ANALYSIS OF DOUBLY FED INDUCTION GENERATOR PERFORMANCE WITH VARIATION IN ROTOR RESISTANCE

Nitin Goel, Paras Ram Sharma,
YMCA University of Sci. & Tech., Faridabad, India

Dheeraj Joshi
Delhi Technological University, New Delhi, India

ABSTRACT — In this paper the analysis of doubly fed induction generator has been done for varying rotor resistance. Effects of the rotor resistance and rotor injected voltage on the stator active and reactive power, rotor active and reactive power, stator and rotor currents and net power of doubly fed induction generator are studied, when the machine run with below synchronous speed and above synchronous speed. After finding the induction machine parameters, analysis is done by MATLAB/ Simulink. It has been shown that with variation in rotor resistance and rotor injected voltage would control the mode of operation of induction machine; motoring mode and generating mode.

***Keywords*—Doubly fed induction generator, Wind energy, Asynchronous operation**

INTRODUCTION

Text Since traditional power generation technologies lead to some environmental issues, and also face a limitation of fuel resources, renewable energy conversion becomes more and more popular now days. Meanwhile the consumption of electrical energy increasing day by day and more electricity is preferred to be generated from renewable energy resources.

The amount of energy converted from renewable sources was growing relatively slowly in past 60 years. The wind energy has been started to be utilized since the early 1980s. However wind energy generation increased slowly in the past several decades. In recent years, when the advanced technologies like the decoupled control of doubly fed induction generator (DFIG), pitch angle regulated wind turbine and large capacity and high efficient power converters, were implemented into wind energy conversion, more and more power captured and fed to grid.

The worldwide installed capacity of wind power reached 539.581 GW by the end of 2017 Fig.1. China (188.232 MW), US (89.077 MW), Germany (56.132 MW) and Spain (23.170 MW) are ahead of India in fourth position (32.848 MW) [1].

The development of wind power in India began in the 1990s, and has significantly increased in the last few years.

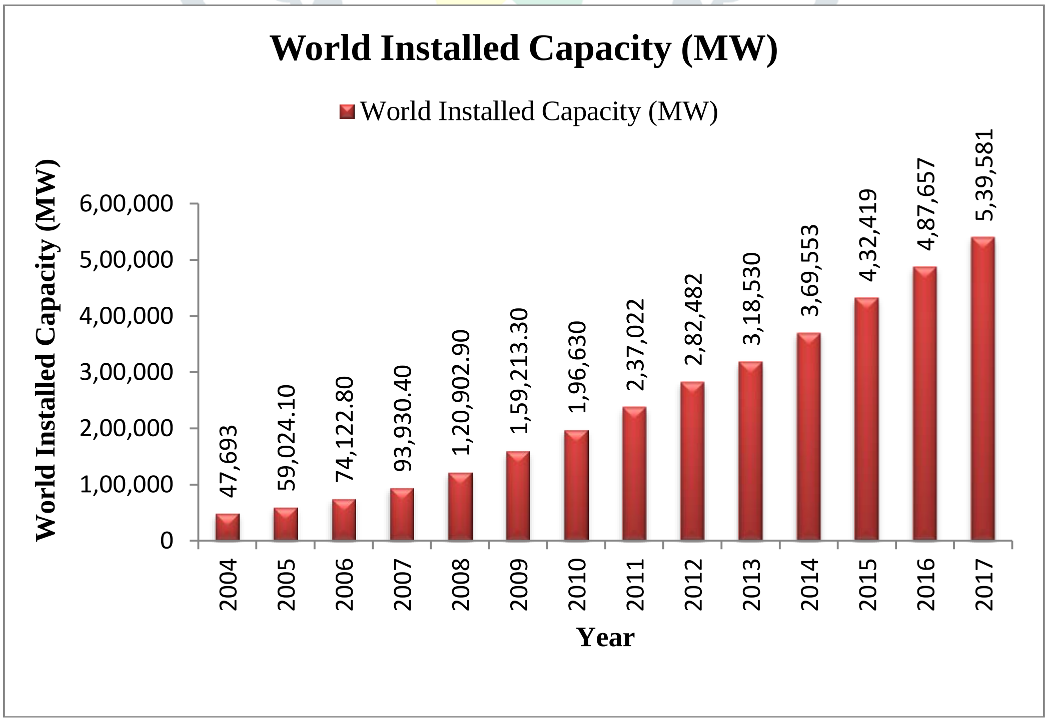

Fig.1. World Installed Capacity (MW)

As on March 2018 the installed capacity of wind power in India was 34043 MW[2]. Installed capacity of wind energy plants in different states in shown in Fig.2.

