Research Journal of Applied Sciences, Engineering and Technology 6(5): 825-834, 2013
DOI:10.19026/rjaset.6.4127
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: September 25, 2012 Accepted: December 28, 2012 Published: June 25, 2013

**Research Article**

# An Effective Wind Energy System based on Buck-boost Controller

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**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

## 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 (Jingquan *et al*., 2006; Rashid, 2004).

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. 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 are in this range and thus the overall efficiency of the conventional Wind Machine system is limited to 20%.

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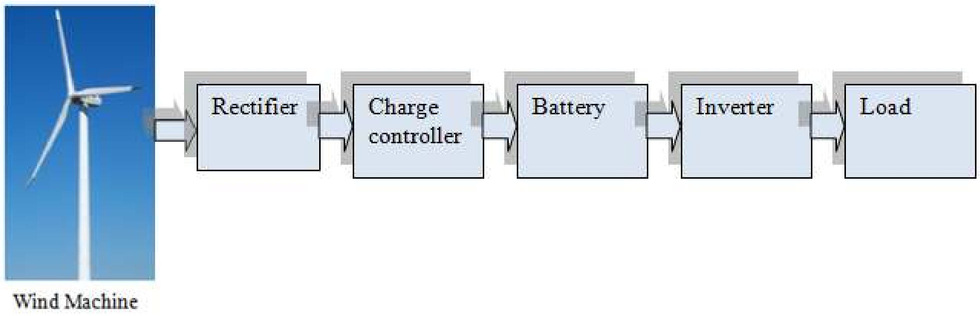


Fig. 1: Block diagram of existing wind machine system

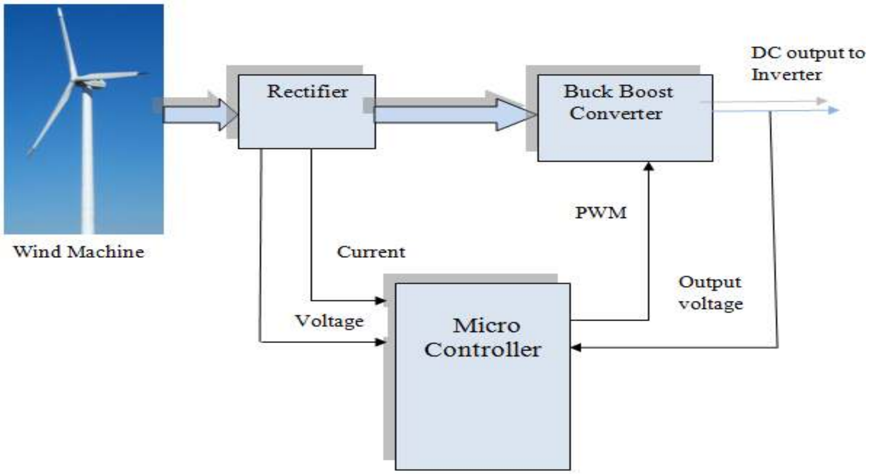


Fig. 2: Block diagram of the proposed system

## PROPOSED SYSTEM

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.

