Analysis of torque control in SRM by Neuro-Fuzzy SMC

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Abstract— **Among the various electric drives available, switched reluctance motor (SRM) has become a popular choice for the domestic and industrial applications due to its simple and robust construction. Moreover, this motor does not have winding in the rotor; hence it is suitable for high speed applications (usually above 10000 rpm). These motor are extensively used in aerospace, automotive and other home appliances. The motor have winding in the stator which is excited from a separate source. The control of these motor drives is obtained using converter circuits that control the excitation of the phase by switching converter switches. The conventional converter circuit suffers from low power factor and high harmonic content which is turns affects the performance of the motor drive. The aim of the work is to develop a suitable converter circuit that could give an improved power factor and low torque ripples. Various converter topologies are studied and simulation of asymmetric bridge converter was carried out using MATLAB/SIMULINK to study its performance on the various parameters of the switched reluctance motor (SRM) drive. Three phase asymmetrical power converter using IGBT is used in the feedback of motor to control the power factor of motor. Further for minimization of ripples in torque an optimization technique named Bacterial Foraging Optimization is used. It takes torque in the objective function and calculate ripples, assign new values to turn on and off angle of motor so that an optimum position to the stator and rotor of motor can be assigned where ripples are minimum.**

Keywords— **PV-Grid,inverter,SMC.**

I. Introduction

The switched reluctance motor (SRM) represents one of the earliest electric machines which was introduced two centuries back in the history.It was not widely spread inindustrial applications such as the induction and dc motors due to the fact that at the time when this machine was invented, there was no simultaneous progress in the field of power electronics and semiconductor switches which are necessary to drive this kind of electrical machines properly. The problems associated with the induction and dc machines together with the revolution of power electronics and semiconductors in the late sixties of the last century led to the reinvention of this motor and redirected the researcher stopay attention to its attractive features and advantages which helped in overcoming alot of problems associated with other kinds of electrical machines such as brushes and commutators in dc machines and slip ring sin wound rotor induction machines besides the speed limitation in both these motors. The simple design and robustness of the switched reluctance machine made it an attractive alternative for these kinds of electrical machines for many applications recently specially that most of its disadvantages which are mentioned in the following chapter could bee liminated or minimized by use of high speed and high power semiconductor switches such as the power thyristors power GTOs power transistors, power IGBT sand the power MOSFETs. The availability and the in expensive cost of the power switches now a day's besides the presence of microprocessors and microcontrollers ,PIC controllers and DSP chip smakesit a strong opponent toother types of electrical machines. In industry, there is a very wide variety of design of the switched reluctance machines which are used as motors or generators ,the use designs vary with number of phases, number of poles for both stator and rotor, number of teeth per pole the shape of pole so whether a permanent magnets included . These options together with the converter topology used to drive the machine led to an enormous number of designs and types of switched reluctance machine systems, which mean both the switched reluctance machine with its drive circuit, can suit varied applications with different requirements. It is well known to those who are interested in this kind of electrical machines that the drive circuit and the machine is an integrated system, one part of such a system cannot be separately designed without considering the other part. A switched reluctance machine is a rotating electric machine where both stator and rotor have salient poles. The stator winding is comprised of a set of coils, each of which is wound on one pole. Switched reluctance motors differ in the number of phases wound on the stator. Each of them has a certain number of suitable combinations of stator and rotor poles. When operated as a motor, the machine is excited by a sequence of current pulses applied to each phase. The individual phases are consequently excited, forcing the motor to rotate. The current pulses need to be applied to the respective phase at the exact rotor position relative to the excited phase. The inductance profile of switched reluctance motors is triangular shaped, with maximum inductance when it is in an aligned position and minimum inductance when unaligned. When the voltage is applied to the stator phase, the motor creates torque in the direction of increasing inductance. When the phase is energized in its minimum inductance position the rotor moves to the forthcoming position of maximum inductance. The profile of the phase current together with the magnetization characteristics defines the generated torque and thus the speed of the motor. There are several advantages of the switched reluctance machines that give it preference over other the types of electrical motors in many applications, these advantages are enumerated below as follows:

