LOW COST WIND TURBINE ENERGY MAXIMIZER

By

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Abstract

Wind generation systems generate variable voltages at variable frequency because of variable wind speeds. Wind turbines exhibit non linear power characteristics at load variations and have power peak at certain speed of the wind turbine. Because of variable nature of output power at variable wind flow speeds, it is not practical to use the power output directly to any load. Rather, the variable ac power from the wind generator is stored in a storage battery using an interface converter. The battery then supplies power to the desired load or utility using an inverter. We aimed at constructing an interface converter that would always extract maximum power from the wind generator within the battery capacity limit.

A lead acid battery with a nominal voltage of 12V will be charged according to IEC 60896. While tracking the maximum power from the wind generator, if the main battery becomes unable to store the whole power, the rest power will be diverted to a secondary storage battery. In case of low wind speed, the secondary storage power may be pumped to the main battery if situation permits. Firstly we proposed a scheme which will provide all necessary protections to safeguard different components in the whole system under abnormal conditions. New topology of buck boost operation with a common ground and novel ideas of driving floating power MOSFETs, will be incorporated in the converter design. This report includes the test results of charging a 12V, 70Ah Lead Acid Battery at various charging states with our proposed circuitry.

Different individual parts like frequency measurement, LCD interfacing, serial communication were integrated, modified and tested into a single scheme-results of which are included in this report. Different input and output power were observed while varying the duty cycle from the Microcontroller. It also includes the data for testing of power maximizing algorithm at different wind speeds. Wind speeds have been simulated using a three phase synchronous generator set coupled with a compound dc motor used as a prime mover along with different maximum power point tracking results. All the advancements of the circuits and algorithms made so far and different newly implemented parts like protection scheme are included in this report.

Acknowledgements

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Finally we express thanks from my heart to all teachers, students and staffs of Department of Electrical and Electronic Engineering of East West University and all of my family members, friends whose names are not mentioned here.

Authorization Page

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1. Introduction

Limitation of available energy and the increasing demand of fossil fuel for generation of electricity and applications in other industrial activities and households have made the emergence of renewable energy sources inevitable worldwide. Unlike the other fossil energy sources, renewable energy provides almost zero pollution and low variable costs but at the same time suffers from some practical problems. Wind energy, like other renewable energy sources, is a very important source but cannot be directly fed to most loads or utility because of its variable nature.

Hence the necessity of an efficient power electronic converter for stable power flow comes into consideration. In this project focuses on the aspects of wind energy in household applications, and the team is dedicated for the development of an efficient energy maximizer. In order to produce electricity and feeding the power useful load or to a utility, it is necessary to stabilize the output voltage. Normally, the output power obtained from a wind turbine is made to charge a stationary battery through a power electronic converter.

Then another converter (inverter) converts the dc power into ac and then boosts it to the required level for feeding to a power system. For this, a significant number of theoretical and practical challenges are to be met and innovation in some areas is required.

2. Block Diagram

The following block diagram of wind generation power maximizer is shown in Fig. 1. The block diagram utilizes an integrated buck-boost topology using a common ground that is best suited for this application. A 3-phase Full bridge rectifier converts the wind generator ac voltage into dc that is fed to the charging circuitry through a normally closed relay contact. Provision is made for charging a secondary storage that is another stationary type lead acid battery of the same voltage as the main one.

