International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 10 (2018) pp. 8525-8529


# Torque Ripple minimization of Switched Reluctance Motor using Pole Embrace and Pole Configuration Methods

**A Veera Reddy[1], B Mahesh Kumar[2]**

[1]*Department of Electrical and Electronics Engineering, Pondicherry Engineering College, Puducherry, India.*

[2]*Department of Electrical and Electronics Engineering, Pondicherry Engineering College, Puducherry, India*

**Abstract**

Switched Reluctance motor(SRM)has been chosen as the right candidate to drive this small scale electric vehicle due to the advantages of simple construction, wide constant power region and effective torque speed characteristic. There are however a few downsides while applying exchanged hesitance engines like high torque swells, little proficiency at high speed and acoustic clamor, which choose about its aggressiveness in examination with different sorts of electric engines like enlistment engines, particularly in electric auto drive applications. Higher torque swell is one of the disadvantages. To have a decent execution of SRM, one of the factor needs to been taken is the post grasp. The adjustments in shaft grasp will influence the yield of engine as far as torque swell and normal torque is concerned. In this work by differing the stator and rotor post grasp with the goal that most elevated torque normal and least torque swell rate are accomplished. The normal torque and torque swell were estimated and the best blend of stator and rotor post grasp (pole embrace) was utilized to outline an exchanged hesitance engine with high normal torque and low torque swell rate and will be confirmed utilizing limited component examination. The test has been directed utilizing ANSYS FEA reproduction by fluctuating the stator and rotor post grasp incrementally from 0.3 to 0.5.

**Keywords:** Switched Reluctance motor, finite element analysis (FEA), Pole embrace, Torque swell (Torque ripple).

## INTRODUCTION

Switched Reluctance Motor (SRM) is cheap brush less, straight forward, tough, prepared to do fast and fault tolerant, so its applications are extending from roof fans to electric vehicles. In [1] given the overall view of the switched reluctance motor with design equations. The parameters sensitivity analysis (PSA) in switched reluctance motor to get optimal torque value and ripple given in [2], Different combinations of pole arc to pole pitch ratios to get the good torque explained in [3].In [4] perspective of this, SRM used in applications such as electric and hybrid electric bicycles.

Upgrading the unwavering quality is more vital for the SRM to be put into task in modern offices. Being a solitary energized, SRM gives bring down torque yield than a PM engine of a similar edge estimate. A portion of alternate downsides that are should have been enhanced in SRM are torque throb, high commotion low power factor and utilizing position sensor which makes the SRD structure more perplexing and decreases the running security. The real downside is high torque swell. So as to guarantee effective execution of the engine, an appropriate outline system must be performed. In our venture we built up an ideal outline of SRM demonstrate with the plan geometry, so torque swell is limited.

According to [5],[6] the design procedure of motor using empherical formulae and effect of pole embrace in 6/4 switched reluctance motor on torque and torque ripple presented. It is estimated as the distinction in most extreme and least torque more than one finish upheaval, for the most part communicated as a percentage. One of the real downsides of exchanged hesitance engine task is high torque swell looked at than other air conditioning compose machines. In [7],[8]Pole design formulae given to get improved torque profile of the system and verified for various combinations and pole arc design for better performance . Keeping in mind the end goal to dispense with torque swells numerous examinations have been embraced as of late and numerous torque control methods are presented.

To have a decent execution of SRM, one of the factor must be taken is the post grasp. By and large, grasp coefficient of SRM will impact the rotor and stator instrument width. Post hold onto is characterized as the proportion of shaft curve (x) to shaft pitch (y) as appeared in Fig. 1. The adjustments in post grasp will influence the yield of engine regarding torque swell and normal of torque. The significance of shaft grasp is featured to meet the engine condition with respect to on the beginning capacity, the base estimation of inductance amid the misaligned state of the polar posts, and keeping in mind that limiting the exchanging recurrence of stage winding. The torque ripples are one of the major issues in switched reluctance machines, to reduce this problem overlap of current pulses given in [9].Proper design of motor avoids the usage of various complicated techniques like Genetic algorithm [10] to lessen the torque ripple during operation. Choice of space post mix of SRM relies upon application, in light of the fact that an opening shaft blend yielding great execution in one application may not be appropriate for another. In this paper section II deals with pole embrace variation for 8/6 SRM and pole configuration methods to reduce the torque ripple content, previous paper gives information with respect to 6/4 SRM only . Section III deals with simulation results and section IV gives overall conclusions.

