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Maximum Power Extraction from Active Pitch Controlled Standalone Variable Speed Wind Turbine

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Abstract*: This paper focuses on modelling of a standalone variable speed wind turbine using MATLAB and increasing its performance by extracting the maximum power below rated wind velocity using MPPT algorithm and maintaining constant power using active pitch angle control for above rated wind velocity. The wind turbine is coupled to a Permanent Magnet Synchronous Generator (PMSG) which can operate on variable speed. A variable resistive load will extract the maximum energy possible and utilise it for heating applications.

***Keywords* : Active pitch angle control, Average modeling, Heating applications, Maximum Power Point Tracking (MPPT), Variable-speed wind turbine, Wind Energy conversion systems (WECS),**

I. INTRODUCTION

With remarkable advancements in power electronics, wind energy sector grows rapidly and becomes equally competitive to other types of renewable sources and also due to its reliability, cost effectiveness and quality of power [1]-[2]. Wind energy conversion system (WECS) consists of either horizontal axis or vertical axis wind turbines, either doubly fed induction generator (DFIG) or permanent magnet synchronous generator (PMSG) generators, control system, and interconnection apparatus [3]. PMSG is preferred mostly because of its reliability and size for standalone system. It does not require gear box for interconnection which gives and advantage of less maintenance and high efficiency [4]-[5]. Use of DFIG is limited due to the necessity of slip rings brushes and gear box [7]-[8].

The mathematical modeling of the wind turbine is done based on its aerodynamics is presented in several research papers [9]-[11]. In order to maximize the output when the speed of wind is medium and light the pitch angle control is used. The value of pitch angle is chosen based on the wind speed [13]-[15]. The MPPT algorithm is used in order to obtain the optimal operating point of the turbine. [16-17].

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This paper is mainly based on mathematical modelling of wind turbine and connecting it to an average model of PMSG. The PMSG output is connected to a resistance load whose value will vary depending upon the power input to extort the utmost power from the generator. The resistance load produces heat which can be used for heating applications.

In this paper, section II discusses the mathematical modelling of WECS and Section III discusses control of wind turbine. The simulation outcomes were discussed in section IV and the conclusion is prearranged in section V.

II. MATHEMATICAL MODELLING OF WECS

This section discuses about the modelling of the standalone wind turbine of variable speed with active pitch control above rated wind velocity and to extract maximum power using MPPT algorithm below rated wind velocity. It also explains the average model of PMSG. This average model returns the average values of the terminal voltage, current, load angle and back emf of the PMSG when the input torque is given along with the control signal of the angular velocity of the generator at which it must rotate to extract the maximum power based on MPPT algorithm.

A. Wind Turbine Modelling

The kinetic energy of the flowing air mass per unit time which is the power contained in wind given by

$$P_{wind}=1/2(\text{air mass per unit time})*(\text{Wind velocity})^{2}$$
$$=1/2*(\rho AV)*(V)^{2}$$
$$P_{wind}=1/2*(\rho AV)^{3} \quad (1)$$

Where, P_{wind}- wind power (Watt)

ρ- Density of air = 1.225 kg/m^3 at 15°C atmospheric pressure

A-blade swept area (m^2)

V- Wind velocity (m/s) without rotor interference, at infinite distance from the rotor.

Even though equation (1) gives the wind power, the actual power transferred to the rotor of the wind turbine is abridged by the power coefficient C_P

$$C_p = P_{wind\ turbine} / P_{wind}$$
$$P_{wind\ turbine} = C_p * P_{wind} = \frac{1}{2}\rho A v^3 C_p$$

The coefficient of power is a nonlinear function of the tip speed ratio λ and the pitch angle of blade β in deg. If the blade sweep area and density of air are invariable, then C_p is a function of λ. At an optimal value of tip speed ratio λ_{opt}, the value of C_p is maximum. In order to utilize the wind energy completely the tip speed ratio λ should be maintained at λ_{opt}, which is determined from the design of the blade.

Turbine power $P_t = \frac{1}{2}\rho A v^3 C_p$ (2)

Power coefficient $C_p(\lambda, \beta)$ is given by the standard equation as in (3)

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{\frac{-21}{\lambda_i}} \quad (3)$$

From [1], for a range of values of the pitch angle β, the characteristic function C_P (λ, β) vs λ, is illustrated in Fig.1. From the graph it is found that C_{Pmax} =0.36, for β = 2° and λ=9.6. This meticulous value λ_{opt} provides the best possible efficiency where the greatest power is captured by the wind turbine.