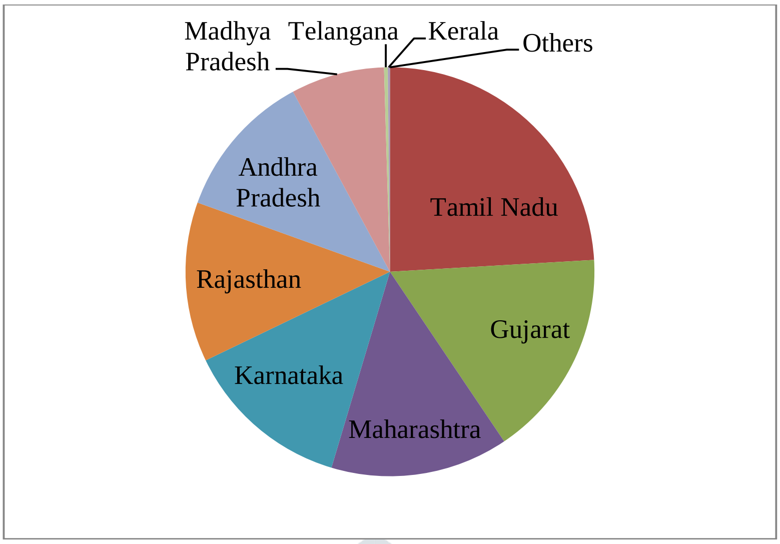

Fig.2. State wise Installed capacity in India

The major components of a wind energy conversion system include a wind turbine, generator, interconnection apparatus and control systems. Wind turbines can be classified into the vertical axis type and the horizontal axis type. Most modern wind turbines use a horizontal axis configuration with two or three blades. A wind turbine can be designed for a constant speed or variable speed operation. The electrical energy generation by wind depends on different factors, in particular the wind speed and the characteristics of the wind turbine generator [3]. Traditionally the wind power generation has used fixed speed induction generators that represent a simple and robust solution, and then variable speed turbines have been considered. The advantages of variable speed turbines are that they provide higher energy, allow an extended control of both active and reactive power and presentless fluctuation in output power.

Induction generator and synchronous generators both can be used for wind turbine systems. Induction generators can be used in a fixed speed system as well as variable-speed system, while synchronous generators are normally used with power electronic interfaced variable-speed systems. Mainly, three types of induction generators are used in wind power conversion systems: cage rotor, wound rotor with slip control by changing rotor resistance, and DFIG [4]. The cage rotor induction machine can be directly connected into an ac system and operates at a fixed speed or uses a full-rated power electronic system to operate at variable speed. The wound rotor generator with rotor resistance- slip control is normally directly connected to an ac system, but the slip control provides the ability of changing the operation speed in a certain range. The DFIG provides a wide range of speed variation depending on the size of power electronic converter systems. In this paper we discuss the systems without power electronics.

Doubly-fed induction machines can be operated as a generator as well as a motor in both sub synchronous and super synchronous speeds. Only the two generating modes at sub synchronous and super synchronous speeds are of interest for wind power generation. In a DIFG the slip rings are making the electrical connection to the rotor [5-6]. If the generator is running super-synchronously, electrical power is delivered to the grid through both the rotor and the stator. If the generator is running sub-synchronously, electrical power is delivered into the rotor from the grid.

STEADY STATE ANALYSIS OF DFIG

The steady state performance can be described by using equivalent circuit model shown in fig. 4. In this figure, V_1 is stator voltage and E_j is rotor injected voltages, $I_1$and $I_2$are the stator and rotor current, $R_1$and $R_2$are the stator and rotor resistance, $X_1$and $X_2$are the stator and rotor leakage reactance, $X_m$is the magnetizing reactance and s is slip.

