Development of a Sensor System Suitable for Condition Monitoring of Railway: Part-II

A Project Report

submitted by

RATHEESH TS

EE17M016

in partial fulfillment of the requirements

for the award of the degree of

MASTER OF TECHNOLOGY

in

CONTROLS AND INSTRUMENTATION ENGINEERING

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY MADRAS

MAY 2019

THESIS CERTIFICATE

This is to certify that the thesis titled "**Development of a Sensor System Suitable for Condition Monitoring of Railway: Part-II"** submitted by **Ratheesh TS** to the Indian Institute of Technology Madras for the award of the degree of **Master of Technology** in Controls and Instrumentation Engineering is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Dr. Boby George
Project Guide
Professor
Dept. of Electrical Engineering
IIT-Madras, 600036

Date : May 19
Place: Chennai

ACKNOWLEDGEMENTS

At the outset, I express my deep sense of gratitude to my Project Guide Dr. Boby George for his guidance, support, encouragement and help throughout the period of the project work. I am highly indebted to him for devoting his valuable time to help me to complete the work in time.

I thank all the teaching and non-teaching staff, Shri. Manikandan and Smt. Rekha of the Electrical Science Department for extending all the support and cooperation to me throughout. My lab mates Shekhar Yadav and R Karthikeyan have always supported me during the work.

I also avail this opportunity to express my sincere gratitude to the Indian Air Force for giving me the opportunity to be a part of this prestigious institute.

All this wouldn’t have been possible if it was not for the unconditional support by my parents, wife Aswathi, and daughter Vedha Lekshmi.

Last, but not the least I thank Almighty for the blessings he showered upon me during the course of the project, and indeed the entire life.

Ratheesh TS

ABSTRACT

KEYWORDS: Micro wind turbine; battery management system; lithium polymer rechargeable battery; energy conversion and storage.

Powering today's portable world poses many challenges for system designers. The use of batteries as a prime power source is on the rise. As a result, a burden has been placed on the system designer to create sophisticated systems utilizing the battery's full potential. Each application is unique, but one common theme rings through: maximize battery capacity usage. This theme directly relates to how energy is properly restored to rechargeable batteries. No single method is ideal for all applications. An understanding of the charging characteristics of the battery and the application's requirements is essential in order to design an appropriate, reliable and safe battery charging system. Each method has its associated advantages and disadvantages. It is the particular application with its individual requirements that determines which method will be the best to use. Far too often, the charging system is given low priority, especially in cost-sensitive applications. The quality of the charging system, however, plays a key role in the life and reliability of the battery.

In this project I attempt to explain an innovative method of generating energy in a fast moving vehicle, here, in a train. The wind energy produced by a moving train can be utilized for generation of electricity. Due to the movement of train, the wind will flow in the opposite direction of train which will collide on the blades of the turbine, which will further spin the shaft connected to it. The shaft is then connected to a permanent magnet direct current generator. Thus the kinetic energy of the wind which is created is used to generate electricity. This electrical energy can be stored and utilized for powering up various electronic components of Railway Track Crack Detection System.

Here the battery power from the train is not used, as this will demand additional wiring, mostly through not easily accessible locations in the bogie. Also, such sensors need to be installed large in numbers. Hence self-powered modules are preferred as that helps the deployment relatively easy.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

PMDC	Permanent Magnet Direct Current Generator
LiPo	Lithium Polymer
BMS	Battery Management System
NiCad	Nickel Cadmium
NiMh	Nickel Metal Hydride

NOTATIONS

C Rating	Charge/ Discharge rate
mAh	Battery Capacity in milli-ampere-hour
V_o	Output Voltage
$E_{kin, wind}$	Kinetic Energy due to wind
P_{wind}	Wind power
P_{eff}	Effective power
C_P	Power coefficient
C_{Pmax}	Maximum power coefficient
P_{avail}	Available power

CHAPTER 1

INTRODUCTION

1.1 General

Energy resources in our world are depleting quickly, hence it is indispensable to find new ways to generate energy which are self-sustaining, easily manageable, and available freely and easily. Energy harvesting (also known as energy scavenging) is the conversion of ambient energy present in the environment into electrical energy for use in powering autonomous electronic devices or circuits. The energy harvesting resources can be solar, vibration (piezoelectric), thermal, wind etc. The problem with solar harvesting is the panel needs to be placed on the top of the bogie with proper routing and specific packaging is required to save it from vibrations. Also it is low efficient and high in cost. In piezoelectric (vibration) the energy generated is very low and it is relatively expensive. The main disadvantage of solar and thermal resources is that they produce energy only on day time. Thus wind energy is used widely and most prominently to generate electricity through wind turbines, and it has been proved to be one of the most reliable renewable energy sources across the world. However there are very few regions in the world that experience windy conditions throughout a year so this method becomes restricted to few regions only. This concept of wind is implemented in this project, but with a different idea.

In the prior art, the energy is generated from fixed wind mills. But the wind is not available at all places also the force of the wind is sometimes not adequate and also due to varying direction of wind it becomes difficult for generation. Therefore, we have attempted to use the wind which is created due to the movement of trains, which is available throughout the year, whenever the train moves. In our project a micro wind turbine is used and it is connected to the bogey of the train. One inlet and outlet may also be provided alongside of the turbine for the proper ventilation of air without producing disturbance or difficulty in the rotation of the turbine. The shaft is then connected to a Permanent Magnet Direct Current (PMDC) Generator. Due to the motion of the train, the air flowing in the opposite side of the train will strike on the blade of the turbine which will lead to rotation of the turbine. As it is coupled to the PMDC Generator through the shaft the electric energy will be produced by the rotation of turbine.

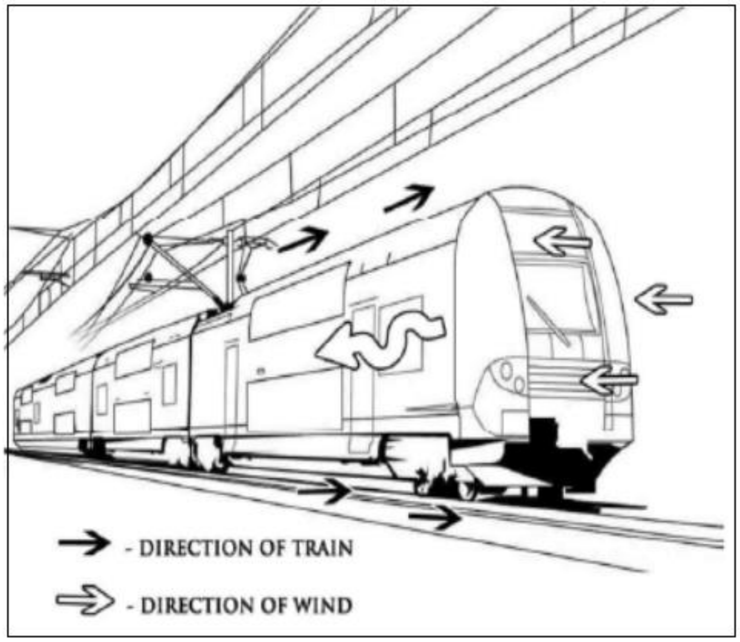

Figure 1.1: Direction of wind on a moving train [5]

