

PERFORMANCE ANALYSIS OF DOUBLY FED INDUCTION MACHINE

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ABSTRACT

In this paper steady state performance of doubly fed induction machine has been studied. A modified equivalent circuit is used for analysis in which core losses and harmonics are ignored. Doubly fed induction machine in a wind turbine system gives desired electric power output at variable speed. Here represent performance analysis of doubly fed induction machine in term of stator and rotor power, developed mechanical power, net power, shaft power, stator and rotor reactive power and current with variation in machine speed from sub synchronous to super synchronous regions and variation in rotor injected voltage (excitation voltage). After finding the machine parameters, analysis is done by MATLAB/Simulink. It has been shown that at variable speed, excitation voltage would control the mode of operation of induction machine: generating mode and motoring mode.

Keywords: Doubly fed induction machine, induction machine, wind energy, asynchronous operation

I. INTRODUCTION

Electrical power is most widely used source of energy for industries, homes, work place. Electricity generation by using non renewable sources (coal, oil, gas) causes enhanced green house effect, leading to the warming of the earth's atmosphere. The wind energy is emerging as potential source among various non conventional energy sources. Almost every country across the world is promoting wind energy generation units [1]. A single wind power plant can have an installed power of hundreds of MW today and thus the influence of these plants on the transmission network can no longer be neglected. Wind power generation is continued to increase worldwide. India has the fifth largest installed wind power capacity in the world [2]. The latest annual report of installed wind power worldwide of 283 GW at 2012 year's end, which is enough to cover 3.5% of the world's electricity demand. Traditionally, synchronous generators have been used for power generation but induction generators are increasingly being used these days because of their relative advantageous feature over conventional synchronous generators [3].

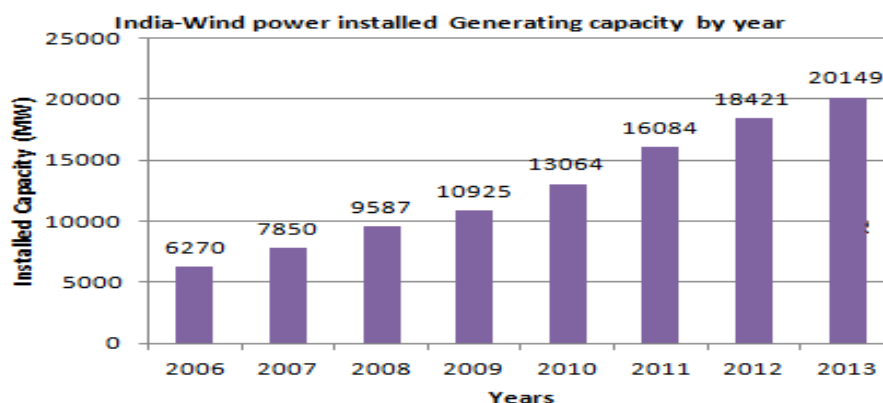


Fig.1 Progress in India's installed wind power generating capacity since 2006

A wound rotor induction motor has a stator like the squirrel cage induction motor, but a rotor with insulated windings brought out via slip-rings and brushes. However, no power is applied to the slip rings. A wound rotor induction motor may also act as a generator when driven above the synchronous speed. Since there are connections to both the stator and rotor, such a machine is known as a doubly-fed induction generator (DFIG). A modified equivalent circuit is used in the analyses in which core losses and harmonics are ignored. Steady state analysis for such machines is essential to estimate the behaviour under actual operating conditions [3].

1.1. DIFFERENT TOPOLOGY FOR ELECTRICITY GENERATION FROM WIND POWER

- Standard squirrel cage induction generator directly connected to the grid.
- Wound rotor induction generator with variable rotor resistance.
- Doubly fed induction generator.
- Direct drive synchronous generator.

The first one is simplest and oldest system that consists of a conventional directly grid coupled squirrel caged induction generator. In this method no converter is required. In DFIG, the stator is directly connected with grid but a converter is connected between rotor and grid. In this only a fraction of the total power produced is fed through the power converter system. In direct drive synchronous generator, the power converter system is connected between stator and grid [4].