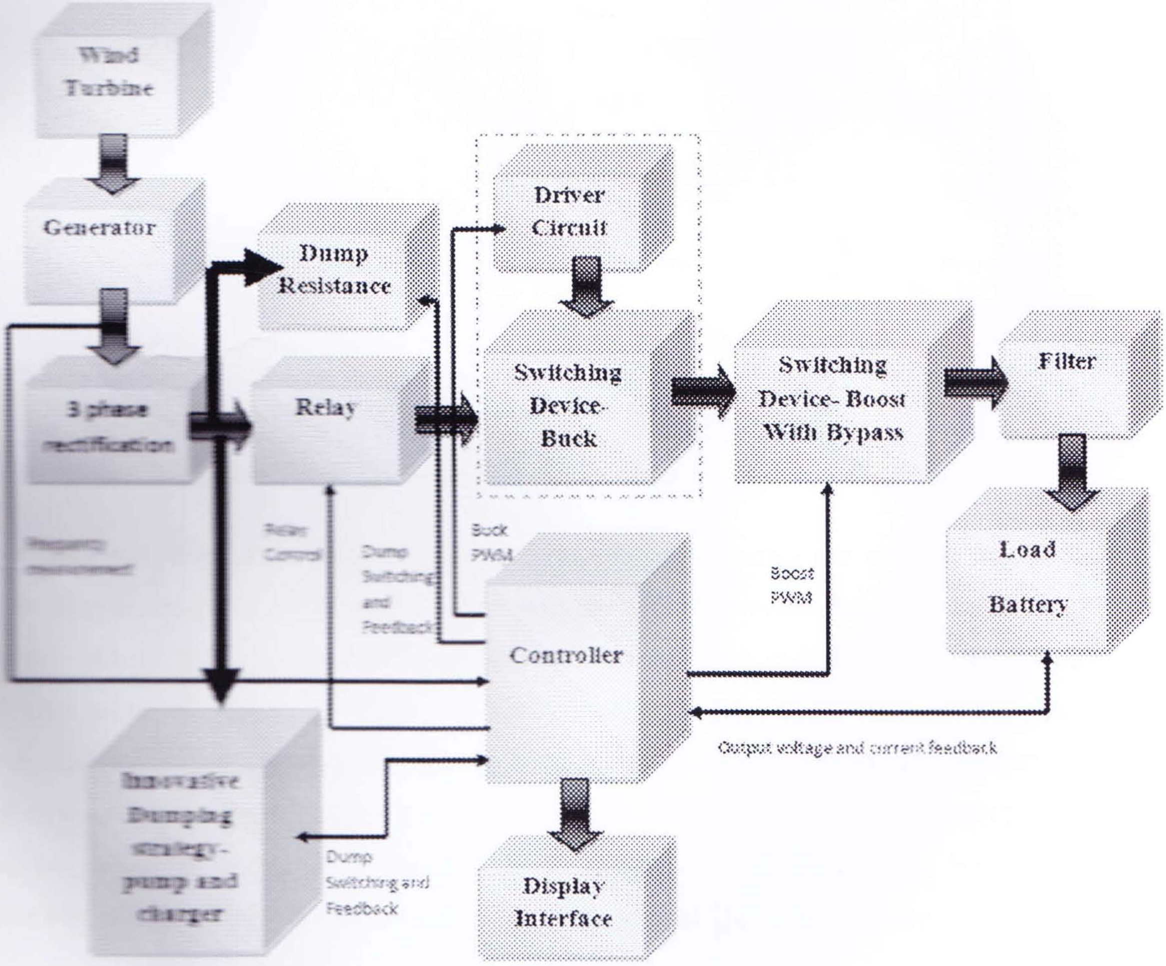

Figure 1: Block diagram for the scheme of the wind energy maximizer converter

3. Power Electronic Circuit for the Energy Maximizer

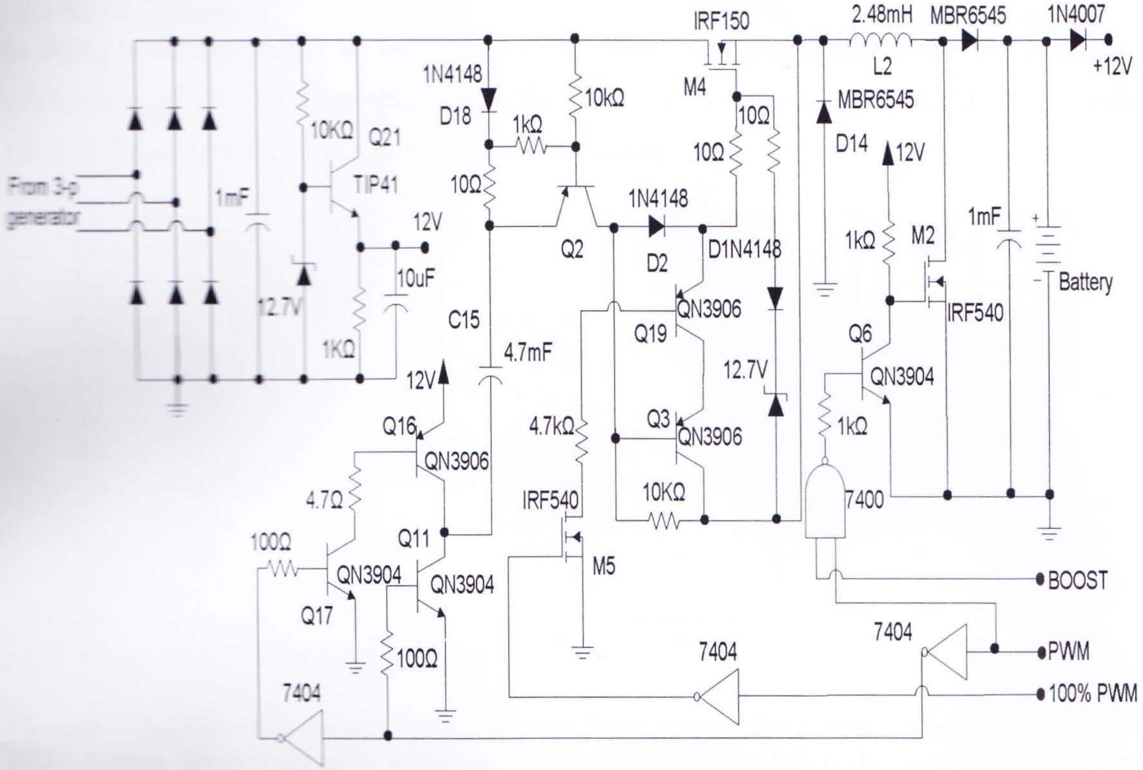

Figure 2: Finalized Power Electronic Interface for the Low Cost Energy Maximizer

Experiment was done with a motor generator set. To comply with the rotating machines output, some changes have been made. After connecting with the motor generator set the gate to source voltage decayed faster for large duty cycles. For complimentary set of transistors Q11, Q06 when the collector voltage was 12V the charge went through Q2. The capacitor was discharging through this process. But when the voltage is 0V the capacitor is charged. At large duty cycles, the capacitor got less time to discharge and more time for charging. As a result the voltage of the capacitor fall and the gate to source voltage also fall. So C2 was replaced by a large valued capacitor and the base resistance of Q11 was decreased.

The constraint of maximum PWM duty cycle of 90% was solved by adding 'Refresh with buck' strategy. The refresh pin enables a constant gate to source volt of 12V. The boost MOSFET is kept off. When the available power is less than the maximum charging current this strategy can be taken.

4. Simulation results

4.1 Buck Converter

In doing buck conversion, an input of 20V has been used. PWM duty cycle was 60% and refresh was off. In the following figure, the input voltage, the source voltage of the buck MOSFET and the load battery voltage has been shown.

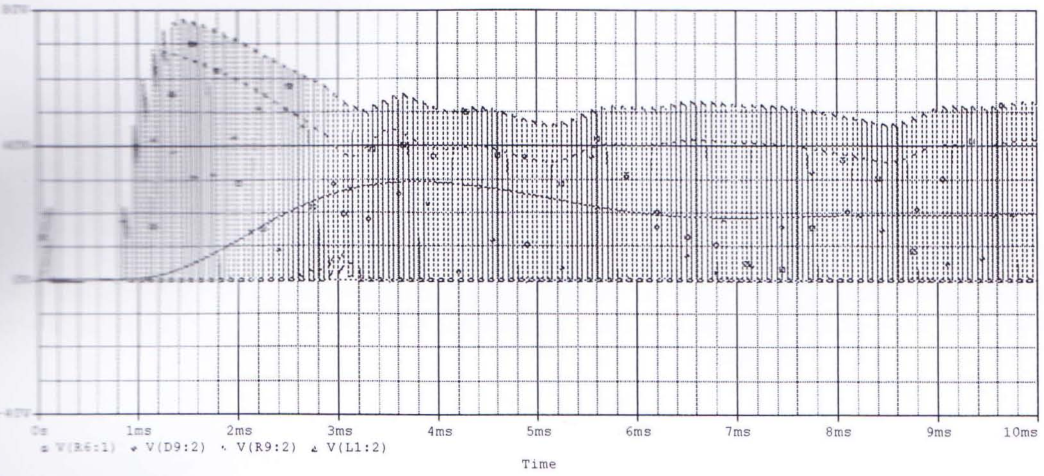

Figure 3: Voltage (R6:1) is the input voltage for buck MOS; Voltage (D9:2) is the output voltage for buck MOS; Voltage (R9:1) is the input voltage for boost MOS; Voltage (L1:2) is the input voltage for boost MOS

4.2 Boost Converter

In doing boost conversion, an input of 20V has been used. PWM duty cycle was 60% and refresh was on. In the following figure, the input voltage, the source voltage of the buck MOSFET, the drain voltage of the boost MOSFET and the load battery voltage has been shown.

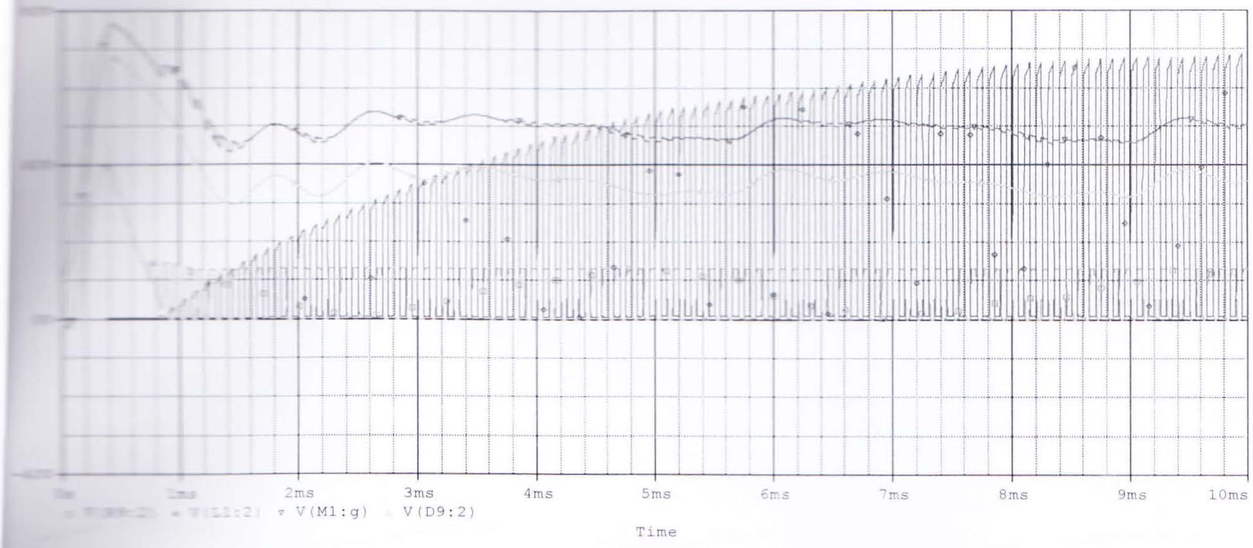

Figure 4: Voltage (M1:g) is the input voltage for buck MOS; Voltage (D9:2) is the output voltage for buck MOS; Voltage (R9:2) is the input voltage for boost MOS; Voltage (L1:2) is the input voltage for boost MOS