1.2 Use of Micro Wind Turbine in the Project

The micro wind turbine, used in the project is placed in such a manner that the turbines will not rotate due to the natural movement of air, which would be in the range of 10-15 km/hr. Instead micro wind turbines will rotate due to the wind currents which are created due to the movement of train. The wind currents which will be created due to motion of train would be directed towards the blades of the turbines. The turbines would rotate as the air strikes the blades. This turbine is further connected to a shaft which is then connected to a PMDC generator where the electricity is generated and can be used to power up the entire electronics components of this project. The micro wind turbine is connected to the bogeys of the train. The turbines would be placed on the outermost surface of the bogeys, taking into consideration the aerodynamics of the bogeys. There will be an opening provided for the air to pass (an inlet) then inside there is a turbine placed in it and the air will come out through an outlet provided. This mechanism of inlet turbine and outlet is provided to keep the balance of train and for free movement of turbine. Also this mechanism will help to protect the turbine from any external damages.

1.3 Objective and scope of the work

The main objective of the work described in this thesis (Part – I) is to throw some lights on electric energy generation from wind with the help of micro wind turbine and PMDC generator, while the train moves in different speeds. The second part is, to store the generated electrical energy safely in a Lithium Polymer (LiPo) battery bank to provide uninterrupted electrical supply to the components of vibration measurement and processing unit of Railway Track Crack Detection System.

The scope of this thesis is restricted to the study and practical demonstration of energy generation from wind and its storage, which is Part – I of the project "Railway Track Crack Detection System".

1.4 Organization of work

A brief introduction to the generation of electrical energy is presented in Chapter1. Chapter 2 deals with typical configurations of dc power generation and storage. Chapter 3 describes hardware set up used for the power generation and storage. Chapter 4 provides experimental set up, calculations and results of the project. The conclusion of the work carried out and its future scope is provided in Chapter 5.

CHAPTER 2

TYPICAL CONFIGURATIONS OF DC POWER GENERATION AND STORAGE

2.1 Introduction

Micro wind turbines work by converting the kinetic energy in the wind first into rotational kinetic energy in the turbine and then electrical energy with the help of a PMDC generator. This generated energy can be store in a battery and further can be supplied to the electronic components of various systems. The energy available for conversion mainly depends on the wind speed and the swept area of the turbine. So before getting into the details of the components used for power generation and storage, a brief on the Physics of wind turbines is inevitable.

2.2 Physics of Wind Turbines

We first show that for all wind turbines, wind power is proportional to wind speed cubed. Wind energy is the kinetic energy of the moving air. The kinetic energy of a mass m with the velocity v is

$$E_{kin} = \frac{1}{2} mv^2$$

The air mass m can be determined from the air density ρ and the air volume V according to

$$m = \rho V$$

Then, the KE due to moving wind is given as

$$E_{kin,\,wind} = \frac{1}{2} V\rho v^2$$

We know, power is energy divided by time. We consider a small time, Δt, in which the air particles travel a distance $s = v\,\Delta t$ to flow through. We multiply the distance with the rotor area of the wind turbine, A, resulting in a volume of

$$\Delta V = A\, v\, \Delta t$$

which drives the wind turbine for the small period of time. Then the wind power is given as [6], [7]

$$P_{wind} = \frac{Ekin,wind}{\Delta t} = \frac{\Delta V\, \rho v^2}{2\, \Delta t} = \frac{\rho A\, v^3}{2}$$

The wind power increases with the cube of the wind speed. In other words: doubling the wind speed gives eight times the wind power. Therefore, the speed of the vehicle is very important for power generation.

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the *Betz Limit* or *Betz' Law*. The effective usable wind power is less than indicated by the above equation. The wind speed behind the wind turbine cannot be zero, since no air could follow. Therefore, only a part of the kinetic energy can be extracted. Consider the following picture:

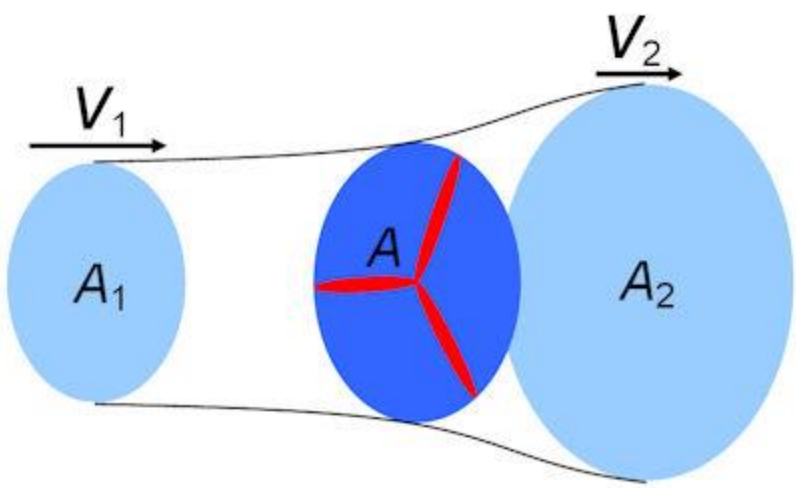

Figure 2.1: Wind flow pattern around turbine blade [6]

The wind speed before the wind turbine is larger than after. Because the mass flow must be continuous, the area A_2 after the wind turbine is bigger than the area A_1 before. The effective power is the difference between the two wind powers:

$$P_{eff} = P_1 - P_2 = \frac{\Delta V\, \rho}{2\, \Delta t}(v_1^2 - v_2^2) = \frac{\rho A}{4}(v_1 + v_2)(v_1^2 - v_2^2)$$

If the difference of both speeds is zero, we have no net efficiency. If the difference is too big, the air flow through the rotor is hindered too much. The power coefficient C_P characterizes the relative drawing power:

$$C_P = P_{eff} / P_{wind} = \frac{(v_1+v_2)(v_1^2-v_2^2)}{2v_1^3} = \frac{(1+x)(1-x^2)}{2}$$

