MATLAB/Simulink Based Design and Simulation of Speed Control of Three Phase Slip Ring Induction Motor Using Chopper

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6 authors, including:

Chaitanya Jambotkar
Jain College of Engineering & Research

MATLAB/Simulink Based Design and Simulation of Speed Control of Three Phase Slip Ring Induction Motor Using Chopper

Chandana Sooji[1], Mala Bogar[2], Megha Dhage[3],Shuklambari Madiwalar[4], Vijayshree Horadi[5],Asst.Prof.Chaitanya J[6]

[1,2,3,4,5] 4th SEM Students in Department of Electrical and Electronics Engineering, KLE.I.T, Hubballi, Karnataka, India.

[6] Assistant Professor in Department of Electrical and Electronics Engineering, KLE.I.T, Hubballi, Karnataka, India.

***Abstract*— In recent years, advancement in power electronics has created a huge impact on operation and speed control of Induction motor drives. This paper initiates a novel idea to control the speed of three phase induction motor using chopper. As literature suggests, the speed of a three phase induction motor can be controlled either by using armature voltage control technique or by adding external resistance in the rotor circuit manually. The paper deals with developing a power electronic based control system which allows to control the speed of three phase induction motor by overcoming the drawbacks of conventional techniques. In this technique, chopper circuit is so developed such that as duty cycle of the chopper is increased the speed of the three phase induction motor should be increased. Initially, the name plate details of three phase slip ring induction motor whose speed is to be controlled is noted and by conducting No-Load Test and Locked rotor Test on the motor the equivalent electrical circuit is developed. The same is simulated on the MATLAB/Simulink platform with chopper controlled external resistance. The complete system is executed for different duty cycles of chopper to evaluate the control parameters and performance parameters of system. It is found that the high chopper frequency tend to improve the performance of three phase slip ring induction motor drive such as, rotor rectified current, rotor phase current, speed smoothing with reducing the torque pulsation and ripple of rotor rectified current whereas increase in the duty cycle of chopper, the speed of the three phase induction motor is found to be increased. So we conclude that, the proposed technique of speed control is optimum compared to conventional techniques of speed control of three phase slip ring induction motor. Further the same system could be upgraded to wireless speed control platform by providing control signal to circuit from remote place.**

***Index Terms*—DC-DC Converter, Induction motor, PWM Technique.**

I. INTRODUCTION

Induction motors are the most widely used electrical motors due to their reliability, low cost and robustness. However, induction motors do not inherently have the capability of variable speed operation. Due to this reason, DC motors found applications in the electrical drives. But the recent developments in speed control methods of the induction motor have led to their large scale use in almost all electrical drives.

Induction motors are a constant speed machines which account for 90% of the electrical drives used in Industry. Induction motors are usually constructed to work with a small value of slip, normally less than 5% at full load. Therefore the deviation of the motor speed from the synchronous speed is practically very small. However, there are certain applications that require enormous variation of the motor speed. With the increase in availability of high current power electronic devices, smooth and quick variation of external resistance introduced in the rotor circuit of slip ring induction motor to control its speed, can be accomplished electronically.

Schemes employing chopper control resistance can be used to obtain a constant torque, constant speed or any desired characteristics by using a proper feedback circuit along with it. Such circuits are widely used in industrial applications where the drive operation is intermittent such as hoists, cranes, conveyors, lifts, excavators and high starting torque are more important with low starting current to avoid voltage dip. The torque depends on motor resistance. Therefore, increasing the rotor resistance at a constant torque causes a proportionate increase in the motor slip with decrease in rotor speed. Thus, the speed for a given load torque may be varied by varying the rotor resistance.

The function of this resistance is to introduce voltage at rotor frequency, which opposes the voltage induced in rotor winding. Conventionally, the rotor resistance is controlled manually and in discrete steps. The main demerit of this method of speed control is that energy is dissipated in rotor circuit resistance. Because of the waste-fullness of this

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method, it is used where speed change are needed for short duration only.

