2.1 WORK ON SENSORLESS DRIVES FOR SR MOTOR

Adrian Cheok and Nesimi Ertugrul (1999) presented SRM drives may be used applications due to their simplicity and low cost and these drives require rotor position feedback to operate. The position sensorless scheme is described which uses fuzzy modeling, estimation and prediction. Instead, a fuzzy-logic-based model is constructed from both static and real-time motor data and from this model the rotor position is estimated. The system incorporates fuzzy logic-based methods to provide a high robustness against noise. It also includes a fuzzy predictive filter which combines both fuzzy-logic-based time-series prediction and heuristic knowledge based algorithm to detect and discard feedback signal error.

Cheok and Ertugrul (1995) proposed Sensorless rotor position detection techniques in switched reluctance motor drives. The position sensors are commonly employed to obtain rotor position measurements; however, many systems advantages can eliminate the sensors. It includes the elimination of electrical connections to the sensors, reduced size, low maintenance and insusceptibility to environmental factors. Hence, a diverse range of indirect or sensorless position estimation methods is presented.

Zhan et al. (1998) proposed a novel position and velocity observer for robust control of switched reluctance motors. It uses simplified linear motor models and involves complex mathematical computations and requires large numerical lookup tables. It makes the schemes practically difficult to implement due to the fact that the motors normally operate under magnetic saturation and described by a nonlinear model.
Lyons et al. (1991) proposed flux/current methods for SR motor rotor position information. SR motor position estimation schemes use a numerical table of measured static motor data to describe the motor and measured motor data that provide a numerical model of the static angle versus flux linkage and current characteristics. The size of the table must be large for accurate position estimation and impractical for low-cost or embedded applications.

Cheok (1998) proposed a new fuzzy logic based sensorless rotor position estimation algorithm for switched reluctance motor drives. It considers under steady-state speeds, the rotor position and flux linkage trajectories will be regular and periodic functions. However, during transients, the fuzzy predictors do not perform as well, due to the learning period always required with new events. Thus, under steady speeds and conditions, the confidences in predicted values are high, whereas under transient speeds and conditions, confidence might be low.

Chung and Sul (1998) proposed analysis and compensation of current measurement error in vector controlled ac motor drives. It consists sensorless estimation schemes that measured motor feedback signals to calculate the motor position in real time. However, motor drives are electrically noisy environments and practical measurement equipment is imperfect. Thus, the feedback signals usually be corrupted by noise and error is reported by Rehman & Taylor DG (1996).

Cheok and Ertugrul (1999) proposed high robustness of an SR motor angle estimation algorithm using fuzzy predictive filters and heuristic knowledge based rules. The fuzzy predictive filter used both fuzzy-logic-based prediction algorithms and heuristic decision-making techniques.

Cheok and Ertugrul (1996) proposed a model free fuzzy logic based rotor position sensorless switched reluctance motor drive. The experimental were performed on the motor to determine the performance and reliability of the fuzzy logic sensorless rotor
position-detection scheme under all conditions. It has the scheme works accurately at low and high speeds, chopping and single-pulse inverter switching modes, and torque and speed transients.

2.2 WORK ON SRM CONSTRUCTION AND CONTROLLERS FOR NONLINEAR MOTOR

Muhammad Rafiq (2011) performance comparison of pi and sliding mode for speed control applications of SR motor. This work presented a performance comparison of Proportional Integral (PI) Controller with Sliding Mode Controller for speed control of SRM. A robust controller is suggested for high performance speed regulation and tracking problem of SR motor. The motor speed converges to the desired speed significantly faster than other conventional techniques are also presented.

Karakas Ercument and Vardarbasi Soner (2007) proposed speed control of SR motor by self-tuning fuzzy PI controller with ANN. The proposed controller takes inputs in the form of rotor position, rotor speed, phase currents and reference speed and finds out the required phase currents to keep the motor speed near to the reference speed. These controllers are better than PI controller in providing faster dynamic response.

Inanc and Ozbulur (2003) proposed torque ripple minimization of a switched reluctance motor by using continuous sliding mode control technique. A comparison of sliding mode with PI and fuzzy controller was investigated for speed regulation problem of SR motor. It presented that controller was capable of removing low frequency oscillations and provides effective and robust than PI and fuzzy controllers.

