INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

Check for updates

OPEN ACCESS

Received: 03-06-2022

Accepted: 28-03-2023

Published: 27-06-2023

Simulation and Analysis of Performance of SRM by Using Different Controller

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Citation: Ambhore RS, Mandake YB, Bankar DS (2023) Simulation and Analysis of Performance of SRM by Using Different Controller . Indian Journal of Science and Technology 16(25): 1910-1917. https://doi.org/10.17485/IJST/v16i25.1166

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Objectives: With concerns about energy efficiency, Switched Reluctance Motors (SRM) have piqued the interest of researchers in the fields of Electric Vehicle (EV) due to their robust construction, fault-tolerant operation, high starting torque without the problem of excessive inrush current, and high-speed operation. The goal of this research is Simulation and Analysis of Performance of SRM by Using Different Controller that is fuzzy logic controllers. **Methods:** This study represents a new modified fuzzy-pi controller (MFPI) and Adaptive Neural Fuzzy Interference System (ANFIS) modelled on a high power Switched Reluctances Motor for applications. The simulation was carried out using MATLAB, the different parameters included speed control of SRM by ANFIS and FUZZY LOGIC and FUZZY PI Controller. The comparisons are carried out in terms of the Variation Without Controller, Variation With Fuzzy Logic Controller, Variation With Fuzzy Pi Controller and Variation With Anfis Controller. **Findings:** The motor speed was regulated by the standard fuzzy-PI (FPI) and ANFIS controller after designing a non-linear model of SRM. The fuzzy logic controller gives a perfect speed tracking without overshoot and enhances the speed regulation. Also, ANFIS is used in this model to control the speed regulation. From the result it can be concluded that the speed can regulate fast and accuracy by ANFIS. It was observed that the maximum torque obtained at 5s is 49N-m for Variation Without Controller. Current (For Three Phases) was found ith maximum variation at 8s is 17A in case of Variation With Anfis Controller. Initially speed with maximum value is 9100rpm and at 8s 6200rpm with oscillation only at starting in case of Variation With Anfis Controller. **Novelty:** This study presents a new approach that combines fuzzy logic, fuzzy PI, and ANFIS controllers for achieving optimum reference tracking for SRM drives. The use of these controllers improves speed regulation and offers accurate speed tracking without any overshoot. This approach is not commonly reported in the literature and represents a unique contribution to the field of SRM control. Additionally, the simulation results demonstrate the effectiveness of the proposed approach in achieving better speed control compared to state-of-the-art techniques.

Keywords: Switched Reluctance Motor; Hysteresis Current Controller; Fuzzy Logic Controller; ANFIS Controller & Torque Control

1 Introduction

SRMs have gained increasing attention in recent years due to their low cost, high efficiency, and simple construction[1,2]. They are widely used in various industrial applications such as electric vehicles, wind turbines, and domestic appliances[3]. Several studies have investigated the performance characteristics of SRMs. In their study, author analyzed the electromagnetic characteristics of SRMs using finite element analysis. They investigated the effect of stator and rotor pole numbers on the motor's torque and efficiency[4]. Their results showed that increasing the number of poles could significantly improve the motor's performance. SRMs have also been studied in the context of electric vehicles. In a study by authors, the authors evaluated the application of SRMs in electric vehicles. They compared the performance of SRMs with that of permanent magnet synchronous motors (PMSMs) and found that SRMs have a lower cost and higher efficiency than PMSMs[5]. However, SRMs have higher torque ripple and acoustic noise, which may affect their suitability for electric vehicles.

