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A REVIEW ON POSITION ESTIMATION OF SWITCHED RELUCTANCE MOTOR FOR AUTOMOTIVE APPLICATIONS

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ABSTRACT:

In this paper the detailed review was given on Sensor less Control of SRM for Automotive applications. As the demands for automotive vehicles are increases electric motor play a vital role in automotive applications. SRM provides more advantage than other electric motors and hence it is better to use SRM in EV applications. In the SRM drive mechanism it is essential to estimate the rotor position exactly at stand still and running condition for high performance control. Estimation of rotor position can be done by using sensors. But Rotor position sensors may not be work reliably during harsh environment conditions like dust, humidity, huge vibrations, electromagnetic disturbances, high temperature and also sensors makes the system complex, which will improve the cost of the system. Hence sensor less control techniques have been developed to estimate the Rotor Position and to control the speed of the motor. Due to improper estimation of rotor position, torque ripples produced in motor, which causes more acoustic noise and vibrations produced in the motor. This paper reviews the various SRM Rotor position estimation control strategies and their advantages and disadvantages.

Index Terms: Switched Reluctance Motor, Electric Vehicle, Torque Ripple, Position Sensor.

I. INTRODUCTION

Presently, the attractiveness of electric vehicles (EVs) increases speedily. The key parameters for EVs are safety, cost, Reliability, speed control and its efficiency. The Researchers think about the way of reaching these demands in an electric vehicle. This results rich quality vehicle elements which are low price, highly protected, highly reliable and highly competent. In order to fulfill these demands Rare Earth Magnetic Materials are commonly uses different variant types about Electric motors consecrated into the Electric Vehicle implementation such as boron, Samarium, Iron, cobalt, sintered and Neodymium. Nonetheless that price about Natural earth magnetic materials (NEMM)- base motors increases so far many decades. Furthermore because of inadequate sources, NEMM is to use in based motors in Electric Vehicle (EV)appliances are impeach. Hence the researchers probe on new machine technology might be more competing as regards sizing, cost, robustness, density of torque and efficiency. Among all the electrical motors Switched Reluctance Motor can meet these all demands. SRM is a simple construction, low cost, a very wide speed range, Robustness and highly efficient. The SRM performs and operates in a various industrial and automotive applications. Although, there are several advantages for SRM compared to Conventional DC and AC motors, SRM suffers from acoustic noise and high torque ripple. In order to eliminate the source of Noise and torque ripple in SRM, its necessary to rotor position estimation exactly. Some of effectively sensors less control strategies have been discussed in this paper.

II. MATHEMATICAL MODELING OF SRM

SRM has a simple and rugged construction, but the mathematical modeling of SRM is somewhat difficulty because of the high non-linearity nature. Basically flux-linkages endure the functions about the stator phase currents and position of rotor. A 6/4-SRM has three stator phase windings. The flux linkages curves ofΨ versesI characteristics of SRM as shows in Fig.(1).

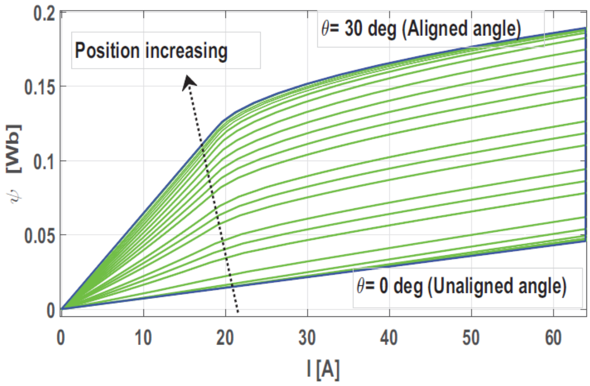

Fig 1: Flux-linkage Curve.

