

Performance Analysis Of Switched Reluctance Motors Using Fuzzy Logic Speed Controllers In MATLAB

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Abstract

Switched reluctance motors (SRMs) are gaining significant attention due to their simple construction and high reliability. These motors generally employ a two-pole structure, where the stator consists of concentrated windings placed on each pole, while the rotor is composed solely of laminated iron without any windings or permanent magnets. This straightforward design makes the SRM a cost-effective, rugged, and highly reliable solution for variable-speed applications. Since the motor primarily consists of laminated magnetic materials and concentrated coils, its overall performance is strongly influenced by the magnetic characteristics of the core material. However, SRMs suffer from certain limitations such as torque ripple, acoustic noise, vibrations, and relatively low torque density.

Conventionally, a proportional–integral–derivative (PID) controller is employed to control the speed of the switched reluctance motor. The PID controller is capable of maintaining speed regulation even under sudden variations in load conditions. In this study, a fuzzy logic controller (FLC) is proposed as an alternative approach for speed control of the SRM drive system. The dynamic performance of the SRM under fuzzy logic control is investigated using the MATLAB/Simulink environment. To validate the effectiveness of the proposed controller, the obtained results are compared with those achieved using a conventional PID controller, highlighting the improved performance of the FLC.

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I. Introduction

Switched reluctance motors (SRMs) are recognized for their simple and rugged construction, low manufacturing cost, high-speed operating capability, and the absence of permanent magnets. Owing to these advantages, SRMs have emerged as a competitive alternative to permanent magnet motors. They show strong potential for future applications in electric traction systems and are extensively employed in industrial sectors such as pumps, compressors, and ventilation systems. Although SRMs without permanent magnets are more widely adopted, permanent magnet motors continue to play an important role in electric drive systems. To overcome inherent challenges in SRMs, including high torque ripple, acoustic noise, and relatively low torque density, significant research efforts have been devoted to improving their performance. For in-wheel traction applications, axial flux SRM configurations are considered more suitable than radial flux designs due to their higher torque density [1].

An SRM is characterized by salient poles on both the stator and rotor, making it a double-salient machine. The rotor does not contain windings or permanent magnets, which results in low inertia and enhanced dynamic performance. In SRMs, the stator poles are typically larger than the rotor poles, contributing to improved magnetic interaction. The absence of rotor windings reduces manufacturing cost and increases efficiency. Despite these advantages, SRMs suffer from torque ripple and strong magnetic nonlinearity, which limit their applicability in systems requiring smooth torque and speed responses. Conventional linear control techniques are often inadequate for SRMs due to their nonlinear magnetic characteristics, necessitating the adoption of nonlinear and intelligent control strategies [2].

Chen et al. [3] proposed a four-phase SRM drive system that utilizes only two current sensors. By employing an asymmetric half-bridge topology, the proposed drive allows current sensing for two phase windings using a single sensor per phase pair, thereby reducing hardware complexity while enabling additional charging and discharging functionalities without extra sensors or circuit elements. Wathewaduge et al. [4] presented a comprehensive review of electromagnetic modeling techniques for SRMs, including analytical models derived from Maxwell's equations, interpolation and curve-fitting approaches, and numerical methods such as the finite element method (FEM) and boundary element method (BEM). The magnetic equivalent circuit (MEC) approach was also discussed as an effective modeling tool.

To improve SRM performance for electric vehicle applications, the optimal design of multilayer SRMs was investigated in [5]. In recent years, advanced control techniques have gained increasing attention for enhancing the dynamic response and efficiency of SRM drive systems. These techniques are broadly classified

into intelligent controllers and sliding mode-based approaches, including fuzzy logic control. A fast terminal sliding mode control (FTSMC) strategy for SRM speed regulation was proposed in [6], where a fuzzy logic compensator was integrated to enhance the signal gain. The proposed approach demonstrated superior performance compared to conventional sliding mode control (SMC) and proportional-integral (PI) controllers in both time and frequency domains.