Tahour et al. (2008) proposed sliding mode controller of SRM. It performance comparison of sliding mode control with PI control for SR motor. Chen et.al. (2000) presented the stabilization of chaos in a voltage-mode DC drive system and the basis of these control techniques lies in the fact that a chaotic attractor contains several unstable periodic orbits (UPO) which can be located and stabilized.

Defoort et al. (2007) proposed higher order sliding mode control of a stepper motor. It works on stepper motors and designed third order sliding-mode controllers for
position tracking problems. It was based on geometric homogeneity and integral term enhanced in the controller to cater for uncertainties. The robustness of the developed controller against parametric variations and load disturbances is reported.

Laghrouche et al. (2004) proposed a higher order sliding mode controller for a class of nonlinear systems: application to PM synchronous motor control. It investigated nonlinear systems and developed HOSM controller for position control of permanent magnet synchronous motor and finite time convergence and good robustness is presented.

Traore et al. (2008) proposed high-order sliding-mode controller and adaptive interconnected observer for sensorless induction motor. The observer estimated the motor parameters and the estimated values are given to the controller for speed tracking application.

Sahoo et al. (2000) proposed a current modulation scheme for direct torque control of switched reluctance motor using fuzzy logic.

Luis et al. (2000) reported the nonlinear magnetics of the SRM is compensated to modulate the current waveforms sequentially presented a new method for shaping the motor currents to minimize the torque ripple, using a neurofuzzy compensator.

Giaouris et al. (2008) proposed the Stability Analysis of the Continuous Conduction Mode Buck Converter via Filippov's Method and stabilization technique is to ensure that the absolute values of the eigen values of the Monodromy matrix (the Floquet multipliers) remain within the unit circle irrespective of the system parameter variation.

Nesimi Ertugrul and Adrian Cheok (2000) proposed indirect angle estimation in SRM drives using fuzzy logic based motor model. A novel rotor position estimation scheme is to overcome the drawbacks of the sensor less techniques to provide accurate and continual position data over a wide range of speeds at different operating conditions is presented.
Kavanagh et al. (1991) proposed torque ripple minimization in switched reluctance drives using self-learning techniques. It is more convenient to compensate for the torque pulsations through phase current wave shaping at low speed.

Iqbal Hussain and Ehsani (1996) reported the current reference signal should vary as a function of position, speed and load torque to produce the desired compensation. In fact, the optimum compensating signal is a highly non-linear function of position, speed and load. The torque ripple minimization in switched reluctance motor is driven by PWM current control.

Lovatt and Stephenson (1994) proposed computer-optimized current waveforms for SRM. It uses the inverse of the static torque-current-position relationship which are tabulated and stored in memory; however, this method is quite laborious and sensitive to parameter variations.

Vikas et al. (2009) proposed Performance Analysis of SRM Drive Using ANN Based Controlling of 6/4 Switched Reluctance Motor This paper proposes and investigates the fast on-line training back propagation algorithm for feed-forward ANN. It presents an ANN based architecture suitable to identify the status of a Switched reluctance motor to minimize the torque ripple. A hardware implementation of this scheme is on the way to testify the results and implement the scheme to other SRM.

Haijun Zhang, et al. (2009) proposed a novel method of phase current compensation for switched reluctance motor system based on finite element. Torque ripple is a major problem of SRM drive system, which causes undesirable vibration and acoustic noise. The special characteristics of static torque current-angle are calculated by finite element method and the phase current is treated as the nonlinear function of phase torque. The control concept, a compensating signal is added to the phase current that can vary with the fuzzy control ruler to minimize the torque ripple.
Ercument Karakas and Soner Vardarbari (2007) proposed speed control of SR motor by self-tuning fuzzy PI controller with artificial neural network. The dynamic model, flux-current-rotor position and torque current-rotor position values of the SRM are obtained in this work. Motor control speed is achieved by self-tuning fuzzy PI (Proportional Integral) controller with artificial neural network tuning (NSTFPI) and performance is compared with fuzzy logic and fuzzy logic PI (FLPI) controllers.

Xiang Chen et al. (2005) presented a speed control design for SRM drive powered by a fuel cell system. The control mechanism consists of a hysteresis current controller to minimize the torque ripple and a P-I speed controller. The control design is validated in real-time on a two-node RT-Lab TM platform, together with a fuel cell stack model. Although the PI control is designed based on a low-order simplified model, for simulation purpose, the nonlinear inductance model of an 8/6 SRM is used with classic power chopper.

