International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 5, Number 2 (2012), pp. 197-207

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Performance Enhancement of Wound Rotor Induction Motor by Rotor Capacitive Reactance Control using Fuzzy Controller

[1]K. Ranjith Kumar, [2]S. Palaniswami and [3]G. Lourds Shiny

[1]Assistant Professor, Dept. of Electrical Engineering,
Govt. College of Technology, Coimbatore-641013, Tamilnadu, India
E-mail: ranjith_salem@yahoo.com
[2]Principal, Govt. College of Engineering,
Bargur, Krishnagiri Dt., Tamilnadu, India
E-mail: joegct81@yahoo.com
[3]P.G. Scholar, Govt. College of Technology,
Coimbatore-641013, Tamilnadu, India
E-mail: lourdseee@yahoo.co.in

Abstract

This paper investigates the enhancement in the performances of a three phase wound rotor induction motor by rotor capacitive reactance control using Fuzzy Logic Controller (FLC). The problem with the capacitive reactance control is the demand of high capacitance requirement and high torque ripples during motor operation. In the proposed control, dynamic capacitor is used for emulating the high rotor capacitance for control and eliminates the torque ripples significantly. The rotor circuit is employed with a three phase diode bridge with a dynamic capacitor which is controlled using (FLC). The dynamic capacitor is an H-bridge electronic switch with a fixed capacitor of low value in which the duty ratio is varied with the help of FLC to vary the capacitance value dynamically at different speed and loading conditions. The (FLC) has been designed to operate the rotor circuit closes to resonant. Under rotor resonant conditions, the performance parameters such as torque, power factor, efficiency and harmonics of the motor is analysed. The proposed method is simulated in MATLAB /Simulink environment. It is inferred from the results that the proposed fuzzy design improves the performances of the motor with reduction of torque ripples while compared with existing rotor resonant control schemes.

Keywords: Wound rotor Induction motor, Dynamic capacitor, Rotor resonant control, three phase bridge rectifier, Fuzzy controller.

Introduction

It is known from the literature and energy saving points that more than 60% of total electrical energy consumed worldwide is by Induction motors. Although Induction motors, specifically, squirrel cage types are widely used in electrical drives, wound rotor induction motor has some distinct applications like high torque, starting with high inertia loads, adjustable speed drives and soft starts. Hence the utility of wound rotor induction motor has also been increased on par with squirrel cage types of motors. In recent years, more attention has been given for efficiency and power factor improvement of these motors for significantly saving electrical energy.

Several methods have been proposed for performance improvement of wound rotor induction motor by rotor control. These can be distinctively classified as rotor resistance control and rotor impedance control.

In rotor resistance control, if equal resistances are included in each secondary phase of three phase induction motor, the speed, starting current and torque can be controlled. However speed decreases as the secondary resistances increases. At the same time, if the rotor circuit is added with additional resistances, the losses increases which in turn decrease the efficiency of the motor. There are number of chopper controlled rotor resistance control methods which have been presented and its performance were analysed in [1-5].

In order to overcome the problem faced by rotor resistance control, instead of varying the rotor resistance alone, the rotor impedance variation and control have been proposed in the literature to control the speed, torque and performance of the motor in [6-11].

A novel method for controlling the speed of wound rotor induction motor by operating such a motor close to its resonance have been introduced in [12]. In this method, the induction motor produces maximum torque when the rotor resistance is approximately equal to the slip times the rotor reactance. In order to get the resonant condition, a capacitive reactance has been introduced in the rotor circuit for cancelling the inductive reactance of the rotor circuit. Speed control of an induction motor is possible by having a resonant rotor circuit, which is adjusted according to the slip frequency. The main drawback of this method is high value of capacitance (order of Farad) required to operate the machine closes to rotor resonance conditions.

In order to overcome the problem faced in [12], a switched capacitor concept has been adopted for the secondary control of an induction motor to improve the efficiency, power factor and torque in [13]. It utilizes the concept of switched capacitor [14] 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. This paper describes the improvement of various performance parameters and speed control of the wound rotor induction machine. This paper has suggested implementing a fuzzy control in the rotor circuit for enhancing the performances of the motor.

The Space vector mathematical model of a static leading VAR secondary impedance controlled induction machine is presented in [15]. This paper has also described the rotor copper losses and its control with external capacitve reactance as control parameter for efficieny optimization of the motor.

