Wind-Turbine Speed Control Using MATLAB

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Abstract- The output frequency of a self excited induction generator (SEIG) driven by wind turbine and supplies static load are controlled, using MATLAB/simulink. The PID controller which employed for turbine rotor speed control and hence the frequency regulation is proposed and simulated by MATLAB software package. The modern wind turbines implement pitch control in order to tap maximum energy at wind speeds lower than rated wind speed. They are simple and rugged in construction and offer impressive efficiency under varying operating conditions. The PID controller which employed for turbine rotor speed control and hence the frequency regulation is proposed. In this paper, a turbine blade pitch control has been assumed for this purpose.

Index Terms- Wind Turbine, Speed Control, PID Controller, Wind Generating System, MATLAB

I. INTRODUCTION

Wind power is a clean, emissions-free power generation technology. Like all renewable sources it is based on capturing the energy from natural forces and has none of the polluting effects associated with ‘conventional’ fuels.

In 2011 the Indian wind sector experienced a record annual growth, with over 3 GW of new installations. 2012 was a slower year due to a lapse in policy, but India still experienced significant new wind energy capacity which reached 2.3 GW at the end of 2012, for a cumulative total of 18.4 GW. As of January 2013, total renewable energy installations in the country reached 26.9 GW. By the end of 2012, renewable energy accounted for over 12 % of total installed capacity, and about 6% of electricity generation, compared to 2% in 1995. Wind power accounted for about 69% of total renewable energy capacity or about 8% of the total installed capacity in India.

Wind Turbines By definition, a wind turbine is a rotary device that extracts energy from the wind. If the energy captured from the wind is used for machining purposes such as cutting lumber or grinding stones, the machine is called a windmill. If on the other hand, it is used for pumping water, it is referred to as a wind pump.

Pitch Control Through pitch control, the blades can be turned out or into the wind. This results in variation of the force exerted by the wind on the rotor shaft. The advantages of this type of control are:

- Good power control,
- Assisted startup, and
- Emergency stop.

The pitch function gives full control over the mechanical power and the most common method is used for the variable speed wind turbines. At wind speeds below the rated power of the generator, the pitch angle is at its maximum though it can be lower to help the turbine accelerate faster. Above the rated wind speed, the pitch angle is controlled to keep the generator power at rated power by reducing the angle of blades.

II. PRINCIPLE OF CONTROL

A) Aerodynamic Power Control for Wind Turbines

The pitch angle is controlled to keep the generator power at rated power by reducing the angle of the blades. By regulating, the angle to be on the of stalling, fast torque changes from the wind will be reutilized (Nayar and Bundell 1987).

The power captured by the turbine is given by

$$P_m = P_w \times C_p \qquad \text{………… (1)}$$

The mass flow rate is a constant for upstream (0), the rotor (1) and downstream (2) mass flow rate mass as shown in Figure 4.

$$m = \rho A_0 V_0 = \rho A_1 V_1 = \rho A_2 V_2 \qquad \text{… (2)}$$

The turbine model represents the power captured by the turbine. The power in the wind (Pm) in an area A is given by, the output power of the wind turbine, can be calculated from the following equation

$$P_m = \frac{1}{2}\rho A C_p V_w{}^3 \qquad \text{……… (3)}$$

Where (ρ) is the air density, and (A) is the swept area by the blades, and

$$C_p = 0.44 - 0.0167\beta sin\frac{\pi(\lambda-3)}{15-0.3\beta} - .00184(\lambda-3)\beta \qquad \text{………… (4)}$$

The wind turbine is characterized by no dimensional curves of the power coefficient (Cp) as a function of both the tip speed ratio(λ) and the blade pitch angle(β). In order to fully utilize the available wind energy, the value of (λ) should be maintained at its optimum value. Therefore, the power coefficient corresponding to that value will become maximum also.

Also, the torque available from the wind turbine can be expressed as:

$$T_m = \rho A R C_T V_w{}^2 \qquad \text{………… (5)}$$

Where C_T is the torque coefficient which is given by $C_T = Cp/\lambda$

Then, the aerodynamic torque, Tm can be written as follows:

$$T_m = 0.5A\left[\left(0.44 - 0.0167\beta sin\frac{\pi\left(\frac{\omega_t R}{V_W}-3\right)}{(15-0.3\beta)} - 0.00184\left(\frac{\omega_t R}{V_W} - 3\right)\beta\right]\frac{{V_W}^3}{\omega_t}\right. \quad \text{………} (6)$$

The fundamental dynamics of the variable-speed wind turbine are captured with the following simple mathematical model:

$$J_t\omega_t = T_w - T_m \quad \text{…………} (7)$$

B) Dynamic Model Linearization

A traditional approach to design commonly used linear controllers such as proportional-integral-derivative (PID) requires that the non-linear turbine dynamics be linearized about a specified operating point. Linearization of the turbine equation (7) would yield:

$$J_t\Delta\omega_t = \gamma\Delta\omega_t + \varepsilon\Delta V_w + \delta\Delta\beta \quad \text{……} (8)$$

Where the linearization coefficients are given by

$$\gamma = \frac{\partial T_m}{\partial \omega_t}\bigg| op = \frac{\partial}{\partial\omega_t}(J_t\omega_t)\bigg| op = \frac{1}{2}\rho A {V_{wop}}^3\frac{\partial}{\partial\omega_t}\left[\frac{C_p(\beta,\lambda)}{\omega_t}\right]\bigg| op$$

$$\varepsilon = \frac{\partial T_m}{\partial V_w}\bigg| op = \frac{1}{2}\rho A\frac{1}{\omega_{top}}\frac{\partial}{\partial V_w}[C_p(\lambda,\beta) \times V_w^3]\bigg| op$$

$$\delta = \frac{\partial T_m}{\partial \beta}\bigg| op = \frac{\partial}{\partial\beta}(J_t\omega_t)\bigg| op = \frac{1}{2}\rho A\frac{V_{wop}^3}{\omega_{top}}\frac{\partial}{\partial\beta}C_p(\lambda,\beta)\bigg| op$$

Here, Δω, ΔVw, and Δβ represent deviations from the chosen operating point, ω_{top} , V_{wop} , and β_{top} .

