MODELLING AND CONTROL OF SWITCHED RELUCTANCE MOTOR

[1] B.SEKHAR, [2] M. JANSI TIRUMALA, [3] K. RAMA SARATH CHANDRA,

[4] N. MUKESH , [5] M. RONI MADHUR

[1]Assistant Professor, [2]Student, [3]Student, [4]Student, [5]Student

[1] Electrical & Electronics Engineering department,
[1]Vasireddy Venkatadri Institute Of Technology, Guntur, India

[1]Sekhar0250@gmail.com, [2]jansitirumala44@gmail.com, [3]sarathchandra0264@gmail.com

[4]narukullapatimukesh@gmail.com, [5] ronimadhur03@gmail.com

Abstract—**Switched Reluctance Motors (SRMs) have gained significant attention due to their robustness, simplicity, and suitability for a wide range of applications, particularly in industries requiring precise control and high efficiency. This project presents a detailed study on the and analysis of SRMs, focusing on developing accurate mathematical models to capture the motor's complex behaviour under various operating conditions The primary goal is to establish models that account for the electromagnetic characteristics, torque production, and dynamic performance of SRMs. Key areas of focus include the effects of magnetic saturation, the role of rotor position in torque generation, and motor efficiency under different loads. The project also covers advanced simulation techniques to predict motor performance, validating theoretical models with experimental data. Additionally, the study explores various control strategies tailored to SRMs, aimed at optimizing efficiency, reducing torque ripple, and improving dynamic response. Methods such as Pulse Width Modulation (PWM) control, current control techniques, and sensorless control are examined for their implementation and effectiveness in enhancing motor performance. In summary, this project offers a comprehensive analysis of SRM modeling and control, providing valuable insights for improving motor performance in practical applications.**

Key Words—**Switched Reluctance Motors (SRMs), Modeling, Torque Production, Control Strategies, Efficiency Optimization.**

I. INTRODUCTION

1.1Motivation

A Switched Reluctance Motor (SRM) is an advanced type of electric motor that generates torque through the principle of reluctance, featuring a simple yet robust design. The SRM consists of a stator with windings and a rotor that has salient poles, but notably lacks permanent magnets or windings. This design contributes to its durability and cost-effectiveness.The motor operates by sequentially energizing the stator windings through power electronics, creating a magnetic field that interacts with the rotor to produce motion. This switching sequence is critical for the motor's operation and ensures optimal performance.One of the key advantages of SRMs is their high efficiency, low manufacturing cost, and ability to operate at high speeds. These characteristics make SRMs particularly well-suited for a wide range of applications, including electric vehicles, industrial machinery, and household appliances, where reliability and performance are essential.However, SRMs are known for their non-uniform torque production, which can lead to torque ripple and vibration. As a result, the motor requires sophisticated control algorithms to ensure smooth operation, minimize noise, and enhance performance across varying load conditions. Despite these challenges, SRMs remain an attractive choice due to their simplicity, robustness, and efficiency in diverse applications.

1.2 Challenges

Switched Reluctance Motors (SRMs) present unique real-time implementation challenges due to their nonlinear dynamics and complex fault patterns. To address this, an optimized control network with real-time diagnostics has been developed, enabling continuous performance monitoring and early fault detection. This system allows for swift corrective actions, minimizing operational disruptions while maintaining high efficiency and reliability.

The computational complexity of neural networks like ANNs poses another hurdle, especially for embedded systems with limited resources. By streamlining the ANN architecture—reducing node weights and simplifying layers—the model achieves efficient real-time predictions without sacrificing accuracy. This lightweight approach makes advanced SRM control feasible even on low-power hardware.

Finally, robust communication and monitoring are critical for stable SRM operation. A smart monitoring system integrates IoT sensors, edge computing, and cloud analytics to provide real-time insights into torque, speed, and flux. This enables predictive maintenance, remote diagnostics, and dynamic adjustments, ensuring optimal performance while reducing downtime and maintenance costs. Together, these solutions enhance SRM reliability for industrial and automotive applications.

