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# Control Unit Design Utilizing ESC for Switched Reluctance Motor

Deepak Saini[1], Manvish Ghusinga[2], Lakshya Kumar Jindal[3], Pulkit Dhangar[4]
[1]Assistant Professor, [2,3,4]UG Student, Department of Electrical Engineering, Swami Keshvanand Institute of Technology Management & Gramothan, Jaipur, Rajasthan, India

***ABSTRACT: Switched Reluctance Motors (SRMs) have a basic design, robustness, and fault-tolerant nature, offering scope for their extensive use in industrial and automotive applications. Still, their performance is hampered by significant disadvantages, including acoustic noise and high torque ripple, whose solutions often involve expensive driver circuits. The goal of this project is to design and create a controller for a Switched Reluctance Motor with the intention of minimising cost while maintaining acceptable torque ripple and efficiency levels. The suggested controller utilises an Arduino Nano, implementing extreme seeking optimisation for ideal turn-on and turn-off angles, as well as appropriate phase excitation control. Compared to traditional control techniques, the developed controller offers acceptable output voltage pulses and other characteristics within the acceptable range for the operation. Effective controller design improves SRM cost-effectiveness considerably while also keeping the design simple for easy scalability.***

***KEYWORDS: Switched reluctance motor controller, Extreme seeking optimisation, Switched reluctance motor, Arduino nano, Asymmetrical bridge converter, ESC Optimization.***

## I. INTRODUCTION

Switched reluctance motors (SRM) are a type of motor with no magnets in them, which provides advantages, such as a simple construction, a lack of permanent magnets, making them immune to supply chain disruptions, and the capacity to function in demanding circumstances [1, 5, 6, 9]. Due to recent advancements in optimisation techniques, electronics and driver circuits, these motors have become quite popular recently [4, 8]. SRMs are mechanically simple and have become relatively economical as the price of rare earth magnets has skyrocketed [1, 3, 9]. Also, double salient construction with windings just on the stator sets them apart from traditional AC and DC motors and provides similar efficiency [5, 7, 10]. SRMs are therefore perfect for use in domestic appliances, industrial drives, and electric cars. Their application in electric vehicles is particularly more appealing in places with extreme temperature variations [3, 4, 6, 7, 11].

SRMs generally have high torque ripples due to their discrete phase excitation and nonlinear magnetic behaviour [2, 4, 12]. Torque ripple limits the motor's application in high-performance situations since it causes vibration, acoustic noise, and lower efficiency [5, 11, 12]. Thus, SRM's performance depends much on the design of an effective controller. Due to the requirement of a sophisticated controller, the overall cost of SRM becomes quite high [1, 4, 8].

By regulating the phase currents and excitation angles by implementing extremum seeking optimisation to control the output voltage waveform, this project aims to create a controller for a Switched Reluctance Motor that is able to perform with an acceptable range of operation while keeping the overall computational and financial cost to a minimum. Smoother output voltage waveform from the controller, guaranteeing correct synchronisation between phase current and rotor position [2, 4, 12].

## II. STATEMENT OF THE PROBLEM

Though Switched Reluctance Motors have many benefits, they present the following difficulties:

1) High-speed switching of FETs
2) High torque ripple causes more acoustic sound and vibrations
3) Nonlinear magnetic features
4) Low efficiency with improper current control

Particularly at low speeds, traditional control methods frequently fall short of providing smooth torque output. Therefore, a better controller design is needed to properly handle phase currents and lower torque pulsations while preserving system simplicity.

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## III. PROJECT TARGETS

The project is mostly about:

*1)* Reducing the overall complexity and cost of the controller for SRM
*2)* To maintain motor efficiency by means of correct phase excitation
*3)* To evaluate SRM performance under the suggested controller
*4)* Implementation of Extreme Seeking Optimisation

## IV. PROPOSED CONTROLLER DESIGN

The controller design presented uses Arduino Nano because of its low cost and decent computational power for the phase excitation and implementing Extrem Seeking Optimization (ESO) for the determination of the optimal turn-on and turn-off angles. The Asymmetrical Bridge Converter is used as the driver circuit for the controller. Since the motor phases are inductive in nature a RL (200 ohm and 1mH) load is used to act as the motor phases.