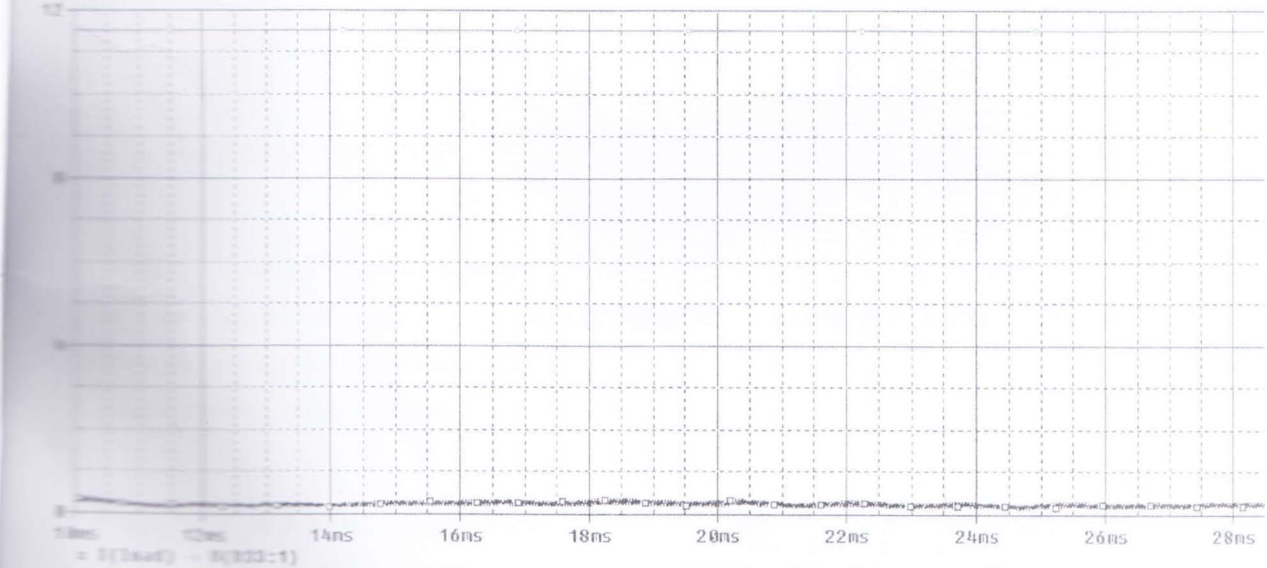

Figure 5: Load voltage and load current in Constant Voltage Mode With input 25V ac

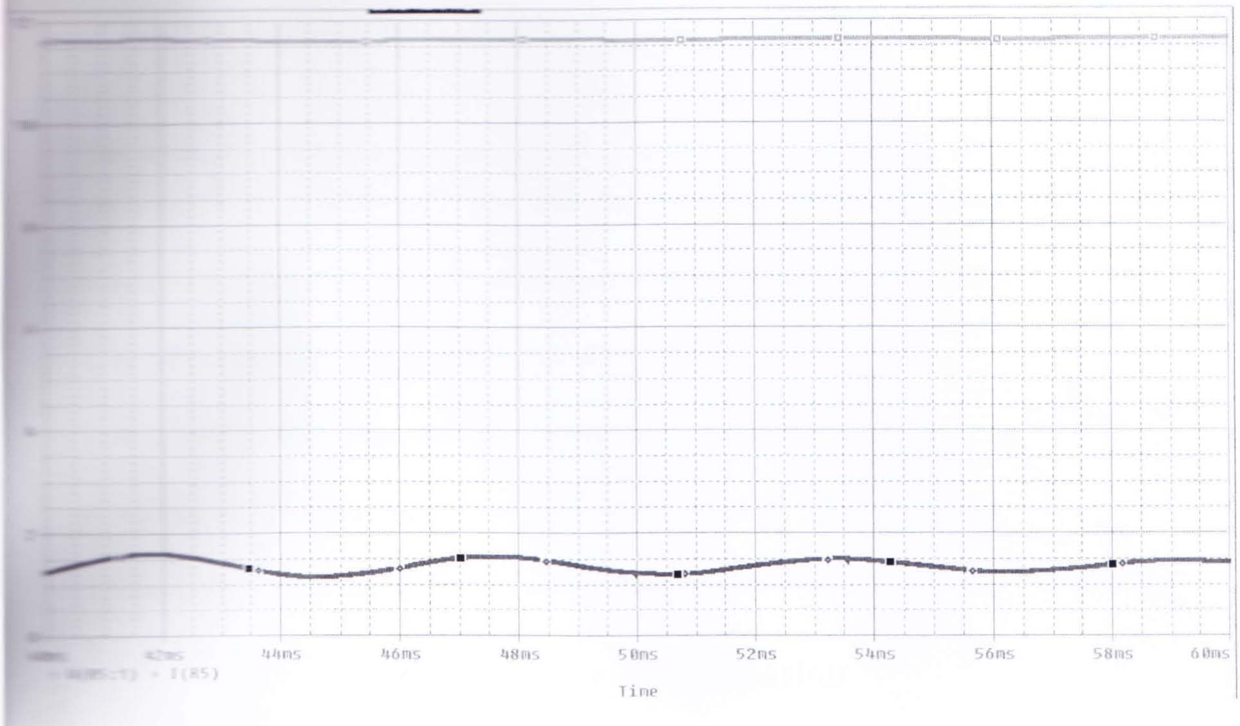

Figure 6: Load voltage and load current in Constant current Mode with input 25Vac

4.3 Experimentation

4.3.1 Buck Converter

The buck regulator is built with an IRF150 MOSFET. Variable duty PWM is generated from ATMega32 microcontroller with a switching frequency of 10 kHz. Operational performance for input voltages 13-50V and load current of 3A has been tested in a breadboard.

4.3.2 Boost Converter

The main part of the boost converter is a MOSFET, IRF540 and an inductor of 200uH. The value of the inductor is chosen carefully so that the output voltage can be boosted according to its requirement. The inductor used is a ferrite core inductor which has been made manually by the team for getting the exact inductance value. The boost operation is tested for input voltages 6-12V.

4.4 Frequency Measurements

The method of frequency measurement is tested involving timer2 (8-bit timer) and an interrupt (INT0) of ATMega32. The following algorithm is used for frequency measurement:

1. At first positive edge, store the current value of the timer2 as value1, diff=0
2. At timer2 overflow increase the value of diff by 256
3. At second positive edge, store the current value of the timer2 as value2
4. Add the difference between value2 and value1 with diff
5. Divide the CPU clock by diff and get the frequency.

5. Power maximization

5.1 Maximization Conditions

5.1.1 Battery Characteristics

In constant current charging stage, the power should be maximized according to the available wind power but should not exceed the maximum power requirement of the battery. In constant voltage charging stage power drawn by the battery is decreasing with time and turbine power does not need to be maximized.

5.1.2 Power Frequency Curve

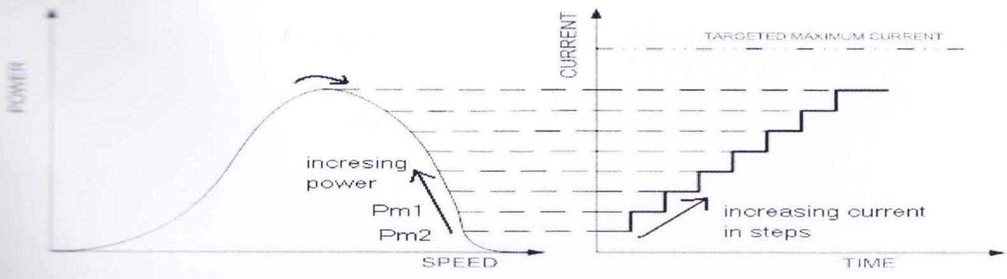

Figure 7: Charging when the maximum available power is less than the maximum charging power (maximizing output)

First two curves represent the case of being maximum power less than the power for the maximum battery charging current. The current is increasing gradually from no load to the maximum point of the turbine power speed curve. Here it is assumed that the wind speed is constant.

