Review Article

Comprehensive Overview of Modern Controllers for Synchronous Reluctance Motor

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Synchronous reluctance motor drives (SynRM) are the best promising machines utilized in modern industries and electric vehicles, according to the current study. Research on new SynRM drive systems has increased as a result. This review article disseminates the most recent developments in these technologies’ design, modeling, and controlling. First, a simple comparison between the main motor technologies and SynRM is made. To aid researchers in selecting the appropriate motor controller for their motor drive systems, the most common motor control approaches are examined and classed.

1. Introduction

Special electric motors known as synchronous reluctance motors (SynRM) use the principle of magnetic reluctance to produce torque. These motors are superior to other types of motors in a variety of ways, including high efficiency and robustness. However, using a specific controller is required to operate a SynRM. The purpose of synchronous reluctance motor controllers is to deliver accurate control over the rotor position and speed of a SynRM [1–3]. They frequently make use of sensorless control techniques such as field-oriented control (FOC) to achieve high accuracy and dynamic performance. Some controllers employ advanced control algorithms such as space vector modulation (SVM) and direct torque control (DTC) to increase performance [4–10].

For this study, we compiled the most significant research publications in the area of SynRM. An orderly qualitative assessment of the evidence about SynRM drive systems is provided as follows: the most promising motor technology as well as potential alternatives is examined in the second part. In addition, it investigates the applications and possibilities and contrasts the motors’ performance in terms of price and eco-friendly considerations. The possibilities for SynRM modeling are examined in Section 3, along with each model’s applications, advantages, and disadvantages. The control methodologies for various machines are discussed in Section 4. Future direction and conclusions are listed in Sections 5 and 6.

2. Need for Synchronous Reluctance Motor

For several reasons, SynRMs are suitable in industrial and commercial applications, [1, 11–14] including

(I) SynRMs are extremely efficient because of their simple rotor structure and lack of rotor windings, which reduces power losses in the motor.

(II) Low Cost: Because SynRMs have a simple rotor structure and do not require rotor windings, the motor is less expensive.

(III) SynRMs have a high-power density due to their fundamental rotor structure, allowing them to produce significant torque at high speeds.

(IV) Less Noise: Because of its simple rotor structure and absence of rotor windings, SynRMs produce less noise, making them excellent for low-noise applications.
Robustness: SynRMs are suitable for industrial applications since they are robust to changes in motor properties as well as external disturbances. SynRMs are perfect for applications that need significant torque at low speeds since they have a high torque. Pumps, fans, compressors, conveyors, and other industrial and commercial applications, among others, can all use SynRMs. SynRMs provide a great degree of control flexibility, making it possible to boost performance and energy efficiency by employing current control algorithms such as FOC and (DTC) [9, 15].

Table 1 summarizes the types, advantages, disadvantages, and main applications of dominant motors, and in most of the industrial applications, induction motors are used, which can be effectively replaced using SynRM [1, 2, 15–25].

### 3. AC Motor Classifications

AC motor drives are often employed in a widespread range of industrial and consumer applications [26]. The motor type used is determined by the individual application requirements such as power output, efficiency, and dependability. Based on their design and working principles, AC motors are categorized into numerous categories. Here are some examples of popular AC motor classifications:

(I) Synchronous AC motors: The rotor of this motor rotates at the same speed as the stator's revolving magnetic field. High-power applications such as compressors, pumps, and generators require this sort of motor [27–30].

(II) Induction AC motors: These are the most popular form of AC motors, often known as asynchronous motors. They work based on electromagnetic induction, and the rotor speed is always somewhat variable [21, 31].

(III) Single-phase AC motors: These motors are employed in low-power appliances and machinery. They have only one winding (for starting purposes, auxiliary windings are used), and the magnetic field direction changes in time with the alternating current.

(IV) Three-phase AC motors: These motors, which have three windings in the stator, are employed in industrial applications. They are more powerful and efficient than single-phase motors [26].

(V) Brushless alternating current motors: These motors use a permanent magnet rotor and an electronic controller which controls the stator current of the stator windings [32, 33]. They are utilized in robots, electric cars, and HVAC systems, among other things.

(VI) Universal AC motors: Used in various applications such as power tools and general fans and these motors can run on either AC or DC power.

(VII) Stepper AC motors: These motors are mostly used in precision applications, such as robotics and 3D printers. They move in small steps, and the speed and direction of rotation can be controlled with precision.

