Buck-Type Power Converter Battery Charger for Wind Energy System

Mr.KANNAN.J., M.Tech(P.E.D), M.B.A
Deparment Of Electrical & Electronics Engineering
Prist University- Trichy
solarkannan@gmail.com.

***Abstract*— In this paper, a Buck-type power converter as the battery charger for the Small wind power system. This paper presents the basic method of controlling the charging of battery banks. The proposed power converter can harvest power from the small wind turbine. The pulsating battery charging current is implemented by the discontinuous conduction mode operation of the proposed power converter. Degradation of the battery can be reduced by giving rest to the chemical reaction and its life time can be improved. Circuit simplicity and high reliability are the major advantages of the proposed buck type power converter.**

***Index Terms*—Battery bank, Buck-type power converter, wind turbines, Bridge rectifier, variable Resistor.**

I. INTRODUCTION

RENEWABLE energy has been developed recently because of the fossil fuel exhaustion and environmental problems. Compared with other renewable energy, such as solar energy, wind power is more suitable for some applications with relatively low cost. 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 is a 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 a load with a various resistance. For large type wind turbine, permanent magnet (PM) generator is widely used and for small type wind turbine, DC micro alternator is used because of its high reliability and simple structure.

Another key issue of the stand-alone wind power system is the lifetime of the battery bank. Based on the cost consideration, the lead–acid battery is still the most commonly used energy storage component for the stand-alone wind power system. However, the degradation of the lead–acid battery will affect the system’s reliability dramatically. It had been reported that using pulsating currents to charge the battery can improve the charging efficiency as well as to increase the lifetime of the battery.

In this paper, the stand-alone wind power system with integrated pulsating charging current function for the battery is proposed. The proposed battery charger can generate pulsating currents to charge the battery. Circuit simplicity and high reliability are the major advantages of the proposed power converter.

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 turbine is well known and can be found in many books with different expressions. One of them can be written as follows.

$$P_m = \frac{1}{2}\pi\rho\, C_p(\lambda,\beta) R^2 V_w^3 \quad \text{---------1}$$

Where *Pm* is the output power of the wind turbine, ρ is the air density, Cp (λ, β) is the power conversion coefficient that is related to tip-speed ratio λ 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 *V*tip 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.

The blade-connected generator in the wind turbine plays the role to converter mechanical power into electric one. In this paper, the PM generator or DC micro alternator is adopted because of its high reliability and structural simplicity.

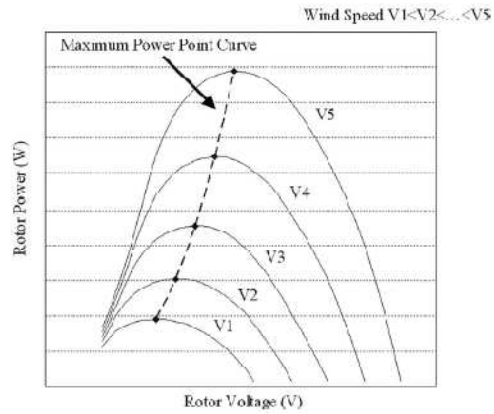

Fig. 1. Wind turbine output power curves under various wind speeds.

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 a constant power conversion coefficient *Cp* , the MPP curve is found to be a cubic function of the turbine speed. Here, due to the usage of small wind mill, the MPPT method is not included.

III. BATTERY

A battery is a cluster of cells connected together for greater voltage and/or current capacity. The lead-acid battery is an electrical storage device that uses a reversible chemical reaction to store energy. It uses a combination of lead plates or grids and an electrolyte consisting of a diluted sulphuric acid to convert electrical energy into potential chemical energy and back again.

Lead acid batteries are one of the oldest electro-chemical storage cells. Since their discovery by Plante in 1859 their energy density, charge and discharge characteristics have been improved greatly but the basic cell elements are still the same. They are available in a variety of sizes from 1 to over 1000
Ampere-hours (battery capacity) and are almost always the least expensive storage battery for any
application. Lead-acid batteries are composed of a Lead-dioxide cathode, a sponge metallic Lead anode and a sulphuric acid solution electrolyte.

