Comparative Performance Analysis of Hysteresis Current Control and Direct Torque Control of 4 Phase 8/6 Switched Reluctance Motor Drive

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Abstract. The Switched Reluctance Motor drives have been widely used in special applications like conveyer belts, compressors, vacuum cleaners etc., because of advantages like simple construction, no winding on rotor, high speed operation and high temperature handling capability. But its operation is not spread to the other applications because of presence of high torque ripple. The torque ripple can be minimized by adopting the Direct Torque Control Technique. In DTC technique, flux and torque are maintained within the set of hysteresis bands by applying suitable Space Voltage Vectors. This paper makes the comparative performance analysis of Switched Reluctance Motor drive with Hysteresis Current Control and Direct Torque Control techniques. The detailed simulation results based on MATLAB / SIMULINK is also presented.

Keywords: Direct Torque Control, Switched Reluctance Motor, Hysteresis Current Control.

1 Introduction

Switched Reluctance Motor drives have become popular in recent years because of simple mechanical structure, absence of winding on the rotor, high efficiency over a wide speed range, adaptable to harsh environment etc. But its applications are restricted to some areas because of its high ripple content in the torque due to double saliency structure [1]. The popularly used conventional control technique of SRM drives is Hysteresis Current Control [2],[3]. It has the disadvantage of high torque ripples. To minimize the torque ripple DTC technique is proposed in [4]. This paper which uses the concept of short flux pattern has the disadvantage of requirement of new winding topology. The new winding scheme is expensive and also inconvenient. In [5],[6] a novel DTC technique is applied to 3-phase 6/4 SRM. This paper has elaborately discussed the difference between conventional DTC applied to AC machines and the new DTC proposed to SR motor, showing experimental and simulation results. The performance of SRM using DTC applied to 3 phase 6/4 SRM is discussed in [7],[8]. DTC technique of 4 phase 8/6 SRM is analyzed in [9].

This paper compares the performance of 4 phase 8/6 SRM drive using Hysteresis Current control and DTC techniques.

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2 Direct Torque Controller

The approximate equation for torque developed by the SR motor [5] is given by: $T \approx i\ \partial\psi(\theta,i)/\partial\psi(\theta)$, where $\psi(\theta)$ is the phase flux linkages as a function of rotor position θ and stator current i. The DTC technique for SRM is explained in [5].

Asymmetrical converter is popularly used for the SRM drives. As shown in Fig. 1, when both the switches are turned ON, the state is defined as 'magnetizing' (state 1). When one switch is turned ON and other is turned OFF, the state is defined as 'freewheeling' (state 0). When both the switches are turned OFF, the state is defined as 'demagnetizing' (state -1). The 4 phase Asymmetrical converter can have a total of 81 possible Space Voltage Vectors. But in order to apply DTC to SRM, eight Space Voltage Vectors that are separated by 45^0 are sufficient. The eight Space Voltage Vectors that lie in the center of eight sectors N = 1, 2…8, are shown in Fig. 2.

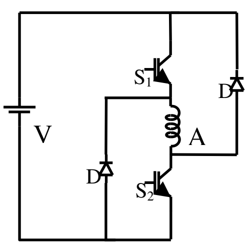

Fig. 1. Asymmetrical Converter

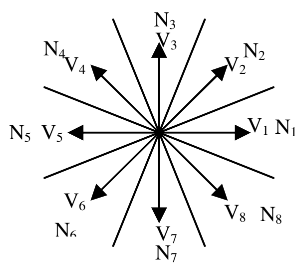

Fig. 2. Space Voltage Vectors for DTC

If the stator flux vector lies in the k^{th} sector, the magnitude of the flux can be increased by using the Space Voltage Vectors V_{k+1} & V_{k-1} and can be decreased by using the vectors V_{k+2} & V_{k-2}. Hence, whenever the stator flux linkage reaches its upper limit in the hysteresis band, it is decreased by applying Space Voltage Vectors which are directed toward the center of the flux vector [5]. If an increase in torque is required, Space Voltage Vectors which accelerate the stator flux linkage vector are applied across the motor. Thus if the stator flux linkages lie in the k^{th} sector, V_{k+1} and V_{k+2} Space Voltage Vectors are selected. If torque is to be decreased, voltage vectors which decelerate the stator flux linkage vector are applied to the motor. This corresponds to the vectors V_{k-1} and V_{k-2} in k^{th} sector [5]. Based on the output of the torque and flux hysteresis blocks, appropriate Space Voltage Vectors are selected.

3 DTC Implementation

The Block diagram of the DTC based 4 phase 8/6 SRM drive is shown in Fig. 3. The flux in each phase is calculated by flux linkage computation block. The output of the flux linkage computation block is given to the α–β block where the flux in 4 phases is converted into 2 phases. The magnitude Ψs and angle δ of the flux vector are calculated by flux vector calculation block. The flux vector magnitude Ψs and flux reference are fed to the flux hysteresis block. The flux hysteresis block compares the reference flux and the actual flux and outputs the flux increase or decrease Ψ_Q. The motor actual torque T and reference torque are fed to torque hysteresis block. The torque hysteresis block compares the reference torque and the actual torque and outputs torque increase or decrease T_Q. The switching table and Asymmetrical converter apply the suitable voltage vector to the SRM windings.