To derive the above equation, the following was assumed: $A_1 v_1 = A_2 v_2 = ½ A (v_1 + v_2)$. We designate the ratio v_2/v_1 on the right side of the equation with x. To find the value of x that gives the maximum value of C_P, we take the derivative with respect to x and set it to zero. This gives a maximum when x = 1/3. Maximum drawing power is then obtained for $v_2 = \frac{v_1}{3}$, and the ideal power coefficient is given by

$$C_P = P_{eff} / P_{wind} = \frac{16}{24} = \mathbf{0.59\ \%}$$

The theoretical maximum power efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the "Power Coefficient" and is defined as:

$$C_{P\ max} = \mathbf{59\ \%}$$

Also, wind turbines cannot operate at this maximum limit. The Cp value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once we incorporate various engineering requirements of a wind turbine - strength and durability in particular - the real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines. Hence, the power coefficient needs to be factored and the maximum extractable power from the wind is given by:

$$P_{avail} = \frac{\rho A v^3}{2} C_P$$

2.3 Energy conversion

The micro wind turbine contains an electrical generator that converts the mechanical energy produced by the rotor blades (the prime mover) into electrical energy or power. This energy conversion is based on Faraday's laws of electromagnetic induction that dynamically induces an e.m.f. (electro-motive force) into the generators coils as it rotates. There are many different configurations for an electrical generator, but one such electrical generator which is been used in this wind power system is the Permanent Magnet DC Generator or PMDC Generator.

Permanent Magnet Direct Current (PMDC) machines can be used as either conventional motors or as DC wind turbine generators as constructionally there is no basic difference between the two. In fact, the same PMDC machine may be driven electrically as a motor to move a mechanical load, or it may be driven mechanically as a simple generator to generate an output voltage. This then makes the permanent magnet DC generator (PMDC generator) ideal for use as a simple micro wind turbine generator.

If we connect a DC machine to a direct current supply, the armature will rotate at a fixed speed determined by the connected supply voltage and its magnetic field strength thereby acting as a “motor” producing torque. If however, we mechanically rotate the armature at a speed higher than its designed motor speed by using rotor blades, then we can effectively convert this DC motor into a DC generator producing a generated emf output that is proportional to its speed of rotation and magnetic field strength.

Generally with conventional DC machines, the field winding is on the stator and the armature winding is on the rotor. This means that they have output coils that rotate with a stationary magnetic field that produces the required magnetic flux. Electrical power is taken directly from the armature via carbon brushes with the magnetic field, which controls the power, being supplied by the permanent magnets.

The rotating armature coils pass through this stationary or static magnetic field which in turn generates an electrical current in the coils. In a permanent magnet DC generator, the armature rotates, so the generated current must pass through a commutator or split-rings and carbon brushes arrangement providing electrical power at its output terminals as shown above.

2.4 Battery Management System (BMS)

BMS HX-3S-A01 is a three series of lithium battery protection board. It automatically cancels protection after protection conditions restore. Its main functions are overcharge protection, over discharge protection, short circuit protection and over-current protection for a variety of 3.7V lithium batteries. HX-3S-A01 is suitable for lithium battery pack of 11.1V, 12V and 12.6V. This BMS module consumes very less power as its quiescent current is less than 30uA. Also HX-3S-A01 is small in size, suitable for many requirements of high integration, low cost and also to meet a wide range of performance requirements to ensure that the battery pack is absolutely safe and reliable.

In BMS HX-3S-A01 (also called Lithium Battery Charger Board Protection Module), 3S stands for 3 cells of lithium polymer batteries in series combination. With this module, 11.1 V lithium polymer batteries can be charged safely and efficiently to a maximum of 12.6V.

BMS HX-3S-A01 will help to charge LiPo battery by using the constant current / constant voltage charging method (cc/cv). Here a constant current is applied to the battery during the first part of the charge cycle. As the battery voltage closes in on the 100% charge voltage, the BMS HX-3S-A01 will automatically start reducing the charge current and then apply a constant voltage for the remaining phase of the charge cycle.

2.5 Lithium Polymer Battery Pack

A lithium polymer battery, or more correctly lithium-ion polymer battery (abbreviated as LiPo), is a rechargeable battery of lithium-ion technology using a polymer electrolyte instead of a liquid electrolyte. High conductivity semisolid (gel) polymers form this electrolyte. These batteries provide higher specific energy than other lithium battery types and are used in applications where weight is a critical feature, like mobile devices and radio-controlled aircraft.

2.6 Design origin and terminology

Lithium polymer cells have evolved from lithium-ion and lithium-metal batteries. The primary difference is that instead of using a liquid lithium-salt electrolyte held in an organic solvent, the battery uses a solid polymer electrolyte

A typical cell has four main components: positive electrode, negative electrode, separator and electrolyte. The separator itself may be a polymer, such as a microporous film of polyethylene (PE) or polypropylene (PP); thus, even when the cell has a liquid electrolyte, it will still contain a "polymer" component. In addition to this, the positive electrode can be further divided into three parts: the lithium-transition-metal-oxide, a conductive additive, and a polymer binder of poly. The negative electrode material may have the same three parts, only with carbon replacing the lithium-metal-oxide.

2.7 Working principle

Just as with other lithium-ion cells, LiPos work on the principle of intercalation and de-intercalation of lithium ions from a positive electrode material and a negative electrode material, with the liquid electrolyte providing a conductive medium. To prevent the electrodes from touching each other directly, a microporous separator is in between which allows only the ions and not the electrode particles to migrate from one side to the other.

This project uses a LiPo battery for storage of energy, even though it is costly and less life span (500 charge cycles), because of the following reasons

(a) LiPo batteries are light weight and can be made in almost any shape and size.

(b) LiPo batteries have large capacities, meaning they hold lots of energy in a small package (high energy density).

(c) LiPo's are very good at maintaining a consistent voltage/power output as they discharge.

(d) LiPo batteries have high discharge rates to power the most demanding loads. LiPo does also allow for fairly high charge rates so recharging in an hour or less is possible.

(e) Since the cells uses flexible *pouch cell* package, they can be considered as safe to some extend in case of any thermal expansion and gassing due to electrolyte decomposition.

(f) Unlike NiCad or NiMh; LiPo's have no "memory-effect".

2.8 LiPo Battery Construction

Figure 2.2: LiPo Battery Plastic Pouch Cell and Soft Cased LiPo Battery [4]

Almost every LiPo battery cell is packaged in a flexible plastic pouch coincidentally called a "pouch cell". The picture shows both a single pouch cell, along with three of the cells combined to create a typical 3 cell (3S) LiPo battery pack.