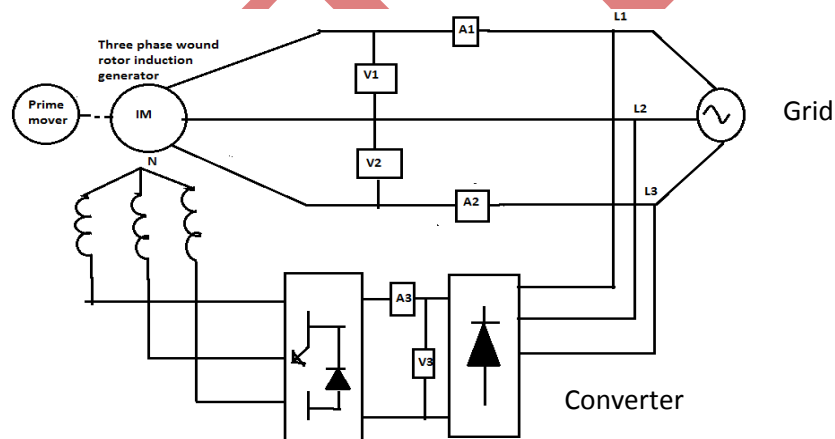


Fig.2 Connection diagram of doubly fed induction machine

1.2. MODES OF OPERATION

The induction machine can be operated in grid connected or self-excited mode. Induction generator in self-excited mode is capable to generate the power even in the absence of power grid. This makes it to be most useful generator for remote windy locations [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. A speed variation of $\pm 30\%$ around synchronous speed can be obtained by the use of a power converter of 30% of nominal power. Furthermore, it is possible to control both active (P_{ref}) and reactive power (Q_{ref}), which gives a better grid performance, and the power electronics enables the wind turbine to act as a more dynamic power source to the grid [6].

II. STEADY STATE ANALYSIS OF DOUBLEY FED INDUCTION MACHINE

The steady state performance can be described by using equivalent circuit model shown in fig. 4. In this figure, V_s is stator voltage and E_j is rotor injected voltages, I_1 and I_2 are the stator and rotor current, R_s and R_r are the stator and rotor resistance, X_s and X_r are the stator and rotor leakage reactance, X_m is the magnetizing reactance and s is slip [7].

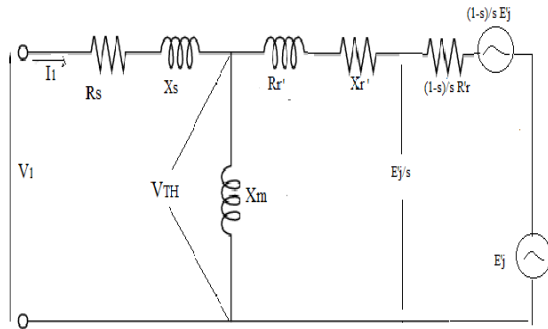


Fig.3. Equivalent circuit of Induction Machine

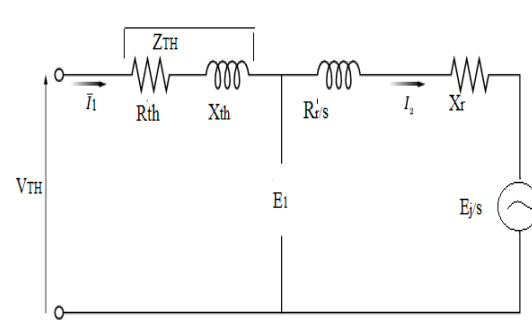


Fig. 4 Thevenin's equivalent of induction machine

By the application of Thevenin's theorem to stator part, replace the equivalent circuit by the circuit shown in fig.4. [8].

The equivalent source voltage,

$$V_{th} = \frac{V_1 + jX_m}{Z_s + jX_m} = V_{th} \angle \theta_{th}, \quad \text{where } Z_s = R_s + (X_s) * 1i \quad (1)$$

Equivalent stator impedance,

$$Z_{th} = \frac{Z_s * jX_m}{Z_s + jX_m} = R_{th} + j X_{th} \quad \text{where } X_m = X_{mag} * 1i \quad (2)$$

Rotor current,

$$I_2 = \frac{V_{th} \angle \theta_{th} - \frac{E_j \angle \theta_j}{s}}{Z_{th} + Z_r} = I_2 \angle \theta_2 \quad \text{where } Z_r = \frac{R_r}{s} + (X_r) * 1i \quad (3)$$