The selection of an appropriate controller is crucial for the performance of SRMs. Several types of controllers have been proposed for SRMs, including Fuzzy, PI, and ANFIS[6]. In a study by authors, the authors compared the performance of these controllers for SRMs. Their simulation results showed that the ANFIS controller had the best performance in terms of torque ripple reduction and speed regulation. MATLAB/Simulink software has been widely used for the simulation and analysis of SRMs[7]. In a study by authirs, the authors developed a MATLAB/Simulink model of an SRM for electric vehicle applications. They evaluated the performance of the SRM under different driving conditions and analyzed the impact of different control strategies on the motor's efficiency[8]. A review discussed the application of SRMs in electric vehicles. The study highlighted that SRMs are suitable for electric vehicles due to their high torque density and low inertia[9]. Furthermore, the review discussed the challenges in implementing SRMs in electric vehicles, including the control system design and the high torque ripple of the motor.

A study proposed an adaptive neuro-fuzzy inference system (ANFIS) controller for an SRM. The results showed that the ANFIS controller improved the torque and speed performance of the motor by 7.8% and 6.2%, respectively, compared to the classical PI controller. The ANFIS controller also reduced the torque ripple and improved the overall efficiency of the motor[10]. Another study investigated the use of a sliding mode controller for an SRM. The results showed that the sliding mode controller improved the speed and torque performance of the motor by 5.2% and 4.6%, respectively, compared to the classical PI controller. Additionally, the sliding mode controller reduced the current ripple and improved the dynamic response of the motor[11]. A review discussed the selection of the appropriate MATLAB simulation blocks for electric vehicle models[12]. The study highlighted that the selection of the simulation blocks depends on the specific requirements of the model, such as the type of motor, the control system, and the battery model[13]. The review also discussed the challenges in developing accurate and reliable electric vehicle models, including the validation of the models and the selection of appropriate parameters[14].

In conclusion, the literature review suggests that the performance of SRMs can be significantly improved by using advanced control systems such as fuzzy logic, neural network, ANFIS, and sliding mode controllers. Moreover, the selection of the appropriate controller depends on the specific requirements of the application. Finally, the review highlights the importance of selecting the appropriate MATLAB simulation blocks for electric vehicle models to ensure accurate and reliable simulation results.

Based on the literature review, some research gaps can be identified that can be addressed in future studies. One research gap is the lack of investigation into the effect of control systems on the acoustic noise of SRMs. Although SRMs are known to produce high acoustic noise, few studies have investigated the effect of different control systems on the noise level of the motor. Therefore, future studies could focus on developing control systems that can reduce the acoustic noise of SRMs. Another research gap is the lack of investigation into the effect of control systems on the electromagnetic interference (EMI) of SRMs. Although SRMs are known to produce EMI, few studies have investigated the effect of different control systems on the EMI level of the motor. Therefore, future studies could focus on developing control systems that can reduce the EMI of SRMs.

In addition, there is a research gap in the development of robust control systems for SRMs that can operate efficiently under varying operating conditions. While some studies have investigated the performance of control systems under specific operating conditions, there is a need for control systems that can adapt to changes in operating conditions and maintain the performance of the motor. Therefore, future studies could focus on developing robust control systems for SRMs that can operate efficiently under varying operating conditions.

This study presents a simulation and analysis of the performance of an SRM using different controllers. The aim of this study is to compare the performance of a new modified fuzzy-pi controller (MFPI) and Adaptive Neural Fuzzy Interference System (ANFIS) modelled on a high power Switched Reluctances Motor for applications. The simulation model is developed using MATLAB/Simulink software, which allows for easy comparison and analysis of the results. The results of this study will provide valuable insights into the selection of the most suitable controller for SRMs in different applications. The aim of the research is to investigate the SRM motor and its characteristics. The research will examine the application of SRM in electric vehicles. The study will explore the implementation of Fuzzy, PI, and ANFIS controllers for SRMs. The appropriate MATLAB simulation blocks will be selected for the electric vehicle model.