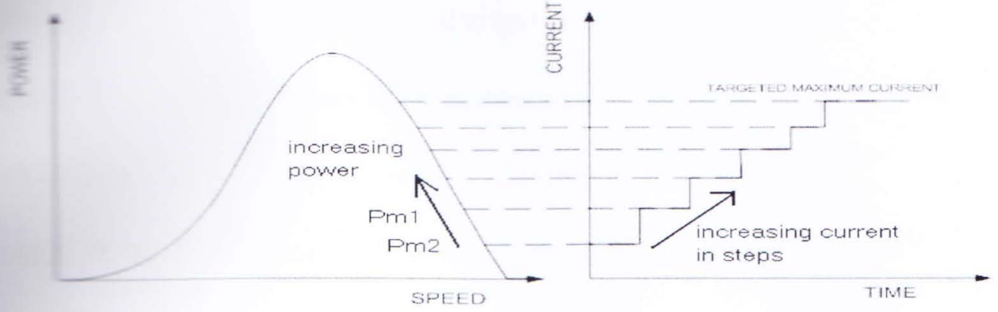

Figure 8: Charging when the maximum available power is more than the maximum charging power (maximizing output)

In Figure it represents the case of maximum available power more than the maximum battery charging power. Also here the starting point is at no load. The current is increased normally as the previous. But when it is required to cross the maximum charging current, the converter stops increasing current and stalls to maximum charging current and power is not maximized.

6. Maximizing algorithm

6.1 Operating Algorithm

Previously an auxiliary battery charging scheme was proposed, which is excluded in the final scheme .Thus it is also excluded from the final algorithm. For dumping the extra power some innovative ideas are included in the later part of the report.

Terminology

f	Wind generator frequency
$f(i)$	Wind generator present frequency
$f(i-1)$	Wind generator previous frequency

IBAT	Charging current of main battery
IBATUL	Maximum charging current of main battery
VBAT	Main battery terminal voltage
VBATUL	Main battery voltage upper limit
PBAT	Power supplied to main battery
PBAT(i)	Present value of main battery power
PBAT(i-1)	Previous value of main battery power
MAX_POWER	Maximum available power from the wind generator
KPWM1	PWM duty cycle

The following algorithm was used to search for the maximum power point.

Algorithm

1. Keep the Relay in off state (main contact closed, NC).
2. Initialize duties of KPWM1 .
3. Acquire the three-phase rectifier output voltage, V_S.
4. If $V_S < 5V$ or $V_S > 50V$, go to step 39 else go to step 5.
5. Display "System Normal" in the LCD module.
6. If $V_S > 14V$, go to 7 else go to 8.
7. Operate in BUCK Mode (M1 in PWM mode, M2 off).
8. Operate in BOOST Mode (M1 in refresh mode and M2 PWM mode).
9. Activate the converter if it was not activated before(first time), else continue operation (send PWM signal to respective MOSFETs) and charge the battery.
10. Acquire V_S, I_{BAT}, V_{BAT} and f.
11. Calculate power, $P_{BAT}(i) = V_{BAT}(i) * I_{BAT}(i)$.

12. Wait for a while.

Battery Charging with Maximum Power Tracking

13. Acquire V_S, I_{BAT}, V_{BAT} and f.

14. If $V_S > 5V$ or $V_S < 50V$ go to 15, else go to 39

15. If IBAT(i)>= IBATUL or VBAT (i)>= VBATUL ,decrease PWM, go to 13,else go to16

16. Calculate power, $P_{BAT}(i) = V_{BAT}(i) * I_{BAT}(i)$ and $\Delta P(i)$,($\Delta P(i) = P_{BAT}(i) - P_{BAT}(i-1)$) and $\Delta f(i)$, ($\Delta f(i) = f(i) - f(i-1)$)

17. If $\Delta P(i)$ is not zero find derivative of power change, $\Delta^2 P = \Delta P(i) - \Delta P(i-1)$,go to 18, else go to 38

18. If $\Delta P(i)>0$ and $\Delta f(i)>0$ go to 19, else go to 22

19. If $\Delta P(i-1)>0$ and $\Delta f(i-1)<0$ go to 20, else go to 21

20. If $\Delta^2 P > 0$, make PWM step size k as k=k+p (p is a fixed step size) and p=p+1,else make k=k-n (n is a fixed step size), (k>=2)

21. If $\Delta^2 P < 0$,make step size k as k=k-p and p=p+1,else make k=k-n, (k>=2)

22. If $\Delta P(i)<0$ and $\Delta f(i)<0$ go to 23 else go to 24

23. If $\Delta^2 P > 0$, make step size k as k=k-p and p=p+1,else make k=k-n

24. If $\Delta P(i)>0$ and $\Delta f(i)<0$ go to 25 else go to 26

25. If $\Delta^2 P > 0$, make step size k as k=k+p and p=p+1,else make k=k+n

26. If $\Delta P(i)<0$ and $\Delta f(i)>0$ go to 27 else go to 28

27. If $\Delta^2 P > 0$, make step size k as k=k+p and p=p+1,else make k=k+n

28. If $\Delta P(i)<0$ and $\Delta f(i)<0$ go to 29 else go to 33

29. If ΔP(i-1)>0 and Δf(i-1)<0 go to 30 else go to 33
30. Make MAX_POWER = P_{BAT}(i-1) , go to 31
31. Store P_{BAT}(i) at P_{BAT}(i-1) ,go to 32
32. Store present f(i) value at f(i-1)
33. If ΔP(i)<0 and Δf(i)>0 go to 34 else go to 37
34. If ΔP(i-1)>0 and Δf(i-1)>0 go to 35 else go to 37
35. Make MAX_POWER= P_{BAT}(i-1) go to 36
36. Store P_{BAT}(i) at P_{BAT}(i-1) and Store present f(i) value at f(i-1) , go to 38
37. Go to step 6
38. Go to step 4

System operation in abnormal condition

39. Turn ON relay to disconnect the converter from the 3-phase rectifier.
40. Display "System Abnormal" in the LCD module.
41. Go to "Sleep Mode".
42.

6.2 MATLAB Simulation

For simulating our algorithm (modified dual slope maximizing strategy) we firstly simulated in MATLAB wind turbine's power versus speed characteristics curve at different wind speeds using following equations [1].

$$P_m = \frac{1}{2}\rho A V_{\omega}{}^{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$$C_p = \frac{1}{2}(\gamma - 5.6)e^{(\ 0.17\gamma)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

$$\gamma = \frac{V_{\omega}\left(\frac{mile}{hr}\right)}{W_{\omega}\left(\frac{rad}{sec}\right)} \text{ ----------------------------- } (3)$$

Where:

P_m = mechanical input power

ρ = density of air, (1.205 kg/m3 assumed for simulation)

A = area swept by blades, (1.7 m2 assumed for simulation)

V_{ω} = wind speed

C_p = turbine power coefficient

γ = tip speed ratio

W_{ω} = generator speed

The maximum value of C_p=0.4176, when γ =11.5 and gear ratio is assumed to be 95.