Wang et al. [7] investigated a torque sensor-less direct torque control (DTC) scheme for SRMs and proposed an adaptive Takagi-Sugeno-Kang (TSK) fuzzy sliding mode controller. Abdel-Fadil and Szamel [8] explored the application of fuzzy logic control in electric vehicle systems to reduce current ripple during SRM startup and phase conduction. The fuzzy current controller ensures that the motor current closely follows the reference signal, thereby minimizing torque ripple. Several studies [9], [10] developed fuzzy logic controllers for SRM speed regulation and compared their performance with conventional PI controllers, demonstrating improved transient and steady-state responses. A novel control approach for linear switched reluctance motors (LSRMs) was introduced in [11].

In [12], a Type-2 Takagi-Sugeno fuzzy control scheme was applied to approximate SRM behavior under uncertainty. Upper and lower membership functions were employed to represent system parameter variations. An adaptive sliding mode controller with an integral sliding surface was designed, and system stability was validated using Lyapunov theory. Torque ripple reduction was further addressed in [13] through a fuzzy logic-based current chopping controller, which regulates the PWM duty cycle during each switching period. An auto-tuning proportional-integral controller for SRM speed control was presented in [14], where fuzzy logic was used to determine PI gains. The control algorithm was implemented using a programmable logic controller, while MATLAB/Simulink was used for fuzzy inference processing.

Advanced control techniques such as adaptive control and artificial neural networks (ANNs) have also been applied to SRM systems [15]–[17]. However, these methods typically involve complex design procedures and require expert knowledge, limiting their practical implementation. Optimization-based approaches, including ant colony optimization, particle swarm optimization (PSO), and optimal control methods [18]–[21], aim to enhance speed response by minimizing predefined performance indices under specific constraints. Despite their effectiveness, these methods often demand high computational resources, placing increased requirements on controller hardware in real-time applications.

Fuzzy logic controllers have gained widespread acceptance in modern engineering systems due to their robustness and ability to handle system uncertainties. FLCs are particularly effective when accurate mathematical models are difficult to obtain. Under transient and nonlinear operating conditions, fuzzy logic controllers have been shown to outperform conventional PID controllers [22], [23].

In this work, a fuzzy logic controller is implemented to improve SRM speed regulation under varying speed commands and constant load conditions. The organization of this paper is as follows: Section 2 presents the modeling of the SRM. Section 3 describes the design and implementation of the fuzzy logic controller for SRM speed control. Section 4 discusses the simulation results, and Section 5 concludes the paper.

II. The Switch Reluctance Motor And Its Mathematical Modelling:

The motors are supposed to obey physics laws but SRM motors fail to do so. In reluctance motors the torque is highly advanced that indicates the alternate virtue in terms of reluctance with rotor recognized a role. On the basis of this particular principle, the SRM isn't the same as other kinds of electric powered machines which includes the DC system, synchronous gadget and induction device. The general concept of reluctance machines and their traditional aspects is a system of synchronous aspects and in the beginning of 20th century this principle was introduced and it was based on the park equations. The easier concepts regarding SRM or reluctance motors make it easier to operate such motors, the concept for the driving of these motors is easier as compared to other rotor motors. Most of the electromagnetic relays giving protection to the magnets are seen to be application on this courting along with solenoid based actuators, various kind of gadgets. In all these, the common aspect is the pressure that among magnetic surfaces is produced and all machines with saliency are included in it.

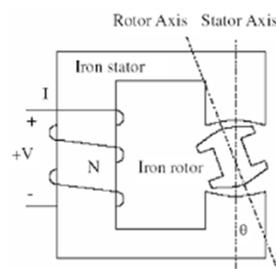


Figure 1. single phase SRM

Mathematical equation of SRM

Torque equation

To derive the basic torque equation of the SRM, let us consider an elementary

The following figure 1 indicates the SRM motors. The main system is based on the excitation of a single phase, it is considered the best one for the winding of other parts of machine at the stator. At the stator, the excited winding is wound and unfastened rotor is allowed to move and make its rotation.

