POWER CAPTURE OPTIMIZATION IN WIND ENERGY CONVERSION SYSTEMS

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Abstract

This paper proposes Linear Controller to capture maximum power output in a variable speed wind energy conversion system (WECS). Maximum energy capture from the wind and maintaining constant power supply to the utility grid is necessary. It is obtained by turbine shaft speed control of the system. Matrix converter interfaces doubly fed induction generator (DFIG) with the grid and adjusts generator terminal frequency and thus turbine shaft speed. It also performs power factor control at the grid interface. The design of the controller is to track the desired active and reactive powers delivered to the grid and to adjust the Matrix Converter (MC) control variables. Linear Quadratic (LQ) method is used to design the closed loop state feedback integral controller. Simulation is carried out using MATLAB and the result shows the better performance of the controller to track the reference output and to produce maximum power output.

Keywords: Wind Energy Conversion System, Matrix Converter, Controller, Maximum Power Output.

I. INTRODUCTION

It is necessary to optimize Wind Energy Conversion System (WECS) for increasing the wind energy electric power production. Wind Turbines (WT) are optimized to produce maximum power output at variable speeds. Wind turbines can either operate at fixed speed or variable speed. For a fixed-speed wind turbine the generator is directly connected to the electrical grid. For a variable-speed wind turbine (VSWT) system the generator is controlled by a power electronic converter called matrix converter to control active and reactive power. Variable speed wind turbine gives maximum power output compared to the fixed speed [5].

For a VSWT, mechanical power output is $P_t = \frac{1}{2} C_p \rho \Pi R^2 V_w^3$, where the turbine power, C_p is the power coefficient, R is the turbine radius and V_w is the wind velocity. A WT can only generate a certain percentage of power associated with the wind. This percentage is represented by C_p which is a function of wind speed, turbine rotational speed and the pitch angle of specific wind turbine blades. The tip speed ratio λ of the WT is $\lambda = \frac{RW_t}{V_w}$ where turbine shaft speed $W_t = \frac{P_t}{T_t}$ and T_t is the turbine torque. [Fig. 1 non-linear relationship between C_p and λ that can be obtained experimentally for any given WT. As shown in Fig. 2, for a particular wind speed within the range from cut in to rated wind velocity, the turbine rotational speed can be adjusted so that the maximum C_p can be obtained. This, in turn, causes the WT to generate a maximum power at that wind speed [5] [1].

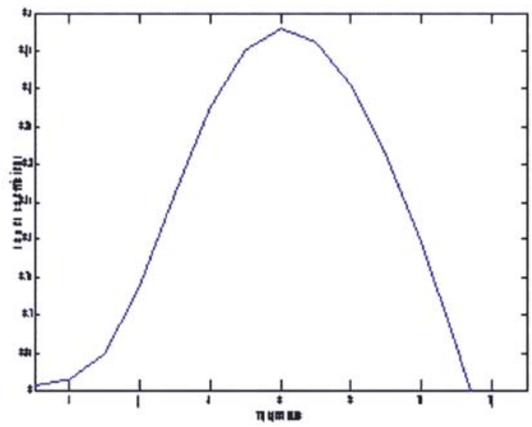

Fig. 1 Power Coefficient of the Wind Turbine model

Many of the WT control systems are based on linear models. For low wind speeds, it is more important to optimize wind power capture while it is recommended to limit power production and rotor speed above the rated wind speed. The controller, for power capture optimization, that takes into consideration the nonlinear nature of the WT behaviour is designed considering the control state inputs.

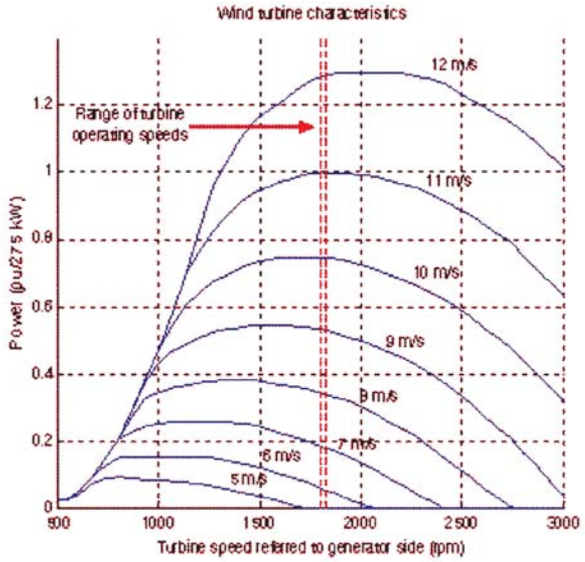

Fig. 2 Power Characteristics of the Wind Turbine

The organization of rest of the paper is as follows: The section 2 presents the Wind Energy Conversion System Configuration. The section 3 focuses on the overall dynamic model of the system. The section 4 explains the linear controller design. While section 5 gives the results and discussions and section 6 talks about conclusion of the work.