6.3 Simulation Algorithm

1. Give present wind speed as input
2. If input is given, set Pm2 (power that is set) =0, go to 3,else stand by
3. At the given wind speed start from any arbitrary generator speed Ω1

Mid progress report for IFEC2009 project "Low Cost Wind Turbine Energy Maximizer" by
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BUET and EWU, Bangladesh
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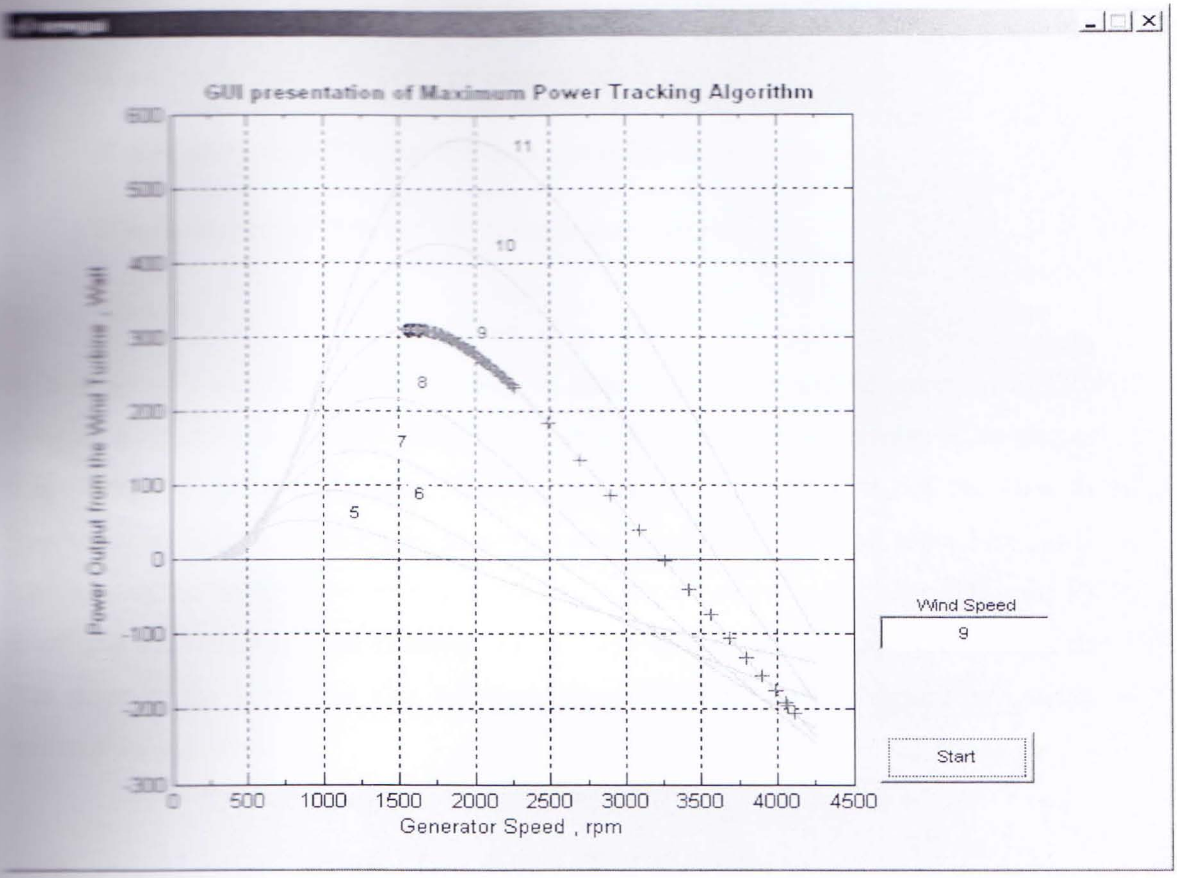
4. Calculate power Pm1, at Ω1 using equation (1) , (2) and (3)

5. Store present $\Omega 1$ value at $\Omega 2$(stack variable)
6. Find power difference, $\Delta P(i) = Pm1-Pm2$ and generator speed difference, $\Delta\Omega(i) = \Omega 2-\Omega 3$ ($\Omega 3$ is a stack variable)
7. Find derivative of power change, $\Delta 2P= \Delta P(i) - \Delta P(i-1)$
8. If $\Delta P(i)>0$ and $\Delta\Omega$ $(i)>0$ go to 9, else go to 12
9. If $\Delta P(i-1)>0$ and $\Delta\Omega$ $(i-1)<0$ go to 10, else go to 11
10. If $\Delta 2P >0$, make step size k as $k=k+p$ (p is a fixed step size) and $p=p+1$,else make $k=k-n$ (n is a fixed step size), $(k>=2)$
11. If $\Delta 2P <0$,make step size k as $k=k-p$ and $p=p+1$,else make $k=k-n$, $(k>=2)$
12. If $\Delta P(i)<0$ and $\Delta\Omega(i)<0$ go to 13 else go to 14
13. If $\Delta 2P >0$, make step size k as $k=k-p$ and $p=p+1$,else make $k=k-n$
14. If $\Delta P(i)>0$ and $\Delta\Omega(i)<0$ go to 15 else go to 16
15. If $\Delta 2P >0$, make step size k as $k=k+p$ and $p=p+1$,else make $k=k+n$
16. If $\Delta P(i)<0$ and $\Delta\Omega(i)>0$ go to 17 else go to 18
17. If $\Delta 2P >0$, make step size k as $k=k+p$ and $p=p+1$,else make $k=k+n$
18. If $\Delta P(i)<0$ and $\Delta\Omega(i)<0$ go to 19 else go to 23
19. If $\Delta P(i-1)>0$ and $\Delta\Omega(i-1)<0$ go to 20 else go to 23
20. Make MAX_POWER = Pm2 go to 21
21. Store Pm1 at Pm2 go to 22
22. Store present $\Omega 2$ value at $\Omega 3$
23. If $\Delta P(i)<0$ and $\Delta\Omega(i)>0$ go to 24 else go to 27
24. If $\Delta P(i-1)>0$ and $\Delta\Omega(i-1)>0$ go to 25 else go to 27
25. Make MAX_POWER= Pm2 go to 26
26. Store Pm1 at Pm2 and Store present $\Omega 2$ value at $\Omega 3$, go to 28
27. Go to step 3
28. Go to step 1

6.4 GUI output of MATLAB Simulation



Wind Speed

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Figure 9: The Power vs frequency curve implemented in GUIDE of MATLAB.

In the GUI red crosshairs represent the jumps from lower to immediate higher power. The jump steps near the maximum power are small to trace the maximum power accurately.

7. Battery Charging

The algorithm for charging the battery is

a. Acquire battery terminal voltage and state of charge

b. If state of charge < 70% charge using constant current

c. If state of charge >70% but <90% charge using constant voltage

d. If state of charge >90% but <95% use trickle charging

e. Go to a

In this report it was said that the voltage vs state of charge would be stored in EEPROM. Programming of the EEPROM has been implemented in the microcontroller. Charging using this strategy is being worked on. However voltage vs SOC curve is not the same at all temperatures. The current charging strategy incorporates the using of an Asynchronous timer for charging the battery. The timer generates an interrupt on every 4 minute. Than the PWM is off and the battery is open circuited. The voltage of the battery is measured after a delay. The slope of the voltage is also calculated to verify if the battery should be charged in constant voltage mode.

8. Implemented Results

The data below was taken connecting a potentiometer in the output and varying the output resistance. Input DC voltage was fed to the DC motor coupled with a synchronous generator. Three phase output was taken from the synchronous generator and fed to a three phase rectifier. Its output DC voltage was fed to the proposed converter. Varying the load resistance different output power was extracted. Plotting the output power vs frequency in MATLAB a maximum power point is found .This power vs frequency curve is symmetrical though not completely alike the wind turbine curve. Using the proposed converter the dual slope maximizing algorithm tracked the maximum power point of this curve.

