control technique so the weight of the transfer function matrix is improved and the system is controlled perfectly by totaling the input weight noise function matrix value and weight uncertainty. The weight of the transfer function matrix is changed at every different system states. The SRM motor is used in various industrial applications due to its profitable advantages. Initially PI controller used for speed control of switched reluctance motor. Then fuzzy logic and H-Infinity control methods are used for speed control of switched reluctance motor. The process of finding an optimal control weight is complex because the H-Infinity control process is a closed loop control. This would be fall of control accuracy and also increases the merging time. To overcome these problems, an optimal GA based H-Infinity control concept is proposed. In the proposed control process, the optimal transfer function matrix weight is obtained by Genetic Algorithm. The proposed GA based optimal H-Infinity control method is simulated in MATLAB and also speed of the SRM is controlled by the proposed optimal GA based H - Infinity control method.

KEYWORDS: Switched Reluctance Motor, PI control, Fuzzy logic control, H-Infinity control, Robustness and GA based H- Infinity control algorithm.

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1. INTRODUCTION

The Switched Reluctance Motor is applied in various industrial applications are gaining much interest in industrial applications such as wind energy systems and electric vehicles due to its simple and rugged construction, high speed operation ability, insensitivity to high temperature, and its features of fault tolerance [1]. But, the robustness speed of SRM is one of the major drawbacks, which greatly affects the performance of motor. Control the speed of SRM using H-infinity control strategy. This H-infinity control technique is stronger against robustness. In the proposed speed controller, the rotor position of the SR motor is applied to the controller. The speed variation of the rotor is determined from the reference speed and applied to the controller as input [2]. Then, the speed difference and the same sensitivity function are determined. The sensitivity function prediction is based on the input side weight of the controller. The weight adjustment process is repeated until a stable speed condition is achieved. Then, the output of the proposed control technique is compared with the existing control technique and the robustness is analyzed [3].

In normal control technique have the uncertainties have parameters namely model error and variation outer disorder. But, the H-infinity control technique is an external control technique. The weight of the transfer function matrix is improved and the system is controlled perfectly by totaling the input weight noise function matrix value and weight uncertainty. The weight of the transfer function matrix is changed at different system state. Therefore, an optimal control weight is needed to make the system robust. The process of finding optimal control weight is complex because the H-infinity control process is a closed loop controller [5]. This would result in fall of control accuracy and also increases the merging time. To overcome these difficulties, the optimal H-infinity control concept is proposed. In the proposed control procedure, the optimal transfer function matrix weight is obtained by genetic algorithm which is an efficient optimization algorithm. The proposed GA based optimal H-infinity control method is implemented in MATLAB [4]. Also, the speed of the switched reluctance motor is controlled by the proposed optimal H-infinity control technique and the speed controlling concert is tested with the straight H-infinity control technique. The

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weight noise setting is obtained for every time instant and optimal weight noise is calculated. The optimal weight noise setting can be attained by H-infinity optimal control using GA approach [6].

II. SRM DRIVE SYSTEM

The digital controller is connected with the converter and firing circuit, which can activate the converter of the SRM to have the control over the pulsating signals. The main function of the controller is to give the power supply to SRM [7]. And the output voltage of the converter and compare with the reference voltage to produce the actuating signal to have the error signal which will compensate with the set voltage, thus the SRM will now be applied the rated voltage. Converter gets activated by the windings of the SRM. The torque production in SRM is explained using the elementary principle of electromechanical energy conversion in a solenoid. Figure 1 shows the digital controller based SRM Speed control. Digital Controller such as H-Infinity controller and GA based Controller. However, the SRM has the disadvantages of high current harmonics and low power factor because of the pulse-type discontinuous excitation. This paper investigates an SRM drive system with reduced harmonics and improved power factor. The system consists of a switching power converter with power factor corrections. This describes a new converter topology for switched reluctance motor drives. The new topology consists of a pair of boost-buck power converters and a machine converter.

Digital controller used for corrects the error and improve the performance of SRM. Depending upon the error signal, digital controller fed the signal to converter circuit and activates the SRM phase winding. Speed of SRM maintained constant by digital controller

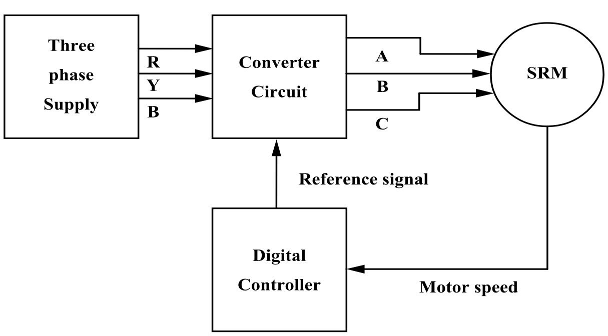

Figure 1 Block diagram of Switched Reluctance MotorSwitched Reluctance Motor

II. PI CONTROL TECHNIQUE FOR SRM

Proportional-Integral (PI) controllers are widely used in Switched reluctance motor drive for accurate speed control and better speed holding capacity. The combination of proportional and integral increases the speed of the response and reduces the steady state error.

The PI controller is widely used in industry as it is a simple and effective controller for applications that do not require a more sophisticated approach [8]. For the speed control of this SRM, the PI controller has been deemed adequate for a variable speed SRM not requiring servo like control. Figure 2 shows the PI controller based switched reluctance motor drive. SRM current controller sees a nonlinear plant with varying plant gain even within normal operating condition. Additionally, the current reference is time-varying. As expected and verified experimentally, integral (I) control is not effective in case of a finite-time tracking problem. The controller gains [9] had been increased to reduce the tracking error in the rising and falling portions of the current reference. This had resulted in oscillations in current for constant part of current reference. This establishes that constant gain PI current controller is not suitable for high performance current controller in SRM [10].

