CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The literature review is done for WRIM on two major categories; Conventional Rotor Side Control schemes and Intelligent Control based techniques. The conventional rotor side control schemes include Rotor Saturable Reactor Control, Saturistor Control, Thyristor based RRC, Chopper based RRC, Rotor Impedance Control by varying either rotor inductive reactance or capacitance reactance or both, Rotor Voltage Injection Control, and Soft Starting methods.

The Intelligent techniques are based on implementation of Genetic Algorithm, Fuzzy Logic Controller and Artificial Neural Network for rotor impedance and non impedance control schemes.

Figure 2.1 shows the overview of number of research work carried out in control of WRIM. It can be seen that the area of intelligent control techniques for WRIM is still to be concentrated upon to bring it on par with the other related research before it can be wide spread applications implemented.
2.2 REVIEW OF ROTOR SIDE CONTROL SCHEMES OF WRIM

This section gives an overview of the various schemes of Rotor side control of WRIM.

2.2.1 Saturable Reactor / Saturistor Based Rotor Side Control

Alger and Ku (1956) proposed a novel method with a Saturable reactor – resistor network on the rotor side to obtain good performance over a wide speed range of WRIM. This method is shown to be better than the rotor resistance control. The Saturable reactor in this method is controlled by Direct Current that is proportional to motor speed. Szablya (1958) has demonstrated the Torque – Speed control of WRIM using Saturable reactor control.
However, the efficiency considerations limit the use of these controls to applications where the operation is intermittent, high torque is needed over only a moderate speed range, or where the power losses are not important.

Alger et al (1963) introduced a Saturistor in the leakage flux paths of the rotor circuits of WRIM. The Saturistor is a resistor, whose resistance can be controlled by magnetic saturation. The significance of this method is that the starting current can be limited to only 3 - 4 times of the rated current which would otherwise be in the order of 5 - 6 times of the rated current. This control provides a high locked rotor torque per ampere of stator current with same values of break down torque, full-load speed and any other characteristic parameters.

Gunn (1963) studied the performance of the WRIM during starting using Saturistors in the rotor circuit. In this technique, the motor can be started with less than twice the rated current while producing a torque which is more than the rated value. Dubey and De (1971) have presented a scheme for the DC dynamic braking of motor with Saturistor in the rotor circuit. The results have shown that DC dynamic braking performance of a motor with a Saturistor in the rotor is superior to that obtained without the Saturistor.

Bland and Shepherd (1975) investigated the performance of Saturistor motor by addition of a capacitor in the secondary circuit. The main characteristic features of such a motor are
- an improvement in torque production
- reduction in supply current
- power factor nearer to unity
- increased braking torque.

However, in Saturable reactor and Saturistor based control methods, the efficiency of the motor will be poor and heating is greater.

2.2.2 Thyristor / Chopper based Rotor Resistance Control

Basu (1971) described a closed-loop control system for WRIM by using Thyristors on the secondary. The Thyristors act as phase-controlled AC switches operating at slip-frequency. The phase-controlled Thyristors allow the torque of the machine to be varied from zero to values bounded by the normal Torque - Speed characteristic of the basic motor. When the overall speed control is applied, the motor exhibits shunt-type Torque - Speed characteristics.

Ray and Datta (1974) proposed chopper controlled rotor resistance control using thyristor in the secondary circuit for controlling the speed of the motor. The principle of the scheme is that the slip frequency voltage of the secondary is rectified and chopped at a preset repetition rate with variable ON time. This eliminates the complex triggering circuitry necessary to sense the slip frequency as used in earlier phase controlled method (Basu, 1971).

A feedback circuit maintains the speed within reasonable limit of set speed at all load conditions. It is expected that the scheme will be useful for variable speed drives particularly in cranes and un-loaders in the place of conventional resistance-contactor controls that are being used.
Joshi and Dubey (1974) presented a novel control scheme based on the optimum DC dynamic braking of the machine. It uses a rotor rectifier cascade feeding a resistance whose effective value is controlled. In this scheme, a thyristor chopper is connected in parallel with it.

Speed regulation of a rotor chopper controlled external resistor under Time Ratio Control (TRC) strategy has been investigated by Sen and Ma (1975). The performance analysis of the motor is done using DC and AC circuit models when the chopper operates under TRC strategy. The Torque – Speed characteristics shown in this scheme has a linear relationship for a particular time ratio.