The linkage of flux is mentioned in the following equation

$$\lambda(\theta) = L(\theta)i \tag{2.1}$$

The independent enter variable is i and the rate at which current moves is considered from the stator, the torque equation obtained overall is mentioned as follows [6]

$$T_e = \left[\frac{\partial W'}{\partial \theta} \right]_{i=const} \tag{2.2}$$

The co energy is mentioned as W' . the Co energy is actually the magnetization process under the location and this is mentioned in the following curve as shown in figure 2. The exact integration in other phases is mentioned as well.

$$W' = \int_0^{i_1} \lambda(\theta, i) di \tag{2.3}$$

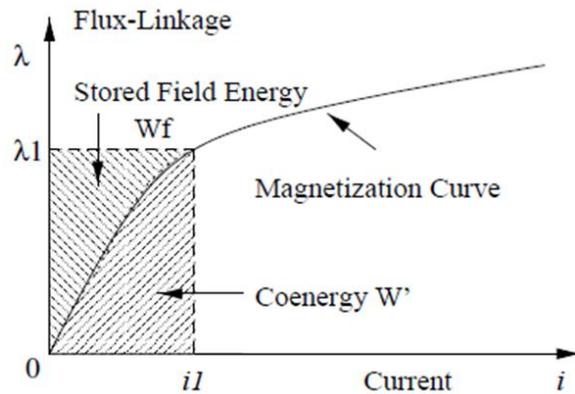


Figure 2. Flux-Linkage Graph

So the torque equation (2.2) will become

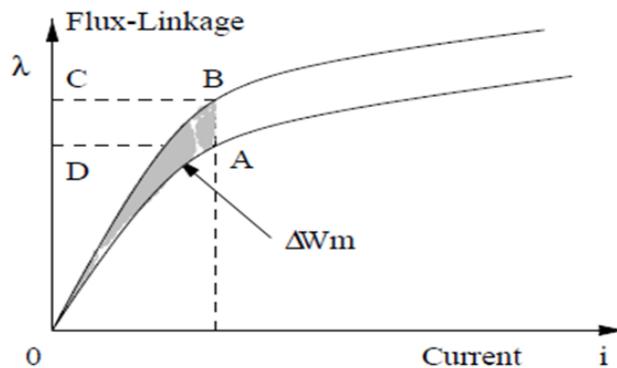


Figure 3 Diagram of Energy Exchange

$$T_e = \int_0^{i_1} \frac{\partial \lambda(\theta, i)}{\partial \theta} di \tag{2.4}$$

The immediate torque is seen for all the equations and there is a graphical visualization of this torque. The far painting of it is mentioned as ΔW and the essential divisions are made by Δe and in this process, ΔW_m is the stator motor obtained at the constant work and in this way, the displacement obtained is infinitely smaller and this is mentioned in FIGURE 3 as it is illustrated by Δe . In this kind of simple but controlled displacement, the electrical supply is made by the alternate use of power and in the disciplined energy there is an alternative use of power. In the displacement of this kind, the mechanical paintings are carried out and the constant modern constraints ensure this easy process and this process is considered similar to the co energy changes that are taking place

The effortless proving of this statement is mentioned as below:

In the same way from Δe to the displacement from the figure 3 is shown from A to B at in this case, the power exchange is taken as a cutting edge and it is represented as

$$\Delta W_e = S_{ABCD}$$

The stored field power changes are mentioned as:

$$\Delta W_f = S_{OBC} - S_{OAD}$$

The work done that is needed mechanically is mentioned as follows:

$$\begin{aligned} \Delta W_m &= T_e \Delta \theta \\ &= \Delta W_e - \Delta W_f \\ &= S_{ABCD} - (S_{OBC} - S_{OAD}) \\ &= S_{ABCD} + S_{OAD} - S_{OBC} \\ &= S_{OAB} \\ &= \Delta W' \end{aligned}$$

