ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 7, July 2014

Torque Control in Switched Reluctance Motor by BFO Optimization

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Abstract: These motor are extensively used in aerospace, automotive and other home appliances. These motors 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 in turns affects the performance of the motor drive. The aim of the work is to develop a suitable converter circuit that would give and improved power factor and low torque ripples. 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 and 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 ripple are minimum.

Keywords: SR motor,Matlab/Simulink,3-phase power converter, IGBT,BFO optimization, torque ripple minimization.

1. INTRODUCTION

In this chapter, we are going to discuss about the principle of operation of a switched reluctance motor, the principle of torque production, the basic characterstics of electrical hardware and finally the various configurations of switched reluctance motor. 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 in industrial 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 researchers to pay attention to its attractive features and advantages which helped in overcoming a lot of problems associated with other kinds of electrical machines such as brushes and commutators in dc machines and slip rings in 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 be eliminated or minimized by use of high speed and high power semiconductor switches such as the power thyristors, power GTOs, power transistors, power IGBTs and the power MOSFETs. The availability and the inexpensive cost of these power switches nowadays besides the presence of microprocessors and microcontrollers, PIC controllers and DSP chips makes it a strong opponent to other 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, these designs vary with number of phases, number of poles for both stator and rotor, number of teeth per pole, the shape of poles or whether a permanent magnet is included or not. 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. 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.

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2. BACTERIAL FORAGING OPTIMIZATION

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 4.1 depicts how clockwise and counter clockwise movement of a bacterium take place in a nutrient solution.

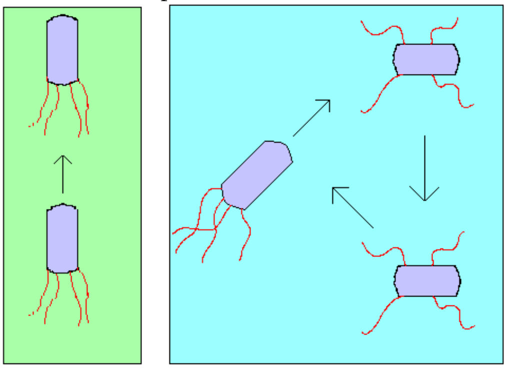

Fig.2.1. Swim and tumble of a bacterium

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. Thus search for food of E.Coli can be categorised into four steps: Chemotactic, Swarming, Reproduction and Killing/ Dispersion.

1. CONVERTER CIRCUITS FOR SWITCHED RELUCTANCE MOTOR DRIVES

Earlier the switched reluctance motor employed a simple converter circuit which proved to be disadvantages on the performance of motor, problems like high current harmonic and low power factor were faced as the excitation for the stator phase winding produced discontinuous pulses. Here we are discussed about from some topologies.

MODIFIED ASYMMETRIC BRIDGE CONVERTER: In a single-phase switched reluctance motor (SRM) drive, the dc voltage source is generally supplied by a circuit consisting of a bridge rectifier and a filter capacitor connected to an ac line. The charging time of the capacitor is shorter from the ac source as capacity increases. The bridge rectifier draws pulsating current from the ac source, which results in a degraded power factor (PF) and lower system efficiency. A single-phase SRM drive system is presented here, which includes the realization of a drive circuit for the reduction of torque ripple and PF improvement with a novel switching topology. The proposed drive circuit adds one switch and one diode, which can separate the output of the ac/dc rectifier from the large capacitor and supply power to the SRM alternately. This allows the drive system to realize torque ripple reduction and power factor improvement through the switching scheme.

ASYMMETRIC CONVERTER FOR SINGLE PHASE SRM: The drive circuit has a simple diode rectifier, a filter capacitor and an asymmetric bridge converter. The rectifier and the filter capacitor supply the dc source. The filter capacitor reduces dc voltage ripple and stores the recovered energy from the motor during demagnetization. This drive structure is very simple, but the capacitor charges and discharge which gives a pulsating ac line current and results in a low PF. The low PF of the motor increases the reactive power of the power line.