Fahimi et al. (1999) proposed design considerations of SRMs, vibration and control issues. In the power chopper side, the phase windings are connected in series with the upper and lower switches, shoot-through fault does not happen in case of the switches is shorted. The disadvantages of SRM drive, such as high level of acoustic noise and torque ripple, especially at low operating speed. Therefore, the performance of a SRM drives to accommodate different applications, which has to be tailored through appropriate control.

Henriques et al. (2000) proposed torque ripple minimization in a switched reluctance drive by neuro-fuzzy compensation. It has several drive control methods for SRM have been presented such as, sensorless control using a mechanical position sensor, fuzzy logic control, artificial intelligence control, fixed angle control, etc.

Sharma et al. (2002) proposed performance simulation of SRM drive system operating with fixed angle control scheme. The sensorless control strategy reduces the cost and dimension of the drive and improves the product reliability, although all other methods have their own pros and cons depending on the principles of operation applied.
Le-Huy (1999) presented the SRM has becoming an attractive alternative in variable speed drives, due to its advantages such as structural simplicity, high reliability and low cost.

Gribble et al. (1996) reported SRM has an important characteristic that the inductance of the magnetic circuit is a nonlinear function of the phase current and rotor position.

Elmas et al. (1994) proposed modeling of a nonlinear switched reluctance drive based on artificial neural networks. To obtain the model is not an easy task, because the magnetic circuit operates at varying levels of saturation under operating conditions.

Mendel (1995) proposed to control SR drives using fuzzy logic control (FLC), which is applied to complex plants, where it is difficult to obtain accurate mathematical model or when the model is severely nonlinear. It has the ability to handle numeric and linguistic knowledge simultaneously.

Gupta and Bishnoi (2010) proposed sensorless control of switched reluctance motor drive with fuzzy logic based rotor position estimation. It describes accurate rotor position estimation, which is important for high performance operation of SRM. Earlier, a rotor position sensor is used for sensing the rotor position. The position sensor used in SRM drives have the disadvantages of additional cost, electrical connections, mechanical alignment problems, less suitability to space restricted applications and significant disadvantage of being inherent source of unreliability.

Buju et al. (1993) presented SR motor have gained momentum in the highly competitive market of adjustable speed motor drives. SRM drives have made a successful entrance into various sectors of industry such as aerospace, automotive and home appliances.
Krishnan (2001) reported simple construction, due to the absence of magnets; rotor conductors and brushes improve system efficiency over a wide speed range make the SRM drive an interesting alternative to other commercially available drives.

Miller (2001) presented the accurate knowledge of the rotor position is required for good performance of the SRM drive. The entrance of SRMs in the sensitive applications in industries has proved the need for highly reliable and fault tolerant rotor position sensing methods. It needs for the rotor angle information in SRM has been traditionally satisfied by the use of some form of rotor position sensor.

Soares et al. (2001) presented rotor position sensing is an integral part of SRM control because of the nature of reluctance torque production. In fact, excitations of the SRM phases need to be properly synchronized with the rotor position for effective control of speed, torque and torque pulsation, but it needs a mechanism to detect rotor position for correct operation.

Ramasamy et al. (2005) reported the modeling of SRM drive system using Matlab/Simulink for performance analysis of current controllers.

Baoming and Nan (2006) proposed DSP- based discrete-time reaching law control of switched reluctance motor. The direct rotor position sensors, simply by indirectly determining the rotor position to avoid additional cost, size and unreliability associated with the external position sensors, developing a reliable, precise and low-cost position sensorless control seem necessary.

Bu and Xu (2001) proposed eliminating starting hesitation for reliable sensorless control of switched reluctance motors. A technique to completely detect the rotor positions for the switched reluctance motor drives in all modes of operation. It is desirable to have a sensorless scheme which uses only terminal measurements and does not require additional hardware. The idea for rotor position detection is to use the relationship between the rotor position, the phase current, and the flux linkage.
Hongwei Gao et al. (2004) proposed inductance model based sensorless control of the SR motor drive at low speed. The SRM is modeled by equations based on some parameters such as flux, current and torque, speed and inductance. The parameters are obtained from the measurement of SRMs but some are undetermined. There are some intelligent control methods based on fuzzy control that has found applications in the detection of the rotor position in switched reluctance motors.