Nomenclature:

θ =Rotor angular position

I_j= j^{th}phase current

ω = motor Angular velocity

Ψj = Flux-linkages of j^{th} phase

T_e=Total Electromagnetic Torque

R_j = j^{th} Phase Ohmic Resistance

f_r = Coefficient of Frictional movement

L= line Inductance

J= moment of inertia (vehicle among with rotor)

V_j = j^{th} Phase voltage

J_{load} = Moment of inertia of the vehicle

J_{SRM} =Moment of inertia of SRM

T_L =Load torque

Mathematically SRM can be modeled as follows:

$$V_j = R_j I_j + \frac{\partial_{\Psi j}}{\partial t}(\theta, I) \dots \dots \dots (1)$$

Where,

J = 1, 2, 3.

Dynamic modeling of the SRMs along with the vehicles load might be follows

$$\frac{d\omega}{dt} = \frac{1}{J}[T_e(\theta, I) - f_r\omega - T_L] \dots \dots \dots (2)$$

Total moment of Inertia

$J = J_{Load} + J_{SRM}$ ……….. (3)

Torque is produced in j[th] phase endure:

$$T_j = \frac{1}{2} I_j^{\,2} \frac{dL(\theta)}{J\theta} \qquad \ldots \ldots \ldots (4)$$

The torque produced by from the motor is that total torques produced by all phases:

$$T_e = \sum_{j=1}^{3} \mathrm{T_j} \ldots \ldots \ldots \ldots (5)$$

III. ROTOR POSITION ESTIMATION METHODS:

A. Flux Linkage Methods:

This method endures most applicable about to maximum speed along with medium speeds application with heavy load. At no-load and low speed conditions effectively times about to commutation endure false in this case due to that there will be some Position error will occur which leads torque ripple will occur [3]. Rotor position estimation by conventional flux linkage method requires huge experimental data of flux among with the data can acquire large memory space in data. To overcome such drawback simplified flux linkage method has been proposed. It is needed to gauge just not many transition linkage bends of specific rotor position of SRM. To keep away from look-into tables, this strategy utilizes the Taylor's condition of straight inductance model to gauge the transition linkage of SRM. In effective case the time of commutation endure wrong because of that there will be some Position error will occur which leads torque ripple.

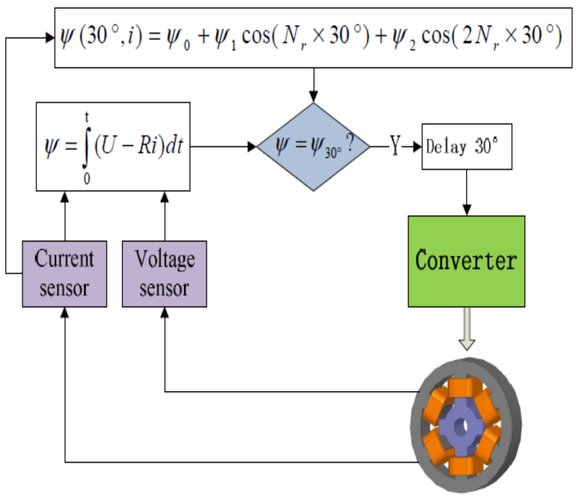

Fig.2: Functional diagram of flux linkage control case.

B. Fuzzy Logic approach:

Nesimi Ertugru et.al Proposed fuzzy logic control method to rotor position estimation. To minimize effective position of rotor error, the fuzzy speed controller has been designed to put into practice in effective beginning and transient states[19].

Advantages:

- Mathematical modeling of the motor is not required.
- It is applicable for all speed range applications
- This method reduces the vibrations and mechanical stress

Disadvantages:

- Rotor position error is medium.
- The performance is poor during transient.