It is easily estimated by the above mentioned equations that there is no generation of electricity and via mechanical paintings the electricity is supplied. The magnetic subjects are used to save some of the aspects. There is no wastage of any power saved inside the magnetic field during this process and in the same way power conservation process is easily operated at some stages especially if the motion is considered from point A to point B. In case of absence of magnetic saturation, the curves of magnetisation can be used in lines at once. The example of rotor motors can be considered whereby the co energy is generated and kept save in the magnetic gadgets and is provided via following equation:

$$W_f = W' = \frac{1}{2} L(\theta) i^2$$

There is a reduction of instant torque to

$$T_e = \frac{1}{2} i^2 \frac{\partial L}{\partial \theta} \tag{2.5}$$

In [7] the indication of this kind of motor is given. In the motors of other kinds, there are some problems as we can see in the unmarried SRM phase. In this case, blank zones are existing as well and they form the torque zones that are highly successful. The inertia is applied in the form of load and this pulls the motor through some load. Throughout one revolution, there is no chance for the angular torque to work and produce the simple motion of the machine. Hence, the reluctant motors are not used in the multiple phase. The multiple sections of the motors are considered for this purpose and summation is added to represent the torque equation.

$$T_e = \sum_{j=1}^m T_{ej}$$

The torque generated is represented by T_{ej} with the help of phase named j th and the variety is seen in the overall process for reluctant motors and their working.

III. Fuzzy Logic Control For SRM

Introduction

For the purpose of trouble, solving the fuzzy logic is considered as an ideal method and in this package with higher variations are included. The results are recorded and controls are embedded. Easy manner to control the reaction is the fuzzy logic, precise conclusion is drawn from the vague, and statistics are kept constant in this

phase. The human selection in making is resembled by the fuzzy logic and in this way the working potential is increased from the unique answers and their location. The fuzzy control logic is a system of deep learning for the classical logic functioning and the system is made efficient enough to generate genuine equations and numeric values are obtained in particular. The complicated system is used and abstraction degree is made better. The know how and experience is made easier. In the same way fuzzy sets are published by the end of 1965 and in the field of mathematics it is defined as the fuzzy set of theory. The fuzzy logic is applied to make the sense here. The false and actual values are obtained and this idea suggests the membership in terms of functioning and actual values are performed again [0.0, 1.0]. the suggestions were made regarding new operations and calculus logics and the generalization of the principle is mentioned in terms of fuzzy and classic logic [18].

The automobiles that are working on the principle of switched reluctance have a higher potential of manipulation in terms of bending. Multiple combinations are there, they can form the highlighted parameters and forward input execution is obtained while doing this. The cars working on DC conventional current, the variations can be made in voltage and present-day technology to make the vehicles working on the principle of switched reluctance. The angles of turning on and turning off are located inside the communication of the direct current and motors working on it and these can be brushed as well. The speed is decreased and the segment current is then controlled. This is done by switching the modulation width and phase voltage. For getting the torque at steady state under the bottom base is used. It is abbreviated as (ω_{base}). This form obtains the current manipulation and it can control the output of torque on any material by this current manipulation.

The angles for turning off and turning off the reluctance motor are often added in addition to the controls. This allow the freedom of rotation and other movements and in this way the execution can be made easier. This also allows the satisfaction of unique targets over the variety of prolonged speed. In order to control the angles of turning off and on, the manipulation is needed and it is known as segment angle manipulation. It is one of the ideal approaches for the perspective control as only fewer variables are needed so that speed can be adjusted and the work is obtained as per desire. The current is not able to move inside and on the basis of this fact, the time is needed in all rotations it makes. This allows in the inductance growth of the motor.

