A Comprehensive Literature Review of Wound Rotor Induction Motor Drive System by Rotor Impedance Variation

Bekhal Abdulla* and Hilmi F. Ameen

Salahaddin University- Erbil, College of Engineering, Electrical Engineering Department

Corresponding Author: (bekhal.muhammadamin@su.edu.krd)

https://doi.org/10.31972/iceit2024.038

Abstract

To improve Wound Rotor Induction Motor (WRIM) drive system performance, this work offers a comprehensive literature assessment of an adjustable speed drive with a variety of control approaches of rotor impedance variation. It begins with a synopsis of the key elements of the WRIM drive system control approaches and moves on to discuss other control strategies, such as non-static impedance control, static rotor resistance control, dynamic capacitor in rotor circuits, and optimal controlling like artificial neural network, fuzzy logic control, PSO and genetic algorithms have been reviewed in this paper. It also looks at how these strategies affect motor performance, efficiency, simplicity, reliability, economically, dependability, and operational flexibility. The results highlight how important rotor impedance control is to maximizing WRIM performance and how continuous innovation is being made to make them more useful in a variety of industrial settings.

Keywords: Wound Rotor Induction Motor Rotor (WRIM), Rotor Impedance Variation, Chopper Circuit, Dynamic Capacitor, Optimal Control Techniques

1-Introduction

Induction motors are a type of AC motor that are commonly used in industrial operation sectors. In general, induction machines are significant in the field of electromechanical energy conversion systems (IM) , (Hannan et al., 2020). (Duc et al., 2023)stated that are over 60% of the electricity utilized globally by induction motors. IM has special benefits such as low cost, high resilience, and slow maintenance, this qualifies it for use in industrial settings (Algamluoli and Abbas, 2021). The WRIM is used in numerous applications that call for high starting torque, wide variable speed drives, and high inertia loads. Resistance and reactance are two of the rotor control techniques used to enhance WRIM performance.

There are two types of rotors of induction motor, which are slip rings or wound rotors, and squirrel cage rotors (Bakshi and Godse, 2009) and (Altaira, 2018). The wound rotors are commonly used when high starting torque is required. There are several methods and techniques used to control the speed of induction motors. (Mahapatra et al., 2015) used the PSO-ANFIS hybrid technique to speed control IM, and (Kumar et al., 2017) used the software of graphic user interface (GUI) to maximize the efficiency of squirrel cage IM. Figure 1 depicts the WRIM connected to external resistance. Three slip rings installed on the rotor shaft are connected to the three terminals of the WRIM windings. Using slip rings allows the rotor circuit to be connected electrically to three phase external resisters via carbon brushes. The purpose of this electrical connection is to regulate rotor speed, maximize starting torque and lowering starting current. A slip-ring motor's speed can be reduced and adjusted to 25% of its rated speed. A further reduction may greatly diminish the cooling effect and reduce the output in a much larger proportion and will not be worthwhile.

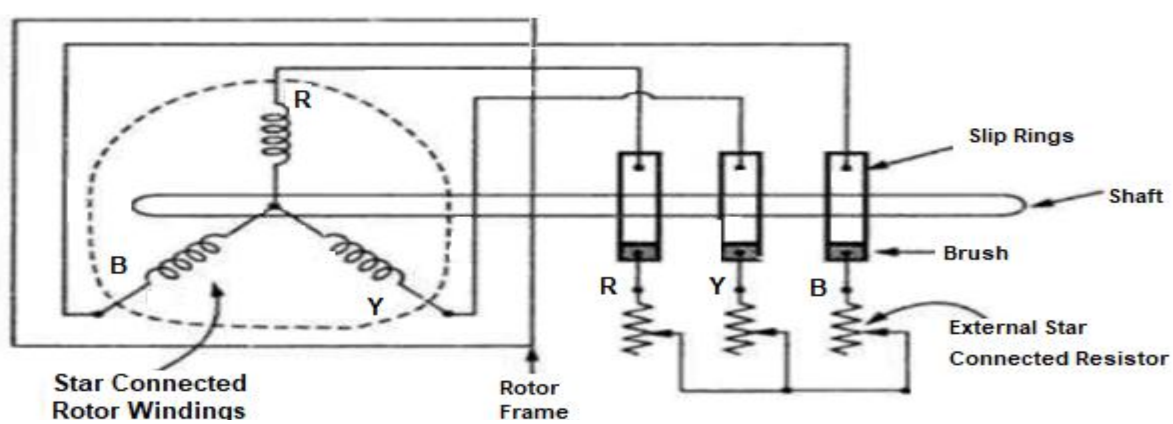


Figure 1: The WRIM connected to external resistance (Altaira, 2018)

The advanced and economical scheme of the speed control of WRIM can be obtained by dissipating the rotor slip power into external resistances, or by recovering the energy and returning it to the ac grid through line voltage commutated inverter as in Kramer scheme. The characteristics of speed control improved by adding further circuits to the rotor terminals giving WRIMs better than other commercial SCIMs. The general control scheme of WRIM controlled by rotor impedance variation is shown in Figure 2.