Stator induced emf,

$$E_1 = \frac{I_2 * Z_r}{E_j/s} = E_1 \angle \theta_m \quad (4)$$

$$\text{Magnetizing current, } I_m = \frac{E_1}{X_m} \quad (5)$$

$$\text{Stator current, } I_1 = I_2 + I_m = I_1 \angle \theta_1 \quad (6)$$

$$\text{Stator input power, } P_1 = \text{real}(3V_1 I_1), Q_1 = \text{img}(3V_1 I_1) \quad (7)$$

$$\text{Power through the slip ring, } P_2 = \text{real}(3E_j I_2), Q_2 = \text{img}(3E_j I_2) \quad (8)$$

$$\text{Developed mechanical power, } P_m = \left(3 \frac{(1-s)}{s} |I_2|^2 R_r \right) - \left(3 \frac{(1-s)}{s} |I_2| E_j \cos(\theta_j - \theta_2) \right) \quad (9)$$

$$\text{Net power from supply, } P_0 = P_1 - P_2 \quad (10)$$

$$\text{Shaft Power, } P_{shaft} = P_m - P_{mloss} \quad (11)$$

$$\text{Generator efficiency, } \eta = \frac{P_0}{P_{shaft}} \quad (12)$$

III. RESULTS AND DISCUSSION

In present study excitation voltage is applied at rotor side of machine and speed varies from sub synchronous to super synchronous. Rating of machine has been taken as, 75 kW, 400 volts, 50Hz, 1480rpm. Excitation voltage (rotor side injected voltage) varies from zero to 60 volts in five steps (0V, 15V, 30V, 45V and 60V) and slip varies from -0.2 to +0.2. Fig-5 to 12 represents performance of doubly fed induction machine in term of stator and rotor power, shaft power, mechanical power, net power, stator current, stator and rotor reactive power with respect to slip.