### 3.1. Induction Motor Classification

Induction motors are one of the types of AC motor that operates based on the principle of electromagnetic induction. They can be classified into different types based on their construction, rotor type, and method of starting. Here are some common induction motor classifications:

(1) Squirrel cage induction motor (SCIM): This is the one of the commonly used induction motors. It possesses rotor with conductive bars that are permanently short-circuited at the ends, resembling a squirrel cage. When the stator windings are energized, it produces a rotating magnetic field that induces rotor currents in the bars, causing it to rotate [1–3, 34].

(2) Wound rotor induction motor (WRIM): This type of motor possesses windings in the rotor which are connected to slip rings. The slip rings are used to connect external resistors which can be added to the rotor circuit. This external resistance will control the starting torque and speed of the motor [21, 35].

(3) Double cage induction motor: This type of motor will have two sets of rotor bars, one of them in the outer periphery and another in the inner core. This design provides higher starting torque and better efficiency compared to the single-cage motor [31, 36–38].

(4) Synchronous induction motor: This type of motor combines the features of both synchronous and induction motors. It has a rotor with salient poles, which align with the rotating magnetic field in the stator, resulting in synchronous operation. However, the rotor also has conductive bars to induce currents, allowing it to start as an induction motor [37, 38].

(5) Single-phase induction motor: These motors have a stator with single-phase winding, making them suitable for small appliances and machines. They use auxiliary windings or capacitors to create a revolving magnetic field that induces currents in the rotor.

(6) Variable frequency drive (VFD) induction motor: These motors can operate at different speeds and torque levels by varying the frequency of the power supplied to the motor. VFDs are used in applications such as HVAC systems, pumps, and conveyor belts to improve energy efficiency and control motor speed [37, 38].
<table>
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<tr>
<th>Motor</th>
<th>Rotor types</th>
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<th>Main applications</th>
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<tbody>
<tr>
<td>Induction motor</td>
<td>(i) Rugged squirrel cage rotor (ii) Wounded rotor</td>
<td>(i) High inertia (ii) Wide range of power ratings (iii) High torque capability (iv) Flux ripple due to magnetic saturation (v) Good speed regulation (vi) Robust and simple mechanical structure (vii) Cost-effectiveness (viii) High efficiency</td>
<td>(i) Moderate torque ripple (ii) Moderate speed ripple (iii) Moderate total harmonic distortion (THD) (iv) Moderate weight and volume/weight ratio</td>
<td>Industrial applications, pumps, fans, conveyors, etc.</td>
</tr>
<tr>
<td>Synchronous motors [2]</td>
<td>(i) Wounded rotor</td>
<td>(i) Wide range of power ratings (ii) High torque capability (iii) Low-torque ripple (iv) Low-speed ripple (v) Low total harmonic distortion (THD) (vi) Excellent speed regulation</td>
<td>(i) Relatively higher cost compared to induction motors</td>
<td>Robotics, automation, and high-performance applications</td>
</tr>
<tr>
<td>SynRM [18–22]</td>
<td>(i) Skewed rotor (ii) Rotor with asymmetric flux barrier</td>
<td>(i) Reliable (ii) High dynamic response (iii) High-speed control</td>
<td>(i) High torque ripple (ii) Low-power factor</td>
<td>Industrial applications such as pumps, fans, traction, etc.</td>
</tr>
<tr>
<td>PMSYNRM [15]</td>
<td>(i) Skewed rotor (ii) Rotor with asymmetric flux barrier (iii) PM materials</td>
<td>(i) Reliable (ii) High dynamic response (iii) Very high performance</td>
<td>(i) The manufacturing process is very hard (ii) The installation process is quite difficult</td>
<td>Traction applications</td>
</tr>
</tbody>
</table>
3.2. About Synchronous Reluctance Motor. SynRM, as the name implies, generates reluctance torque by varying magnetic reluctance, also known as magnetic resistance. The magnetic flux flows into the magnetic resistance with the lowest value. As a result, the flux produced by the stator flows into the rotor with the lowest magnetic resistance. As a result, if the rotor is not aligned with the flux, the reluctance torque will cause the rotor to revolve in the direction with the least magnetic resistance [22, 36, 39–44]. In this sense, the magnetomotive force (MMF) is caused by the saliency ratio, and the reluctance torque spins the rotor. SynRM’s rotor design, which lacks bars and magnets, results in chily rotor operation. As a result, SynRM offers commendable loadability, especially at lower speeds. This motor may be loaded up to 2.5 times its nominal torque [18–20, 23, 35, 45].

