Design and Development of A Model of Wasted Energy Harvesting from Vibration and Backlash Wind as a Source

Chapter 1

1.1 INTRODUCTION:

Today every country draws its energy needs from a variety of sources. These sources can be categorized as conventional and non-conventional source of energy. The conventional sources are Fossil Fuel Energy, Hydraulic Energy and Nuclear Energy. Out of these, the fossil fuels are used to generate energy in more than 85% of all energy sources. Hydraulic Energy system has got a high setup cost, while Nuclear Energy involves a high risk. On the other hand, there has been a rapid and massive depletion and exhaustion of fossil fuels globally, for last few decades. Currently, there is hardly a stock of around 100 years of fossil fuel at the present rate of turnover *(International Energy Annual 2006)*[1].There are a number of wars, massive economic and political instability on gaining control over the fossil fuel reserve in the world.

Another important aspect in the area of energy conservation is prevention and utilization of wastage of energy drawn from various conventional and non conventional sources. During execution of the activity of various machines, a part of energy is lost due to friction and vibration and dissipated as unused heat. Systems have been developed to reduce these energy losses; however it cannot be completely prevented.

These byproducts of machine operations can be suitably used to generate power.

Energy harvesting stands for recovering energy wasted in a process and to store and reuse that energy in another process.

In the present project, we intend to utilize the vibration and wind backlash generated during locomotives operation as a means of energy harvest and to use them as a source to carry out other purposeful activities. We have aimed to develop an alternate source of energy instrument. The source is fed with the unused energy produced due to locomotive movements such as noise, heat, backlash wind and vibrations and produces a controlled electric power.

1.2 OBJECTIVES:

The objective of this project can be divided in two parts as listed below,

— To derive the generalized equation for electromagnetic induction generator using vibration as a source and small scale wind turbine generator uses backlash wind of a locomotive as a source.

—To design an induction generator and small scale wind turbine such that they can be used as a voltage source with good power rating.

1.3 MOTIVATION OF THE PRESENT PROJECT:

Among various forms and types of non conventional energy system, the entities which reasonably attracted maximum attention to the academia and the industry are solar energy, wind energy, tidal energy, biomass fuel system etc. However, relatively lesser emphasis has been poised on the form of energy harvesting utilizing mechanical vibration and backlash wind produced during operation of the machines; as a source.

In view of the potential role of vibration and backlash wind produced in a moving automobile or a locomotive in generating power, which can be appropriately stored and used; it will be highly prudent to explore this area of non-conventional energy sources.

1.4 LITERATURE REVIEW AND PRESENT STATE OF KNOWLEDGE:

1.4.1 Vibration power generator

The field of energy harvesting has become increasingly important in recent years. There are numerous situations when 'lost energy' (e.g. kinetic energy, present in the form of vibrations, random displacements or force) converted into 'usable energy' (e.g. electrical energy) could be used to power devices with requirements ranging from large to small-scale power generators.

The main transduction mechanisms used to extract energy from the system and to implement a vibration power generator are: electromagnetic, piezoelectric, magnetostrictive and electrostatic.

The electromagnetic mechanism employs electromagnetic induction arising from the relative motion of the magnetic flux gradient and a conductor (the Faraday's law). According to the fundamentals of electromagnetism, it is known that the electromotive force induced in a circuit is linked to the product of the flux linkage gradient and the velocity. The flux linkage gradient is dependent on the magnets used to produce the field, the arrangement of these magnets and the area and number of turns for the coil. The majority of recent developments of devices using electromagnetic energy conversion is focused on generators with microwatt or milliwatt power levels of vibration frequency of the order of hundreds of hertz and amplitudes of the order of micrometer. These generators are used first of all in applications for wireless monitoring and automation.

In the last decade many articles have been published on the topic of generators using electromagnetic, piezoelectric, magnetostrictive and electrostatic energy conversion mechanisms. For example, El-Hami *et al* (2001) [2] showed the electromechanical power generator was capable of generating energy of about of 0.5 mW for a vibration amplitude of tens of micrometer and a frequency of hundreds of hertz. (Beeby *et al* 2005) [3,4] reported the design, fabrication and performance testing of a micro-machined generator. Glynne-Jones *et al* (2004) [5] demonstrated that the micro-generator used in car engine compartments was capable of producing a 100 μW level of power. Waters *et al* (2008) [6] showed the design and applicability of a generator to a MEMS-scale device. Anton and Sodano (2007) [7] discussed the research works in the area of power harvesting with piezoelectric materials and goals which had to be achieved so that self-powered devices could be used on an everyday basis. Roundy and Wright (2004) [8] described the modeling and design of a piezoelectric vibration-to-electricity converter to be used as a power source for wireless electronics.