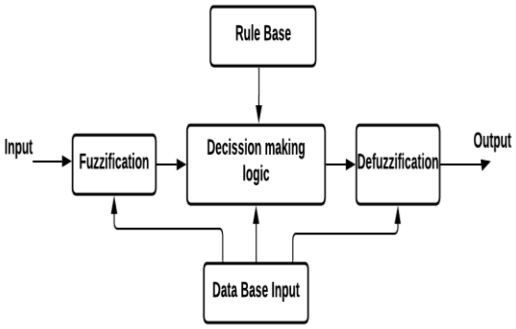

Fig 3: Fuzzy logic controller

C. Rotor position Estimation by ANN:

Felix Paulson et.al proposed to estimate the rotor position using back propagation method in neural network algorithm. In this ANN based algorithm was used which provides accurate training which is used to predict the angular position with high accuracy [7].It eliminates the difficulties in conventional flux estimation method and it also eliminates the mutual flux effect. Position of Rotor might be estimated with a accuracy by using electrical parameters between mechanical parameters constructing a map the motor by giving adequate huge practice data sets, along with the ANN method can construct the correlation and flux linkage (λ), current(i) and rotor position (θ). At that point this disconnected prepared ANN can be considered in contrast to a test informational index which may have distinctive transition linkage-current qualities and then used as an online position estimator.

There are two algorithms in neural network to Calculate the position of rotor SRM.

- Feed forward neural network method
- Back propagation Method.

Compared to above two methods BPN method most flexible and error tolerant. For that BPN method need accurate training data [4-6].The algorithm to construct the BPN is explained as follows.

- Obtain the ϕ and I values from Flux- current curve of SRM.
- Get the individual rotor position esteems for comparing Flux along with Current qualities.
- Flux along with Current insert values into Neural Networks Training module.
- Train the Neural Network training kit until the output reaches to preset values.
- After adequate training it estimates the accurate rotor position.
- Stop the process.

The block diagram about to ANN functional based process is as shown in fig.4

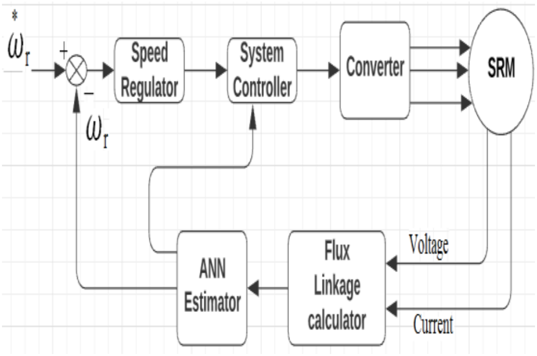

Fig.4: Rotor position Estimation by ANN

By providing the large number combination of neurons into effectively hidden layer about to neural networks which allows solving more complex problems, but it require huge computations.

Advantages of ANN:

1. Compared to fuzzy logic based method ANN method needs less memory.

2. Production of negative torque can be eliminated by commutating the energized phase just before the aligned rotor position.

Disadvantages of ANN:

1. Estimation update ratio for the ANN is slower than fuzzy-logic based method.

D. ANFIS Method:

P. Ramesh et al proposed ANFIS software is used to position of rotor estimation to the SRM system. It can also provide performance and comparison between FLC, ANN and ANFIS. ANFIS method overcome the drawbacks of Fuzzy logic control method and Artificial Neural network methods and also incorporates the advantages of both the methods [8]. Using ANFIS Software it can estimate the rotor position error and torque ripples also minimum.

Paramasivamet. al. proposed a method is used to the position of rotor estimation at steady state condition along with running conditions with high degree of accuracy. In This approaches the Flux versus Current characteristics along constructs the mapping between input and output. It depends on both human information and foreordained information yield information sets. The flux Linkage and current is taken care of to the ANFIS software. According to the enrollment upsides of the flux linkage along with current, and ANFIS software is used the rotor position (θ) estimation.

Once effective rotor position is estimated then stator phase windings are switch ON and OFF at suitable instant to rotate the motor in required directions. Initial rotor position estimation is also very important to drive the SRM in proper direction [9-10].

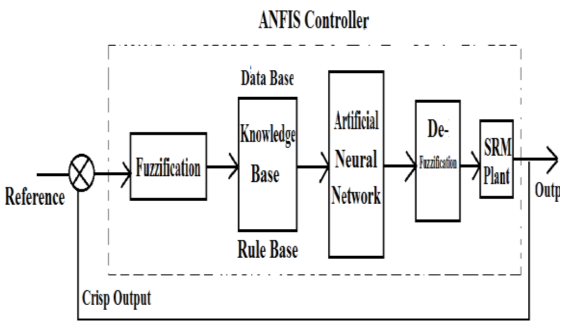

Fig.5: Block diagram of ANFIS Controller

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Advantages:

1. High accuracy and reliability

2. Computational speed is high.

3. The rising time, settling time and peak

overshoot are less for SRM Speed

response.

