Control Strategy on Ducting Vertical Axis Wind Turbine Based on Permanent Magnet Synchronous Generator

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Abstract. Control methodology for a standalone vertical axis wind turbine with variable speed with a PMSG is studied in this research. Where a simplified control strategy adopted for the generator side converter in order to harness ultimate power was investigated and achieved employing Sim power dynamical system simulating code. The controller is able to maximize output of varying speed vertical axis turbine during variable wind. Vector control scheme is utilized to control the load side PWM inverter. This is to sustain the inverter's amplitude output voltage. It was noticed that, the controller can keep the load voltage well at a load and kept constant by changing the load status. Generating system having this proposed control statement is viable for the installation of the small-scale wind turbine. This wind turbine system is characterized by its standalone status and variable speed. Such types of wind turbines are suitable for rural areas power supply. Results reveal that controller runs very well and depicts very well dynamical and a good steadily performance.

Keywords: Drive train, inverter, LC filter, tip speed ratio, vertical axis wind turbine, pitch angle.

1. Introduction

The capability of changing wind turbines speed may be greatly enhanced by using a PM synchronous with a direct motor. PMSG received a lot of interest in applying with wind turbine [1]. PMSG have, self-exciting, that permits running at a high factor of power and good efficiency [2]. It works in at higher relatively factor of power due to the miss-magnetization current which may be more effective over induction machines. For production of ultimate power gained from the variable wind velocities; running of the wind turbine conversion system generator is essential. It needs a proven controlling scheme. Optimal tracking of torque and produced power is a well-known control strategy as it serves to provide optimal harvesting of wind energy [3-5]. These strategies do not appropriate because of its high cost for micro-scale turbines. Many sources of wind energy have been fitted in remote villages and isolated islands [6]. In recent years, wind power generation systems present a focus point in the search for renewable energy resources. This is largely because of the quick progress in the capacity of wind turbines, further the advancement of power electric and their applications in wind power production. For the isolated settlements settled far away from the utility grid, a sensible trend to independent power generating consists employing turbines having storages to initiate complete system [7]. Many studies have been conducted focusing on establishing the energy capturing privileges associated with changeable wind speed operation. Xabier Juankorena et.al 2009 [8] demonstrated a procedure for initial regulating of the variable-speed vertical axis wind turbine.
Basic management is the method by which the unsteadiness or fluctuations between the power produced and the energy required are stabilized. The system involves of the linear change of the power generated with the network frequency, and if the network frequency rises, the power would generated be reduced and so on. This proposed methodology is included by varying the power, and the speed curve of the wind turbine according to the network frequency, hence changing the percent of the ultimate available power added into the network. It is obtained by running the turbines at different rotating speeds than the ideal, with uncontrolled angle. This study recommends that the primary method of pitch regulation in depend on of wind speed and do not require controlling the angle of pitch. Rajveer Mittal 2010 [9] proposed a battery storage system for different speed of turbines using (PMSG). Off-network wind systems inherently have storage because of the wind availability doesn’t provide the requested energy demand continuously. If the load request is fewer than the power generated by the wind. Thus, the overstocking power is consigned in the batteries. K.Kalyan Raj.et.al 2012 [10] literate and compared various methods and schemes for the stability of voltage of SEIG insulated variable speed drops. Their concluded that power electronics transformers ensure promoting results on voltage control. Arshad Nawaz.et.al2013 [11] studied the regulation method of output voltage of independent wind turbines run at a variable wind speed. This method bases upon the voltage regulating utilization for the vibration voltage of the wind turbine driven at variable speed. The voltage regulation is provided for utility. The battery system is also suggested for a system that can ensure power when the wind regulator voltage is fallen below threshold value because of wind absence or low wind speed. Samanvorakij and Kumkratug 2013 [12] this study presented of PMSG modelling. It includes of wind turbine, PMSG, the angle of pitch control and the AC/DC/AC converter model. Permanent magnet synchronized generator and converter are created in (d-q) model. Results of simulation showed that the angle of pitch controls actively with at high wind speeds, to set the power coefficient for generator.