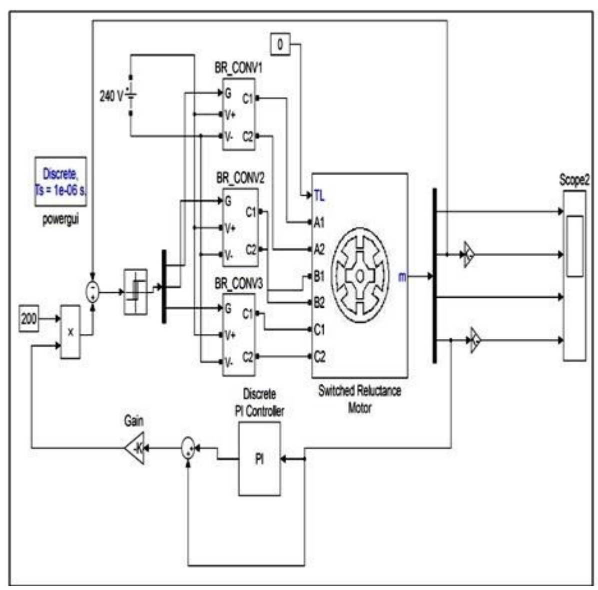

Figure 2 Simulation diagram of PI controller based SRM Drive system

A. *Simulation Results of PI Controller for SRM*

Figure 3 shows the SRM current of PI controller. Initially the starting current nearly 250A and finally settled at 150A [11]. Initial Motor starting torque is 165Nm and finally settled the motor torque at the value of 75Nm.

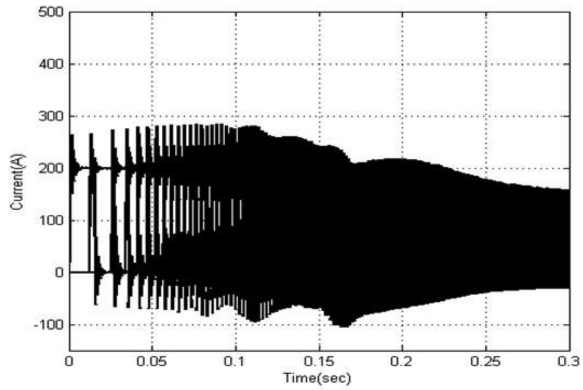

Figure 3 SRM Current of PI controller

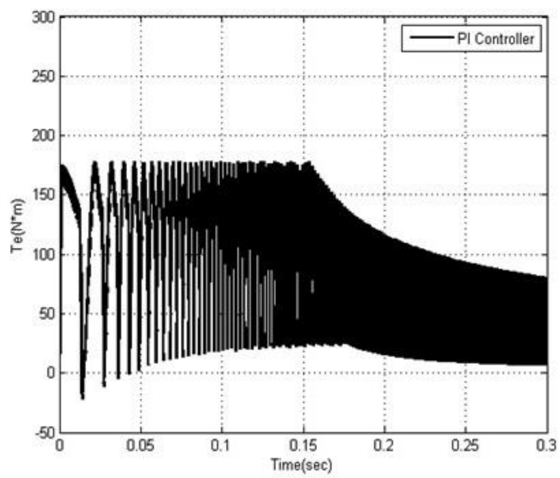

Figure 4 SRM Torque of PI controller

Figure 4 shows the SRM speed of PI controller. Starting speed of SRM rapidly increase to 8200 rpm and after 0.28 sec SRM maintain the speed around 4500rpm.

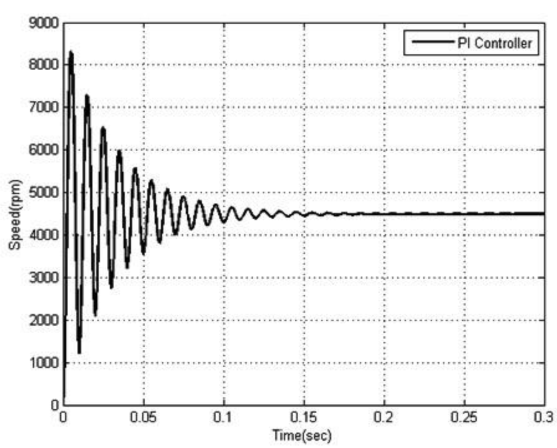

Figure 5 SRM Speed of PI controllers

Figure 5 shows the SRM speed of PI controller. Starting speed of SRM rapidly increase to 8200 rpm and after 0.28 sec SRM maintain the speed around 4500rpm.

III FUZZY LOGIC CONTROLLER FOR SRM

Figure 6 shows the Mamdani fuzzy logic controller based SRM. Fuzzy logic controller block inserted the SRM Simulink mode [12]. The main function of the FLC is to take the output voltage of the converter and compared with the reference voltage to produce the actuating signal which will compensate with the set voltage, thus the SRM will now be supplied with rated voltage. Converter gets activated the windings of the Switched reluctance motor. The torque production in the switched reluctance motor is explained using the elementary principle of electromechanical energy conversion in a solenoid. The fuzzy logic controller is implemented in the SRM drive system. FLC is used in closed loop control and better performance of reduced harmonics and accurate speed regulation as that of the set speed is obtained