E. Inductance based position Estimation Method:

In this method phase winding of stator inductance endures to measure depends on voltage pulses injected techniques are present. A large frequency voltage pulses endure to insert in stator windings, when stator phase winding is De-energized and then measure the current in phase winding to estimate the inductance. The stator winding phase inductance endures effective function position of rotor estimation. The stator winding inductance changes continuously with the rotor position. At the point when the rotor post ways to deal with the stator shaft the inductances increments and when the rotor shaft leaves the stator shaft then inductance diminishes [11].Rotor position is the function of inductance and current in the coil. The voltage pulse is injected alternately in the four phases alternately (for 8/6 SRM) along mapping is completed into continuous checking effective position of rotor ahead four esteem values shown in figure 6.

Voltage pulse can be injected by main converter hence no need of any additional circuit to inject the voltage pulse. This method of estimation is accurate for low speed range. This method give the average position estimation error is approximately 2^0 mechanical. Due to this position error torque ripple occur.

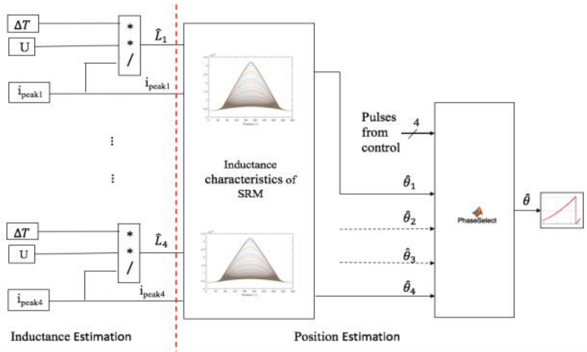

Fig.6:Position estimation by Phase inductance.

F. Back-EMF-based Method:

Ying Tang et all approaches in their work *back*-EMF established position estimation technique. In this method capturing the minimum back-EMF–position to estimate the rotor position. Negative torque can be eliminated by proper exciting the stator phases by using power converter. By utilizing comparator back EMF zero crossing situations might be distinguished. Like As those situations by back-EMF zero crossing point is 0° in, it can utilized as the turn-on stage about to stator phase winding inductance. The analogous time stampings are calculated for different electrical cycles and it must be recorded for estimation of speed. For maximum speed operation effectively minimum back EMF position endures detected rather than Back EMF zero position crossing [12].During the time spent rotor position assessment, here back-EMF is inspected along with its differential worth is determined by a differentiator circuit. At that point an intersection zero comparator is received to catch the situation of least back-EMF method. This can relating season of least back-EMF is observed; among the time-frame between two least back-EMF position about two progressive electrical cycles is observed as ΔT is, at that point with the assistance of time ΔT the speed and rotor position is assessed.

The Differences in between back-EMF crossing-zero identification and least back-EMF recognition strategy are as per the following.

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Operating Condition	Method	
	Crossing-zero detection	Minimum back-EMF detection
At Least speed	YES	YES
At maximum speed	NO	YES

G. Sliding Mode Observer Method:

J.P.Lyons et al. proposed the flux/current method this method required large memory to store vast data and plenty of computational efforts are needed during the difference of actual speed and estimated speed was given to speed controller and then output value of i_{ref} was obtained which is compared with stator phase current i_{ph} and by adjusting the controller triggering pulses are obtained for SRM Converter. The actual flux can be calculated based on phase voltage u_{ph} and phase current i_{ph}.

