Power control system of small scale wind turbine using PSF technique

Umpol Seedadee, Sarayooth Vaivudh, Nipon Ketjoy and Pisit Maneechot

Ph.D. Student, School of Renewable Energy Technology (SERT), Naresuan University, Phitsanulok, Thailand
Tel. +66-55963180, Fax. +6655963182, Email:Seedadee@yahoo.com

Abstract

The power control system of small scale wind turbine using the power signal feedback (PSF) technique is presented in this paper as a strategy to increase the efficiency of gaining the maximum power from a wind turbine. Generally, a small scale wind turbine is a direct drive permanent magnet generator (PMG), which is designed to operate at a fixed speed. It has no optimum load when wind speed changes. Hence, a wind turbine has to be controlled on the optimum rotational speed against varying wind speed in order to provide the maximum power. The proposed control method, is designed using an analog to digital converter (ADC) to decrease the rotational speed at optimum for maximum power point tracking to extract the maximum power. A prototype wind turbine has been constructed and tested using a wind tunnel. Experimental results of the proposed system indicated the optimal wind turbine generator output power where the maximum power coefficient was 0.37 at a tip speed ratio of 6.54, and the power output increased by 11%–66% compared to a wind turbine directly connected to load. The control system enables the turbine to operate at optimal speed to acquire maximum power for the whole range of assigned wind speed.

Keywords: *Power signal feedback (PSF), small scale wind turbine, maximum power, optimum rotational speed, microchip analog to digital converter (ADC).*

1. Introduction

The energy related environmental issues have created a crises in recent decades and attracted researchers around the world. Wind is one of the most attractive sources of alternate energy. Most wind turbines operate at fixed rotational speed except when starting and stopping. It should be noted that the maximum coefficient of performance is only available at one particular wind speed [1-2]. The small wind turbine generator is a variable speed permanent magnet generator driven by a wind turbine shaft without gearbox. Normally a variable speed wind turbine tries to rotate at a speed where it can capture the maximum power (P_{max}) up to the rated speed by varying the rotational speed to keep the system at the optimum rotational speed (ω_{opt}) [3]. The power coefficient characteristic of a wind turbine (C_p) has a single maximum at a specific value of rotation speed. For achieving the highest annual energy capture, the value of the power coefficient must be maintained at the maximum level all the time [4]. Control system should have been developed to suit for local wind speed efficiently.

2. Principle and Algorithm

2.1 Physics of Energy Extraction from Wind

The power which is captured by the blades, P_{turb} can be calculated by

$$P_{turb} = \frac{1}{2}\rho\pi R^3 v_t^3 C_p \tag{1}$$

2.2 Variable Speed Wind Turbine

When the rotational speed is λ_{opt}, it will also get $C_{p\,max}$. The following expression is obtained:

$$\lambda = \lambda_{opt} = \frac{\omega_{opt} R}{\lambda_{opt}} \tag{2}$$

then

$$v^3 = \frac{\omega_{opt}^3 R^3}{\lambda_{opt}^3} \tag{3}$$

$$P_{a,opt} = K_{opt}\omega_{opt}^3 \tag{4}$$

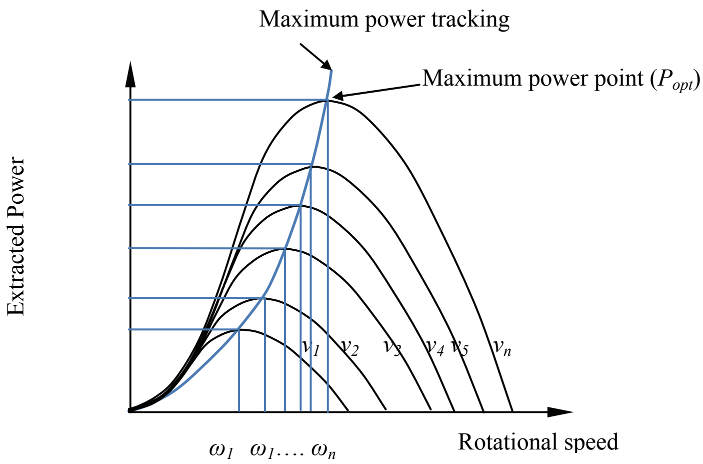


Figure 1 Power characteristic and optimum power tracking paths[4]

The maximum power points for various wind speeds are shown in Figure 1. A variable speed wind turbine follows the P_{max} to capture the maximum power up to the rated speed by varying the rotational speed to keep the system at the optimum rotational speed ω_{opt} [3].

