CHAPTER 2
LITERATURE SURVEY

2.1 LITERATURE SURVERY

2.1.1 Switched Reluctance Motor (SRM)

(Y.Z. Xu et al 2012) have proposed an analytical method for attaining good feasible angles for turn on and turn off criterion for SRM drives. This method has been carried on the basis of non-linear SRM model of low- region of inductance. The precise nature of this method along with good efficiency than other pre-existing methods is to be well appraised. (Lei Shenet al 2011) have made a successful attempt in pointing out the initial position of SRM having sensor less controls. Their method has totally damped the problems existing in other similar methods in this topology like high bandwidth requirements and presence of electromagnetic interference etc. This method is based on the bootstrap circuit analysis during stand still time of the rotor. (Gregory Pasquesoone al 2011) have also put forth another method for calculating the exact position of SRM at its initial positions. This method is described to be based on injected current comparison technique during the stand still phase of SRM. This work has been successful in providing a clear picture on position estimation of SRM. (Keunsoo Ha et al 2011) have described a method for finding out the position of an SRM very precisely. Here they have employed an asymmetrical converter and a proportional integral current controller for achieving this purpose, unlike older equipment's like modulators and de modulators which increase the costs. They have given a cost-effective solution for position estimation of SRM. (Christos Mademlis, & Iordanis Kioskeridi, 2010) have come up with a good solution for obtaining the control on position in SRM drive through making certain advancements in PI and PD controllers. They have implemented a gain scheduling methodology along with average torque control technique in order to fulfill their purpose. (X. D. Xue, et al 2007) presented a numerical technique for predicting the position of SRM drive. Here boundary and continuity limitations were utilized in finding out the position of the motor along with the help of 2-D bilinear spline mechanism for appropriate modelling of the motor.

(Adrian David Cheok & Zhongfang Wang 2005) have come up with a Fuzzy logic-based methodology for appropriate calculation of positions. The design of phase sector aliment was carried out so as to get an error free outcome of the scheme. This work is based on pragmatically valid digital signal processor. (Jin-Woo Ahn et al 2006) have damped the drawbacks in using optical encoders by replacing them with low-cost analog encoders. They have also provided a good control algorithm for accurate switching signal generation purpose. A strong claim was stated in their work in support of their work. (Y. Sozer & D.A. Torrey 2007) presented a feasible method for turn off and turn on angles of a SRM drive. They have suggested this method on basis of automated control of excitation variables. The appropriated current needed to produce the exact amount of torque is validated by the control parameters. They have claimed that efficient angles have been obtained through this methodology. (Mahesh Krishnamurthy et al 2006) describe a sensor less technique for accurate calculation of rotor position which is based on a time limited current diagnostic methodology. An error analysis is done for the outputs obtained in this theory. These types of studies have given a strong base for understanding the concepts of angles and positions of the rotor in a SRM drive. (Emilia Nunzi) given three techniques for obtaining feasible calculation of atomic clocks which are based on stochastic and reactive topologies. These methods were claimed to be having a better stand than remaining methods that exist in this particular study. (Yan Yang et al, 2010) have presented a brief explanation about bearing-less SRM along with its control strategy. By using two windings the levitation is progressed here in order to suspended the rotor in proper position.

(Gang Yang et al 2008) have given a clear picture of the winding mechanism involved in bearing-less motors. The importance of the winding arrangement is high lightened, where the different factors which vary under the influence of improper winding were emphasized. (Feng-Chieh & Sheng-Ming Yang 2007) have implemented the bearing-less strategy of SRM through sinusoidal currents which are available in the model. The effect of mutual inductance between the poles is clearly stated through which a better performance can be obtained by properly placing them. Here the phase pole currents are stimulated by the help of phase shifted sinusoidal currents. (Li Chen & Wilfried Hofmann, 2012) have provided a comprehensive stand on bearing-less SRM topology by describing a simple single winding model. They have claimed that their new set-up is capable of running with initial speed of 5000 r/min through levitation. This work has been taken for obtaining a good understanding over the entire mechanism of BSRM.