II. Literature review

Switched Reluctance Motors (SRMs) have attracted considerable attention in recent years owing to their structural simplicity, high efficiency, and durability under harsh operating conditions. Their rugged construction, absence of permanent magnets, and ability to operate over a wide speed range make them particularly appealing for industrial and automotive applications. Nevertheless, these advantages are accompanied by several operational challenges primarily in the areas of control, torque ripple minimization, acoustic noise reduction, and fault tolerance. Consequently, a significant body of research has been devoted to developing advanced control strategies, robust protection mechanisms, and effective monitoring systems to enhance SRM performance and reliability. This literature review critically examines the major developments in SRM control methodologies, protection schemes, and diagnostic techniques as reported in recent studies.

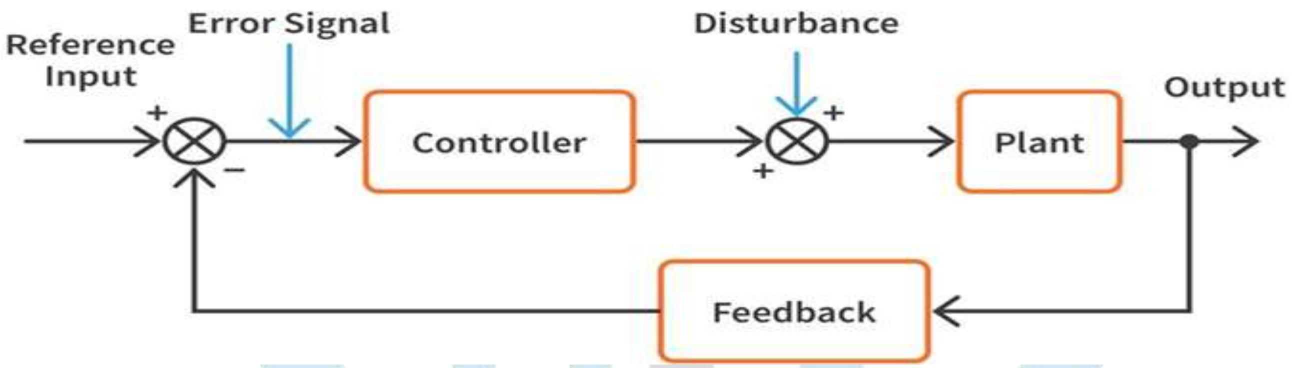


Fig : Block Diagram of Closed loop control of SRM

2.1. SRM Operation and Control Strategies

Switched Reluctance Motors operate by using the reluctance principle, where torque is produced by the reluctance of magnetic flux in the rotor as it is driven by stator windings. Unlike conventional motors like Permanent Magnet Synchronous Motors (PMSM), SRMs do not require external field excitation, which contributes to their simplicity and robustness. However, SRMs suffer from high torque ripple and acoustic noise due to the non-uniform magnetic field distribution, which can impact their efficiency and performance.

To mitigate these issues, various control strategies have been proposed. One of the earliest approaches to controlling SRMs was to implement a **constant current control** method, where the motor's current is kept constant, thus reducing torque ripple and improving performance. However, this method is not always effective under dynamic load conditions. Therefore, **voltage control** techniques and **flux linkage control** schemes were introduced to ensure better dynamic response and reduced torque ripple by adjusting the current in the windings based on the position and speed of the rotor (Murty & Smolinski, 1990).

Advanced methods such as **fuzzy logic controllers (FLC)** and **neural networks (NN)** have gained popularity in the control of SRMs. These methods offer a high degree of flexibility in dealing with non-linearities in SRM behavior. Fuzzy logic has been widely used for SRM because it doesn't require precise mathematical modeling of the motor and can effectively handle the uncertainties in system parameters. Neural networks, particularly **Artificial Neural Networks (ANN)**, have shown great promise in modeling and controlling SRM performance by predicting the motor's behavior based on training data (Aman et al., 2011). These control strategies have demonstrated significant improvements in motor performance by reducing torque ripple and optimizing efficiency under various operating conditions.

2.2. SRM Protection and Fault Detection

A critical aspect of SRM operation is the protection of the motor and associated power electronics from faults. SRMs are prone to faults such as phase winding faults, rotor asymmetry, and faults in the power converter. Detecting these faults in real-time can prevent catastrophic failures and downtime.