1. Simple design and robust structure.
2. Unwind rotor.
3. Low cost.
4. High starting torque without the problem of inrush currents compared with induction motor.
5. Suitable for high speed applications.
6. High reliability due to the electric and magnetic independency of the machine phases.
7. Suitable for high temperature applications compared to other machines of similar ratings.
8. Motor torque is independent of the phase current polarity.
9. Four quadrant operations.
10. A wide constant torque or power region in the torque speed characteristics.
11. High efficiency throughout every part of torque speed range

II.RELATED WORK

The Development of SRM has been proposed by many researchers.The selection of control strategy depends on the converters of the drive including power, speed, performance and the possible system costs. previous method proposed the power factor improvement technique in the midpoint converter based Switched Reluctance Motor (SRM) drive using a AC-DC three level Pulse Width Modulation (PWM) converter The SRM drive with converter is modeled and its performance is simulated in Matlab/Simulink environment. some researcher examines the feasibility of using artificial neural networks (ANNs) and genetic algorithms (GAs) to develop discrete time dynamic models for fault free and faulted switched–reluctance–motor (SRM) drive systems. Then presents a new control structure to reduce torque ripple in switched reluctance motor. Although SRM possesses many advantages in motor structure, it suffers from large torque ripple that causes some problems such as vibration and acoustic noise.

III. PROPOSED WORK

Main objective will be to minimize the torque ripples in the motor but before that we have to be familiar with problems faced in synchronous reluctance motor so that a methodology to sort out that problem can be designed.

3.1 Problem Formulation

SRM has the advantages of simple structure, low cost and high efficiency. Along with those advantages SRM has a nonlinear magnetic structure and motor parameters are time varying. The primary disadvantage of SRM is the higher torque ripples when compared to conventional machines, which results in acoustic noise and vibration. The origin of torque pulsations in SRM is the highly non linear and discrete nature of torque production mechanism. The total torque in an SRM is the sum of torques generated by each of the stator phases, which are controlled independently. Torque pulsations are the most significant at the commutation instants when torque production mechanism is being transferred from one active phase to another. The resonant vibrations of the stator are the dominant source of acoustic noise in an SRM. The minimization of torque ripples is essential in high performance servo applications which require smooth operation with minimum torque pulsations. The excellent positive features of an SRM may be utilized in a servo system by developing techniques for reducing the torque ripples. Because of these features, traditional controllers PI (Proportional Integral), PD (Proportional Derivative), PID (Proportional Integral Derivative) are insufficient in SRM control. Hence, non-linear controllers are needed in SRM control.

3.2 Torque Ripples Reduction Scheme

In torque reduction scheme three phase assymetrical converters is used in feedback circuit for current feedback to control torque ripples. But in this case the turn on and turn off angles are fixed. The position angle of rotor and stator is fixe which may give rise to ripples in torque. To minimise the ripples position of rotor and stator should be optimum, so optimisation technique is used to find the optimum position of rotor and stator of SRM. Bacterial foraging optimisation (BFO) is used in our case as it is the best global search optimisation technique available. In this premature termination of iterations is not a problem. An algorithm describing the steps in BFO is quoted in 3.3

3.3 Bacterial Foraging Optimisation

Bacteria Foraging Optimization Algorithm (BFOA), is a new comer to the family of nature-inspired optimization algorithms. For over the last five decades, optimization algorithms like Genetic Algorithms (GAs), Evolutionary Programming (EP), Evolutionary Strategies (ES), which draw their inspiration from evolution and natural genetics, have been dominating the realm of optimization algorithms. Recently natural swarm inspired algorithms like Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) have found their way into this domain and proved their effectiveness. Application of group foraging strategy of a swarm of *E.coli* bacteria in multi-optimal function optimization is the key idea of the new algorithm. Bacteria search for nutrients in a manner to maximize energy obtained per unit time. Individual bacterium also communicates with others by sending signals. A bacterium takes foraging decisions after considering two previous factors. The process, in which a bacterium moves by taking small steps while searching for nutrients, is called chemotaxis and key idea of BFOA is mimicking chemotactic movement of virtual bacteria in the problem search space.

