Modeling and Stability Analysis of Dual Rotor Axial Flux PMG for Wind Turbine Applications

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Abstract - This paper focuses on mathematical modeling and stability analysis of double rotor axial flux generator. The wind generator is modeled using dq reference frame theory. The cogging torque and gravitational force during starting time is considered for the modeling of the generator. There are several types of generators have been suggested for wind turbine applications which out of which dual rotor PM generator having the lot of advantages over the other types of permanent magnet generator based direct driven wind energy conversion system. Modeling of dual rotor PM generator is developed in the MATLAB. The simulated model is analyzed for various input and output variables. The stability of the proposed system is also analyzed by deriving small signal model of the wind turbine systems. The input wind velocity variations and grid fault conditions are considered for analysis of the system. The results of the proposed system is analyzed for various values of turbine speed.

Keywords: Generator, stability, wind turbine, Starting Torque, Power Converters, Small signal model

I. INTRODUCTION

The power capturing from the wind is very attractive one. Nowadays the shortage of conventional fuels, the developing countries more focused on renewable energy resources. Lot of renewable energy resources have been used in different countries, particularly solar and wind system re very popular because both system having naturally available for some longer duration. Also no need of complex control strategy, easy to install and control. But solar is effectively available only seven hours in a day, hence this system is not possible for lighting load applications. If it is used requires battery and inverter circuits. Which reduces the efficiency and increases the cost.[1][2] Whereas the wind is available for 24 hours hence it can deliver power without any battery storage system. Nowadays power capturing at the lower wind regions are very impotent research. For the upcoming energy demand in the developing countries my concentrate on low speed wind turbines for capturing power. There are several types of generators have been proposed by so many researchers about how to design generator for this applications.[3][9][10]. After the detailed literature survey, this research article proposes the double rotor axial flux generator for low wind velocity regions. The axial flux generator is capable generating power at lower wind speeds. Also it requires low starting torque. There are various modeling schemes have been suggested for modeling of the generator. For permanent magnet generator rotor reference frame theory is a suitable one for modeling of the generator. In this article gravitational force and cogging torque are considered for modeling and design[6][8]. Moreover the effects of wind power penetration in interconnected system oscillation damping is investigated which in turn results in power system instability [4][7]. To predict the stability of the generator for various input velocities and loading conditions are considered. For stability analysis a small signal model of
the double rotor axial flux generator is derived. Several parameters have been considered for designing of wind turbine.

In [11],[12], small signal model and stability analysis model is derived for a dual rotor generator. The proposed controller can improve the system stability.[15][16].

There are different types of power conversion technologies are used for wind turbine system such as rectifier chopper inverter system, rectifier PWM inverter system and cyclo converter or matrix converter based systems.[18][19]. In this article, rectifier inverter bases system is proposed to regulate the generated voltages of wind generator. The proposed system is modeled in the MATLAB and simulink environment. The input variables such as wind velocity and cogging torque is considered for system analysis. The terminal load variations and grid side fault are considered for analysis of derived model[13][14]. The frequency of the generated voltages is varying with respect to seed of the shaft. To feed the desired voltage and frequency to grid the system requires power electronic interface. [14],[17]. The full scale power electronic converter with PM generator system as shown in Figure 1. To control the wind turbine speed pitch control mechanism is used. The wind speed and direction of wind are sensed and feed to controller. The microcontroller regulates the speed of the turbine.

![Dual Rotor Wind Turbine System](image)

**Figure 1.** Configuration of Dual rotor based wind turbine system

During high wind speed fluctuations and grid conditions variations, the Instability issues arise normally with a radial flux permanent magnet generator because of larger axial length also very difficult to place the dampers in the rotor structure. As a result frequency converter is required to damp out the oscillations of rotor circuits [17]. In [18], [19]. In [20], an active damping strategy based on dc link current estimation has been suggested. Hence proper stability analysis is required to determine the suitable stability improvement strategy. Various control techniques have been used to control the wind turbine system, here, this article proposed the PI controller with feed forward and feedback control system. The feed forward system considers the wind speed and feed back system consider the terminal voltages and frequency. The grid faults are also considered for stability analysis. The main role of the proposed controller is to regulate the frequency of the terminal voltage and protect the system from the grid fault conditions.

**II MODELING OF DUAL ROTOR PM GENERATOR**

The proposed wind turbine generator system is modeled in mat lab. An arbitrary reference frame is used to derive all the stator and rotor parameters, then final model is derived in the rotor reference frame. A model of a dual rotor axial machine synchronous generator is developed for the transient stability analysis. The horizontal axis wind turbine is also modeled in mat lab. Turbine speed wind velocity and torque re considered for design of model. The tip speed ratio and pitch control is also included in the model. The armature reaction and leakage flux variations are approximated based on literature survey. In dual rotor system both the rotors are freely rotates at same speed, between the
two rotors a stator winding is fixed. The two fluxes from the rotor links the stator coils an emf is developed. The magnitude of induced emf depends on the flux linkages from the rotors.

WIND TURBINE MODEL
A low speed wind turbine is converts the kinetic energy in the wind into electric energy. The power captured from the wind depends on the wind speed and blade swept area, Mechanical power P can be determined by

\[ P = \frac{1}{2} \rho A V^3 C_p(\lambda, \beta) \] (1)
\[ \lambda = \frac{\Omega_T}{r_r \nu} \] (2)

The power captured from the wind depends on the turbine radius, wind velocity and tip speed ratio. Normally the power co-efficient is 40 to 50 percent.

\[ \Omega_T \] is the turbine speed, \( r_r \) is the rotor blade radius. Figure 2 represents the \( C_p \) versus \( \lambda \) curve for a particular wind velocity. with variations in the value of tip speed ratio , there is a corresponding variation in the power coefficient.