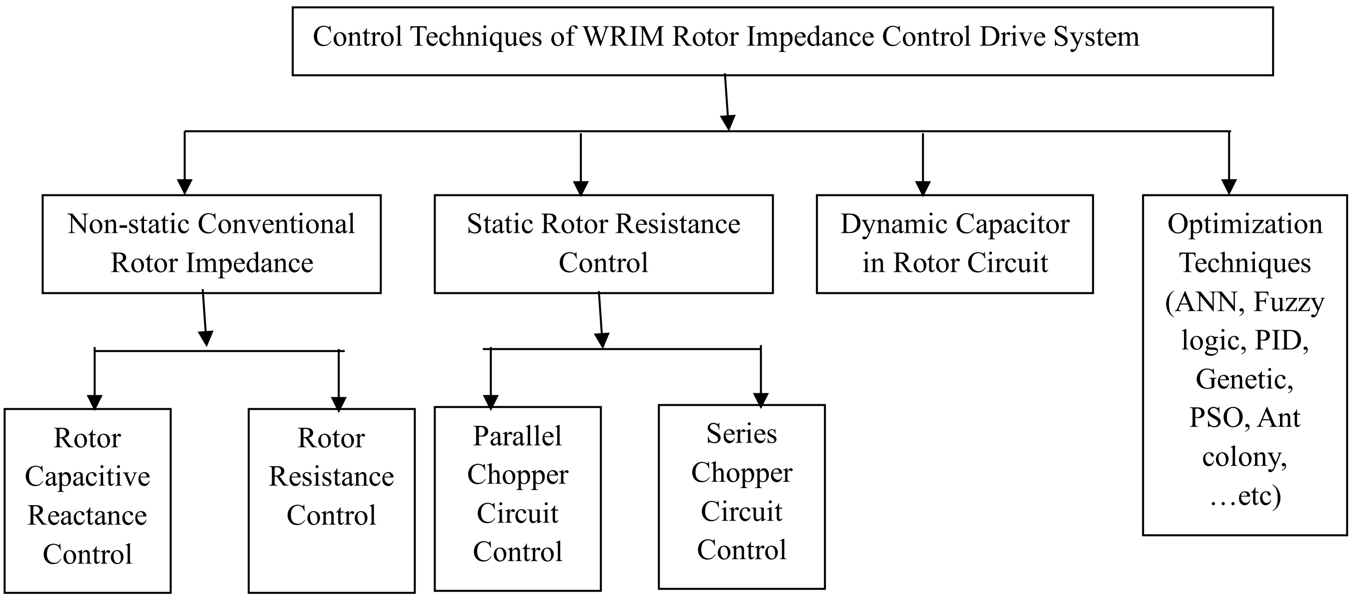


Figure 2: The Classification of WRIM Drive System Control by rotor Impedance Variation

(Dubey et al., 1975) presented that WRIM may be change its torque slip characteristic. It has been known that you may modify a motor's rotor circuit by adding external resistances technique, some of the input power that is supplied to the stator is taken out of the rotor and lost as a result of external resistance, which causes the speed to decrease. Maximum torque can be attained at the beginning and throughout acceleration by selecting an adequate resistance and adjusting it accordingly.

2-The Control Techniques of WRIMRIM Drive System:

Based on the literature that has been published to date and their notable contributions, this section addresses the control strategies employed for WRIM performance enhancements by rotor impedance variation. Variations in control methods and rotor impedance variation model types are categorized as:

2.1 Non-static Conventional Rotor Impedance Control:

Rotor resistance control, rotor reactance control, rotor capacitance control, or a combination of these can be used as the WRIM speed control method based on the rotor circuit impedance variation. The rotor losses will rise with this strategy. Reactive circuits in the rotor allow the motor to be operated near resonance, which results in high breaking and starting torque. Due to the rotor resonance's relationship to the fluctuating motor speed, this approach has limitations.

As shown in Figure 3, a straightforward technique for WRIM speed management involves a mechanical adjustment of the rotor circuit resistance. According to (Ameen and Aula, 2020) approximate equivalent circuit model of a three-phase induction motor, the electromagnetic torque created can be expressed as:

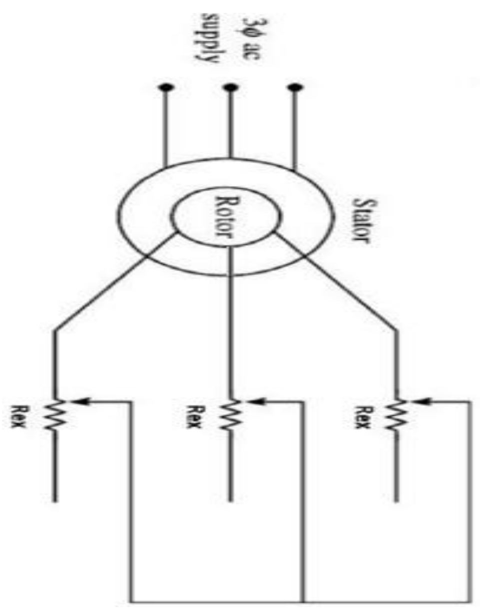
$$T_e = \frac{3V^2\frac{R'}{s}}{\omega_s\left[\left(R_s+\frac{R'}{s}\right)^2+(X_s+X_r)^2\right]} \quad (1)$$

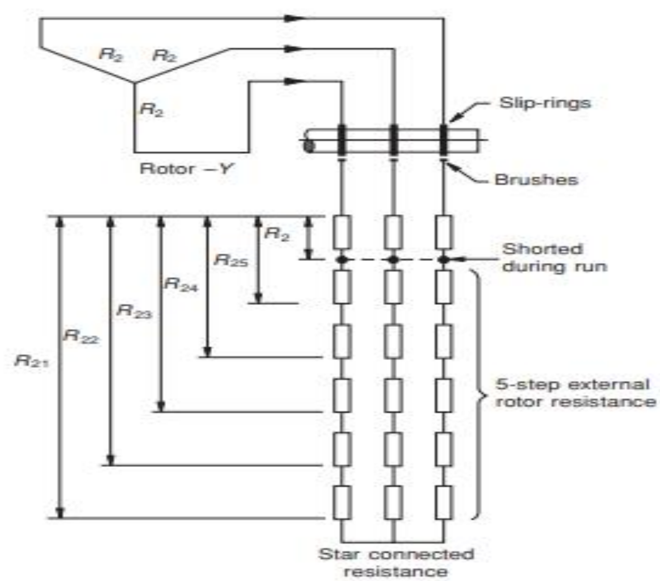
Where, s is the slip, R'=R_{ex} +R_r, ω_s is the angular velocity in rad/sec, R_s is the stator resistance, R_r is the original rotor resistance referred to stator side, R_{ex} is external resistance, ($X_s + X_r$) are the stator and rotor leakage reactance referred to stator side and the voltage per phase is V. Variations in the external resistances at the rotor terminals govern the speed of WRIM. Equation 1 can be expressed as follows at high rotor speed or low value of slip:

$$T_e = \frac{s}{R_r'} \quad (2)$$

Consequently, as rotor resistance increases, speed decreases. The stator current and speed drop when using the traditional resistance control of WRIM, as illustrated in Figure (3), by increasing the rotor circuit resistance. The advantages are the absence of in-rush starting current and, availability of full-rated torque at starting, absence of line current harmonics and the smooth range of speed control.

