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Research Paper

Maximum Power Point Tracking and Battery Charging for Stand-Alone Wind Power System

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Abstract— In this paper, a boost-type power converter and the battery charger for the stand-alone wind power system is proposed. The proposed power converter can produce the maximum power from the wind turbine while generating pulsating current for the battery bank to improve the charging efficiency. The maximum power point tracking function is obtained by the constant on-time control, the circuit parameter design of the power converter, and the characteristics of wind turbine. The pulsating battery charging current is implemented by the discontinuous conduction mode operation of the power converter. Also, the over speed protection of the wind turbine can be naturally realized when high power output occurs. Circuit simplicity and high consistency are the major benefits of the power converter. The performance of system is simulated in MATLAB-SIMULINK

Keywords— Battery charger, constant on-time control, maximum power point tracking (MPPT), wind turbines.

I. INTRODUCTION

Wind energy is one of the most important, free, renewable, clean and non-polluting sources, which is vigorously pursued in many countries. Of the several alternative energy sources wind is perhaps the most suitable and cost effective. Compared with solar energy sources, wind is more sensitive to variations with topography and weather patterns. Wind energy has the potential to provide services to the grid, utilities, and downstream customers by improving power quality, reliability and adding needed capacity. By tapping into its enormous renewable energy potential and manufacturing know-how, we will be able to meet the increasing power demand in the future. For rural and remote areas, the small-size Stand-alone wind power system with a battery bank as the energy storage component is common and essential for providing stable and reliable electricity. It can be installed at selected locations with abundant wind energy resources more flexibly and effectively. For the stand-alone wind power system, the load isa battery that can be considered as an energy sink with almost constant voltage. The battery can absorb any level of power as long as the charging current does not exceed its limitation.Since the voltage remains almost constant, but the current flows through it can be varied, the battery can be also considered as aload with a various resistance. Among different types of small-size wind turbine, permanent magnet (PM) generator is widely used because of its high reliabilityand simple structure. One of the most importantfeatures of the wind turbine is its maximum output power characteristic. One way to draw the maximum power from the wind turbine is to control the pitch angle of the wind turbine blade. However, for a small-size wind turbine, the pitch angle control method becomes unrealistic because of its mechanical structure. Therefore, the maximum power point tracking (MPPT) feature of the small size wind turbine is realized by the power converter control scheme. Many MPPT strategies have been proposed, where the perturbation and observation method is the most commonly used control strategy. A review of the state-of-the-art of power electronics for wind turbines have been published that introduced many MPPT strategies for the wind turbine . For the stand-alone wind power system, a commonly used control method is based on the rotor characteristic that is stored in a memory. By measuring the rotor speed, the optimal rotor power can be obtained and compared with the actual rotor output power. Then, the error between those two quantities is used to control the output power of the rotor. Other control schemes, such as fuzzy logic or neural networks, have also been proposed for the wind turbine . However, most of the aforementioned control strategies need a microcontroller to fulfill the task that results in high cost and circuit complexity. For small-size and stand-alone wind power systems located in remote area, the simplicity and reliability of the power controllers very important.

II. WIND TURBINE

The wind turbine is a device that can convert the kinetic energy of wind into electrical energy. The blades of a wind turbine are the media for the kinetic-to-mechanical energy conversion. The blade is a beam of finite length with airfoil as cross sections. While the air flows through the blade, it creates pressure difference between the upper and lower sides of the blade that can make the blade to rotate. Then, the rotating blade will drive the blade-connected generator to convert the mechanical energy into the form of electricity. To derive the expression of the power generated by the wind turbine, several assumptions should be made. First, the blades are considered to be ideal. It means that they are frictionless and rotational velocity is not considered. Also, the air flow is perpendicular to the rotational plane of the wind turbine. The mathematical derivation of output power of the wind turbines well known and can be found in many books with different expressions.

$$P_m = \frac{\pi}{2}\rho C_p(\alpha,\beta)R^2 V_w^3$$

Where Pm is the output power of the wind turbine, ρ is the air density, Cp (α, β) is the power conversion coefficient that is related to tip-speed ratio $\alpha$and pitch angle β, R is the blade radius, and Vw is the wind speed. In (1), the power conversion coefficient Cp plays the most important role to the output power of the wind turbine under a constant wind speed. For a wind turbine with fixed pitch angle, the Cp is only affected by the tip-speed ratio λ, which is defined as the rotational speed of the tip of the blade Vtip over the wind speed Vw . In other words, the wind turbine should operate at different rotational speed under different wind speed in order to draw the maximum power from the wind energy.