4. RESULT AND DISCUSSION

Result with no optimization: Fig 4.1` 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.

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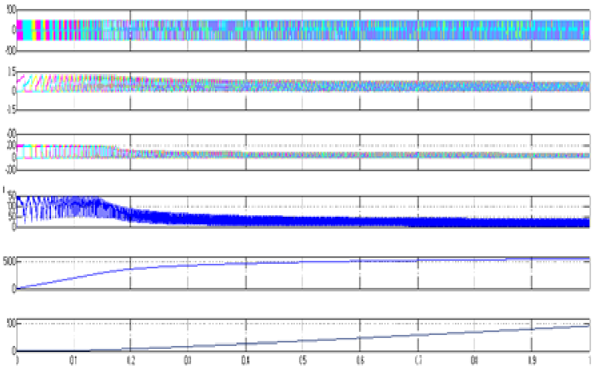

Fig. 4.1: Output Waveforms of Switched Reluctance Motor Drive

Fig 4.2 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 voltages. 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.

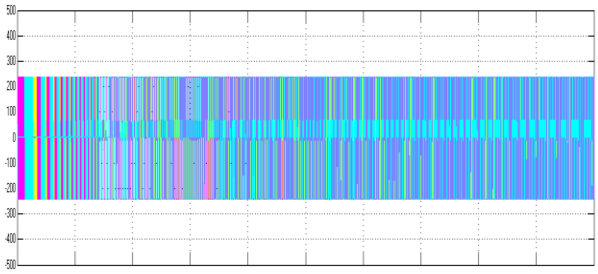

Fig 4.2 Stator Voltage Waveform of Switched Reluctance Motor Drive

Fig 4.3 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.

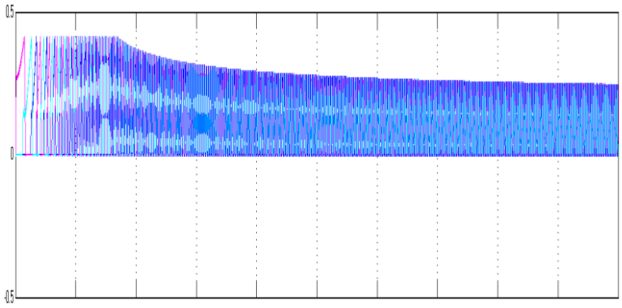

Fig. 4.3: Flux Linkage Variation of Switched Reluctance Motor Drive

Fig 4.4 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.

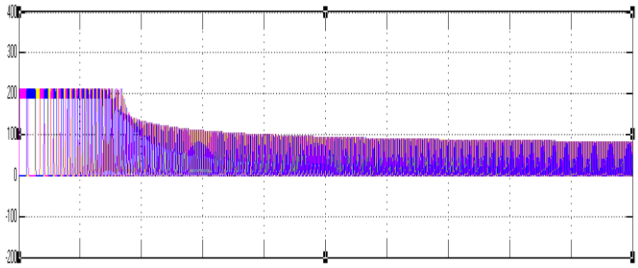

Fig. 4.4: Stator Current Variation of Switched Reluctance Motor Drive

Fig 4.5 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. We have observed from the waveform that the torque at starting period is high but after 0.15 seconds it gradually reduces and becomes constant. 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.

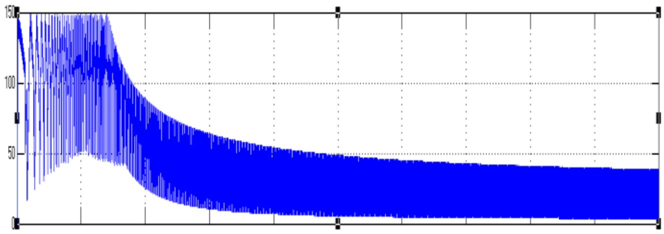

Fig 4.5 Electromagnetic Torque Characteristics of Switched Reluctance Motor Drive

Fig 4.6 shows the rotor speed of the switched reluctance motor and its variation is plotted with 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.