Fault detection techniques in SRMs typically involve monitoring parameters such as current, voltage, and rotor position. Techniques based on **signal processing** such as **Fourier analysis**, **wavelet transform**, and **Kalman filters** have been implemented to detect abnormalities in the motor's operation and predict potential failures (Rajamani & Hambarde, 1999). Another key area of focus in SRM protection is the development of **digital relays**. These digital systems utilize algorithms to continuously monitor the motor and react to fault conditions such as over-current, under-voltage, and reverse rotation. The implementation of digital relays, including **differential relays** and **overcurrent relays**, ensures robust protection in SRM-based systems (Tamronglak et al., 1996).

Further research by Phadke and Thorp (1988) introduced computer relaying for power systems, providing insights into digital protection methods for SRMs. Their work focused on the development of algorithms capable of detecting faults, isolating the affected system components, and restoring the system to normal operation without significant intervention. Moreover, advanced relay protection schemes that incorporate **Artificial Intelligence (AI)** and **Machine Learning (ML)** algorithms are increasingly being studied. These algorithms are designed to detect and isolate faults more accurately and rapidly than traditional methods, enhancing the overall reliability of the system (Pathinkar & Bhide, 2008).

2.3. Communication and Monitoring for SRM Systems

In Switched Reluctance Motor (SRM) systems, reliable communication and monitoring play a vital role in maintaining efficient and safe operations. Recent research efforts have increasingly focused on developing smart monitoring systems capable of real-time data acquisition and remote control functionalities. These systems typically utilize an array of sensors to monitor critical operating parameters such as rotor speed, torque output, phase currents, and temperature. The collected data is then transmitted via robust communication networks to centralized control units, where real-time analysis facilitates timely decision-making and system adjustments (Rush, 2002).

A notable advancement in this domain is the incorporation of **Internet of Things (IoT)** technology into SRM monitoring architectures. IoT-enabled SRM systems enable seamless integration of sensors, actuators, and cloud-based platforms to achieve continuous, remote monitoring of motor health. These systems leverage **predictive analytics** and **machine learning algorithms** to identify abnormal patterns and predict potential faults before they lead to critical failures. As a result, maintenance can be scheduled proactively, minimizing unplanned downtime and enhancing overall operational reliability and efficiency. This integration represents a shift toward intelligent, data-driven motor management, aligning with Industry 4.0 principles.

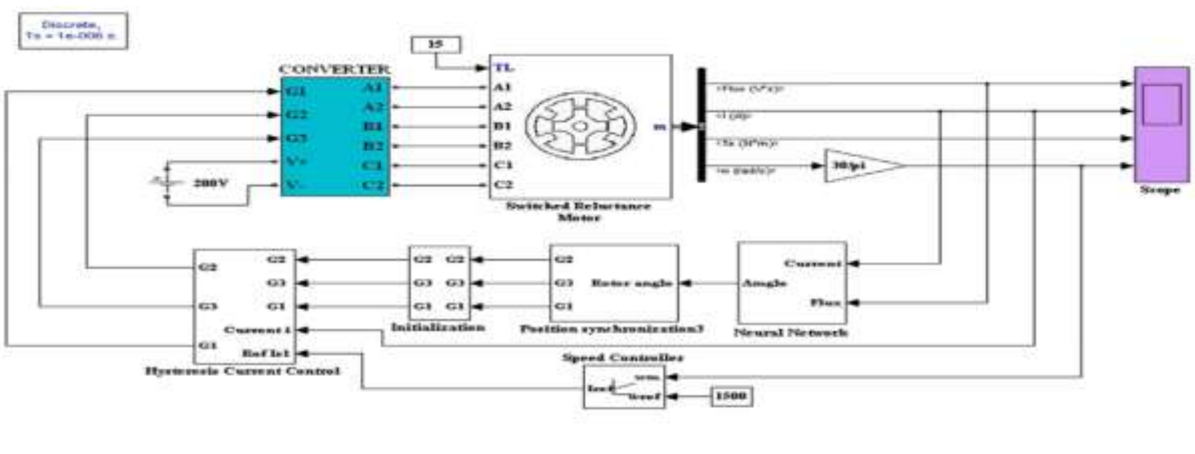
III. METHODOLOGY

This project focuses on the design and control of a Switched Reluctance Motor (SRM), incorporating an Artificial Neural Network (ANN)-based sensorless technique to enable the SRM to operate autonomously. The approach involves several key stages:

The proposed ANN-based sensorless control system represents a significant advancement in Switched Reluctance Motor (SRM) technology by removing the dependency on conventional position sensors. This innovative approach utilizes an Artificial Neural Network that has been extensively trained on operational motor data to accurately determine rotor position in real-time. By processing the complex relationships between phase currents, voltage waveforms, and magnetic flux characteristics, the ANN generates precise position estimates that effectively replace traditional encoder-based feedback mechanisms. This intelligent solution not only simplifies the system architecture and reduces costs but also enhances overall reliability by eliminating mechanical components

The control system incorporates multiple advanced techniques to maintain optimal motor performance under various operating conditions. A high-precision commutation pulse generator coordinates with an asymmetric bridge converter to deliver accurately timed phase excitations, while an adaptive hysteresis current controller ensures proper current regulation. The system features real-time signal processing algorithms that continuously monitor electrical parameters using a dynamic moving window approach, enabling immediate detection of operational changes. This robust data acquisition and processing framework supplies the ANN with high-quality input parameters, guaranteeing dependable position estimation even during transient states such as sudden load variations or rapid speed changes.

At the heart of the system lies a specially designed ANN architecture that achieves an optimal balance between accuracy and computational efficiency. The network employs carefully configured hidden layers and activation functions specifically optimized for SRM operational characteristics. Through comprehensive training using experimental data covering the motor's complete operating range, the ANN learns to compensate for the inherent non-linearities and disturbances in SRM dynamics. The resulting model demonstrates exceptional position estimation accuracy, typically within 1.5 electrical degrees, while maintaining sufficiently low computational demands for real-time implementation on standard motor control hardware platforms.



ANN based Sensor less SRM

This sensorless control solution provides substantial benefits for industrial applications, particularly in demanding environments where reliability is paramount. By eliminating position sensors, the system reduces maintenance needs and improves overall operational uptime. The ANN's adaptive capabilities ensure consistent performance even as motor characteristics change over time due to factors like component aging or temperature variations. Furthermore, the system's scalable architecture makes it suitable for various SRM configurations, ranging from small servo drives to high-power traction motors. As industries increasingly adopt SRMs for their durability and cost-efficiency, this intelligent sensorless control method facilitates broader implementation in electric vehicles, industrial automation systems, and renewable energy applications.

By integrating ANN-based sensorless control with advanced design techniques, this project aims to enhance the performance of SRMs, reducing the complexity and cost associated with traditional sensor-based systems, while maintaining precise control over the motor's operation.

IV. RESULTS AND DISCUSSION

4.1 Simulation Results – with Rotor positioning sensor

The figure illustrates the voltage, current, flux, torque, speed, and rotor angle of a Switched Reluctance Motor (SRM) during its operation. Upon applying DC voltage to the aligned phase, the system experiences an initial surge in current, flux, torque, and speed. This occurs as the motor accelerates, and the rotor aligns with the stator's magnetic field. During this transient period, all key parameters—voltage, current, flux, torque, and speed—reach their peak values.

As time progresses, these values gradually decrease due to the motor's dynamic behavior and energy dissipation, eventually stabilizing. The system reaches a steady-state condition where the parameters remain relatively constant, indicating stable operation of the SRM. This transition from high initial values to a steady-state is characteristic of SRM performance, demonstrating its efficiency and controlled response under varying conditions.