*a) Arduino Nano*

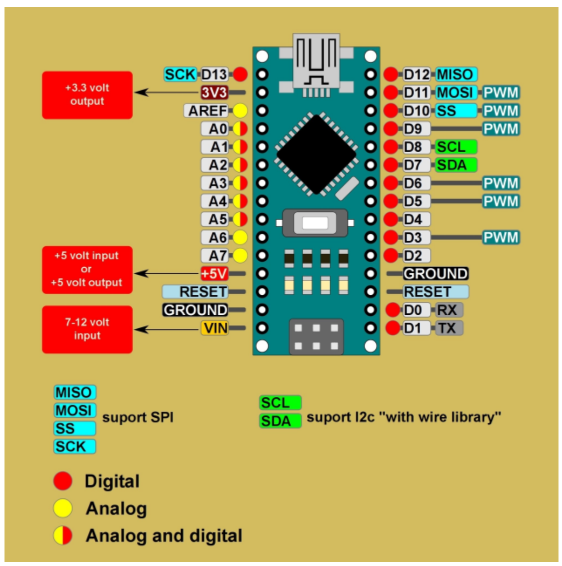


Fig 1 Arduino Nano Pin Layout

The Arduino Nano serves as the core processing unit for the controller, handling signal generation, sensing, and implementing the control algorithm. The main reason for using Arduino Nano was

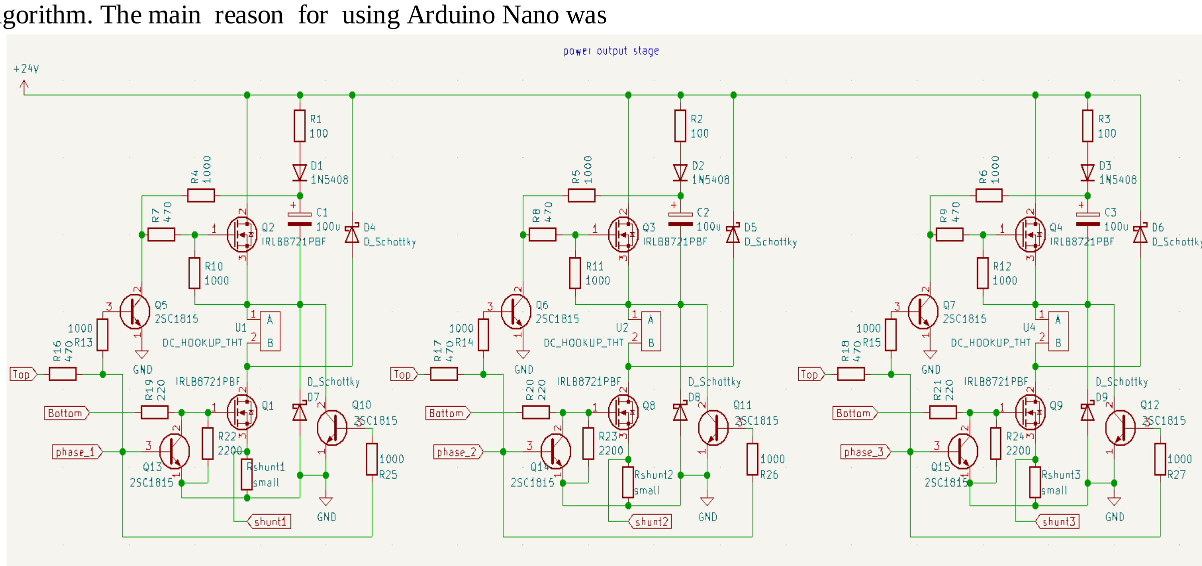


Fig. 2 Circuit Diagram Of Asymmetrical Bridge Converter [13]

its low cost and good computing capabilities, and the capabilities Power provided by ATmega32P, extensive documentation, and a large user community facilitate easy assistance and high levels of optimization. The module integrates an 8-bit AVR RISC-based processor running at a clock frequency of 16 MHz, equipped with 32 KB of ISP flash memory for program storage, 2 KB of SRAM, and 1 KB of EEPROM. It offers 22 GPIO pins, including 8 analogue inputs and 6 PWM outputs, supporting SPI, I2C, and UART communication for easy sensor integration via the Arduino IDE.