This paper proposes a speed control concept which eliminates the drawbacks of a conventional scheme by using a 3 phase un-controlled bridge rectifier and a chopper controlled external resistance. However, this arrangement for controlling the average value of rotor current (external resistance) introduces the additional problems of discontinuity in the rotor winding currents and voltage spikes across the chopper. These problems can be eliminated by having a filter circuit in the rotor of slip ring induction motor.

II. CONVENTIONAL TECHNIQUE OF SPEED CONTROL

Conventionally, the rotor resistance is controlled manually and in discrete steps. The torque is proportional to product of rotor current and fundamental magnetic flux cutting rotor. The maximum torque is independent of rotor resistance, but the value of slip at which maximum torque occurs is directly proportional to the added rotor resistance. Increase in the rotor resistance does not affect the value of maximum torque but increases the slip. The Equation 1 illustrates that when a high starting torque is required, the R2 should be chosen appropriately to obtain Tmax at stand still.

$$\mathrm{T} = \frac{\mathrm{K_s E_z^2 R_2}}{\mathrm{R_2^2 + s^2 X_2^2}} ----------- (1)$$

The following Fig. 1 shows conventional method of speed control of three phase slip ring induction motor.

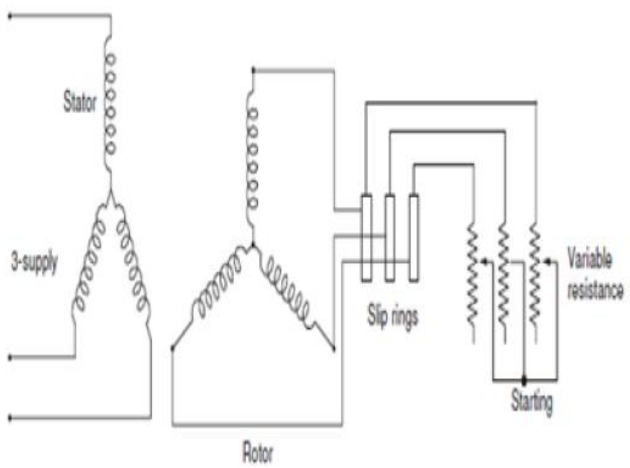

Fig. 1 conventional scheme of speed control

The Following Fig. 2 shows the speed-torque characteristics of a slip ring induction motor for different values of rotor resistances.

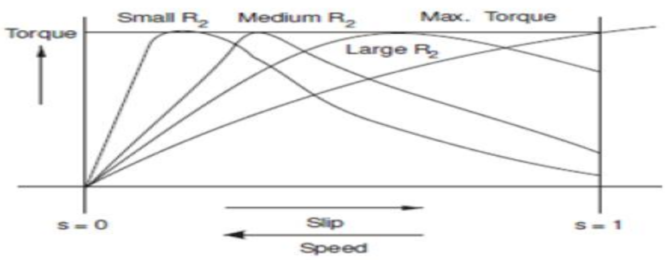

Fig. 2 speed-torque characteristics of a slip-ring induction motor for different values of rotor resistances.

The main drawback of the conventional scheme is, energy is dissipated in rotor circuit resistance. Because of the waste-fullness of the energy, it is used only where speed change is needed for short duration.

III. PROPOSED TECHNIQUE OF SPEED CONTROL

With the advent of power semiconductors, the conventional resistance control scheme can be eliminated by using a three-phase rectifier bridge and a chopper controlled external resistance as shown in Fig. 3.