A. Power in wind

$$P(t) = \frac{1}{2}\rho A V(t)^3$$

Where ρ is the density of air, which is around 1.22kg/m³. The energy (kWh) is the product of power and time

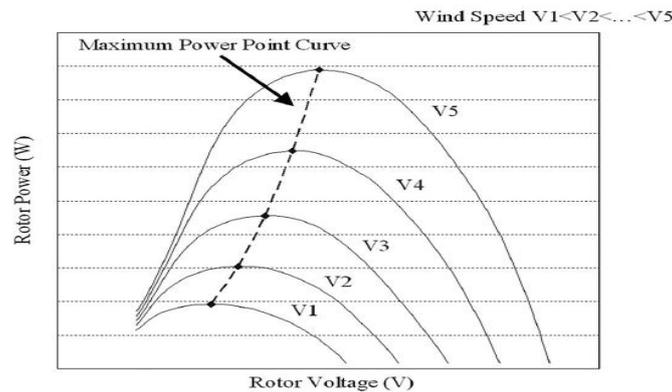$$E = PT = \frac{1}{2}\rho A\Delta t \sum_{i=1}^{N} v_i^3$$

Fig. 1. Wind turbine output power curves under various wind speeds.

Basically, as the wind speed increases, the output power of the wind turbine increases, too. For each wind speed, there exists a MPP. The dash line shown in Fig. 1 represents the MPP curve of the wind turbine under different wind speed. Theoretically, under constant power conversion coefficient C_p , the MPP curve is found to be a cubic function of the turbine speed. However, during the preliminary tests for the PM's output power measurements, it is found that the MPP curve can be approximated by a second-order polynomial equation. The discovery of this characterize the motivation of this research project. The design of the proposed MPPT control strategy is based on the approximated MPP curve of the wind turbine

III.   CONTROL STRATEGY

The circuit diagram of the proposed buck-type MPPT battery charger is shown in Fig. 2. There are two battery charging modes: pulsating current mode (PCM) and constant voltage mode (CVM). When the battery voltage V_b is below the threshold value V_{bth} , the proposed battery charger is operated in PCM with SW2 opened. On the contrary, when V_b is higher than V_{bth} ,the proposed battery charger is operated in CVM with SW2closed.For PCM operation, the charger is operated in the discontinuous conduction mode (DCM) with constant on-time control to generate the pulsating charging current for the battery bank. As the wind speed increased, the output voltage of the wind turbine will increase too. The proposed charger may enter the continuous conduction mode (CCM). Fortunately, the increased current will result in decreasing the rotor speed as well as the input voltage of the proposed charger. However, in order to obtain the best performance of the charger, the boundary between the DCM and CCM need to be carefully designed.
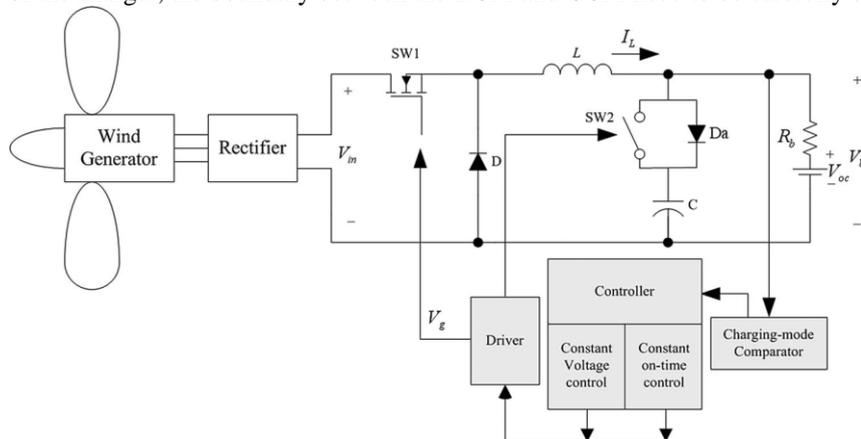