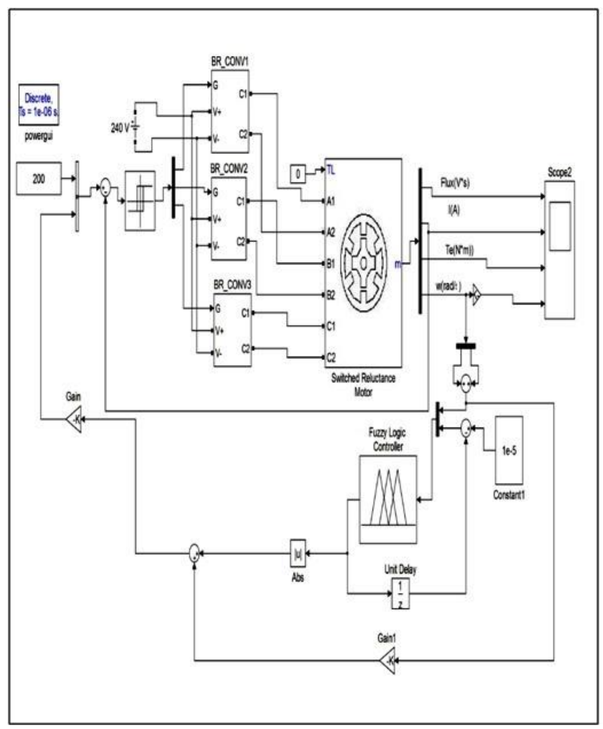

Figure 6Mamdani fuzzy controller based SRM Control Model

A.Fuzzy Rules Description

Fuzzy rules for the FLC to control the error in speed can be given as follows: there are nine rules are used for fuzzy logic controller based SRM drive.Figure 6 shows the implementation of fuzzy logic controller based on SRM drive system. FLC is robust to load disturbance [13] or sudden change in reference speed. It has got significant steady state error as compared with that for conventional proportional integral controller. Hence an implementation of a hybrid controller is necessary to overcome with the drawbacks existing in the FLC [14].

Table 1 Fuzzy rule set

Δ E	L	M	H	L	M	H	L	M	H
L	L	L	H	L	L	H	L	L	H
L	L	L	H	L	L	H	L	L	H
L	L	L	H	L	L	H	L	L	H
M	L	M	H	L	M	H	L	M	H
M	L	M	H	L	M	H	L	M	H
M	L	M	H	L	M	H	L	M	H
H	L	M	H	L	M	H	L	M	H
H	L	M	H	L	M	H	L	M	H
H	L	M	H	L	M	H	L	M	H

B.Simulation Results of Fuzzy Logic Controller for SRM

Figure 7 shows the SRM Torque performance under FLC. Initially starting torque value of 155Nm and torque settled at 75Nm.

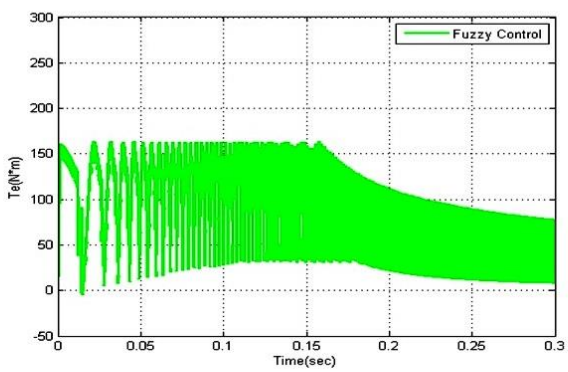

Figure 7 SRM Torque performances under FLC

Figure 8 shows the SRM current of Fuzzy logic controller. Initially starting current nearly 200A and finally settled at 98A.

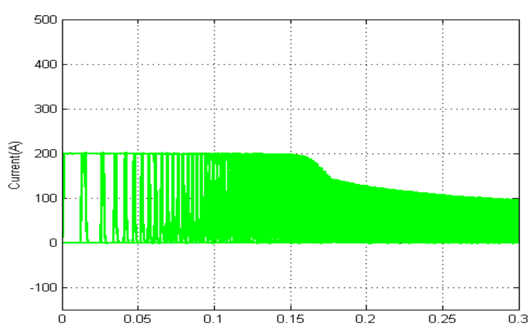

Figure 8 SRM Current under FLC

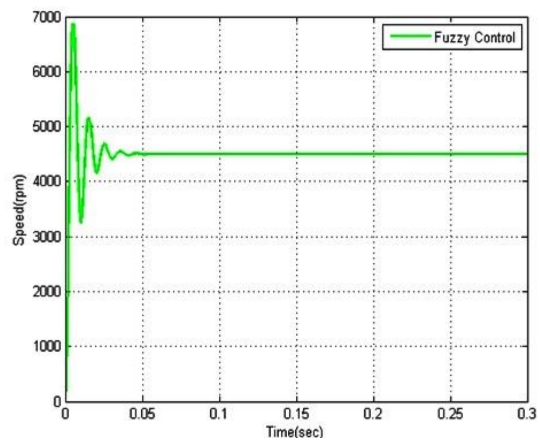

Figure 9 FLC based SRM Speed

Figure 9 shows the SRM Speed of Fuzzy logic controller. Initially stating Speed of 6900rpm and after 0.05sec finally speed is settled at 4500 rpm

The PI-controller [15] takes decision during steady state to reduce steady state error of the system and the fuzzy logic controller takes decision during transient state to get fast response and low overshoot when the absolute value of speed error is greater than 7 rpm. This set value depends upon the fuzzy logic controller and the sampling frequency of for the case of steady state, the PI-controller dominates the control output to significantly reduce steady state error of the system and the FLC contributes to the output to provide fast response and low overshoot when the absolute value of speed error is higher than 7 rpm [16].

The control system designer describes the desired reaction and noise-suppression properties by weighting the plant transfer function in the frequency domain the resulting 'loop-shape' is then 'robustified' through optimization. The general structure of H-infinity control is illustrated as shown in Figure 10.