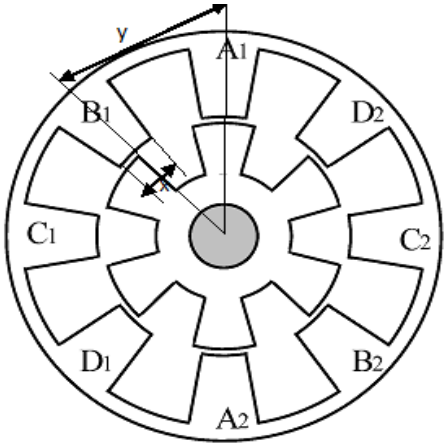


**Figure 1.** Stator pole arc to pole pitch of 8/6 SRM

## PROPOSED METHODS

This section will explain on the simulation method to determine the effect of pole embraces variation and pole changing.

*A. Pole Embrace Method:*

The pole embrace is defined as the ratio of actual pole arc to the pole pitch. To investigate the effect of pole embrace on Switched Reluctance Motor, ANSYS FEA is used to execute the task. The simulations runs with the few combination of pole embrace to achieve highlighted condition. In this study, the effect of pole embrace was investigated and given parametrically as in Table. 1.

**Table 1.** Pole embrace variation and %ripple

| Stator | Rotor | %Torque ripple |
|---|---|---|
| 0.30 | 0.30 | 78.6971% |
| | 0.35 | 82.2163% |
| | 0.40 | 73.5907% |
| | 0.45 | 65.3326% |
| | 0.50 | 56.1999%. |
| 0.35 | 0.30 | 82.9691% |
| | 0.35 | 76.1690% |
| | 0.40 | 67.9381% |
| | 0.45 | 60.2626% |
| | 0.50 | 40.0814% |
| 0.40 | 0.30 | 77.5717% |
| | 0.35 | 70.8273% |
| | 0.40 | 62.4653% |
| | 0.45 | 51.8215% |
| | 0.50 | 40.4936%. |
| 0.45 | 0.30 | 72.7196% |
| | 0.35 | 65.5285% |
| | 0.40 | 54.3892% |
| | 0.45 | 44.7321% |
| | 0.50 | 36.7053% |
| 0.50 | 0.30 | 82.9691% |
| | 0.35 | 76.1690% |
| | 0.40 | 67.9381% |
| | 0.45 | 40.0814%. |
| | 0.50 | 33.2850% |

In FEA, pole embrace for both poles can vary from 0 to 1. But in this study, the value of stator pole embrace and rotor pole embrace is varied from 0.3 to 0.5 only. Using finite element analysis software, stator pole embrace was set to constant value from 0.3 values while the rotor pole embrace was varied from 0.3 to 0.5 with step 0.05 value.

*B. Pole Changing Method:*

The simulations run with three configurations like 6/4, 8/6 and 12/8. The output of average torque and torque ripple were measured and the best combination of stator, rotor pole embrace and pole configuration was obtained for further analysis. Selection poles affect the cost of machine so according to application necessary pole configuration should be considered.

## SIMULATION RESULTS

*A. Pole Embrace Method:*

This segment will show the after effect of impact on Pole embrace on SRM displaying. The outcome demonstrates impact on the yield torque profile. The most extreme torque, normal torque and level of torque ripple had been estimated to know which pole embrace blend gives the ideal yield of SRM in term of torque generation. Fig. 2. demonstrates the after effects of the blends of stator post hold onto kept consistent as 0.3 and change the rotor shaft grasp from 0.3 to 0.5. when we take blend of 0.3 of stator and 0.3 of rotor the normal torque is 0.6638N-m and the torque ripple is 78.6971% by fluctuating the rotor post embrace to 0.35 the normal torque is 0.7316N-m and the torque ripple is 82.2163% by differing the rotor pole embrace to 0.4 the normal torque is 0.8541N-m and the torque ripple is 73.5907% by changing the rotor pole embrace to 0.45 the normal torque is 0.0.9987N-m and the torque ripple is 65.3326% by shifting the rotor pole embrace to 0.5 the normal torque is 1.1690N-m and the torque ripple is 56.1999%. In 0.3 blends the most elevated torque average is delivered at 0.5 rotor pole embrace.