Priya (2007) [9,10] presented comprehensive coverage of the recent developments in the area of piezoelectric energy harvesting using low profile transducers and the results for various energy harvesting prototype devices. Wang and Yuan (2007, 2008) [11] reported the design, development and testing of a micro-vibration generator based on a magnetostrictive material (Metglas 2605SC) used in building practical energy harvesting wireless sensor networks. Roundy *et al* (2002) presented the electrostatic generator fabricated and tested using silicon MEMS technology as a power source for wireless sensor nodes. Despesse *et al* (2005) [12] described an electrostatic micro-device with high electrical damping designed for vibration energy harvesting to operate over a wide frequency range <100 Hz. Lee *et al* (2009) [13] compared the capabilities of different electrostatic mechanisms for energy harvesting and discussed the relations among the contributing parameters involved in maximizing the energy output that can be harvested from an electrostatic MEMS device.

A comprehensive review of the state-of-the-art in vibration energy harvesting for wireless, self-powered systems is presented by Beeby *et al* (2006)[3,4]. Their article describes energy harvesting systems based upon electromagnetic, piezoelectric and electrostatic technologies, and provides the main characteristics for generators using these technologies. An excellent overview of fundamentals, current developments and prominent applications in the field of energy harvesting is provided by Priya and Inman (2009)[9,10]. This book presents the current state of knowledge and achievements of leading researchers both in academia and industry.

Alongside a growing number of publications on energy harvesting strategies, several new applications have been designed. There are also industries which specialize in the research, development, manufacturing and assembly of converting 'lost energy' into 'usable energy' and work with unique power solutions which employ electromagnetic or piezoelectric transduction mechanisms to generate electrical energy from motion. The electromagnetic mechanism of electrical power generation has been used in generators for many years.

The electromagnetic generators used today for large-scale applications are based on rotations, while for applications with microwatt or milliwatt levels of power they use both rotational and linear devices.

Several articles have been published about electromagnetic power generators and the MR damper. Cho *et al* (2005) [4]described a conceptual design of the electromagnetic generator in self-powered MR damper based vibration reduction systems and proposed its application for large-scale civil structures.

Also Cho *et al* (2007) [14] demonstrated the structure of the electromagnetic generator to be used with the MR damper and some test results. Choi *et al* (2009)[15] reported a similar concept of the generator for the electro rheological (ER) damper in a vibration control system of a vehicle suspension. In this system the ER damper was completed with a rack and pinion mechanism converting a linear motion into rotary motion.

However, not many reports are being published regarding vibration power generator in automobile and locomotives.

1.4.2**Wind turbine power generator:**

Wind power has been harnessed as a source of power around the world for a long time.

Wind is air in motion, caused by the uneven heating of the Earth by the sun. Wind occurs when warm air rises, and cooler air moves in to fill the space. It is estimated that 2% of the solar energy reaching the earth is converted into wind energy. Air is constantly being interchanged between the warm tropics and the cold polar caps. The rotation of the Earth also produces wind.

The sun radiates the most heat over the equator and therefore the air there is warmer. Air from both hemispheres is constantly moving toward the equator. The rotation of the Earth causes the cool winds to be deflected from east to west. As the surface of the earth heats and cools unevenly, pressure zones are created that make air move from high pressure to low pressure areas.

Wind energy: The process by which the kinetic energy of wind is used to generate mechanical power or electrical energy is known as wind power or wind energy. Kinetic means being related to or produced by motion such as the blowing wind.

A windmill converts the force of the wind into turning force acting on the rotor blades. The strength of this turning force is known as torque.

History of Wind Power: Wind has been used for centuries to propel ships and the wind routes were well known and used by explorers such as Magellan and Columbus. Wind power was used as a source of mechanical energy on land for thousands of years. The Babylonians constructed windmills for irrigation as early as 1700 BC and Europeans were using windmills by 1000 AD.