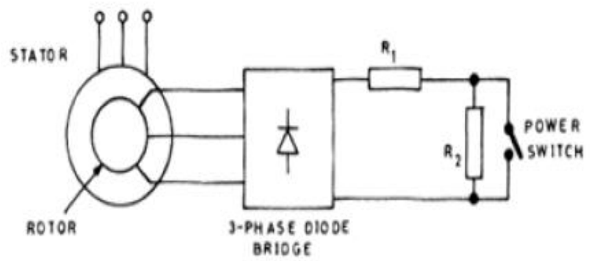

Fig. 3 Proposed method of speed control

A chopper is a power switch which is electronically controlled by a control circuit. When the chopper is in the ON mode of operation, the equivalent resistance in the rotor circuit is R1. When the chopper is in the OFF mode of operation, the equivalent external resistance in the rotor circuit is (R1 + R2). If the chopper is periodically regulated so that, in each chopper period, it is ON for some time and OFF for the rest, it is possible to obtain a variation in equivalent external resistance between R1 and (R1 + R2). Thus the chopper electronically alters the external resistance R2 in a continuous and contactless manner.

The duty cycle (D= ton/(ton + toff)) of the chopper is controlled by a pulse width modulation (PWM) circuit.

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This simple arrangement for controlling the average value of rotor current (external resistance) introduces the additional problems of discontinuity in the rotor winding currents and voltage spikes across the chopper. These problems are eliminated by having either a first or second order filter in the rotor circuit.

The following tables, Table-1 to Table-4 give details regarding the electrical parameters of the machine whose speed is to be controlled.

Name Plate Details of the Machine

General Parameters:

Table1-1 General parameters of the machine

Parameter	Specification
Phase	3 Phase
Frequency	50 Hz
Pole	6
Speed	1000 RPM
% Efficiency	81 %
Power	2.2 KW / 3 H.P

Stator:

Table1-2 Details of stator winding

Parameter	Specification
Voltage	415 V
Current	6.6 A
Connection	Star Connected

Rotor:

Table1-3 Details of rotor winding

Parameter	Specification
Voltage	120 V
Current	11.6 A
Connection	Star Connected

Initially, the name plate details of three phase slip ring induction motor whose speed is to be controlled is noted and by conducting No-Load Test and Locked rotor Test on the motor the equivalent electrical circuit is developed.

The stator and rotor resistance and inductance as referred to stator determined by conducting No–Load test and Locked Rotor test is shown in Table4,

Table1-4 Details of Equivalent circuit as referred to stator winding of the machine

Parameter	Value
Stator Resistance (Rs)	0.7384 Ohm
Rotor Resistance (Rr)	0.7402 Ohm
Stator Inductance (Ls)	3 mH
Rotor Inductance (Lr)	3 mH
Mutual Inductance (Lm)	0.1241 H
Rotor Inertia (J)	0.0343 Kg-m^2
Torque (T)	14.85 N-m

The complete proposed system is designed and then simulated on MATLAB/Simulink Platform. The following Fig. 4 shows the Simulink model of the proposed concept.

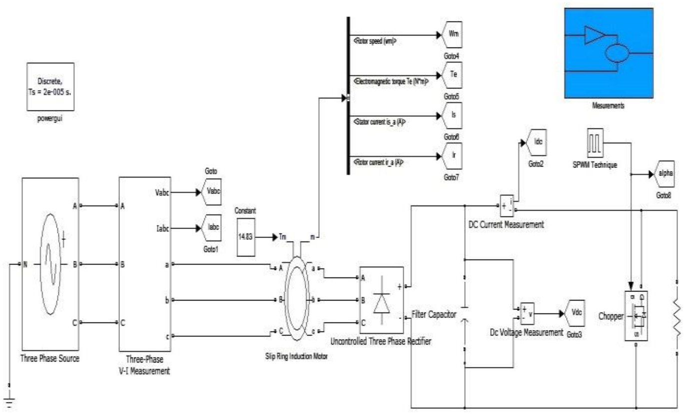

Fig. 4 Simulink model of the proposed concept.

IV. SIMULATION RESULTS AND DISCUSSION

The Simulink model of proposed concept had been simulated for duty ratios varying from 0% to 100% by having fixed external resistance. The procedure was repeated for different external resistance values such as 30 ohm, 60 ohm, 90 ohm and 120 ohm. In the next simulation, the duty cycle was maintained constant first at 50% then at 80% and the switching frequency of chopper was varied from 50 Hz to 4K Hz. The results of both these simulations are shown in Table-5 and Table-6 respectively.