Meanwhile, for 0.35 stator pole embrace, Fig. 3. demonstrates the after effects of the blends of stator post hold onto kept consistent as 0.35 and change the rotor shaft grasp from 0.3 to 0.5. when we take blend of 0.35 of stator and 0.3 of rotor the normal torque is 0.7070N-m and the torque ripple is 82.9691% by fluctuating the rotor pole embrace to 0.35 the normal torque is 0.8483N-m and the torque ripple is 76.1690% by differing the rotor pole embrace to 0.4 the normal torque is 1.0056N-m and the torque ripple is 67.9381% by changing the rotor pole embrace to 0.45 the normal torque is 1.1687N-m and the torque ripple is 60.2626% by shifting the rotor pole embrace to 0.5 the normal torque is 1.5182N-m and the torque ripple is 40.0814%. In 0.35 blends the most elevated torque average and less torque ripple is delivered at 0.5 rotor pole embrace.

Meanwhile, for 0.40 stator pole embrace, Fig. 4. demonstrates the after effects of the blends of stator post hold onto kept consistent as 0.40 and change the rotor shaft grasp from 0.3

to 0.5. when we take blend of 0.40 of stator and 0.3 of rotor the normal torque is 0.8911N-m and the torque ripple is 77.5717% by fluctuating the rotor pole embrace to 0.35 the normal torque is 0.9967N-m and the torque ripple is 70.8273% by differing the rotor pole embrace to 0.4 the normal torque is 1.2101N-m and the torque ripple is 62.4653% by changing the rotor pole embrace to 0.45 the normal torque is 1.5583N-m and the torque ripple is 51.8215% by shifting the rotor pole embrace to 0.5 the normal torque is 1.9383N-m and the torque ripple is 40.4936%. In 0.40 blends the most elevated torque average and less torque ripple is delivered at 0.5 rotor pole embrace.

Fig. 5. Shows the results of the combinations of constant stator pole embrace 0.45. It demonstrates the after effects of the blends of stator post hold onto kept consistent as 0.45 and change the rotor shaft grasp from 0.3 to 0.5. When we take blend of 0.45 of stator and 0.3 of rotor the normal torque is 0.9826N-m and the torque ripple is 72.7196% by fluctuating the rotor pole embrace to 0.35 the normal torque is 1.1849N-m and the torque ripple is 65.5285% by differing the rotor pole embrace to 0.4 the torque is 1.5530N-m and the torque ripple is 54.3892% by changing the rotor pole embrace to 0.45 the normal torque is 1.9173N-m and the torque ripple is 44.7321% by shifting the rotor pole embrace to 0.5 the normal torque is 2.3215N-m and the torque ripple is 36.7053%. In 0.45 blends the most elevated torque average and less torque ripple is delivered at 0.5 rotor pole embrace. Average torque also observed that ,its value is increasing ,it is an important factor in design of motor for a particular application.

