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Improvement and Performance of Switched Reluctance Motor by Using Different Torque Ripples Controller Methods

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ABSTRACT – The generated torque ripple and acoustic noise in switched reluctance motors (SRM) can be considered as one of the major disadvantages of the motor. It is mainly due to frequent switching of phases for rotation of the motor and changes of the air gap length between the rotor and stator teeth. It decreases the average developed torque; diminish the efficiency, causes noise and vibration in the motor. So, in order to improve the performance of SRM and extend its applications in industry, it is essential to reduce these torque ripples. So far, many torque ripple reduction methods have been introduced. These have been done through changing and improving the structure and geometry of the motor or using some control strategies. This paper reviews a variety of control strategies to reduce the torque ripple in SRM. Each of the methods described in details. Different techniques are compared and the best and most efficient one is introduced.

I. INTRODUCTION

One other method is designing and obtaining particular current. Selection of optimal switching angles based on the maximum torque and current ratio criterion is appropriate for high speed SRM. In this case, the minimum torque ripple criterion can be approximated over low speed range. Attempt has been made in 2003 by C. Mademlis et.all., to optimize on- and off-switching angles for reduction of torque ripple in SRM. D.H. Lee in 2009 had introduce the torque distribution function technique may be used to alleviate the torque ripple. This technique controls torque variation rate over commutation period according to a pre-defined torque distribution function.

In 2013, in order to take into account a precise non-linear model for inclusion of SRM drive nonlinearity, advanced methods such as artificial natural network (ANN), fuzzy-logic or their combination can be applied by J. Faiz. In ANN non-linearity of SRM characteristics is trained by NNs and then current graph for ripple reduction is obtained . In , ANN has been used as an intelligent controller by Y. Cai in 2006-07. The fuzzy-logic model has the advantageous of simple mathematical computations in processing fuzzy-logic rules which leads to a quick operation. Fuzzy-logic has been used as an intelligent method by M. Rodrigues in .

J. Faiz in 2010, can be also used torque control techniques for torque ripple reduction . A torque controller has been designed K. Russa and I. Husain in 2002 in [11] while in [12] the ripple have been reduced by controlling the excited phase output torque through adjusting the relevant co-energy by tracking the co-energy diagram by K.F. Wong in 2009 . Direct torque control (DTC) has been followed in [15, 16]. A new pattern called two-phase excitation has been suggested in [17] by C. Ma 2013, which have the highest average torque and lowest torque ripple compared to the two conventional patterns. The attempt has been made in [13] to decrease the torque ripple through changing the geometry of the motor by D.H. Lee in 2013. In [14], a four-level converter has been utilized to improve the torque and speed ripple which also shorten the response time and current peak in SRM by J.W. Ahn in 2007.

One of useful and efficient method in reducing the cost and enhancing efficiency is decreasing the losses and number of switches in each leg of the converter. A. Deriszadeh in 2011, has been introduced a new converter with one switch per phase in [19] which have low cost and high efficiency advantages as well as lower torque ripple. Novel and advanced methods and algorithms have been suggested by E. Daryabeigi et all, in 2014, in [18] in order adjust the speed or current controller and reduce the torque ripple.

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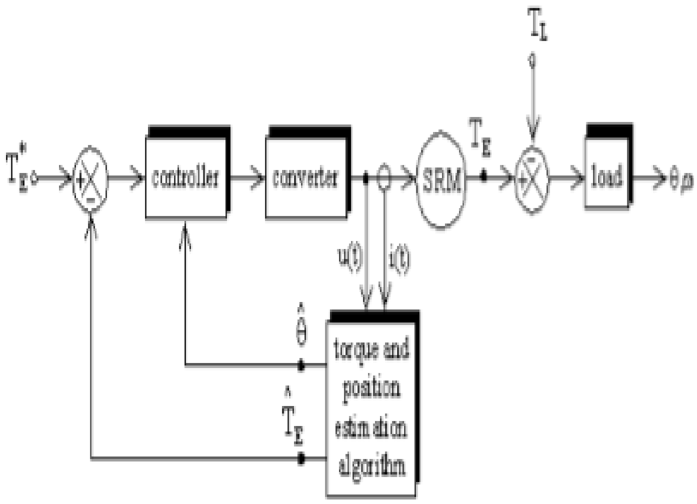
II. DIFFERENT TORQUE RIPPLES CONTROLLER METHODS

A.Modern Method of Neural Network:

An SRM torque ripple reduction scheme using a two-dimensional (2D) B-spline neural network (BSNN) has been proposed in [20]. BSNN is a kind of associative memory neural network which is suitable for online nonlinear adaptive modeling. Closed-loop control can be implemented by using on-line torque estimator. Due to the local weight updating algorithm used for BSNN, an appropriate phase current profile for torque ripple reduction can be obtained on-line in real time. It has good dynamic performance with respect to the changes in the demand torque .This scheme does not require high-bandwidth current controllers.