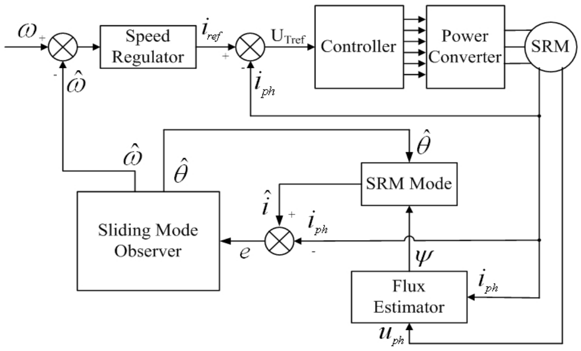

Fig.7: Sliding mode observer Method.

Sliding mode observer (SMO) will estimate the Rotor Position angle and angular

Velocity based on error signal between i_{ph} and $\hat{i}$ which are derived from SRM Model[14-17]Operation. SMO method is has been proposed to reduce the computational efforts along with improved robustness with stability in system. SMO approach requires phase currents with phase voltages[13] position of rotorto estimate the angle and speed.

H. Pulse injection method:

Ahmed Khalil et al. Proposed a Position estimation method by injecting a current pulse in non-active phase to estimate the rotor position in steady stable and low speed. A current pulse is used to inject in an inactive phase of the SRM to measure the phase inductance and that measurements are stored in table 1[18]. This table is to position of rotor estimation. The following fig shows flow diagram for pulse injection method. This method eliminates the effect of mutual flux-linkage. It is extremely hard to execute at maximum speed conditions.

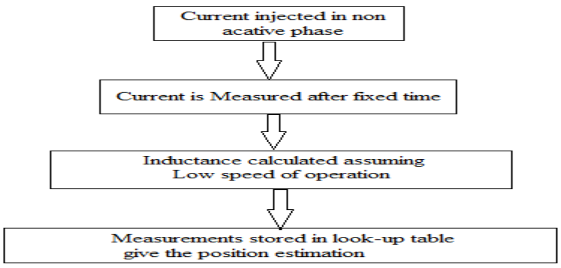

Fig.8: Flow diagram of Pulse injection method

Table-1 Summery of Performance of Rotor position estimation methods.

S. No	Rotor position estimation method	Performance Parameters				
		Speed applications	Mathematical Computations	Position error	Torque Ripples	Speed of response
1	Simplified Flux	Medium and High speed	Less	high	High	Medium
2	Fuzzy logic control	Low and Medium	Very less	high	medium	Medium
3	ANN	Low and Medium	High	medium	medium	Medium
4	ANFIS	Medium and High speed	Less	less	Less	High
5	Inductance based	Low	Less	medium	medium	Low
6	Back-EMF-based Position estimation	All speed range	Less	medium	medium	Low
7	Sliding Mode Observer	All speed range	Less	less	Less	High
8	Pulse injection	Low and Medium applications	Less	medium	medium	medium

IV. CONCLUSION

In this paper a detailed review of various sensor less rotor position estimation methods of SRM for Electric Vehicle applications have been presented. It provides a clear perspective on various aspects of the rotor position estimation methods to the engineers and researchers working in this field. Different sensor less position estimation methods and their merits, demerits and future trends were discussed. Even though different sensor less position estimation methods have been developed but still research on SRM is necessary todefeat some significant issues like oneself tuning, speed control, Torque ripple, vibrations and acoustic noise to make sensor less SRM drives that gives the better performance.