(Natália S. Gameiro & Antonio J 2012) have given a clear understanding on the basics of power convertors technology in SRM drives. They have put-forth a new method for detecting the presence of any fault in the drive. Their method relies on the input supply current of the power converter. The effected motor is detected at an early stage, which helps in reducing the overall failure rate. (Dong-Hee Lee & Jin-Woo Ahn 2007) introduced a four-level converter for a good response rate. This convertor model is equipped with an extra capacitor in order to provide an additional charge as per the requirement. (Shang-Hsun Mao & Mi-Ching Tsai 2005) have simplified the stator winding by introducing C-cores. This modification has claimed to attain a better performance along with swift computation time than the existing models. (Hung-Chun Chang & Chang-Ming Liaw 2011) have proposed a suitable SRM for electric vehicles with an improved Miller convertor circuit. The DC to DC boost converter is employed in obtaining the sudden requirements of energy during over-taking situations of the vehicle. They have developed good control schemes for obtaining an enhanced working of the system. (Jianing Liang et al 2010) developed a passive boost three phase converter for suppression of negative torque production in rear currents. They have been successful in providing an in-depth knowledge on various current-overlap sequences. (H. Chen et al, 2012) given a model to retrieve the change in temperatures by employing finite-element method (FEM). This process is carried out on FLUX software tool. The best way to place a heat sink and other power devices was analyzed. (J. Liang, D.-H. Lee & J.-W. Ahn 2010) suggested a DITC of SRM. This method was implemented using a four-level convertor configuration. The excess ripples present in the torque characteristic have been considerably reduced in this format. (H.C. Chang, 2010) showed a feasible way to control a SRM drive by employing an appropriate converter. For this model to succeed, they have embedded two 3- phase converters in the circuit. The techniques for current control and speed control have been illustrated. (Hung-Chun Chang & Chang-Ming Liaw 2008) have designed a SRM embedded with a front-end converter in its circuit. This SRM is specialized to run on an external battery setup. Various control schemes are studied for this model of SRM drive configuration. (Neville McNeill et al 2009) implemented a SRM with lower number of isolation transformers; only two transformer configurations are employed here. This circuit is powered by a gate driver circuit of supplying the required amount of power to the device. The prototype of the circuit is shows here, whereas the actual pragmatic device is left undeveloped. (Amit Kumar Jain & Ned Mohan 2005) have illustrated the working of the SRM with the help of a High demagnetization voltage. Through this setup we can gain an increase in the needy torque for the motor. In this work, the need for proper demagnetizing voltage was emphasized.

(Khai D. T. Ngo et al 2005) have suggested a dated modulator configuration for SRM operation. The problems with the transient performances have been left un-mentioned and were left over for future development. (Jae-Hak Choi et al 2005) have employed a time-step voltage source technique for the commutation of SRM. This leads to a detailed analysis on its behavior under presence of voltage ripples in the circuit. An effective technique for coupling of SRM drive has been put-forth. (Peng Zhang et al 2010) introduced a precise method to calculated the inductance of SRM. This technique is very essential in finding out the actual control parameters required in a SRM. However improper input values of air-gaps were leading to an erroneous stand in obtaining a precise topology. (Y.W. Lin et al 2012) modelled a cooling fan mechanism based on SRM technology. They have proposed a control mechanism for driving the motor. They have shown that the performance is widely dependent on good commutation shift of SRM. (Keunsoo Ha et al 2007) mitigated the cost factors of single phase converters to a good extent. In order to achieve this, they have made a quantitative analysis in each and every parameter involved in its construction and used of a split ac converter to this topology. (Berker Bilgin et al 2012) have stressed on the importance of SRM for future of electric vehicles propelling technologies. In addition to this, they have proposed a pole design formula for SRM configuration, this is claimed to improve the performance when compared to other motors available. (Hala Hannoun et al 2010) have modelled the SRM to be operated under a variety of speeds based on a speed control scheme. The control can be done effectively both discontinues and continues conduction modes of the circuit respectively. However, the theoretical results for this method couldn't be able to match under pragmatic conditions.