2.3 Optimum Loads of Permanent Magnet Generator for Wind Turbine

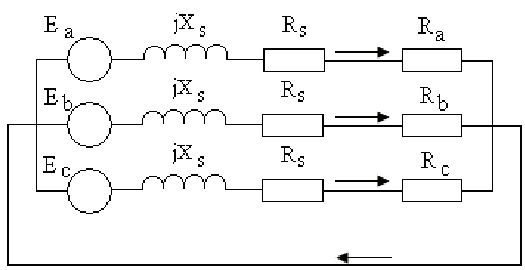


Figure 2 The PMG connected to a resistive load [5]

The PMG circuit is shown in Figure 2. The three line-to-neutral generated voltages E_a, E_b, and E_c are all displaced from each other by 120 electrical degrees [5].
The power of the PMG per phase is given by

$$P_e = I_a^2 R_a \qquad \text{W/phase} \tag{5}$$

The power of the PMG per phase can further be written as

$$P_e = \frac{E_a^2 R_a}{(R_s + R_a)^2 + X_s^2} \qquad \text{W/phase} \tag{6}$$

The generated voltage E_a is given by

$$E_a = K_e \omega \quad \text{V} \tag{7}$$

The reactance X_s, is given by

$$X_s = \omega L_s \qquad \Omega \tag{8}$$

Now

$$P_e = \frac{K_e^2 \omega^2 R_a}{(R_s + R_a)^2 + \omega^2 L_s^2} \quad \text{W/phase} \tag{9}$$

3. Experimental Setup

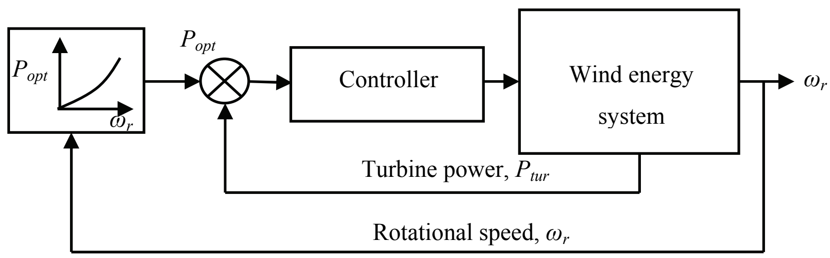


Figure 3 Block diagram of PSF control

PSF control method is proposed for the control system designed for this particular wind turbine under study. The controller was designed to follow the characteristic of the maximum power curve and to tracke this curve through the control mechanism as shown in Figure 3. The maximum power curve was obtained from an experiment on individual wind turbine. The output power curve was the characteristic of each controlled wind turbine [3].

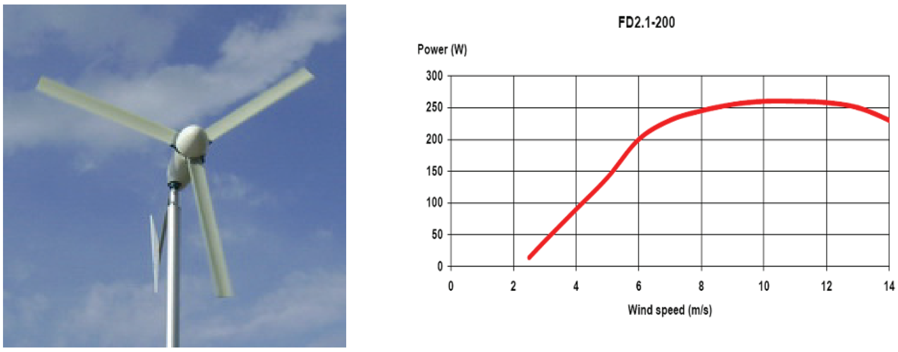


Figure 4 The 200 W wind turbine

The control system was composed of a small horizontal axis wind turbine with an axial flux permanent magnet generator without a gearbox as shown in Figure 4. The horizontal axis wind turbine had the higher aerodynamic power coefficient of wind turbine and the optimal rotational speed was relatively higher than other types [6].