The switched capacitor concept [14] has been adopted for the control of the phase difference between voltage and current in inductive circuits, using fuzzy logic control in [16] for improving the power factor of the circuit. The developed fuzzy model provides good results, even if the parameters of the circuit are unknown. This concept has been efficiently used in the proposed rotor resonant circuit.

In [17], The performance analysis of wound rotor induction motor with PI and Fuzzy has been discussed. In [18], the performance enhancement of induction motor with VSI fed dynamic capacitor controlled rotor circuit is presented.

This paper introduces a fuzzy controller in the rotor circuit for enhancing the performances of the motor. The proposed scheme focuses on operating the rotor circuit at unity power factor hence improving the motor power factor, efficiency and torque. The fuzzy model is established using Matlab/Simulink with rotor power factor (error) and change in rotor power factor (change in error) as inputs and duty ratio of the dynamic capacitor in the rotor control circuit as output. In the conventional rotor resonant control scheme [19], the torque ripples is high which is significantly reduced in the proposed FLC scheme.

Rotor Capacitive Reactance Control Scheme

Rotor resonance and impedance control schemes

In [12], the rotor circuit is operated by resonating at slip frequency by adding external rotor capacitive reactance which cancels the rotor inductive reactance

$$X_{L_r} = X_{ce_r} \tag{1}$$

This method is effectively used for controlling the speed. This method has also shown improvement in power factor for about 5%. This technique has also proved large torque at starting and low speed conditions. The drawback of this method is large capacitance required to operate the rotor at resonant conditions and no control strategy has been adopted for speed - torque control and performance improvement. In order to overcome the large capacitance requirement, switched capacitor can be used in each phase of the rotor circuit as described in [13] and [14]. A fuzzy controller based rotor resonant control has been investigated for the performance enhancement WRIM in [18]. An adaptive fuzzy controller for improving the speed of induction motor is discussed in [20].

Dynamic Switched Capacitor circuit

In [14], the paper describes the switched capacitor concept which is used to improve the power factor of the inductive circuit. It consists of placing an ac capacitor in the middle of an H bridge with bi-directional switches as shown in Fig.1 and Fig.2. The complementary switch pairs (S1, S4) and (S2, S3), respectively, are switched using pulses generated using DSP controller. During time interval, the switch pair (S1, S4) is ON the capacitor is charging and a serial RLC circuit is modelled.

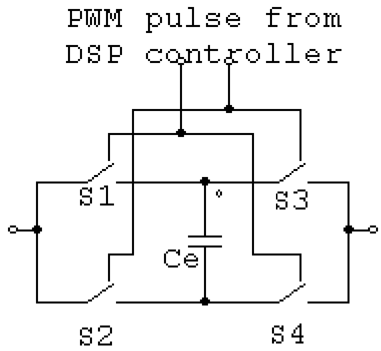


Figure 1: Basic H-Bridge switches with Capacitor

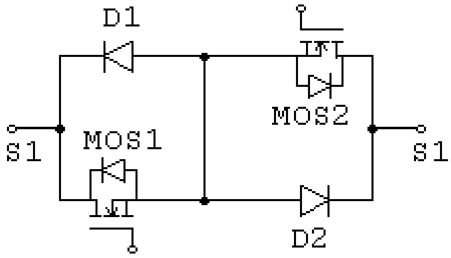


Figure 2: Bidirectional switch S_1

In the time interval, the switch pair (S2, S3) is ON the capacitor is applied with reverse polarity to the R_r-L_r circuit and the capacitor starts discharging. The time period is given by

$$T = T_{on} + T_{off} \tag{2}$$

$$d = \frac{Ton}{T} \tag{3}$$

In this way, the effective value of the rotor capacitance is given by

$$Ce = \frac{C}{(2d-1)^2} \tag{4}$$

The switched capacitor concept is adopted in the proposed method to change the capacitance value dynamically in the rotor circuit. The effective value of capacitance with respect to duty ratio for C=100µF is shown in Fig.3.