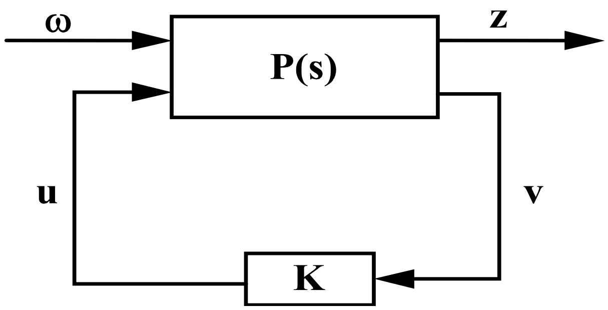

Figure 10 Control Block Diagram of H-Infinity Controller

B. H-INFINITY CONTROL FOR SWITCHED RELUCTANCE MOTOR

The SRM controlling problem is one of the mixed sensitivity control problems. The H-infinity control technique is proposed for controlling the rotor speed of SR motor [17]. The function of the proposed control technique is to identify the position of the rotor. The rotor position variation is identified from the speed performance of the motor. The speed of the motor is compared with the reference speed and the actual speed of the rotor is determined. Based on the rotor position, the controller weight is adjusted. By satisfying the control strategy condition, the rotor speed of the motor is maintained as stable. From the controlled output, the torque, speed, and current characteristics are analyzed.

C. ROBUST CONTROLLER FORMULATION FOR SRM

H-Infinity is one of the robust control techniques, used to synthesize controllers for achieving robust performance of SRM [18]. To use H-infinity method, a control designer first expresses the control problem as a mathematical optimization problem and then finds the controller that solves this problem. It consists of a plant 'P', a controller 'K', reference speed 'ω', commanded input i.e., manipulated variable'u', output 'z' and error speed'e'. In order to include some performance objectives in the system model, the standard feedback structure is modified by adding weighting functions. The weight function measures the components in different metrics. The standard feedback H-infinity control structure configurations are shown in Figure 11.

The general formula for the above system is illustrated below,

$$\begin{bmatrix} z \\ v \end{bmatrix} = P(s) \begin{bmatrix} \theta \\ u \end{bmatrix} \tag{1}$$

where,z and v are the error and output of the H infinity feedback control system.
The value of P(s) is the transfer function of SRM, which is given as,

$$P(s) = \frac{\left(\frac{1}{R_m}\right)}{\left(\frac{L}{R_m}\right)s+1} \tag{2}$$

where, the R_m be the transfer function resistance, the condition for satisfying the closed loop system is,

$$T_{z\omega}(s)\ \|_{\infty} \leq \gamma \tag{3}$$

where, $T_{z\omega}(s)$ is the closed-loop transfer function matrix and γ the machine impedance angle. The weight of the matrix is adjusted to control the output of the motor. The weight adjustment process is repeated till the SRM speed reaches a stable condition that is described [19]. The output of the system is represented in the frequency domain. The input and output weight of the system are W_P and W_u. Usually, the H-infinity control problem is solved using Riccati equations. Here, the control problem is considered as the mixed sensitive problem. The closed loop stable speed condition of SRM is described as,

$$\left\| T_{z\omega} \right\|_{\infty} = \left\| \begin{matrix} -W_p GS & -W_p S \\ -W_u T & -W_u KS \end{matrix} \right\|_{\infty} \leq \gamma \tag{4}$$

where, GS, S, T and KS are the pre-specified templates of all the closed loop transfer function of SRM. The sensitive weight functions W_P and W_u are defined as follows. The inverse of the weighting function $W_P(j\omega)$ is used to impose a performance specification in terms of the sensitivity functions.

$$W_P(j\omega) = \frac{\left(\frac{J\omega}{M_s}+\omega_b\right)}{(j\omega+\omega_b A_s)} \tag{5}$$

The control output u is weighted according to the SRM limitations.

$$W_u(j\omega) = \frac{\left(\frac{J\omega+\omega_{bc}}{M_u}\right)}{(j\omega\mathcal{E}+\omega_{bc})} \tag{6}$$

Where, M_u, M_s are the mutual inductance of the output and saturation conditions, A_s is the specific electrical loading of the system, ω_b, ω_{bc} are the angular velocity parameters of SRM, Ɛis the damping ratio. So, the steady state error of the system is reduced and the controller gain is ensured. The purpose of ensuring the controller gain is to make the speed of the SRM in a stable range at any speed variation. The speed variation is compensated by reducing the uncertainty of the system by means of adding weight. The weight matrix of the system is defined based on the rated speed of SRM. Once the weight function is defined, then the output speed of the SRM is applied to the H-infinity controller [20].

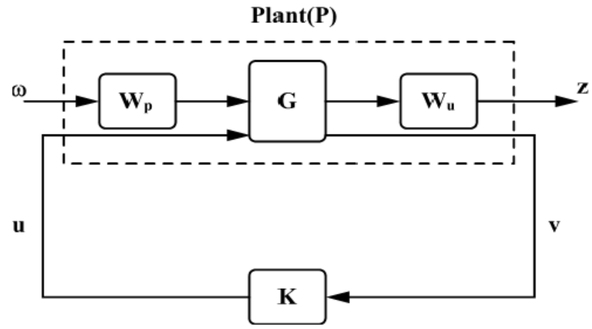

Figure11 H-infinity Feedback Control Structure Configuration

D.H-INFINITY CONTROLLER BLOCK DIAGRAM

Here, the angular velocity is controlled by the H-infinity controller. Through the control value of angular velocity, the friction of the system is reduced. The block diagram of drive system is shown in Figure 12