8.1 Data

Table 1: Experimental data of the converter

Obs	Output voltage (V)	Output current (A)	Output power (W)	Freq (Hz)
1	44	0.21	9.4	28
2	43.8	0.22	9.63	27
3	42.3	0.25	10.57	26
4	36.6	0.38	13.9	24.5
5	32.1	0.42	13.5	22.5
6	26.5	0.58	15.37	21
7	19.9	0.68	13..53	18
8	17.3	0.78	13.49	17
9	14.6	0.79	11.53	16
10	10.9	0.87	9.48	15

8.2 Plot of the Data

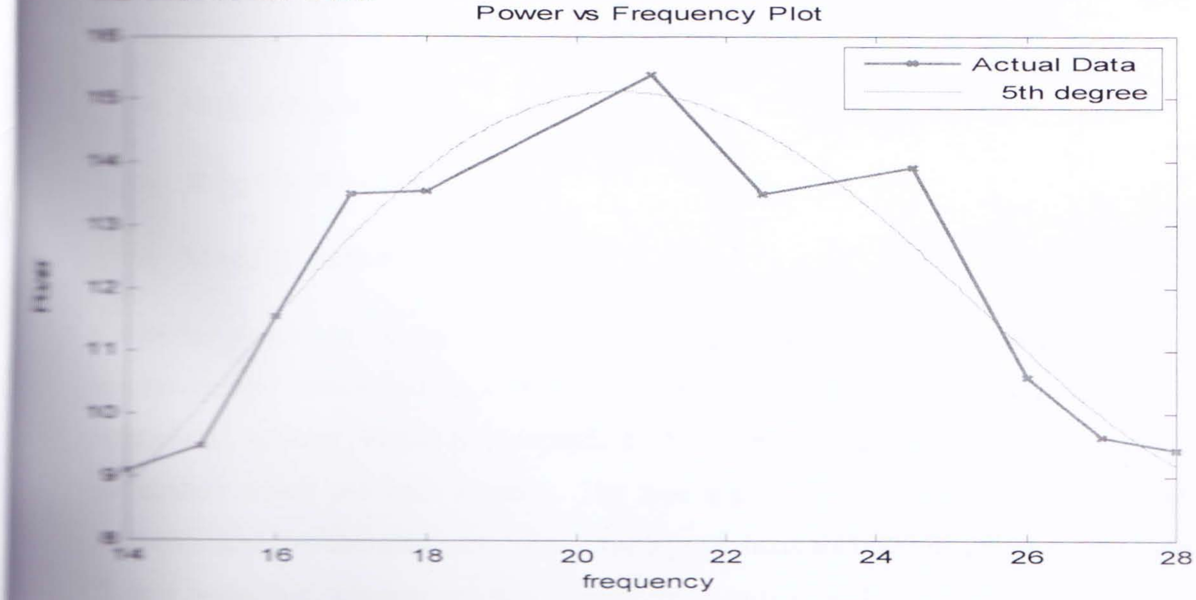

Figure 10: The MATLAB plot of power vs. frequency from the data tabled above

8.2 Motor Generator Setup

The current testing is being performed on a synchronous generator coupled with DC motor used as prime mover. The DC motor is separately excited and its armature has a series resistance. It is to be noted that at running condition when the motor and resistance has the same voltage drop then the motor is assumed to take maximum power.

Table 2: Specification of the motor generator set

DC Motor	Synchronous Generator
AEG	AEG
220V 10.3A	Δ/Y 400 / 230V 2.8/2.17A
DB 1.7kW DYn Type G 237	DB 1.5kVA cosΦ .9/1
1340/2300 rpm	1500 rpm
	Epress 180V 0.8A

9. Protection

The protection system of the converter is so designed that if any of the control fails than another one takes over it. These protection schemes have been tested individually. There are three types of protection system for the converter

a. Controller protection

b. Independent Analog Protection

c. Mixed protection

Controller protection is the scheme in which the actuator is the microcontroller. The microcontroller senses and decides what to do. Independent Analog protection only uses sensor and actuator which is independent of the microcontroller. There are also some protections which use both a and b. The type a protection system is Over temperature protection and overcharging protection. Type b protections are opposite polarity, over-voltage Type c protection schemes are short circuit, over-current, under voltage protection. These protection schemes are discussed below

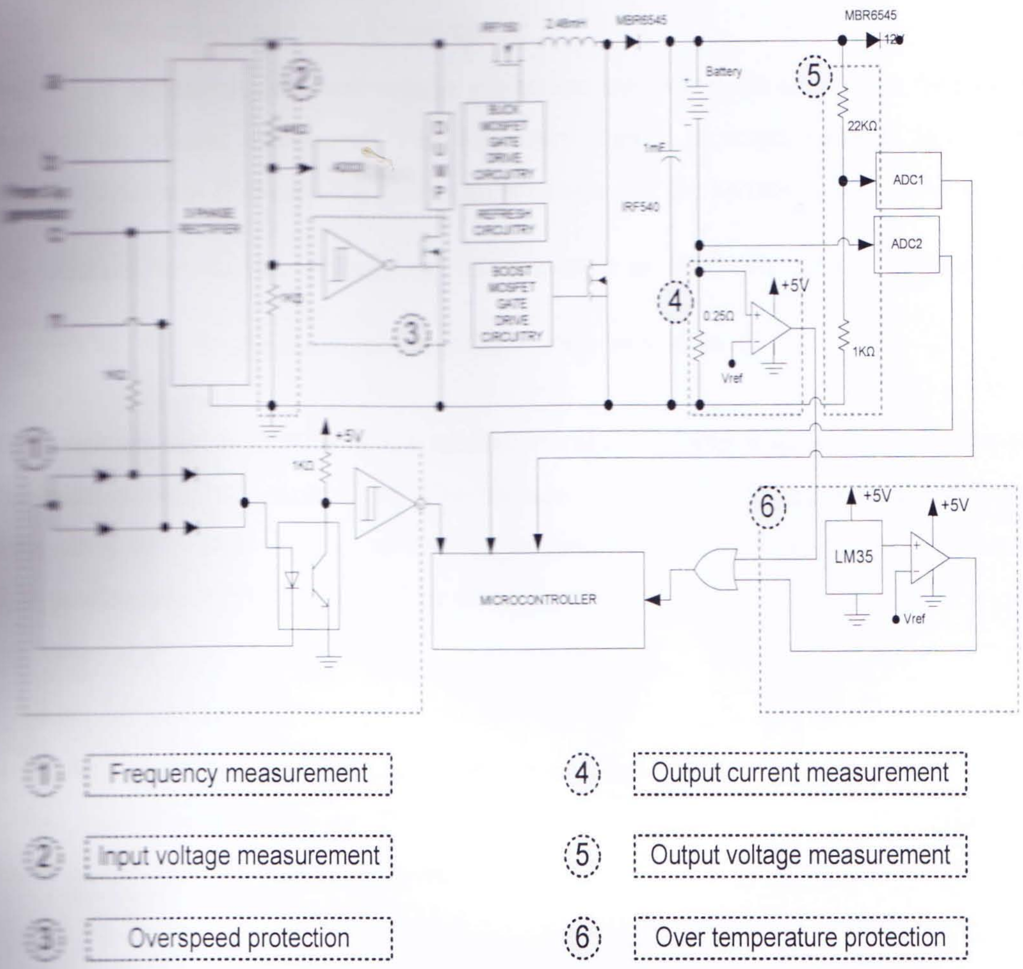

Figure 11: Measurements and Protection systems

9.1 Opposite Polarity

This uses a relay which is excited when the battery terminals are connected in opposite polarity. The relay opens the opposite current conducting path. The operation of the relay is independent of the microcontroller.

9.2 Short Circuit

If the terminals are short circuited and the turbine has available power, large current flows to the output. The absence of voltage and high value of output current is detected by the microcontroller. This triggers a relay which opens the output terminals so that the current can not flow. This relay remains open as long as the short circuit in the output terminal is there.

9.3 Over voltage and Over-speed

Over-speed protection and over voltage protection are almost the same. The frequency of the generator is always monitored. The frequency cannot increase without failing the over voltage protection. If the analog protection schemes fail, the converter will make sound.

The highest line to line voltage of the generator is 50V this means rectifier output of $\frac{50\times3}{\pi}$V=47.7V. So the maximum rectifier voltage should be 47.7V.