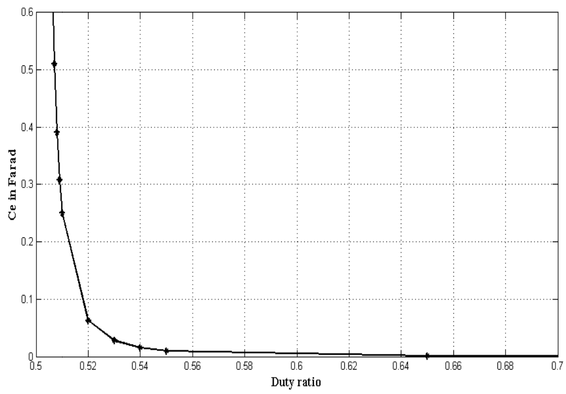


Figure 3: Ce Vs Duty ratio for C=100µF

Proposed Rotor Resonating using Fuzzy Control

Block diagram of Proposed Control Scheme

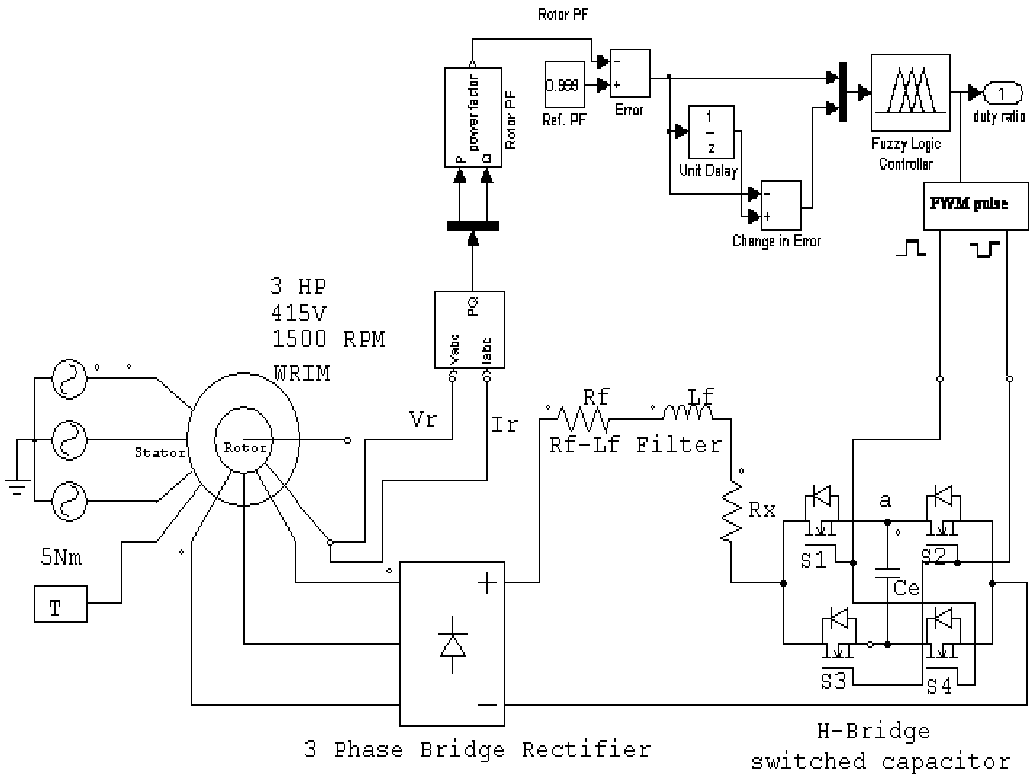


Figure 4: Block diagram of propose Fuzzy control scheme

Fuzzy Logic control scheme

The process of fuzzy logic controller design consists of four steps. (i) Fuzzification: the process of representing inputs as suitable linguistic variables. (ii) Inference Engine (Decision Making): the appropriate control action to be carried out which needs to be based on knowledge. (iii) Defuzzification: the process of converting fuzzified outputs into crisp values. A fuzzy logic controller initially converts the crisp errors and changes in error variables into fuzzy variables. Then they are mapped into linguistic labels.

Proposed Fuzzy Logic control design for resonating rotor circuit

In the case of an induction motor, the changes in circuit parameters are difficult to measure on line, the dynamic control of the capacitance value is very important. In the proposed scheme, dynamic capacitor is connected in each rotor phase and the duty ratio is controlled with the help of Fuzzy control for varying the capacitance value dynamically.