2. Duct and Wind Turbine Model

The flow is considered as one dimensional, steady and incompressible, so the velocity and pressure at out let of convergent duct calculated by [13]:

\[ V_{out} = V_{in} A_{in} / A_{out} \] (1)

\[ P_{out} = P_{in} - \rho_{in} V_{in} (V_{out} - V_{in}) \] (2)

For divergent duct wind turbine, the increment in wind velocity at inlet of the divergent duct is referred to the aspect area ratio [14].

\[ V_{rotor} = A_{out} / A_{in} * V_{\infty} * (1 - a) \] (3)

\[ P_{rotor} = \rho_{\infty} (1/2) V_{\infty}^2 - V_{rotor}^2 \] (4)

Combining the convergent part with the divergent duct via the test section which include the VAWT rotor present the third configuration that is the convergent-divergent ducting system. Figure (1) shows all case of ducted wind turbine for variable wind speed input.

![Figure 1: Matlab simulink ducting system](image-url)
3. Model of Wind Turbine

The wind turbine model shown in figure (2) describes the aerodynamic model that extract power from the wind in the form of mechanical energy which is fed to the generator via a shaft. The aerodynamical power is given by the relation below [15].

\[ P_m = \frac{1}{2} \rho AV^3 C_p \quad \text{(5)} \]

We shall use a generic equation of as proposed by [15]. The equation is expressed below as

\[ C_p(\beta, \text{TSR}) = 0.22 \left( \frac{116}{\text{TSR}_i} - 0.4 \beta - 5 \right) * \exp\left( -\frac{12.5}{\text{TSR}_i} \right) + 0.0068 \text{TSR}_i \quad \text{(6)} \]

And

\[ \frac{1}{\text{TSR}_i} = \frac{1}{\text{TSR} + 0.08 \beta - 0.035} \quad \text{(7)} \]

The relation between the TSR and the angular speed of the wind rotor is given as:

\[ \omega = \frac{\text{TSR} * V}{R} \quad \text{(8)} \]

While, the mechanical torque in terms of mechanical power is given by the equation below:

\[ T_m = \frac{P_m}{\omega} \quad \text{(9)} \]

Substituting for \( P \) from (5) and from (8) into (9), the mechanical torque will be:

\[ T_m = \frac{1}{2} \rho AV^2 C_t \quad \text{(10)} \]

Where the torque coefficient is given below:

\[ C_t = \frac{C_p}{\text{TSR}} \quad \text{(11)} \]

![Figure 2: Matlab simulink of VAWT](image)

4. Modeling and Control of the Variable vertical axis Turbine

4.1 General
The control frame of a PMSG installed wind turbine operating with variable speed shown in figure (3) which involve the wind turbine - vertical axis. PMSG with single switch and (3) phase switch-ode rectifier and also a vector controlled (PWM) voltage source inverter. PMSGs do not appropriate for implementing as it is variability in amplitude and the frequency because variability of wind speed. Constant DC voltage will be desired for a direct usage, storing or converting to AC by employed inverter. The proposed single switch 3- phase rectifier includes a 3-phase diode bridge rectifier and also DC to DC converter. The output of the switch-mode rectifier may be controlled via managing the duty cycle of the active switch at any the air speed to produce ultimate power gained from the wind rotor and hence to provide the demand consequentially.

Figure 3: Control Structure of a PMSG based standalone variable speed VAWT [16].