On the two SRM manipulation policies there are several versions available in the study. The cutting edge manipulation or the hybrid segment perspective are used that are used in combination to various new methodologies and technologies and they help in the optimization of speed and in this way overall performance of the motor is increased. The torque is maximised and the efficiency of the torque is increased and in this way the acoustic noise or rippling torque are used as well. The instant torque manipulation is obtained and this is variable and depends on the input and output torque so that the waveform of the current is shaped according to the turning off and turning on angles. In this way there is a manipulation of rippling torque and the voltage can be controlled in the hybrid section. The variations are there on the angle of manipulation as a variant and in this way excitation phase is obtained by the voltage phase. The preferred acoustic noise and other features of torque are obtained as well. This helps in the management of various strategies for SRM so that the overall working of this application is increased. The servo motor application is a unique form of manipulation of torque and it is used commonly. The strategies for the rotation of SRM motors can be applied to increase the overall performance of the reluctant motors. The acoustic noise is reduced by manipulation of this kind. We will discuss other strategies in the following section that are considered essential for the easier operation of SRM in both contemporary and phase angles.

Functional membership:

Fuzzy logic controller generates current reference modifications (ΔI_{Ref}) primarily based on speed error e_{mref} and its modifications e_{m-} e_m has its minimal cost whilst the motor speed has its nominal value, 850 rad/sec, and is inverted to -850 rad/sec, so in line with equation (5.7), then the rate mistakes equal: $e_m = (-850) - (850) = -1700$ rad/sec

The most value, +1700, is obtained inside the contrary scenario as shown in figure 4.

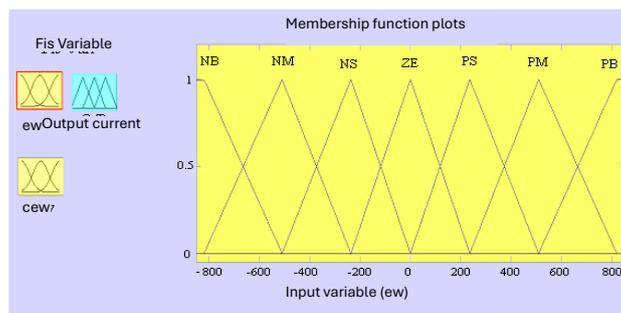


Figure 4. Speed Error (e)

The adjustments of speed error (ce ω) and according to equation (3.1) can be written in another form:

$$\begin{aligned}
 ce\omega &= e\omega(k+1) - e\omega(k) \\
 &= e\omega(k+1) - e\omega(k) \\
 &= (\omega_{ref} - \omega(k)) - (\omega_{ref} - \omega(k-1)) \\
 &= -(\omega(k) - \omega(k-1)) = -\Delta\omega
 \end{aligned}
 \tag{3.1}$$

Substituting equation (3.1) and (3.2) into equation

$$\Delta t = 0.0013\text{sec}, J = 0.01 * 10^{-2}\text{kgm}^2, \tau = 1.5\text{Nm}$$

Δt is the interruption time, J is the moment of inertia, τ is the advanced torque in Nm and maximum absolute cost for the ΔI_{ref} universe changed into acquired by trial and mistakes. The preliminary limits for the universes after some manual adjustments of the antecedents (ω_e , ω_{ce}) and consequent (ΔI_{ref}) were:

$$\begin{aligned}
 e\omega &= -850,850\text{rad/sec}; \\
 ce\omega &= -20,20\text{rad/sec/sec}; \\
 \Delta I_{ref} &= -1.5,1.5\text{A}.
 \end{aligned}$$

Figure 5 shows the membership function for the antecedent, the second one enter is the trade within the speed error.