The following Table 5 shows the simulation results of the proposed concept by having the following constraints for the Simulink model Fsw = 50 Hz, Tsw = 0.02 sec, Rext = 30 ohm, T = 14.85 N-m.

The following Table 6 shows the simulation results of the proposed concept for the Simulink model by having the following constraints D = 50%,Rext = 30 ohm,T = 14.85 N-m.

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Table-5 Simulation results of effect on speed due to change in duty cycle

Duty Cycle in %	(Vabc)rms in V	(Iabc)rms in A	Nmean in RPM	Tmean in N-m	(Is)mean in A	(Ir)mean in A	(Vdc)mean in V	(Idc)mean in A
0	239.6	7.032	907.1	15.53	-1.079	-0.8054	50.74	3.408
10	239.6	5.718	935.6	13.68	0.4687	0.9534	35.23	3.064
20	239.6	7.079	961.4	14.24	2.208	0.3057	19.78	2.869
30	239.6	6.264	953	14.66	-0.03	-2.934	14.3	4.11
40	239.6	6.089	954.6	13.73	-1.03	-1.039	15.17	3.095
50	239.6	6.115	965	15.04	-0.901	2.806	11.63	2.668
60	239.6	6.658	975	14.7	0.4058	0.2435	5.349	2.915
70	239.6	6.379	977.6	14.69	0.1021	-2.793	3.637	2.871
80	239.6	6.601	981.1	14.83	0.3097	-2.748	2.064	2.838
90	239.6	6.571	978.7	14.04	-0.2036	-1.321	1.489	2.894
100	239.6	6.656	974.8	14.09	1.037	-0.4262	1.037	2.931

Table-6 Simulation results of effect on speed due to change in switching frequency

Switching Frequency in Hz	(Vabc)rms in V	(Iabc)rms in A	Nmean in RPM	Tmean in N-m	(Is)mean in A	(Ir)mean in A	(Vdc)mean in V	(Idc)mean in A
50	239.6	6.466	965.6	14.85	0.596	2.028	12.31	9.485
100	239.6	6.755	970.2	13.61	0.1373	1.914	7.95	6.856
500	239.6	6.062	975.3	14.98	-0.0405	-0.7482	4.46	5.645
1000	239.6	6.272	979.9	15.12	0.045	-2.788	3.021	4.644
1500	239.6	5.904	977.9	15.13	-0.1483	-2.957	2.746	4.592
2000	239.6	6.178	977.7	14.96	-0.0132	-3.114	2.673	4.725
2500	239.6	6.884	978.3	14.62	-0.0509	-2.99	2.203	4.28
3000	239.6	6.813	980.1	14.27	0.095	-2.748	1.873	3.831
4000	239.6	6.814	980	14.24	0.084	-2.751	1.878	3.839
4500	239.6	6.807	980.3	14.33	0.107	-2.745	1.85	3.813
5000	239.6	6.827	979.2	14.21	-0.0601	-2.817	1.968	3.979

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The following Fig. 5 shows the nature of three phase input voltage in volts which is fed as input to the stator of three phase induction motor.

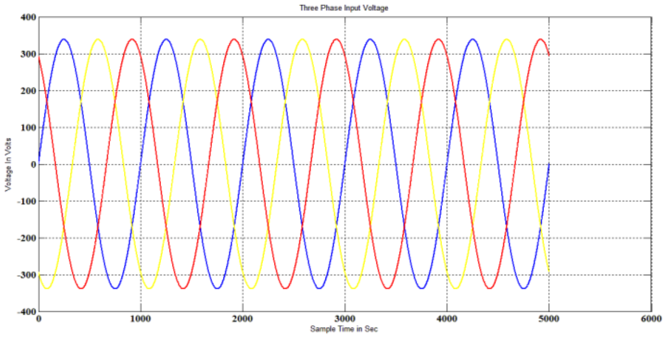

Fig. 5 Three phase input voltage to stator

The following Fig. 6 shows the plot of stator current in amperes. As it can be referred from the figure 6 that, the motor draws 10 times more the rated current during starting as there is no back emf available in the circuit then further it settles at the rated current provided a rated load is applied on the motor.