REFERENCES

1. Gabriel Gallegos-L´opez, Philip C. Kjaer, and T. J. E. Miller "High-Grade Position Estimation for SRM Drives Using Flux Linkage/Current Correction Model", IEEE, pp 859-869,1999.
2. Yakoub SAADI, Rabia SEHAB, Ahmed CHAIBET, Mousaa BOUKHNIFER, Demba DIALLO "Sensorless control of Switched Reluctance Motor for EV Application using a Sliding Mode Observer with Unknown Inputs" IEEE, pp 516-521, 2018.
3. Tao Wang, Wen Ding, Yanfang Hu, Shuai Yang, ShuaiLi."Sensor less control of switched Reluctance motor drive using an improved simplified flux linkage model method", IEEEApplied Power Electronics Conference and Exposition (APEC), 2018.
4. IFelixPaulson ,VVasanPrabhu," Back Propagation based ANN technique for rotor positionestimation of 8/6 Switched Reluctance Motor" IEEE Conference 2015.
5. E. Mese and D. A. Torrey, "An approach for sensor less position estimation for switched Reluctance motors using artificial neural networks,"*IEEE Trans. Power Electron.*, vol. 17, no.1, pp. 66–75, Jan. 2002.
6. Beno, M. Marsaline, L. Rajaji, V. M. Varatharaju, and Arnold N. Santos. "Rotor positionestimation of 6/4 Switched Reluctance Motor using a novel neural network algorithm", 2011IEEE GCC Conference and Exhibition (GCC), 2011.
7. Jignesh A. Makwana. "ANN based sensorless rotor position estimation for the SwitchedReluctance Motor", 2011 Nirma University International Conference on Engineering, 12/2011.
8. P Ramesh , P Subbaiah," Design and Control of SR Drive System using ANFIS"IEEEConference PP 3815-3819, 2016.
9. Paramasivam, Dr.R.Arumugam, Dr.B.Umamaheswari ,S.Vijayan, S.Balamumgan, and M.Vasudevan," Indirect Rotor Position Estimation of Switched Reluctance Motor usingANFIS" IEEE, pp 921-926, 2003.
10. Chang-Liang Xia and JieXiu," Sensor less Control of Switched Reluctance Motor Based on ANFIS" Springer, pp 645-653, 2006.
11. HongweiGao, FarzadRajaeiSalmasi , MehrdadEhsani, "Inductance Model-Based Sensorless Control of the Switched Reluctance Motor Drive at Low Speed"IEEE Transactions on Power Electronics, pp 1568-1573,2004.
12. Ying Tang, Yingjie He, Fengxiang Wang, Dong-Hee Lee, Jin-Woo Ahn, Ralph Kennel."Back- EMF-based sensor less control system of hybrid SRM for high-speed operation", IET Electric Power Applications, 2018.
13. Xiao Wang, FeiPeng, and Ali Emadi, "A Position Sensorless Control of Switched Reluctance Motors Based on Sliding-Mode Observer" IEEE, 2016.
14. Mohammad S. Islam, Iqbal Husain, Robert J. Veillette, and CelalBatur, Design and Performance Analysis of Sliding-Mode Observers for Sensorless Operation of Switched Reluctance Motors, IEEE Transon control systems technologyvol.11, NO. 3, pp.383-389,May 2003.
15. Ahmed Khalil , Samuel Underwood, Iqbal Husain, HaraldKlode, Bruno Lequesne, Suresh Gopalakrishnan and Avoki M. Omekanda, "Four-Quadrant Pulse Injection and Sliding- Mode- Observer-Based Sensorless Operation of a Switched Reluctance Machine Over Entire Speed Range Including Zero Speed" VOL. 43, NO. 3, pp 714-723, May/June 2007.
16. Pang Li , Lei Zhang, Yue Yu," A Novel Sensorless for Switched Reluctance Motor Based on Sliding Mode observer" IEEE, pp 1560-1564, 2017.
17. Roy A. McCann, Mohammad S. Islam," Application of a Sliding-Mode Observer for Position and Speed Estimation in Switched Reluctance Motor Drives, *IEEE Trans. Ind. Applicat,* VOL. 37, NO. 1, pp 51-58, January/February 2001.

18. A.Khalil, S.Underwood, I.Husain, H.Klode, B.Lequesne, S.Gopalakrishnan, A.Omekanda" Four-Quadrant Pulse Injection and Sliding Mode Observer Based Sensorless Operation of a Switched Reluctance Machine Over Entire Speed Range Including Zero Speed"IEEE, pp 2147- 2154, 2005.
19. NesimiErtugrul, Adrian Cheo Indirect angle estimation in switched reluctance motor drives using Fuzzy logic based predictor/corrector, IEEE, pp 845-851,1998.