Block-diagram of the proposed scheme is shown in Fig. To practically implement this scheme, a digital signal processor for on-line estimation of the torque and ripple reduction, evaluation module to implement the current controller and an encoder to get the position are required. Torque model and the inverse torque model have been developed in [21] based on BP neural network model of Levenberg-Marquardt algorithm using the measured static torque characteristic. Then torque ripple have been minimized by optimum profiling of the phase current based on instantaneous torque control. Also an efficient commutation strategy for minimizing torque ripple while avoiding power converter voltage saturation over a wide speed range of operation has been proposed. The phase used to produce the desired torque is controlled by the hysteresis current controller. The desired phase torque in this interval is obtained subtracting the sum of the other phases torque from the total torque command. Here, the generated torque by the other phases is estimated using BPNN model of SRM torque. Then, the SRM inverse torque model built by BP neural network is used to generate a phase current command. The torque ripple minimization can be achieved by optimum phase current profiling.

B.Torque Control:

B.1. Torque Controller Design:

A controller for an SRM has been developed to minimize torque ripple [26]. This controller is robust, and can be easily implemented in standard digital hardware (DSP). Also, a new, simple and efficient commutation strategy is proposed. The objective is to design a cost effective controller to minimize torque ripple which can be adaptively updated in real time. The algorithm is suitable for both low and high speeds and does not require pre-calculated flux or current profiles. However, the computation time of the control cycle increases. Block-diagram of the controller has been presented in Fig. The function of the electronic commutator is to designate the appropriate phases for torque development and commutation. The algorithm used by the electronic commutator maximizes the overlapping

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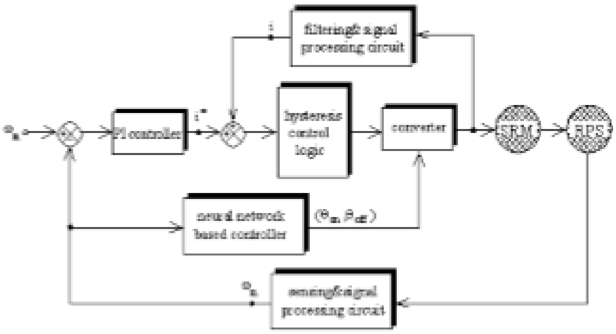
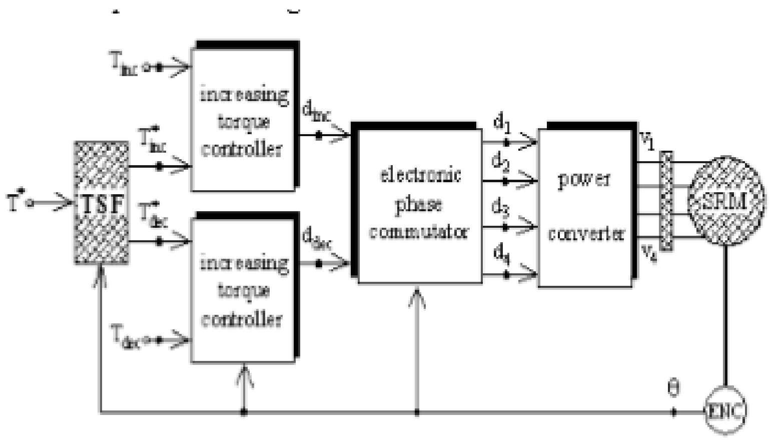
conduction region in which more than one phase can be used for positive torque generation. The torque controller uses measured phase currents to estimate the torque produced by each phase, except the one designated by the electronic commutator. The suitable phase torque is obtained extracting the total reference torque. The command torque is then transformed to current commands and is fed to an external hysteresis controller that drives the power converter. The proposed approach, together with a new commutation scheme compensates the non-ideal operation of the remaining phases. A DSP is required to implement controller and also an encoder to obtain the rotor position.



In addition to a review of the previous approaches adopted to minimize torque ripple, [24] has presented a hybrid controller to minimize the torque ripple. The proposed method is based on merging the past developed techniques. The concept of torque sharing over an extended region is merged with the balanced commutator approach to minimize torque ripple.

C. Direct Torque Controller:

A novel Lyapunov function-based direct torque controller (DTC) to minimize of the torque ripple in an SRM drive system is reported in [25]. The DTC scheme avoids the complex process of torque-to-current conversion which is common in indirect torque control scheme. The traditional DTC scheme uses a hysteresis-type torque controller leading to a large amount of torque ripple when implemented digitally. The proposed controller is intended to take care of the nonlinear system dynamics of magnetic characteristics associated with accurate torque control using DTC scheme for an SRM drive system. In the proposed Lyapunov function-based controller, the variable feedback gain is adopted using a heuristic technique. The stability of the proposed controller is ensured using the direct method of Lyapunov. The proposed control scheme is presented in Fig.