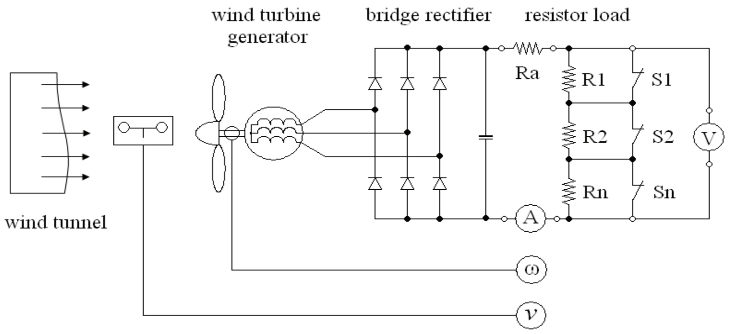


Figure 5 Load adjustments by switching resistors

The microcontroller unit (MCU) design requires the data from wind turbine which was obtained from the test by measuring output power and the optimum rotational speed as shown in Figure 5.

Table 1 Power output value

Step Number	Wind velocity (m/s)	Rotational speed (rpm)	Electrical Power output (Watt)	Resister Load(Ω)	Load Number
1	3.0 m/s	147	14.22	7	1
	3.5 m/s	190	23.25	7	
	4.0 m/s	219	43.21	6	
2	4.5 m/s	260	73.95	6	2
	5.0 m/s	280	102.54	6	
3	5.3 m/s	301	132.77	5	3

The test of wind turbine parameters to achieve the rotational speed for maximum power against each wind speed could model different load resistance value (load 1, load 2, and load 3) at wind speed 3.0-5.3 m/s as shown in Table 1.

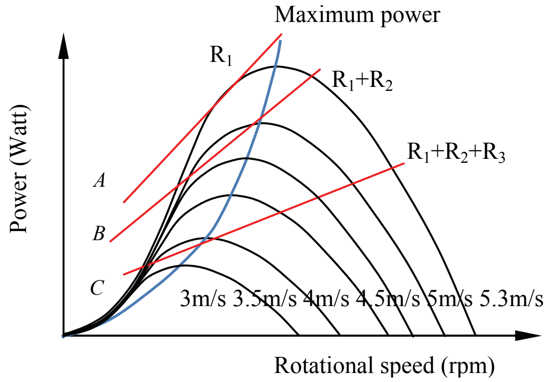
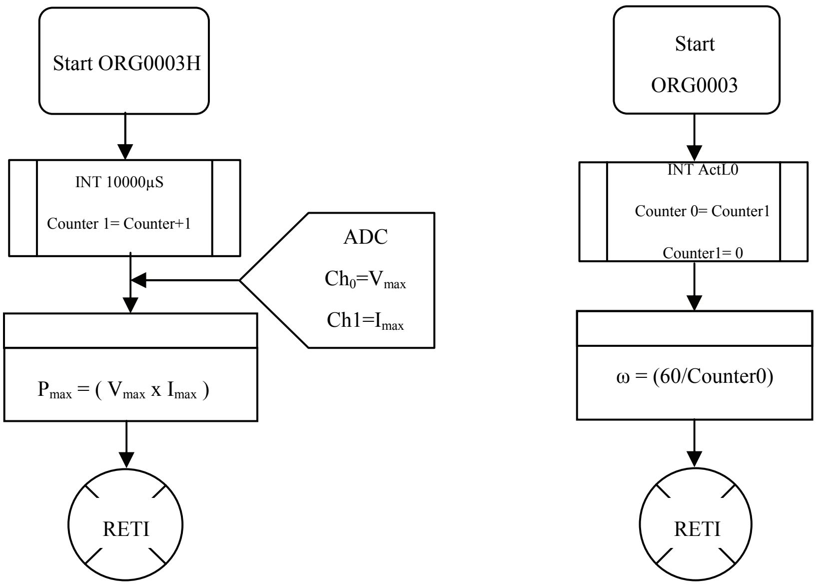