When voltage exceeds 100% of the maximum value, a dump load is on. The extra power is dissipated through the dump load. The voltage reduces. The dump load power dissipation stops when the voltage reduces to 90% of the maximum voltage. The dump load is merely a high power resistor. The control of the dump load is analog.

9.4 Over current

A simple op-amp is used which generates an interrupt to the microcontroller. The triggering of the op-amp also stops the PWM input to the power converter. The microcontroller decreases the PWM to reduce the over current.

9.5 Over charging

If the voltage becomes constant for around 2 hours than the battery is supposed to e charged fully. If the charging finishes, the PWM is made off. The battery voltage is periodically measured to see if voltage has been decreased.

9.6 Over-temperature

The temperature sensor LM35 gives a proportional output to the temperature. The voltage increase beyond limit (60'C) sensed by an op-amp. This op-amp creates an interrupt to the microcontroller. The microcontroller then temporarily shuts down the entire converter until the temperature becomes normal again.

9.7 Under-voltage protection

The lower voltage of the generator is 6V which means rectifier output of $\frac{6\times 3}{\pi}$ V=5.73V. An op-amp senses this under-voltage condition and makes an interrupts to the microcontroller. The microcontroller then shuts down all of its jobs.

10. Innovative Ideas for dumping the extra power and Heat sink Design

This is not a part of the power converter. The motor uses the excess power of the converter to drive water or an air pump. The motor starts automatically when the rectifier output voltage exceeds 80% of the maximum rectifier voltage, and stops when the voltage drops to 60% of the maximum value. If additional power is needed for the battery the motor can be kept off.

10.1 Water pump

The water pump works when the motor is started by the MOSFET. This system can be used at rural areas. The water can be irrigated through different channels to the upper lands. In systems placed on top of houses, the pump can pull water to the rooftop tanks. The only disadvantage of this system is that it has to be active only at high winds.

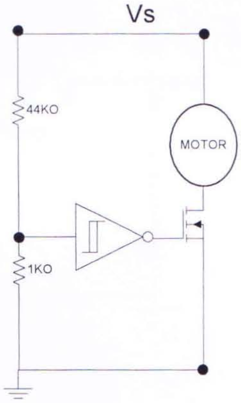

Figure 12: Motor Connection

10.2 Air compressor pump

The pump sucks air from atmosphere and air is collected at higher pressure through compressor. This system can be used **as power storage as the air can drive a turbine.**

10.3 Heat sink design

Here are the necessary calculations for a targeted junction temperature 80^0C where ambient temperature is 35^0C (maximum).

For the buck MOSFET (IRF150) total power dissipation is calculated below

At 25^0C junction temperature, $R_{DS}(ON)$ =0.055Ω

At 80^{0}C effective R_{DS} (ON)=0.055Ω ×1.5 = 0.0825Ω

Maximum current in our testing = 8A

Total power dissipation = $(8A)^2 \times 0.0825\Omega = 5.28W$

For maximum ambient temperature 350°C we have a span of 800 °C -350 °C = 450 °C

Total thermal resistance required TR= 45/5.28 °C /W = 8.523 °C /W

Using the datasheet the thermal circuit will become,

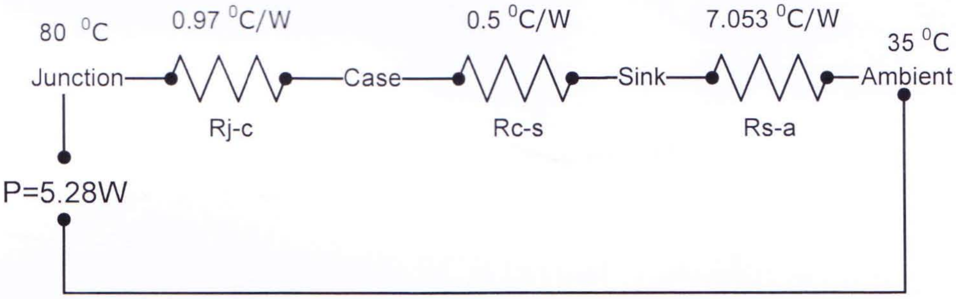

Figure 13: Thermal resistances from junction to ambient

So we have to design a sink having a thermal resistance of (8.523-0.97-0.5) = 7.053 °C /W. Here aluminum is used for its good thermal conductivity: 209.3 W/mK

The thermal resistance of a heat sink is determined by the total surface area, the number of fins, the actual alloy used, its thickness, the color (matte black is best), availability of unrestricted air flow and its temperature. For 7°C/W the surface needed for 0.3cm thick aluminum is $75cm^2$.

For designing purpose fin length is taken 1.5cm and fin spacing is 0.75cm for natural convection. Fin spacing could be .5cm for 1m/s airflow.

To meet the area $75cm^2$ fin width will be 4cm for 6 fins.

So the area will be A= 1.5*4*(6*2) = 72cm2. Spacing area will compensate rest of the area.

Roughly is estimated that boost MOSFET (IRF540) dissipates same amount of power.

As power vs frequency curve for the announced withstand wind speed 40m/s is not studied yet, power dissipation from dump resistance is not calculated.

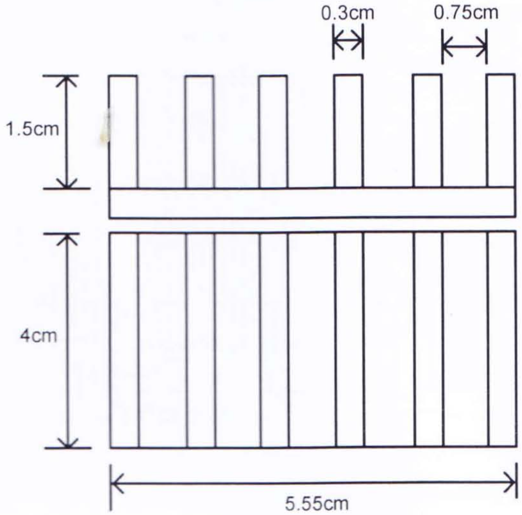

Figure 14: Top and side dimensional view of heat sinks

11. PCB layout

The prototype PCB has been designed and built. Another PCB for controller operation and serial communication with pc and communication with LCD has been implemented.

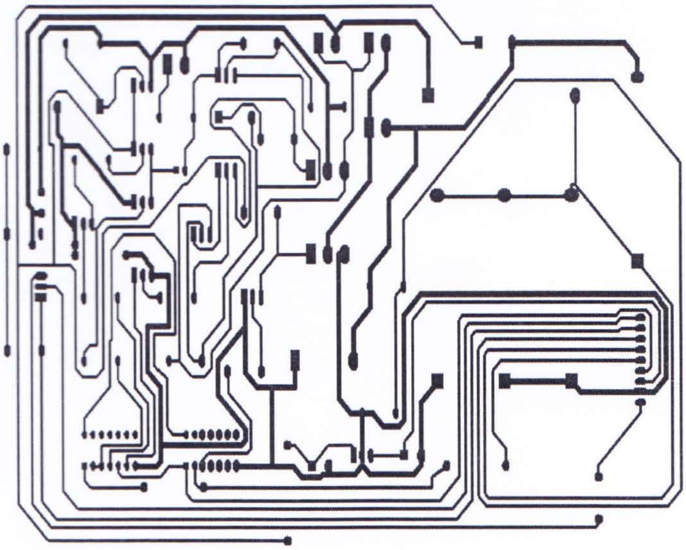

Figure 15: Layout of the converter PCB

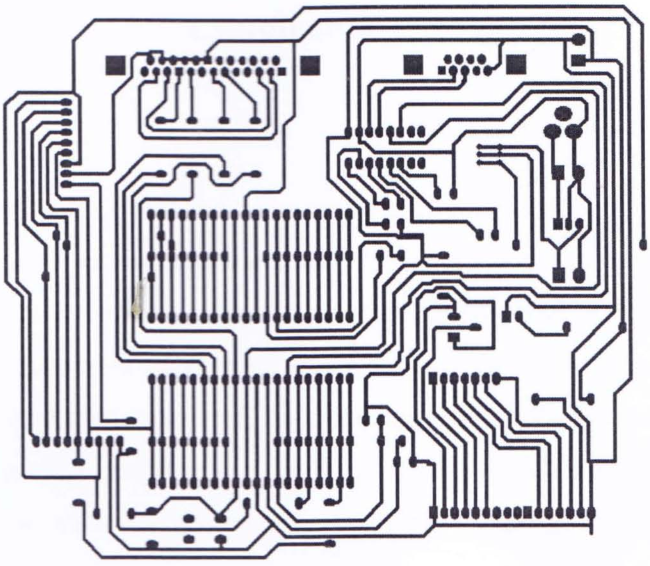

Figure 16: Layout of ISP with serial communication & LCD interfacing

Layout of the converter PCB and Layout of ISP with serial communication & LCD interfacing were implemented properly.

