An Effective Wind Energy System based on Buck-boost Controller

Ansari Nabila AAH¹, Prof. R.K. Agrawal²

¹Department Of E&TC, SNJB College of Engineering Chandwad, Nashik. Email: deshmukh_nabila@yahoo.in

²Department Of E&TC, SNJB College of Engineering Chandwad, Nashik. Email: rkdhule@yahoo.co.in

Abstract-In Domestic Wind Machines, if the wind speed is low, the output voltage is not sufficient to charge the battery as it is lower than the rated charging voltage of the battery. This limits the overall efficiency of the Wind Machine to 20%. This study proposed to design and develop a Buck Boost Controller for the effective utilization of the wind machine. By implementing a controller based Buck Boost converter, the voltage produced at the lower wind speeds can also be utilized effectively by boosting it to the rated charging voltage of the battery. Also if the wind speed is high (>14 m/s), the DC output voltage will increase to more than 65 V. The converter bucks this high voltage to the nominal battery charging voltage (52 V), thereby protecting the battery from over charging voltage. Thus the effective utilization of the wind machine has been achieved by the use of the proposed Buck Boost Controller.

Keywords- Buck boost converter, Continuous Current Mode (CCM), control circuit, Pulse Width Modulation (PWM), wind machines.

I. INTRODUCTION

The demand for energy has increased tremendously in the past few decades. As a result, the use of renewable energy sources like solar energy, wind energy etc., is gaining popularity. Thus the Domestic Wind Machines (<10 kW) are extensively used in both rural and urban areas to generate electric power from wind energy (Tan et al., 2006). In Domestic Wind Machines, if the wind speed is low, the output voltage of the Wind Machine after rectified into DC is less. The battery will not charge as it is lower than the rated charging voltage. This happens most of the time in a day, since the wind speed in domestic regions is in the range of 0 to 4 m/s. This limits the efficiency of a conventional domestic Wind Machine to 20%. Therefore, an efficient control mechanism is needed, so as to utilize the wind power effectively (Zhang et al., 2011).

The rectified DC output from the Wind Machine (1.8 kW) varies from 0 V to 60 V depending upon the wind speed. The rated charging voltage of the battery (4×12 V, 4×100 Ah) is 52 V. When the wind speed is low (i.e., ranging from 2.5 m/s to 4 m/s), the output voltage varies from 30 V to 50 V. During this period, the battery is not charging even though considerable output is available from the Wind Machine (Jiao and Patterson, 1999). By implementing a controller based Buck Boost converter, the voltage produced at the lower wind speeds can also be utilized effectively by boosting it to the rated charging voltage of the battery. Also if the wind speed is high (>14 m/s), the DC output voltage will increase to more than 65 V. The converter bucks this high voltage to the nominal battery charging voltage (52 V), thereby protecting the battery from over charging voltage.

The controller produces the Pulse Width Modulation (PWM) signal that is used to control the operation of MOSFET in the power circuit of the Buck Boost Converter. ATmega8L Microcontroller, with an inbuilt ADC and PWM generator, has been used for PWM generation.

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The Microcontroller generates a PWM signal at a frequency of 8 kHz, and the MOSFET is switched using this PWM signal to regulate the output voltage. The input and output voltages are measured dynamically and converted to digital values by the Voltage Sensor Circuit and ADC (Mechi and Funabiki, 1993). The PWM duty cycle is varied in accordance to this feedback and the output voltage is either bucked or boosted, thereby ensuring that the battery is charged effectively. Thus effective utilization of the wind machine has been achieved by the use of Buck Boost Controller (Stihi and Ooi, 1988; Eno and Thompson, 2006). The Exiting system block diagram is shown in Fig. 1.

In the existing system, the rectified output of the Wind Machine is used to charge the battery directly. If the output voltage is less than the rated battery charging voltage, the battery will not charge even when considerable output is available. Almost 30% of the total output is in this range and thus the overall efficiency of the conventional Wind Machine system is limited to 20%.

In this study we have proposed a controller based Buck Boost converter, so that the voltage produced at the lower wind speeds can also be utilized effectively by boosting it to the rated charging voltage of the battery. The controller constantly monitors the output voltage from the Wind Machine. Corresponding to the magnitude of the DC output from the rectifier, the controller calculates and changes the width of the pulse given to the converted, to boost it to the rated voltage of the battery. Thus the battery is charged even when the wind machine rotates at lower speed (0-4 M/S). If the wind speed is high (>14 m/s), the DC output voltage is also high. The converter bucks this high voltage to the battery charging voltage thereby protecting the battery from over voltage. Figure 2 shows the block diagram of the proposed system.

Buck boost converter: A Buck Boost Converter is a DC-DC regulator which provides an output voltage that may be less than or greater than the input voltage - hence the name “Buck-Boost”. As the polarity of the output voltage is opposite to that of the input voltage, the regulator is also known as an inverting regulator (Farhangi and Farhangi, 2005; Wang et al., 2008). Among all the topologies that are used to Buck as well as Boost the voltage, Buck Boost converter has wider acceptance as it provides a significant improvement in performance and efficiency by eliminating the transition region between buck and boost modes (Mitchell, 1988; Mohan et al., 1995). The circuit arrangement of the Buck Boost converter is shown in Fig. 3.

2.1.Operation modes:
The circuit operation can be divided into two modes:
Mode 1: Let D be the duty cycle and TS be the time period of the PWM signal. During mode 1,
the transistor is turned ON by the PWM signal for a period (DTS) and the diode is reverse biased. The input current flows through the inductor \( L \) and the transistor. Figure 4 shows the mode 1 operation of Buck Boost Converter.

