Maximum Power Point Tracking for Small Scale Wind Turbine With Self-Excited Induction Generator

Márton Örs

Technical University of Cluj-Napoca Department of Automatic Control
26-28 Gh. Baritiu Str. 400027 Cluj-Napoca, Romania
(e-mail: ors.marton@aut.utcluj.ro)

Abstract: This paper presents the basic methods for MPPT (Maximum Power Point Tracking) controlling only the charging of the battery banks. This is a cheap solution for small scale wind turbines. A simple MPPT method is presented by changing the load of the SEIG (Self Excited Induction Generator) driven by the wind turbine. Two systems are compared: one with MPPT and one without it. This paper also shows the effect of the load variation caused by the MPPT on the voltage of the SEIG.

Keywords: Power Coefficient, Maximum Power Point Tracking, Self Excited Induction Generator

1. INTRODUCTION

Renewable energy sources (solar, wind, hydro ect.) are attracting more attention as alternative energy sources for conventional fossil fuel energy sources. This is not only due to the diminishing fuel sources, but also due to environmental pollution and global warming problems. (Th.F. El-Shatter et al., 2001)

Small renewable-based power supply systems are marketable only in remote places where grid based electricity is not available, high capital cost makes it uncompetitive against large power stations. (Stephanie Jennings et al., 2000)

It is estimated that two billion people in small villages in developing countries currently lack grid based electricity service. In many cases, grid extension is impractical because of low population density and rugged terrain. (E.M. Nfah et al., 2006)

Stand-alone renewable-based systems are not reliable enough. Diesel generators are needed to make the system more reliable. Systems with no diesel generator need to bee oversized to get appropriate Loss of power load probability (LPSP=0). LPSP=0 means that the chance of power loss is 0. This means that larger battery banks are needed to ensure power all the time. A larger generator is also needed to extract all the power even in peak power situation as high winds, to store enough energy for periods when the renewable source is not available. A hybrid system with a diesel generator has no such problems. If no energy is available from the renewable source the diesel generator starts. This means that no over sizing is needed so a lower levelized cost of energy (LCE) is possible. Levelized cost means the total cost of the energy including capital cost of the power system, maintenance cost and fuel cost calculated for the lifetime of the power system. The diesel generator for a hybrid system with battery bank is also smaller than one that uses only diesel power. A system without battery bank must be oversized to generate enough power in peak load situations. A hybrid system ensures the power need from the battery bank, so if a high power load appears for a short period, the stored energy ensures the sufficient power. The smaller generator can charge the battery bank when the power demand is lower. (S. Diaf et al., 2006)

The development of remote, renewable-based energy is hindered by the high capital cost and high maintenance costs because a system failure usually means a costly travel to the isolated system by a specialist.(Stephanie Jennings et al., 2000) The comparison is based on cost, efficiency and reliability. Actually only cost and reliability are important, efficiency is important only for reducing costs by choosing smaller cheaper components.

2. WIND GENERATOR MODEL

2.1 Wind turbine power and torque

The power available in the wind is given by (1):

$$P_W = \frac{1}{2}\rho_a A_T V^3 \quad (1)$$

where P_W is the wind power, ρ_a is the air density, A_T is the cross-sectional area of the rotor and V the wind velocity .

The power extracted from the wind by a wind turbine is given by (2):

$$P_T = \frac{1}{2}\rho_a A_T V^3 C_P \quad (2)$$

where P_T is the power produced by the wind turbine and C_P is the power coefficient.

The rotor torque is given by (3):

$$T = \frac{1}{2}\rho_a A_T V^2 R C_T \quad (3)$$

The relation between C_P and C_T is (4)

$$\frac{C_P}{C_T} = \lambda \tag{4}$$

where λ is the TSR (tip-speed ratio) which means how many times the speed of the tip of the turbine blade is grater then the wind speed (5):

$$\lambda = \frac{V_T}{V_W} = \frac{R\Omega}{V_W} \tag{5}$$

where Ω is the angular velocity of the wind turbine in rad/s.

Typical power coefficient (C_P) and torque coefficient (C_T) curves for most wind turbines are given in Fig.1.

Usually three-blade airflow wind turbines are used for electric energy generation because, they have the highest power coefficient, so for this paper a horizontal axis three-bladed wind turbine is considered. The power coefficient curve of the wind turbine used in this paper is presented in Fig.2.