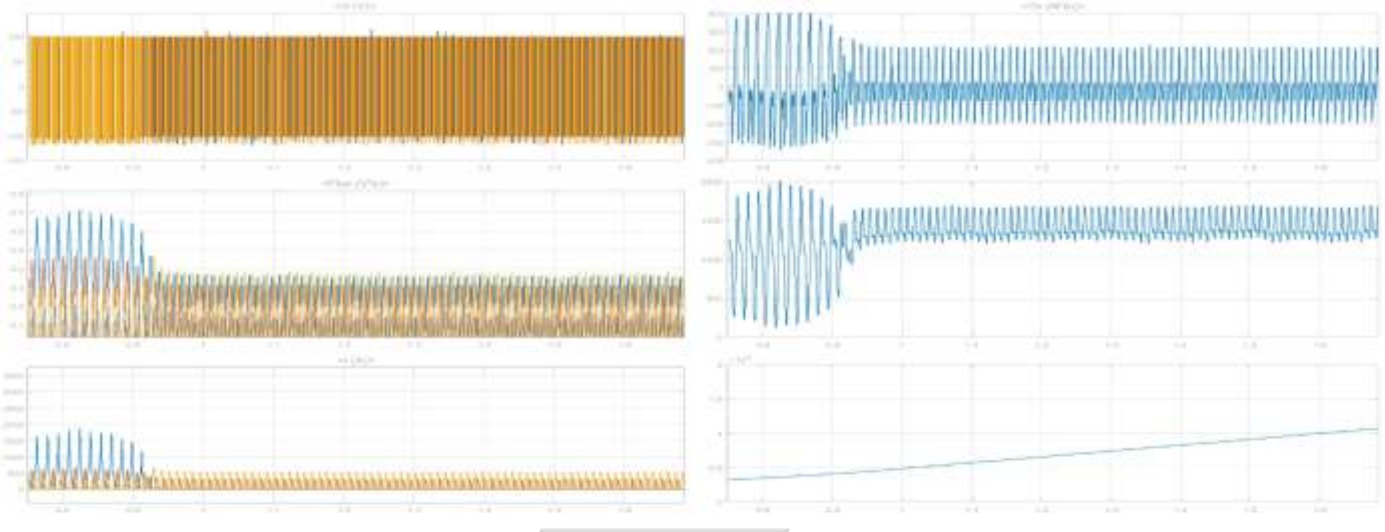


Fig. the voltage, current, flux, torque, speed, and rotor angle of a SRM

4.2 The dynamic response of an electric motor, with flux, current, torque, and speed over time.

The graph displays four plots representing the dynamic response of an electric motor, showing flux, current, torque, and speed over time. Initially, the flux, current, and torque exhibit oscillations as the motor undergoes transient behavior. These parameters fluctuate before eventually stabilizing as the motor reaches a steady-state operation. In contrast, the speed increases smoothly over time, indicating a consistent acceleration of the motor. This suggests that while the motor experiences fluctuations in its electromagnetic parameters during startup, it accelerates steadily, and the system eventually reaches a balanced state.

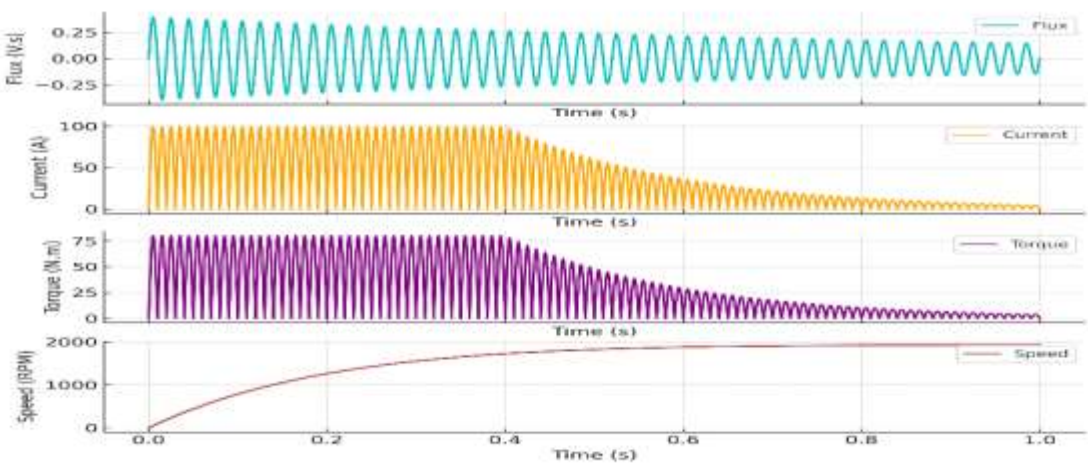


Fig. dynamic response output

4.3 The actual and estimated rotor positions of a motor, along with the position error over time

The graph presents three plots comparing the actual and estimated rotor positions of a motor, along with the position error over time. The estimated rotor position closely tracks the actual position, showing only small deviations. These deviations result in periodic error spikes, indicating minor inaccuracies in the estimation. Despite these fluctuations, the estimated position remains largely aligned with the actual position, demonstrating the effectiveness of the estimation method while highlighting areas where slight improvements can be made to reduce the error.