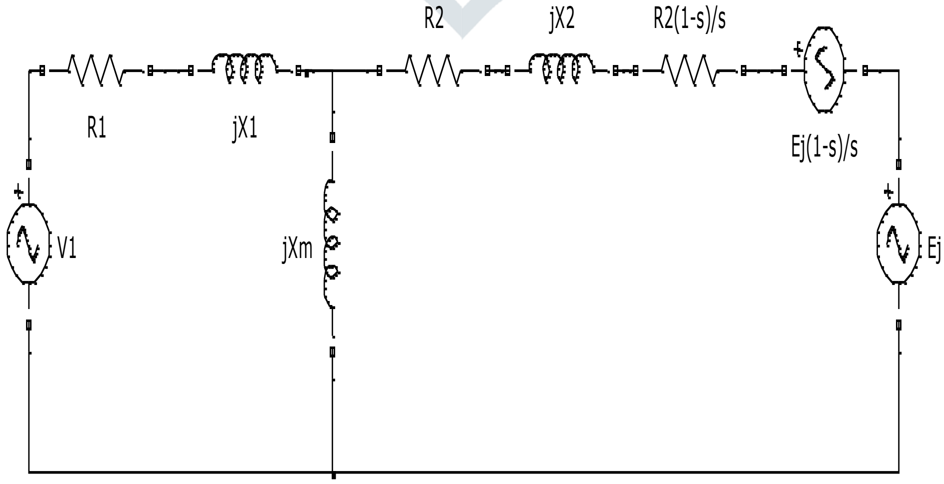

Fig- 3 DFIG equivalent circuit with injected voltage in the rotor

By the application of Thevenin's theorem to stator part, replace the above equivalent circuit by the circuit shown in fig-5. [7]

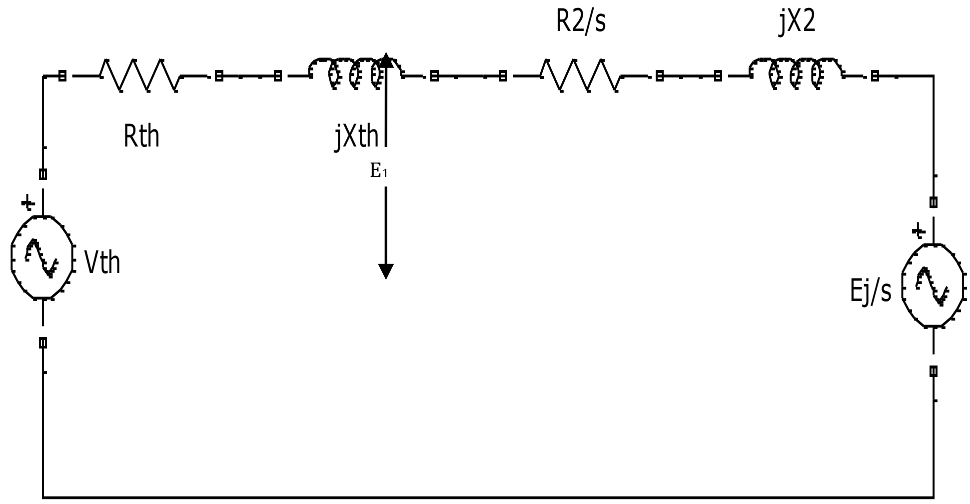

Fig-4 Thevenin's equivalent circuit of DFIG

The equivalent source voltage

$$V_{th} = \frac{V_1 \angle 0^o \times j\, X_m}{R_1 + j(X_1 + X_m)} = V_{th} \angle \theta_{th}$$

equivalent stator impedance

$$Z_{th} = \frac{(R_1 + jX_1)\,(jX_m))}{R_1 + j(X_1 + X_m)} = R_{th} + jX_{th}$$

Rotor current

$$I_2 = \frac{V_{th} \angle \theta_{th} - \frac{E_j \angle \theta_j}{s}}{\left(R_{th} + \frac{R_2}{s}\right) + j(X_{th} + X_2)} = I_2 \angle \emptyset_2$$

Stator induced emf

$$E_1 = I_2 \left(\frac{R_2}{s} + jX_2\right) + \frac{E_j}{s} = E_1 \angle \theta_1$$

Magnetizing current

$$I_m = \frac{E_1}{jX_m}$$

Stator current

$$I_1 = I_2 + I_m = I_1 \angle \emptyset_1$$

Stator input power

$$P_1 = 3V_1 I_1 cos\emptyset_1$$

Power through the slip ring

$$P_2 = 3E_j I_2 \cos(\theta_j - \emptyset_2)$$

Developed mechanical power

$$P_m = 3\frac{1-s}{s} I_2^2 R_2 + 3\frac{1-s}{s} E_j I_2 \cos(\theta_j - \emptyset_2)$$

Net power from supply

$$P_o = P_1 - P_2$$

Shaft Power

$$P_{shaft} = P_m - P_{m,loss}$$

Results are in negative power for negative slip in generating mode.