**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

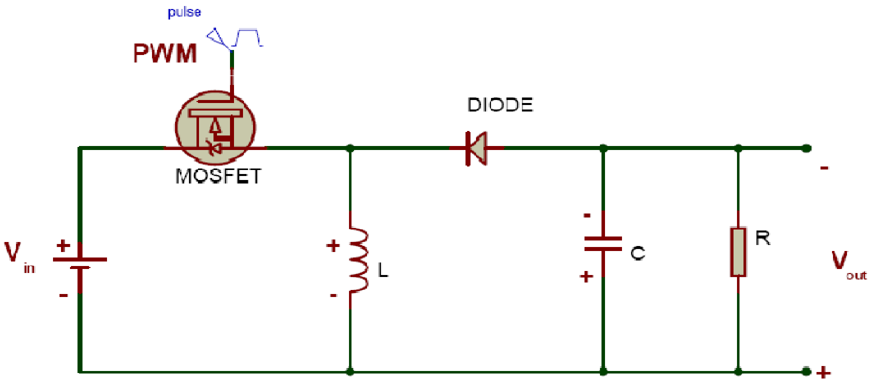


Fig. 3: Circuit arrangement of buck boost converter

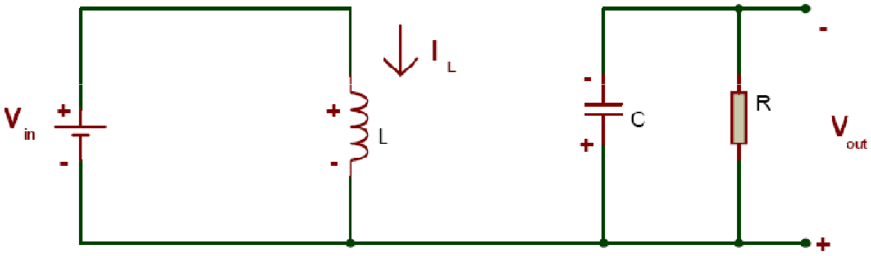


Fig. 4: Operation of buck boost-mode 1

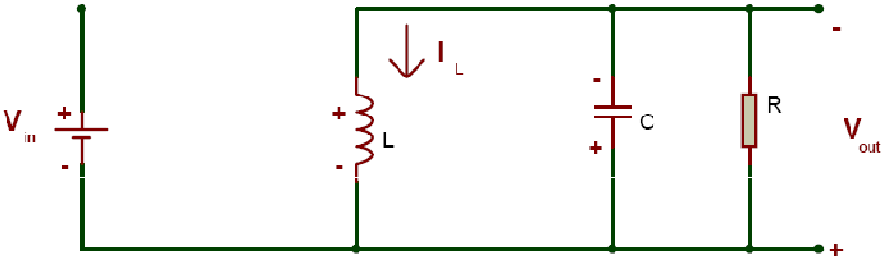


Fig. 5: Operation of buck boost-mode 2

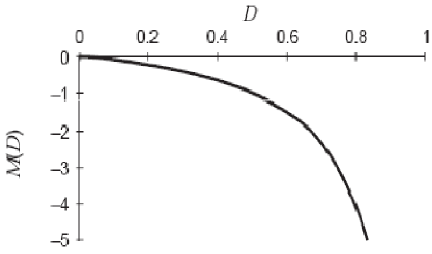


Fig. 6: DC conversion ratio of the buck boost converter

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. The 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:

$$M(D) = V_o/V_{in}$$

where, Vo-output voltage of the Buck Booster converter and Vin-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.

## DESIGN OF BUCK BOOST CONVERTER CIRCUIT

The integral part of Buck Boost converter design is to choose proper values of an inductor (L) and Capacitor (C) because the output voltage depends on the L and C values. The inductor and capacitor also play a major role in filtering the output from the circuit to provide stiff DC. For the effective charging of the battery the Buck Boost controller must operate in Continuous Current Mode (CCM). In order that the buck boost converter operates in CCM, optimum values of inductor and capacitor must be chosen because if their values are higher then the cost of winding, core size will also be high. If their values are low, then the high switching frequency is needed to obtain the same voltage level. This increases the cost of the switch involved. Therefore it is necessary to choose optimum values of L and C.

For the Buck Boost converter operates within the safety limit, the components used in it should have higher ratings than the values obtained in the design. In general, the safety limit is chosen as 125% i.e., if the design rating is 100 A, the device is chosen such that it should withstand up to 125 A.

The average load current is found to be 15 A and the peak current is 24 A. Rated charging voltage of the battery is 54 V and the maximum DC output voltage of the wind machine is 65 V. Hence, for the reliable operation of the circuit, the components used in the circuit are chosen with 100 V, 40 A ratings. Table 1 shows the specifications of the devices used in the power circuit.