(H. Wang et al 2012) accomplished in providing the basic of a bearing-less SRM model. They have set-up the structure with the help of decoupled torque and stator suspended at the poles. a prototype model has been illustrated in their work. (Kyohei Kiyota & Akira Chiba 2012) investigated an SRM design with comparison to a permanent magnet motor which is install in Toyota Prius vehicle. The performances differences and the speed various have been analyzed in this study. However, that vehicle's propeller mechanism is considered to be quite outdated. (Jun-Ho Kim et al 2007) have put-forward a switch-on configuration for SRM. This design is produced by introducing a parking permanent magnet to the start-up circuit. Various design elements present in start-up mechanism of SRM are known.

2.1.2 Self-Bearing Switched Reluctance Motor (SBSRM)

(H. J. Wang et al, 2008) have cited that modern industrial field such as high-speed machine tool, turbomolecular pump, centrifugal pump, compressor, flywheel energy storage and aerospace need high speed or ultra-high-speed machine. (R. Bosch, 1988; J. Bichsel 1991) have discussed many problems when traditional mechanical bearing is taken to bear the shaft of high speed or ultra-high-speed machine. For example, the mechanical bearing can cause increasing of frictional drag, thermal problem and will give heavy wear in high-speed motor, which not only leads to reduce efficiency of machine and decreases service life of bearings, but also increases burden of maintenance for machine. In addition, lubrication oil cannot be used in high vacuum, ultra-high and low temperature atmospheres. (M. A. Rahman et al 1995) have compared the merits of self-bearing motors in high power as well in high speed areas. Since self-bearing concept attracted by researchers, successfully applied to SRM to avoid its drawbacks. (H. J. Wang 2009) has started research on self-bearing SRM after successful implementation and comparison of self-levitation of induction motor and PM (Permanent Magnet) motor. Compared with other type bearingless motors, research on SBSRM's started lately and the technology is primitive. (T.J. E Miller 1993) gives the concept of SRM. In this work SRM presented with double salient and also excited with single source. Simple series concentric windings laid on the stator itself. No PM or windings were on this rotor. (D.H. Lee et al 2007; K. Ohyama 2006; S. Ayari 1999, Dong-Hee Lee et al 2011, M. Takemoto et al, 2002) have presented the mechanical structures of SRM to have advantages of tolerance, cheap, robustness and work in harsh environments like high temperatures and at high speeds.

SBSRM mimics the working of SRM and maglev systems. Therefore, SBSRMs will have benefits of the SRM and maglev such as absence of rotor winding and friction less condition etc. Hence (M. Takemoto et al 1998; M. Takemoto et al 2000; M. Takemoto et al 2000; M. Takemoto, H. Suzuki, A. Chiba, et al 2001; M. Takemoto, A. Chiba and T. Fukao 2001; M. Takemoto, A. Chiba, H. Suzuki, et al 2004) have first realized SBSRM. they proposed differential windings for SBSRM with two different windings on same stator pole. However, some draw backs, like torque regions can't be used, flux linkages and high cost of converters due to requirement of 2 IGBTs per each levitation winding. To overcome such drawbacks (L. Chen & W. Hofman, 2006; L. Chen & W. Hofman, 2007; L. Chen & W. Hofmann, 2010; Li Chen& Wilfried Hofmann, 2010) have proposed 8/6 SBSRM with three windings loaded at various magnitude of currents. Hence, three different torques and levitation forces were obtained. Consequently, reduction in rotor speed and controlling algorithm became complex in steady levitation. (C. R. Morrison et al 2004; Carlos R. Morrison et al 2008) also proposed Morrison type rotor. This structure reduced complexity of stator design. The rotor has a circular lamination for suspension and multi-pole lamination stack for torque generation. However, this structure also exhibits some drawbacks like high axial length, reduction in rotor critical speed and can't be avoided of high torque reversals.