Fig. 2. Proposed MPPT battery charger for the stand-alone wind turbine
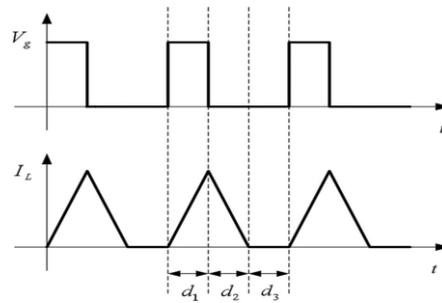
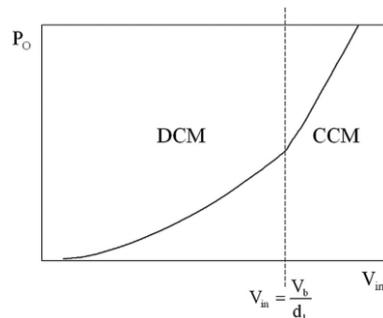Fig. 3. Typical waveforms of the gate signal and the inductor current in DCM.

Fig. 4. Output power curve of the proposed MPPT charger.

When the battery reaches the end of the charging status with V_b higher than V_{bth} , the proposed charger will enter the CVM operation with SW2 closed. Instead of pulsating current, a constant voltage provided by the output capacitor will be applied to the battery bank. The constant on-time control of the charger is replaced by conventional voltage-mode control to regulate the output voltage of the charger as well as to protect the battery from being overcharged.
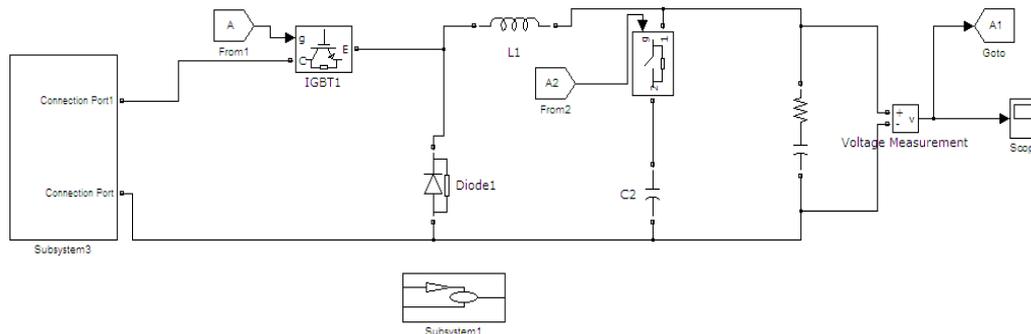
IV.   SIMULATION RESULT