Table 1: Specification of power circuit devices

| S. no | Component | Part name | Make | Rating |
|---|---|---|---|---|
| 1 | MOSFET | IRFP150N | International rectifier | 40 A, 100 V |
| 2 | Power diode | PA040A | Modern power | 40 A |
| 3 | Capacitor | - | - | 250V, (2*470 µF = 940 µF) |
| 4 | Inductor | - | Own make | 40 A, 1 mH |

The Buck Boost Converter circuit along with feedback terminals that need to be connected with the ADC pins of the Microcontroller is shown in Fig. 7. The MOSFET is switched based on the PWM signal given to its gate. Thus, the ON time and OFF time of the MOSFET is governed by the duty cycle of the PWM signal. When the MOSFET is switched ON, the diode is reverse biased and hence the inductor stores the energy from the Wind machine. When the MOSFET is switched OFF, the diode becomes forward biased and hence the inductor transfers the stored energy to the capacitor. Higher the duty cycle, greater will be the energy stored in the inductor and hence higher will be the output voltage.

**Control logic design:** Pulse Width Modulation technique is most often used for controlling various switching devices. The PWM technique includes receiving a reference voltage signal associated with the switching devices. This reference voltage signal is

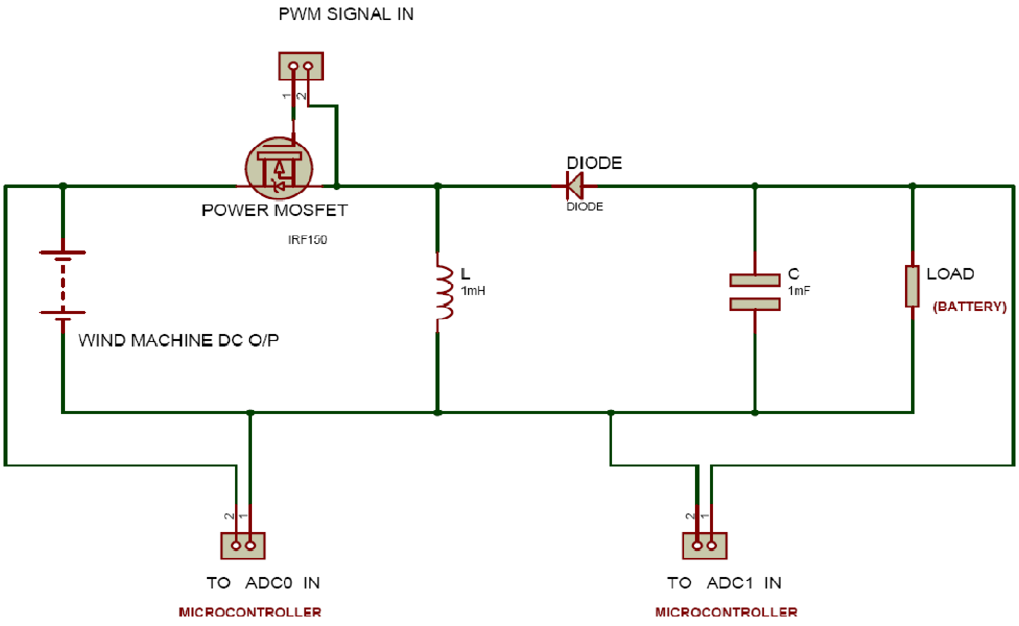


Fig. 7: Buck-boost converter circuit

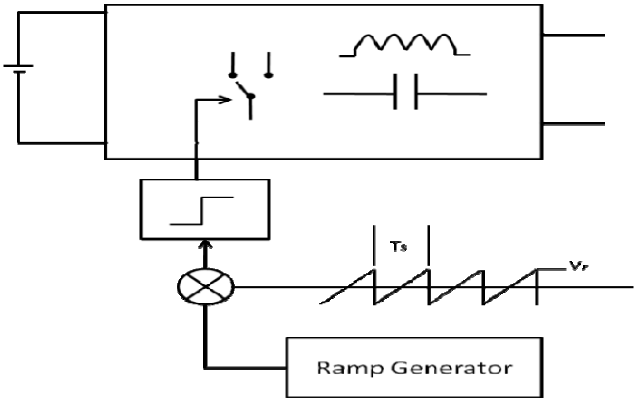


Fig. 8: Duty ratio controlled DC-DC converter

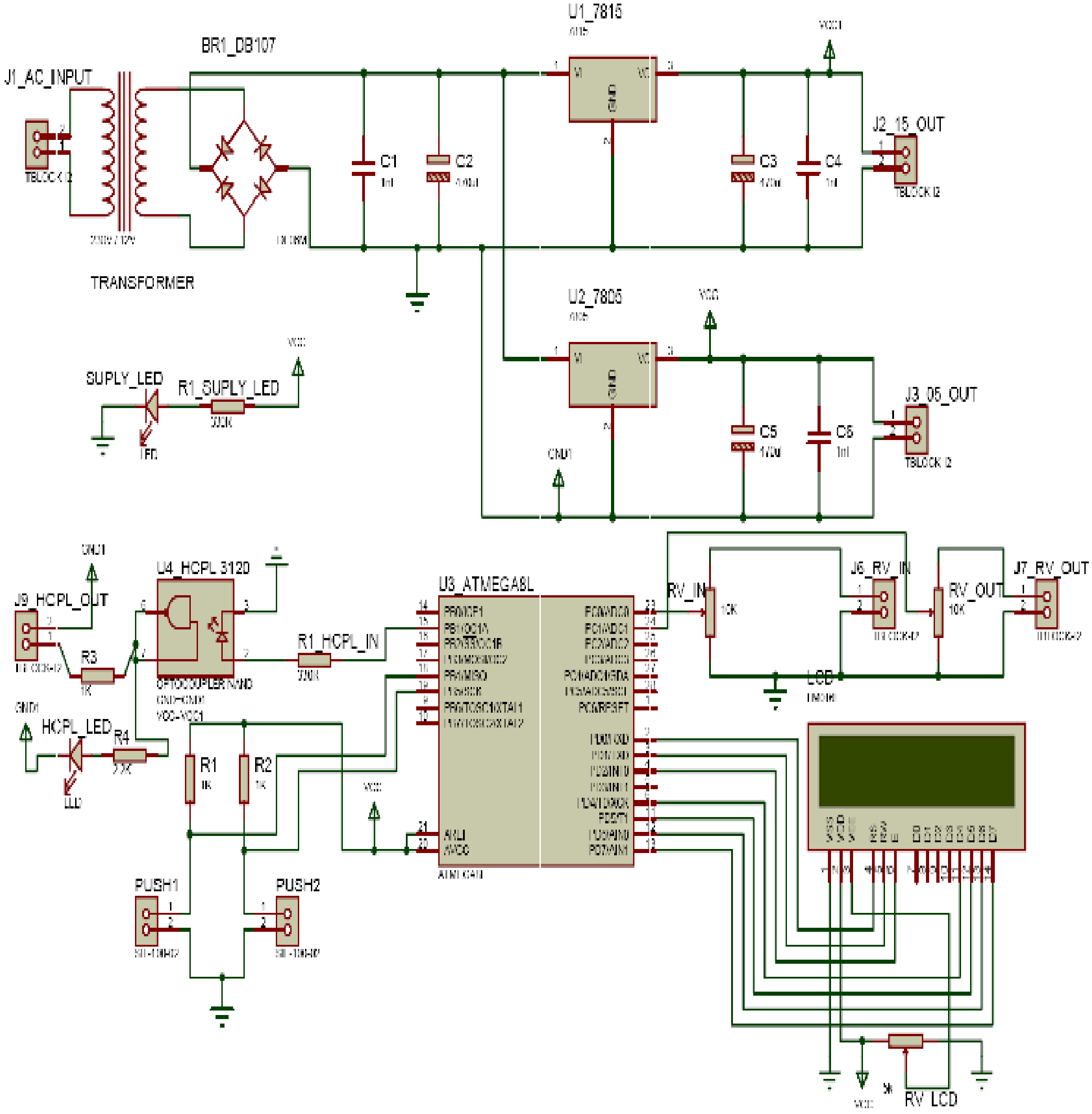


Fig. 9: Control circuit of buck boost controller

Table 2: Specification of control circuit devices

| Device | Specification |
|---|---|
| Transformer | 230 V / 12 V , 1A |