Figure 6 Electrical power output in variable speed operation [2]

From the testing, the optimum point to extract maximum power could be found in accordance with maximum power line by modeling loads in 3 steps as shown in Figure 6. The resistance line *A* was optimal for the wind speed 3.0 and 3.5 m/s, the resistance line *B* was optimal for the wind speed 4.0, 4.5 and 5.0 m/s, and the resistance line *C* was optimal for the wind speed 5.3 m/s.



(a) Time interruption

(b) Rotational speed

Figure 7 Time and rotational speed interruption

The maximum power and the rotational speed were the main parameters to be controlled by microcontroller as shown in Figure 7. The maximum power was transformed as time interruption, which was received as part of the data transmitted from wind turbine. The value was obtained from the product of maximum power voltage (V_{pm} and maximum power current (I_{pm}), and would receive the data to analize every 1000 μs as shown in Figure 7(a). The rotational speed was transformed as speed interruption which was received from the rotational speed in rpm to encode it into a unit of time period and continuously transfer to be the input as shown in Figure 7(b).

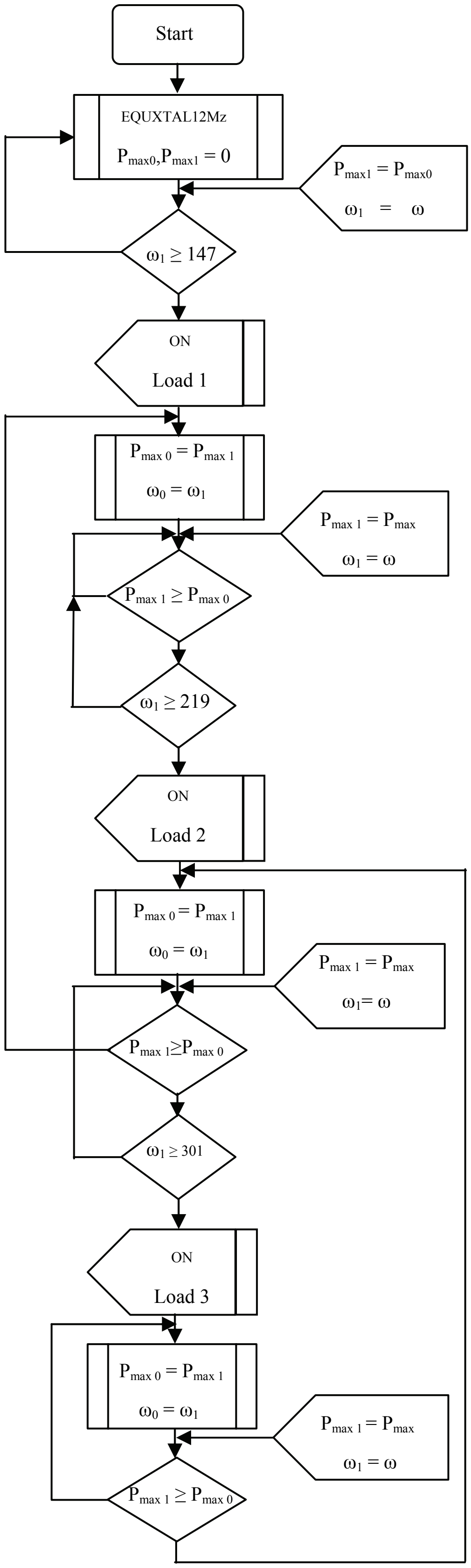


Figure 8 Flow chart of power control system

The operation of this system in Figure 8 was started at the ORG 0000H position which was the first point of MCU by checking the rotational speed. Whenever, the rotational speed reached at 147 rpm or higher, load 1 would be commanded to operate. In the case of the rotational speed and output power increased, load 2 would be commanded at the 219 rpm and load 3 would be commanded at 301 rpm. On the contrary, in the case of the rotational speed increased but the output power decreased, load 2 would be replaced for load 3 and load 1 would be replaced for load 2.