Wani and Ramamoorthy (1977) introduced filter circuits in the Thyristor controlled chopper circuit on the rotor side. This control scheme provides continuous variation of rotor resistance. This work presents a thorough analysis of steady state performance of the motor with and without filters on the rotor sides. The problems associated with simple chopper circuit such as excessive voltage across Thyristor and discontinuity in the rotor current, are eliminated by introducing a filter in the rotor circuit. The filter gives wider variation of speed-torque characteristics.

Sen and Ma (1978) proposed a novel chopper control scheme for the WRIM operating at constant torque mode for wide speed range. This scheme presents a DC dynamic braking method for fast braking by eliminating DC source.

Ramamoorthy and Arunachalam (1979) addressed the dynamic behavior of a closed loop variable speed induction motor drive system. It uses three phase-controlled SCRs connected in delta configuration and placed at the open star point of the rotor circuit.
Abdelfattah and Abdelaziz (1991) investigated the performance of a Chopper controlled induction motor. Saeed lesan et al (1993) has presented the operation of WRIM with a Thyristor controlled resistor network in the secondary circuit. The effective value of rotor resistance was calculated using the principle of power invariance. This resistance value proved to be a function of the motor speed and Thyristor firing angle as well as of the resistor values for the configuration investigated.

Abdelfattah (2003) adopted a new approach in the chopper controlled external resistance that is enhanced with a DC capacitor for controlling the speed of motor and improving the performance of the motor. The presence of DC capacitor along with the rotor resistance improves the power factor and the speed control range from zero to rated value without sacrificing the efficiency of the motor. However, due to the use of fixed DC capacitor, the improvement in power factor and efficiency is only limited and not quantified. This control scheme emphasises only on the wide speed control.

The dynamic simulation of starting and speed control of WRIM based on mathematical modeling and simulation is presented by Saleh Al-Jufout and Kamal Khandakji (2006).

However, since the Thyristor / Chopper based control schemes primarily focus on the control of rotor resistance, the losses cannot be avoided which in turn reduces the overall efficiency of the motor.
2.2.3 Rotor Impedance Control Schemes

The rotor impedance control is achieved by adding a fixed or variable elements consisting of either resistance and inductive reactance or inductive and capacitive reactance or both.

Shepherd and Slemon (1959) presented the concept of rotor impedance control. In this work, the rotor network is not limited only to reactor – resistance combinations. It also deals with the rotor circuit consisting of other combinations of resistance, inductance and capacitance. If any two of these elements or combinations are connected in series, the resultant rotor impedance locus is determined by vector addition on the impedance plane of the two loci at corresponding values of slip. By properly choosing the rotor network, the desired Speed – Torque characteristics can be achieved. The rotor circuit with Resistive and Capacitive network has been discussed for a Hoist control application.

Constant starting torque of WRIM is achieved by using fixed external elements of resistance and inductive reactance combinations in the rotor circuit (Luke and Yu, 1970). This work derives a list of equations for external parameters such as resistance and inductive reactance required for constant torque operation of the motor. This work is based only on steady state aspects. The performances of the motor under dynamic conditions have not been discussed.

Ayyadurai et al (1979) proposed a novel rotor impedance control technique by introducing external elements of resistance, inductive reactance and capacitive reactance combinations for improving the performance of constant speed operation of WRIM. The improvement in speed regulations and reduction in the physical size of capacitor for entire speed control range is achieved by this method. The analytical equations for effective resistance
and reactance required for the optimal operation of the motor is presented. For lower speed settings, RLC series circuit is used in order to reduce the physical size of capacitor. However, for higher speed settings, parallel RL circuit combination along with series RLC circuit is used. This method is a good alternative to those applications where discrete speed settings are sufficient and where precise speed regulation is not required. This technique can be used as a good alternative to DC machines.

Baghouz and Tan (1989) proposed a method to improve the efficiency and power factor of the rotor resistance controlled induction motor by having a capacitor and a reactor in the rotor circuit, in addition to the external rotor resistor. A mathematical model of the WRIM with inclusion of capacitive reactance was developed in this work. Sen (1990) has reviewed and presented the various stator and rotor side control schemes.

A study was made by Saeed lesan and William shepherd (1993) in which the impedances to be connected into the secondary circuits of the motor are not resistors but passive impedances.