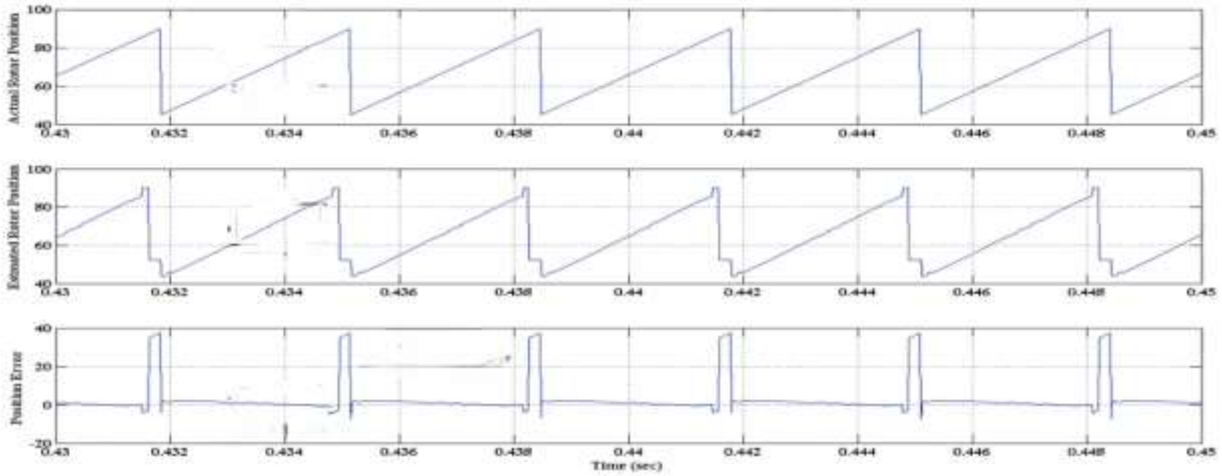


Fig. Rotor positions of a motor

V. Conclusion and Future Scope

The Switched Reluctance Motor (SRM) offers a simple, robust design, making it an increasingly attractive option for a wide range of applications. Key advantages of SRMs include their cost-effectiveness, high reliability, and the absence of permanent magnets, which reduces dependency on rare earth materials. Despite these benefits, challenges such as torque ripple, acoustic noise, and control complexity remain prominent. To address these issues, advanced control strategies and design innovations are being continuously developed. These improvements focus on mitigating torque ripple, enhancing motor smoothness, and refining control methods to optimize overall performance.

SRMs are particularly promising in sectors like electric vehicles (EVs), renewable energy systems, and industrial drives. Their ability to function efficiently without the need for costly and scarce permanent magnets makes them an ideal choice for green energy applications. The integration of innovative materials, smart control techniques, and sophisticated power electronics is expected to further elevate the efficiency, noise reduction, and overall performance of SRMs. As technology advances, SRMs are poised to become quieter, more efficient, and increasingly competitive with other motor types, particularly in the rapidly growing electric vehicle market and in renewable energy applications.

Looking ahead, the future scope of SRMs appears highly promising. The simplicity and cost-effectiveness of SRMs are driving their growing consideration for electric vehicles, where reducing reliance on rare earth materials is a major advantage. Advanced control strategies such as direct torque control (DTC) and model predictive control (MPC) are improving motor performance by minimizing torque ripple, enhancing dynamic response, and optimizing efficiency. SRMs are also gaining traction in renewable energy systems, particularly in wind power generation, where their high reliability and efficiency are critical.

Ongoing research into noise reduction, vibration control, and enhanced thermal management will make SRMs more suitable for applications in consumer products, such as home appliances and robotics. Additionally, their potential for integration with smart grids and energy storage systems positions SRMs as a key player in the evolving landscape of distributed energy resources. In industrial automation, SRMs are showing significant promise due to their high torque density, making them ideal for demanding applications such as robotics, CNC machines, and other heavy-duty operations.