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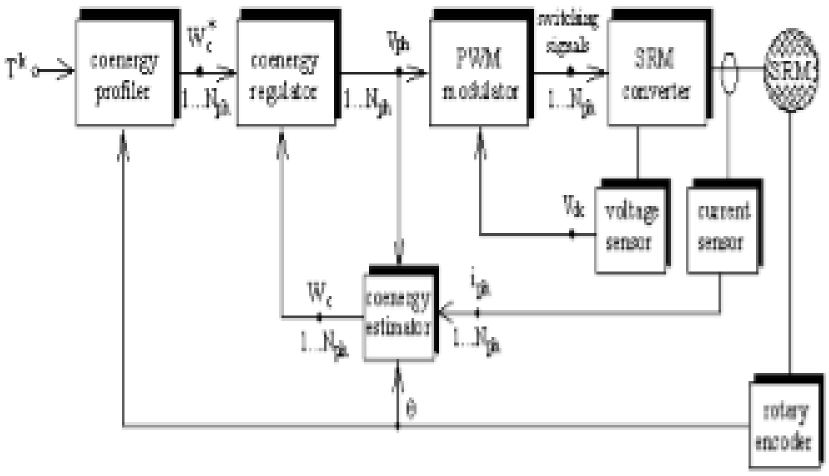
Comparing hysteresis torque controller and the Lyapunov function torque controller indicates that using Lyapunov function controller demand torque follows the reference torque more accurately. Ripple related to average torque is within the acceptable range and it is less than that of hysteresis controller. A comparative study of DTC method with direct instantaneous torque control methods (DITC) and current profiling technique, for 3-phase SRM has been performed [23] shows that DTIC does require rotor position information or encoder. However, using DTC, higher phase SRM current is necessary to maintain constant flux-linkage in all situations of the rotor. This reduces the ratio of torque to current and diminishes efficiency as a result. Furthermore, using DTC approach, different flux-linkage references are required to produce the same torque at different speeds for optimum torque/ampere. Then a new DTC scheme has been proposed in which the voltage vectors are chosen, so that the current of the active phase is controlled to produce the desired torque and the current of outgoing phase is made to decay quickly. Thus, the torque/ampere is improved reducing the conduction time of each phase. Also flux-linkage is maintained constantly only during phase current commutation to eliminate the need for rotor position information; thus the performance of this scheme is not very sensitive to the flux-linkage reference. Result shows that unlike previous DTC scheme, one reference flux-linkage can be used to produce the same torque at different speeds in this proposed DTC scheme. Comparing the resulted waveforms deduces that using proposed DTC method, phases conduct to a shorter period and less negative torque is produced compared to DTC method. As a result, ripple torque is also improved. Comparing the table of obtained results it is realized that: 1) Considering the minimum effective current, minimum phase current peak and maximum torque/ampere, the current profiling technique and then the proposed DTC scheme takes place, 2) DITC and the proposed DTC scheme have the minimum amount of switching transitions. 3) The torque/ampere is more sensitive to variation of reference flux-linkage in DTC scheme compared to the proposed DTC scheme.

D. Instantaneous torque control:

An on-line instantaneous torque control technique for an SRM operating in the saturation region has been presented in [22]. The proposed methodology realizes the instantaneous output torque controlling for each excited phase by regulating its associated co-energy in order to follow the co-energy profile. The design of the proposed controller is simple when compared to that of traditional current controllers. The reason is that in the proposed methodology, the parameters of the feedback controller are independent of the motor parameters in the analysis of the co-energy control system. Smooth shaft torque is obtained by torque sharing among the active phases during commutation. The proposed controller structure is presented in Fig.



In this structure, the reference torque and rotor position are used to obtain the co-energy references $WC*$. Also, phase current signals, terminal voltage and rotor position are used to estimate co-energy to control it. The co-energy can be estimated on-line without extensive knowledge of the motor magnetic characteristics. Simulation and experimental results shows that the proposed algorithm yields smooth output torque algorithm that follows the torque command well. In addition, it is obvious from the presented results that high-frequency torque ripple is reduced.

III. CONCLUSION

This paper is a comprehensive overview of already proposed methods to reduce the torque ripple and acoustic noise of SRM. Among the discussed various current optimization processes, fuzzy intelligent technique (FIT) have provided better results. better dynamic response and more robust against external fluctuations. Results of the torque sharing function method, which is one of the most popular methods, is very good and satisfying. Another method is the use of neural networks which despite its complex nature shows better results than fuzzy-logic. To optimize and obtain the appropriate values of speed or current controller gains or both, methods and smart algorithms have been used recently. Apart from the method presented in [65], the results of the rest of methods are very good, satisfactory and have minimum torque ripple.

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