For every rotor circuit, (Lesan et al., 1996) developed a resistive network controlled by a thyristor. The successful firing of thyristors across a wide speed range was one of the major issues with the experimental realization of the drive. Over the whole range of thyristor firing angles, the motor performance characteristics of output power, stator current, power factor, and efficiency were derived as functions of speed. (Mer et al., 2014) Used non-static rotor resistance control to control the speed of WRIM. (Aljaism, 2014) Used conventional rotor resistance control for comparison between the WRIM and Squirrel Cage IM with variable speed.





(a) (b)

Figure (3) (a) Conventional Rotor Resistance, (b) Five-step resistance Control of WRIM (Ameen and Aula, 2020)

A slip-ring motor's speed can be adjusted by up to 25% of its rated speed. As seen in Figure (4), a further reduction may significantly lessen the cooling effect and reduce the production in a much higher proportion, making it unwise.

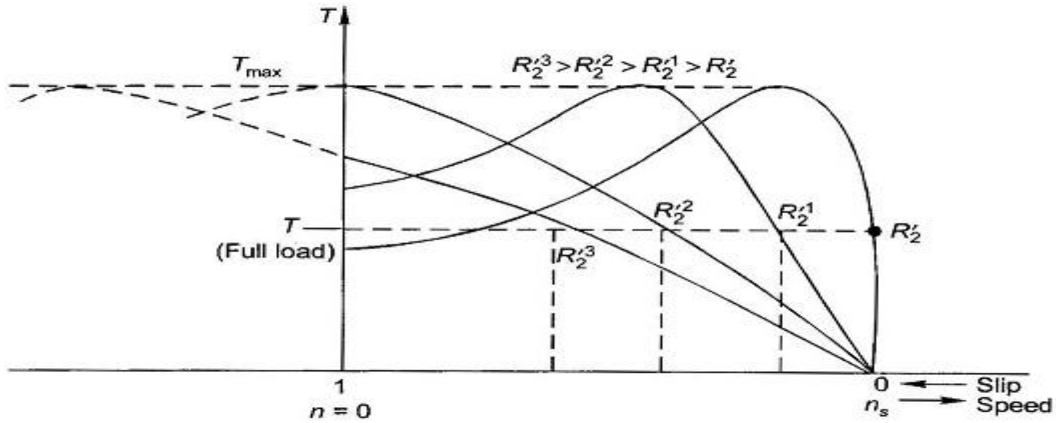


Figure (4) Torque-slip curves of WRIM with increasing rotor resistance (Aljaism, 2014)

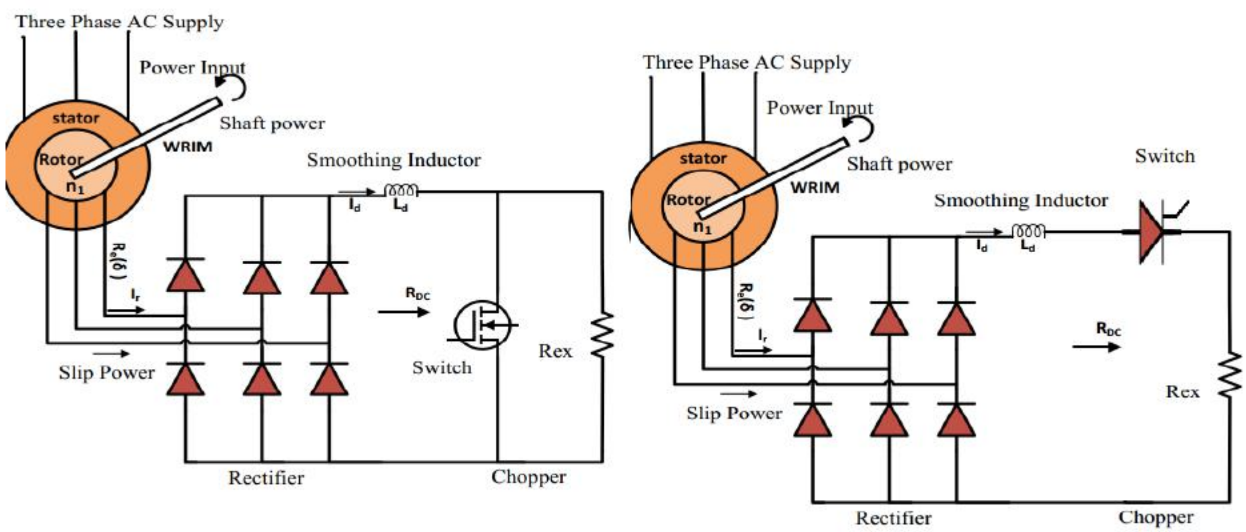
Table (1) shows the non-static conventional rotor impedance control that some researcher used in their papers.

Author	Methodology used	Found
(McFarland and Alvarez, 1948)	Application of the liquid rheostat is for acceleration and speed adjustment of WRIM.	Design of modern liquid rheostats and the basic data on types of loads and control systems.
(Badr et al., 1995)	Developed a plan to use a phase balancer that is correctly chosen to get maximal beginning torque to start the motor from a single-phase supply.	It has been discovered that this beginning strategy can cut start-up times significantly—up to 80% for large motors.
(Badr et al., 1996)	When the stator and rotor windings are shunted across the supply for a pre-defined brief duration, the motor generates a very high initial torque.	The motor developed an extremely high starting torque which was sufficient to start the motor at less than 20% of the normal starting time.
(Hamouda et al., 1999)	Provided a comparison of three phase WRIM starting performance under various beginning conditions.	The findings suggested that the electromechanical resonance effect might occur when the motor is started against load, even a modest load.
(Lesan et al., 1996)	Thyristor-controlled resistive network.	Speed control and increasing performance of WRIM.