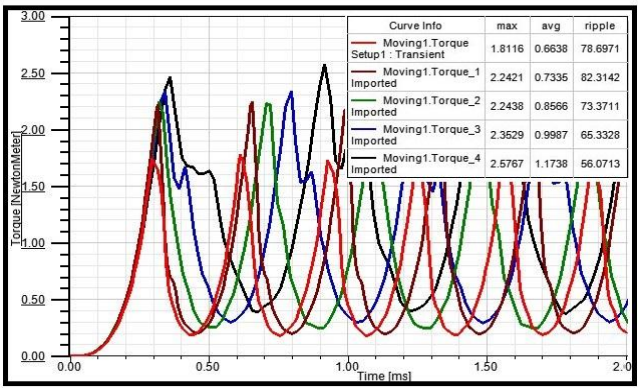


**Figure 2.** Stator embrace: 0.3; rotor embrace: 0.3 to 0.5

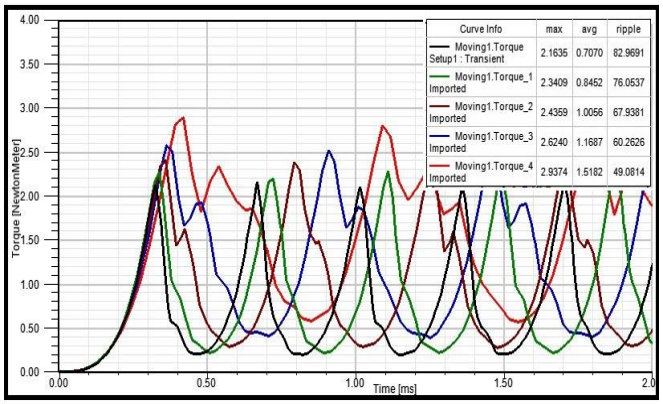


**Figure 3.** Stator embrace: 0.35; rotor embrace: 0.3 to 0.5

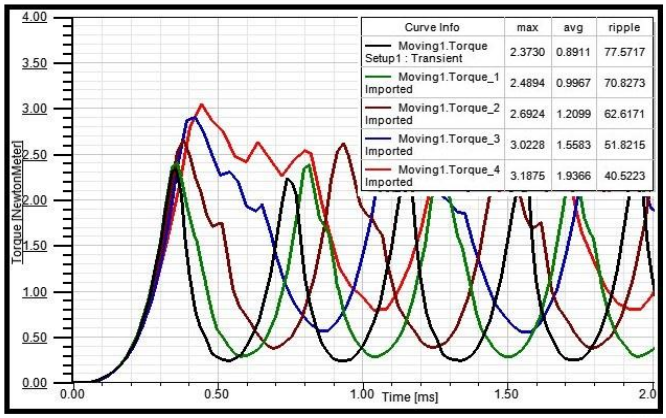


**Figure 4.** Stator embrace: 0.4; rotor embrace: 0.3 to 0.5

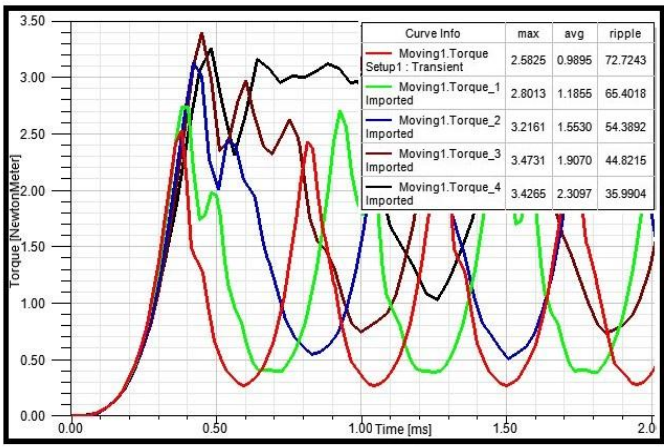


**Figure 5.** Stator embrace: 0.45; rotor embrace: 0.3 to 0.5

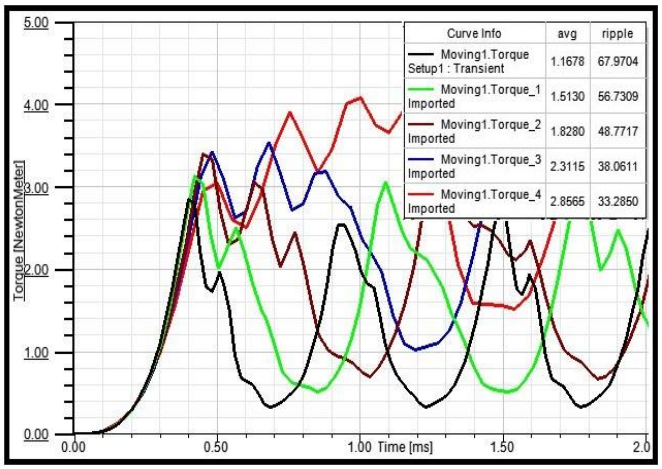


**Figure 6.** Stator embrace: 0.50; rotor embrace: 0.3 to 0.5

Meanwhile, for 0.50 stator pole embrace, Fig. 6. demonstrates the after effects of the blends of stator post hold onto kept consistent as 0.50 and change the rotor shaft grasp from 0.3 to 0.5. when we take blend of 0.35 of stator and 0.3 of rotor the normal torque is 0.7070N-m and the torque ripple is 82.9691% by fluctuating the rotor pole embrace to 0.35 the normal torque is 0.8483N-m and the torque ripple is 76.1690% by differing the rotor pole embrace to 0.4 the

normal torque is 1.0056N-m and the torque ripple is 67.9381% by changing the rotor pole embrace to 0.45 the normal torque is 1.1687N-m and the torque ripple is 60.2626% by shifting the rotor pole embrace to 0.5 the normal torque is 1.5182N-m and the torque ripple is 40.0814%. In 0.35 blends the most elevated torque average and less torque ripple is delivered at 0.5 rotor pole embrace.