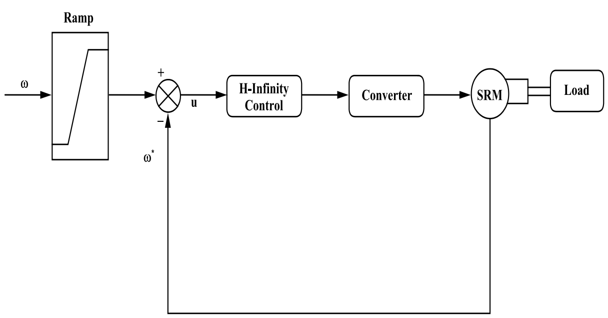

Figure 12 H-Infinity controlled SRM Drive System

E. SIMULATION AND RESULTS

The proposed H-infinity robust controller based SRM rotor position speed control technique is simulated in Matlab working platform (version 7.12). From the simulated model, the rotor speed control performance of the proposed control technique is analyzed. Then, the speed control characteristics of the H-infinity control technique are compared with the existing speed control technique such as PI controller and fuzzy controller. After that, the torque, flux, and transfer function of the SR motor are described. The simulink model of the proposed control system is illustrated in Figure 13.

Figure 14 shows the Speed Control of H - Infinity controller for SRM. Initially speed is increased from 0 to 4500rpm at small time interval. After 0.04 sec SRM maintained the constant Speed of 4500 rpm.

Figure 15 shows the SRM current of H- Infinity controller. Initially starting flux nearly 0.4Wb and finally settled at 0.25Wb.

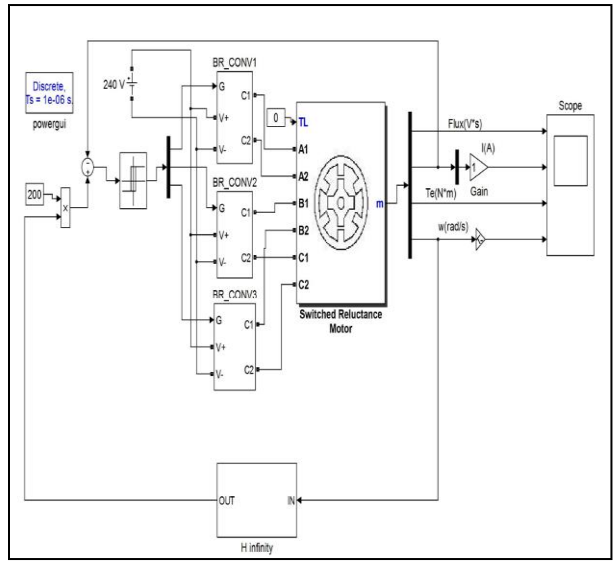

Figure 13 Simulink Model of the H-Infinity Controller

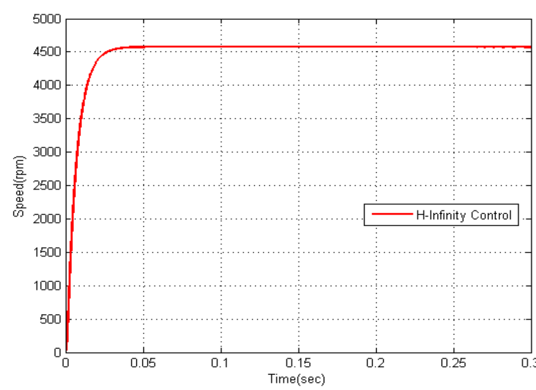

Figure 14 Rotor Speed control of H-infinity control

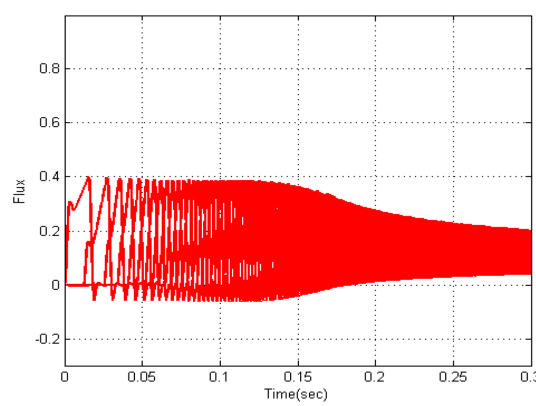

Figure 15 SRM Flux variation of H-infinity control

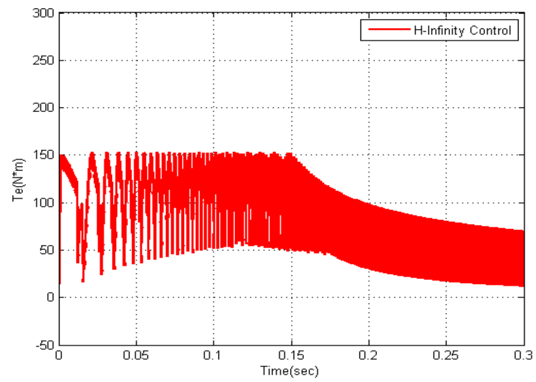

Figure 16 SRM torque of H-Infinity control

Figure 16 shows the SRM torque of H-Infinity controller. Initially starting Torque nearly 150Nm and finally settled at 75Nm.

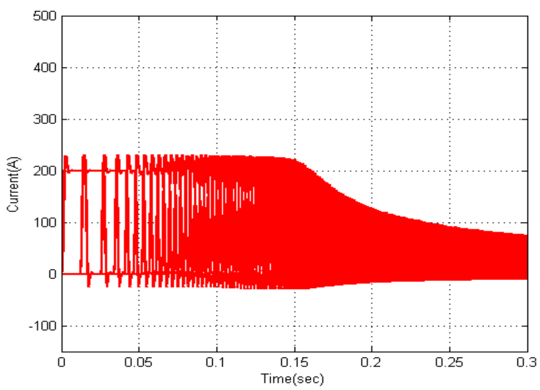

Figure 17 SRM current of H-Infinity control

H - Infinity controller of SRM, the rotor speed control performance accuracy and controlling time are analyzed. In Figure 17, the rotor speed of SRM is smoothly controlled by H-infinity controller.