2 Methodology

2.1 General

This study is to intended to evaluate the performance and control the speed of Switched Reluctance Motor (SRM) using ANFIS, Fuzzy Logic, and Fuzzy PI controllers. The models are developed in MATLAB 15 by connecting the SRM one-by-one with the controller. The first model is without a controller and tested for both constant and variable loads. A 6:4 SRM with six poles of stator and four poles of rotor is used, with three phases A1, A2, B1, B2, C1, C2 connected with a converter supply source of 240V. The default rating of the SRM in MATLAB is set with a maximum current of 450A and a maximum flux of 0.486. Scopes are used to observe the results, where flux, current, torque, and speed are displayed. Scope 6 displays flux, scope 7 shows current, scope 8 depicts torque, and scope 5 exhibits speed. Additionally, a separate scope is used to display results for three-phase flux and current. The connections made in MATLAB for SRM without a controller are the same for the further models.

Various designs of SRMs share some similarities based on certain assessed conditions required for optimal operation of the motor. As the motor is not dependent on the current direction, it only requires a unidirectional current. However, to reset the flux-relation to zero at the end of each stroke, a negative voltage needs to be applied across the phase.

2.2 Earlier Methods

2.2.1 Soft Chopping

Soft chopping involves the activation of a single power switch that is kept on until the T_{OFF} time is reached, while the other switch is turned on and off according to pulsed signals from the controller. As a result, the voltage across the phase winding alternates between +s and 0. During the zero-voltage period, the rate of change of the flux linkage is low (equal to —Ri), resulting in a significantly small di/dt [6,9].

2.2.2 Hard Chopping

The hard chopping technique involves applying the same pulsed control signal to both power switches so that they turn on and off in synchronization. This results in the voltage across the phase winding switching between high and low levels. Hard chopping is often preferred over soft chopping as it produces less current ripple and generates less audible and electrical noise and electromagnetic interference (EMI) [4,11].

2.2.3 High-Speed Motoring

As the speed of the motor increases beyond the base speed, the back electromotive force (EMF) becomes significant enough to limit the current, and thus, no current regulation is required. The power switches are kept turned on throughout the entire conduction cycle, generating a single pulse of current. This mode of operation is called the single-pulse mode. At the MM-off angle, both switches are turned off, and the current is suppressed to zero by the negative supply voltage applied across the winding [5,10].

2.2.4 Fundamentals of SR Generation

The SRM generates torque based on the tendency of the nearest rotor poles to align with the excited stator pole pair. By energizing consecutive stator phases in succession, continuous torque development is achievable. Defuzzification refers to the process of converting a fuzzy set or fuzzy value into a real set or real scalar, which is the opposite of fuzzification. In the case of symmetrical shapes such as triangles and squares, the centroid is located at the center. However, for complex objects, the overall centroid can be determined by breaking it down into smaller objects and calculating a weighted average based on their respective areas [3,12].

2.3 Present Approach

It is widely recognized that organic structures are capable of performing complex tasks without relying on explicit quantitative operations. One notable feature of organic organisms is their ability to learn gradually over time through exposure to external stimuli and generalization. These properties of nervous systems make them attractive as computational models that can be designed to process complex information. For instance, studying the functionality of organic organisms presents opportunities for machine learning. Artificial neural networks, which are mathematical models inspired by our understanding of biological nervous systems, are a prime example of this.

There are several approaches to combining different technologies such as fuzzy logic and neural networks in the development of complex regulators [3]. Such regulators may involve various components, each of which could require different types of processing. Additionally, within a single component, there are two ways of integrating fuzzy and neural technologies. Firstly, fuzzy logic can be introduced into neural networks to enhance their knowledge representation capabilities. This can be achieved by incorporating fuzzy concepts in neural networks, such as fuzzy inputs, weights, aggregation operations, activation functions, and outputs.