The above outcomes demonstrated that stator pole embrace is 0.5 and rotor pole embrace is 0.5 gives the high torque and low torque ripple. Another blend is likewise gives the best results that is stator pole embrace is 0.45 and rotor pole embrace is 0.45 by taking these mixes of pole embraces.

*B. Pole Changing Method:*

The technique called pole changing method. By expanding the quantity of stator and rotor shafts the normal torque is increasing however we can diminish the torque ripple in that 6/4 Switched reluctance motor the normal torque is 2.2503N-m and torque ripple is 66.8640% where as in the case of 8/6 motor the normal torque is 2.8651N-m and torque ripple is 32.6976% ,In case of 12/8 SRM the torque is 3.4407 N-m and torque swell is 27.1928%.So the average torque value increases with minimal torque ripple with the increment stator poles and rotor poles.

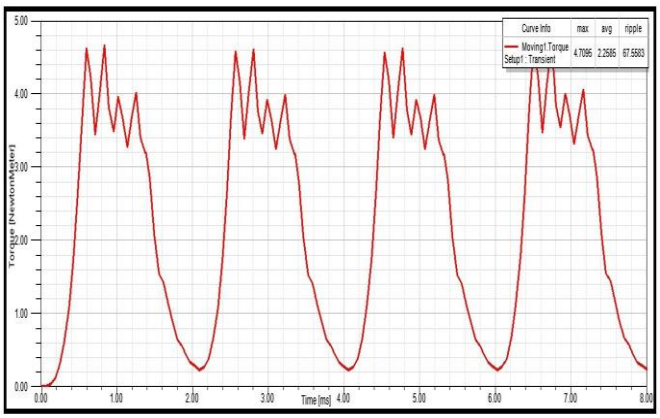


**Figure 7.** 6/4 SRM Torque waveform

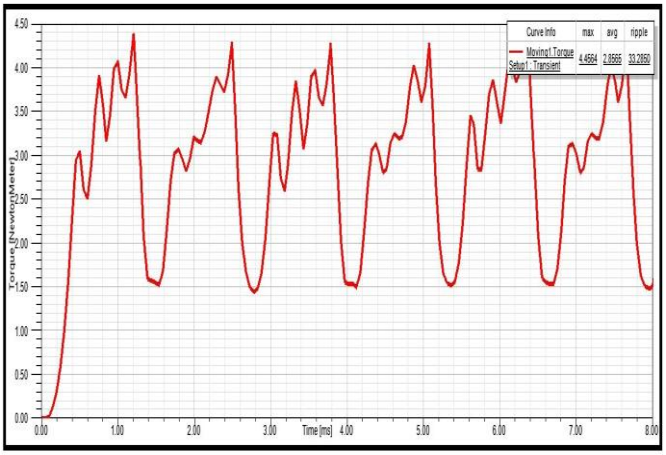


**Figure 8.** 8/6 SRM Torque waveform

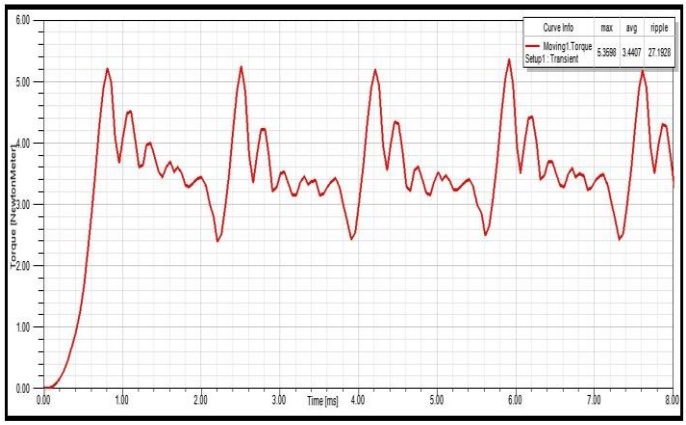


**Figure 9.** 12/8 SRM Torque waveform

The percentage change in torque ripple for various configurations stator and rotor pole are given in Table.2. As number of poles increases the air gap decreases, it improves the inductance profile of the machine and also torque profile. In 12/8 motor also torque ripple percentage is 27.19 %, when compared with 6/4 it is very less .But if we go for very large number of pole combinations the financially not feasible until ,it is used for very high power applications where large rated machines are needed like aero space ,Electric vehicle and Hybrid electric vehicles. Modeling, simulation of switched reluctance motor given in [11],[12].