(Zhenyao Xu, Dong-Hee Lee & Jin-Woo Ahn 2013) presented excellent contribution of work towards shorting the long return paths and natural de coupling of torque and levitation forces by designing a 12/14 SBSRM model and also, they have implemented a controlling scheme to overcome aforementioned SBSRMS structures. This 12/14 model was controlled by using two PID controllers in rotor displacement position control loop and one PI controller was used in speed loop. The main draw backs with this controlling scheme are settlement of speed is very slow to reach desired or set speed, converters have been drawing high magnitude of currents in both torque and levitation windings. Hence ratings of IGBT switches are going to increase, motor gets heated up quickly, increase in overall system cost and rotor speed exhibit more oscillations at center with PI controller.

Therefore, there is a need to go for a new controlling scheme by replacing conventional PI and PID controllers with hybrid intelligent controllers to guarantees more stable operation at center position and reduce the cost of the overall system cost. This work presented a complete analysis on 12/14 SBSRM characteristics and implemented a new controlling scheme, show an excellent performance tracking and reduced the magnitudes of both torque and levitation windings.

Present all industrial looking for high speed applications such as compressor and aerospace especially these two areas require ultra-high speed and also fail-safe machines [1], but the conventional bearings at higher speeds causes frictional drag, lubrication oil cannot be used in ultra-high-speed applications [2-3]. Self-bearing switched reluctance motor (SBSRM) is the combination of conventional switched reluctance motor and active magnetic bearing hence this type of motors persists the advantages of both SRM and active magnetic bearing such it can operate in very high temperature atmosphere due to no winding on rotor, it can catch ultra-high speeds due to absence of bearings. [4-6]. numerous verity structures of self-bearing SRM's have been existed in literature. But each structure has its own disadvantages like, reverse toque, using high converter switches, low power density, can't be utilized full torque region, critical speed is reduced in Morrison type motor, long magnetic flux paths and reversal of flux in stator core and core losses etc. to overcome the aforementioned problems with the different bearing less structures, 12/14 hybrid pole type SBSRM is presented with two types of stator poles. SBSRM has eight torque poles (A_1 to A_4 which are in series connection to form A-Phase winding and B_1 to B_4 which are in series connection to form B-Phase winding as shown in fig.1), 4 radial force poles (P_{s1}, P_{s2}, P_{s3} and P_{s4}) on stator and 14 poles on rotor. Characteristics show that radial force is completely decoupled from torque.

Section-I presents the introduction and literature survey on bearing less motors and also presented the need to go for 12/14 self-bearing switched reluctance motor and its stator and rotor pole information. Section-II presents the mechanical design and controlling scheme of 12/14 SBSRM. Section-III presents the description of performance characteristics and also shows the magnetic flux distribution of 12/14 self-bearing hybrid pole switched reluctance motor. Section IV presents the simulation block diagram and results.

With the beginning of digital signal processors (DSPs), digital skill has impacted significantly on the motion control engineering. The accessibility of sophisticated languages has permitted the beginning of software design methodologies and testing procedures. A new combination of neural fuzzy controller has been tested for reference tracking positions with robustness has been found in [1-4]. An evolutionary algorithm (EA) based fuzzy –PID type adaptable controller has been introduced for a PMSM drive in real time can be found in [5-6]. Brain-emotional-learning-based intelligent controller has been adopted and implemented for induction motor drives in a real-time platform in [7], the working of this controller is mainly based on the input data of sensors and emotional cues. A single neuron artificial neural network has been proposed to interior permanent magnet synchronous motor (IPMSM) [8] it doesn't require offline training and wide knowledge of the motor behavior of various drive systems. A direct model reference intelligent rule-based controller has been applied to a highly nonlinear system with the requirement of a little knowledge on the overall system and its variable parameter values [9]. Design of Fuzzy PID Controller in a parallel combination and is implemented for Brushless Motor Drives for high performance [10]. Implementation of new hybrid type controller for electric drive control has been found in [11]. Adaption of fuzzy PID controller is introduced in [12-14] by merging the fuzzy rule-based system with the PID controller to get better performance. Self-tuning mechanism of PID controller has been applied for controlling the position and shaping in actuators and simulations for this self-tuned fuzzy PID controller on the servo motor presented in [16-17]. For the bearing less SRM, the design of hybrid stator and enhancement of electromagnetic forces has been presented in [18-21].