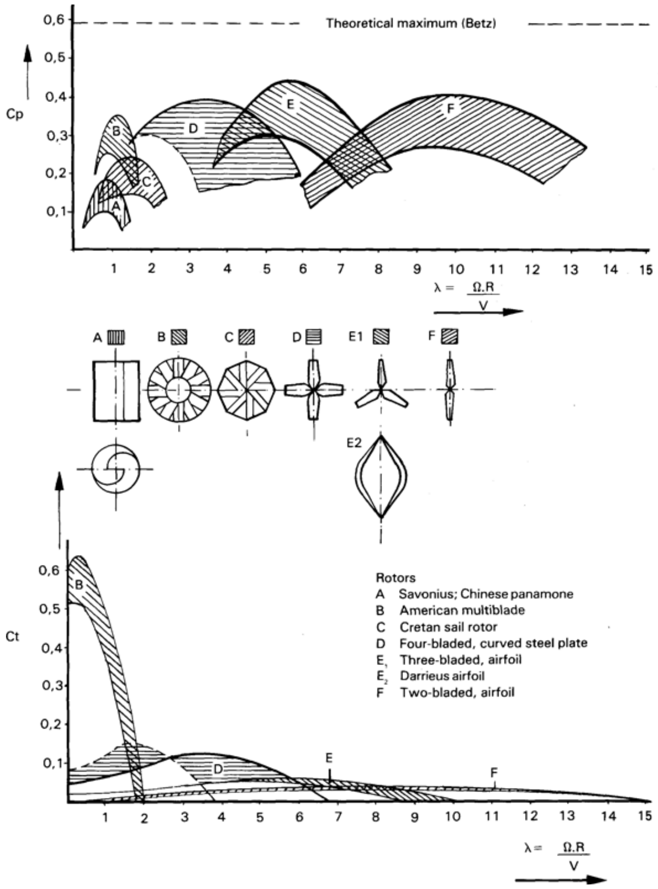

Fig.1. The power coefficient (CP) and the torque coefficient (CT) of various types of wind turbine plotted against tip-speed ratio (λ)

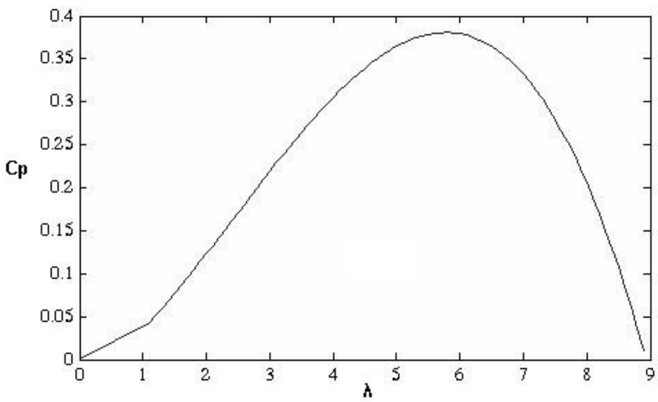

Fig.2. Power coefficient curve plotted against tip-speed ratio

2.2. Self-excited induction generator

The d-q model is used to simulate the electric behaviour of the SEIG. The electromagnetic torque is given by (6-8)

$$T_e = 1.5p(\varphi_{ds} i_{qs} - \varphi_{qs} i_{ds}) \tag{6}$$

$$\varphi_{qs} = L_s i_{qs} + L_m i_{qr} \tag{7}$$

$$\varphi_{ds} = L_s i_{ds} + L_m i_{dr} \tag{8}$$

Where T_e is the electromagnetic torque, p is the number of pole pairs, i_{qs}, i_{qr}, i_{ds}, i_{qs}, are the stator and rotor currents on the d-q axis, L_s the stator leakage inductance and L_m the magnetising inductance.

The mechanical part of the wind turbine driven induction generator is given by (9)

$$T = J\frac{d\omega}{dt} + D\omega + T_e \tag{9}$$

Where T is the torque of the turbine, J is the combined inertial coefficient of the wind turbine, gearbox and generator, and D is the combined friction coefficient of the gearbox and generator.

3. POWER POINT TRACKING METHODS

In order to harvest the maximum amount of energy from the wind, the wind turbine must have a specific rotation speed to maintain the optimum tip-speed ratio. The purpose of the MPPT is to maintain the tip-speed ratio of the wind turbine as close as possible to the optimal tip-speed ratio.