The PI controller has smoothly controlled the rotor speed but it is inefficient in achieving the desired rotor speed. So, the performance of the SRM would be affected. In Figure 18 the fuzzy control technique has taken more time for achieving desired rotor speed. Among the control techniques, the proposed H-infinity control technique has controlled the rotor speed robustly and the control action response is quick compared to PI and fuzzy controller. The speed control action time performance of the H-infinity, PI, and fuzzy controller are described as follows.

The fuzzy control technique has taken *4.3038 seconds* extra time compared to H-infinity controller. Similarly, compared to PI controller, the H-infinity control has taken 0.0609 *seconds* less for making robust speed system. Hence, the H-infinity control strategy is more efficient for creating robust system than the PI and fuzzy controller. Then, the SRM rotor speed control action of the H-infinity control technique is compared with the PI and fuzzy controller, which are shown in Figure 18. From the above performance analysis, the H-infinity controller has achieved a remarkable level in reducing the robustness.

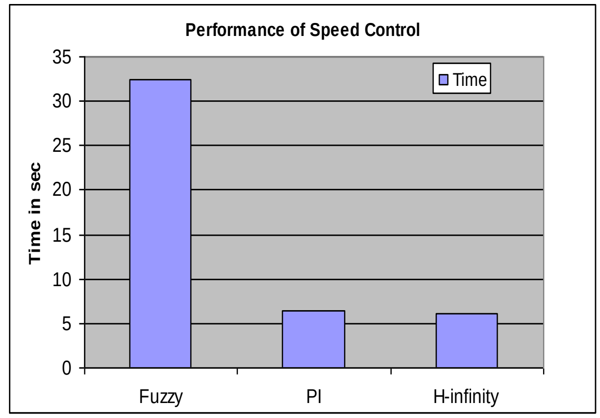

Figure 18 Performance of Speed Control Action in Time

B.GA BASED H-INFINITY SIMULATION AND RESULTS

The proposed H-infinity robust controller based SRM rotor position speed control technique was simulated in MATLAB working platform. From the simulated model the rotor speed control performance of the proposed control technique is analyzed. Then, the speed control characteristics of the H-infinity control technique are compared with the existing speed control technique such as Speed Controlled by Genetic Algorithm Based on Optimal H-infinity Control. After that, the torque, flux, and transfer function of the SR motor are described. The Simulink model of the proposed control system is shown in Figure 20.

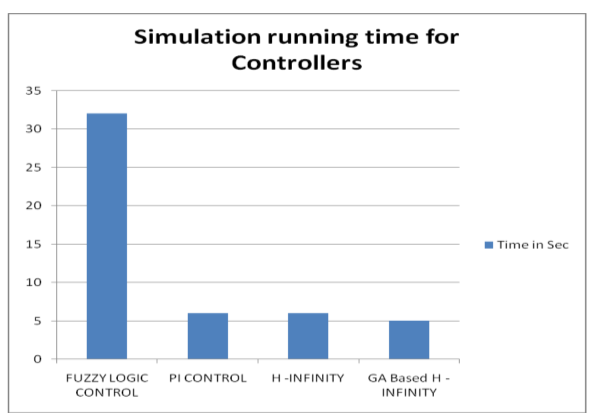

Figure 21 Simulation running time for various controllers

C. SIMULINK MODEL DESCRIPTION

The Figure 20 shows the simulation running time for all controllers. Compared with other controllers, Fuzzy take 32 sec and GA based H-infinity takes only 5 sec.

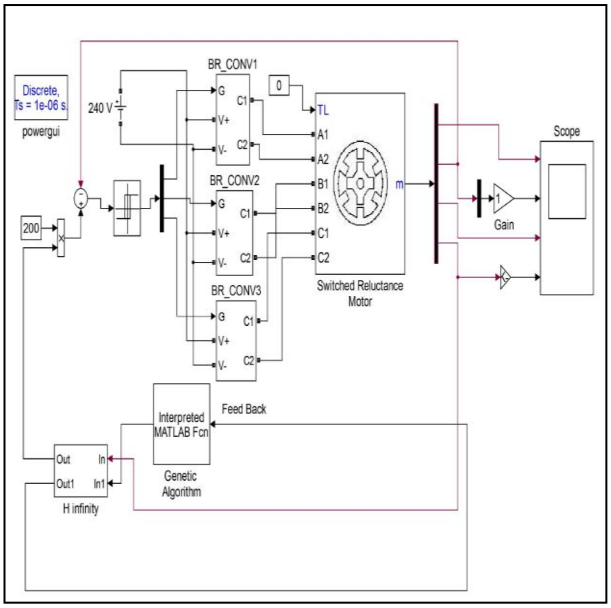

Figure 20 Simulink Model of Proposed Controller for SRM

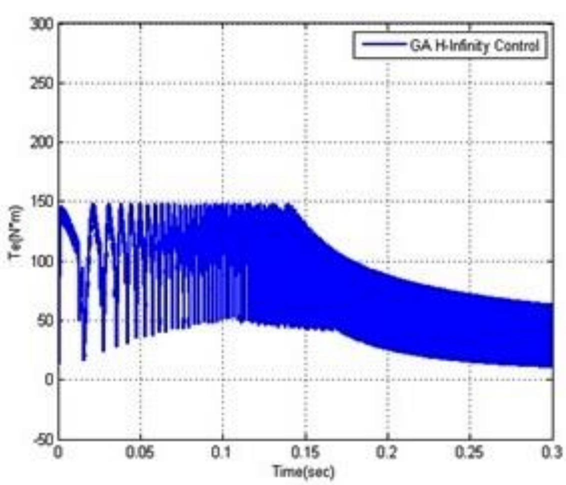

Figure 21 SRM Torque performance of GA based H-Infinity control

Figure 21 shows the SRM Torque of GA based H-Infinity controller. Initially starting torque be the 148 Nm and finally settled at 70Nm.