(Abdel-Halim et al., 1997)	Suggested a novel approach that involves paralleling the addition of capacitance, inductance, and resistance to the rotor circuit.	According to the suggested scheme, an external impedance made up of a parallel combination of appropriately chosen capacitance, inductance, and resistance.
(Badr et al., 1998)	The development of mathematical models and the associated computer simulation is done, and the theoretical conclusions are also verified experimentally.	Slip-ring induction motors have been found to operate as series-connected motors as long as the rotor winding is linked in the opposite order as the stator winding.
(Aljaism, 2014)	Conventional rotor resistance control.	Comparison between the WRIM and Squirrel Cage IM with variable speed.
(Mer et al., 2014)	Non-static rotor resistance control.	Controlling the speed of WRIM.
(Mohammedsaeed and Karrar, 2016)	Design of a liquid-rheostat reduced-voltage starter using the finite-element approach for three-phase squirrel-cage IM, which are usually used to drive irrigation pump loads.	The liquid rheostat impact of the material of the electrolyte tank on the starting resistance.
(Sarwito et al., 2017)	Seeking to understand the performance of a three-phase asynchronous slip ring motor in both loaded and unloaded conditions. Under certain conditions, the resistance varies between 0 and 25 Ω.	According to the torque formula, a decrease in motor torque has been associated with an increase in motor speed. The other result indicates that when the load increased, efficiency increased as well.
(Ameen and Aula, 2020)	Variations of the external resistances of rotor chopper resistance control.	Controlling the speed of WRIM drive systems.

2.2 Static Rotor Resistance Control

In the basic structure of Static Rotor Resistance Control(SRRCC) in WRIM, the rotor windings within slip rings are directly connected to a full-bridge diode rectifier in which the rotor slip power is rectified and then fed to a chopper circuit with external resistance and a smoothing inductor as shown in Figure (5a) shows the parallel chopper of static rotor resistance control, while Figure (5b) is a series chopper of static rotor resistance control. The purpose of connecting the DC link inductor is to reduce discontinuous connections and eliminate DC link current ripple. The SRRCC offers several advantages over the traditional rotor resistance control method, such as smooth and stepless control, fast response, low maintenance costs, compact size, simple closed-loop control, and resistance that is evenly distributed across the three phase rotor windings at all operating speeds. (Nasir, 2022) Controlled the speed and performance of the WRIM using the static rotor via the thyristor chopper control in conjunction with the Hitachi Resonant Commutation Circuit for the parallel chopper circuit, and contrasted it with the conventional rotor control.



(a) (b)

Figure 5: Control Scheme of SRRCCIM Drive System (a) Parallel Chopper Circuit, (b) Series Chopper Circuit (Ameen, 2011)

(Kumar et al., 2017) used the single thyristor at the rotor side of WRIM by the MATLAB/Simulink. The rotor resistance of a wound rotor induction motor increases when external resistance is added, resulting in low rotor current and high starting torque during starting.

(Ameen and Aula, 2021)presented the SRRCC and Slip power recovery (SPR), of wound rotor induction motors for speed control and increasing performance. (Sen and Ma, 1975) used a rotor chopper-controlled external resistor. This control scheme provides continuous and contactless variation of rotor resistance and thereby eliminates the undesirable features of the conventional rotor resistance control method.

(Ameen, 2007) examined how the properties of SRRCCIM were affected by the duty cycle and chopper switching frequency. The researcher concluded that with increasing chopper frequency the torque pulsation and speed ripple had been reduced. Also, the amplitude of harmonic levels depended on the slip, duty cycle, and chopper frequency. (Ameen, 2011) suggested introducing a third harmonic method into the SRRCCIM rotor circuit. The goal of this technique was to minimize the rotor current distortions, torque pulsation, and ripples in the speed. The proposed technique reduced the THD in rotor current from 25% to 3%, and the power factor of the motor increased by 3%.

(Porate and Kochar, 2014) Used Series chopper resistance to minimizing the power loss in WRIM and the simulation by MATLAB/Simulink. (Prasad et al., 2014)utilized a single thyristor that acts as an ON/OFF switch at the rotor side of the slip ring induction motor to control the motor's speed. One can run the slip ring induction motor from the rotor side or the stator side. The main method of controlling this high-power machine is to use a single thyristor to directly alter the load current or the rotor side current after a three-phase rectifier bridge consisting of six diodes has converted the available load side current into a DC current.

Table (2) Shows the methods of static Chopper rotor resistance control of WRIM that some researcher used in their papers.

Author	Methodology used	Found
(Sen and Ma, 1975)	Used a rotor chopper-controlled external resistor.	Removed the drawbacks of the traditional rotor resistance control approach by offering continuous and contactless rotor resistance fluctuation. It also speeds up WRIM.
(Joshi and SK, 1980)	Capacitor in series with external resistance are connected.	Increasing the control range of speed.
(Wani and Ramamoorty, 1977)	Have used a thyristor controlled chopper and the problem of excessive voltage across thyristor .	By adding a filter to the rotor circuit, discontinuities in the rotor current are removed, and by combining a capacitor and resistor, the speed control range is extended.
(Wani and Ramamoorty, 1977)	A dynamic model of tiny signals was created for a	The dynamic performance was significantly enhanced by