The MPPT methods can be divided in two main groups. The first group has no information about C_P curve of the wind turbine, this method is called P&Q (Perturbation and Observation). The second group uses the C_P curve to calculate the optimum operating point.

3.1. Perturbation and Observation

This method uses only measured data and doesn't need any information about the C_P curve, the optimum TSR, the wind speed or angular velocity.

The operating point can be on the positive slope, maximum point or negative slope. If the operating point on in the positive slope, the operating point must be moved to the right to obtain the maximum point. This can be achieved by reducing the load current. By reducing the load current the electromagnetic torque will be reduced, and the difference between the turbine torque and electric torque will accelerate the wind turbine. If the operating point is on the negative slope the load current must be increased to increase T_e. If the torque developed by the turbine is smaller than T_e and the losses caused by friction, the turbine will decelerate.

When the wind speed steps over the cut-in speed the controller will produce a perturbation. This perturbation will lead to power increase or decrease so the controller finds out on witch side of the slope is the operation point at the given moment. After that the load is increased or decreased until the slope is zero. When the slope becomes zero the system has reached the maximum power point. A more advanced form of this method takes in account the slope for calculating the size of the step. The step is proportional with the slope. This will lead to a faster response. The tracking process is shown in Fig.3.

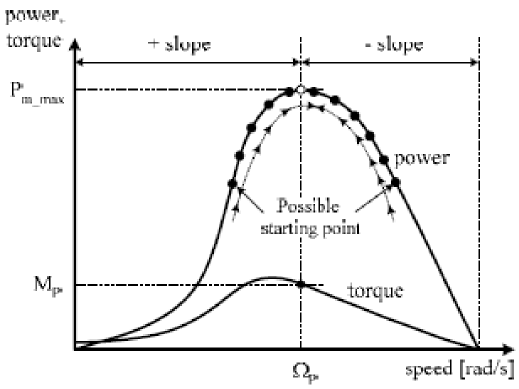

Fig.3. MPPT process with P&Q

3.2. Model based control

The second method uses a predetermined equation of C_P. The main advantage of this method is a higher performance the main disadvantage the need of the C_P curve, the rotation speed of the turbine and the wind speed. An anemometer or an estimator is needed to measure the wind speed. Any changes in the C_P curve will lead to a decline in performances.

The MPP curve for the considered wind turbine is given in Fig.4. The MPPT is necessary only until 750 W because this is the nominal power of the used induction generator. For higher wind speeds instead of the MPPT an electric breaking system must be used. This paper focuses only on the MPPT.

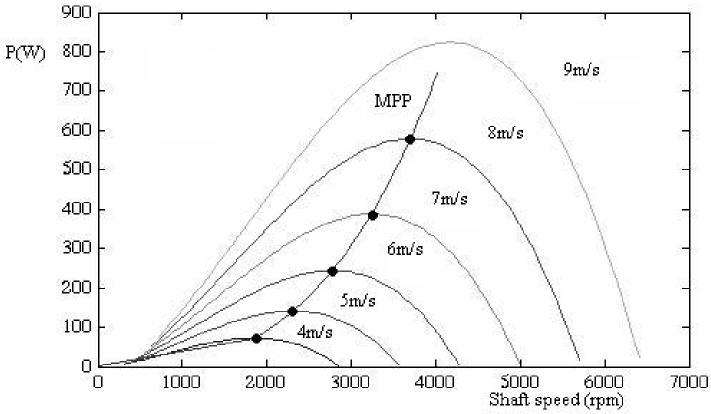

Fig.4. Maximum power point for different wind speeds

4. SIMULATIONS

The Proposed system is shown in Fig.5. The blocks are implemented using the equations presented in section two and simulated using Matlab Simulink.

The parameters are chosen for a 3m diameter horizontal axis three-bladed airflow wind turbine, a 1:12 ratio gear box and a 750 W induction generator.

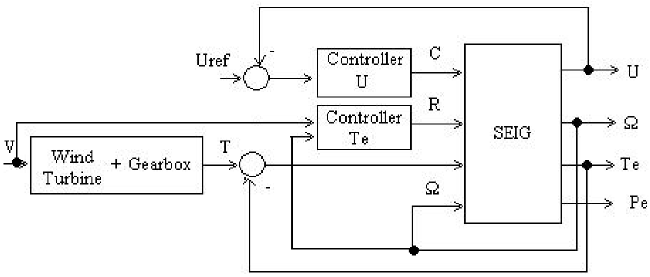

Fig.5. The block diagram of the proposed system

For the voltage control a PI controller is used. For high frequency the voltage control becomes instable so the proportional and integration constant are chosen experimentally for high frequency.