The relationship between the duty ratio and the desired rotor phase angle φ for the rotor circuit is deduced as given in (4.1) is derived as in [9] from the mathematical model for the circuit shown in Fig. 2.

$$\varphi_{\mathrm{r}} = \tan^{-1}\left(\frac{\omega \mathrm{rLr}}{\mathrm{Rr}} - \frac{(2\mathrm{d}-1)^2}{\omega \mathrm{rCrRr}}\right) \tag{5}$$

The rotor power factor can be expressed

$$\cos\varphi_{\mathrm{r}} = \frac{Pr}{\sqrt{Pr^2+Qr^2}} \tag{6}$$

The value of the duty ratio is influenced not just by the desired phase angle, but also by the parameters of the circuit: rotor resistance Rr, inductance Lr, pulsation ωr and the external capacitor C. These considerations can be effectively rectified by the proposed fuzzy controller to control the duty ratio dynamically as a function of a desired phase angle and not necessary on the values of the circuit parameters. The fuzzy controller is designed for the following criterion

$$\text{Duty ratio, d} = \text{minimizing f}(cos\varphi_{\mathrm{re}}, \Delta cos\varphi_{\mathrm{re}}) \tag{7}$$

Where,

φ_{re}- rotor phase angle (error) and

$\Delta\varphi_{\mathrm{re}}$- change in phase angle (change in error)

For the Fuzzy logic control, the first variable is the power factor (error- $cos\varphi r*(k)$), and the estimated power factor $cos\varphi r(k)$difference:

$$e(k) = cos\varphi r*(k) - cos\varphi r(k) \tag{8}$$

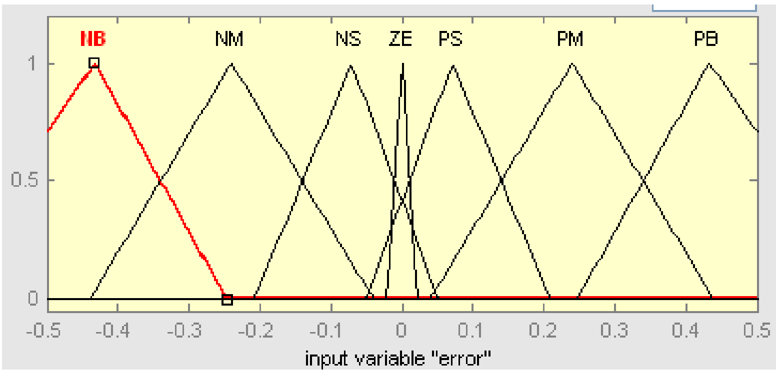
The second variable is the error variation, i.e.

$$\Delta e(k) = e(k) - e(k-1) \tag{9}$$

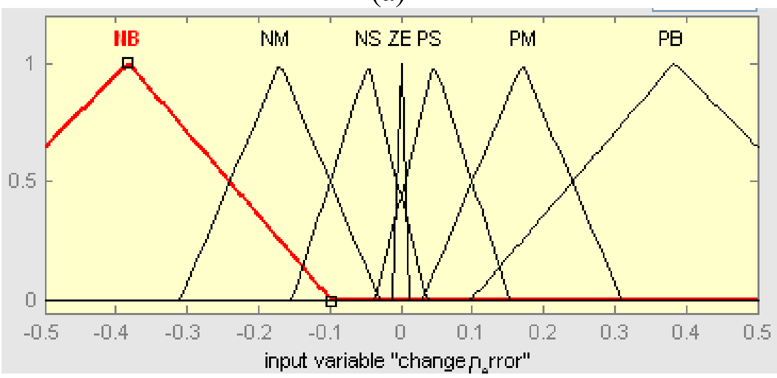
The control variable is the value of the ratio between incremental time command and the switching period:

i.e. duty ratio: $\mathrm{d}= \frac{\Delta \mathrm{t_{on}(K)}}{\mathrm{T}} = \frac{\mathrm{t_{on}(K)-t_{on}(K-1)}}{\mathrm{T}}$ (10)