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SRM is equipped with a biased permanent magnet setup [1]. The necessity of improving the radial forces based on stator and rotor poles is known [2] along with its modeling. After this, for further enhancing the suspension strength of the stator, a hybrid pole is introduced in the system. This modification helps in reducing core losses also [3]. On application of loads, any variations in position of rotor are reverted back to the center by electromagnetic force produced by EM poles in the system. The displacements at different loads are studied [4]. A power electronic convertor is employed for configuration schemes of SBSRM [5]. Initially, single bearing less 8/6 SBSRM has been analyzed [6]. Upon proper selection of converter numbers, a lowered voltage and current ratings can be seen. For reducing ripples caused by torque, a vector control is employed. Along with speed, a good accuracy is attained by enhancing mutual inductance parameters [7]. A few flaws in the previous generation which are to be subsided are- to attain well advanced control angle, lower torque ripples, reduced stator vibrations etc- These are improved by introducing 12/8 type SBSRM, having two windings inbuilt to act as generating modes after full periods are suggested [8-9]. Additionally, a SRM having single phase was suggested to reduce the torque ripples in the drive [10]. Then an application of SRM in EV has been suggested with good efficiency and performance traits [11]. Few examples of high speed required systems are centrifugal pumps, aerospace equipment, hydraulic pumps etc. [12-14]. In a 12/14 SBSRM, a finite element technology was employed for obtaining their respective static characteristics [15-16]. The problems with air gaps and modeling of its suitable hybrid pole SBSRM were illustrated in [17-18]. A neoteric method in which more rotor poles are placed than that of stator poles in contradiction to previous studies was suggested [19]. A numerous study on bearing less technology have come up with their own importance and respective drawbacks.

Self-bearing motors works under the principle of electromagnetic levitation. The stator of these self-bearing motors generates magnetic forces to levitate the rotor without maintaining mechanical contact. Hence the system has been free from mechanical friction and lubrication. Therefore, working span has been increased and also achieved high speeds. In application point of view, this particle drive has most suitable for aerospace, turbo molecular pumps, blood pumps [1-2]. This paper presents 12/14 SBSRM with proposed method to control the rotor eccentric X –Directional, Y-Directional position and speed. Fuzzy and neural emerging techniques have been used in recent years as they are very much effective in solving human decisions. 12/14 SBSRM has a highly non-linear control structure [5-6]. This paper used Takagi-Sugeno FLC model with back-propagation algorithm [7-10]. The simulation results of SBSRM show the satisfactory control performance with less overshoot and steady-state error. This paper also presented the real-time response of speed, torque winding currents and positions of suspended rotor.

The drawbacks from the literature have been mentioned as below

The drawbacks and limitations of applications of existing controlling methods:

In the literature, it is shown that the following are the significant drawbacks of existing controlling methods. Application of these methods will result in

- These works involved in complex levitation algorithms for the selection of poles as the number of poles are increased.
- The conventional controllers for levitation are showing in stability of rotor.
- Drawing more currents at the time of starting.
- Complexity involved in tuning methods
- High cost of displacement sensors because of complexity in controlling algorithm

To overcome the above-mentioned drawbacks of existing controlling methods, a new Parallel fuzzy PID controller has been suggested in this thesis.

2.2 RESEARCH PROBLEM FORMULATION

Nonlinearity of SBSRM makes design complicated and major challenging. SBSRM's modeling is precisely needed to approximate the performance. Furthermore, closed-loop implementation for speed as well in rotor levitation was challenging in practice owing to torque ripple, vibrations, long magnetic paths through air gap and complex control algorithms. The stator vibration also leads to acoustic noise.