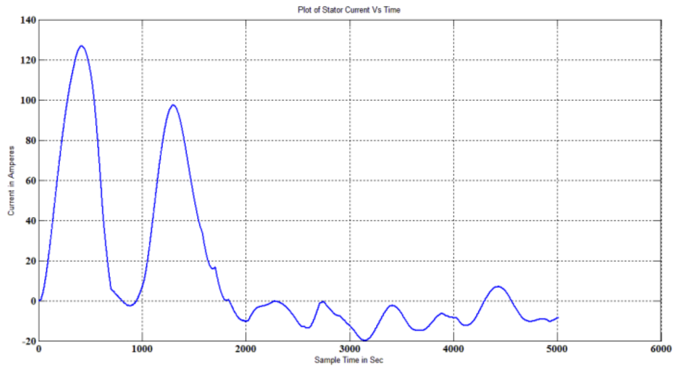

Fig. 6 Plot of stator current

The following Fig. 7 shows the plot of rotor current in amperes.

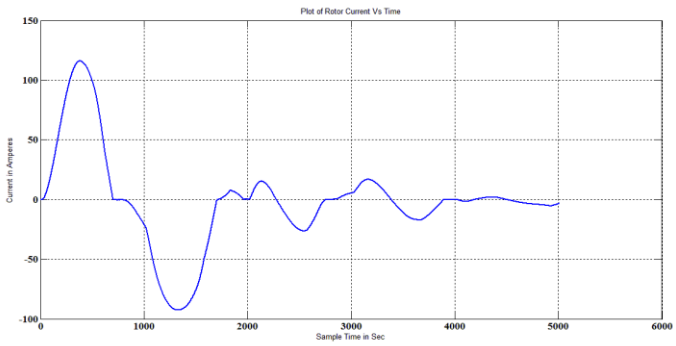

Fig. 7 Plot of rotor current

The following Fig. 8 shows the plot of speed in rad/sec. As shown in the figure 8 we can observe that the motor is taking more transient time before settling at the constant speed.

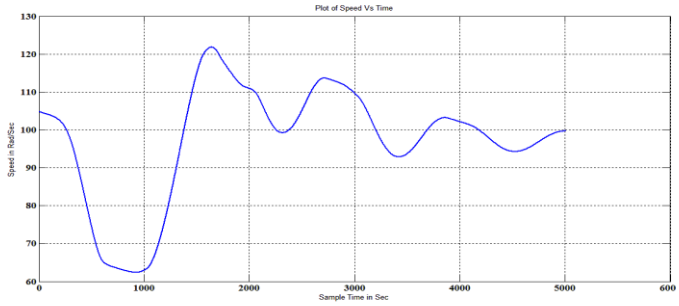

Fig. 8 Plot of speed

The following Fig. 9 shows the plot of PWM signal. As shown in the figure 9, we can observe that it is the PWM signal with the duty cycle been set to 50%. However the provision is provided in the model to vary duty cycle from 0% to 100%.

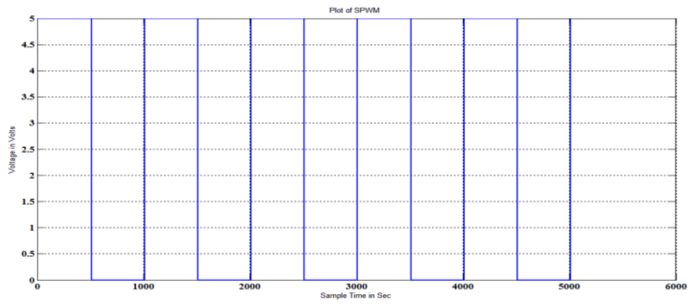

Fig. 9 Plot of PWM signal

The following Fig. 10 shows the plot of change in speed as duty cycle is increased from 0% to 100%. It is observed that as duty cycle of chopper is increased the speed of three phase slip ring induction motor is also increased. Interesting observation from the graph obtained is that the change is not completely a linear it is because of resistance offered during speed control through chopper.