| Bridge Rectifier | DB107 |
| Voltage Regulator | 7805, 7812 |
| Micro controller | ATmega8L |
| Optocoupler | HCPL 3120A |
| LCD | JHD 162A (16×2 chars) |
| POT | Rotary Trim POT 5 kΩ, 10 kΩ |
| Resistor | 330 Ω, 470 Ω and 1 kΩ |
| Capacitor | 1 nF, 470 µF |

compared with the carrier ramp signal and a switching signal is generated. The duty cycle of the switching signal is varied based on the value of the reference voltage signal .The operation of the switching device is thus controlled based on the reference voltage signal and the switching signal.

A typical pulse width modulated switching mode power converter consisting of a switch, an inductor and a capacitor are shown in Fig. 8. Power is supplied to the converter at a DC voltage of $V_g$. The converter feeds power to the load (R) at a voltage Vo. The switch operates at a high switching frequency with a switching period $T_S$.

The switch is kept ON for a fraction $DT_S$ of the switching period. For the rest $(1-DT_S)$ of the switching period, the switch is OFF. The generation of the switch control signal is by the popular ramp-control voltage comparison method. The switching ratio d is related to the control voltage $V_C$ and peak ramp voltage $V_P$ by the relationship $D = V_C/V_P$.This duty cycle ratio based PWM technique can be realized either by an op amp comparator circuit or using a Microcontroller. In this study, we use ATmega8L Microcontroller to generate PWM.