Gilberto et al. (1994) proposed a fuzzy set theory based control of a phase controlled converter DC machine drive. The concept of fuzzy logic for rotor position estimation in sensorless control of SRM drive can cope with inherent uncertainty in the input signals. It deals with situations where sharp distinctions between the boundaries of application of rules do not occur. However, fuzzy logic does not need a complex mathematical model and thus, has the advantage of relatively simple mathematical calculations used for the rule processing.

Adrian Cheok and Nesimi Ertugrul (1998) proposed high robustness and reliability of a fuzzy logic based angle estimation algorithm for practical SRM drives. It also presented that the fastest possible universal computation scheme corresponds exactly to the operations in fuzzy logic methods using Max–Min composition. Therefore, in terms of real-time sensorless SRM operation, describe that fuzzy logic techniques is an ideal choice in some reasonable sense.

Cheok and Nesimi Ertugrul (1999) proposed use of fuzzy logic for modeling, estimation and prediction in SRM drives. The model is utilized during the operation of the sensorless rotor position estimation scheme to calculate the rotor position from measured values of flux linkage and current is presented. In the mode of operation, the fuzzy model is essentially used as a nonlinear mapping of flux linkage and current to angle, based on the fuzzy rule base.
Becerra et al. (1993) presented the motor speed can be increased by increasing the conduction period or by advancing the firing angles or by a combination of both. By adjusting the turn-on and turn-off angles, the phase commutation begins sooner and gains the advantage of producing current in the winding while the inductance is low.

Miller (1993) proposed SRM having additional time to reduce the current in the winding before the rotor reaches the negative torque region. The control of the firing angles can be accomplished a number of ways which is based on the type of position feedback available and the optimization goal of the control.

Ahmed Tahour et al. (2008) proposed speed control of switched reluctance motor using fuzzy sliding mode. FLC is designed which is based on the similarity between the FLC and the sliding mode control (SMC) for a class of nonlinear system to tackle the nonlinear control problems with modeling uncertainties, plant parameters variations and external disturbances. The proposed scheme gives fast dynamic response with no overshoot, zero steady-state error. It also represents the validity and the effectiveness of the control method and simulations which are performed for the speed control of a SRM.

Soares and Costa Branco (2001) proposed simulation of a 6/4 SR Motor based on Matlab/Simulink environment, aerospace and electronic system. The switched reluctance machine motion is produced because of the variable reluctance in the air gap between the rotor and the stator. When a stator winding is energized, producing a single magnetic field, reluctance torque is produced by the tendency of the rotor to move to its minimum reluctance position.

Utkin (1993) proposed sliding mode control design principles and applications to electric drives. The sliding mode control (SMC) systems or variable structure control systems is studied extensively to tackle problems of the nonlinear dynamic control systems with modeling uncertainties, time varying parameter fluctuation, and external disturbances.
Tzu-Shien Chuang and Charles Pollock (1997) proposed robust speed control of a switched reluctance vector drive using variable structure approach. The main disadvantage of this approach is the high switching frequency of the control action or chattering that VSC system exhibit. Chattering is undesirable since it can excite the unmodeled high frequency dynamics in the non-linear system control.

Hounsel (2004) proposed evolutionary design and adaptation of high performance digital filters within an embedded reconfigurable fault tolerant hardware platform presented a system for intrinsic evolution of linear and non-linear filters. It described a test bed and showed how simplified versions of the configuration can be used to produce linear band pass filters; the different outputs allow a simple choice between low pass and band pass characteristics.

Adrian Stoica et al. (2002) presented intrinsic hardware evolution for the design and reconfiguration of analog speed controllers for a DC Motor. The stand-alone board level evolvable system (SABLES) was used as a test bed for electronic circuit evolution and recovery. The reconfigurable circuitry consists of 14 transistors connected through 44 switches and enable to implement different building blocks for analog processing, such as two and three stage Op-Amps, logarithmic photo detectors or Gaussian computational circuits.