RESULTS

Fig-5 to Fig-8 represents variation of stator and rotor active power with rotor resistance at below synchronous and above synchronous speed and zero, in phase and out phase injected voltage at rotor side of machine.

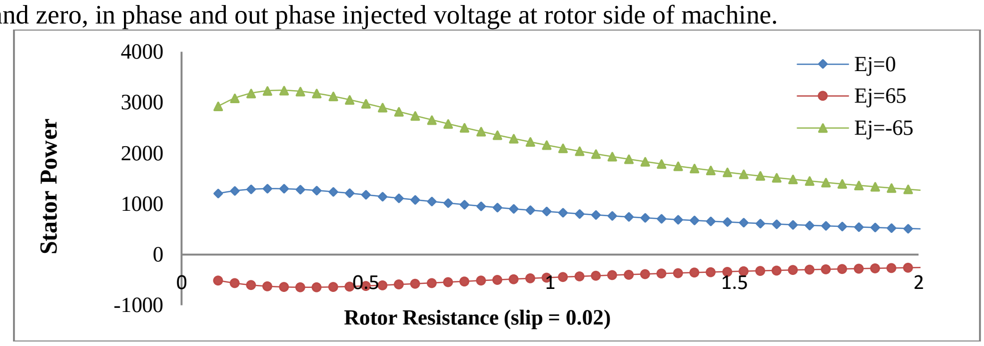

Fig-5 Variation of Stator Power with Rotor Resistance at slip=0.2

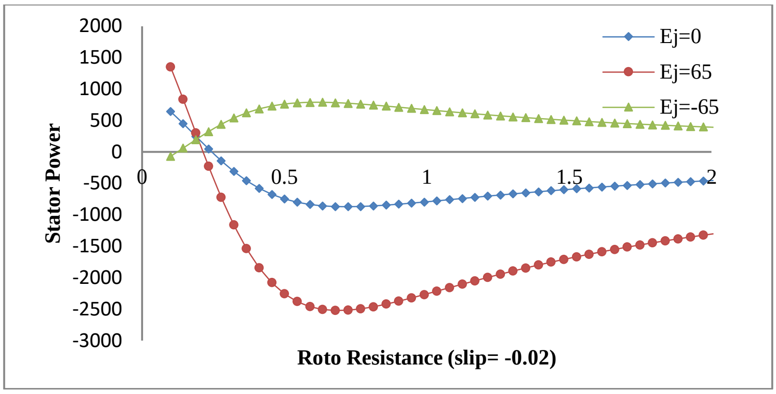

Fig-6 Variation of Stator Power with Rotor Resistance at slip= -0.2

Fig-5 and 6 shows that, at slip 0.2 and –0.2 with in-phase rotor injected voltage, stator supplies power to the mains. Stator power gradually increases in generating region with rotor resistance and after attaining maximum value power start decreasing.