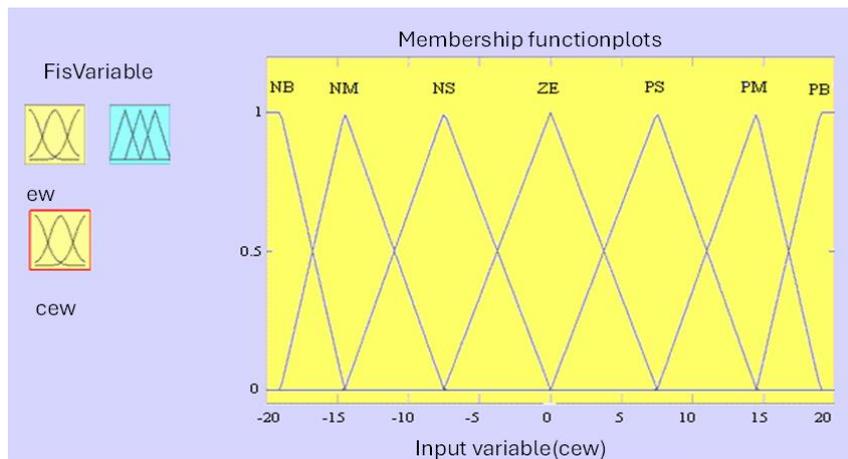


Figure 5. Change of Speed Error (CE)

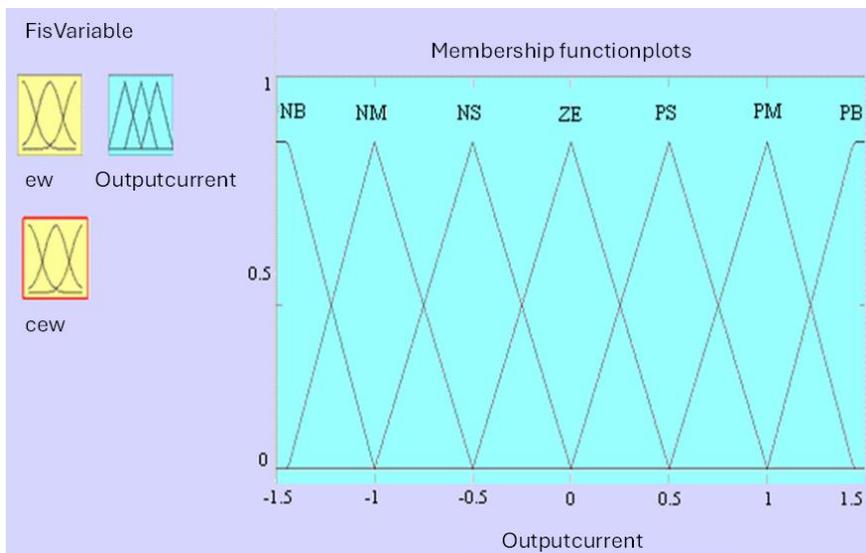


Figure 6. Member Function for Output.

IV. Results And Analysis

The operational efficacy of the Switched Reluctance Motor (SRM) drive was evaluated through a comparative analysis between Fuzzy Logic (FLC) and PI control strategies, implemented within the MATLAB/Simulink environment. A constant 350V DC supply was applied to the SRM input terminals to establish the testing conditions. Figure 7. illustrates the dynamic response characteristics of both controllers, highlighting the SRM's performance during the initial startup phase and its subsequent transition to a steady state following a load disturbance.