This research work is aimed to consider SBRM, which includes smooth starting by shorting the flux paths in air gap by considering a hybrid stator pole. The present work aims to develop, analyze and control of 12/14 SBSRM. Generally, most of engineers do not have familiarity with this peculiar type motors. Furthermore, most of the researchers have a bit negative defiance over reluctance motors, and this has been the main root cause for discouraging the new researchers. In this connection reluctance motors need to add self-bearing property to expose and compared with other conventional electric motors. The self-bearing reluctance motors need good amount of knowledge and well experience in view of controlling mechanical, computer and electrical skills in order to resolve the arising practical issues. Here are some particular sections, where engineers have to have good amount of knowledge and experience

1) Real-time control of displacements and speeds and interfacing with exterior functions in economic digital controllers.
2) Design of power electronic converters (Asymmetric), generally suitable for the operation of reluctance motors.
3) Professional design awareness in controller structures.
4) Good experience in sensors for getting information of shaft eccentricity.
5) Professional awareness designing and operational control of suspension systems.
6) Electro Magnetic levitation necessities both an electrical + mechanical (mech-electronics) engineering background.

2.3 OUTLINE OF THESIS WORK

This thesis work deals with the following topics:

❖ Bearing less technology of motors

- ❖ Applications of bearingless technology over conventional bearings
- ❖ Conventional Structures of bearingless motors & their drawbacks
- ❖ Considered 12/14 SBSRM Stator Structure & advantages over conventional structures
- ❖ Magnetic flux distribution using FEM analysis
- ❖ Inductance and torque characteristics of the 8/10 and 12/14 SBSRM motor drives
- ❖ Proposed Controlling scheme for 12/14 SBSRM motor drive
- ❖ Proposed Parallel fuzzy PID controller to bring the rotor to center position in a faster rate
- ❖ Simulation Results
- ❖ Experimental Results

2.4 OBJECTIVES

1. Analysis of inductance, torque and speed characteristics of Hybrid Pole Self Bearing SRM for Effective controlling of Rotor suspending position at center
2. To analyze the loading effect on both toque and suspension characteristics to design a suitable controller.
3. To design a hybrid intelligent controller for SBSRM for a better training session which will result in a good modeling validation and prediction.
4. To compare the performance of Conventional PID controller with intelligent controllers.

2.5 RESEARCH FLOW

The research flow of SBSRM is given in four phases. First phase involves theoretical approach, Gives brief insight into conventional methods and structures of SBSRM. So that all the merits and drawbacks of each conventional structures of SBSRM structures could be identified with clear knowledge. The Second phase involves FEM analysis, it has been carried out to describe the inductance and torque characteristics in order to obtain both θ_{on} and θ_{off} angles and to create their lookup tables. The third phase involves with pure mathematical and mechanical equations to build equivalent MATLAB/Simulink model to better understanding of Self bearing and to get performance capabilities and brief controlling of SBSRM. Hence performance of real-time hardware can be increased using this Simulink prototype. The fourth phase involved in converting the Simulink model into real time hardware setup with RTIO (Real time input output) controller. Real time Hardware test setup. The total research flow has been shown in below Figure. 1.1

The fourth stage of hardware test setup was the main stage. Because this peculiar Self bearing mechanism can be replaced with conventional SRM drives due to their draw backs mentioned in literature. In short, this drive was constructed with 12 stator poles, 14 rotor poles, no bearings, no rotor windings. The winding presented on stator was separated as radial force winding and other as a torque winding. Levitation winding is a four-phase winding, connected individually to four poles placed in geometric means. Torque winding is a two-phase winding, connected diagonally opposite poles in series it can be shown in Figure. 2.16

2.6 AUTHOR CONTRIBUTION

Six phase asymmetric converter has been designed (four phase converters for suspension and two-phase converter for motoring operation). FEM analysis has been carried out to know these static characteristics of inductance, torque and also to create lookup tables to in Mat lab/Simulink models. Based on these characteristics and controlling structure was mad developed suspension algorithm, to decrease the cost of two displacement sensors, one is form X-Direction and other is form Y-Direction. Hence total cost of displacement sensors has been reduced. Another control algorithm was developed based on the hysteresis current controller with conventional PID controller, to reduce error signal in a faster rate, to bring the rotor to the center position with less ripple. Real time loading effect with case studies has been carried out on both torque as well radial force windings. In the next phase conventional PID controller has been replaced by the Parallel Fuzzy PID (PFPID) controller to stable the rotor at a faster rate and results have been compared with conventional PID controller.