II. WIND ENERGY CONVERSION SYSTEM

The wind energy conversion system shown in the Fig. 3 consists of a wind turbine, shaft with gearbox, a doubly fed induction generator and a matrix converter with controller. The matrix converter interfaces the induction generator with the grid and implements a shaft speed control to achieve maximum power-point tracking at varying wind velocities. It also performs power factor control at the grid interface and satisfies Var demand at the induction generator terminals [4].

MC as an electronic power converter/static frequency changer interfaces the DFIG with the grid and implements shaft speed control. The MC input is connected to the grid and the generator terminals are connected to the MC output. It consist of nine bidirectional switches with LC filter to filter out the high frequency harmonics of the input current. Also it provides direct AC/AC conversion and bidirectional power flow [4].

Rotor of the DFIG is connected to the grid by matrix converter (direct AC-AC power conversion) between rotor circuit and grid. Stator of the generator is directly connected to the utility grid. DFIG works in Sub Synchronous and Super Synchronous mode. Stator power is delivered to the grid in both the modes.Rotor active power is supplied to the machine in sub synchronous mode and delivered to the grid in super synchronous [4].

The controller adjusts the MC control variables in order to improve the system steady state and transient performance. It controls the shaft speed to maximize the power captured from the wind [5].

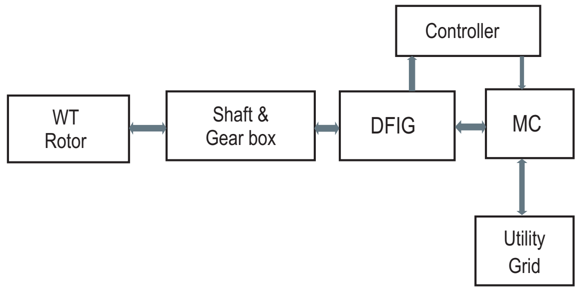

Fig. 3 Wind Energy Conversion System

III. THE OVERALL DYNAMIC MODEL

The nonlinear state space model for the WECS consists of thirteen nonlinear equations [4]. In combination gives eleven equations. It is characterized by six inputs (u), two outputs (y), and eleven state variables (x) as shown in the Fig 4.

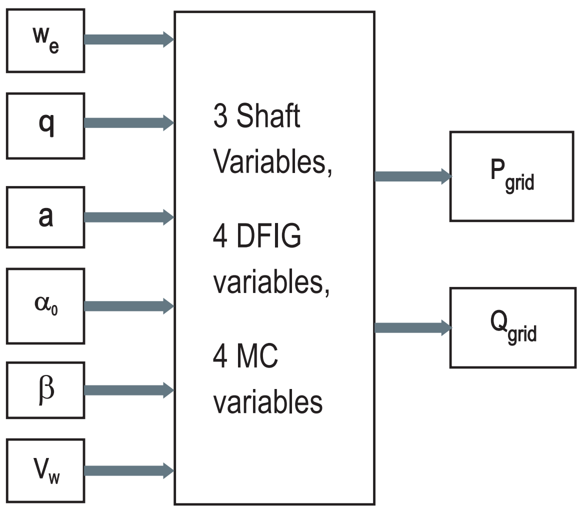

Fig. 4 Inputs, Outputs and State Variables

Out of the six input variables, output angular speed W_e, voltage gain q, parameter a related to input displacement power factor and phase angle of the output voltage α_0 are adjustable control variables, the wind velocity V_w is an uncontrollable disturbance input, and the pitch angle β is taken as fixed pitch angle as zero.

IV. LINEAR CONTROLLER DESIGN

The closed loop feedback controller based on the linear model is designed in this chapter. The nonlinear model is linearized using Jacobian and WT linearized model consists of two input vectors $u = [W_e, a]^T$ and two output vector $y = [P_{Grid}, Q_{Grid}]$ with eleven state variables. The 11th order state space model is reduced to the 9th order model with balanced realization using direct deletion method [2] [6].

The objective of the controller is to track an output power reference signal. In this analysis, the desired active and reactive powers delivered to the grid are selected as the references $Y_{ref}, = [P_{ref}, Q_{ref}]^T$. The tracking error is $e = y - y_{ref}$. Integral action is taken in the controller in order to maintain zero steady state error. This controller includes integrator [I/s], feedback matrices $K = [K_1, K_2]$ and A, B, C and D matrices are jacobian matrices calculated for the linearized model. Tracking of step reference signal Y_{ref} by the output signal y with no steady state error is done using the controller designed. The WT closed loop system with state feedback controller is shown in the Fig 5. The linear method is based on the Linear Quadratic method. Weighting matrices is determined using trial and error basis.