During foraging of the real bacteria, locomotion is achieved by a set of tensile flagella. Flagella help an *E.coli* bacterium to tumble or swim, which are two basic operations performed by a bacterium at the time of foraging. When they rotate the flagella in the clockwise direction, each flagellum pulls on the cell. That results in the moving of flagella independently and finally the bacterium tumbles with lesser number of tumbling whereas in a harmful place it tumbles frequently to find a nutrient gradient. Moving the flagella in the counter clockwise direction helps the bacterium to swim at a very fast rate. In the above-mentioned algorithm the bacteria undergoes chemotaxis, where they like to move towards a nutrient gradient and avoid noxious environment. Generally the bacteria move for a longer distance in a friendly environment. Figure 3.1 depicts how clockwise and counter clockwise movement of a bacterium take place in a nutrient solution.

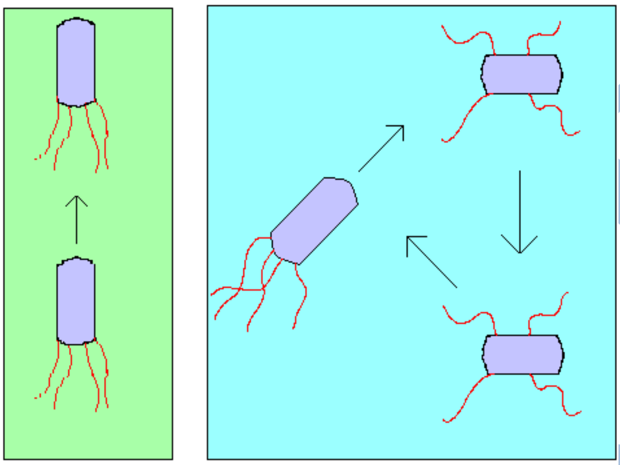


Fig.3.1. Swim and tumble of a bacterium

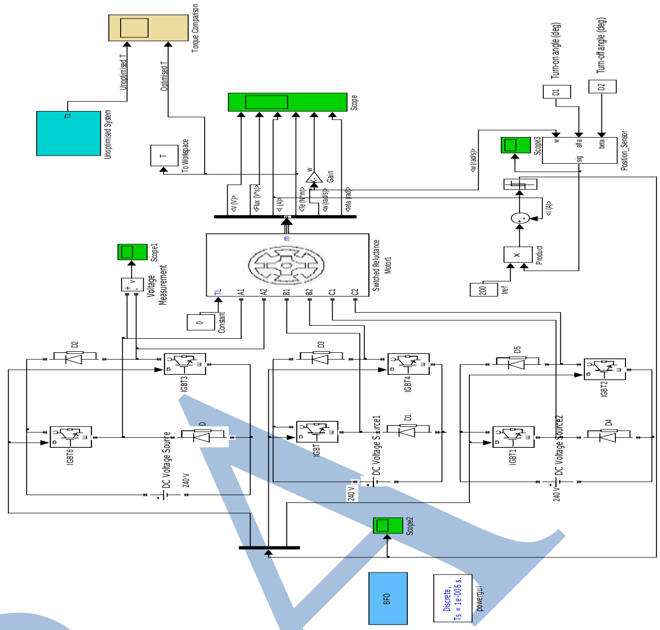
When they get food in sufficient, they are increased in length and in presence of suitable temperature they break in the middle to from an exact replica of itself. This phenomenon inspired Passino to introduce an event of reproduction in BFOA. Due to the occurrence of sudden environmental changes or attack, the chemotactic progress may be destroyed and a group of bacteria may move to some other places or some other may be introduced in the swarm of concern. This constitutes the event of elimination-dispersal in the real bacterial population, where all the bacteria in a region are killed or a group is dispersed into a new part of the environment.

IV. MATLAB SIMULINK MODEL DESCRIPTION

The objective of my work is to reduce the torque ripples, so a controlling mechanism using bacterial foraging optimization is used. The simulated resultsare obtained in MATLAB/SIMULINK environment and they are discussed thoroughly in this section.