**Control circuit operation:** The control circuit used for PWM generation is shown in Fig. 9. The transformer converts 230 V AC to 12 V AC. The 12 V AC is then converted to DC by the bridge rectifier DB107 and is given as input to the regulators 7805 and 7812. The Regulator 7805 regulates the input to 5 V DC to power the Microcontroller ATmega8L. Table 2 gives the specifications of the devices used in the control circuit.

ATmega8L is a low-power CMOS 8-bit Microcontroller based on the AVR RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega8 achieves throughputs approaching 1 MIPS per MHz, allowing the system designer to optimize power consumption versus processing speed.

The Micro controller is used to generate the PWM signal which controls the switching of the MOSFET in the power circuit. An inbuilt 16 bit timer of the Microcontroller is used to generate the ramp signal. A voltage sensing circuit is used to sense the input and output voltages. The output from the wind machine is scaled by a 10 kΩ POT so that the maximum voltage swings between 0 V-5 V and is then fed back to the ADC1 of the Microcontroller. The input is also scaled and fed to the ADC0 of the Microcontroller. Based on the ADC0 and ADC1 values, the value of the reference signal is varied. The duty cycle of the PWM signal is adjusted based on these values and the output voltage is always maintained above the battery charging voltage.

The PWM signal generated is given to the gate of the MOSFET through the Optocoupler. The Optocoupler HCPL A-3120 is used to isolate the control circuit and the power circuit. In case of any short circuit or malfunction in the power circuit, the control circuit remains unaffected. Thus the switching of the MOSFET is controlled by the PWM signal.Control circuit diagram of Buck boost converter is shown in Fig. 9.