	driving system that controls static chopper resistance.	current feedback loops and speed.
(Crowder and Smith, 1979)	Presented a system that combines the stator-voltage control regulator WRIM with the rotor chopper resistance control.	Results from analyses and experiments indicate that steady four-quadrant operation is appropriate for applications using hoists.
(Gupta et al., 1985)	Have used rotor resistance control in a closed loop to improve the dc dynamic braking performance of wound rotor induction motor.	Both braking time and energy losses considerably reduced
(Lesan et al., 1996)	Used resistive network controlled by a thyristor in every rotor circuit.	The successful firing of thyristors over a wide speed range.
(Amin, 2005)	Design a high chopper resistively frequency drive System.	The harmonic in rotor current and torque pulsation are reduced.
(Ameen, 2007)	Examined how duty cycle and switching frequency affected SRRCC performance.	Torque pulsation and harmonics of stator and rotor current waveform are reduced with increasing chopper frequency.
(Ameen, 2011)	The use of the third harmonic approach to the chopper resistance control rotor circuit.	The suggested technique's power factor and THD both increased by 0.84 and 3.12%, respectively.
(Porate and Kochar, 2014)	Used Series chopper resistance.	Minimizing the power loss in WRIM.
(Prasad et al., 2014)	Utilized a single thyristor on the rotor side of this slip ring induction to function as an ON/OFF switch.	Change the rotor side current or the load current directly to regulate the high power machine.
(Kumar et al., 2017)	Used the single thyristor at the rotor side of WRIM by the MATLAB/Simulink.	Causes the rotor resistance to increase during starting, which results in low rotor current and high starting torque.
(Nasir, 2022)	Used the Hitachi resonance commutation circuit in conjunction with the thyristor chopper control to operate the static rotor.	Control the speed and performance the WRIM and compared with the Conventional Rotor control.
(Ameen and Aula, 2021)	Described the Slip power recovery (SPR) and (SRRCC) under unbalanced	The rotor speed and power factor are reduced with increasing the degree of

	supply voltage conditions.	asymmetry of supply voltage.
(Ameen, 2023)	Looked into the effects of harmonics produced by the power semiconductor devices in SRRCC of WRIM running in a voltage-asymmetric rotor circuit.	Finding the relationships between torque, rotor currents, and all harmonic order frequencies, as well as the stator frequency and rotor speed.

2.3 Dynamic Capacitor in Rotor Circuit

There are several techniques for dynamic capacitor in rotor circuit that several researchers developed in their researches we discussed and reviewed some papers. In order to increase the inductive circuit's power factor, the switched capacitor concept was explained by (Rajinith and Palaniswami,2011). As illustrated in Figure 6, it entails putting an ac capacitor in the center of a H bridge equipped with bi-directional switches. Fuzzy control pulses are used to switch the complementary switch pairs (S1, S4) and (S2, S3), respectively.

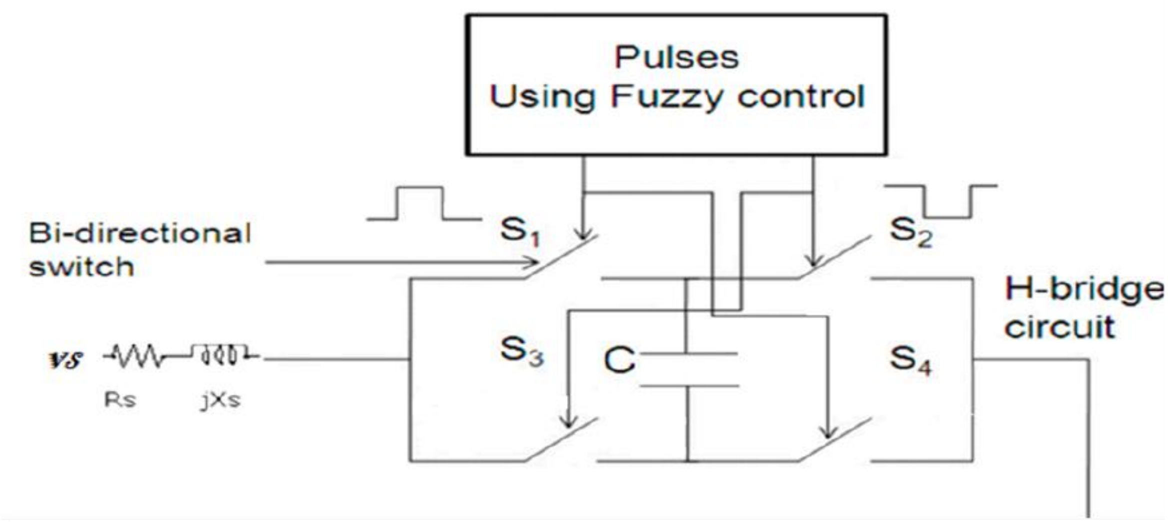


Figure (6) Basic H-Bridge switches with Capacitor (Rajinith and Palaniswami,2011)

(Suciu et al., 2002) presented a mathematical Algorithm to predict the control of induction motors by inserting the capacitance in the secondary circuit that improved the efficiency, power factor, and torque for induction motors.

In comparison to conventional rotor impedance control, a lower number of switches have been employed in the dynamic rotor capacitive reactance control scheme by (Kumar et al., 2012), which has been implemented using a DSP controller. As a result, the control strategy is very straightforward and inexpensive to execute. The suggested method can be applied to high beginning and running torque, speed control, high power factor, and high efficiency motor operation. (Kumar et al., 2010) enhanced performance metrics, such as the induction motor's efficiency and power factor, by using the dynamic capacitive control method, which involves adjusting the duty ratios to simulate the dynamic capacitor values.

According to (Ibrahim et al., 2016) , an ANN controller is used to predict the efficiency and power factor of a three-phase WRIM. A dynamic capacitor, which is an H-bridge switch with a fixed capacitor connected in each phase of the rotor circuit, is used to control the rotor impedance. The capacitance value of the H-bridge circuit is dynamically adjusted by varying the duty ratio. By dynamically adjusting the capacitance value, the power factor, efficiency, and load torque of varied loaded conditions were enhanced.