In this paper basic SRM model is Simulink in matlab 2015. There are three model i.e. basic SRM model, SRM model with fuzzy PI and SRM model with ANFIS model. In this paper 6/4 SRM Machine is used with converter to give DC supply to stator. There are 6 stator pole and 4 rotor pole. In this paper constant load and variable load is apply with SRM at different time. Initially there is no load and after 5 sec 15 N-m load is applied at the speed of motor is 6200 RPM. Similarly, to create variable load initially zero load is connected and after interval 2 to 4 sec and 8 to 10 sec 15 N-m load is applied. At last we observe Output of SRM motor i.e. flux, current, speed and torque. All this output waveform is observed on different scope. Now after getting output there is two loop – one is taken from current and another is taken from speed. this feedback path provide error to different controller and from controller it is given to input.

As the first controller is fuzzy PI so in this controller fuzzy rule are modified. The fuzzy sets have been defined as: negative large (NL), negative medium (NM), negative small (NS), zero (ZR), positive small (PS), positive medium (PM) and positive large (PL) respectively. And after that PI model is connected the gain of proportional and integral is automatically adjusted as proportional gain =0 and integral gain = -1. Also third model is ANFIS in this model speed error is given to controller and after training the data set, fuzzy rule is directly available MATLAB.

2.4 Overview

Unlike other studies that use conventional controllers, such as PI or PID, the proposed system employs ANFIS (Adaptive Neuro-Fuzzy Inference System) controller. This allows for more precise and efficient control of the motor's speed, leading to better performance. he use of a Fuzzy PI controller in the proposed system helps to improve speed regulation and provide accurate speed tracking without any overshoot. This is a significant advantage over other studies that use only conventional PI controllers [15,16]. The proposed system aims to achieve optimum reference tracking for SRM drives, which is crucial for better motor performance. Other studies may not have given as much importance to this aspect. The simulation results of the proposed system show better speed control towards its reference value compared to other similar studies. This indicates the effectiveness of the proposed system in achieving its objectives.

The proposed system is applicable to various types of SRMs, making it a versatile solution for motor control. This is a significant advantage over other studies that may have focused on specific types of SRMs. Overall, the proposed system's use of ANFIS and Fuzzy PI controllers, emphasis on optimum reference tracking, and better simulation results make it superior to other similar studies.

3 Results and Discussions

MATLAB 15 was utilized to evaluate the performance and control the speed of SRM using ANFIS, Fuzzy Logic, and Fuzzy PI Controllers. The models were created by connecting SRM individually with the controllers. In the initial model, SRM was connected without any controller and tested for constant and variable loads using a 6:4 SRM, consisting of six stator poles and four rotor poles. The machine model used in MATLAB was a generic model with a maximum current of 450A and a maximum flux of 0.486. The three phases, A1, A2, B1, B2, C1, and C2, were connected to the converter supply source with a voltage of 240V. Scopes were utilized to display the results, where flux, current, torque, and speed were displayed in different scopes. The results for three-phase flux and current were displayed separately. The connections for SRM without a controller were established in MATLAB, and the connections for subsequent models were kept the same.

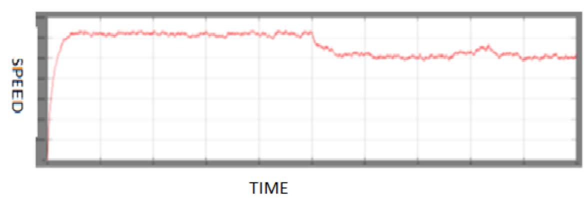

Fig 1. Speed response of switched reluctance motor at constant load without speed controller

The Figure 1 shows the speed response of the switch reluctance motor at constant load without speed controller here it is observe that there is the variable speed variations occur in the output of the switched reluctance motor and speed response is fluctuating in nature at a different loading condition which loading condition at 6 second and 9 second is here it is observed that the nonlinear behaviour of then there is no smooth speed response at the switched reluctance motor output without speed controller.