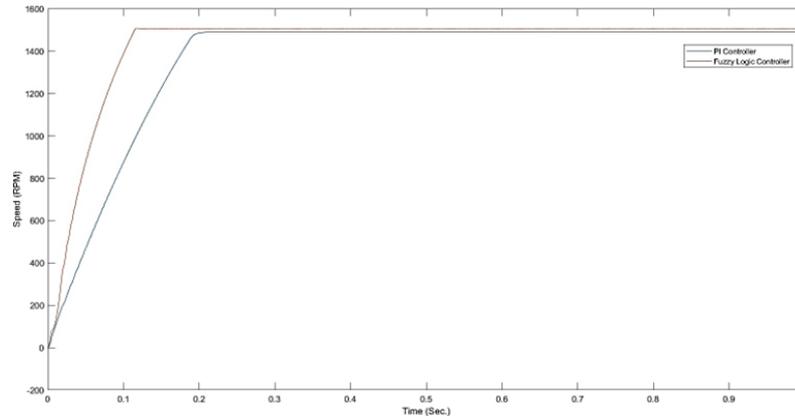


Figure 7. Performance comparison of FLC and PI controller

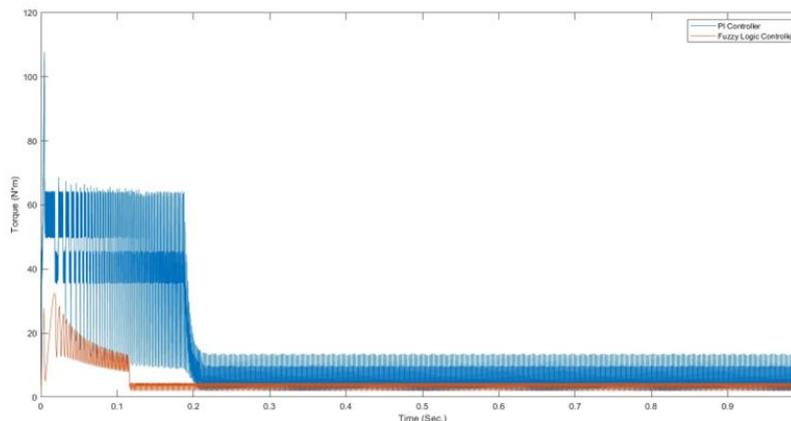


Figure 8. Torque Performance comparison of FLC and PI

Analyzing the results from both the **Speed Response (Figure 7.)** and the **Torque Response (Figure 8.)**, we can observe the distinct performance advantages of the Fuzzy Logic Controller (FLC) over the traditional PI Controller for the Switched Reluctance Motor (SRM) drive.

As illustrated in the speed-time plot, the **Fuzzy Logic Controller** (represented by the orange/red curve) demonstrates superior agility compared to the **PI Controller** (blue curve).

- **Faster Acceleration:** The FLC exhibits a significantly steeper slope during the startup phase, reaching the reference speed of 1500 RPM in approximately **0.12 seconds**.
- **Reduced Settling Time:** The PI controller shows a slower rise time and takes nearly **0.2 seconds** to stabilize, whereas the FLC reaches a steady state almost twice as fast.
- **Smooth Transition:** Both controllers effectively reach the target without significant overshoot, but the FLC maintains a more linear and aggressive approach to the setpoint.

The torque response graph provides critical insight into the mechanical stress and efficiency of the SRM drive.

- **Startup Peak Torque:** The PI controller experiences a massive initial torque spike exceeding **100 N·m**, which can cause mechanical wear over time. In contrast, the FLC limits the startup torque peak to a much safer range (under **40 N·m**).

- **Torque Ripple Reduction:** During the transient phase (0 to 0.2 seconds), the PI controller exhibits high-amplitude torque oscillations. The FLC significantly dampens these ripples, leading to smoother motor operation.
- **Steady-State Performance:** Once the motor reaches its nominal speed at roughly 0.2 seconds, the FLC maintains a lower and more consistent torque ripple compared to the PI controller. This reduction in ripple is essential for minimizing acoustic noise and vibration in SRM applications.