Pouch cells are the perfect solution for building multi-celled battery packs because the flat pouch cell can be stacked with no wasted air spaces like found within round celled battery packs. Since LiPo’s use this light weight plastic pouch instead of a metal can, less weight is the result making pouch celled LiPo’s the preferred choice in weight conscious radio controlled aircraft applications. These LiPo pouch cells also allow for more thermal expansion and even gassing (electrolyte decomposition) due to the flexible pouch over a metal can that most Li-Ion cells are encapsulated. So, they can also been considered as a safety feature to some extent.

As shown in the below soft cased LiPo, the cells are simply encased in a light weight shrink wrap to create the battery pack. There may or may not be a thin, light weight layer of foam protection also wrapped around the pack before the shrink wrap is applied. Both power and balance wiring is soldered direct to the cells within the pack further reducing weight and avoid more failure prone connection points.

As shown with the above soft cased LiPo, the cells are simply encased in a light weight shrink wrap to create the battery pack. There may or may not be a thin, light weight layer of foam protection also wrapped around the pack before the shrink wrap is applied. Both power and balance wiring is soldered direct to the cells within the pack further reducing weight and avoid more failure prone connection points.

The main advantage to a soft case is obvious - less weight and a smaller form factor as there is no bulky case around the cells. The other advantage with soft cased LiPo batteries is, you can see when they are puffed. Hard cased packs on the other hand can have puffed cells totally hidden within the case, but the hard case will usually burst when the puffing gets bad enough. LiPo cells enclosed in thin heat shrink also have moderately better heat dissipation over ones that are enclosed in a hard case.

So, for this project, soft cased LiPo battery packs are used for those primary advantageous reasons.

2.9 LiPo Battery Ratings

The important ratings that we have to consider for the Li-Po battery are given below:

(a) Voltage

(b) Capacity

(c) Charge Rate

(d) Discharge Rate

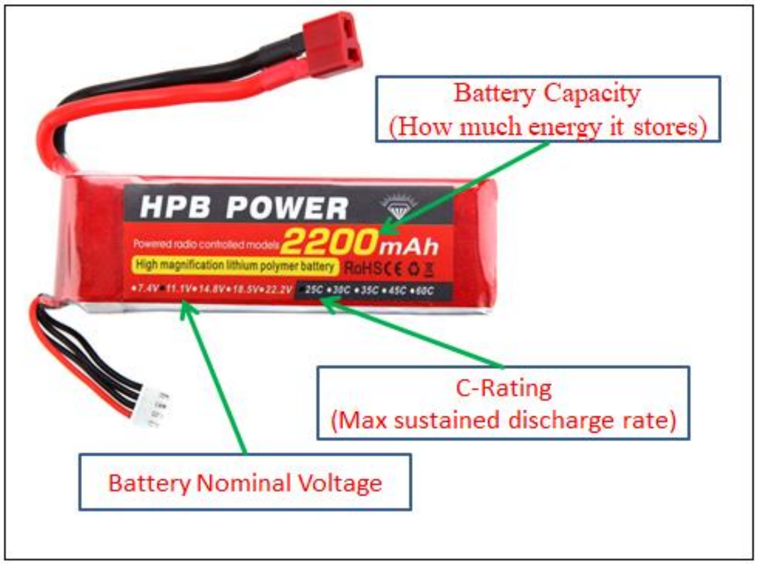

Figure 2.3: LiPo battery ratings

(a) **Nominal Voltage**

Unlike conventional NiCad or NiMH battery cells that have a nominal voltage of 1.2 volts per cell, LiPo battery cells have a nominal voltage of 3.7 volts per cell. The benefit here is fewer cells can be used to make up a battery pack and in some cases on smaller micro sized radio controlled aircraft like most toy helicopters, a single 3.7 volt LiPo cell is all that is needed to power the motor and electronics.

Here, the nominal voltage is usually referred to as the "resting voltage" of the battery cell or battery pack. There are exceptions of course in this determination. Nominal resting voltage is an industry standard (agreed convention) that varies for all battery chemistry types; but for our LiPo chemistry, the usual nominal voltage standard given is 3.7 volts per cell. That voltage however is not the fully charged voltage of the cell (which is as high as 4.2V), nor is it the 50% storage voltage (3.85V), or even the 80% discharged state resting voltage (apx. 3.75V).

Generally, LiPo battery packs will have at least two or more cells hooked up in series to provide higher voltages. Here is a list of LiPo battery pack "nominal" voltages with cell counts.

Sl No	Cell Voltage (Volts)	No. of Cells (in series)	Nominal Voltage (Volts)	Fully Charged Voltage (Volts)
1	3.7	1	3.7	4.2
2	3.7	2	7.4	8.4
3	**3.7**	**3**	**11.1**	**12.6**
4	3.7	4	14.8	16.8
5	3.7	5	18.5	21.0
6	3.7	6	22.2	25.2
7	3.7	8	29.6	33.6
8	3.7	10	37.0	42.0
9	3.7	12	44.4	50.4
10	3.7	14	51.8	58.8

Table 2.1: Voltage Details of LiPo Battery [4]

(b) **Capacity**

Capacity indicates how much power/energy the battery pack can hold and is indicated in milliamp hours (mAh). This is just the standard way of saying how much load or drain (measured in milliamps) you can put on your battery for 1 hour at which time the battery will be fully discharged.

For example an LiPo battery that is rated at 2200 mAh would be completely discharged in one hour with a 2200 milliamp (or 2.2 Amp) load placed on it. If this same battery had 1100 milliamp load placed on it, it would take 2 hours to drain down and so on. If more endurance required, then increase the capacity of your battery pack.

It is to be noted that, as the discharge rate increases, the capacity of a battery actually becomes less than stated due to efficiency losses.

Figure 2.4: LiPo Battery Capacity-Cell Size Comparison [4]

(c) **Maximum Charge Rate**

This is the highest charge current rating the manufacturer states the battery can be charged at safely. A 35C charge rate would mean that you can safely charge that battery at 35 times its capacity. With that 2200 mAh pack, the calculation is 35 x 2200 mA = 77,000 mA or 77 Amps.

Please note however, charging at maximum rates will shorten battery life. This is a safe maximum number, not a best for maximum life number in other words. Lower charge rates are always better for increasing LiPo battery life.

(d) **Discharge Rate**

This one is probably the single most over rated & misunderstood of all battery ratings. Discharge rate is simply how fast a battery can be discharged safely while remaining healthy. A battery with a discharge rating of 10C would mean you could safely discharge it at a rate 10 times more than the capacity of the pack, a 15C pack = 15 times more, a 20C pack = 20 times more, and so on.

Here, a 2200 mAh battery is used with discharge rating as 35C, that would mean you could pull a maximum sustained load up to 77,000 milliamps or 77 amps off that battery (35 x 2200 milliamps = 77,000 milliamps or 77 amps).