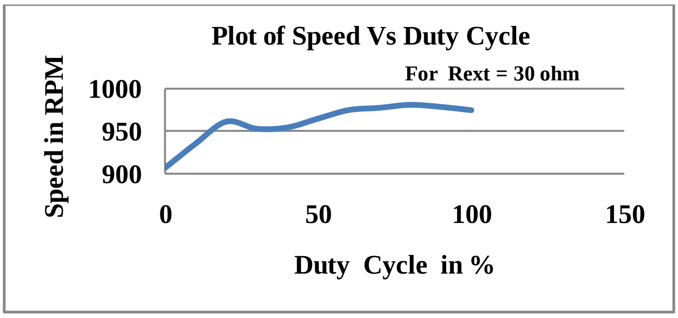

Fig. 10 Plot of speed Vs duty cycle

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The following Fig. 11 shows the plot of change in voltage drop across external resistance as duty cycle is increased from 0% to 100%. It is observed that as the duty cycle of chopper is increased the potential across external resistance decreases. The potential drop across external resistance is proportional to the resistance offered by the external resistance at that duty cycle.

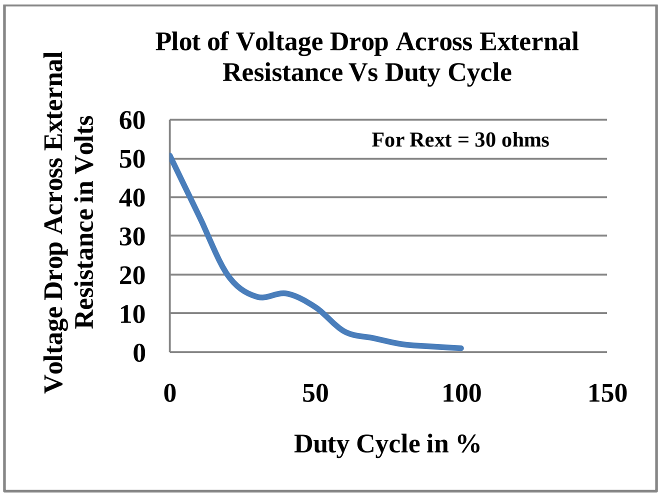

Fig. 11 Plot of voltage drop across external resistance Vs duty cycle

The following Fig. 12 shows the plot of change in speed as switching frequency is varied from 50Hz to 5000 Hz maintaining duty cycle constant at 50%. It is observed that having duty cycle constant, change in switching frequency has got very less effect on the speed of three phase slip ring induction motor.

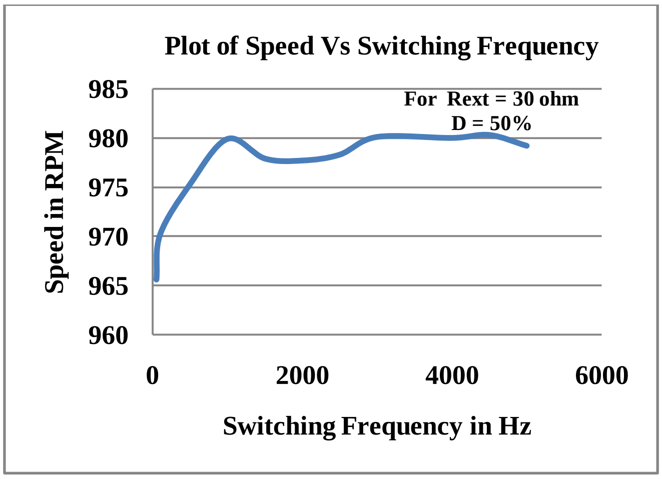

Fig. 12 Plot of speed Vs switching frequency

The following Fig. 13 shows the plot of change in voltage drop across external resistance as switching frequency is varied from 50Hz to 5000 Hz. It is observed that keeping duty cycle constant at 50% if switching frequency is altered from 50 Hz to 5000 Hz the voltage drop across external resistance follows a negative exponential curve and attains saturation at 3000 Hz.