A novel method for controlling the speed of WRIM by operating it closer to its resonance has been introduced by Reinert and Parsley (1995). Speed control of an induction motor is possible by having a resonant rotor circuit, which is adjusted according to the slip frequency. In order to get the resonant condition, a capacitive reactance has been introduced in the rotor circuit for cancelling its inductive reactance. The main drawback of this method is that a high value of capacitance (in the order of Farad) is required to achieve rotor resonance.

The reactive components capable of conducting large currents and withstanding high voltages are relatively expensive. In order to implement
this scheme, some form of a control system will be needed to carry out a reactive component switching strategy.

A closed loop control scheme to operate the WRIM at rotor resonant condition is adopted in the proposed thesis.

Suciu et al (1998) developed the Space Vector mathematical model of a static leading VAR secondary impedance controlled induction machine. The motor copper loss and its control with external capacitive reactance as control parameter for efficiency optimization of the motor are described. In this scheme, the equivalent capacitor values required for optimal performance forms the basis of electronic gyrator design. This is explained with two different ratings of motor models.

A GA based approach is used for efficiency optimization of WRIM in the proposed work.

Suciu et al (1999) adopted a switched capacitor concept for the control of the phase difference between voltage and current in inductive circuits. A FLC based control scheme to control the dynamic capacitor for improving the power factor of the circuit is presented by Suciu et al (2000). In this scheme, the capacitance value can be varied from zero to infinity. The developed fuzzy model provides good results, even if the parameters of the circuit are unknown.

A switched capacitor concept has been adopted for the secondary control of an induction motor to improve the efficiency, Power factor and Torque by Constantin Suciu et al (2002). It utilizes the concept of switched capacitor which makes use of four thyristors as switches to form H-bridge circuit and a single capacitor in the middle of the H-Bridge and connected in each rotor phase. The complementary switch pairs are switched using a PWM
strategy. Improvement in performance and speed control of WRIM was established. The main drawback of this method is the usage of more number of switches and capacitors in the rotor circuit.

A novel method using fuzzy logic control scheme in the rotor circuit for dynamic control and enhancing the performance of the WRIM is proposed.

The double capacitor, double switch switched capacitance topology was proposed by Elwakil and Darwish (2007). In this scheme, the range of capacitance value that can be varied between the two capacitor’s capacitance values for improving the performance of the motor is presented.

Hui Rong Xiao et al (2007) designed and implemented a rotor control circuit with a capacitive voltage source to improve the Power factor, reduce starting current, and improve efficiency and ability to overload. The principle of the reactive power compensating device for WRIM is described.

A single phase to three phases AC-AC cycloconverter is adopted in order to produce capacitive voltage in the rotor circuit by Hui Rong Xiao et al (2010). This makes the circuit simple and capacity of transformer much decremented. The drawback of this scheme is the use of large number of Thyristors which limits its application to large capacitive drives. More cost and complexity of the drive limits its wide use. In order to reduce cost, weight and volume of the drive, the transformer could be eliminated. But this results in poor Power factor.

Several soft starting schemes and control strategies for smooth and fast starting of Induction Motors were presented by Chin Moo et al (1989); Badr et al 1996; Abdel-Halim, 1997. Hamouda et al (1999) have studied and
reviewed the different starting methods of three phase induction motors. Zenginobuz et al (2001) have described schemes for minimizing torque ripples by introducing a novel soft start control. Liwei Wang et al (2008) have analyzed the starting transients in rotor chopper controlled WRIM.

Sharifian et al (2011) used a parallel combination of resistors, self-inductors and capacitors in rotor circuit for soft and higher starting torque operation of the motor. This scheme has limited starting current compared to the shorted rotor method and has no external driver requirements.

In this method, the starting time is much lower and starting torque is much higher than the shorted rotor method. The improved power factor during starting is ensured by the capacitor in the rotor circuit. The Rotor losses are less than the common method in which a resistor added to rotor circuit.

2.3 REVIEW OF INTELLIGENT CONTROL SCHEMES

The concept of intelligence for devices was first introduced in 1936. Alan Turing explained the universal mathematics concept for machines, a basic theory in the computational mathematics.

Turing and Emil Post independently proved that determining the decidability of mathematical propositions is equivalent to asking what sort of sequences of a finite number of symbols can be recognized by an abstract machine with a finite set of instructions. That procedure is related to the machine intelligence concept, accessing the arguments against the possibility of creating an intelligent computing machine and determining solutions to those disputations; in the 1950s, the Turing test was suggested as an experimental measure of intelligence.
The Turing test judges the performance of a machine against a human being. Turing disputes that machine may be considered to be intelligent. In the 1960s, however, computers could not pass the Turing test due to their low processing speed in those days.