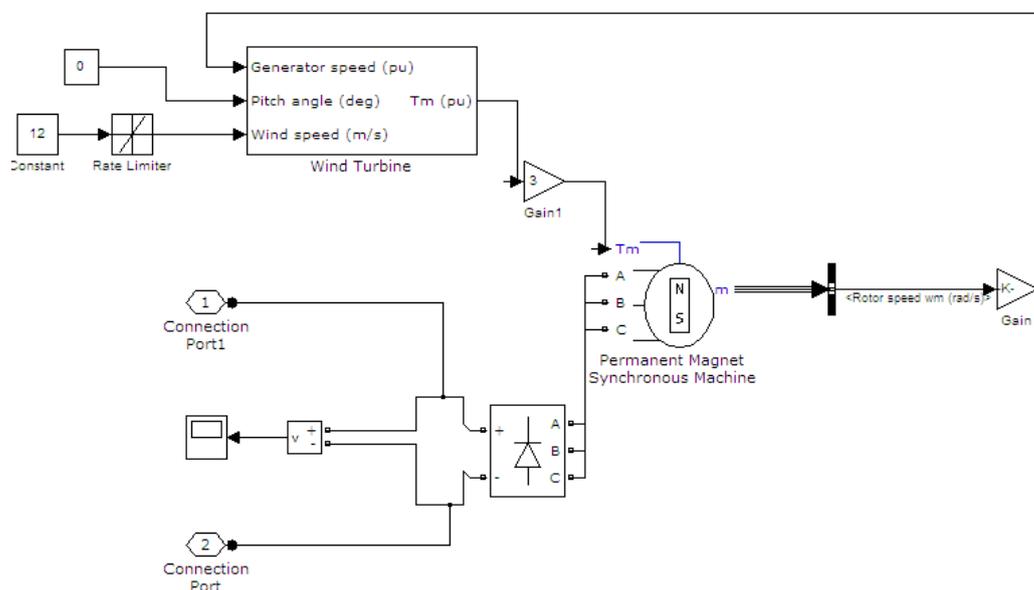Fig 5: MPPT simulation diagram
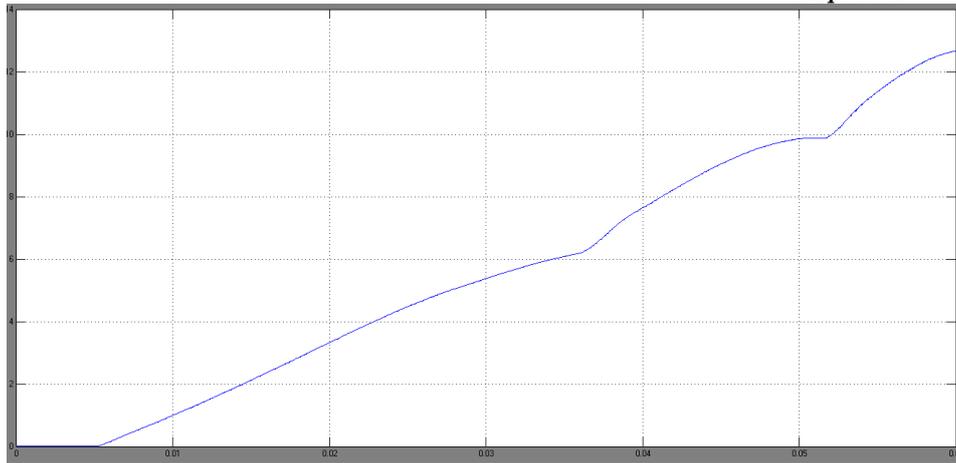

Fig 6: wind turbine simulation

Fig 7: simulation result

V.   DISCUSSION

The pitch angle is maintained as constant based on the control strategy. A closed loop feedback control is employed to control the Permanent magnet synchronous machine speed. Gearing operation controls the limits of the falling and rising rates of wind speed. The DC output is fed into a boost chopper to get the improved output from the system. The relation between the input and output voltage and currents of the boost converter is shown in the following:

$$\frac{Vd_{out}}{Vd_{in}} = \frac{1}{1-D}$$

VI.   CONCLUSION

Modelling and simulation results of a prototype variable speed wind energy system is analysed in this paper. The proposed system does not have self excitation capacitors as those used with induction generators. The absence of self excitation capacitors translates in reduction in cost, increasing in the efficiency. The proposed system utilizes the maximum available power in the wind by forcing the wind turbine generator to rotate around the maximum coefficient of performance. The controller is used to achieve the optimal operation at constant dc voltage by controlling the modulation index of PWM inverter and duty ratio of the boost converter to utilize completely the available wind power. The proposed controller has a stable operation for different wind speed. The electrical utility line currents have a very low THD because of the PWM inverter. Wind power generation has grown at an alarming rate in the past decade and will continue to do so as power electronic technology continues to advance.

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