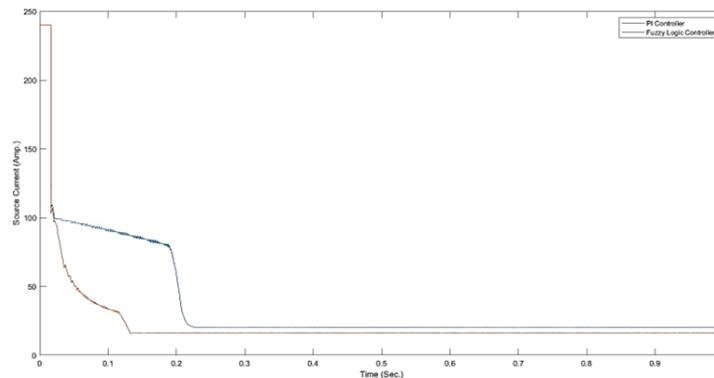


Figure 9. Source Current comparison of FLC and PI

The source current characteristics (Amp. vs Time) illustrate how efficiently each controller manages energy during the motor's transient and steady-state phases.

- **Initial Inrush Current:** Both controllers exhibit a high initial peak of approximately **240A** during the first few milliseconds of operation. This is typical for a Switched Reluctance Motor (SRM) as it attempts to overcome inertia and start from a standstill.
- **Transient Phase Efficiency:** The **Fuzzy Logic Controller (red line)** shows a significantly more efficient current profile. After the initial peak, the FLC rapidly reduces the source current to approximately **50A** within **0.05 seconds**. In contrast, the **PI Controller (blue line)** maintains a much higher current level (near **100A**) for a longer duration, only beginning its sharp descent after **0.18 seconds**.
- **Settling Time:** The FLC reaches its steady-state current level at roughly **0.13 seconds**. The PI controller takes significantly longer, reaching its steady-state current at approximately **0.23 seconds**. This suggests that the FLC enables the motor to reach its target speed with less energy waste and faster stabilization.
- **Steady-State Current Levels:** Once the system stabilizes, the FLC maintains a slightly lower steady-state current compared to the PI controller. This indicates improved electrical efficiency and reduced thermal losses in the motor windings under Fuzzy Logic control.
- **Reduced Current Ripple:** The FLC waveform appears smoother during the transition to steady state, whereas the PI controller shows a more prolonged period of moderate current consumption, reflecting the slower rise time observed in the speed graphs.

V. Conclusion

The main objective of this study was to achieve efficient and robust speed control of a switched reluctance motor (SRM) under varying operating conditions. The controller design and performance evaluation were carried out using the MATLAB/Simulink environment. A fuzzy logic-based speed control strategy was implemented for the SRM drive system to address the inherent nonlinearities and performance limitations associated with conventional control methods. The proposed approach combines fast dynamic response with effective disturbance rejection, ensuring stable operation during sudden load variations while eliminating oscillatory and chattering effects.

Extensive simulation results demonstrate that the fuzzy logic controller provides reliable speed regulation over a wide range of reference speeds under loaded conditions. To validate its effectiveness, the performance of the proposed controller was compared with that of a conventional proportional-integral-derivative (PID) controller. The comparison reveals that the fuzzy logic controller achieves faster rise time and shorter settling time, allowing the motor speed to converge to the reference value within a finite duration even when load torque is applied. In contrast, the PID controller exhibits slower dynamic response and larger speed deviations in the time domain under similar conditions.

In addition, the fuzzy logic controller shows superior robustness against torque-load disturbances and speed ripple. The reduced magnitude of speed drop and improved ripple suppression indicate enhanced steady-

state and transient performance. These results confirm that the fuzzy logic-based control approach outperforms the traditional PID controller in terms of speed tracking accuracy, stability, and disturbance rejection.

The findings of this work confirm the reliable operation of the SRM drive system and highlight the effectiveness of artificial intelligence-based control techniques for industrial motor drive applications. The proposed controller maintains the desired reference speed without overshoot under various load conditions, making it suitable for practical implementations. Future research may focus on integrating optimization techniques such as genetic algorithms (GA) and ant colony optimization (ACO) to further improve controller tuning, reduce computational complexity, and enhance overall system performance.

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