Figure 22 shows the SRM Speed of GA based H-Infinity controller. Initially starting speed be the 4500 rpm and finally settled at 4550 Nm.

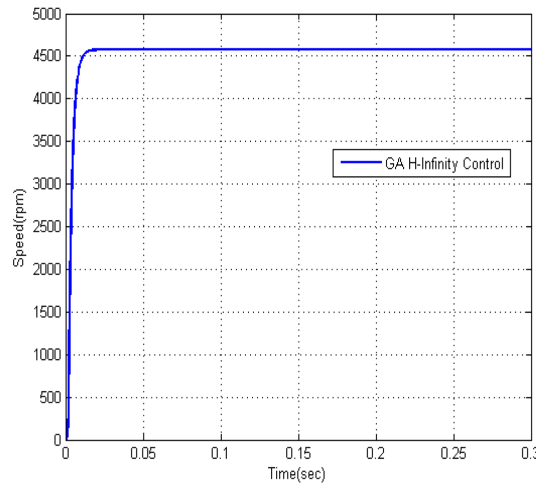

Figure 22 SRM Speed control of GA based H-Infinity control

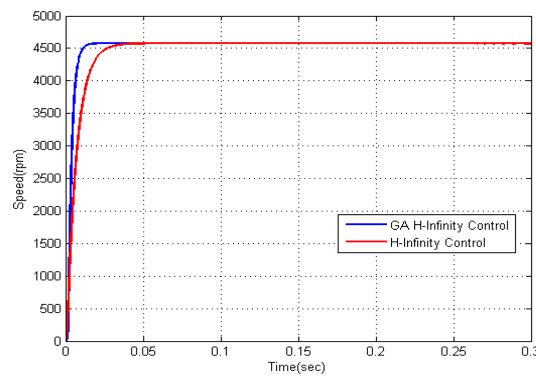

Figure 23 Rotor Speed Comparison of H-Infinity control and proposed control

Figure 23 shows the SRM Speed comparison between GA H-Infinity control and H-Infinity controller.

From the speed comparison performance, the rotor speed control performance accuracy and controlling time are analyzed. Among the control techniques, the proposed H-infinity control technique has controlled the rotor speed robustly and the control action response is quick.

The PI controller, Fuzzy logic controller, H infinity controller and proposed GA based H infinity controller based Switched reluctance motor control. GA based H - Infinity controller for SRM give minimum torque ripple, low starting torque and low steady state error. Overall performance of the Proposed method more suitable for reducing robustness of SRM and improve the Speed control operation of the Switched reluctance motor. Compared all the controller graphs are plotted and tabulated the values.

VI. COMPARISON OF RESULTS

Table 2 Comparison of various SRM controller performances

Motor Parameters	PI Controller	Fuzzy Controller	H infinity Controller	GA based H infinity controller
Speed control action in sec	6	32	6	5
Speed in rpm	4500	4500	4550	4550
Torque in Nm	85	85	80	75
Current in Ampere	150	110	80	50
Flux in Weber	0.35	0.4	0.4	0.4

The comparison of Speed performance of Fuzzy Logic control and PI controller for SRM shown in Figure25.The PI and fuzzy controller technique has taken more time for achieving desired rotor speed.

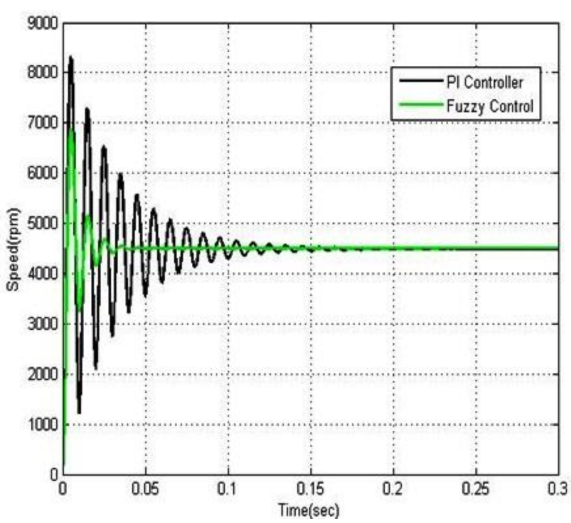

Figure 25 Comparison of Speed performance under Fuzzy and PI controller for SRM

The comparison of Speed performance of Fuzzy Logic control, H-Infinity control and GA H-Infinity controller for SRM shown in Figure 26

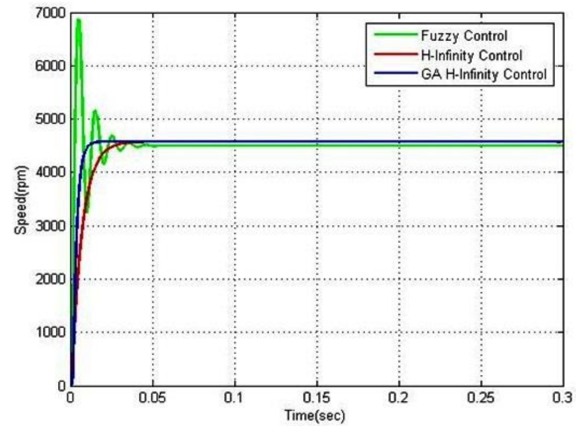

Figure 26 Comparison of Speed performance under Fuzzy, H-Infinity and GA based H-Infinity controller for SRM