V. DISCUSSION OF RESULTS

The converter model of switched reluctance motor drive consists of a dc source, switched reluctance motor model, an asymmetric bridge converter i.e. used for converting dc into



required ac, and a scope which shows the various output parameters of the motor like stator voltage, flux linkage, stator current, electromagnetic torque, rotor speed and rotor position. **Results with no optimization**

Fig 5.2 shows the various output characteristics of the switched reluctance motor drive without optimization. In this SRM motor angular speed and current is fed back into positions sensor block which according to turn on and turn off angle control the torque characteristics. These characteristics are simulated output of SRM converter model.

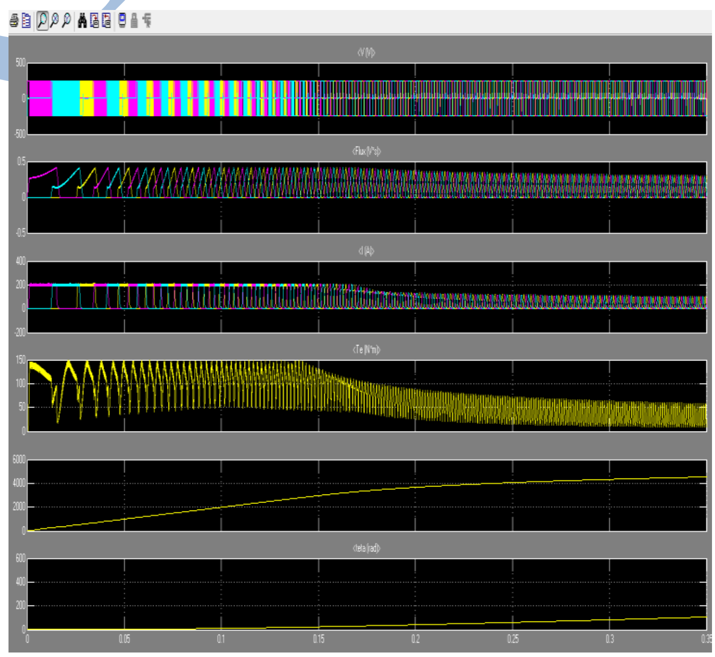


Fig. 5.2: Output Waveforms of Switched Reluctance Motor Drive

Fig 5.3 shows the stator voltage of SRM which is the voltage versus time graph, voltage varies on y-axis and time is shown on x-axis the three color of graph shows the output of three different dc voltage source. There is a small delay in trigging ON of the power switch, hence the wave form starts from near to the zero point and no other delay period is observed in the whole graph of the voltage. The magnitude of the voltage is approximately 240V.