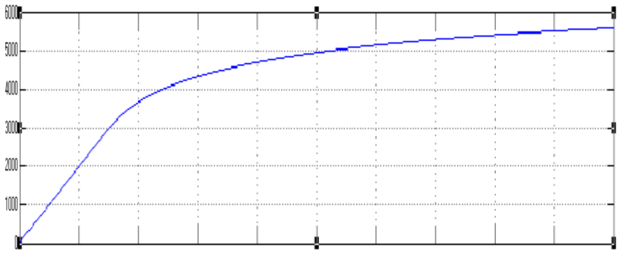

Fig. 4.6: Rotor Speed Profile of Switched Reluctance Motor Drive

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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 4.7. there is improvement in every output as torque ripples have been minimized. The minimization of torque ripples are clearly shown in figure 4.8. 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 plus.

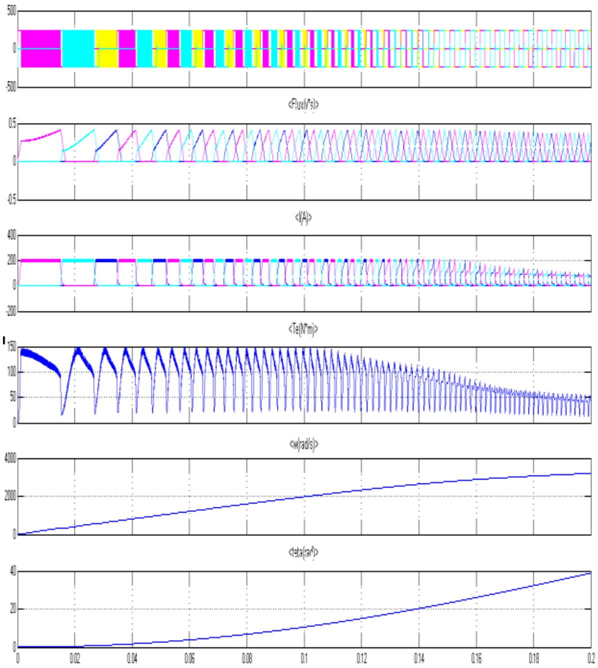

Figure 4.7: optimized output of SRM

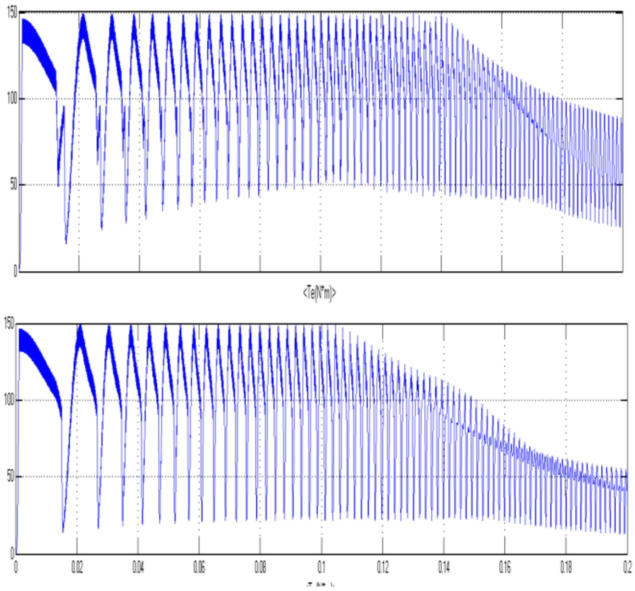

Figure: 4.8 Comparison of Unoptimized and

Optimized torque ripples

The torque ripples produces because of position change of rotor and stator of SRM. Once both stator and rotor sets into an optimum position then ripples are reduced.

5. CONCLUSION

Various converter topologies employed in switched reluctance motor drives have been discussed in Chapter 3.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. After simulating the model for many iteration and in each iteration new position of stator and rotor is assigned, an optimum position is reached where ripples are very less. To show the comparison a graph in figure 5.9 is shown which clearly depicts the reduction in torque ripples.

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BIOGRAPHIES

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