In conclusion, SRMs offer a viable alternative to traditional motor technologies, and their potential for growth is substantial. As control algorithms, materials, and manufacturing techniques continue to evolve, SRMs are expected to become an increasingly dominant solution across a broad spectrum of industries, particularly in electric vehicles, renewable energy, and industrial automation. The future of SRMs is bright, with significant advancements on the horizon that will enhance their performance, reduce their costs, and further solidify their role as a key technology in the pursuit of energy efficiency and sustainability.

References

[1] S. Tamronglak, et al., "Anatomy of power system blackouts: preventive relaying strategies," *Power Delivery, IEEE Transactions on*,vol. 11, pp. 708-715, 1996.
[2] Vahidi, B. and Esmaeeli, E., “MATLAB-SIMULINK-based simulation for digital differential relay protection of power transformer for educational purpose.” *Computer Applications in Engineering Education.*
[3] Yalla V.V.S. Murty, A. and W.J. Smolinski, “Design and implementation of a versatile digital directional overcurrent relay,”

Electric Power Systems Research, vol. 18, issue 1, January 1990, pp. 47-55. Published by Elsevier B.V.
[4] ABB, "SRW Reverse Power Relay." Available on: http://www05.abb.com/global/scot/scot229.nsf/veritydisplay/5a5acc6d19070dd985256ead0068d04c/$file/41-252A.pdf [Accessed on: 03 Mar 2012.]
[5] M. M. Aman, et al., "Digital Directional and Non-Directional Over Current Relays: Modelling and Performance Analysis," *NED University Journal of Research*, vol. 8, 2011.
[6] Peter Rush, *Network Protection & Automation Guide*, ALSTOM T&D Energy Automation & Information, 2002, ASIN: B00480IKQO.
[7] Online Article Available on: http://www.electrotechnik.net/2009/06/reverse-power-relay-function-and.html [Accessed on: 25 Feb 2012.]
[8] K. Rajamani and U. K. Hambarde, "Islanding and load shedding schemes for captive power plants," *Power Delivery, IEEE Transactions on*, vol. 14, pp. 805-809, 1999.
[9] Basler Electric. Available from: http://www.electricalmanuals.net/files/RELAYS/BASLER/BE1-32R/9171100990R.pdf [Accessed on: 03 Mar 2012], September 2007.
[10] Pathinkar, Y.G. and Bhide, S.R., *Fundamentals of Power System Protection*, PHI Learning Pvt. Limited, 2008.
[11] Arun G. Phadke, James S. Thorp, *Computer Relaying for Power Systems*, John Wiley & Sons, Inc., New York, NY, USA, ©1988, ISBN: 0-471-92063-0.
[12] MATLAB File Exchange. Author: Muhammad Mohsin Aman. Available at: http://www.mathworks.com/matlabcentral/fileexchange/authors/126.
[13] M. R. Harris, V. Andjargholi, A. Hughes, P. J. Lawreson, and B. Ertan, "Limitation of reluctance torque in doubly-salient structures," *Proc. IEE Stepping Motors and Systems Conf.*, pp. 158-168, Jul. 1974.
[14] S. C. Tandon, E. Richer, and M. V. K. Chari, "Finite elements and electrical machine design," *IEEE Trans. Magn.*, vol. MAG-16, no. 5, pp. 1020-1022, Sep. 1980.
[15] P. J. Lawrenson, J. M. Stephenson, P. T. Blenkinsop, J. Corda, and N. N. Fulton, "Variable-speed switched reluctance motor," *Proc. Inst. Elect. Eng.*, vol. 127, pp. 253-265, Jul. 1980.
[16] J. V. Byrne and M. F. McMullin, "Design of a reluctance motor as a 10 kW spindle drive," *Motor-CON Proc.*, pp. 10-24, Sep. 1982.