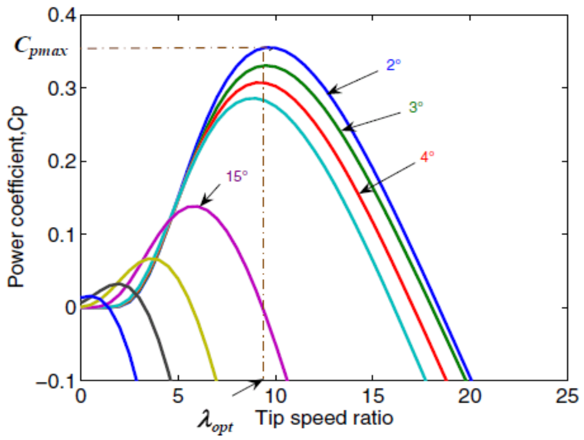

Fig.1. C_P (λ, β) vs λ

B. PMSG Modelling

The average model of PMSG is designed as well as coupled with wind turbine. The torque from the turbine T_m is given as mechanical input to the generator. The reference angular velocity ω_m is obtained from the MPPT algorithm. The back emf is directly proportional to the angular velocity.

$E_b = K\,\omega^3$ (4)

The rated back emf at steady state is assumed to be 440/√3 per phase. Knowing the steady state angular velocity of the rotor, the value of k can be calculated. Based on the value of k, the value of back emf is calculated for various rotor angular velocities. Since the load connected to the generator is purely resistive which has unity power factor and the frequency variation does not affect the load. The terminal voltage can be calculated from the vector diagram as exposed in Fig.2.

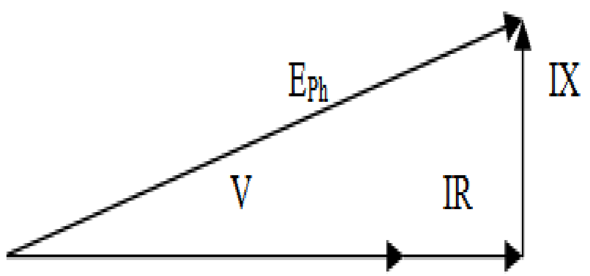

Fig.2 Vector diagram

The algorithm for finding out the terminal voltage is revealed in Fig.3. Initially, the terminal voltage is assumed to be 90% of the back emf, assuming 10% losses. Using the following iteration, the terminal voltage is calculated.

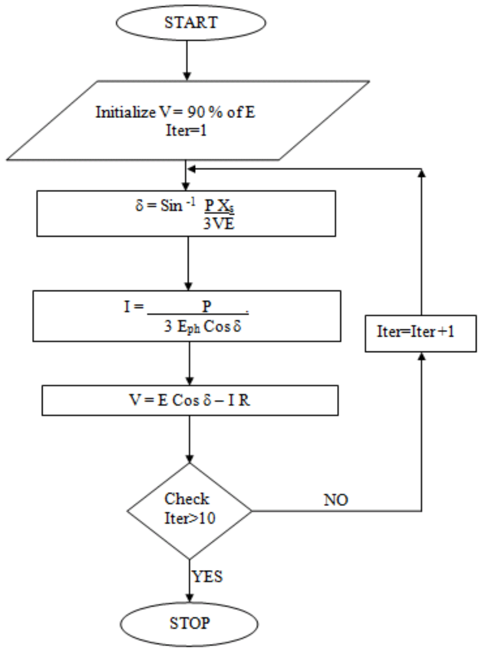

Fig. 3. Terminal Voltage Calculation

III. CONTROL OF WIND TURBINE

The performance of the wind turbine is based on the wind velocity. There are two control strategies, namely active pitch angle control and Maximum Power Point Tracking. The former is implemented for wind velocity above the specified base wind speed. The latter is used when wind velocity is lesser than the rated base velocity.