Table (3) Shows the method of Dynamic Capacitance control of WRIM that some researcher used in their papers.

Author	Methodology Used	Found
(Suciu et al., 2002)	Exhibited An algorithmic approach to forecast the regulation of IM through the incorporation of capacitance into the secondary circuit.	Improved the efficiency, power factor, and torque for Induction motors
(Kumar et al., 2010)	Changed the duty ratios in order to simulate the dynamic capacitor values using the dynamic capacitive control approach.	Improved performance parameters such as efficiency and power factor of induction motor.
(Kumar et al., 2012)	Used a hardware-implemented dynamic rotor capacitive reactance control technique with DSP.	High starting and running torque, power factor and efficiency when operating the motor, speed control.

(Ibrahim et al., 2016)	Controlling the rotor impedance with an ANN controller and a dynamic capacitor, which is an H-bridge switch with a fixed capacitor connected in each phase of the rotor circuit.	By dynamically adjusting the capacitance value, increased power factor, efficiency, and load torque of different loaded circumstances were achieved.

2.4 Optimal Control Techniques of WRIM

There are several Optimal techniques for controlling WRIM like Genetic Algorithm, Arterial Neural Network (ANN), Particle Swarm Optimization (PSO), Fuzzy controller, and neural PID controller. That some researchers used in their papers we discussed some of them in this article.

(Saed and Ameen, 2011) provided a thorough analysis and design of the input filter, boost DC-DC switching converter, and three phase bridge rectifier components for the static chopper resistance control in order to satisfy the demands for low current distortion and address the issues brought about by the harmonics introduced by the rotor rectifier circuit. WRIM speed control with chopper resistance in the rotor circuit was accomplished using fuzzy logic control by (Ameen, 2011). The rotor circuit's duty cycle of the chopper rotor resistance is adjusted to limit the speed at a range of sub-synchronous speeds.

(Mahapatra et al., 2015) created a prototype model to use the PSO-ANFIS hybrid technique to manage the speed of an induction motor. They explain how to develop an ideal fuzzy logic controller for an induction motor using Particle Swarm Optimization (PSO) and ANFIS.

(Dakheel et al., 2020) applied two controllers, one based on an artificial neural network (NARMA-L2) and the other on a traditional proportional integral derivative (PID) controller, for WRIM as illustrated in Figure (7). These controllers have been compared to one another. It has been demonstrated that, in comparison to its conventional counterpart, the neural network controller improves the motor's starting torque.

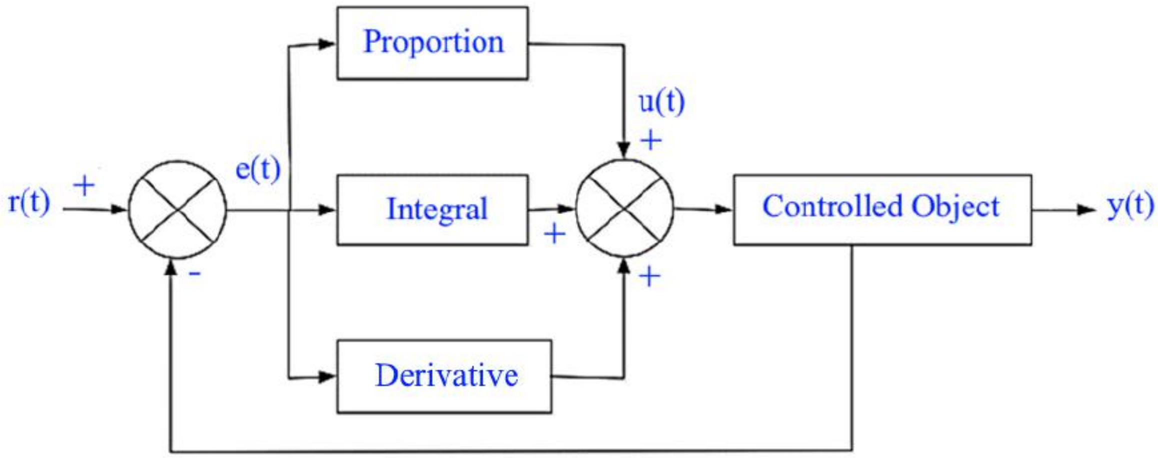


Figure (7): Block diagram for PID controller

(Etemadi and Haghighian, 2019) has been suggested to use a genetic algorithm to manage the WRIM with objective functions that include motor weight and power losses. Following Magnetic Equivalent Circuit (MEC) modeling, various parameters are first chosen using sensitivity analysis, and a sample of 4.3 MW, 6 kV, 1000 rpm is used to carry out the optimization procedure. In addition to significantly lowering the air gap and magnetic current and increasing power factor, this modification reduced copper losses by about 18%.

The approach of sequential searching with respect to the selected design variables was presented by (Ghosh et al., 2018). Additionally, an additional design that combines synthetic and analytical methods has been created. The designers' experience guided the selection of the design variables. The researchers employed these techniques to improve WRIM's overall performance, efficiency, and starting torque.

Table (4) Shows the method of optimal control of WRIM that some researcher used in their papers.

Author	Methodology Used	Found
(Ameen, 2011)	WRIM speed control with chopper resistance in the rotor circuit was achieved using fuzzy logic control.	By modifying the duty cycle of the chopper rotor resistance in the rotor circuit, the speed is restricted to a range of sub-synchronous speeds.
(Saeed and Ameen, 2011)	Presented a method based on (ANNs) for managing the	The controller circuit was simulated and operated

	rotor side of the WRIM's external chopper resistance circuit.	on both closed and open loops.
(Mahapatra et al., 2015)	Used the PSO-ANFIS hybrid technique.	Control the speed of an induction motor
(Ghosh et al., 2018)	The process of conducting consecutive searches with respect to the selected design factors and analytical methods has been used.	Increase the starting torque, efficiency, and overall performance of WRIM.
(Etemadi and Haghighian, 2019)	Using a genetic Algorithm to control the WRIM with objective functions including power losses and motor weight.	Reduced the air gap and magnetic current, enhanced the power factor, and reduced copper losses by about 18 percent.
(Dakheel et al., 2020)	One based on an artificial neural network (NARMA-L2) and the other using a traditional proportional integral derivative (PID) controller.	Improved Starting torque.