The last few decades have seen a new era of Artificial Intelligence (AI). The focus has been on the principles, theoretical aspects, and design methodology of algorithms gleaned from nature. A few examples include Artificial Neural Networks inspired by mammalian neural systems, Evolutionary Computation inspired by natural selection in biology, Simulated Annealing inspired by thermodynamics principles, and Swarm Intelligence inspired by the collective behavior of insects or microorganisms. These techniques have found their way into solving real-world problems in science, business, technology, commerce, and also to a great extent in measuring systems.

The lack of intelligence, learning, and adaptation capability in the control methods discussed in the general control schemes, reveal the need for continuous expert intervention for the control of WRIM. The AI techniques like GA, FL and ANN have been developed in electrical engineering and their applications in power electronics and motor control is promising.

Controlling and optimizing the performance of Rotor Capacitive Reactance based Control of WRIM is a difficult but promising task. This leads to need for integrating AI control tools with conventional control techniques.
2.3.1 Review of GA based Control Schemes

GA is capable of solving non smooth, non continuous and non-differentiable problems for parallel computation to find global or near global optimal solutions. GA is much simpler, involves less computational complexity, memory burden and yield more optimal solution when compared to other techniques (Goldberg 1989).

Kirschen et al (1987) described the optimal efficient control of three phase AC drives. Thanga Raj et al (2009) have reviewed and presented various optimization techniques for energy efficient control of three phase Induction motors based on a loss minimization model using analytical and soft computing techniques.

Lim and Nam (2004) used the GA as an optimization tool for loss minimization of induction motor. The copper loss model used in these methods are based on the stator side control. Vahid Rashtchi et al (2011), Sadegh Shamlou and Mojtaba Mirsalim (2011) have developed GA algorithms for optimization of machine parameters for improving the performance of the motor. The copper loss model comprising stator and rotor copper losses in the proposed GA scheme includes rotor capacitive reactance in the rotor circuit for enhancing the performance of the motor.

2.3.2 Review of FLC based Control Schemes

Fuzzy systems handle uncertain, imprecise, and vague situations. Zadeh (1965) introduced the concept of Fuzzy Set theory as a theory in which everything is a matter of degree (Zimmermann 1996). Fuzzy Logic (FL) was introduced as a superset of standard Boolean logic. Thus the concept is extended from two valued logic to multi valued logic and has many applications.
The FLC is the most suitable approach to achieve adaptation of non linear systems. Since non linear systems require continuous expert knowledge, FLC provides a systematic method of incorporating human expertise by implementing non linear algorithms. FLC design does not require a formal model of the system. FLC design method is generally based on a fuzzy model, which is constituted by a set of IF – THEN rules. The FLC rules are the rules which specify the appropriate action which should be applied to the system to obtain the specific desired output (Suciu et al 2000).


In this research work, a novel FLC scheme is incorporated in the rotor circuit for improving the performance of the WRIM. The system performs satisfactorily by properly choosing the rules to obtain efficient results i.e. it is adaptable according to the variation in data.

2.3.3 Review of ANN based Control Schemes

ANN with many layers of neurons is analogous to the biological neurons. Their speedy computation capability, can be used to approximate complicated functions. ANN methods for estimation of rotor resistance, rotor time constant and induction motor parameters were investigated by Barazzouk et al (1996, 2002); Mayaleh and Bayindir (1998); Ebrahimi et al (2006); Karanayil et al (2007). Abdelfattah and Ahmed (2002) have used the ANN for speed control of chopper based rotor resistance control schemes.

The overview of the various existing and proposed control schemes is shown in Figure 2.2.

![Figure 2.2 Control Schemes for WRIM](image-url)
2.4 SUMMARY

A detailed literature survey has been done on the research on rotor side controls. The various proposed schemes are also indicated at appropriate places to give context to the contribution and originality of this research. From the literature survey, it is seen that most of the research work is based on the conventional control methods. In general control schemes, no Intelligent Techniques were incorporated in the rotor impedance control schemes. For improving the performance of the WRIM, the Computational Intelligence Techniques are introduced on rotor side controls.

The next chapter presents a novel GA based rotor capacitive reactance control for efficient operation of WRIM.