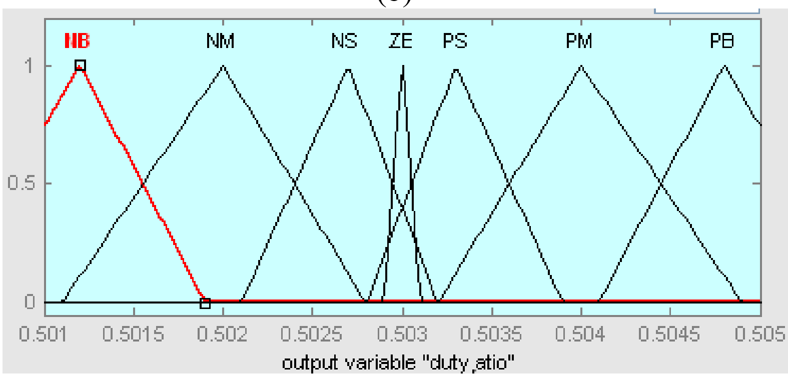
The triangular Membership functions are associated with each label as shown in the Fig. 5. (a)-(c). The linguistic labels are divided into seven groups: NB-negative big, NM- negative medium, NS-negative small, ZE-zero,PS-positive small, PM-positive medium, PB-positive big. Each of the inputs and output contains membership functions with all seven linguistics. The mapping of the fuzzy inputs into the required output is derived with the help of a rule base as given in Table 1. The defuzzification of output membership is done by centroid method for obtaining an accurate value of duty ratio.



(a)



(b)



(c)

Figure 5: Triangular Membership functions

Table 1: Set of fuzzy rules for proposed Fuzzy controller

PF Error / Change in PF error	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PB	PB	PB	PS	PS
NM	PM	PM	PM	PM	PS	PS	PS
NS	PS	PS	PS	PS	PS	PS	PS
ZE	ZE	ZE	ZE	ZE	ZE	ZE	ZE
PS	NS	NS	NS	NS	NS	NS	NS
PM	NS	NS	NM	NM	NM	NM	NM
PB	NB	NB	NB	NB	NB	NB	NB

Simulation Results and Discussions

A three phase wound rotor machine with rating and parameters shown in Table 2 is used for simulation. The machine is initially simulated with rotor short circuit for different loading conditions. Finally the rotor circuit is simulated with a dynamic capacitor which consists of H-bridge switch with a 100μF capacitor. This capacitance value is too small compared with operating the rotor with fixed capacitor. In this attempt, the duty ratio is controlled for varying the rotor capacitance using fuzzy controller. The performance parameters such as torque, power factor and efficiency are found and plotted for no load and full load as shown in the figures Fig.6 to 8 respectively. Fuzzy controller tunes the required duty ratio for H-Bridge switches in order for operating the rotor at resonant conditions and maintain unity power factor.