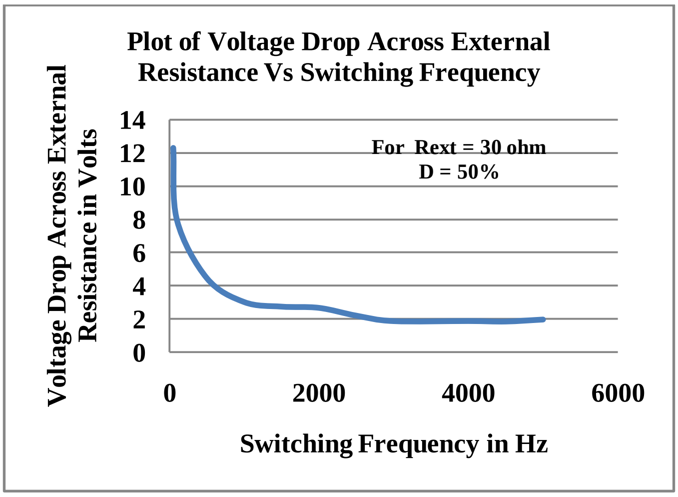

Fig. 13 Plot of voltage drop across external resistance Vs switching frequency

The following Fig. 14 shows the comparison plot of change in speed as duty cycle is varied from 0% to 100%. It is observed that as resistance value of external resistance is increased the range of speed control is increased. But as inclusion of resistance in rotor circuit increases power dissipation in rotor circuit increases. Hence there should be a trade-off between speed control range and power dissipation while selecting the value for external resistance across chopper.

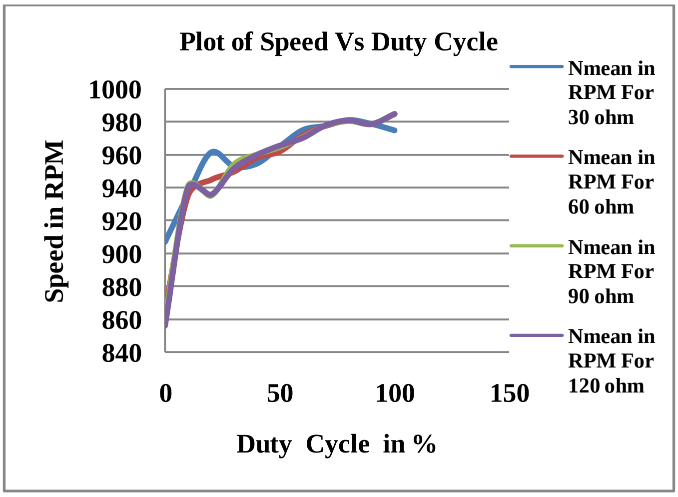

Fig. 14 Plot of speed Vs duty cycle

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The following Fig. 15 shows the plot of change in speed as switching frequency is varied from 50Hz to 5000 Hz. It is observed that as the duty cycle is increased the switching frequency losses the control on speed and hence gives a constant speed at all switching frequency.