The cells with irreversible reactions are commonly known as primary cells, while cells with reversible reactive are known as Secondary cells. Each cell will receive 2V. Every metal or metal compound has an Electromotive force, which is the propensity of the metal to gain or lose electrons in relation to another material. Compounds with a positive electromotive force will make good anodes and those with a negative force will make good cathodes. Larger the difference between the electromotive forces of anode and cathode, the greater the amount of energy that can be produced by the cell.

During discharge, the lead dioxide (positive plate) and lead (negative plate) react with the electrolyte of sulphuric acid to create lead sulphate, water and energy. During charging, the cycle is reversed: the lead sulphate and water are electro-chemically converted to lead, lead oxide and sulphuric acid by an external electrical charging source.

Charging Shedding or loss of material from the plates may occur due to excessive charge rates or excessive cycling. Each lead-acid cell fluctuates in voltage from about 2.12 to 1.75 V. The exact voltage to battery charge correlation is dependent on the temperature of the battery. Cold batteries will show a lower voltage when full than hot batteries. This is one of the reasons why quality alternator regulators or high-powered charging systems use temperature probes on batteries. Degradation of Lead acid battery will affect system reliability. So, pulsating current charging method is used to charge the battery for increasing life time efficiency.

IV. CONTROL STRATEGY

The circuit diagram of the proposed buck-type power converter battery charger is shown in Fig. 2. There are two battery charging modes: On-time control mode and Off-time control mode. When *Vb* is higher than *Vb*th ,the proposed battery charger will start to operate in both the mode continuously. This can be called as Variable Voltage mode (VVM), which can generate the pulsating charging current for the battery bank.

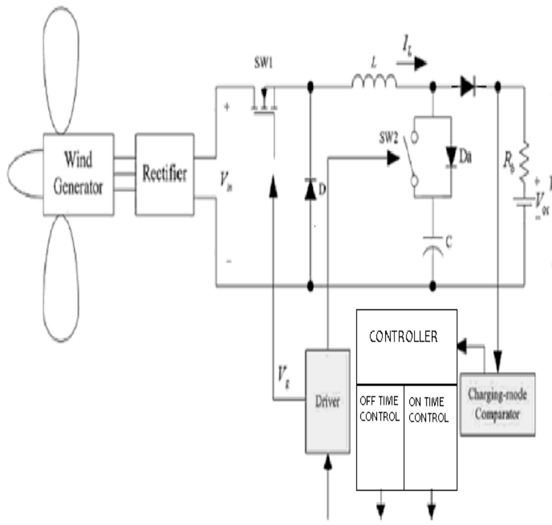

Fig. 2. Proposed Buck type power converter battery charger for Wind turbine.

As the wind speed increased, the output voltage of the wind turbine will increase too. A bridge rectifier will convert the Alternating current into Direct current. The DC level obtained from a sinusoidal input can be improved 100% using a process called full-wave rectifier or bridge rectifier.

From the bridge rectifier, the power is passed to the load through main switch SW1. In between switch and battery, the inductor is used to reduce the spike voltage passage. Both switches were controlled by the Microcontroller and these switches operate in same condition.

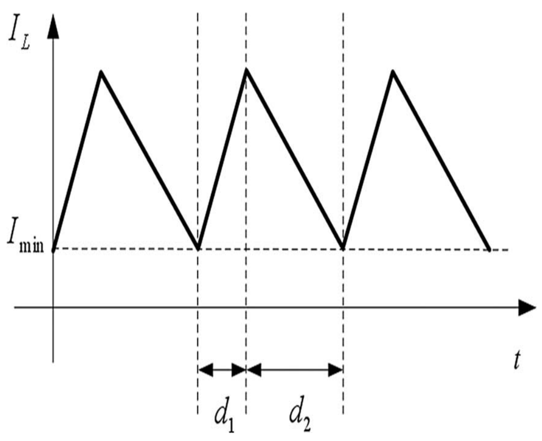

Fig. 3. Typical waveforms of the inductor current in switching process (VVM).