The MPPT control is similar with the second method presented in section three. It is a TSR tracking control, so it needs only the optimum TSR and the maximum C_P. It brings the operation point on the negative slope near to the MPP, because on the negative slope side the system is stable. The wind turbine will accelerate without any load until reaches the optimum TSR. At the optimum TSR a calculated load will be applied. The maximum power available is calculated. The load is calculated to consume 95% of the available power. Because the system is on the negative slope, it will become stable close to the maximum power point. The main advantages of this method are: that it reaches fast to the maximum power point, it doesn't need detailed data about the wind turbine, and it is much more stable than other MPPT control methods. The main disadvantage is that it doesn't extract all the power available. The simulation results for this system are presented in Fig.6.

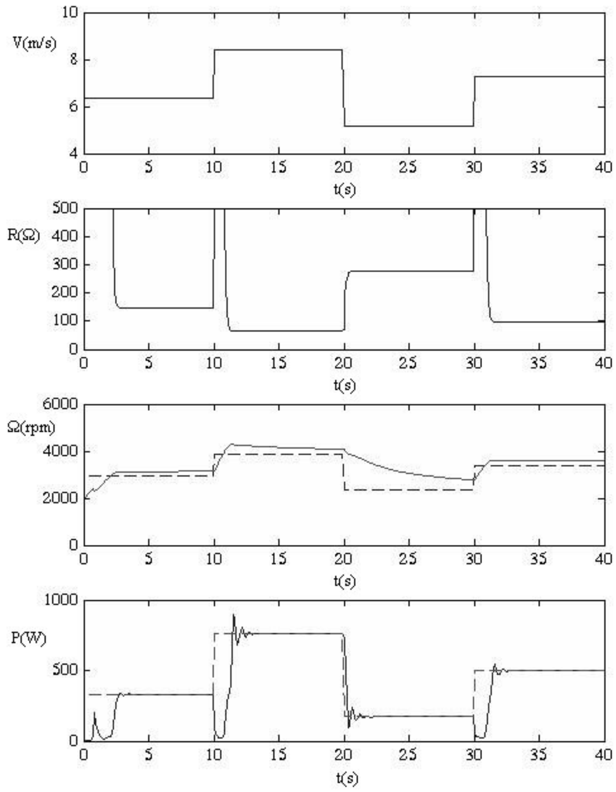

Fig.6. Simulation results for MPPT

The system was simulated for variable wind speed (V).

R is the load applied to the induction generator; Ω is the rotation speed of the high speed shaft (the optimal value with dashed line); P is the electrical power (the target value with dashed line). The simulation shows that the system becomes stable close to the optimum rotation speed, but a little bit higher. This means that the system is on the negative slope.

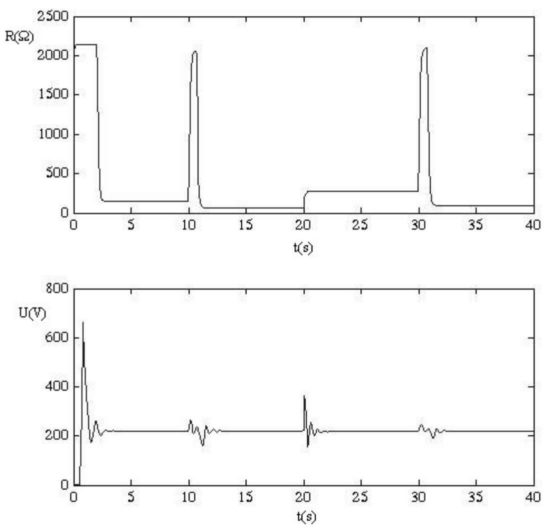

Fig.7. Voltage variation with the load variation

The steps in the wind speed lead to steps in the load resistance. These steps in the load change the voltage of the induction generator presented in Fig.7. The voltage has a high peak at the start-up when the self exciting appears. After that, smaller variations appear for every load variation. Fortunately, steps in the wind speed are not possible in real applications so the load steps will be smaller.