**Table 2.** Motor configuration and % Torque ripple

| Motor | Average torque(Nm) | % ripple |
|---|---|---|
| 6/4 | 2.25 | 67.55 |
| 8/6 | 2.85 | 33.28 |
| 12/8 | 3.44 | 27.19 |

## CONCLUSION

In light of the above investigation for each situation by expanding the rotor shaft grasp we can build the average torque and lessening the torque ripple for each situation the blend with the rotor pole embrace 0.5 gives the best yield when contrasted with other combinations. Finally the mix of 0.5 stator and rotor pole embrace gives the high average torque and low torque ripple. This is because of the limited factor of inductance value while misaligning state of stator and rotor. Going to the shaft changing strategy by expanding the quantity of stator and rotor poles we can build the normal torque and lessen the torque ripple. For low torque ripple we can go for more number of poles but it is more costly than lower pole machine so. For very high rated applications larger pole machines are more suitable. By keeping these two criteria's in view by proper selection of pole embrace combinations and stator, rotor pole configuration at the time of manufacturing, the lower torque ripple and good average torque can be obtained.

**REFERENCES**

[1] R.Krishnan."Switched Reluctance Motor Drives: Modeling, Simulation, Analysis, Design, and Applications," CRC Press, Taylor & Francis Group, Boca Raton,2001.

[2] Mohammad Reza Besmi, "Geometry Design of Switched Reluctance Motor to Reduce the Torque ripple by Finite Element Method and Sensitive Analysis",Journal of electric power and energy conversion systems, pp.23–31, Mar.2016.

[3] R.Arumugam,J.F. Lindsay, and R. Krishnan, "Sensitivity of pole arc/pole pitch ratio on switched reluctance motor performance," Conf. Rec. 1988 IEEE Ind. Appl. Soc. Annu. Meet., pp. 50–54, 1988.

[4] L. Wu, W. Ding, Y. Hu, and A. D. Rules, "Design and Analysis of an External-Rotor Switched Reluctance Machine for Electric Bicycle,"2016 Elev.Int.Conf.Ecol.Veh.Renew Energies, pp. 1–6, 2016.

[5] N. Abdullah, K. A. Karim, M. N. Othman, "Design Switched Reluctance Motor using Empirical Method," International Journal of Energy and Power Engineering Research pp. 6-10, 2014.

[6] K. Abdul Karim, N.Abdullah, M.Nazri Othman, S. Azura Tarusan, R.N. Firdaus, N. Z. Zainal. "Effect of Poles Embrace on Switched Reluctance Motor Design," Journal of Multi disciplinary Engineering Science Studies pp 1661-1664, Vol.3, Apr.2017.

[7] B Bilgin, A Emadi and M Krishnamurthy "Design considerations for switched reluctance machines with a higher number of rotor poles". IEEE Trans. Ind. Electron. 2012; 59(10): 3745–3756.

[8] Bingni Qu, Jiancheng Song , Jianbin Zheng. "Torque ripple minimization in switched reluctance machine by pole arcs design," IEEE Conference on Industrial Electronics and Applications, 25-27 May 2009.

[9] M. E. Zaïm, K. Dakhouche, and M. Bounekhla, "Design for Torque Ripple Reduction of a Three-Phase Switched-Reluctance Machine," IEEE Transactions on Magnetics, vol. 38, pp. 1189- 1192, Mar. 2002.

[10] L. Kalaivani, P. Subburaj, M. W. Iruthayarajan, "Speed control of switched reluctance motor with torque ripple reduction using non- dominated sorting genetic algorithm", International journal of Electrical Power and Energy Systems,pp.69-77,Apr.2013

[11] K.Vijayakumar, R.Karthikeyan ,S.Parama sivam , R.Arumugam ,K.N.Srinivas, "SwitchedReluctance Motor Modeling,Design, Simulation, and Analysis: A Comprehensive Review", IEEE Transactions on Magnetics, vol. 44, pp. 4605 - 4617, Mar. 2008.

[12] I.Husain,S.A.Hossain, "Modeling, Simulation, and control of switched reluctance motor drives", IEEE Transactions on Industrial Electronics, vol. 52, pp. 1625 - 1634, Dec. 2005.