From a purely theoretical time stand point, this equals 1283 mAh of draw per minute so the 2200 mAh pack would be completely exhausted in about 1.42 minutes (102 sec) if it's exposed to the maximum rated 35C discharge rate the entire time.

Calculation as follows: 77,000 mA divided by 60 minutes = 1283 mAh which is then divided into the 2200 mAh capacity of the pack giving us 1.42 minutes (102 sec).

2.10 LiPo Battery Charging Techniques

LiPo, batteries obviously have some very different characteristics from conventional rechargeable battery types. Therefore, charging them correctly with a charger (or with a battery protection module or BMS) specifically designed for lithium chemistry batteries is critical to both the lifespan of the battery pack, and your safety.

(a) Maximum Charging Voltage

A 3.7 volt LiPo battery cell is 100% charged when it reaches 4.2 volts. Charging it past that will shorten life substantially. In fact, the cell phone industry did a study looking at the effect of LiPo fully charged voltages in relation to cycle life. These tests were done under ideal laboratory conditions, naturally at lower phone load discharge rates, and of course the 80% depth of discharge rule was obeyed. Here are the results:

- Charge to 4.1V gave over 2000 cycles.
- Charge to 4.2V gave about 500 cycles.
- Charge to 4.3V gave under 100 cycles.
- Charge to 4.4V gave less than 5 cycles.

If you set your maximum charge voltage to 4.15 volts per cell (if your computerized charge gives you that option), you should definitely be able to get more life out of your packs (if LiPo usage rules are religiously obeyed). There are a few manufacturers that are producing LiPo cells that can handle as high as 4.35 volts and maintain a 500 cycle life is possible.

The charger will stop charging when the 100% charge voltage of the battery pack equalizes with chargers constant voltage setting (4.2 volts per cell) at this time, the charge cycle is completed. Going past that to 4.3 volts will shorten battery life substantially as we have already seen.

(b) Maximum Charging Current

Selecting the correct charge current is also critical when charging LiPo battery packs. The golden rule here remains to be "never charge a LiPo, LiIon, or LiFe pack greater than 1 times its capacity (1C)."

For example (in our case) a 2200 mAh pack, would be charged at a maximum charge current of 2200 mA or 2.2 Amps. Going higher will shorten the life of the pack. Moreover, if you choose a charge rate significantly higher than the 1C value, the battery will heat up and could puff up.

Most LiPo experts say you can safely charge at a 2C or even 3C rate on quality packs that have a discharge rating of at least 20C or more and have low internal resistances safely, but it will reduce LiPo life. Even though there are more and more LiPo packs showing up stating 2C, 3C, 4C and even 5C charge rates; this is just indicating it's still safe to charge at those rates and not risk thermal runaway within the battery; but it really has nothing to do with actual battery life. The simple fact is constantly charging any LiPo over 1C will have an impact on its life expectancy. It is also strongly recommend that never carry out charging over 1C if the ambient air temperature (and the pack) is over 30C (about 90F).

(c) Charging Technique

All LiPo battery chargers will use the constant current / constant voltage charging method (cc/cv). All this means is that a constant current is applied to the battery during the first part of the charge cycle. As the battery voltage closes in on the 100% charge voltage, the charger will automatically start reducing the charge current and then apply a constant voltage for the remaining phase of the charge cycle. The following figure gives a typical charge graph (Cell Capacity - 850mAh, CC/CV Charge at 4.2V, 1C +25ºC).

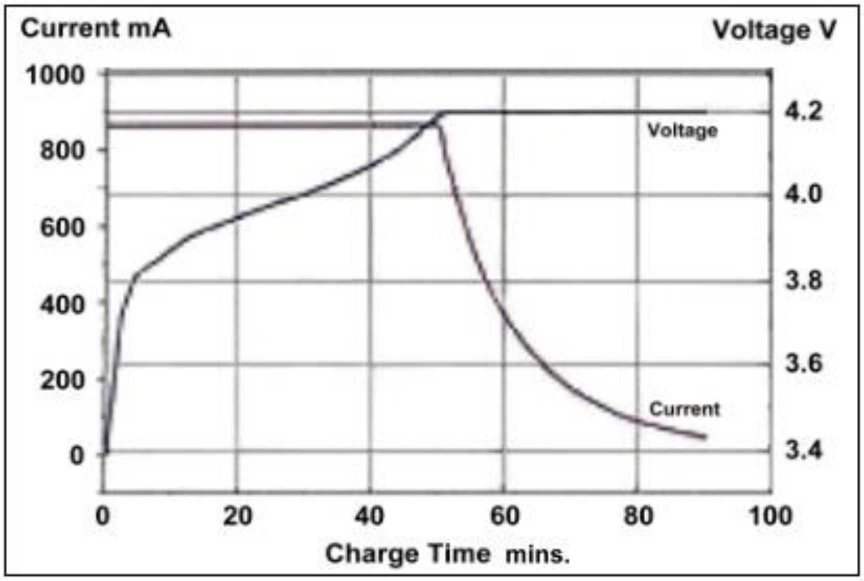

Figure 2.5: Charging current/ voltage vs time graph [8]

2.11 LiPo Battery Balancing

This session will give a brief idea on battery balancing and why it is important while charging.

We know, the 100% charged cell will have a voltage value of 4.2 volts. If it is a single cell (3.7 volt LiPo battery), balancing is not required since the battery charger will automatically stop charging when the 100% charge voltage of 4.2 volts is reached.

Balancing is required however on any LiPo battery pack that has more than one cell since the charger can't identify from different cells and know if one might be overcharged even though the total voltage of the pack indicates otherwise.

Balancing simply ensures multi celled LiPo batteries have the cells in the pack within about 0.02 volts (20 millivolts) of each other, so over charging or discharging of one or more cells won't ruin your battery pack, or become a safety concern with a large voltage difference between cells.

By using the BMS module, these numbers constantly "dance" around during the charge cycle and always trying to maintain as little delta voltage difference between them all as possible.