## 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.

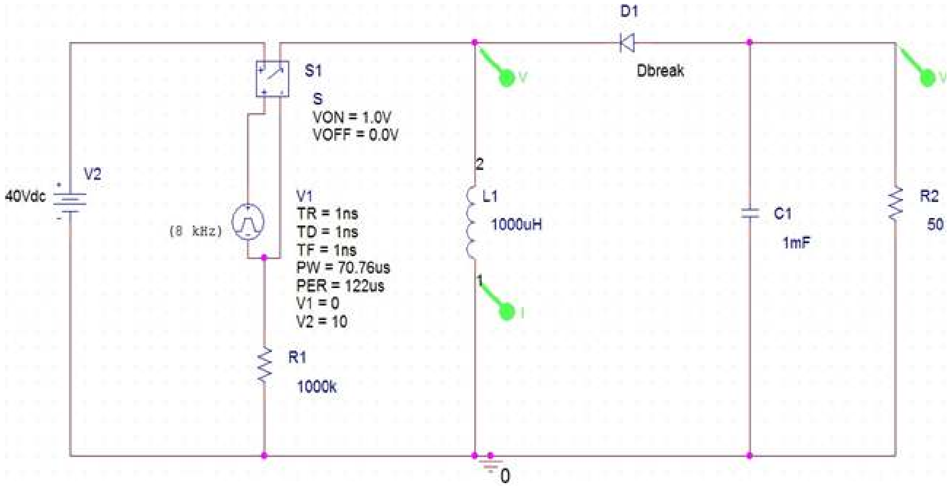


Fig. 10: Power circuit simulation using orcad capture (PSpice 9.2)

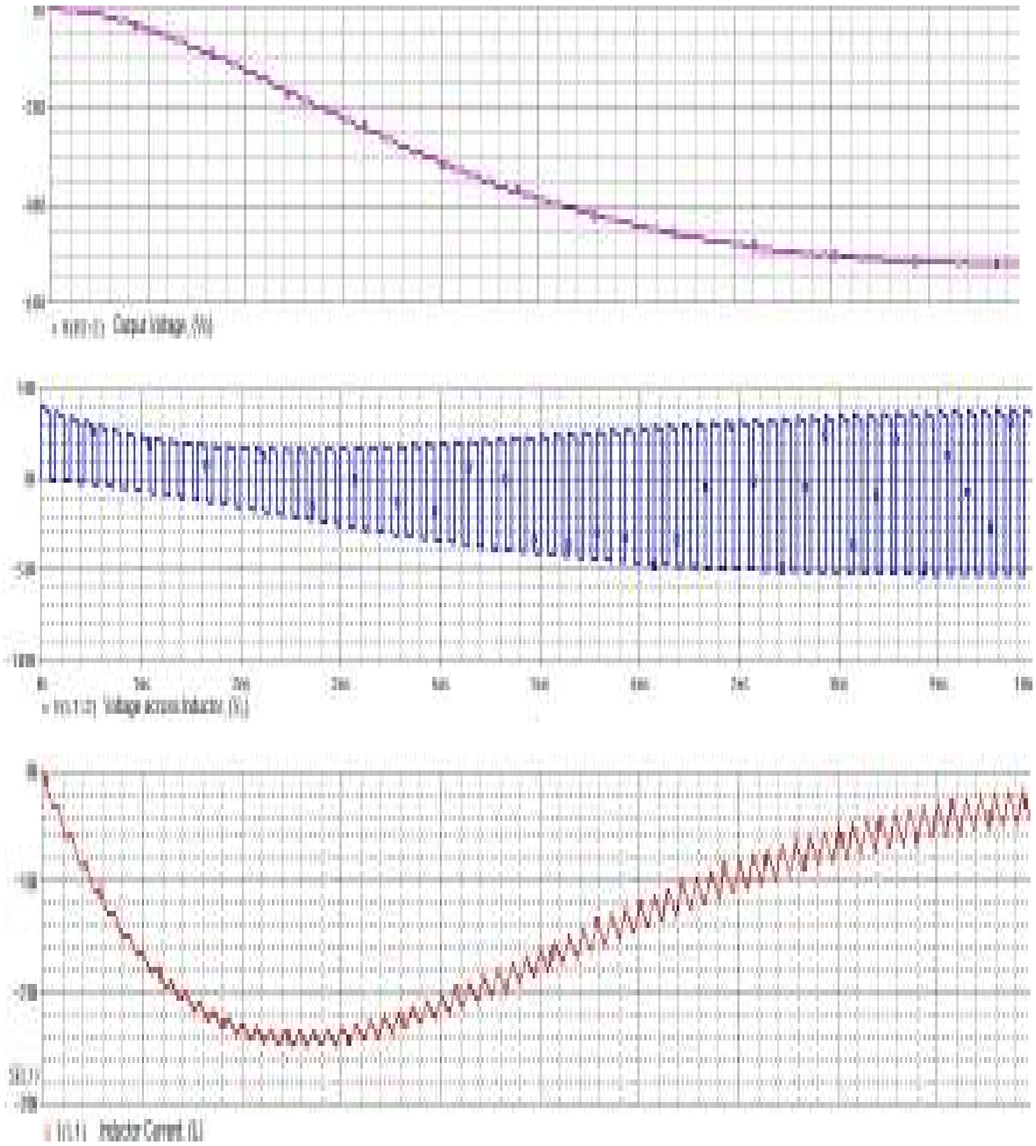
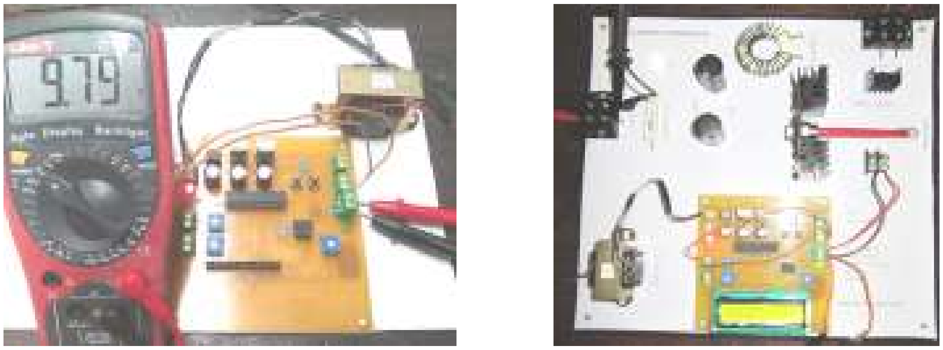