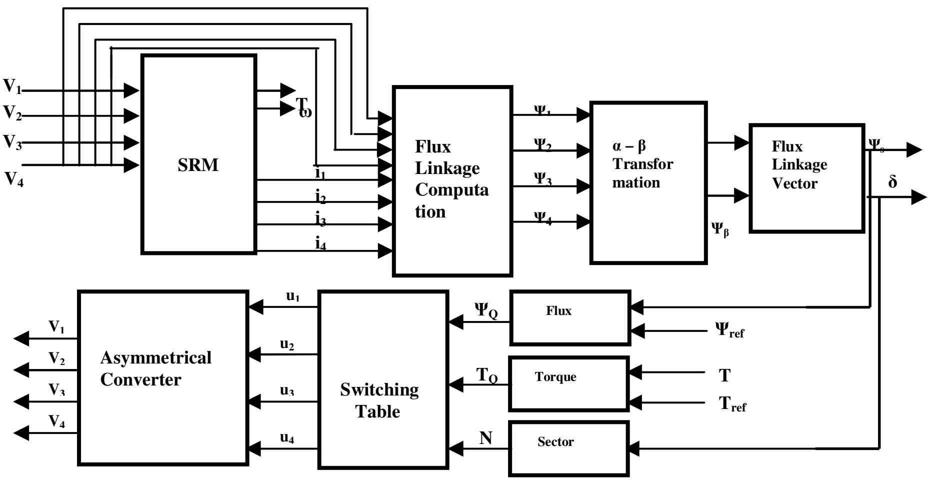

Fig. 3. Block diagram of DTC based SRM drive

4 Simulation and Results

The 4 phase 8/6 SRM drive is simulated in MATLAB/SIMULINK environment with Hysteresis Current Control and DTC methods. The DTC scheme is simulated by selecting the following set of 8 Space Voltage Vectors. V_1 = (-1010), V_2 = (-1-111), V_3 = (0-101), V_4 = (1-1-11), V_5 = (10-10), V_6 = (11-1-1), V_7 = (010-1), V_8 = (-111-1).

Fig. 4 shows the simulation waveforms of SRM drive with conventional Hysteresis Current Control technique for a Fan load of 4 Nm at a speed of 800 rpm. Fig. 4 (a) shows the current in four phases of the motor under steady state. The Hysteresis band of stator current in each phase is maintained at 1.0 A and the maximum current in each phase is 7.0 A. Fig. 4 (b) shows the flux linkages in all the four phases in steady state condition. The maximum flux in each phase is maintained at 0.20 Wb. Fig. 4 (c) shows the total torque developed by the motor. The torque ripple is 55.5%. It can be observed that the torque has high ripples. The speed waveform is shown in Fig. 4 (d). The steady state speed is 801 rpm.

Fig. 5 shows the simulation waveforms of SRM drive with DTC technique with same Fan load. Fig. 5 (a) shows the variation of stator current in all the four phases as a function of time. The maximum current drawn by each phase is 10.9 A, which is higher than the current drawn by each phase with Hysteresis Current Control method. Fig. 5 (b) shows the magnitude of the stator flux vector. The flux is maintained at the

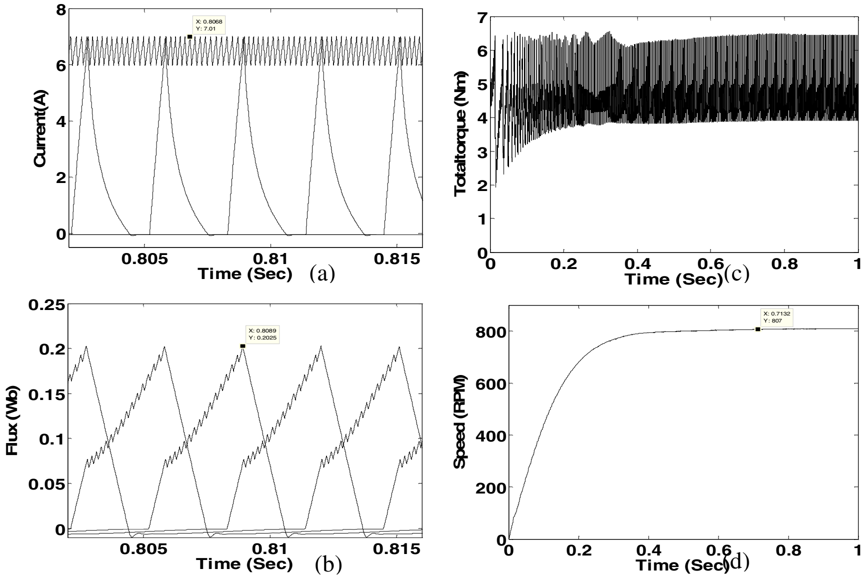

Fig. 4. Simulation waveforms of SRM with Hysteresis Current Control (a) Phase Currents in four phases (b) Fluxes in four phases (c) Total torque (d) Speed