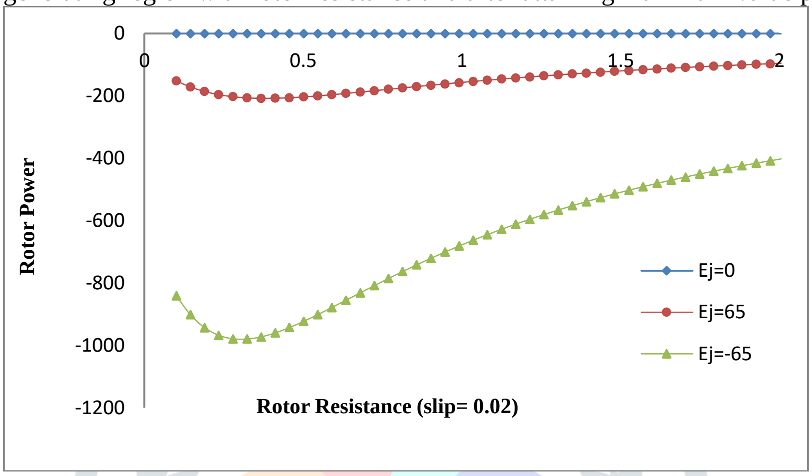

Fig-7 Variation of Rotor Power with Rotor Resistance at slip=0.2

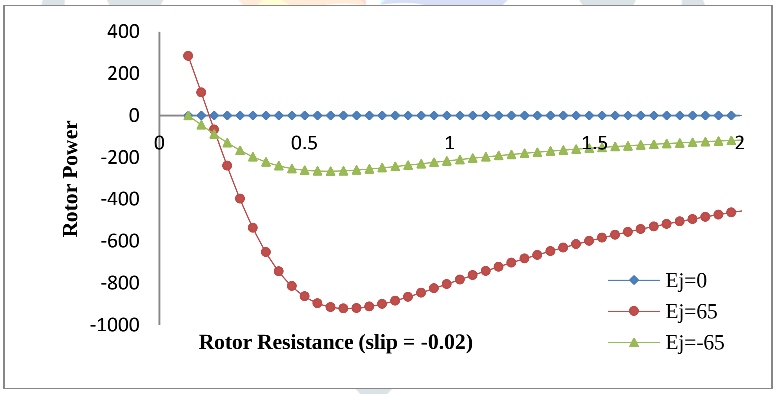

Fig-8 Variation of Rotor Power with Rotor Resistance at slip= -0.2

In fig-7 and 8, at positive and negative injected voltage, rotor also supplies power to the mains.