*b) Asymmetrical bridge converter (ABC)*

ABC provides fast commutation and a path for the demagnetisation of the motor phase. It consists of two MOSFETs and two diodes per phase, arranged such that the motor winding is connected with upper or lower switch legs at a time. This allows for the three operating modes of ABC, i.e., magnetising, freewheeling, and demagnetising modes, which enable precise control over the current pulses required to generate torque in the SRM’s doubly salient structure.

The ABC phase operates independently of each other, which is one of the requirements of the SRM phase. The intentional asymmetry enables all power switches to achieve Zero-Voltage Switching (ZVS) turn-on. This drastically reduces switching losses, allowing for higher frequency operation. Furthermore, it excels at **energy recovery**, as it can return the stored magnetic energy from the motor windings back to the DC link capacitor during the commutation off-cycle, significantly improving the overall efficiency of the drive system.

*c) Extreme Seeking Optimization (ESO)*

Extreme Seeking Optimisation (ESO) is a metaheuristic algorithm inspired by natural movement towards maximum resource density or favourable conditions. Unlike traditional gradient methods, ESO avoids local optima using a stochastic search that balances exploration and exploitation. It mimics "gradient-climbing" (e.g., chemotaxis or foraging), adjusting trajectory based on target variable intensity. This makes ESO ideal for complex, high-dimensional problems where the objective function's derivative is unknown or costly.

This algorithm is implemented digitally to continuously adjust the turn-on theta_on and turn-off theta_off angles to minimise a cost function torque ripple in real-time.

*d) PLX-DAQ*

Version 2.11 of PLX-DAQ by Parallax Inc. was used for the data logging of the output voltage, torque, speed and the optimum angle for the system from the Arduino to Microsoft Excel for data visualisation and post result analysis. The reason for using a newer version of the software was its compatibility with newer office versions and the ability to handle higher baud rates (up to 250,000).

## V. OPERATING PRINCIPLE

In the setup of the controller for SRM, Arduino Nano acts as the brain of the system, which interfaces with the Asymmetrical Bridge Converter to drive the three independent phases of the SRM, which is elulated by the three RL loads, each of 200 ohms resistance and 1mH inductors. The operation of this system is governed by a combination of physical hardware switching, stochastic mechanical simulation, closed-loop optimisation algorithms, Extremum Seeking Control (ESC) and Data logging of the result using PLX-DAQ to plot the result in Excel.

### *A. Hardware Interfacing and Phase Commutation*

The controller dictates phase commutation by outputting low-power 5V digital signals from the Arduino. These signals serve as logic-level triggers for the gate drivers within the ABC circuit. The asymmetrical bridge topology provides independent control over each phase, which safely manages the inductive load. The Switched Reluctance Motor (SRM) phase commutation is controlled by Arduino’s five digital pins interfacing with the Asymmetrical Bridge Converter (ABC). Pins D5, D6, and D9 act as discrete selectors for phase_1, phase_2, and phase_3, energising the respective 1mH stator windings based on the controller's timing algorithm. Current management uses a soft-chopping strategy via the Top (D11) and Bottom (D3) master regulator pins to prevent saturation. The Top pin remains HIGH, enabling the high-side switch for the selected phase to the positive supply. The Bottom pin uses a high-frequency PWM signal from the internal timer to drive the low-side switches.