Torque density was the main area of interest for SynRMs in the past. However, more recent research has shown that these motors are a highly effective option for the industrial sector [46]. The lack of bars in the rotor, which lowers iron loss and promotes proper motor performance, is one of the main elements enhancing their efficiency [45]. The SynRM drive’s payback period is exceptionally short due to its efficiency advantage, making it a practical and sensible alternative to conventional induction motors (IM). For a 37 kW, 1500 rpm SynRM with 8000 yearly running hours, the projected payback time for an IE4 SynRM drive, as opposed to an IE2 drive, is expected to be merely 1.6 years [46]. International Energy-Efficiency (IE) standards included in IEC 60034-30 Parts 1, 2, and 3 determine the efficiency class of electric motors [47]. Better IE ratings imply better motor efficiency, and these codes represent the necessary degree of efficiency. The SynRM offers the even more efficient IES efficiency class (Super-Premium class), whereas the European Union nations have made the IE3 efficiency class (Premium class) required since 2015 [47].

3.3. Modeling SynRM. The process of modeling a SynRM involves simulating the motor’s activity mathematically. For the model to accurately imitate a SynRM, it has to include high precision and linearity. The FEA-based model is frequently utilized for accurate and trustworthy motor simulations. For online applications like control systems, FEA is inconvenient and time-consuming due to its large computational weight. Therefore, FEA is more suited for design and optimization goals in different electrical devices.

Researchers frequently use analytical models instead of FEA for various objectives to overcome this constraint. As an illustration, the inductance values of the winding function model, a typical analytical model used for SynRM, are contrasted with those produced through FEA in References [48–50]. In addition, the SynRM d, q model is another analytical strategy that has been extensively researched in several research papers. In-depth analytical models for permanent magnet synchronous reluctance motors (PMSynRM) have also been created by researchers. In Reference [51, 52], Armando et al. constructed and verified a straightforward model that examines the influence of cross-saturation on rotor position estimation while ignoring cross-saturation effects. In Reference [53], a new method is used to get currents and flux connections in both SynRM and interior permanent magnet synchronous motors (IPM). This method uses radial basis function neural networks. It is said that the connection between these numbers can create magnetic models effectively.

3.4. Summary of Modeling SynRM. The d, q model of SynRM is examined in several research works, and it is determined to be the most appropriate modeling for practical purposes.

4. Control Methodologies

Figure 1 shows the control methodologies for SynRMs, and it is given as follows.

4.1. Conventional P, PI, and PID Controllers. To obtain accurate control of the motor’s states, conventional P, PI, and PID controllers can be employed for synchronous reluctance motors [5]. These controllers employ feedback control to modify control inputs such as voltage and current depending on the error signals between the motor’s actual and desired states. The P controller adjusts the control input based on the error signal using proportional gain. To reduce steady-state error and enhance overshoot time, the PI controller adds an integral term to the proportional gain. The PID controller augments the PI controller with a derivative term to increase stability and prevent overshoot and undershooting [58, 59].

Traditional controllers have several benefits, including simple design, robustness against disturbances, and ease of adjustment.

4.2. FOC for SynRM. The rotor position and speed of a SynRM are routinely managed using the sensorless control approach known as FOC [10, 53]. Using a mathematical model of the motor, it determines the stator current and voltage required to give the specified torque and speed [15, 54–57]. FOC is especially well liked in sectors such as steel and mining where efficiency and steady-state reaction are valued more highly than transient response. To provide practical control, this approach operates in the d, q reference frame and treats the motor as a DC motor.

Direct field-oriented control (DFOC) and indirect field-oriented control (IFOC) are the two basic strategies for controlling the decoupling currents in the synchronous reference frame. While in IFOC, the flux angle is generated from the detected rotor position utilizing a mounted shaft encoder, and in DFOC, the rotor flux angle is determined by estimated flux.

In conclusion, the benefits of FOC include

(i) High performance is there during the steady state
(ii) Precise control of the current is possible
(iii) Compatible with a variety of AC motors
(iv) Implementing a modulation system is simple
(v) Constant frequency of switching is possible
However, the FOC control approach is somewhat sophisticated, the controller design would need a full understanding of the motor dynamics, the system is relatively expensive, and the current control and modulation approach imposes a substantial computational burden on the CPU.