Adrian Stoica et al. (1997) presented toward evolvable hardware chips: experiments with a programmable transistor array. The use of a programmable transistor array creates circuits with specified DC transfer characteristics. It consists of eight CMOS transistors with 24 switches allowing a wide variety of interconnections. The array designed with a view to using several such arrays in series and/or parallel with each other in order to realize more complex circuits, but, the only results reported so far involve a maximum of four chips with pre-determined interconnections.

Ricardo Zebulum et al. (2007) presented an intelligent controller for autonomous systems together with simulation results on a flexible link robot. It needs to be used as an
integral part of intelligent controllers for improved performance. An intelligent controller for a level process control loop, equipped with estimators to estimate the process variable level was presented.

Chidambaram (2004) proposed to improved design of FLC for a first order nonlinear process with dead time. It developed a rule based FLC to compensate for significant measurement delays in the control of product concentration in a batch-fed fermentor. Prediction of future variable is based on derivative of present variable and present change in input variable.

Diallo et al. (2004) proposed fault-tolerant control architecture for induction motor drives in automotive applications. It describes a fault tolerant control system (FTCS) for high performance. The developed system takes the controller transmission smoothness in the event of sensor failure. It requires the presence of an adoptive flux observer and the speed estimator is based on the approximation of magnetic characteristics slope of the induction motor to the mutual inductance value.

Daqi Zhu (2009) proposed design of reliable control systems possessing actuator redundancies the first time, the concept of actuator redundancies is formally introduced by linking the redundant actuators to the controllability of the system. Recognizing that different actuators have different effects to the system, the concept of dynamic pre-compensator has been proposed which equalize the dynamic properties from each actuator channel to the system output (can differ by a scaling factor at the most). Hence, it makes the design of a passive fault-tolerant control much simpler.

Hongbin et al. (2007) proposed a novel approach to reliability evaluation for active FTCSs. A reliability index based on the control performance and hard deadline, a semi-Markov process model is proposed to describe system operation for reliability evaluation. The degraded performance of FTCSs in the presence of imperfect Fault Detection and Isolation (FDI) is reflected by semi-Markov states.
Chai et al. (2006) presented the FEA field solutions are used in the development of a nonlinear SRM model to search the optimal control parameters that extends the constant power range of each motor with maximum torque per ampere. The dynamic performance of each designed SRM is investigated for the optimal control parameters and an iterative process for each design aids in the determination of an appropriate SRM geometry for electric drive applications.

Brisset and Brochet (1998) presented deterministic methods for the shape optimization of SRM with the average torque as the parameter to be optimized. It deterministic methods employed numerical optimization procedure to achieve parameter optimization is also presented.

Faiz and Finch (1993 and 1997) have concentrated on optimizing the various objective functions such as torque, torque per ohmic loss, efficiency, stator back core width through the judicious choice of tooth width/tooth pitch ratio, split ratio (rotor diameter/stator outer core diameter), tooth pitch/air-gap ratio.

Mirzaeian et al. (2002) presented the Genetic-Fuzzy Algorithm (GFA) has been used for optimal design of SRM with two objective functions: high efficiency and low torque ripple and GFA have showed that can be successfully applied to multi-objective optimization problem when all the design variables are considered as discrete variables.

Debi prasad Panda and Ramanarayanan (2007) Proposed Mutual Coupling and Its Effect on Steady-State Performance and Position Estimation of Even and Odd Number Phase Switched Reluctance Motor Drive. For SRM drives, the torque is independent of excitation current polarity and requires only one switch per phase. During commutation, the stored energy has to be dissipated, so as to protect the semiconductor switches from excess voltages across the windings.

Krishnan (2001) proposed switched reluctance motor drives–modelling, simulation, analysis, design and applications. The SRM control requires an inner current loop and an
outer speed feedback control loop. The speed controller’s input is the speed error and its output is the unmodified torque command is also presented.

Pasquesoone et al. (2011) proposed position estimation at starting and lower speed in three-phase switched reluctance machines using pulse injection and two thresholds. It also presents a method of accurate indirect position estimation for switched reluctance machines suitable for starting and continuous operation. The position estimation and control of the SRM is accomplished in terms of a few sectors within an electrical cycle.

Ibrahim and Al-Bahadly (2008) presented method is based on estimating a particular rotor position on a phase-by-phase basis and measuring the flux linkage and current when the estimated position is reached. By comparing the measured flux linkage with the prestored flux linkage corresponding to the particular position for the measured current, the angular difference between the estimated and particular positions can be calculated.