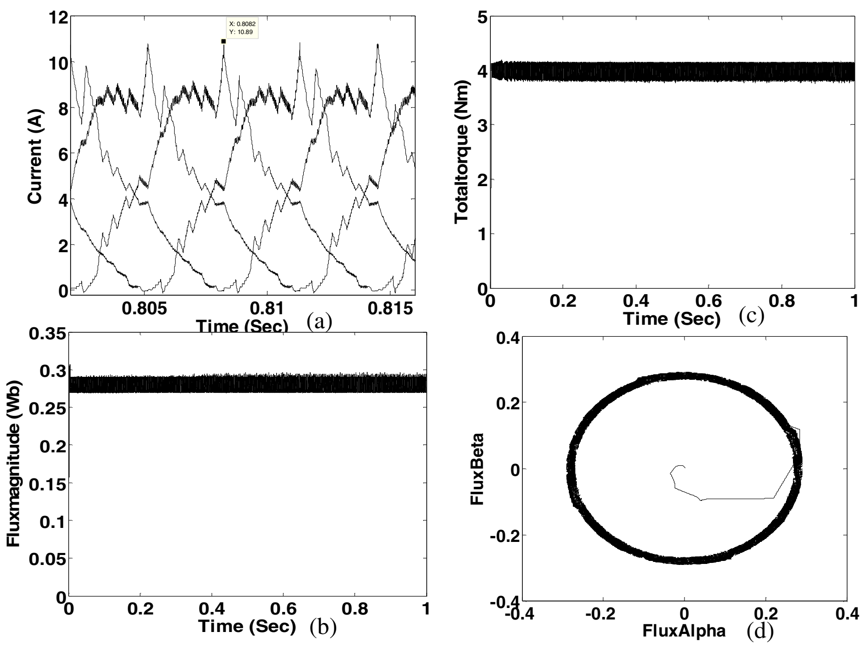

Fig. 5. Simulation waveforms of SRM with Direct Torque Control (a) Currents in 4 phases (b) Magnitude of flux vector (c) Total torque (d) Trajectory of fluxes

reference value of 0.28 Wb by following a hysteresis band of 0.02 Wb. Fig. 5 (c) shows the total torque waveform. It is observed that the torque is maintained within the hysteresis band of 0.29 Nm as against the set band of 0.2 Nm with DTC. The torque ripple is 8.9%. Fig. 5 (d) shows the variation of ψ_α with ψ_β. It can be seen that the trajectory of fluxes between α and β axes is circular in nature.

5 Conclusion

This paper compares the performance of SRM drive with conventional Hysteresis Current control and Direct Torque Control techniques. The performance is compared mainly in terms of torque ripple, phase current variations etc. with a Fan load. It is observed that with DTC technique the torque ripple is reduced by 84%. The torque and flux are maintained at their reference values by following the set hysteresis bands with DTC method. Though the current and flux in each phase with DTC are higher, the rate of change of current and flux are much lower when compared to Hysteresis Current Control method, causing drastic reduction in torque ripple.

References

1. Miller, T.J.E.: Switched Reluctance Motors & their Control. Magna Physics & Oxford (1993)
2. Srinivas, P., Prasad, P.V.N.: Voltage Control and Hysteresis Current Control of 8/6 Switched Reluctance Motor Drives. In: Proceedings of IEEE International Conference on Electrical Machines and Systems, pp. 1557–1562 (2007)
3. Srinivas, P., Prasad, P.V.N.: Torque Ripple Minimization of 8/6 Switched Reluctance Motor with Fuzzy Logic Controller for Constant Dwell Angles. In: Proceedings of the IEEE International Conference on Power Electronics Drives and Energy Systems (2010)
4. Jinupun, P., Luk, P.C.K.: Direct torque control for sensorless switched reluctance motor drives. In: Proc. 7th Int. Conf. Power Electron. Variable Speed Drives, pp. 329–334 (1998)
5. Cheok, A.D., Hoon, P.H.: A new torque control method for switched reluctance motor drives. In: 26 Annual Conference of the IEEE Industrial Electronics Society, pp. 387–392 (2000)
6. Cheok, A.D., Fukuda, Y.: A new torque and flux control method for switched reluctance motor drives. IEEE Trans. Power Electron 17, 543–557 (2002)
7. Guo, H.J.: Considerations of direct torque control for switched reluctance motors. In: Proceedings of the IEEE International Symposium on Industrial Electronics, pp. 2321–2325 (2006)
8. Song, G., Li, Z., Zhao, Z., Wang, X.: Direct Torque Control of Switched Reluctance Motors. In: Proceedings of the IEEE International Conference on Electrical Machines and Systems, pp. 3389–3392 (2008)
9. Jeong, B.H., Lee, K.Y., Na, J.D., Cho, G.B., Baek, H.L.: Direct Torque Control for 4-phase Switched Reluctance Motor Drives. In: Proceedings of the IEEE International Conference on Electrical Machines and Systems, pp. 524–528 (2005)