4.3. DTC for SynRM. Boldea et al. made the first attempt to implement DTC on SynRM in 1991, which has now piqued the market’s attention as shown in Figure 2. This allure is due to its inherent characteristics, which are as follows:

(i) The absence of a PWM signal-generating module
(ii) The current control mode is simple
(iii) Direct torque control enables quick reactions and great dynamics
(iv) High robust control

Direct control of the motor’s instantaneous torque and stator flux linkage is used in the DTC approach, which eliminates the requirement for coordinate transformation. Based on input signals, the switching table, a lookup table, picks predetermined combinations of switching sequences. These inputs include the indications of the stator flux and torque errors, as well as the stator flux sector. DTC enables fast and accurate torque control, which improves performance and boosts energy efficiency. It is extremely suitable for industrial applications due to its resistance to changes in motor characteristics and external disturbances. DTC has a very simple control structure, making it easy to use and understand.

However, the DTC control mechanism is somewhat intricate, the controller design may need a full understanding of motor dynamics, and the system is quite expensive. The lack of a current controller in the DTC block diagram results in large torque ripples. Researchers have investigated numerous solutions to this problem. When paired with DTC, one viable solution includes employing multiple inverters, as illustrated in Reference [9]. The overmodulation approach for SynRM DTC is another solution proposed in Reference [60]. This solution keeps DTC’s simplicity while eliminating torque ripples and maintaining a steady switching frequency. Furthermore, a reference flux-vector calculator (RFVC) has been devised and used in Reference [61] for IPM to prevent high torque ripples in DTC. Through space vector modulation (SVM), RFVC substitutes the two hysteresis controllers and the torque PI controllers, achieving constant switching frequency. This effectively eliminates the disadvantage of the variable switching frequency.

4.4. Sensorless Vector Control (SVC) for SynRM. SynRM employs the reluctance torque generated by the stator and rotor to achieve great efficiency and power density. SVC is a technology for regulating SynRMs that does not require sensors on the rotor and results in a trustworthy and cost-effective control system as shown in Figure 3.

SVC is based on the idea that stator currents and voltages may be utilized to calculate rotor position and speed [62]. To estimate, either a model-based approach or an observer is utilized. The observer-based technique predicts rotor position and speed from stator currents and voltages using a mathematical model of the motor [63]. The model-based method estimates rotor position and speed from stator currents and voltages using a mathematical model of the motor and a parameter identification tool.

The primary advantage of SVC is the elimination of rotor position sensors, which decreases the cost and enhances the reliability of the control system [63]. Because of its excellent performance and robustness, SVC is well suited for high-speed and high-power applications.

The first step in creating SVC is deciding whether to use an observer or a model-based method [62]. The most common algorithms are the extended Kalman filter (EKF), the unscented Kalman filter (UKF), the Luenberger observer, and the sliding mode observer (SMO) [63]. The algorithm of choice is determined by the requirements of the specific application, as well as the benefits and drawbacks of each technique.
After deciding on an observer or model-based method, the next step is to identify the motor parameters. The identification is performed using the stator voltages and currents, as well as the expected rotor position and speed. The least squares (LS), recursive least squares (RLS), and maximum likelihood (ML) identification methods are the most commonly used. Accurate initial estimates of the parameters, as well as a proper identification approach, are critical to the iterative identification process.

The final stage of SVC implementation is the control of stator currents and voltages. To carry out the control, either a model-based controller or a PI controller is employed [63]. The PI controller manages the stator currents and voltages based on the expected rotor position and speed. The model-based controller controls the stator currents and voltages by employing a mathematical model of the motor as well as the estimated rotor position and speed [62].

The SVC of SynRM, which has been fully explored in the literature, has been employed in several high-performance and high-power applications, including electric automobiles, wind turbines, and rapid industrial motors. The SVC has shown to be a successful, trustworthy, and cost-effective control mechanism for SynRMs, and it is expected to be used in more scenarios in the future.

The fundamental disadvantage of SVC is that it is dependent on the validity of the motor’s mathematical model and the technique for detecting its characteristics, which can be influenced by temperature and aging changes in the motor parameters. Another disadvantage of SVC is its vulnerability to measurement noise and disturbances in

**Figure 2: DTC for SynRM [9, 47, 60].**

**Figure 3: Block diagram for sensorless control for SynRM [47, 62].**
stator currents and voltages. This sensitivity can lead to estimation errors and a reduction in control performance.