From the previous work to minimize current ripple and corresponding torque pulsation, the switching frequency must be increased. Furthermore, high frequency is required to avoid any interaction between the chopper frequency and the output frequency of the rectifier for all slip values. Increasing frequency tends to increase the probability of commutation failure of forced commutated thyristor.

3. The Latest Trends and Future Developments in WRIM by Rotor Impedance Variation Drive System

The WRIM drive system is used in several applications for machine capacities ranging from a few kilowatts to megawatts. Advanced power electronics components, including reactors, rotor rectifiers, DC link smoothing inductors, chopper circuits, external resistance, capacitors, and reactors, are used in various combinations and configurations in this system. To further enhance their performance, dc-dc converters have undergone new advances such boosting, buck boost, and increasing the smoothing inductor value in addition to increasing chopper frequency. These converters improvement provide WRIM drive system performance like a power factor, THD, efficiency of the system, speed, and torque pulsation. Given the importance of energy efficiency, research is still required to determine how these disruptions affect WRIM drive system performance. Furthermore, in order to establish a connection between disturbance and modification in WRIM drive performance, the previously mentioned researchers assessed extremely specific imbalance and harmonic distortion circumstances. Based on the aforementioned experiments, we have determined that more research and inquiry are necessary to analyze the WRIM stator resistance chopper control and SPRDS when supplied by a distorted and unbalanced supply voltage simultaneously. In addition to the poor-quality supply, the rotor bridge rectifier and inverter caused increased power derating and IM insulation degradation. This survey aims to provide an overview of the SRRCC performance study of the WRIM drive system. Numerous studies have been conducted in this area utilizing optimization strategies to regulate the system's torque, speed, steady state, and dynamic stability.

4-Conclusion

After reviewing most publications, a thorough literature study on WRIM by rotor impedance variation offers a detailed examination of the several techniques and technologies utilized to regulate and enhance the performance of WRIM drive systems. Different techniques and methods have been reviewed and discussed in this paper to improve the performance of WRIM by rotor impedance variation such as, static rotor resistance control, dynamic capacitor in rotor circuits, and optimal controlling like neural network control, fuzzy logic control, PSO and genetic algorithms. The review discusses historical patterns, practical applications, theoretical foundations, and recent advancements in the field. It highlights the benefits, challenges, and possible applications of rotor impedance variation to enhance WRIM performance in various industrial applications.

5-References

ABDEL-HALIM, M., BADR, M. & ALOLAH, A. 1997. Smooth starting of slip ring induction motors. *IEEE transactions on energy conversion,* 12**,** 317-322.

ALGAMLUOLI, A. F. & ABBAS, N. H. 2021. Speed controller design for three-phase induction motor based on dynamic adjustment grasshopper optimization algorithm. *International Journal of Electrical and Computer Engineering (IJECE),* 11**,** 1143-1157.

ALJAISM, W. Difference between Slip Ring Motor with Conventional Drive and Squirrel Cage Motor with Variable Speed Drive.

ALTAIRA, M. 2018. *Efficiency Improvement of Three Phase Squirrel Cage Induction Motor by Controlling the Applied Voltage to the Stator Using Simulink Models.* Colorado State University.

AMEEN, H. F. 2007. Stator Current Harmonic Analysis and Torque Pulsation of Wound Rotor Induction Motor Speed Control by Chopper Resistance in Rotor Circuit. *Zanco Journal of pure and Applied Science,* 19**,** 123-134.

AMEEN, H. F. 2011. Computer simulation and mathematical modelling of static rotor resistance chopper control of WRIM by reference frame theory. *Procedia Computer Science,* 3**,** 1009-1017.

AMEEN, H. F. 2023. The Influence of Rotor Converters on the Behavior of Static Rotor Resistance Control of Induction Motor under Supply Voltages Asymmetry. *Zanco Journal of Pure and Applied Sciences,* 35**,** 24-39.

AMEEN, H. F. & AULA, F. T. 2020. Performance Analysis of WRIM Drive System Operating under Distorted and Unbalanced Supply: A Survey. *Zanco Journal of Pure and Applied Sciences,* 32**,** 197-216.

AMEEN, H. F. & AULA, F. T. 2021. Performance Analysis of the Slip Power Recovery Induction Motor Drive System Under Unbalance Supply Voltages. *Advances in Electrical and Electronic Engineering,* 19**,** 192-202.

AMIN, H. High chopper frequency drive of wound rotor induction motor with a resistively loaded rotor chopper. ASTF-SR04 Conference, 2005.

BADR, M., ABDEL-HALIM, M. & ALOLAH, A. 1996. A nonconventional method for fast starting of three phase wound-rotor induction motors. *IEEE transactions on energy conversion,* 11**,** 701-707.

BADR, M., ALOLAH, A. & ABDEL-HALIM, M. 1995. A capacitor start three phase induction motor. *IEEE Transactions on Energy conversion,* 10**,** 675-680.

BADR, M., ALOLAH, A. & ALMARSHOOD, A. 1998. Transient performance of series connected three phase slip-ring induction motors. *IEEE Transactions on Energy conversion,* 13**,** 305-310.

BAKSHI, U. & GODSE, A. 2009. *Electrical machines & electronics*, Technical Publications.

CROWDER, R. & SMITH, G. 1979. Induction motors for crane applications. *IEE Journal on Electric Power Applications,* 2**,** 194-198.

DAKHEEL, H. S., ABDULLA, Z. B., JAWAD, H. J. & MOHAMMED, A. J. 2020. Comparative analysis of PID and neural network controllers for improving starting torque of wound rotor induction motor. *TELKOMNIKA (Telecommunication Computing Electronics and Control),* 18**,** 3142-3154.