The typical waveforms of the inductor current at the time of operation are shown in Fig. 3. During charging period $d1$, switches SW1 and SW2 closed simultaneously and the inductor current increase linearly. At discharging period d2, the inductor current decreased nearly to zero when both the switches SW1 and SW2 are in open position. Here, the rest duty can be achieved automatically which allows the chemical actions in the battery to stabilize and ready for the next charging current that can improve the battery charging efficiency. For each switching cycle, the amplitude of charging current can be derived as follows:

$$\Delta i = \frac{(V_{\rm in} - V_b)d_1}{fL} = \frac{V_b d_2}{fL} \qquad \text{------2}$$

Where f is the switching frequency and L is the output inductance. From (2), the duty $d2$ can be expressed as follows:

$$d_2 = \frac{(V_{\rm in} - V_b)d_1}{V_b}. \qquad \text{--------------3}$$

From (2) and (3), the average current of the output inductor can be expressed as follows:

$$I_{\rm avg} = \frac{1}{2}\Delta i(d_1 + d_2) = \frac{d_1^2}{2fLV_b}(V_{\rm in}^2 - V_b V_{\rm in}) \qquad \text{----4}$$

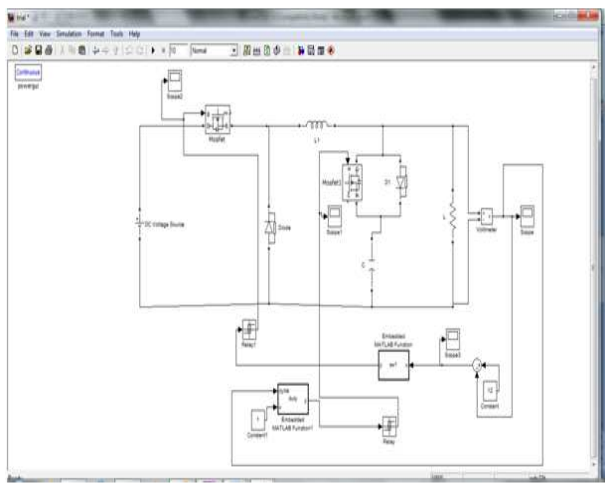

Fig. 4. Simulation Diagram

and the average power charged into the battery during one switching cycle can be calculated as follows:

$$P_o = I_{avg} V_b = \frac{d_1^2}{2fL}(V_{in}^2 - V_b V_{in}). \quad \text{-----5}$$

It can be found that the average power into the battery is a second-order polynomial equation of *V*in that is similar to the MPP curve shown in Fig. 1. If the parameters *f*, *L*, *Vb* , and *d*1 are carefully designed based on the characteristics of the wind turbine, it is possible that the battery charging power is equal to the MPP power of the large wind turbine.

When the proposed charger is operated in the Discontinues conduction mode, which is between the On-time control and the Off-time control. The charging period *d*1 plus discharging period *d*2 equal 1. From (2), *V*in can be derived as follows:

$$V_{in} = \frac{V_b}{d_1}. \quad \text{------6}$$

Equation (6) is an important design consideration for the propose charger. The average current of the output inductor can b derived as follows:

$$I_{avg} = \frac{1}{2}\Delta i + I_{min} \quad \text{--------7}$$

Where *I*min is the minimum inductor current influenced by the internal resistance of the battery *Rb* and the battery open circuit voltage *V*oc. In steady state, the average voltage over the diode D is *d*1*V*in. Then, the average current of the output inductor can be derived as follows:

$$I_{avg} = \frac{d_1 V_{in} - V_{oc}}{R_b}. \quad \text{-----8}$$

Eventually, the average output power during CCM operation becomes

$$P_o = \frac{(d_1 V_{in} - V_{oc})V_b}{R_b}. \quad \text{-----9}$$

Equation (9) implies that the output power is proportional to the input voltage. Fortunately, the output power will be limited by the wind turbines power capability because of its non-MPP operation.