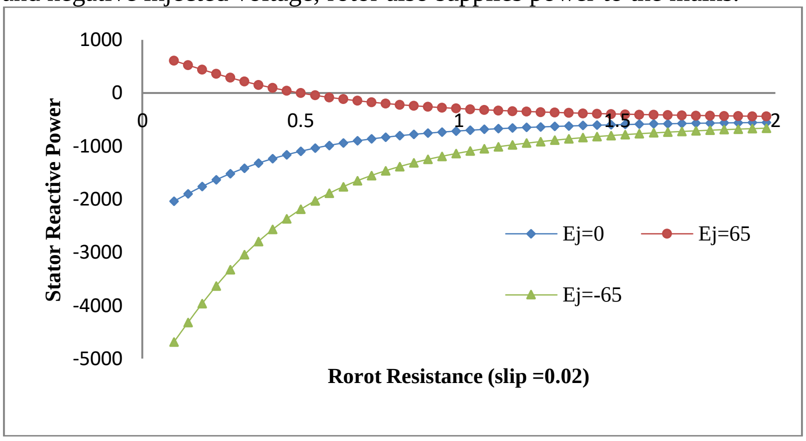

Fig-9 Variation of Stator Reactive Power with Rotor Resistance at slip=0.2

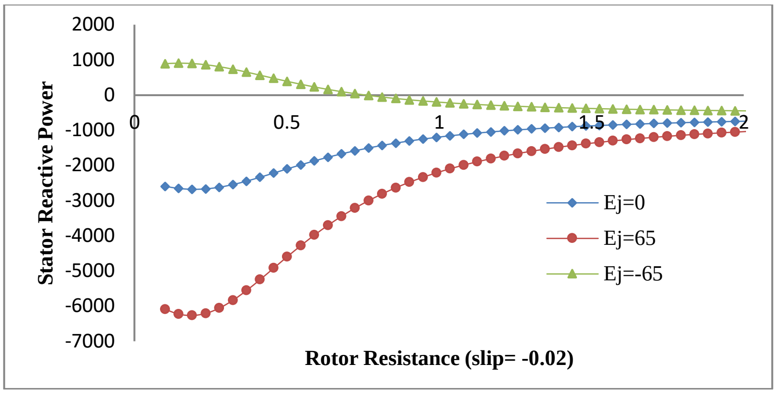

Fig-10 Variation of Stator Reactive Power with Rotor Resistance at slip= -0.2

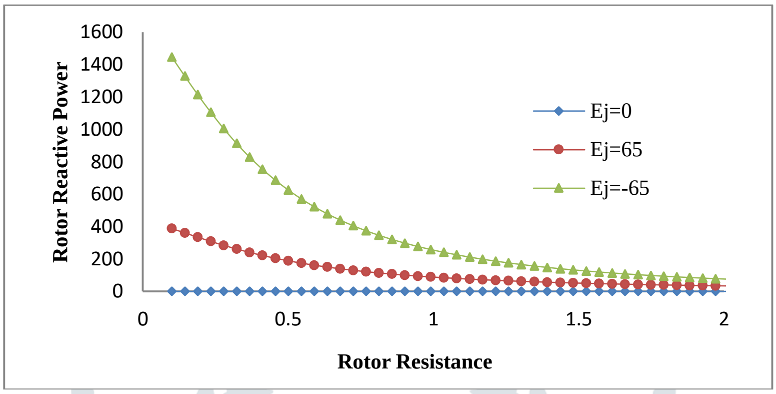

Fig-11 Variation of Rotor Reactive Power with Rotor Resistance at slip=0.2

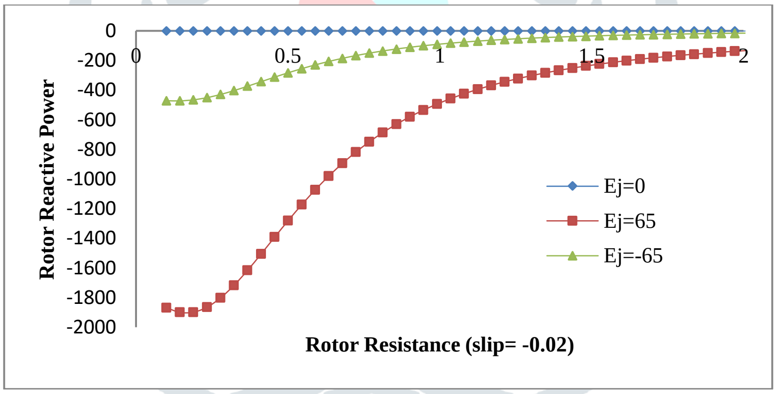

Fig-12 Variation of Rotor Reactive Power with Rotor Resistance at slip= -0.2

Fig-9 to 12 shows the variation of stator and rotor reactive power with rotor resistance. Reactive power decreases with increase in rotor resistance.

Fig-13 to 16 shows the variation of stator and rotor current with rotor resistance.