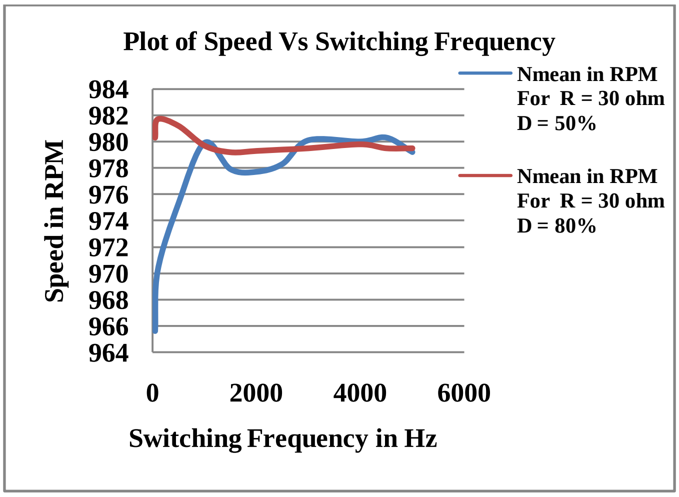

Fig. 15 Plot of speed Vs switching frequency

The following Fig. 16 shows the plot of change in voltage drop across external resistance as duty cycle is increased from 0% to 100%. It is observed that increase in the value of external resistance the potential drop across for a duty cycle is found to be increased, hence increases the range of speed control but affects the performance of the system by introducing a lot of heat in the rotor circuit.

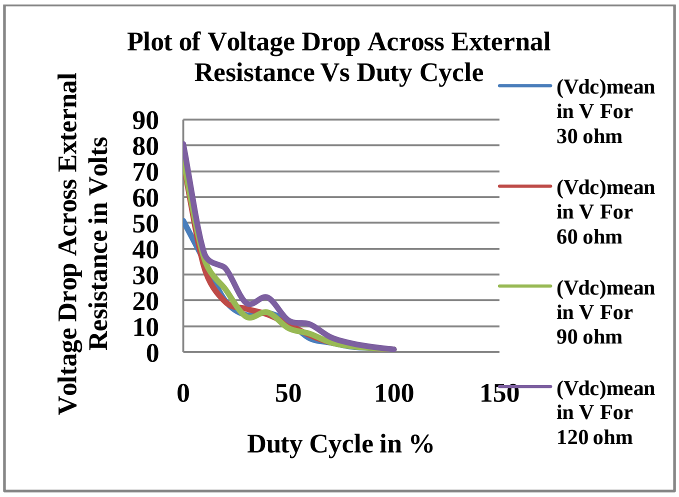

Fig. 16 Plot of voltage drop across external resistance Vs duty cycle

The following Fig. 17 shows the plot of change in voltage across external resistance as switching frequency is varied from 50Hz to 5000 Hz. It is observed that the switching frequency losses the control over the speed if duty cycle value exceeds 50%. Hence voltage drop across the external resistance becomes constant.

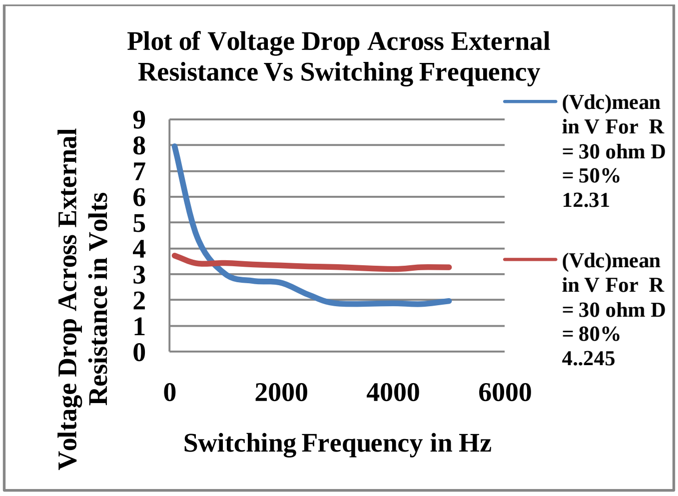

Fig. 17 Plot of voltage drop across external resistance Vs switching frequency

V. CONCLUSION

The chopper based speed control circuit for three phase slip ring induction motor is designed and simulated. The effect of duty cycle for different value of external resistance and effect of chopper frequency at different duty cycles for slip ring induction motor is analyzed. Based on the observations and obtained results the following concepts can be concluded,

- The speed of slip ring induction motor is increased with increase in the duty cycle for a external resistance added in the rotor circuit.
- Low value of chopper frequency causes fluctuation in motor speed and torque pulsation.
- Increase in the chopper frequency, decreases the ripple in rotor rectified voltage, speed variation and improves electromagnetic torque characteristics of the motor.

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