A. Active pitch angle control algorithm

When wind speed is greater the specified speed, turbine power also increases above the rated va ue. When power exceeds beyond the rated value, armature windings can burn out and it is not advisable. Hence, when the blades pitch angle β is increased, then Cp (λ, β) decreases thereby decreasing the turbine power. The required pitch angle that is to be set for achieving the desired power can be calculated using the algorithm revealed in Fig.4.

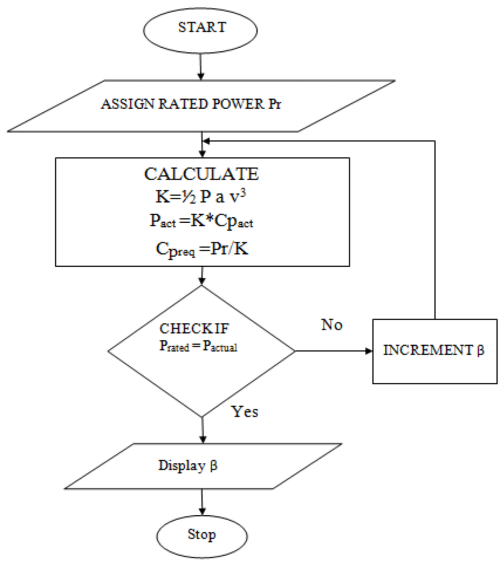

Fig.4 Pitch angle control algorithm

B. Maximum Power Point Tracking Algorithm

When the wind speed is below the specified value, then the pitch angle is set to zero because the aerodynamic power will be less and need not be controlled. The MPPT control is achieved by tracing the power vs. wind generator speed graph for a choice of wind velocities as revealed in Fig.5 and obtaining the required rotor speed corresponding to the input velocity for obtaining the maximum achievable power. For every wind speed, a specific point of ω_{opt} exists in the wind generator power curve for which highest power is extracted.

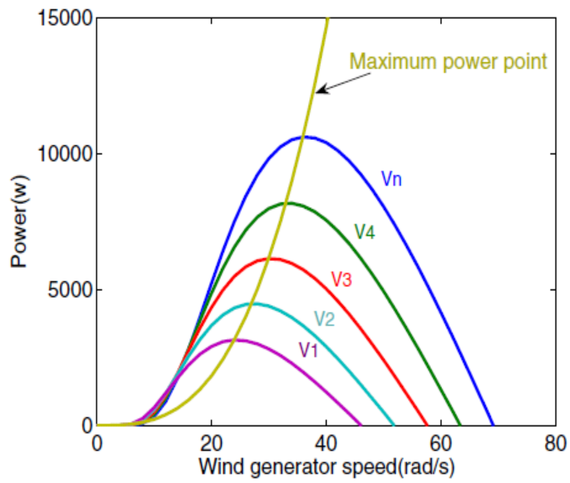

Fig.5 MPPT Graph

IV. SIMULATION RESULTS AND OUTPUT

Wind turbine was simulated using MATLAB Simulink. The varying input of wind velocity is given to the turbine block using repeating sequence. We assume the wind velocity to be gradually increasing for a period of time as revealed in Fig.6 to analyse the operation of the turbine under both over rated and under rated conditions.

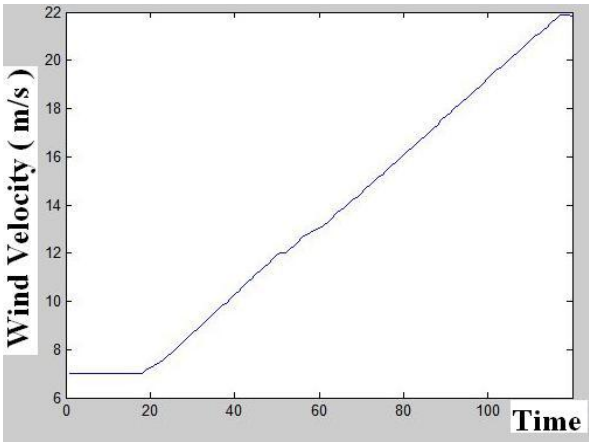

Fig.6 Wind velocity vs. Time

The turbine power output is revealed in Figure.7. The output is maintained as constant after the turbine reaches its rated speed.