To summarise, sensorless vector control is an excellent approach for regulating synchronous reluctance motors. It eliminates the need for rotor position sensors, lowering costs and increasing the dependability of the control system. Its exceptional performance and robustness make it ideal for high-speed and high-power applications.

4.5. **Space Vector Modulation (SVM) for SynRM.** The stator current of a SynRM is regulated using the pulse width modulation (PWM) technique known as SVM as shown in Figure 4 [31]. A mathematical model of the motor is used to find the ideal PWM signal that will provide the necessary torque and speed [40].

The basic principle behind SVM is to manage the stator current to get the motor to produce the proper amount of torque. This requires determining the PWM signal that will provide the required torque and speed. SVM features a closed-loop control system composed of an inner current loop for stator current regulation and a feedback loop for torque measurement.

SVM reduces harmonic distortion in the stator current, improving power factor and decreasing motor losses. Control structure that is simple to understand and implement: SVM features a control structure that is simple to understand and implement [36]. However, the SVM control technique is somewhat sophisticated, the controller design may need a detailed understanding of motor dynamics, and the device is relatively expensive. It is also worth noting that SVM may not be adequate on its own to regulate the motor’s speed and that other control algorithms may be required [36]. Overall, space vector modulation for SynRM provides an efficient and effective means of controlling the motor, delivering improved performance, reduced losses, and smoother operation for various industrial applications.

4.6. **The Modified Predictive Direct Torque Control (MPDTC) for SynRM.** The MPDTC control technology manages the operation of a SynRM as depicted in Figure 5. It is a complex control approach that combines the benefits of DTC with predictive control to improve the effectiveness and efficiency of the motor [64].

The basic idea of MPDTC is to use a predictive model to foresee the motor’s future torque and speed and then use that knowledge to immediately modify the stator current. MPDTC is a closed-loop control system that uses an inner current loop to regulate stator current and a feedback loop to measure torque and speed [27, 64].

MPDTC has several advantages over prior SynRM control techniques, including:

Enhancements to performance and energy efficiency: MPDTC’s ability to adjust torque quickly and precisely contributes to improved performance and energy efficiency. MPDTC is suited for industrial applications due to its resistance to changes in motor settings and external disturbances. MPDTC’s capacity to control nonlinearity makes it an excellent choice for systems with complex dynamics.

MPDTC is well suited for systems with uncertain or imprecise information because it can manage uncertainty and imprecise information. However, because MPDTC is so complex, a thorough understanding of predictive control, direct torque control, and motor dynamics may be required.
for controller design. Furthermore, calibrating the MPDTC controller may be difficult and need a trial-and-error process [47, 65].

4.7. Model Predictive Control (MPC) for SynRM. MPC, a complex control system, is used to govern the performance of a SynRM as shown in Figure 6. It uses mathematics to predict the motor’s future behavior and changes the control inputs to achieve the desired performance [63, 66–71].

In the case of a SynRM, the MPC controller anticipates future rotor position, speed, and torque and uses this information to change the stator current in real time. The controller constantly analyses the rotor position and speed and changes the stator current to eliminate errors and move the system closer to the optimal operating point [5].

MPC has a variety of advantages over traditional SynRM control approaches, including

- MPC improves performance and energy economy by rapidly and precisely regulating the rotor’s position, speed, and torque.
- MPC can manage nonlinear systems, making it a strong fit for systems with complex dynamics.
- Managing ambiguity: MPC is capable of managing uncertainty and imprecise information, making it an excellent fit for systems with these sorts of input.
- MPC is well suited for systems with changing conditions since it is adaptive and can alter with the system’s dynamics.
- MPC can manage both control input and system state limits, making it an excellent choice for systems with operational constraints.
- MPC is a rather challenging control approach; therefore, a thorough understanding of optimization, predictive control, and motor dynamics may be required for controller design. Furthermore, fine-tuning the MPC controller may be difficult and requires a trial-and-error approach.

4.8. Adaptive Recurrent Fuzzy Neural Network (ARFNN) for SynRM. An ARFNN combines the properties of adaptive control, recurrent neural networks, and fuzzy logic to govern the operation of a SynRM [57, 72].