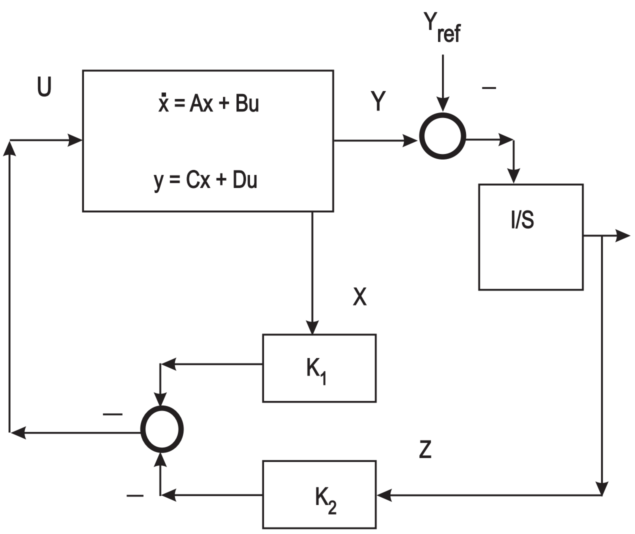

Fig. 5 State Feedback Controller

V. RESULTS AND DISCUSSION

Generally wind turbine system initiates in the motoring mode and draws active power from the grid. When the shaft speeds up and the wind power increases the machine goes to generator mode and power flow will be from the generator to the grid. Considering the operating point of the wind turbine system the input parameter values are $q = 0.5$, $w_e = 376.99$ rad/sec, DPF control parameter a is 0.8, voltage angle is zero and pitch angle is of fixed pitch zero. Wind speed is taken as the uncontrollable disturbance input.

The step response of the system considering the two inputs output frequency W_e, and the DPF control parameter a is shown in the Fig 5 and Fig 6. These two inputs are only considered for the controller design because the output grid power depends in high proportion than others.

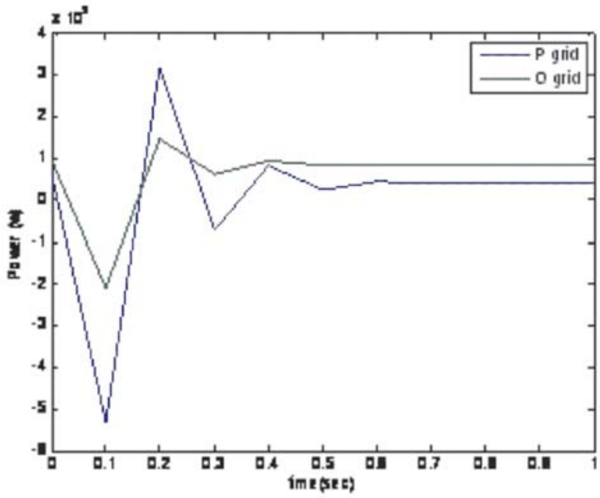

Fig. 6 Step change in output frequency

Before applying step changes the system operates at its steady state operating point. The step response to the 5% increase in the output frequency is shown in the Fig. 6.

The increase in the frequency increases the grid active power and decreases the grid reactive power because frequency increase results in the consumption of the system reactive power.

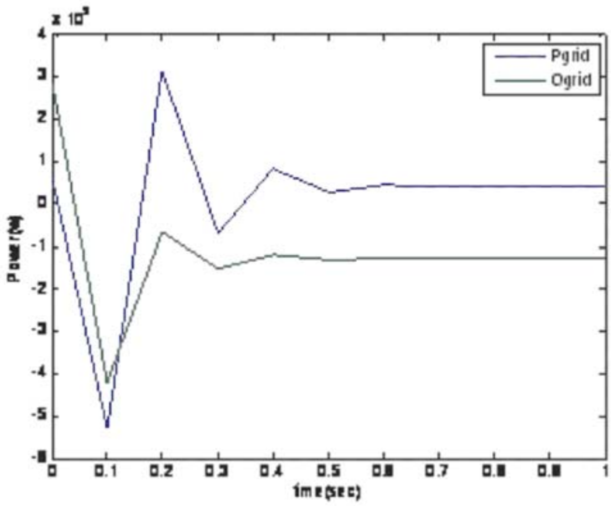

Fig. 7 Step change in DPF control parameter

Fig. 7 shows the step change of 10% decrease in DPF control parameter, which shows the variations in the grid reactive power in lagging and leading regions correspondingly to the decrease and increase of the value.

VI. CONCLUSION

A closed-loop controller based on the state-space linear model is designed. The controller includes state feedback with integral control. The LQ control is simple and effective for adjusting the parameters of the closed-loop controller. The active and reactive powers are made more dependent to the frequency control and input displacement power factor control.

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