DiRenzo and Khan (1997) proposed to use an intermediate magnetization curve for rotor position estimation. The difference is that the intermediate magnetization curve is approximated based on the magnetization curve at the aligned position. The reference position is reached when the estimated flux linkage is larger than the one calculated.

De Araujo Porto Henriques et al. (2011) presented a neurofuzzy learning system used as a “virtual” speed sensor (inferential position sensor) which utilized the voltage from each conducting phase and the reference current signal as inputs to estimate the rotor speed. The main advantage of this method is that instantaneous rotor position can be estimated with minimum real time computation, because the algorithm makes use of a single phase (best phase) for position estimation based on a simple model of machine.

Chang Lo and Ya Hui Kuo (1998) proposed decoupled fuzzy sliding mode control. A fuzzy-Sliding mode controller is developed in which a fuzzy inference mechanism is used to generate the equivalent control law parameters. The fuzzy logic controllers replace
the inequalities which determine the parameters of the equivalent control action and show that a particular fuzzy controller is an extension of an SMC with a boundary layer is reported by Kim & Lee (1995).

Brandstetter et al. (2002) presented the flux linkage of SRM depends on the stator current and position between the rotor and stator poles. The fact determines that during control of SRM current with the help of classical PI controllers in a wide regulation range unsatisfied results occur. In a SRM the stator phase inductance is a non-linear function of the stator phase current and rotor position. Fuzzy controller is mostly presented as a direct fuzzy controller or as a system, which realizes continued changing parameters of other controller.

Kopecky (2002) proposed high efficiency of SRM to use the motor in application of the runabout with battery source. The troubles of the control are strongly nonlinear motor model, which has waveform of the stator inductance in a phase for situation when motor is run. It shows idealized waveforms of the stator inductance in one phase, which is more nonlinear in reality.

Krishnan and Materu (1993) proposed analysis and design of a low-cost converter for SRM drives. In addition, the unidirectional nature of the converter for the SRM provides room for unique and diverse designs that eliminates the problems in bidirectional converters such as requiring “dead-time” to prevent the shoot-through of upper and lower switches.

Pollock and Williams (1990) presented connecting switches in series with a phase winding it is not necessary to add circuitry and in case of a failure, enough time can be provided to shut off the converter to prevent further damage. There is also a greater degree of independence between phases than is possible in other motor drives due to the winding and converter configurations.
Barnes and Pollock (1998) proposed power electronic converters for switched reluctance drives. A fault in a phase in the motor or in the converter affects only the flawed phase and other phases can continue to operate independently. Therefore, uninterrupted operation of the motor drive is possible although with reduced power output.

Schramm et al. (1992) proposed torque ripple reduction of switched reluctance motors by phase current optimal profiling. The phase current optimal profiling in the sense of minimum stator copper loss has two adjacent phases would produce the same torque at the same current level assuming that commutation occurs instantaneously. However, due to the finite bandwidth of current control loop, still generated significant torque ripple during commutation.

Husain et al. (1996) proposed torque ripple minimization in SR motor drives by PWM current control. It distributes the desired torque to two adjacent phases during predetermined commutation interval using the torque distribution function. By assuming an ideal inductance profile, however, incorrect current commands caused torque error and by choosing a short commutation interval the rates of change of currents or flux linkages could not be much reduced.

Wallace et al. (1992) proposed a balanced commutator for SRM to reduce torque ripple. It linearly decreased the outgoing phase current and increased the incoming phase current during commutation accepting possible torque error. A torque distribution function minimizes the rates of change of currents over the commutation interval.

Pillay et al. (1997) presented the possibility of two-phase excitation but mentioned the effects of mutual coupling without suggesting any active control scheme to overcome the effects. The torque ripple caused by the mutual inductance may not be acceptable. Therefore, the effect of mutual coupling should be analyzed to decide whether it is negligible or not.
Bae et al. (1999) presented the parameters are functions of rotor position only if the SRM operates in a magnetically linear region. If the SRM operates in a magnetically saturated region, the parameters become functions of phase currents as well as rotor position. Therefore, when the operation in the entire region is considered the parameters should be expressed in terms of phase currents and rotor position.