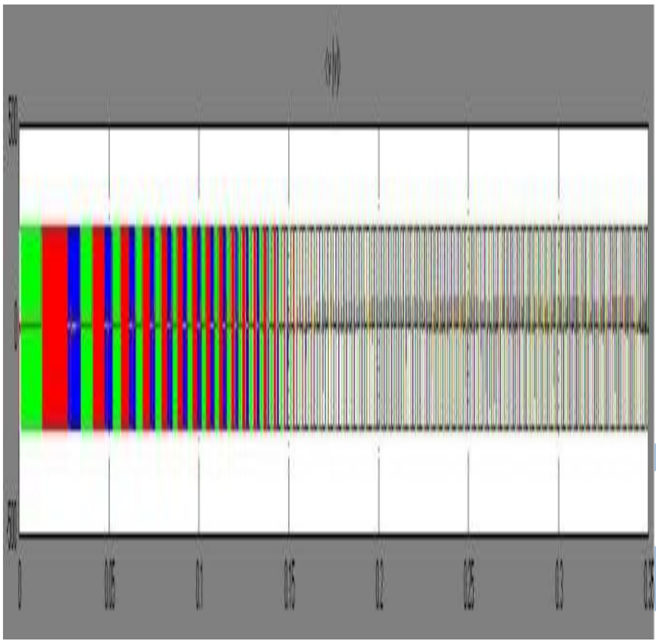


Fig 5.3 Stator Voltage Waveform of Switched Reluctance Motor Drive

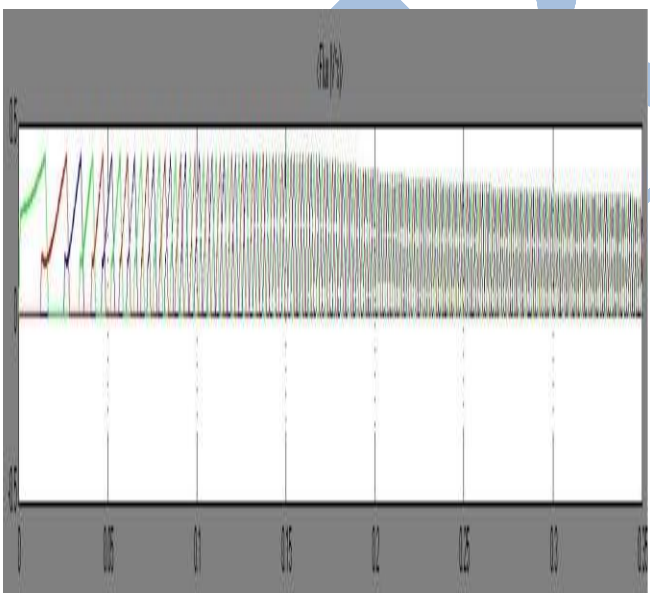


Fig. 5.4: Flux Linkage Variation of Switched Reluctance Motor Drive

Fig 5.4 shows the flux linkage of SRM, where the variation of flux linkage in the stator winding is plotted with respect to time. There are three colors of waveform that shows the flux linkage in three phases, in between stator and rotor pole of SRM. The flux linkage depends on the alignment of the rotor and stator pole. In the graph shown there is no initial delay and output is stable initially. However, there is no delay when the next phase is triggered.Fig 5.5 shows the stator current of switched reluctance motor drive. The maximum value is 200 A. The graph shows the variation of stator current with respect to time. The graph signifies that during the initial stage the starting current is high and it finally comes to a lower and steady value after 0.18Sec.Three different colors signify different phase currents. No delay of switching of the devices is implemented which is observed from the graph.