CHAPTER 3

HARDWARE DETAILS AND SPECIFICATIONS

3.1 Micro Wind Turbine and PMDC Generator

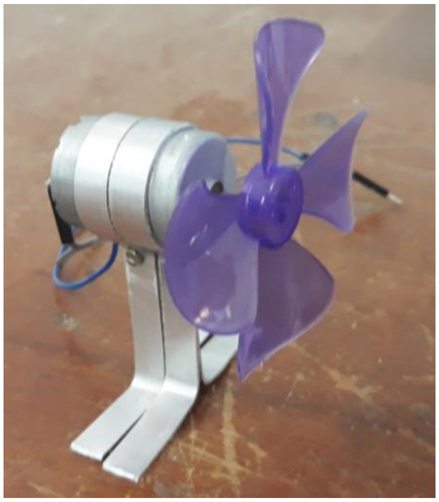

Figure 3.1: Micro wind turbine and PMDC generator

Here the specification of PMDC Generator (RC 370-FT/11670/DV) and the micro propeller used are given below

Place of origin	Guangdong, China
Brand name	RC 370-FT/11670/DV
Type	Tubular Motor
Torque	<50g.cm
Commutation	Brush (Carbon/ Metal)
Construction	Permanent Magnet
Protect feature	Totally Enclosed
Continuous current(a)	<0.3A
Voltage	5V-32V DC
Material	RoHS material
Length	50 mm
Diameter	24 mm
Operating Temp	-40 to +50℃

Table 3.1: Specification of PMDC Generator

Parameters	Dimensions (in mm)
Hub diameter	16.7
Hub thickness	6
Blade length	26.1
Blade root chord	9.6
Blade tip chord	30.3
Blade thickness	1
Blade angle	14.5°
Micro propeller diameter	68.5
Micro propeller material	Plastic
No of blades	4

Table 3.2: Specification of micro propeller

3.2 Battery Management System (HX-3S-01)

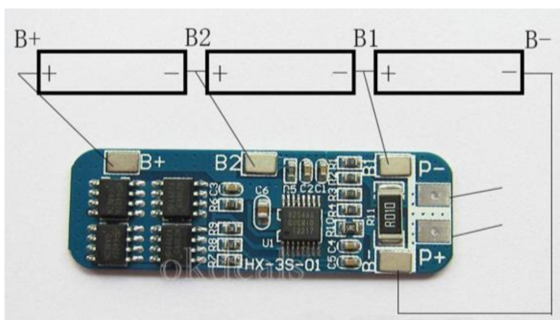

Figure 3.2: Rechargeable battery and BMS connection diagram.

In this project, HX-3S-01 is used as the Battery Management System and the specification is given below:-

Size	50 x 15 x 3 mm.
Over discharge voltage range	2.3-3.0 v ± 0.05
Recharge voltage range	4.25-4.35 v ± 0.05 v
Operating temperature	-40 to + 50 ℃
Current limit	10-13A
Storage condition	-40- + 80 ℃
Resting current	less than 30uA
Effective lifetime	over 30,000 hours
Internal resistance	less than 100mΩ
Charging Voltage	12.6 V-13 V

Table 3.3: Specification of BMS module

3.3 Rechargeable Lithium Polymer battery (2200 mAh)

Here the rechargeable battery used is Lithium Polymer battery and the specification is given below:-

Battery capacity	2200 mAh
The discharge rate	35C
Max charging rate	5C
Battery section	3S (11.1V)
Dimension	108.5 × 35 × 23.2mm
Weight	Approx.176g
Charge Plug	JST-XH
Discharge Plug	T

Table 3.4: Specification of LiPo Battery

3.4 Watt's up Meter

Figure 3.3: Watt's up Meter

"Watt's Up" meter measures DC (direct current) current, voltage and time and from those measurements, calculates peak current (Amps), peak power (Watts), minimum voltage (Volts), power (Watts), energy (Watt-hours) and charge (Amp-hours) values, in real time, for the circuit in which it is connected. This device was used in this project only in lab experiment set up to take various readings easily. [9]

Parameter	Range	Resolution
Voltage	0 - 60 V	0.01 V
Current	0 – 100 A peak	0.01 A
Power	0 - 6554 W	0.1 W
Charge	0 - 65 Ah	0.001 Ah
Energy	0 - 6554 Wh	0.1 Wh

Table 3.5: Electrical Measurements Ranges

CHAPTER 4

EXPERIMENTAL SETUP AND RESULTS

4.1 Introduction

In order to demonstrate the practical generation of electrical energy from the micro wind turbine and the storage of the energy to a rechargeable battery, the following set up (**Figure 4.1**) was made in the lab. The watt's up meter shows the instantaneous values (such as voltage, current, power, energy etc.) produced by the micro wind turbine.

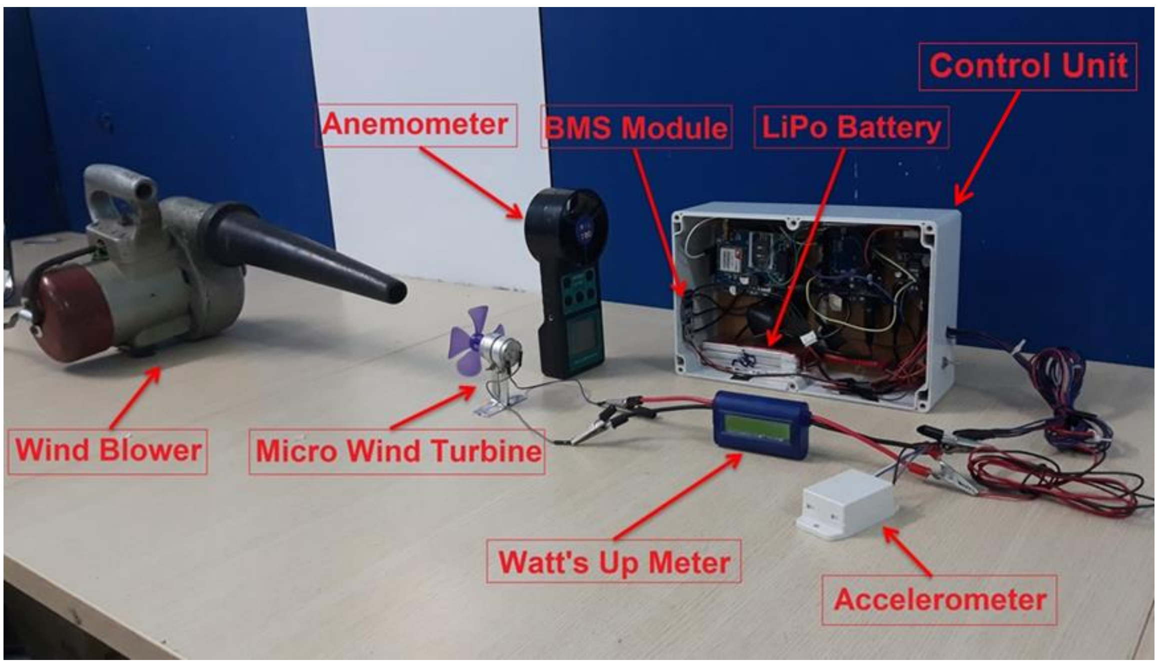

Figure 4.1: Complete Lab Experiment Set-up

Figure 4.2: Wind speed measurement setup using anemometer

The anemometer is used to measure the velocity of the wind, coming out from the wind blower. The required velocity can be obtained by adjusting the distance between the anemometer and the wind blower.