Pitch Actuator System Modeling

$$J_t s\Delta\omega_t = \varepsilon\Delta V_w(s) + \gamma\Delta\omega_t + \delta\Delta U(s)$$

Now the turbine rotor shaft speed can be represented as

$$\Delta\omega_t = \left[\frac{\varepsilon}{J_t}\Delta V_w(s) + \frac{\delta}{J_t}\Delta U(s)\right]\frac{1}{s-D}$$

Model of Actuator

The permanent magnet DC motor is used as an actuator turbine blade adjustment, which may be represented by the block diagram shown in Figure 6 where Ua(s) and Uo(s) are the Laplace transform of the pitch angle input and output respectively, Km is the gain constant, and τ_m is the time constant of the permanent magnet DC motor.

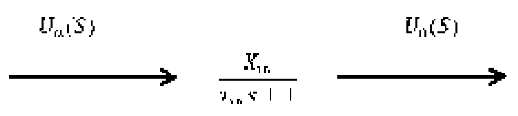

Figure 6. Block diagram of the actuator

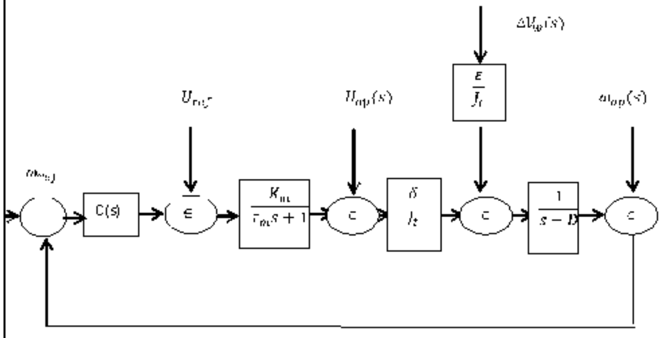

Figure 8 Block diagram of wind turbine speed control system

Complete Speed Control System

The proposed wind-turbine speed control, shown in Figure 8, is simulated by MATLAB -Simulink software package Figure 9. The systematic approach to PID controller design provides a means of visually observing the effect of gain changes on the Root Mean Square (RMS) speed error. So in order to assess controller performance, the root mean square of the error between the actual rotational speed and the desired rotational speed indicates the capability of the controller to reject the wind speed fluctuations. The simulation was used repeatedly. Each of the gains was varied over a wide region. Observation of the system response inputs provides direction in choosing gain values. The PID controller parameters are tuned according this approach to give the optimal performance: K_P = 15, Ki = 20 and K_d = 0.1. The wind speed is changed between 4.7 m/s to 8.1 m/s. In response, the control system will exhibits a corresponding change in blade angle between 5 deg. to 15 deg. in order to keep the rotor speed constant at the reference value 47.1 rad/s, as shown in Figure.10

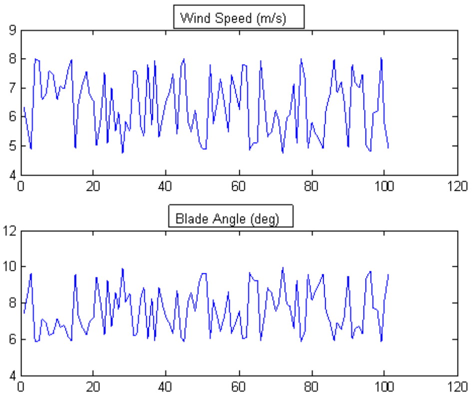

Figure 9 Time series traces of turbine performance using PID controller

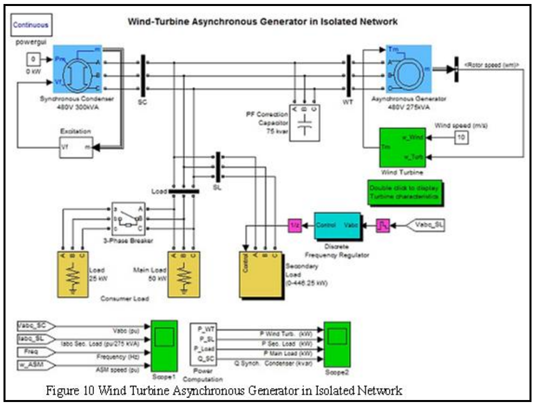

Figure 10 Wind Turbine Asynchronous Generator in Isolated Network

III. RESULTS AND CONCLUSIONS

The wind-turbine speed control is simulated by MATLAB-SIMULINK software package. The PID controller parameters are tuned to give the optimal performance: $K_P = 15$, Ki = 20, and $K_d = 0.1$. The wind speed is changed between 4.7 m/s to 8.1 m/s. In response, the control system will exhibits a corresponding change in blade angle between 5 deg. to 15 deg. in order to keep the rotor speed constant at the reference value 47.1 rad/s.

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