The basic idea behind an ARFNN is to use a fuzzy logic system to mimic the nonlinear dynamics of the SynRM, followed by a recurrent neural network to continually modify the parameters of the fuzzy logic system. The ARFNN also has an inner current loop that regulates the stator current and a feedback loop that measures the rotor position, speed, and torque.

ARFNN has a variety of advantages over other SynRM control techniques, including

- ARFNN’s capacity to control nonlinearity makes it an excellent fit for systems with intricate dynamics. Because it can manage uncertainty and imprecise information, ARFNN is well suited for systems with uncertain or imprecise information.
- Adaptability: Because it can respond to changes in system dynamics, ARFNN is well suited for systems with changing situations.
- ARFNN is well suited for systems with operational constraints because it can manage control input and system state limits. Because of its resistance to changes in motor settings and outside disturbances, ARFNN is well suited for industrial applications.

However, because ARFNN is a very advanced control approach, the controller design may need a thorough understanding of adaptive control, recurrent neural networks, fuzzy logic, and motor dynamics. ARFNN controller tuning may likewise be difficult, necessitating a trial-and-error approach.

4.9. Fuzzy Controller for SynRM. A fuzzy controller is a type of control system that uses fuzzy logic to manage the operation of a SynRM [57, 73]. Fuzzy logic is a mathematical method that allows for the logical representation of ambiguous or erroneous information. In a fuzzy controller for a SynRM, fuzzy sets are generated from input variables such as rotor position, speed, and torque. These fuzzy sets are then used to select the appropriate stator current, the output variable.

The fuzzy controller finds the appropriate stator current for a given set of input variables by applying a set of rules based on the designer’s knowledge or system data [57]. Because the rules are expressed in plain English, the control system is straightforward to understand and modify.

Fuzzy controllers provide several advantages over other SynRM control approaches, including

- Fuzzy controllers are resistant to changes in motor properties as well as external disturbances, making them appropriate for industrial applications. Simple to understand and modify: fuzzy controllers convey control rules in plain language, making the control system simple to understand and modify. Fuzzy controllers’ ability to handle ambiguity and imprecise logic-based information makes them appropriate for systems containing such information. However, because fuzzy controllers are rather complicated, creating and implementing them necessitate a strong understanding of fuzzy logic. Furthermore, tweaking the fuzzy controller may be difficult and need a trial-and-error process. Various types of membership functions based on fuzzy logic control for ac drive are reported [34].
4.10. Sliding Mode Controller (SMC) for SynRM. A sliding mode algorithm in a sliding mode controller, or SMC, controls the functioning of a SynRM [74]. The primary idea underlying SMC is to force the system to work on the chosen sliding surface by using a set of nonlinear equations to describe it. The sliding surface represents the system’s optimal working position, and the controller uses a switching mechanism to ensure that it stays there. In the case of a SynRM, the sliding surface is determined by the planned rotor position and speed and the controller uses the stator current as the control input. The controller constantly measures the rotor position and speed and changes the stator current to keep the system on the sliding surface [74].

SMC outperforms alternative SynRM control approaches in several areas, including the following:

SMC is appropriate for industrial applications because of its resistance to changes in motor properties and external disturbances. SMC ensures the system’s overall stability, ensuring that it will always converge to the desired operating point. Unaffected by parameter variations: because SMC is unaffected by parameter variations, it is an excellent fit for systems that employ ambiguous or erroneous data. However, due to the intricacy of the sliding mode algorithm, creating and implementing SMC controllers necessitate a full understanding of it. Furthermore, tweaking the SMC controller can be difficult and may involve a trial-and-error approach [74]. The fuzzy logic control plus SMC for converters for motor application is well addressed [75].

4.11. Artificial Neural Network (ANN) Controller for SynRM. An ANN controller is a type of control system that uses a neural network algorithm to manage the operation of a synchronous reluctance motor (SynRM) and brushless DC BLDC motor [33, 73, 76]. ANNs, which are used to approximate complex nonlinear systems, simulate the structure and operation of biological brain networks.

In the case of a SynRM, an input-output dataset is utilized to train an ANN controller. The rotor position, speed, and torque are the inputs to this dataset, while the stator current is the output. Once trained, the network can predict the stator current for a given set of input variables. The ANN controller constantly adjusts the stator current in response to the neural network output, while the rotor position and speed are continuously monitored. ANN controllers provide a variety of advantages over other SynRM control techniques, including

Handling nonlinearity: ANNs can handle nonlinear systems, making them appropriate for systems with complex dynamics.