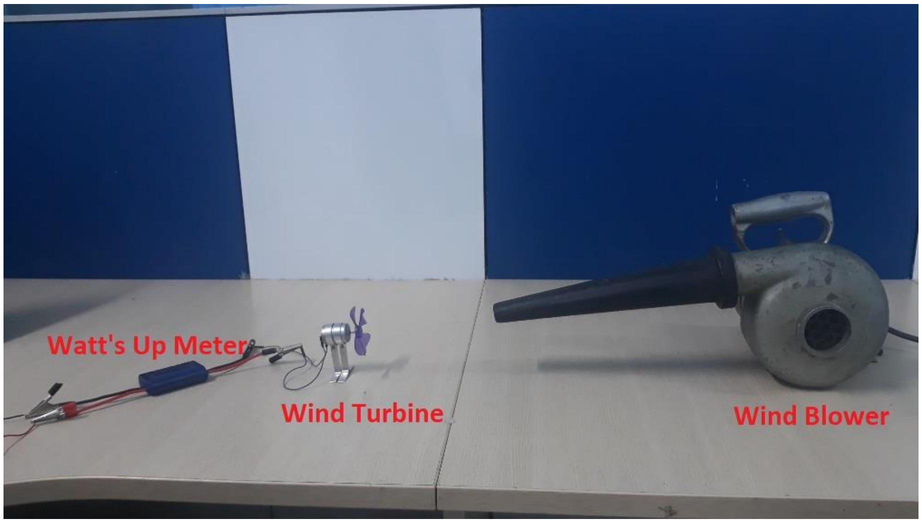

Figure 4.3: Energy generation using micro wind turbine and wind blower

The wind energy was made to fall on the micro wind turbine at various speeds by adjusting the distance between the micro wind turbine and wind blower. The reading was noted down with the help of watt's up meter and the following results were obtained.

Speed (km/hr)	Output Voltage, V_o (Volt)
30	14.2
40	17.6
50	21.6
60	25.7
70	28.1
80	29.8
90	30.1

Table 4.1: Output Voltage at different speed

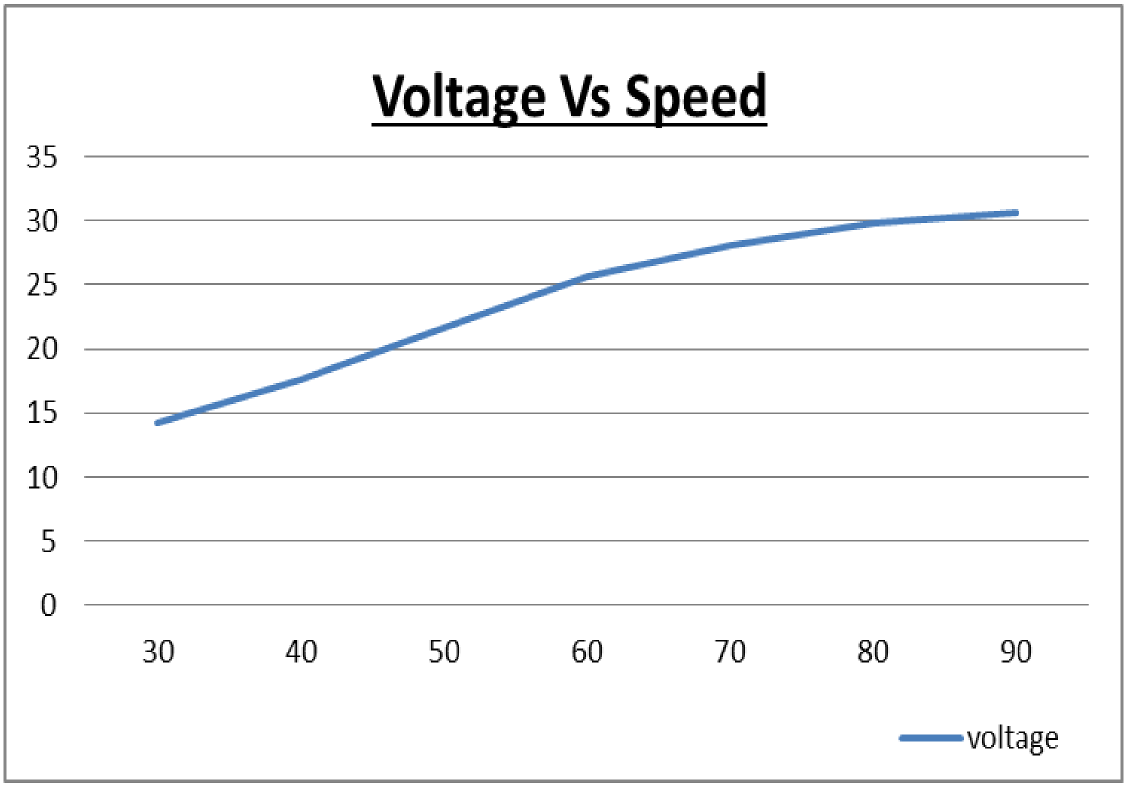

Figure 4.4: Output Voltage Vs Speed Graph

4.2 Outdoor Test Set up

The entire setup was installed on a two wheeler and voltages have been taken for various speeds. The installation set up is shown below.

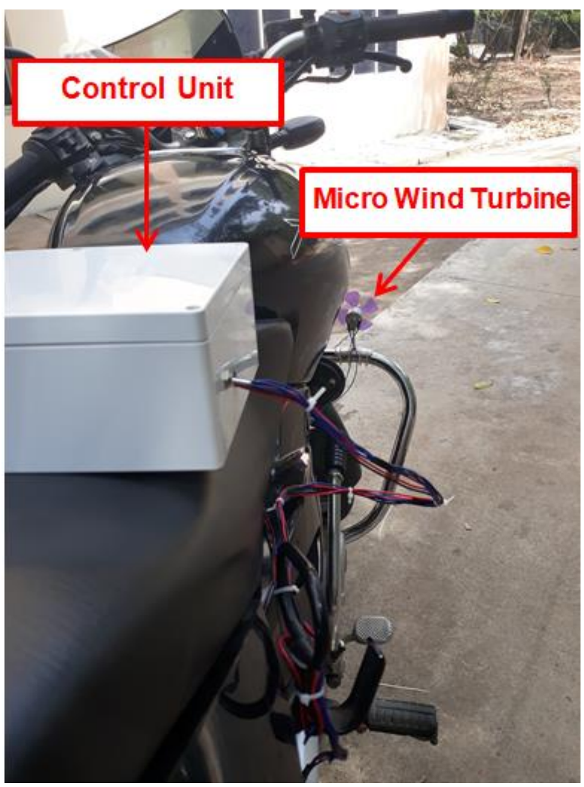

Figure 4.5: Outdoor test setup

4.3 Power Requirements

The table below will give a brief idea on the electronic components and its power ratings, which have been powered up by the rechargeable battery.