For comparison the system without any MPPT is simulated with a fixed load, Fig.8. Because of the high wind speed the system is working but with poor performances. Without MPPT the wind turbine will not start for slow wind speeds and will not produce anything. For high wind speed it starts but extracts only a fraction of the power available. The power coefficients for the two systems are compared in Fig.9. The system without MPPT (dashed line) has clearly a lower power coefficient than the one with MPPT. The difference between the two is even greater at the electric power generation, because without MPPT more power is lost due to friction. For a small period of time it is possible that the system without the MPPT produces more electric power because it uses the kinetic energy built up as rotation speed (the principle of the flywheel).

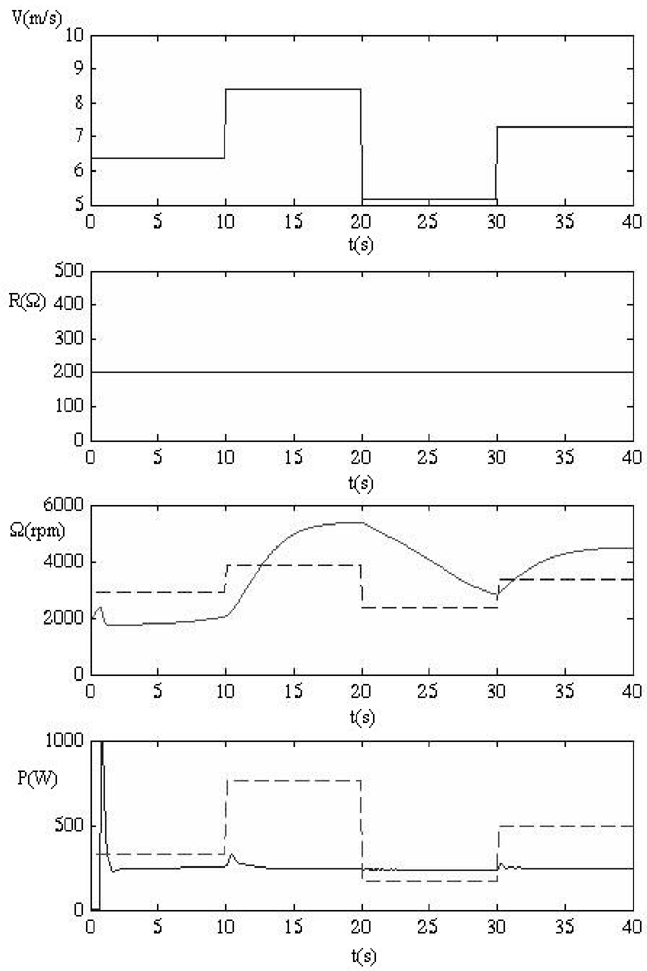

Fig.8. Simulation results without MPPT

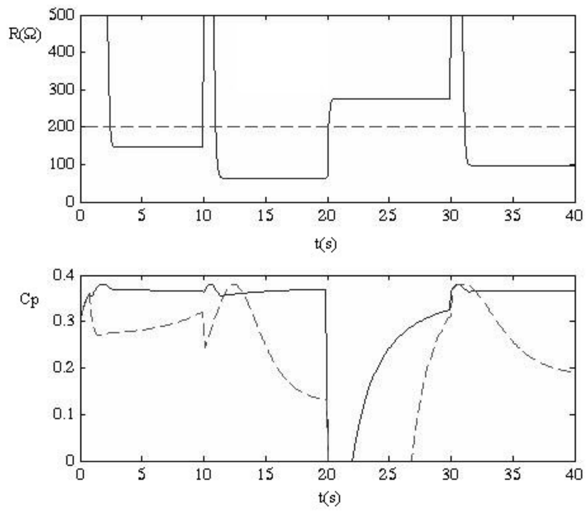

Fig.9. Power coefficient comparison

Fig.9. Shows that for every load the Cp has a peak and becomes stable at a lower value on the negative slope. In situations when the wind speed drops, the power coefficient can become zero or even negative. In this paper the Cp is limited to zero because the polynomial used, approximates the wind turbines Cp only in this range.

5. CONCLUSINS

The proposed control method was simulated. The simulation result clearly shows that the MPPT control is absolutely necessary to obtain acceptable performances. A system without MPPT will not work at all for wind speeds and will work very poorly for high winds. By chance it may work well for a given wind speed.

The advantages of the proposed control method are: it needs only the optimal TSR and the maximum Cp, fast response time, simple controller, and it is more stable than other MPPT controllers. The stability in this case is important because the voltage control of the SEIG is unstable and frequent load changes can bring the system to instability, which leads to loss of the self exciting.

For higher wind speeds the system gets even more unstable and a better voltage controller is needed.

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