When the battery reaches its maximum charging voltage limit, the battery charger needs to enter the Off-time operation in order to protect the battery from overcharge damage.

V. EXPERIMENTAL RESULT

Finally, the design procedure of the proposed buck-type battery charger can be summarized as follows.
1) Measure the wind turbine specifications including the rotor speed.
2) Select the appropriate battery bank voltage based on the characteristic of wind turbine.
3) Determine the duty ratio *d*1 according to the rated voltage of the wind turbine and the battery.
4) Design the circuit parameters *f* and *L* .

Computer simulations of the gate signal operations.

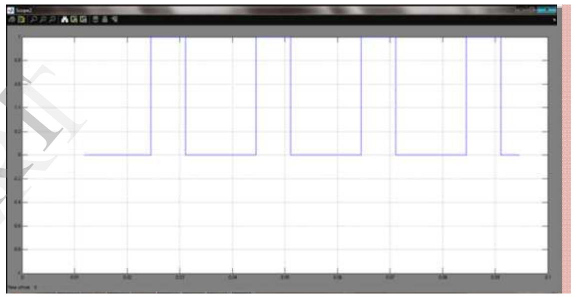

Fig. 5 Experimental output which is tried.

The distribution of duty ratio *d*1 as a function of *f* and *L* is illustrated in Fig.3. It also implies that a small size of *L* is possible in order to reduce the weight of the converter. For the lead–acid battery, which is adopted in this paper, the constant-current/constant-voltage control strategy is the most commonly suggested charging method.

Usually, the maximum charging current, without affecting battery's lifetime, suggested by the battery manufactory is 1/4*C*. The Smaller the charging current is, the better lifetime the battery can have. However, the smaller charging current implies longer charging time. The tradeoff between the charging time and charging current need to be considered, while designing the stand-alone wind power system. That is, the wind energy profile, the rated wind turbine power, and the battery capacity should be carefully matched to achieve a good system performance.

Based on the characteristics of wind turbine and battery bank, the specifications of the proposed buck-type battery charger can be selected as follows.

1) Wind turbine rated voltage V_{wind} = 12 to 15V.
2) Wind turbine rated power P_o = 20 W.
3) Battery floating charge voltage V_{fc} = 15 V.
4) Charger input voltage V_{in} = 0-15 V.
5) Duty ratio $d1$ = 40%.
6) Switching frequency f_{sw} = 1 kHz.
7) Inductor L = 0.006mH.
8) PIC Microcontroller.
9) Variable resistor (comparator).

VI. CONCLUSION

In this paper, the approach to integrate the pulsating-current charging method for a battery with small wind turbine. Here the buck type power converter acts as a battery charger. It has On-time control and Off-time control process which helps to improve the battery life gradually. The formation of abnormal battery temperature and the environmental effects can be avoided through this method. A battery can be damaged, if too much current is applied during the charging process. In general, lower charge rates will extend the overall life of the battery. Degradation of the battery can be avoided by charging the battery in (Variable Voltage mode) pulsating current mode and its life time can be improved by achieving rest duty automatically. A compact hardware was made, to reduce the initial cost and to show the result easily. For high power wind Energy system, many protection equipments have to be added.

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KANNAN J. received his ***B.E*** degree in Electrical and Electronics Engineering from Paavai Engineering College, Naamakkal in 2007, ***M.B.A*** degree in Human Resources Management from Bharathiar University (School of Distance Education) , Coimbatore in 2012 and ***M.Tech*** degree in Power Electronics and Drives from Prist University, Thanjavur in 2013.He already attends the National conference in Sona College of Technology, Salem dt and SRM University, Chennai. His area of interest includes Renewable energy Sources, Transformers, Circuit Breakers, Motors, Social welfare issues and Politics.

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J.Kannan