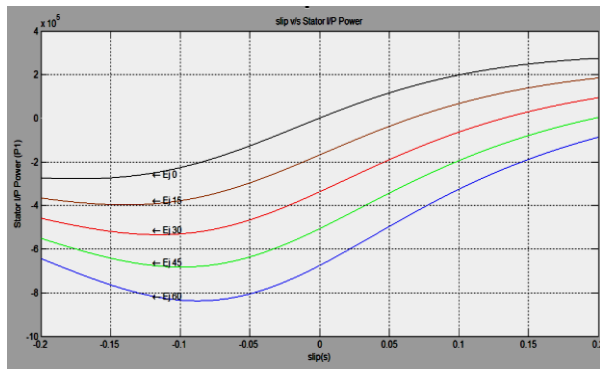


Fig.5. Variation of stator power with slip

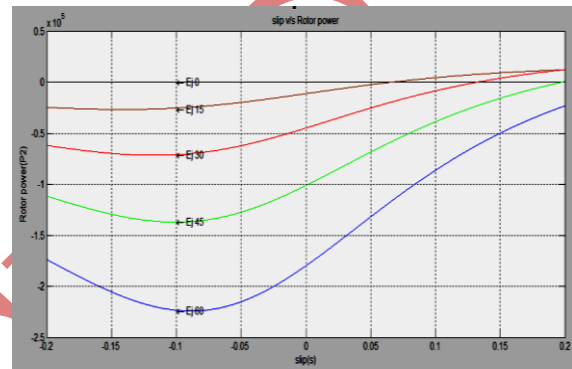


Fig.6. Variation of rotor power with slip

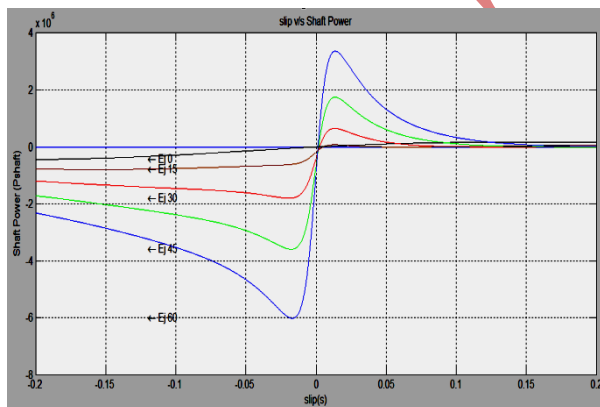


Fig.7. Variation of shaft power with slip

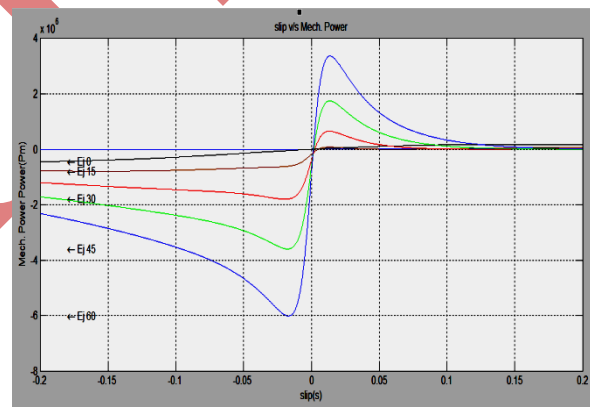


Fig.8. Variation of Mechanical power with slip

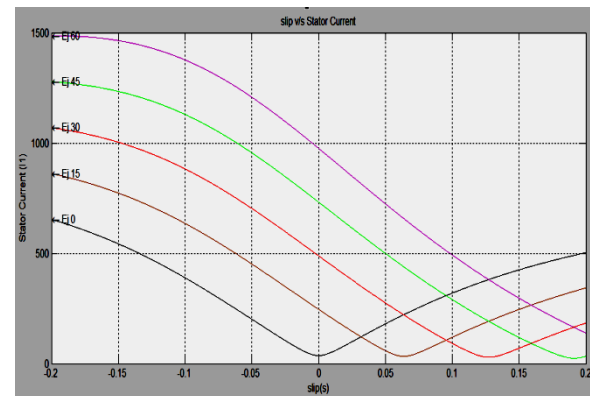
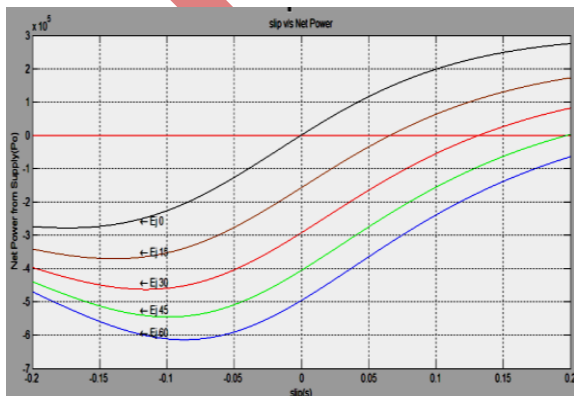


Fig.9. Variation of net power with slip

Fig.10. Variation of stator current with slip

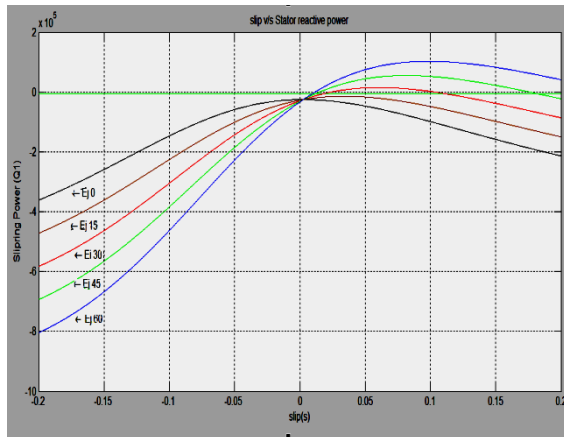


Fig.11. Variation of stator reactive power with slip

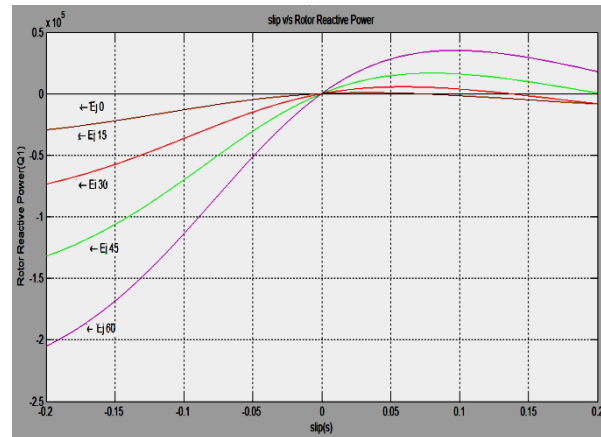


Fig.12. Variation of rotor reactive power with slip

Figures show that at various range of speed, injected rotor voltage would control the output of doubly fed induction machine. At speed less than synchronous speed doubly fed machine give electrical supply through stator side only but at the speed more than synchronous speed, machine give electrical supply through stator as well as rotor side.

IV. CONCLUSION

The steady state analysis of a wound rotor induction generator is essential to understand the behaviour of doubly fed induction machine such that it can operate at maximum power producing point for a given wind speed. MATLAB programming is used to solve the proposed model. Depending on the supplied rotor voltage (E_j), doubly fed induction machine is able to generate real power at rotor speed varies from sub-synchronous to super-synchronous. Results shows that at sub synchronous speed only stator of doubly fed induction machine give electrical power to grid. But at super synchronous speed stator and rotor both give electrical power to grid. Reactive power in the stator and rotor winding of machine can be easily altered by adjusting the angle between V_s and E_j . Analysis has been extended to recognize effectiveness of the machine parameters to improve the operating performance of the machine.

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