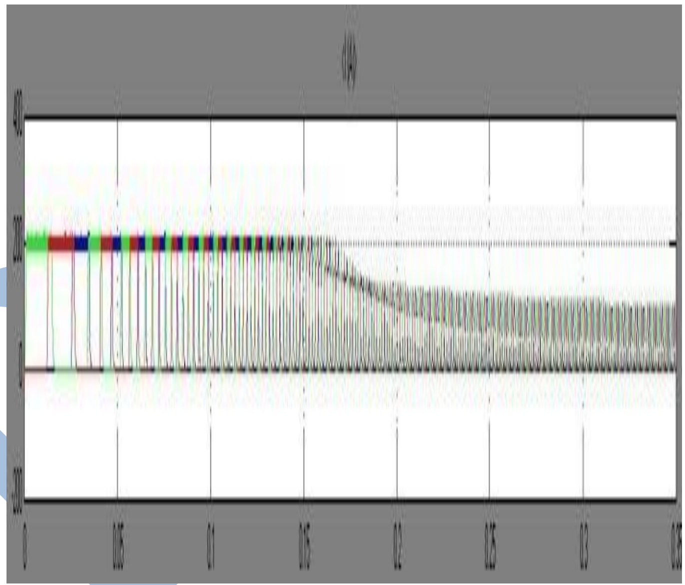


Fig. 5.5: Stator Current Variation of Switched Reluctance Motor Drive

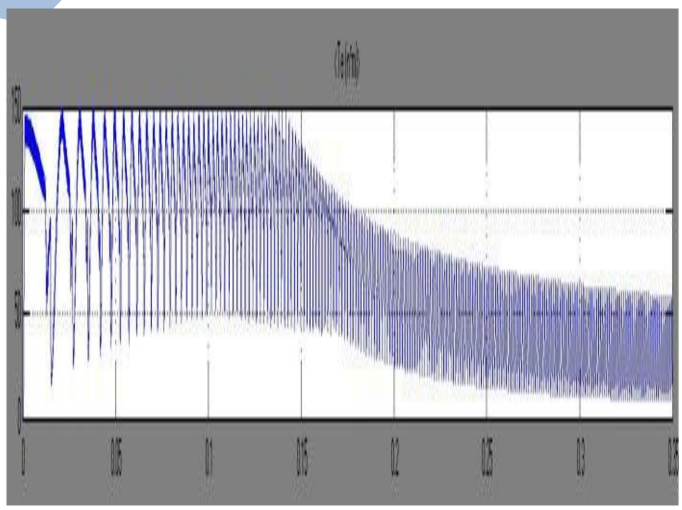


Fig 5.6 Electromagnetic Torque Characteristics of Switched Reluctance Motor Drive

Fig 5.6 shows the developed torque of SRM which shows the plot of torque in N-m with respect to time. Torque characteristics depend on the relationship between flux linkages and rotor position as a function of time. The maximum torque achieved is 150 N-m at starting and after 0.15 it is approximately 80 N-m. This means the starting torque of this motor drive is very high.

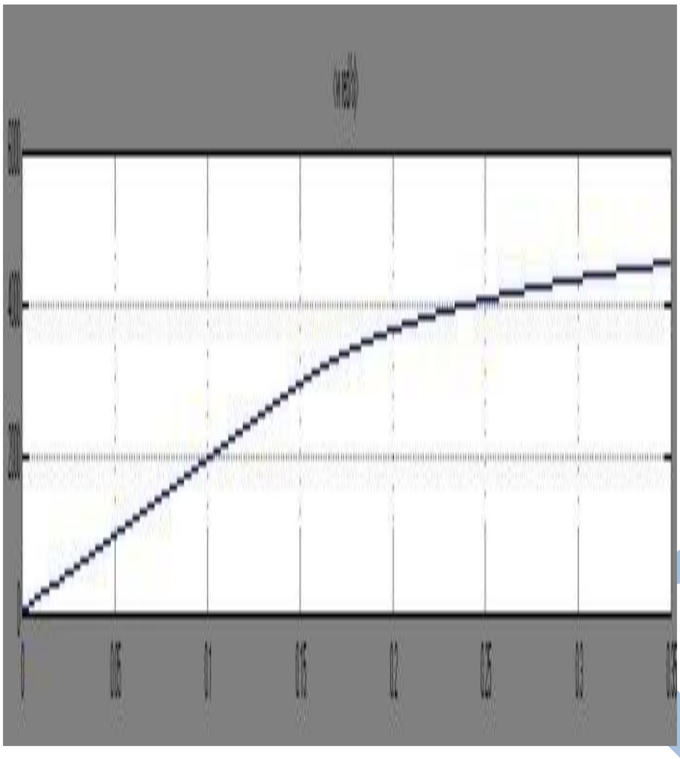


Fig. 5.7: Rotor Speed Profile of Switched Reluctance Motor Drive

Fig 5.7 shows the rotor speed of the switched reluctance motor and its variation is plottedwith respect to time .We have observed that the speed varies initially but becomes constant after a certain point. The maximum speed obtained is approximately 5000 rad/s. The last graph in figure 5.3 shows the variation of rotor position angle theta with respect to time. This angle is the position of rotor and stator pole. The developed torque depends on this angle theta. The maximum angle observed is approximately 100.

The above results reflect the performance of switched reluctance motor drive using a conventional asymmetric converter without any input power factor correction. In the subsequent section, we will discuss a power factor correction circuit for a switched reluctance motor drive and observe its output waveforms.

Optimized SRM results

For optimization double click on BFO block is done and optimization starts. For each new value of turn off and on angle, model simulated until the ripples in torque are not minimized. The output of SRM after optimization is shown in figure 5.8. there is improvement in every output as torque ripples have been minimized. The minimization of torque ripples are clearly shown in figure 5.9. the first graph shows the unoptimised torque waveform. Ripples in every waveform are clearly visible which makes torque non linear and unsuitable for performance servo applications which require smooth operation with minimum torque pulsations. To make it suitable after optimisation ripples are decreased. Second waveform in lower half in figure 5.9 shows the reduction in ripples.