Fig. 11: Simulation output of power circuit



(a) Optocoupler testing, (b) Power supply module testing

Fig. 12: Test setup for control circuit

- 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. 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.

**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 Fig. 12 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

**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.

**Inductor development:**

- **Choice of core:** The type of the core is chosen as Toroidal Ferrite core. When a Solenoid is bent and the ends are joined together, the coil is called as 'Toroid'. If the Toroidal shape is filled with high permeability material, it is called as Toroidal Core or Ring Core.

The advantages of Toroidal core are:

- It is easily saturated as the magnetic circuit is closed.
- The Magnetic Field outside is virtually zero and thus the voltage at the terminals is not affected by the external field.

As Toroidal core occupy less space, moderately high value inductance ($L \approx 1$ mH) can be developed within a considerable space.

- **Conductor size:** Inductor carries the entire load current of the buck boost converter as it lies in series in the converter circuit. The size of the conductor to be used for winding the inductor should withstand the continuous load current through it.

Let,

$I_{L(avg)}$ = Average Load Current (A)
J = Current Density (A/mm$^2$)
A = Cross Sectional Area of the Wire (mm$^2$)
d = Diameter of the wire (mm)

The average load current is determined to be $I_{L(avg)} = 15$A.
The maximum load current $I_{L\ (max)} = 24$ A.
Assuming the current density J = 13 A/mm$^2$.