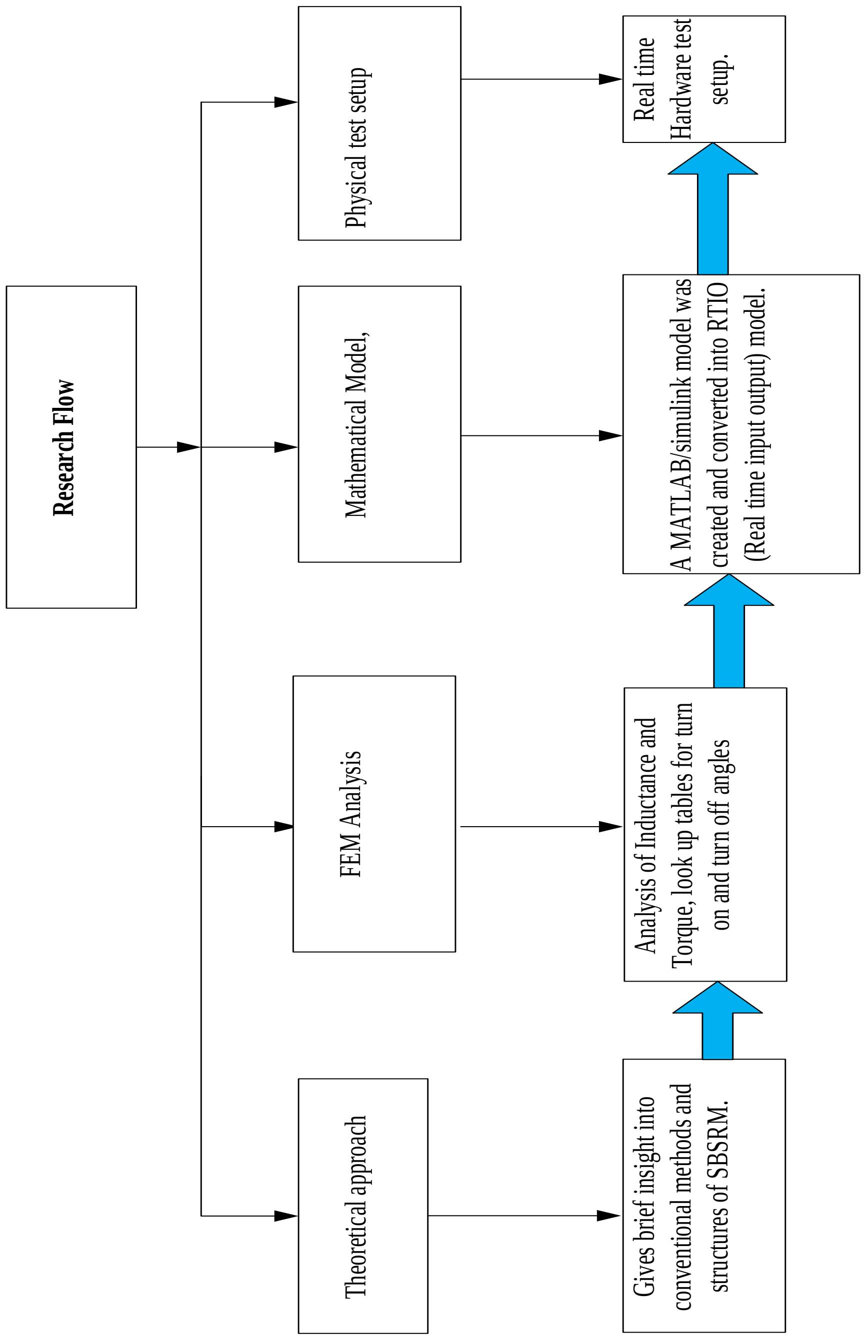

Fig.2.1 Total Research flow