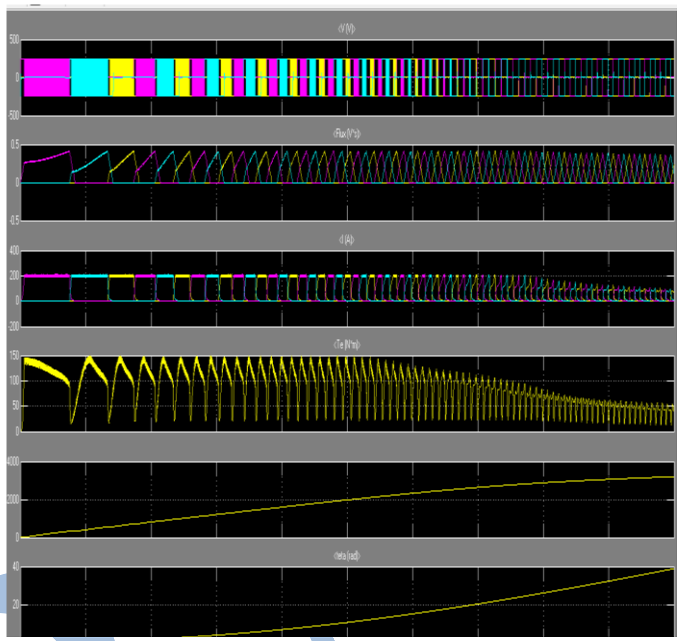


Figure 5.8: optimized output of SRM

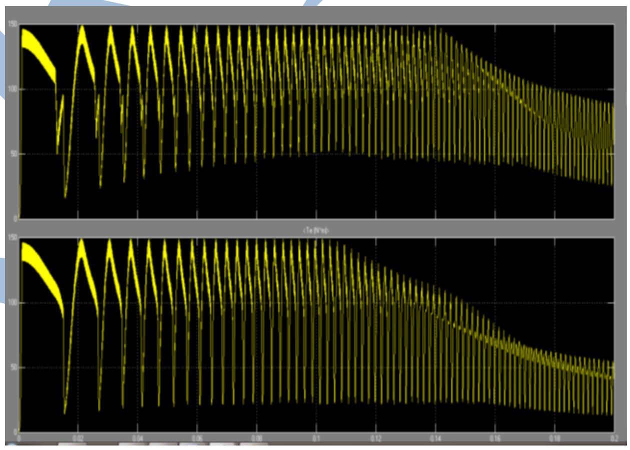


Figure 5.9: Comparison of Unoptimized and optimized torque ripples

VI. CONCLUSION

Various converter topologies employed in switched reluctance motor drives have been discussed in Chapter The main focus was to simulate a new converter topology which could give an improved power factor and less harmonic content based on the various topologies available. The performance of a switched reluctance motor drive is simulated in MATLAB/SIMULINK environment using asymmetric bridge converter where various drives parameter such as stator voltage, flux linkage, stator current, electromagnetic torque, rotor speed and position are being analyzed and discussed. Further bacterial foraging optimization technique is used to locate the best optimum position of rotor and stator where torque ripples are minimized. For this torque is taken as the input in the objective function of BFO and bacterial positions are assign to turn off and on angle of motor..

FUTURE SCOPE

For future study the power factor correction circuit can include a PWM converter or inverter for switched reluctance motor drive system to improve overall efficiency and reliability of the drive. The circuit developed may be used in various applications namely electric vehicles, aerospace automotive and domestic appliances. Further BFO is used in my work but suffers with low computational speed as so many iterations on each bacteria is done, so a modification to BFO algorithm to decrease its computation time can be proposed or any other alternative to BFO can be looked which doesn't terminate prematurely and also have low computation speed. Moreover if PWM inverter is used then the duty cycle of PWM can also be controlled or optimized to give optimum results and less ripples in torque. In this work experiment has been done on 6/4 poles SRM motor, but it can also be checked for 8/6 and 10/8 poles SRM motor.

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