Handling ambiguity: Because ANNs can handle ambiguity and erroneous information, they are an excellent fit for systems with ambiguous or wrong data.

Adaptability: Because ANNs can respond to changes in the system’s dynamics, they are well suited for systems with changing situations. However, because of the complexity of neural networks, building and implementing ANN controllers necessitate extensive knowledge of neural networks. Furthermore, a robust dataset is required to train the network since fine-tuning the ANN controller may be difficult and may necessitate a trial-and-error procedure.

4.11.1. Controller Summary

(i) FOC and DTC are popular control techniques for SynRM, each offering unique advantages in terms of efficiency and dynamic performance.

(ii) SVC utilizes advanced algorithms to estimate the rotor position and flux information, enabling precise control without the need for physical sensors, reducing system complexity and cost.

(iii) SVM optimizes the voltage applied to the motor’s stator, achieving reduced switching losses and improved motor efficiency, making it suitable for various motor types, including SynRM.

Figure 6: Block diagram of MTPA detector schematic for SynRM [47, 63, 66–70].
Table 2: Comprehensive analysis of different motor controls.

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<td>d-q reference frame</td>
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<td>Torque and stator flux</td>
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<td>Rotor position measurement</td>
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<tr>
<td>Implementation cost</td>
<td>Lower cost compared to FOC</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Costly</td>
<td>Costly</td>
</tr>
<tr>
<td>Applications</td>
<td>Electric traction systems</td>
<td>Robotics and automation systems</td>
<td>Electric motor drives in industries</td>
<td>Electric motor drives in renewable energy systems</td>
<td>High-performance robotics and automation systems</td>
<td>Electric vehicle (EV) and hybrid electric vehicle (HEV) applications</td>
</tr>
</tbody>
</table>
(iv) MPDTC is an enhanced version of DTC, incorporating predictive algorithms to achieve improved torque and flux control, lower torque ripples, and enhanced efficiency.
(v) MPC, ARFNN, SMC, and ANN controllers are advanced control techniques applied to SynRM, each utilizing unique methodologies to enhance motor performance and achieve precise control in various operating conditions.

An overview of the main vector control methods regarding the control method structure is presented in Table 2.

5. Future Scope

An evaluation of a high-performance controller for variable speed drive (VSD)-fed SynRMs considered several crucial factors. These factors include the controller’s robustness against parameter variation and external disturbances, the level of torque ripples affecting average torque, and the drive’s efficiency over a wide speed range. The SynRM’s anisotropic rotor structure leads to electrical parameter variability and torque ripple, which can degrade drive system performance. Ignoring system mismatch contradicts efficiency, productivity, and environmental and energy concerns.

To address parameter variation issues, developing a robust control algorithm is essential as it directly impacts machine controllability. Investigating and modifying the controller’s robustness against external disturbances, such as tough load torques, is vital. The study highlights that high torque ripples are a significant concern in SynRM drive systems, leading to pulsation, vibration, decreased efficiency, and increased noise in the environment. Optimizing control techniques and proposals to decrease torque ripples will improve the performance of SynRMs.

Designing a control method that covers the entire motor speed range with desired performance poses challenges due to theoretical and practical constraints. With the extensive potential applications of SynRMs with VSDs, the development of more intelligent control techniques is projected to preserve their efficiency over a wide speed range, encompassing transient and steady-state operation. Approaches from other motor technologies can be adapted for SynRM with modifications, suggesting potential directions for future research.

6. Conclusion

There is no doubt on the importance of motor-drive systems in commercial and residential applications. This review article demonstrated the market debut of the cutting-edge SynRM drive package, which is more efficient than the IM drive package and potentially less expensive. Furthermore, SynRMs’ drive provides comparable performance to PMSM drive at a lower cost, with a more environmentally friendly and straightforward construction. This study looked briefly at SynRM’s potential for improved modeling and design. The study demonstrates a significant improvement in motor function as well as an upward trend in research projects with perhaps.

Data Availability

The data used to support the findings of this study are included within the article.

Disclosure

It was performed as a part of the Employment of Ramash Kumar K, Department of Electrical and Electronics Engineering, Dr. N.G.P. Institute of Technology, Coimbatore-48, Tamil Nadu, India.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References