12. Conclusion

12.1 Conclusion

Variable speed operation is realized in many ways, each differing in significant details. Direct drive systems have a natural capability for a very wide speed range, although even there some restriction on minimum speed may reduce the cost of power electronics. The electrical energy is generated at variable frequency – a frequency related to the rotational sped of the rotor – and then converted, by the converter or inverter (both power electronic devices) to the frequency of the grid. There are several possible configurations, based on both synchronous and induction generators. But for this experiment synchronous generator have been considered.

Efficiency prediction for a buck and boost converter at Pulse Width Modulation (PWM) mode is well analyzed. However, System efficiency is then calculated accordingly. Predicted efficiency within the whole operating range is then compared to test results. In this work, buck and boost converter achieved almost 90% efficiency.

Also prototype designed was good to meet the cost specifications. Different subsystems were designed and tested to reduce the overall cost of the system. The current sensing, driving circuits and passive devices designed for lower cost.

12.2 Suggestion For future work

In this thesis, design and practical implementation have been done successfully. A future development of low cost wind turbine is:

Graphical User Interface

◦Implement Wireless Connectivity

◦Suitable for Windows, Linux, and Mac Users

◦Smart Phone Applications

Battery Charging Algorithm

◦Multiple battery chemistry compatibility (NiCd, NiMH, Li-ion, and lead-acid).

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Appendix

Matlab code for power maximization:

```
clear all
omega=1:.15:45; %in rpm
omega1=omega*2*pi/60;%in rad/sec matrix length 881
A=1.7;
ro=1.2;
Vm=[3 4 5 6 7 8 9 10 11];
for i=1:9
Pm=(.25.*((2.232*Vm(i)./omega1)-5.6)).*(exp(-
0.17.*(2.232*Vm(i)./omega1)))*(A*ro*(Vm(i)^3));
figure(1)
plot(omega*95,Pm,'r')
hold on
grid on
end
Vm=[5 7 9 11];
k=0;
Pm2=0;
omega3=omega1(280-k+1);
omega2=omega1(280-k);
n=1;
MAXIMUMPOWER=0;
DelsqP=0;
for m=1:700
Vm(m)=input('give present wind speed(3 T0 11)');
if Vm(m)<=2
break
```

```
end
p=2;
for i=1:600
Pm1=(.25.*((2.232*Vm(m)./omega1(280-k))-5.6)).*(exp(-0.17.*(2.232*Vm(m)./omega1(280-k))))*(A*ro*(Vm(m)^3));
if (MAXIMUMPOWER~=0)
if ((i>=3)&&(Pm1>MAXIMUMPOWER))
n=n+1;
else if (i>=3)&&(n>=2)&&(Pm1<MAXIMUMPOWER)
n=n-1;
end
end
end
omega2=omega1(280-k);
figure(2)
plot(omega(280-k)*95,Pm1,'g.')
drawnow
hold on
grid on
DelP(i)=Pm1-Pm2;
Delf(i)=omega2-omega3;
if i>=2
DelsqP = DelP(i)-DelP(i-1);
end
if ((DelP(i)>0)&&(Delf(i)>0))
if ((i>=2)&&(DelP(i-1)>0&&Delf(i-1)<0))
if DelsqP>=0
k=k+p;
p=p+1;
else
```

```
k=k+n;
end
else
if DelsqP>=0
k=k-p;p=p+1;
else
k=k-n;
end
end;
else if (DelP(i)<0&&Delf(i)<0)
if (DelsqP>=0)
k=k-p;p=p+1;
else
k=k-n;
end
else if (DelP(i)>0&&Delf(i)<0)
if DelsqP>=0
k=k+p;p=p+1;
else
k=k+n;
end
else if (DelP(i)<0&&Delf(i)>0)
if DelsqP>=0
k=k+p;p=p+1;
else
k=k+n;
end
end
end
```

```
end

end

if (i>=3)&&(((DelP(i)<0)&&(Delf(i)<0))&&((DelP(i-1)>0)&&(Delf(i-1)<0)))

MAXIMUMPOWER=Pm2

% k=k+n;

figure(2)

plot(omega(280-k)*95,Pm2,'k+')

drawnow

hold on

grid on

omega3=omega2;

jkl=111

Pm2=Pm1;

%continue

break


else if (i>=3)&&((DelP(i)<0)&&(Delf(i)>0))&&((DelP(i-1)>0)&&(Delf(i-1)>0))

MAXIMUMPOWER=Pm2

%k=k-n;

figure(3)

plot(omega(280-k)*95,Pm2,'k+')

drawnow

hold on

grid on

omega3=omega2;

jkl=10

Pm2=Pm1;

%continue

break
```

```
end
end
omega3=omega2;
Pm2=Pm1;
end
end
```

Code for frequency measurement for Microcontroller :

```
#include <avr\io.h>
#include <avr\interrupt.h>
#include <math.h>
#include "lcdlib.h"
#include <stdio.h>
#include <string.h>
#include <stdlib.h>
#include "delay.h"
void delay_long(){
long i = 5000;
while(i--){
}
}
int j;
void lcdcall( char p)
{
int i;
PORTB=~PORTB;
Clear_LCD();
LCD_Send(0x80,0);
LCD_Send_String("p");
delay_long();
```

```
LCD_Send(0xC0,0);
LCD_Send_String("p");
Clear_LCD();
for(i=0;i<4;i++){
LCD_Send(0x1C,0);
_delay_ms(262.16);
}
for(i=0;i<4;i++){
LCD_Send(0x18,0);
_delay_ms(262.16);
}
}
void delay_short(){
long i = 1000;
while(i--){
}
}
ISR(TIMER1_CAPT_vect)
{
static int16_t value2,value1,dif;
char freq;
value2=ICR1L+(8<<ICR1H);
dif=value2-value1;
freq=1/dif;
lcdcall(freq);
value1=value2;
}
void main()
{
```

```
DDRD = 0b10111111;
TCCR1B=0b11000001;
TIMSK|=(1<<TICIE1);
int i;
int p=65000;
DDRB=0xFF;
PORTB=0x55;
DDRC = 0xFF;
PORTC = 0x00;
LCD_init();
/*      line1   0x80
line2   0xC0
line3   0x94
line4   0xD4
*/
sei();
while (1)
{
}
}
```

Code for PWM Generation:

```
#include <avr/io.h>
#include<avr/interrupt.h>
ISR(TIMER1_COMPB_vect){
        PORTD=0x10;
}
```

```
int main(void)
{
  DDRD = 0x10;
        //ICR1=0x7F;
        OCR1A=10;
        OCR1B=0x06;
        TCCR1A=0b00110011;
        TCCR1B=0b00011001;
        //PORTD=0x20;
        TCNT1H=0x00;
        TCNT1L=0x00;
        sei();
  while (1)
  {
}
}
```