4.2 Control of Switch-Mode Rectifier
Figure (4) shows the frame of the suggested control policy of the switch mode rectifier. Control top was aimed to control the duty cycle of switch (S) presented in figure (3) for utilizing the power maximum from the variable wind speed vertical wind turbine and transmit the power to the demand load. The program of control consists the following steps:

• Measuring of the speed of the generator,
• Obtain the reference torque considering the equation bellow:

\[ K = \frac{1}{2} \rho A \left( \frac{R}{TSR} \right)^3 C_p \ldots (12) \]

\[ T^*_g = K w^2 \ldots (13) \]

The reference torque is inherently used to compute the value of DC reference current via measuring the output voltage of the rectifier \( V_d \) as it may give as:

\[ I_d^* = T^*_g \times \frac{w^2}{V_d} \ldots (14) \]

The difference occurred between the based DC-current and the DC-current from measurement employed to change the duty cycle of the switch in order to manage the output and generated torque got from the switch-mode rectifier via a PI controller. [16].

Figure 4: Scheme of control process of the switch-mode rectifier [16]
4.3 Control Load Side of Inverter

The supply side converter is targeted to tune the frequency and voltage. The output voltage must be controlled in terms of frequency and amplitude as there is non-grid coexist standalone wind energy conversion system. The control frame for standalone control mode includes of voltage output controller, current controller and dc link voltage controller. Voltage output controller is utilized to control the output-voltage among transient load or fluctuation of speed of wind. DC-link controller voltage is utilized to balance the dc link voltage. The dc-voltage PI controller keeps voltage referred to the referencing value. The PI controller is utilized to modulate the voltage output and current in the internal control loops so the dc voltage controller in the outer-loop. In order to requisite the cross-coupling impact to keep the output filter into the rotating reference frame. The compensating terms are then added as illustrated in the following figure.

![Figure 5. Structure of the vector control for the standalone mode of operation [16]](image)

Figure 5 shows the MATLAB Simulink module of ducted wind turbine based on permanent magnet synchronous generator. This model shows a direct driven generator by wind turbine shaft.

![Figure 6: Wind turbine system Simulink model](image)

Figure 6: Wind turbine system Simulink model

5. Results and Discussion of Wind Turbine Simulink Model:

In Simulink work, for a wind turbine having 0.5 m rotor radius, zero and section pitch angle, the following results were achieved: Figure (7) shows the use of variable wind speed as an input forducted wind turbine- vertical axis, variation in the wind speed is used to describe the process of control of the generated power got from the generator of the change and acceptance of wind speed in
case of ducted and non-ducted wind turbines as well. That the variation in rotor speed according to variable wind speed has reached maximum value about 32 rad/sec of rotor speed. This fluctuation in rotation speed entering the generator lead to variable voltage output as presented in figure (8). Figure (9) shows produced mechanical torque by the wind turbine while the electromagnetic torque was represented in figure (10). It was noticed that the generator torque has a similar behavior of mechanical torque but negative sense as the mean of input generator torque. Figures (11) and (12) depicts the voltage and current at generator terminal respectively. DC-DC converter is utilized to control the voltage. So, the Dc voltage output from the 3-phase diode rectifier depends upon the input voltage which has a varying level. As demonstrated in figure (13) the converter controls the voltage to be approximately constant vs. figure (14). Line to line voltage output from DC-AC converter was illustrated in figure (15) and after filter line to line voltage output becomes presented in figure (16). Figures (17 and 18) illustrate the output voltage (3-phase) from the wind turbine system.
Figure (13) Rectifier output voltage

Figure (14) Controlled Dc voltage

Figure (15): Line to line inverter output voltage before filtering

Figure (16): Line to line inverter output voltage after filtering

Figure (17) Wind turbine system AC output voltage

Figure (18): Wind turbine system AC output current
6. Conclusion

In this paper, the Darrius vertical axis wind turbine was modelled and simulated and conducted using MATLAB/Simulink. The modeled system with all subsystems has specified and investigated for validation. In the modeling process of the mechanical transmission, gear ratio is neglected which leads to a reduction in losses in the system. The algorithm of control for the grid side converter along the LC filter was developed in order to regulate the voltage of grid side with specified power quality.

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