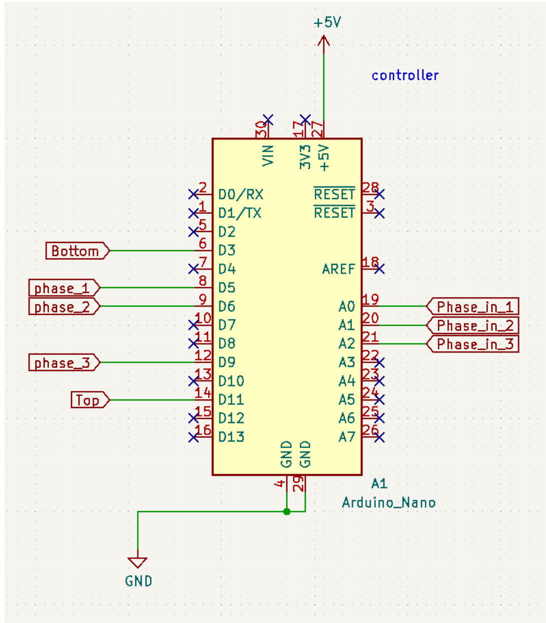


Fig. 3 Arduino Nano Connections

This quick PWM modulation regulates the phase current during commutation, ensuring stable torque and circuit protection.

### *B. Stochastic Speed Simulation*

Due to a lack of access to physical motor, the rotational speed and torque are computationally modelled within the firmware. The system is simulated such that a constant acceleration ramp increases the velocity until it reaches a 1500 RPM is achieved. Noise is introduced in the speed of the motor to mimic a real motor between +/-20 RPM from the base speed. This artificial noise emulates real-world sensor jitter, encoder inaccuracies, and minor load fluctuations. The robustness of the timing logic is a must for microsecond scale changes in phase commutation.

### *C. Firing Angle Optimisation via Extremum Seeking Control (ESC)*

The main function of any SRM controller is to minimise the torque ripple generated by the motor; in order to achieve this Extremum Seeking Control (ESC) algorithm is designed to autonomously minimise torque ripple. Torque ripple is inherently present in the SRMs due to the discrete, sequential nature of their magnetic alignment.

The ESC algorithm starts to work after the motor speed achieves the minimum speed of 1350 RPM. The controller continuously calculates a simulated torque output that is heavily penalised by phase misalignment. By monitoring the effect of the dithering angle on this torque output, the ESC determines the gradient of the efficiency curve. As the operational loop iterates, the algorithm permanently steps the baseline firing angle away from its unoptimized starting position (15.0 degrees) toward the ideal physical angle (24.0 degrees). As the controller successfully converges on this optimum angle, the simulated torque ripple is mathematically attenuated, demonstrating the ESC's ability to smooth mechanical power delivery.

### *D.* **Data Logging and Phase Voltage Sensing**

The output voltage from each phase is sensed on the Arduino as the output voltage is within the maximum of 5 volts that it can sense on the analog pin A0, A1 and A2. The data from there is then logged into Microsoft Excel using the PLX-DAQ software for the data analysis and plotting, to verify the results with the MATLAB SIMULINK results. The results are logged for 200 data points as too much data logging leads to excel crashing because a lot of real time data tries to log into the excel which overwhelms it so to overcome this only 200 points of data is logged into it of which the first 100 data points is logged slowly or for long iterations, every 100 iteration of serial monitor data, to check the speed ramping from 0 to1500 RPM and for next 100 points real time logging is done to obtain the voltage output waveform and see torque ripple reduction since Excel cannot handle real time logging the data from the serial monitor is stored into the 2kb sram of arduino which then log the data at 50 hz in the excel, speed which is easily handled by the Excel.

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## VI. RESULTS AND ANALYSIS

Through experimental testing and simulation, the performance of the SRM with the suggested controller was assessed, and resultant graphs for phase voltage, turn-on angle, torque and speed are given in fig. 4.

The phase voltage waveform in fig 4.a verify that the output voltage waveform produced by the converter is in conjunction with the results expected for SRM. [14]