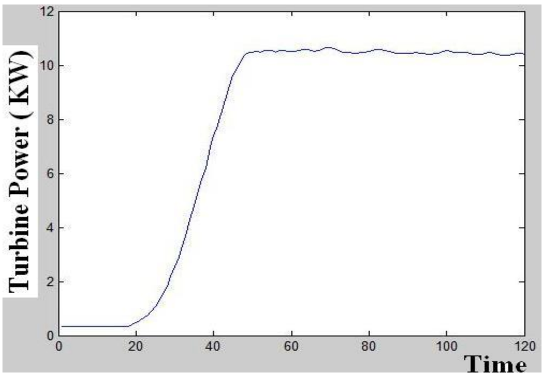

Fig.7 Turbine power vs. Time

The active pitch angle control is achieved using lookup table. The values of C_p is calculated for various values of λ and β and fed to the lookup table. The variation of pitch angle with wind velocity is revealed in Fig.8. The MPPT graph is also fed to the lookup table which will give the desired ω_m.

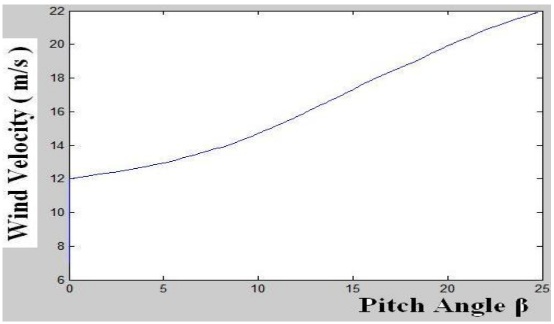

Fig.8 Variation of pitch angle with wind velocity

The PMSG is modelled using the embedded Matlab function. The back emf attains its rated value as soon as the wind velocity reached its rated value. The variation of back emf is revealed in Fig.9

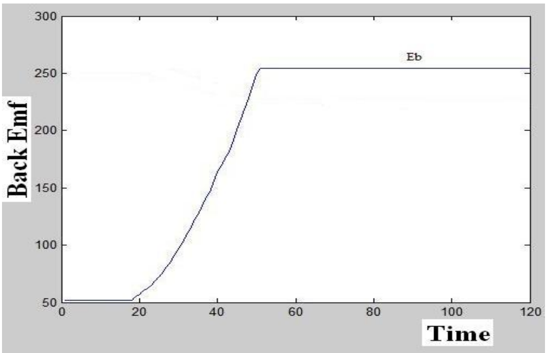

Fig.9 Back Emf of PMSG

The load resistance R_L is varied as per the power input to the PMSG such that

$$T_m\omega_m = I^2 (R_L + R_s) \qquad (5)$$

The variation of load resistance is exposed in Fig.10. As the current from the PMSG increases, the value of resistance decreases gradually such that the power is balanced.

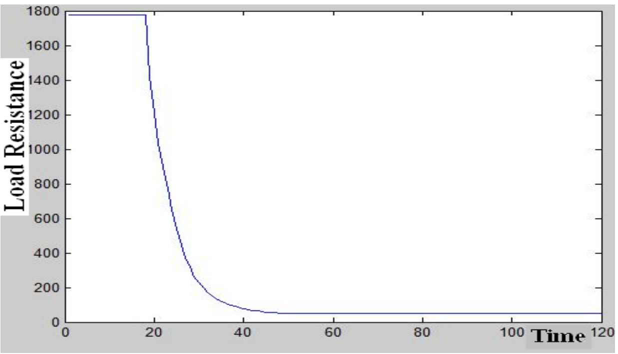

Fig.10 Variation of Load resistance

V. CONCLUSION

Thus a standalone variable speed active pitch controlled wind turbine with resistance load is simulated using MATLAB Simulink such that Maximum power is extracted for heating applications. The heating applications are mostly used in cold countries. The future scope of the project involves connecting a rectifier- inverter model so that the power extracted can be injected into the grid.

APPENDIX

Table 1 Wind Turbine Parameters

Density of air	1.225 kg/m^3
Wind Speed	12 m/s
Rated Power	10 KW
Rated mechanical speed ω_m	36 rad/sec
Blade Radius	3.1905 m

Table 2 Generator Parameters

Stator resistance R	1.985Ω
Inductance L	0.01(H)
Pole pairs p	3
Frequency *f*	60
Line Voltage *V*	440

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