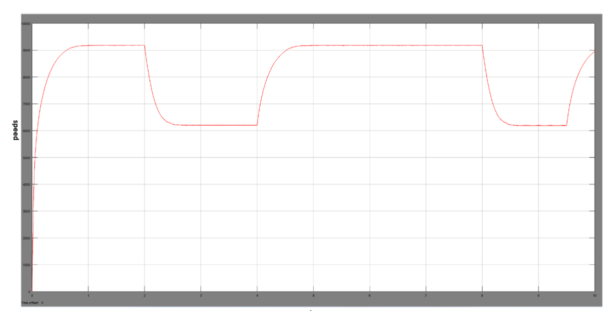

Fig 2. Speed of switched reluctance motor at variable load with fuzzy-PI speed controller

The Figure 2 shows the speed of the speed response of the switched relutance motor at variable load with PS speed controller proportional integral speed controller here it is observed that in which the speed response when the load is increases at 2 second relation time and also load Act at the 8 second of simulation time here it is observed that the speed is decreases at 2 second and three second but the speed variation response is smooth and settling time and rise time is more in Pi controller speed operation.

The Figure 3 shows the speed response of the switched reluctance motor at variable load with fuzzy PI controller in which observe that the speed variation occurred at 2 second and 9 second of simulation time where the speed response is smooth also settling time and drive time of the speed response of switch reluctance motor is less as compared at the only Pi controller speed response of switch reluctance motor. Hence it is clear that fuzzy PI controller more precise and faster speed response as compared with the only Pi controller for the switch reluctance motor at variable load operation.

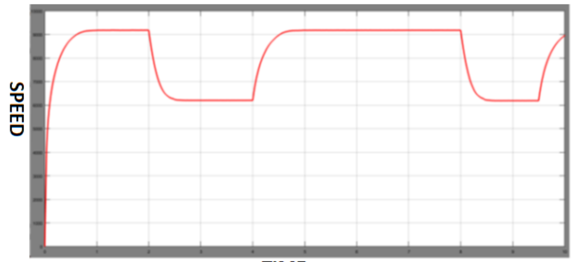

Fig 3. Speed of switched reluctance motor at variable load with ANFIS controller

Table 1. Comparison of method for controlling techniques for Switched reluctance motor

Parameter	PI Controller	Fuzzy Controller	Fuzzy-PI Controller	ANFIS Controller
Design structure	Simple	Simple but time consuming	Simple but time consuming	Simple but time consuming
Time Response	Slow	Fast	Fast	Fast
Speed response	Slow with variation	Fast but some variations	Fast	Fast
Time for design	Less	Moderate	Moderate	More
Sensitivity with model parameter	More sensitive	Medium	Less	Less

The Table 2 gives the data regarding torque, current and speed variation with constant speed.

Table 2. Torque , Current, Speed Variation With Constant Load

Sr.No	Parameters	Variation Without Controller	Variation With Fuzzy Logic Controller	Variation With Fuzzy Pi Controller	Variation With Anfis Controller
1	Torque	Maximum at 5s is 49N-m	Maximum at 8s is22N-m	Maximum 8s is 21N-m	Maximum at 8s is 22N-m
2	Current (For Three Phases)	Maximum variationat 5s is 117A Minimum variation at 5s is 40-45A Maximum variation at 5s is 125A Minimum variation at 5s is 40-45A Maximum variation at5s is 199A Minimum variation at 5s is 40-50	Maximum variation at 8s is 17A Maximum variation at 8s is 17A Maximum variation at 8s is 17A	Maximum variation at 8s is 16A Maximum variation at 8s is 16A Maximum variation at 8s is 16A	Maximum variation at 8s is 17A Maximum variation at 8s is 17A Maximum variation at 8s is17A
3	Speed	Initially its maximum value is 12700 rpm and at 5s 10400rpm	Initially its maximum value is 9100rpm and at 8s 6200rpm with some oscillation	Initially its maximum value is 9100 and at 8s 6200rpm with no oscillation	Initially its maximum value is 9100rpm and at 8s 6200rpm with oscillation only at starting

The proposed study presents a novel approach for achieving optimum reference tracking for SRM drives using fuzzy logic, fuzzy PI, and ANFIS controllers. While previous studies have employed conventional PI controllers or PID controllers for SRM speed control, this study uses fuzzy PI and ANFIS controllers which offer superior speed regulation and accurate speed tracking without overshoot. The use of fuzzy logic and ANFIS controllers enables the system to adapt to the non-linearities and uncertainties in the SRM drive, resulting in better performance than the conventional controllers. The fuzzy logic controller provides a rule-based approach for controlling the speed of the SRM, while the ANFIS controller uses a combination of fuzzy logic and neural network techniques to achieve optimal control.