**Test results of buck boost controller:** The control circuit and the power circuit are mounted and the connections are given permanently. The kit tests for continuity using DVM and then the supply is given using a regulated power supply to test for the proper functioning of the circuit. Figure 13 shows the Hardware testing of the Buck Boost controller by

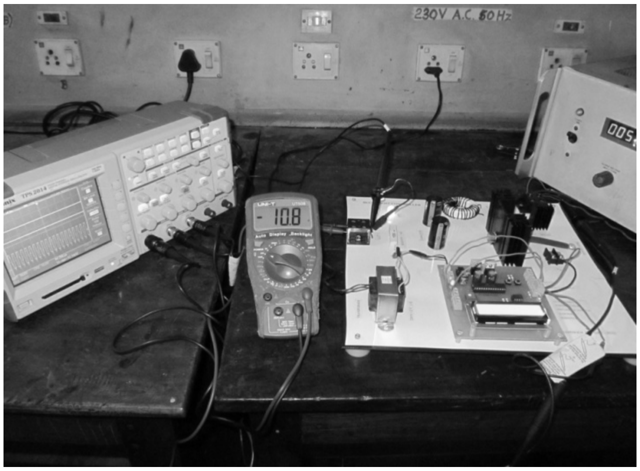


Fig. 13: Hardware testing of the buck boost controller in laboratory

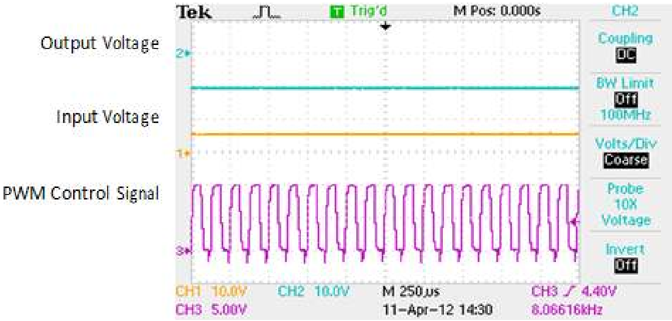


Fig. 14: Waveforms captured for 5 V input

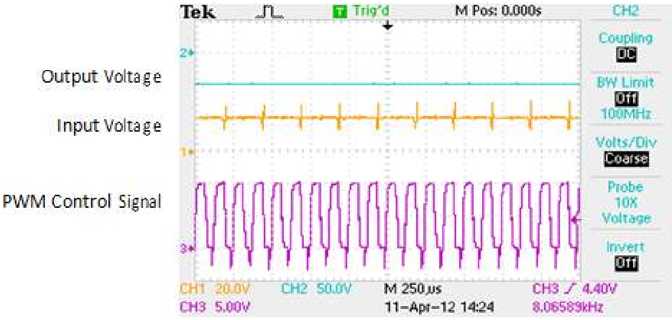


Fig. 15: Waveforms captured 20 V input

connecting the power supply to the input voltage terminals and Digital Signal Oscilloscope (DSO) to check the output waveforms. The testing is carried out by connecting the input terminals of the power circuit to 120 V, 5 A regulated DC power supply and the transformer of the control circuit to 230 V AC power supply.PWM output from the optocoupler is given to the DSO through a 1x probe while the input and output voltages are connected to the DSO through 10x attenuation probe.

The input voltage is then increased to 40 V. The output voltage obtained is shown in Fig. 14. The output voltage (54.8 V) obtained is higher than the rated battery charging voltage thereby ensuring that the battery is charged effectively .The complete circuit is checked for a range of input voltages. The input voltage, the PWM signal and the corresponding output voltage waveforms are captured using a DSO. Figure 15 shows the waveforms of the output voltage, input voltage and PWM signal captured using DSO when 5 V was given as input to the controller. The output voltage is boosted to 10 V (i.e., 200%) and the waveform shows that there are no ripples in it.

The testing of the kit for various ranges of input voltages shows the correctness of the design of the Buck Boost controller. Thus by using this controller the voltage obtained at lower wind speeds can be boosted and used to charge the battery effectively and hence the efficiency of this system is comparatively higher than the existing system

## 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.

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