4. Results and Discussion

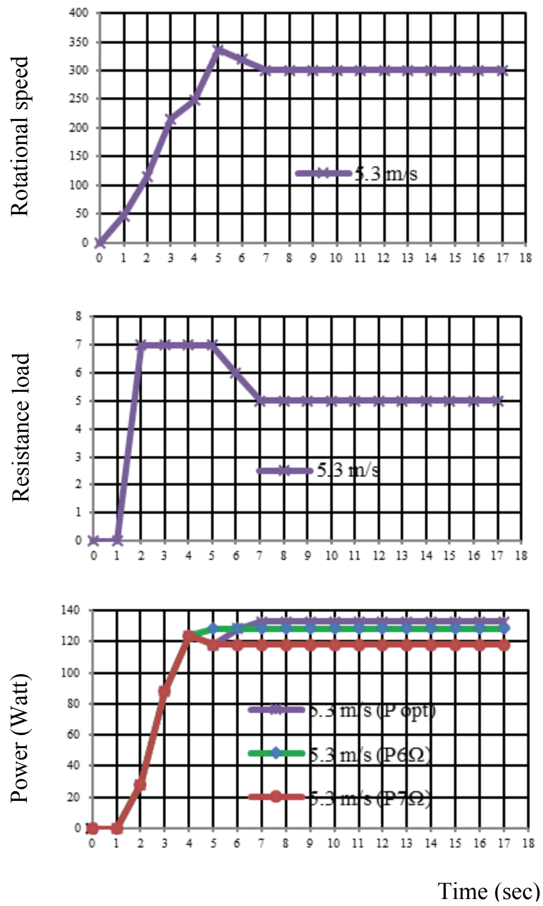


Figure 9 Test result of wind turbine operation at wind speed 5.3 m/sec

Figure 9 shows the results of wind turbine control, based on the constant speed of 5.3 m/s for rotational speed, resistance load and power output.The wind turbine starts connecting 7 Ω resistance (load 1) at the 147 rpm rotational speed and the power output was kept increased until reaching at 219 rpm, the power control would connect the 6 Ω resistance (load 2), the rotational speed and the power output were increased further, power control would be connected the 5 Ω resistance. Test showed that the system could be operated according to the programme and the 5 Ω resistance was the optimal load for wind turbine at 5.3 m/s.

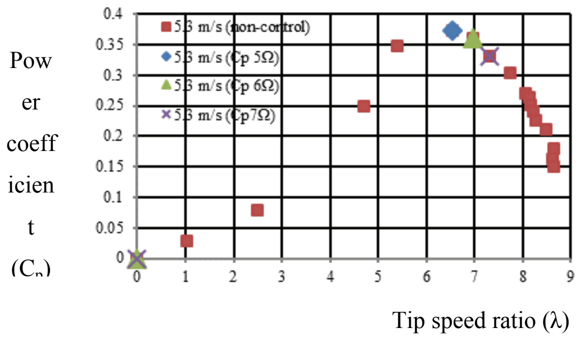


Figure 10 Power coefficient of performance versus tip speed ratio

Figure 10 shows the test results relating to power coefficient and tip speed ratio at 5.3 m/s wind speed. It was found that power coefficient comes out to be 0.37 and tip speed ratio was 6.54**.**

5. Conclusions

Due to wind's unpredictable nature its speed changes constantly, power management concept comes in to capture as much power as possible from the available wind. The PSF control has been designed to maintain the system at the highest possible efficiency by controlling the varying wind speed at optimum. The prototype which memorized the load reference on the optimum rotational speed and maximum power of wind turbine was designed, constructed and tested using a wind tunnel. Experimental results of the proposed system showed that the PSF could control the rotational speed at the optimum point and get the maximum power in each group of varying wind speed efficiently if compared to the wind turbine directly connected to the load. The advantages of this control system arethat the wind turbine characteristic saved in the memory are suitable for maximum power point tracking accurately and are fast and simple to use.

6. References

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