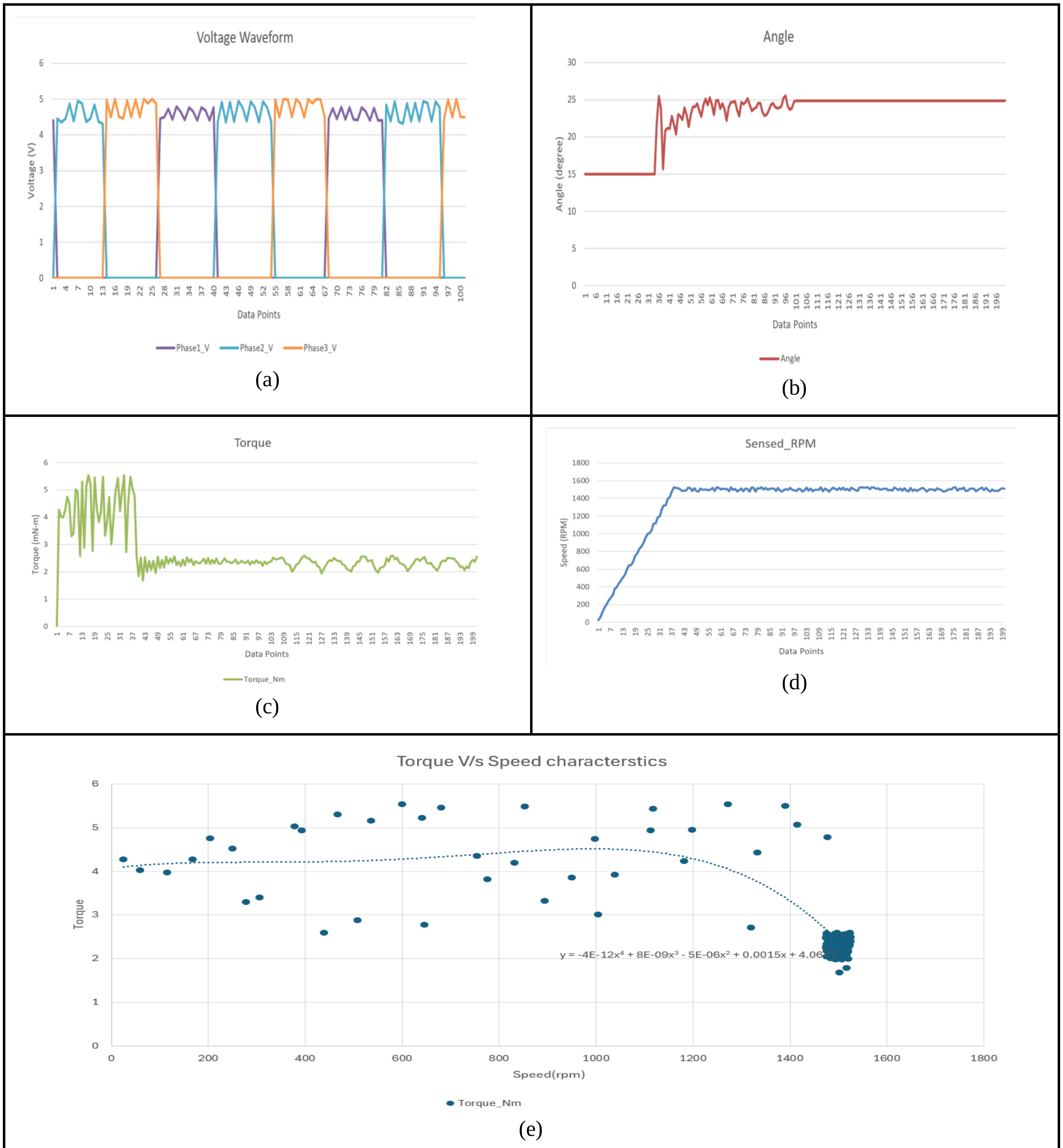


Fig. 4 Output graphs for (a) Voltage waveform, collected after the attenuation of optimal Turn-on angle (b) Turn-on Angle (c) Torque Ripple, from 1 to 200 points of data collection (d) Speed, 0 to 1500 rpm (e) Torque V/s Speed Characteristics with trendline equation used

Waveform in nature and are produced one after another, which magnetise each phase to rotate the rotor of SRM. The voltage of each phase varies between 4.5 to 4.8 volts (V) with some noise causing maxima to reach 5 V. The accurate, cyclical progression through Phase 1, Phase 2, and Phase 3 validates that the timing logic is correctly implementing the computed phase advance. As expected, the waveform does overlap for a very short duration of time.