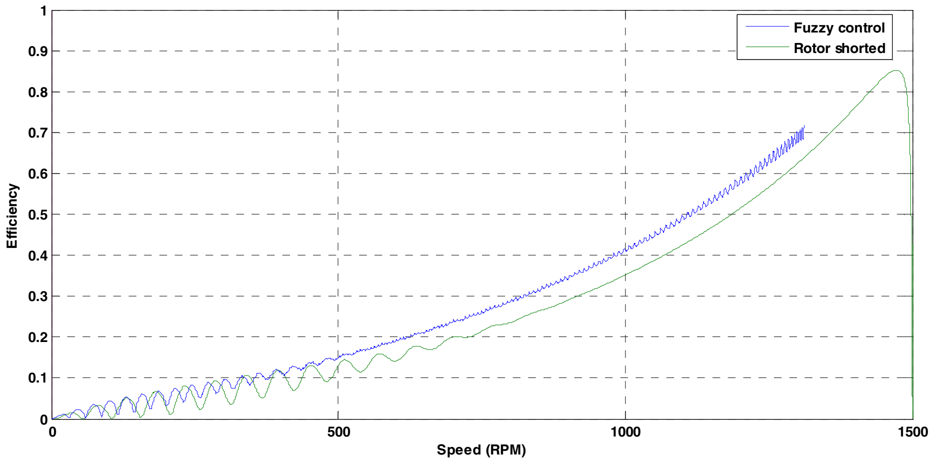


Figure 6: Efficiency vs Speed at full load torque

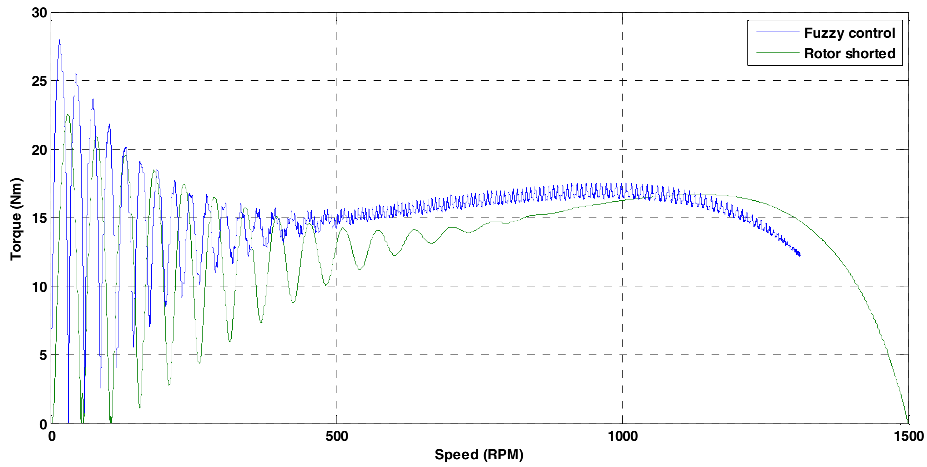


Figure 7: Speed – Torque characteristics at full load torque

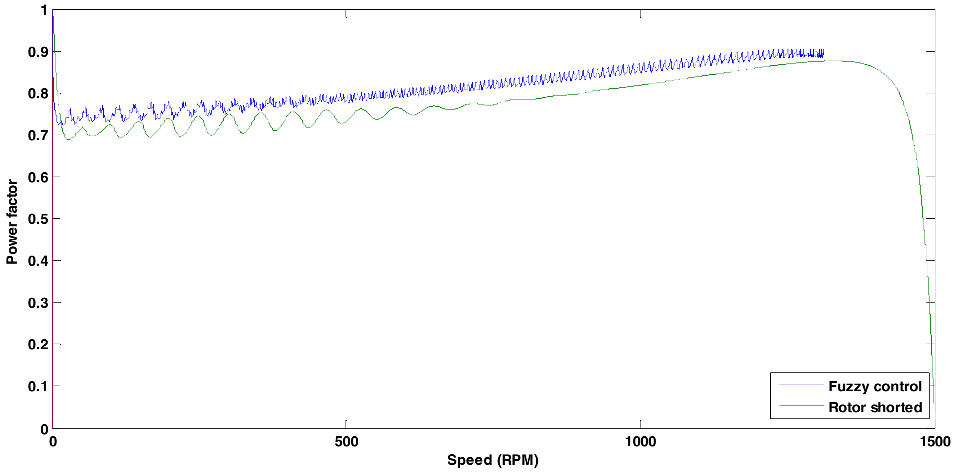


Figure 8: Power factor vs Speed at full load torque

Table 2: Rating and parameter of wound Induction motor

Rating of the motor	2.2 KW, 415V, 50Hz, 4 Poles
Stator resistance R_s in ohms	5.66
Rotor resistance R_r in ohms	2.22
Mutual inductance L_m in Hendry	0.291
Stator and rotor inductance $L_{s=}$ L_r in Hendry	0.0127
Rated load torque T_L in Nm	12

Conclusion

The proposed rotor resonant using fuzzy controller has been successfully simulated at different loading conditions in the Matlab/Simulink environment to improve the power factor and efficiency and torque of the wound rotor induction motor. The performance of the motor is analysed different load conditions. The proposed fuzzy control maintains the motor to operate closes to 0.9 power factor during steady state operations. Even at low speed region, the power factor is relatively more than the rotor short circuited. This is fairly high compared with the results shown in [19] and ripples are minimum. At standstill and low speeds, the torque is high and this high torque can be shifted and operated at any position of speed range. This typical torque characteristic could be an advantage in traction applications in control and breaking modes. The simulation presented has also shown that the rotor resonant with fuzzy control system will be more efficient. Further work should include hardware implementation of Fuzzy control strategy for validity of the results.

References

[1] M.Ray, A.K.Datta, “A variable speed induction motor using thyristor chopper”, Proceedings of IEEE, Vol. 62, No.10, pp.1397-1397, Nov. 1974.

[2] P.C.Sen, K.H.J.Ma, “Rotor chopper for Induction motor Drive: TRC strategy”, IEEE Trans. on Industrial Applications, Vol. IA-11, pp.43-49, Jan./Feb. 1975

[3] N.S.Wani, M.Ramamoorthy, “Chopper controlled slip ring induction motor”, IEEE Trans. on Industrial Electronics and Control Instrumentation, Vol. IECI-24, No.2, pp.153-161, June 1977.