**Mode 2:** During the mode 2, the transistor is switched off by the PWM switching for the period \((1-DTS)\). The current, which was flowing through the inductor \( L \) during mode 1, would now flow through the inductor \( L \), capacitor \( C \), Diode and the load. The energy stored in the inductor \( L \) would be transferred to the load and the inductor current would fall until the transistor is switched on again in the next cycle. The amount of energy stored in the inductor is determined by the duty cycle of the PWM signal. The greater the duty cycle, higher will be the energy stored in the inductor. If the duty cycle of PWM is below 50%, the circuit bucks the output voltage as the amount of energy stored is less and if it is above 50%, the output voltage will be boosted to the nominal battery charging voltage. Operation of Buck Boost converter may be in Continuous Current Mode (CCM) or Discontinuous Current Mode (DCM) of operation depending on the Wind Machine output. The converter should be operated in CCM to charge the battery which depends on the value of the inductor and the load. Figure 5 shows the mode 2 operation of Buck Boost Converter.

**DC conversion ratio:**

The DC conversion ratio \( M(D) \) is the ratio of output voltage to the input voltage of the converter. Figure 6 shows the DC conversion ratio of the buck boost converter. The curve is in the fourth quadrant as the output voltage polarity is opposite to that of the input voltage: \( M(D) = \frac{V_o}{V_{in}} \) where, \( V_o \) - output voltage of the Buck Booster converter and \( V_{in} \) - is a input voltage.

For the duty cycle below 0.5, the DC conversion ratio is less than 1 indicating that the converter will be operating in buck mode. Also for the duty cycle above 0.5, the ratio rises exponentially indicating that the converter boosts the output voltage several times of that of the input even if there is a small increase in the duty cycle. For normal operation of the converter in the boost mode, the duty cycle should be only in the range of 0.58 - 0.67.
II. SIMULATION RESULTS

The simulation tools help in testing the validity of the design and also save costs by reducing the chances of error. Any defect in design can be easily identified and rectified well before the implementation thus saving cost and time. Orchard and Proteus are two main simulation tools used in this system. Proteus 7.5 ISIS (Intelligent Schematic Input System) professional simulation software has been used to simulate the PWM using ATmega8L controller. This software provides an integrated environment and allows the virtual burning of embedded program coding in the controller and simulates the output for various conditions. The Proteus Design Suite comprises a fully integrated package with the following modules.

- ISIS for schematic capture
- PROSPICE for circuit simulation
- ARES for PCB layout and
- VSM for embedded co-simulation

The simulation functions take place entirely within the schematic editor whilst ISIS and ARES share a common, easy to use, Windows user interface. All of which reduces the time it will take to master the software. The Buck Boost Converter circuit was designed and then its validity was tested using the Orcad Capture PSpice 9.2 simulation software. Orcad capture PSpice comprises of three main applications:

- Capture CIS-used to draw a circuit on the screen, known formally as schematic capture. It offers greater flexibility compared with a traditional pencil and paper drawing, as design changes can be incorporated and errors can be corrected quickly and easily.
- PSpice-simulates the captured circuit and its behavior can be analyzed in many ways and confirm that it performs as specified.
PCB Editor-for the design of Printed Circuit Boards. The output is a set of files that can be sent to a manufacturer. The following Fig. 10 illustrates the simulation result of Power Circuit uses Orcad Capture (PSpice 9.2) software.

**Simulation output of power circuit:**
The Buck Boost Converter with the above mentioned values was simulated using Orcad Capture (PSpice 9.2) software and the following results were obtained. The results were found to be in accordance with the expected outcome.

In Fig. 6, Trace 1 represents the output voltage of the Buck Boost converter. It is clear from the plot that the output voltage attains 54 V at steady state. The current ripple shown in the Trace 2 swings between 1 A and 4 A thereby indicating that the converter is operating in continuous current mode. In Trace 3, the voltage across inductor swings equally in both positive and negative directions. Thus the average voltage across the inductor is zero indicating that the Volt-Sec balance is maintained.

**Hardware testing of control circuit:**
The Control Circuit developed is tested in the laboratory to check the correctness of the design. The DVM is shown in measures the average value of the Optocoupler output which has to be given as gate signal input to the MOSFET in the power circuit. The output of the circuit is as expected and program logic is also correct. When the input given to the ADC of the Microcontroller is varied the duty cycle of the PWM signal also varies. Figure 6 shows the test setup for the control circuit of the Buck Boost Controller.

**Simulation output of power circuit:**
The Buck Boost Converter with the above mentioned values was simulated using Orcad Capture (PSpice 9.2) software and the following results were obtained. The results were found to be in accordance with the expected outcome. In Fig. 11, Trace 1 represents the output voltage of the Buck Boost converter. It is clear from the plot that the output voltage attains 54 V at steady state. The current ripple shown in the Trace 2 swings between 1 A and 4 A thereby indicating that the converter is operating in continuous current mode. In Trace 3, the voltage across inductor swings equally in both positive and negative directions. Thus the average voltage across the inductor is zero indicating that the Volt-Sec balance is maintained.

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**Power circuit:** The integral part of development of Power circuit is the development of the inductor. For the inductor development, the type of the core, current density and the diameter of the conductor must be decided first.

IV. CONCLUSION

The proposed system of controller based Buck Boost converter is found to be more compact, user friendly and more efficient. The inbuilt ADC and PWM channels in the ATmega8L Microcontroller make the control module of the converter very compact. The Buck Boost controller with ATmega8L as its integral part senses the output voltage and varies the PWM duty ratio so that the output voltage at lower wind speeds is also maintained above the battery charging voltage (54 V). Hence the voltage produced at lower wind speeds is also effectively utilized and the efficiency of the proposed system is 15% higher than the existing system.

V. REFERENCES

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