No	Item	Voltage	Current (Sleep mode)	Current (Active mode)	Current (Txn mode)	Power (Sleep Mode)	Power (Active Mode)	Power (Txn mode)
1	GPS Module SIM28	4.3V	150 µA	17mA	17mA	0.645mW	73.1mW	73.1mW
2	GSM Module SIM900A	12V	1.5 mA	500mA	2000mA	18MmW	6000mW	24000mW
3	Accelerometer ADXL 335	3.6V	350 µA	350 µA	350 µA	1.26mW	1.26mW	1.26mW
4	Arduino UNO R3	12V	23 µA	500mA	500mA	0.276mW	6000mW	6000mW
5	Blue tooth Module HC-05	3.3V	50mA	50mA	50mA	165mW	165mW	165mW
TOTAL			52.23 mA	1067.35mA	2567.35mA	185.2mW	12.24W	30.24W

Table 4.2: Power ratings of electronic components used

4.4 Rechargeable Battery Back-up Time Calculation

Capacity of the LiPo battery = **2200 mAh**

Endurance of battery in sleep mode = 2200mAh/52.23mA = 42.12

= **42 hrs 7.2 mins**

Total current consumption during normal working mode = 17mA + 1.5mA + 350 µA

+ 500mA + 50mA

= **568.85 mA**

(**NOTE**: The GSM Module will be in active mode, only when it sends SMS)

Endurance of battery in normal working mode = 2200mAh/568.85mA

= 3.87 =232.2 mins

= **3 hrs 52.2 mins**

By taking the average speed of the train as 80km/hr, the current produced be the PMDC generator is 250mA at 25.3 V

Then the time taken to charge the battery = 2200mAh / 250mA

= **8 hrs 48 mins**

In this project, only one unit of micro wind turbine is used. If multiple micro wind turbines are used, the charging time can be reduced drastically.

4.5 Charge Rate and Discharge Rate Calculation

This session will give a brief on, at what C rate the rechargeable battery is charged and discharged. For finding charge rate, the output current from the PMDC generator and the capacity of the rechargeable battery are to be known.

Here, the output current form the PMDC generator is 250 mA (at an average speed of 80km/hr) and the capacity is 2200 mAh. Therefore the charge rate will be 0.11 C (250mA / 2200 mAh).

Likewise the discharge rate can also be calculated. The discharge current is 568.85 mA (refer chapter 4.4) and the rechargeable battery capacity is 2200 mAh. Therefore the discharge rate will be 0.26 C (568.85 mA / 2200 mAh).

4.6 Efficiency of Micro Wind Turbine

Air density, ρ = 1.225 kg/m^3

Velocity, v = 25 m/s (90km/hr)

Area of turbine, A = 0.004 m^2 (radius = 3.43 cms)

The wind power is given as:-

$$P_{wind} = \frac{E_{kin,wind}}{\Delta t} = \frac{\Delta V \rho v^2}{2 \Delta t} = \frac{\rho A v^3}{2}$$

P (wind) = **38.28 watts**

The available power from the wind is given as:-

$$P_{avail} = \frac{\rho A v^3}{2} C_P$$

$P_{avail} = P_{wind} \times Cp$

= 38.28 × 0.59

= **22.59 watts**

At a train speed of 90km/hr, PMDC generator will produce a current of 300mA at 30.7V. So the power from the PMDC is 9.21 W.

Therefore the maximum efficiency is given as (9.21 / 22.59) × 100 = **40.77%**

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

With the use of micro wind turbine, the kinetic energy of the wind was converted into electrical energy. The next step was to store this generated energy to a rechargeable battery so that this stored energy can be utilised to deliver power supply to various load. For storing energy safely and efficiently to the rechargeable battery, a battery management system was placed in between the micro wind turbine and rechargeable battery. As the wind speeds are getting high, the generator produces high voltages correspondingly. The battery management system senses the state of charge of rechargeable battery and required amount of current is supplied to the rechargeable battery to take the rechargeable battery to a fully charged state within the optimum time period and without compromising the safety.

5.2 Future Scope

. The future scope is to use multiple micro wind turbines, connected in parallel to generate more current so that there will be a considerable decrease in battery charging period. Also by using high capacity rechargeable battery with higher charging rate will also enhance the back-up time of the rechargeable battery.

REFERENCE

[1] James F. Manwell, Jon G. McGowan, A L Rogers, *Wind Energy Explained: Theory, Design and Application*, Wiley-Blackwell; 2nd edition

[2] Permanent magnet DC generator, Alternative Energy Tutorials *http://www.alternative-energy-tutorials.com/energy-articles/dc-generator-design.html*

[3] *Designing Electric Vehicle Battery Management System*. Class notes by Nikhilesh Mishra, Project Advisor (Centre of Battery Engineering).

[4] All about LiPo batteries *https://www.rchelicopterfun.com/lipo-batteries.html*

[5] Production of electricity by fast moving vehicles (especially trains) *http://www.iraj.in/journal/journal_file/journal_pdf/1-312-148316256239-41.pdf*

[6] Energy fundamentals *https://home.uni-leipzig.de/energy/ef/15.htm*

[7] Wind Turbine Power Calculations *https://www.raeng.org.uk/publications/other/23-wind-turbine*

[8] Typical Lithium Ion Polymer Technical Data *http://www.ibt-power.com/Battery_packs/Li_Polymer/Lithium_polymer_tech.html*

[9] Watts Up & Doc Wattson Watt Meter User's Manual *https://www.rc-electronics-usa.com/watt-meter/watts-up-dc-watt-meter-amp-meter-user-manual.pdf*

VITAE

Name	:	Ratheeh TS
Date of Birth	:	03 May 1985
Educational Qualification	:	B Tech (Instrumentation and Control Engg:)
		Calicut University
		PG Diploma in Aeronautical Engg.
Occupation	:	Aeronautical Engg. In IAF (Defence)
Contact Address	:	“Sreechithira”, Thuruthissery
		Mekkad PO, Aluva, Ernakulam Dist
		Kerala - 683589
Phone	:	78728 72868 / 90807 66889
E-mail	:	ts.ratheesh@gmail.com