The comparison of Speed performance of H-Infinity control and GA H-Infinity controller for SRM shown in Figure 27

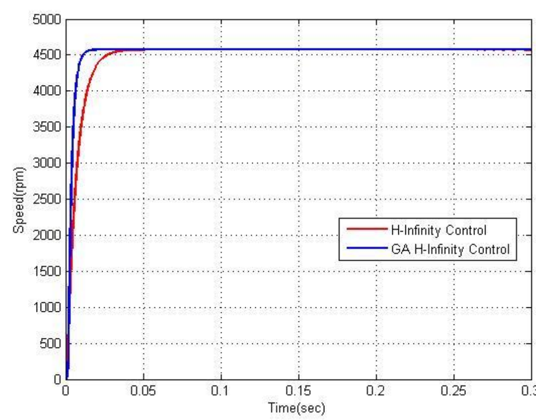

Figure 27 Comparison of Speed performance under H-Infinity and GA based H-Infinity controller for SRM

The comparison of Speed performance of Fuzzy Logic controller, PI controller ,H-Infinity control and GA H-Infinity controller for SRM shown in Figure 28.

The comparison of Torque performance of Fuzzy Logic controller, PI controller, H-Infinity control and GA H-Infinity controller for SRM shown in Figure 29.

The comparison of Current performance of Fuzzy Logic controller, PI controller, H-Infinity control and GA H-Infinity controller for SRM shown in figure 30.

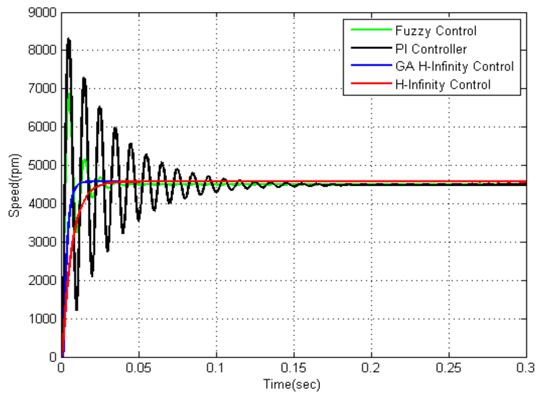

Figure 28 Comparison of Speed performance under various controller for SRM

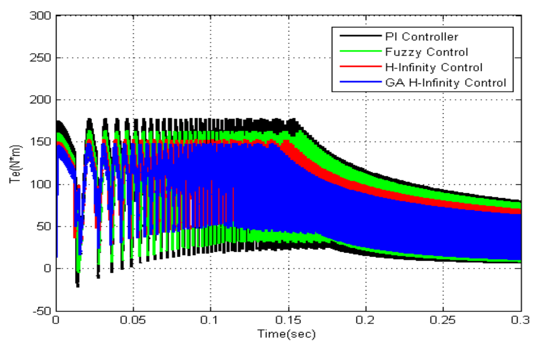

Figure 29 Comparison of Torque performance under various controller for SRM

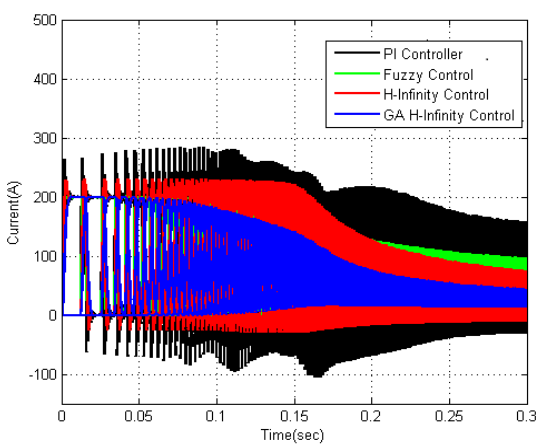

Figure 30 Comparison of Current performance under various controller for SRM

CONCLUSION

The PI controller, Fuzzy logic controller, H infinity controller and proposed GA based H infinity controller based Switched reluctance motor performance. GA based H -Infinity controller for SRM get minimum torque ripple, low starting torque and low steady state error. Compared all the controller graphs are plotted and tabulated the values. From the tabulation GA based H-Infinity control based SRM operate at minimum current of 50A only whereas PI controller operates at 150Aratings.

Overall performance of the Proposed method more suitable for reducing robustness of SRM and improve the Speed control operation of the Switched reluctance motor. Corporately proposed GA Based H –Infinity controller based SRM shown better performance than other controllers. The proposed control technique was simulated and the output drawn was analyzed. The output performance was compared with the other speed control techniques. The control techniques used for comparison were PI controller, H-Infinity Controller and fuzzy controller. From the comparison results, it is found that the proposed control technique is most suitable for controlling the speed of SRM. The response time and steady state error of the H-Infinity controller using GA was less than the H-Infinity, fuzzy logic and PI controllers.

GA based H-Infinity controller gives the robust performance compared with others controllers.GA based H infinity controller based SRM consumes less current value compared with other controllers.GA based H- Infinity controlled SRM achieved low starting time, minimum torque ripple, minimum starting current, overshoot free speed and reduced speed oscillation. So efficiency of the GA based H- Infinity controlled SRM is high. Overall, the proposed H-Infinity control technique using GA has achieved a remarkable level in controlling the rotor speed and smooth speed variation of SRM motor.

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