DUBEY, G., PILLAI, S. & REDDY, P. 1975. Analysis and Design of a Dobly Fed Copper for Speed Control of Slip-Ring Induction Motors-Part I. *IEEE Transactions on Industrial Electronics and Control Instrumentation***,** 522-531.

DUC, H., DO, C., CONG, M. & QUOC, V. 2023. Efficiency Improvement of Induction Motors Based on Rotor Slot and Tooth Structures''. *Journal of Intelligent Systems and Control,* 2**,** 13-22.

ETEMADI, M. & HAGHIGHIAN, R. Design optimization of wound rotor induction motor using genetic algorithm. 2019 5th Conference on Knowledge Based Engineering and Innovation (KBEI), 2019. IEEE, 827-832.

GHOSH, P. K., SADHU, P. K., SANYAL, A., DEBABRATAROY & DUTTA, B. 2018. Design approach to a wound rotor induction motor towards optimization. *JOURNAL OF MECHANICS OF CONTINUA AND MATHEMATICAL SCIENCES,* 13**,** 159-172.

GUPTA, J., SINGH, B. & SINGH, B. 1985. A closed-loop rotor resistance control method for improved dc dynamic braking of wound rotor induction motor. *IEEE transactions on industry applications*, 235-240.

HAMOUDA, R., ALOLAH, A., BADR, M. & ABDEL-HALIM, M. 1999. A comparative study on the starting methods of three phase wound-rotor induction motors. I. *IEEE Transactions on Energy Conversion,* 14, 918-922.

HANNAN, M., ALI, J. A., HOSSAIN LIPU, M., MOHAMED, A., KER, P. J., INDRA MAHLIA, T., MANSOR, M., HUSSAIN, A., MUTTAQI, K. M. & DONG, Z. 2020. Role of optimization algorithms based fuzzy controller in achieving induction motor performance enhancement. *Nature communications,* 11, 3792.

IBRAHIM, A. M., PREMKUMAR, M. & SUMITHRA, T. 2016. Performance Parameters Control of Wound Rotor Induction Motor Using ANN Controller. *International Journal of Industrial Electronics And Electrical Engineering,* 4, 141.

JOSHI, S. & SK, P. 1980. Extension of control Range of pulse resistance controlled wound rotor induction motor.

KUMAR, K. R., PALANISWAMI, S. & KUMAR, K. S. 2012. Artificial neural network based rotor capacitive reactance control for energy efficient wound rotor induction motor. *Journal of Computer Science,* 8, 1085.

KUMAR, K. R., PALANISWAMI, S. & PRIYADHARSINI, K. 2010. Performance Enhancement of Wound Rotor Induction Motor by VSI with Dynamic Capacitor Controlled Rotor Circuit. *International Journal of Computer Applications,* 3, 31-37.

KUMAR, R., DOGRA, R. & AGGARWAL, P. 2017. Rotor side speed control methods using MATLAB/Simulink for wound induction motor. *International Journal of Mechanical and Mechatronics Engineering,* 11, 1378-1386.

LESAN, S., SMIAI, M. S. & SHEPHERD, W. 1996. Control of wound rotor induction motor using thyristors in the secondary circuits. *IEEE Transactions on Industry Applications,* 32, 335-344.

MAHAPATRA, S., DANIEL, R., DEY, D. N. & NAYAK, S. K. 2015. Induction motor control using PSO-ANFIS. *Procedia Computer Science,* 48, 753-768.

MCFARLAND, G. & ALVAREZ, W. 1948. The liquid rheostat for speed control of wound rotor induction motors. *Transactions of the American Institute of Electrical Engineers,* 67, 603-610.

MER, D. D., PATEL, R. A. & PRAJAPATI, M. G. 2014. Comprehensive study of speed control and power loss analysis using rotor resistance and slip power recovery method. *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering,* 2.

MOHAMMEDSAEED, E. K. & KARRAR, A. A. Finite element method based design of a Liquid Rheostat motor starter. 2016 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), 2016. IEEE, 1-6.

NASIR, B. A. 2022. Performance Improvement of Induction Motor Controlled by Thyristor Chopper on the Rotor Side. *IJEER,* 10, 1154-1158.

PORATE, K. & KOCHAR, N. R. 2014. "Minimization of power loss in SRIM with rotor chopper control. *International Journal of Emerging Technology and Advanced Engineering,* 4, 180-91.

PRASAD, V. M., NARASIMHAM, W. P. & RAM, G. S. R. 2014. Rotor Side control of high power slip ring induction motor using single thyristor. *IOSR Journal of Electrical and Electronics Engineering,* 9, 49-53.

Ranjith, K. and Palaniswami, S., 2011. Performance enhancement of Wound rotor induction motor by resonating rotor circuit using Fuzzy controller. European Journal of Scientific Research, 52(4), pp.580-591

SAEED, I. K. & AMEEN, H. F. 2011. ANN-Based WRIM Speed Control and Harmonic analysis of Rotor Chopper Resistance. *Journal of Engineering and Sustainable Development,* 15**,** 151-166.

SARWITO, S., SEMIN, S. & SUHERMAN, A. 2017. Analysis of three phases asynchronous slip ring motor performance feedback type 243. *International Journal of Marine Engineering Innovation and Research,* 2.

SEN, P. C. & MA, K. 1975. Rotor chopper control for induction motor drive: TRC strategy. *IEEE Transactions on Industry Applications***,** 43-49.

SUCIU, C., KANSARA, M., HOLMES, P. & SZABO, W. 2002. Performance enhancement of an induction motor by secondary impedance control. *IEEE Transactions on Energy Conversion,* 17**,** 211-216.

WANI, N. & RAMAMOORTY, M. 1977. Chopper-controlled slipring induction motor. *IEEE Transactions on Industrial Electronics and Control Instrumentation***,** 153-161.