[4] P.C.Sen, K.H.J.Ma, “Constant Torque operation of Induction motors using chopper in rotor circuit”, IEEE Trans. on Industrial Applications, Vol. IA-14, pp.408-414, Sep./Oct. 1978

[5] Chin S.Moo, Chung C.Wei, Ching L.Huang, Chao S.Chen, “Starting control of Wound rotor induction motor by using chopper controlled Resistance in rotor circuit”, IEEE, pp.2295-2300, 1989.

[6] M.Ayyadurai, B.P.Singh, C.S.Jha, R.Arokiasamy, “On the speed control of wound rotor induction motor using rotor impedance control”, IEEE Trans. on Power Appratus and systems, Vol.1, PAS-98, No.5, pp. 1489-1496, Sep./Oct. 1979.

[7] W.Shepherd and G.R.Slemon, “Rotor impedance control of the wound rotor induction motor”, AIEE Trans., Pt III, Vol 78, pp 807-814., Oct 1959.

[8] Y. Baghouz and O. T. Tan, “Optimal efficiency speed control of induction motors by variable rotor impedance,” *IEEE Trans. Energy Conv.,* vol. 4, pp. 216–223, June 1989.

[9] Dr.Saeed lesan, Dr. Mohamed S.Smiai, Prof. William shepherd, 1993, “Control of Wound Rotor Induction motor suing thyrsitor in the secondary circuits,” IEEE Trans., pp.380-389.

[10] Dr.Saeed lesan, Prof. William shepherd, “Control of Wound Rotor Induction motor using rotor impedance variation,” Proc. Of IEEE Trans. IAS Annual Meeting, Toronto Canada, pp.2115-2122, Oct.1993.

[11] H.Salama, M.kansara, P.G.Holmes, Y.Safar, “Optimal Steady state performance of induction motor drives”, in Proc. of OPTIM’ 96, pp- 1347-1360, May 1996

[12] J. Reinert and M. J. Parsley, “Controlling the speed of an induction motor by resonating the rotor circuit,” *IEEE Trans. Ind. Applicat., vol. 31, pp.* 887–891, July/Aug. 1995.

[13] Constantin Suciu,Mohan Kansara, Peter Holmes,and Wilibald Szabo,2002, “Performance Enhancement of an induction motor with secondary impedance control”, IEEE Transcations on Energy conversion, Vol 7, No 2 , pp. 211 – 216.

[14] C.Suciu, M.Kansara, P.G.Holmes, W. szabo, “Phase advancing for current in R-L circuits using switched capacitors”, in Electronics letters, vol. 35, no. 16; pp- 1296-7, Aug. 1999.

[15] C.Suciu, M.Kansara, P.G.Holmes, “A Space vector model of a static leading VAR secondary controlled induction machine”, in Proc. of OPTIM ’98, pp-375-379, May 1998.
[16] C.Suciu, L.Dafinca, M.Kansara, and I.Margineanu, “Switched capacitor fuzzy control for power factor correction in Inductive circuits”, in Proc.IEEE-PESC, Vol 2, pp. 773-777, June 2000.
[17] I.Thangaraju, M.Madheswaran, “Performance Analysis of Double Inverter Fed Wound Rotor Induction Motor using Fuzzy and PI Controller”, International Journal of Computer Applications(0975-8887), Vol. 1, No. 20, pp. 80-86, Jan. 2010.
[18] S.Palaniswami, K.Ranjith Kumar, K. Priyadharsini, July 2010, “Performance enhancement of wound Rotor Induction Motor by VSI with Dynamic Capacitor controlled Rotor Circuit”, International Journal of Computer Applications(0975-8887), Vol. 3, No. 9, pp. 31-37.
[19] K.Ranjith Kumar, S.Palaniswami, “Performance enhancement of wound rotor induction motor by resonating rotor circuit using Fuzzy controller”, European Journal of Scientific Research”, Vol. No. pp.580-591, 2011.
[20] B.K.Bose, “Power Electronics and AC drives”, Englewood Cliffs, NJ: Prentice Hall, 1986.
[21] P.Vas, Vector control of AC Machines, Oxford, U.K.: Clarendon Press, 1990.
[22] B.K.Bose, Adjustable AC speed drive systems, Newyork, IEEE Press, 1981.
[23] Fitzgerald, A.E, Kingsley, C, and Umans, S.D., “Electric Machinery”, 4th edition, McGraw-Hill Book Company, USA, 1983.