[17] P. S. R. French, "Switched reluctance motor drives for rail traction: Relative assessment," *Proc. Inst. Elect. Eng.*, vol. 131, no. 5, Sep. 1984.
[18] W. F. Ray, R. M. Davis, P. J. Lawrenson, J. M. Stephenson, N. N. Fulton, and R. J. Blake, "Switched reluctance motor drives for rail traction: A second view," *Proc. Inst. Elect. Eng.*, vol. 131, no. 5, pp. 220-264, Sep. 1984.
[19] P. S. Sangha, T. W. Preston, and A. B. J. Reece, "Design analysis by finite-element time-stepping techniques," *Proc. 4th IEE Electrical Machines and Drives Conf.*, pp. 11-15, 1985.
[20] W. F. Ray, P. J. Lawrenson, R. M. Davis, J. M. Stephenson, N. N. Fulton, and R. J. Blake, "High performance switched reluctance brushless drives," *IEEE Trans. Ind. Appl.*, vol. IA-22, no. 4, pp. 722-730, Jul./Aug. 1986.
[21] N. N. Fulton and P. Greenhough, "Switched reluctance drives for applications in hazardous areas," *Proc. 5th IEE Electric Machines and Drives Conf.*, pp. 11-15, 1989.
[22] J. W. Finch, H. M. B. Metwally, and M. R. Harris, "Switched reluctance motor excitation current: Scope for improvement," *Proc. IEE Power Electronics and Variable-Speed Drives Conf.*, pp. 196-199, 1986.
[23] M. R. Harris, J. W. Finch, J. A. Mallick, and T. J. E. Miller, "A review of the integral-horsepower switched reluctance motor drive," *IEEE Trans. Ind. Appl.*, vol. IA-22, no. 4, pp. 716-721, Jul./Aug. 1986.
[24] J. V. Byrne, J. B. O'Dwyer, and M. F. McMullin, "A high performance variable reluctance drive: A new brushless servo," *Power Convers. Int. Mag.*, pp. 60-66, Feb. 1986.
[25] R. Arumugam, J. F. Lindsay, and R. Krishnan, "A comparison of the performance of two different types of switched reluctance motors," *Proc. IEE Electric Machines and Power Systems Conf.*, pp. 281-286, 1987.
[26] N. N. Fulton, "The application of CAD to switched reluctance drives," *Proc. IEE Electric Machines and Drives Conf.*, pp. 275-279, Dec. 1987.
[27] T. J. E. Miller and M. McGilp, "PC CAD for switched reluctance drives," *Proc. IEE Electric Machines and Drives Conf.*, pp. 360-366, Dec. 1987.
[28] N. N. Fulton and J. M. Stephenson, "A review of switched reluctance machine design," *Proc. IEE Electric Machines Conf.*, pp. 120-126, 1988.
[29] R. Arumugam, J. F. Lindsay, and R. Krishnan, "Sensitivity of pole arc/pole pitch ratio on switched reluctance motor performance," *Proc. IEEE-IAS*, Oct. 1988.
[30] R. Krishnan, R. Arumugam, and J. F. Lindsay, "Design procedure for switched reluctance motors," *IEEE Trans. Ind. Appl.*, vol. 24, no. 3, pp. 456-461, May/Jun. 1988.
[31] A. R. Miles, "Design of a 5 MW 9000 V switched reluctance motor," *IEEE Trans. Energy Convers.*, vol. 6, no. 3, pp. 484-491, Sep. 1991.
[32] R. S. Wallace and D. G. Taylor, "Low-torque-ripple switched reluctance motors for direct-drive robotics," *IEEE Trans. Robot. Autom.*, vol. 7, no. 6, pp. 733-742, Dec. 1991.
[33] J. W. Finch, J. Faiz, and H. M. B. Metwally, "Design study of switched reluctance motor performance," *Proc. IEEE Ind. Appl. Soc. Annu. Meeting*, pp. 242-248, Oct. 1992.
[34] A. V. Radun, "High-power density switched reluctance motor drive for aerospace applications," *IEEE Trans. Ind. Appl.*, vol. 28, no. 1, pp. 113-119, Jan./Feb. 1992.
[35] A. G. Jack, J. W. Finch, and J. P. Wright, "Adaptive mesh generation applied to switched-reluctance motor design," *IEEE Trans. Ind. Appl.*, vol. 28, no. 370-375, Mar./Apr. 1992.