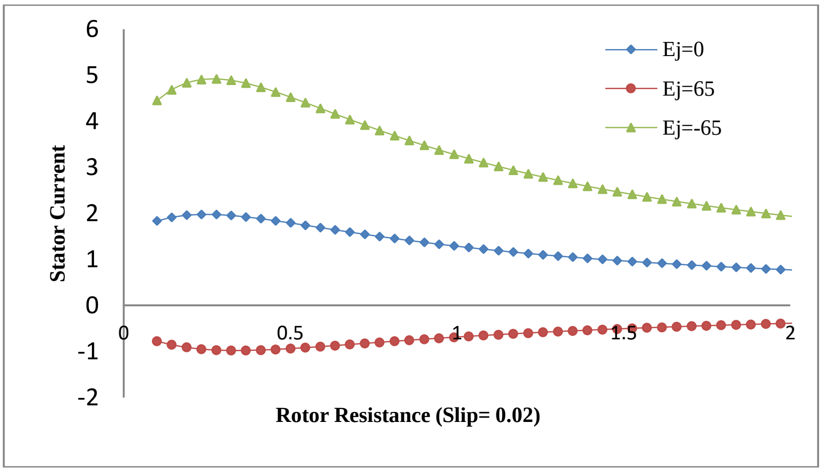

Fig-13 Variation of Stator Current with Rotor Resistance at slip= 0.2

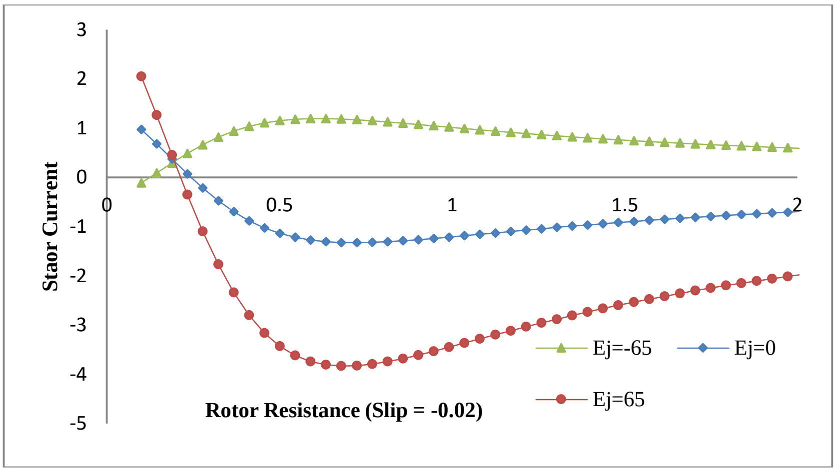

Fig-14 Variation of Stator Current with Rotor Resistance at slip= - 0.2

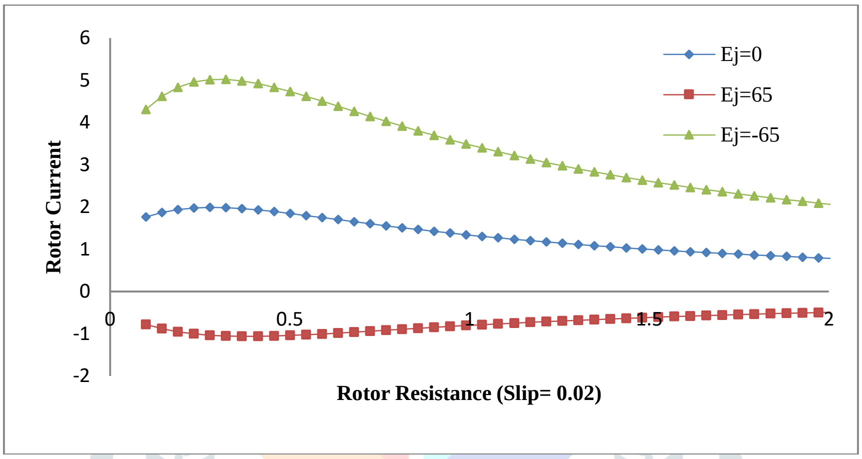

Fig-15 Variation of Rotor Current with Rotor Resistance at slip= 0.2

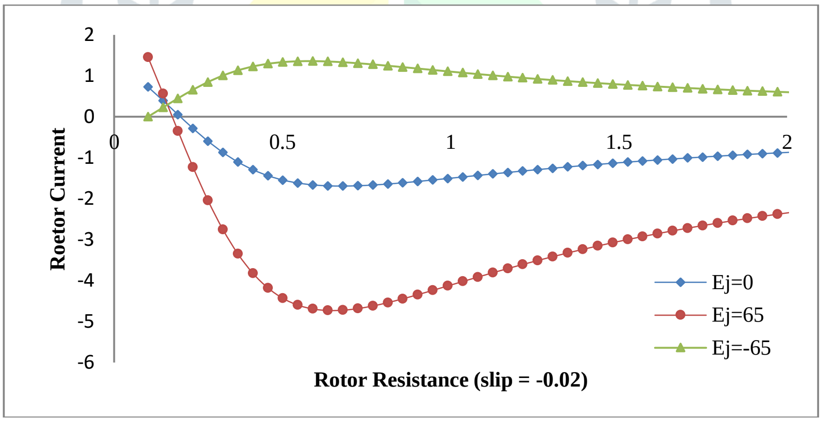

Fig-16 Variation of Rotor Current with Rotor Resistance at slip= -0.2

CONCLUSION

From the MATLAB/Simulink analysis it is concluded that the DFIG performance are affected by rotor resistance. Assume that the machine is excited on the rotor side with zero, in phase and out phase injected voltage. It has been shown that variation of rotor resistance with rotor injected voltage affect the active and reactive powers and currents when the machine runs at sub synchronous and above synchronous speed.

With variation in rotor resistance at sub synchronous speed and zero and out phase injected rotor voltage; stator absorb power from supply and with positive injected rotor voltage stator work in generating mode. With variation in rotor resistance at super synchronous speed and zero and in phase injected rotor voltage stator fed power to supply mains and at out phase injected voltage stator power lie in motoring mode. At zero injected rotor voltage, rotor power is zero. With variation in rotor resistance at super synchronous and sub synchronous speed and at out phase and in phase injected rotor voltage rotor fed power to supply mains.

With variation in rotor resistance at sub synchronous speed and at zero and out phase injected rotor voltage stator and rotor takes current from supply and with in phase injected rotor voltage stator and rotor work in generating mode. With variation in rotor resistance at super synchronous speed and at zero and in phase injected rotor voltage stator and rotor inject current to supply mains and at out phase injected voltage stator and rotor works in motoring mode.

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APPENDIX

Induction Machine Data (Wound Rotor)

Base Values

Base Voltage (L-L) :	380 V
Base Current :	2.2 A
Base Frequency:	314 rad/s

Machine Parameters

Stator resistance	R_1	22 Ω
Rotor resistance	R_2	22.44Ω
Stator leakage reactance	X_1	27.379Ω
Rotor leakage reactance	X_2	27.379Ω
Magnetizing reactance	X_m	246.18Ω