The angle optimisation by the ESC optimisation algorithm is captured in the fig 4.b graph. The turn-on angle is initialtaken as 15°, and the optimum angle is decided to be 24°, which the optimisation algorithm needed to achieve the optimum torque production. By evaluating the resulting torque feedback against these perturbations, the controller incrementally advances the base angle. As can be seen by the plot, the turn-on angle increases from an initial 15° to 24.8 ° slowly and finally reaches 24° by the 100th point (each point taken at an interval of 100ms). The algorithm starts to work after the motor reaches 1350 RPM until it attain the desired result the optimization technique still runs in behind to in order if there's a change in optimal turn-on angle due to environmental changes. The graph clearly shows the algorithm introducing a controlled periodic perturbation (dither) to "hunt" for the optimal firing angle. The automated phase advancement compensated for the increase in back-EMF.

The mechanical output characteristics of the motor are depicted in the fig 4.c, torquegraph. During the initial acceleration phase (data points 1 to 40), the system demands a high average torque, fluctuating heavily between 2.5 mN-m and 5.5 mN-m. This high-amplitude, high-ripple phase is characteristic of the fixed 15° firing angle combined with the heavy current draw required to overcome rotor inertia. Crucially, as the ESC algorithm begins its optimization and advances the firing angle,stabilization occurs. By data point 45, the average torque drops to a steady-state value of approximately 2.3 mN-m, which is due to the turn-on angle moving closer to the optimal turn-on angle. It should be futher noted that since the data entry upto 100 points in not real time but of every 8$^{th}$ iteration of data collected the torque data during that time is merely for the correctio purposes that it is within the expted range. Furthermore, the torque ripple is significantly attenuated once the optimal 24.8° angle is locked around the 100$^{th}$ data point.

The dynamic speed response of the Switched Reluctance Motor (SRM) under the designed control unit is illustrated in the fig. 4.dsensedRPM graph. The controller exhibits a stable and highly linear acceleration profile, ramping the motor speed from a standstill to the target velocity of 1500 RPM with noise introduced which mimics a real world SRM. This initial acceleration phase occurs over the first 40 data points, demonstrating the effectiveness of the initial high-torque command.The slight fluctuations observed around the 1500 RPM setpoint represent the active, real-time adjustments made by the control loop to counteract simulated load variations or sensor noise, ensuring robust speed regulation.

The plot in fig 4.e display the torque-speed characteristics which are in conjuction with the theoretical torqure-speed characterstics which shows that the result obtained follow the theretical order.[15] The the initial nature of the plot is linear then it reduces as the speed is reached to the rated speed this shows the plot moving from the current limited region to constant power region to finally natural region.

The torque ripple is calculated using the following formula [16],

$$\Delta T = \frac{T_{\max} - T_{\min}}{T_{\max}} \cdot 100\,\%,$$

Using this formula the torque ripple after the attenuation of optimal turn-on angle is

Table-Torque Ripple after attaining Optimal turn-on angle

| Cycle | Local Tmax | Local Tmin | Torque Ripple (ΔT) |
|---|---|---|---|
| 1 | 2.566 | 2.007 | 21.78% |
| 2 | 2.486 | 1.977 | 20.47% |
| 3 | 2.560 | 2.078 | 18.83% |
| 4 | 2.584 | 2.060 | 20.28% |
| 5 | 2.565 | 2.013 | 21.52% |
| 6 | 2.518 | 2.081 | 17.36% |

Average torque ripple came out to be ~20.04%.

## VII. CONCLUSION

A controller for a Switched Reluctance Motor was created and successfully implemented in this project to obtain acceptable controller which produced torque ripple of about 20.04% while keeping the overall cost of the machine to be as low as possible. The 20 % is considered a standard value for torque ripple.[17] The suggested control approach enables effective control of phase currents and excitation angles, hence provide smoother torque output. The controller's success is confirmed by experimentalfindings which are in accordance with the theoretical and prior research. Through the appropriate control methods, SRMs can be rendered fit for high-performance applications, as shown by the developed system.Further performance improvement may include the implementation of sophisticated control systems, such as neural networks or fuzzy logic, in the next research which are found to reduce the torque ripple to sub 10%-20% .[18,19,20]

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