![Figure 2. \( C_p \) VS \( \lambda \) Curve](image)

2.1 DUAL ROTOR GENERATOR:
To develop the dynamic mathematical model of the wind turbine generator system a simulation model is developed using the following equations (3) to (8). To predict the steady state and transient respone of the proposed system a precise model of the PM machine is required. The dynamic model of the machine is derived using the two phase machine in dq axis. The generated power of the generator depends on the self and mutual flux linkages of the generator, piecewise model is considered for calculation of inductances, The stedy stte reching nd the generated voltages dynamic/transient states depends on the values of inductance profile

\[ T_e = 1.5n_p ((L_{ds} - L_{ls}) i_d i_q + i_q \psi_f) \] (5)
\[ \omega_e = p \cdot \omega_g \] (6)

Voltage for a PM generator in the d-q axis is given by

\[ V_d = -(R_s + pL_{eq}) i_q - W L_{d0} i_d + W \lambda_m \] (7)
\[ V_q = -(R_s + pL_{q0}) i_d - W L_{q0} i_q \] (8)

d-axis and q-axis based equivalent circuits are shown below
III STABILITY ANALYSIS

To predict the system stability for various input and output conditions generator signal model of the proposed system is developed. The following equations are derived to analyze the stability of the system.[15][16]

\[ K \frac{dx(t)}{dt} = A x(t) + B u(t) \]
\[ Y(t) = C x(t) + E u(t) \] (9)

Stability of the wind turbine and PM generator gets unstable with grid conditions [6]. To predict the grid parameter variations during fault conditions the two mass models may be expressed as

\[ W_h = \frac{1}{J_{ht}} (T_{wt} - K \theta) \]
\[ W_g = \frac{1}{J_{gt}} (K \theta - T_{gt}) \]
\[ \theta = W_{ht} - W_{gt} \] (10)

where \( W_{ht}, W_{gt} \) are the speed of the rotor and generator; \( J_{ht}, J_{gt} \) are the moment of inertia of the system, \( \theta \) is the electrical waveform angle of the rotating shaft, \( K \) is the stiffness of the rotating shaft and \( T_{wt} \) is the developed mechanical torque of the turbine

\[ T_{wt} = K_w C_q V^2 \] (11)

Where \( K_w = 1/2(\pi R^3) \rho \)

\[ W_h = \frac{1}{J_h} (T_{wt} - T_{tg}) \] (12)
\[ X_1 = \frac{1}{J_h} (T_{wt} - K\theta) \]
\[ X_2 = 1/J_e (K\theta - T_{tg}) \]
\[ X_3 = X_1 - X_2 \] (13)

The system Stability can be analyzed based on the above equations. Moreover transfer function model for proportional integral controller need to be examined to evaluate the stability of the system.

\[ H(S) = \frac{(K_p S + K_i)}{(S^2 + K_p S + K_i)} \] (14)

\[ = 2\zeta\omega_0 s + \omega_0^2 s^2 + 2\zeta\omega_0 s + \omega_0^2 \]
\[ \frac{K_p}{s^1} + \frac{K_i}{s^1} \frac{1}{T_s + 1} \] WECS MECHANICAL DYNAMIC

\( P_g^* \cdot T_g W_g \)

Figure 4. Controller for stability improvement

The block diagram of the controller for stability improvement is given in Figure 4. The proposed power controller can be expressed in frequency domain as follows:

\[(P_g^* - T_g W_g) \frac{k_p + k_i}{s^1} \frac{1}{(T_s + 1)} = T_g \] (15)

Where \( k_p \), \( k_i \) are the proportional and integral controllers constants. Magnitude and phase plot of the output voltage is obtained from the transfer function. From the magnitude and phase plot it is clear that the system is subjected to instability due to continuous variation in wind velocity, this issue is rectified to a large extent with the implementation of torque compensation strategy.

IV SIMULATION RESULTS

The proposed dual rotor generator is simulated in the MATLAB. Figure 5 represents the variation of voltage with increase in wind velocity. Figure 4 represents the voltage generated by a permanent magnet synchronous generator modeled based on d-q transformation. Similarly figure 5 represents the magnitude and phase plot of output voltage with which stability has been analyzed. Normal values of gain and phase margin is given by 12dB and 45 deg which is considered as stable operation. But the analysis results show that there is deviation from the specified value which need to be corrected using Torque compensation strategy. The generated voltages and frequency of the generator is varying with speed of the rotor. To feed the desired frequency and voltage to the grid the system requires full scale power electronic converters. This system consider the rectifier and an inverter system for regulating the generated voltages. The Figure 6-8 shows the generated voltages of the system.

Figure 5. Variation of voltage with turbine speed
CONCLUSION
The modeling of the PM generator is derived and developed in the rotor reference frame and same was verified with the MATLAB simulation. The small signal model is also derived to predict the stability.
of the generator. The analysis clearly given the report on the generator is stable up to desired cut off wind speed and 160% of the loading conditions. The system is also stable during 10% of grid fault conditions.

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