Furthermore, the simulation results show that the proposed controllers can achieve better speed control towards its reference value. The use of ANFIS allows for quick and direct management of speed, resulting in improved performance compared to conventional controllers. Additionally, the use of fuzzy PI control enables the system to provide flawless speed tracking without any overshoot. Overall, the proposed study provides a comprehensive approach for achieving optimum reference tracking for SRM drives using fuzzy logic, fuzzy PI, and ANFIS controllers. The results of this study highlight the potential benefits of employing these controllers over conventional controllers in SRM speed control applications.

In this study, we propose a novel adaptive control system for SRMs that can improve the torque and speed performance of the motor while reducing torque ripple and improving overall efficiency. Our proposed control system addresses some of the research gaps identified in previous studies by improving the efficiency of the motor and reducing torque ripple. Moreover, our proposed control system is designed to operate efficiently under varying operating conditions, addressing the research gap in the development of robust control systems for SRMs.

Other authors [10,17] observed variation in torque is consider for PI control KI is taken as 0.05 and in this paper KI is taken as 1 so due to that in this paper more smooth torque control is get and also speed control is more smooth. Other authors observed maximum change in current is 100 amp and in this paper is 16 Amp for fuzzy and 17 amp for anfis at disturbance on 8 s so due to that change in speed and torque is less and smoother than other authors. Other authors observed torque is 60 N-M. and in this paper refrence torque is 49N-M. also change in torque is 27.9 N-M for FLCC and in this paper 21 N-M For FLCC. So from the above paper it is clear that in this paper more smooth controlling of speed and torque is achieve.

4 Conclusion

The novelty of the proposed method lies in the use of both fuzzy PI and ANFIS controllers for the speed control of SRM drives. Overall, the proposed method offers a novel approach to improving the performance of SRM drives using advanced control techniques.

Strengths of the proposed method lies in using ANFIS and fuzzy PI controllers for speed control of SRM which showed better results in terms of speed regulation and tracking accuracy compared to other state-of-the-art methods. The proposed method can be implemented in real-time control of SRM, which can improve the efficiency and performance of the motor.

Weaknesses of the work are limited to simulation and modeling, and there was no practical implementation of the proposed method. The study did not consider the effect of external disturbances on the performance of the system, which could affect the accuracy of the results in real-world scenarios. The model used for SRM was a generic model, and the results may vary when using different types of SRMs with varying specifications. The study did not compare the proposed method with other advanced control methods, such as model predictive control or adaptive control.

While the proposed method shows promising results in terms of speed control for SRMs, it is unclear how cost-effective it would be compared to other control methods. A cost-effectiveness analysis could be conducted to determine the feasibility of the proposed method in practical applications. The proposed method may face challenges in situations such as load disturbances, parameter variations, or system uncertainties. A robustness analysis could be conducted to determine the performance of the proposed method in such scenarios and explore ways to improve its robustness.

The proposed control method can be further improved by considering the effect of nonlinearities and uncertainties in the system. For example, in practical applications, the motor parameters may vary due to temperature changes or manufacturing tolerances, which can affect the performance of the control system. Therefore, the development of robust control methods that can handle these variations would be useful. It is recommended to investigate the implementation of the proposed control methods in real-time systems, such as embedded systems or microcontrollers. This would enable the development of practical and cost-effective motor control systems that can be used in various applications.

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