Wind speed and energy: The amount of energy that can be captured from the wind is exponentially proportional to the speed of the wind. If a windmill were perfectly efficient, the power generated is approximately equal to:

P (watts) = 1/2 D (air density) x A (area of rotor) x V cube (wind velocity)

Therefore, if wind speed is doubled, the power in the wind increases by a factor of eight, i.e. 2 x 2 x 2. In reality, because wind turbines are not perfectly efficient, changes in wind velocity do not have such a dramatic effect on wind power.

Wind Turbine Rotor Design: There has been a great deal of research on rotor design including whether the turbine will be upwind (rotor facing the wind) or downwind (rotor on the lee side), the number, size and shape of blades, the load (forces acting on the rotor) and other rotor aerodynamic considerations. Generally speaking, larger windmill rotors and higher wind speed produce more power.

Most wind turbines are the classic Danish three-bladed design with the rotor positioned up-wind (facing the wind). Even numbers of blades cause instability. Some designs are two bladed, saving the cost of a blade and reducing rotor weight. They need higher rotational speeds to produce the same amount of power as a three bladed design. These speeds produce more noise. There are one bladed designs that require a counter-balance on the other side of the hub. They also require higher rotational speed.

Aerodynamics of Rotors: Rotor blades act like airfoils. An airfoil is a structure around which air flows creating lift. Rotor blades have a special shape so that when the wind passes over them, it moves faster over one side. Bernoulli's Principle states that increased air velocity produces decreased pressure.

When the wind blows there is a pocket of low pressure formed on the downwind side of the blade. The blade is pulled toward the low pressure making the rotor turn. This is called lift. The lift force is stronger than the force, known as drag, acting on the front side of the blade. The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity. In wind turbine design, the objective is to have a high lift-to-drag ratio. This is accomplished by twisting the blades. The blades are twisted so that the wind hits them at the correct angle of attack. This twist is known a pitch.

In the last decade many articles have been published on the topic of wind turbine. On January 2001 Muljadi and Butterfield proposed a paper on operation of variable-speed wind turbines with pitch control [16]. The system the authors considered is controlled to generate maximum energy while minimizing loads. In this paper they show that by pitch control and generator load control, the wind turbine can be operated at its optimum energy capture while minimizing the load and thus extending the range for wind speed.

Slootweg *et al* published a paper (2001) [17]where they discussed on a wind turbine concept where the rotor speed , pitch angle all can be controlled . This model is simulated and studied. Nichita *et al* proposed (2002)[16] two modeling procedures for wind speed simulation. Miller *et al* propose (2003) [18] a new model for high power turbine where they described the modeling of a 3.5 M.W. turbine. Tapia *et al* [19] modeled a simulation of a grid-connected wind driven doubly fed induction machine (DFIM) together with some real machine performance results.

Researches are conducted on optimization and control strategy of a wind turbine. Tan and Islam proposed (2004) [20] a prototype version of the control strategy of a 20-kW permanent-magnet synchronous generator (PMSG) for maximum power tracking and compares with the results produced by previous strategies and demonstrate its advantage over the existing ones. Also Quincy Wang and Liuechen Chang developed another algorithm (2004) [21] for obtaining maximum power from wind turbine. Yazhou Lei *et al* discussed on variable speed wind turbine using a doubly fed induction generator to increase the efficiency of the turbine (2006) [22]. Liserre *et al* performed a study in 2006 [23] on photovoltaic solar cells and wind turbine grid inverters for long term stability. Xingjia Yao *et al* (2007) [24] presented a study on the performance of Doubly-fed Induction generator based Wind Turbine.

Chapter 2

Vibration power generator

2.1 Theoretical Background

The field of energy harvesting is a very important field in recent year's research. There are numerous researchers trying to convert the 'lost energy' (e.g. kinetic energy, present in the form of vibrations, displacements or force) into 'usable energy' (e.g. electrical energy which could be used to power devices).

The main target is to extract energy from the system by using a vibration power generator. Those which are mostly in use are piezoelectric, magnetostrictive, electrostatic and electromagnetic.

The principle of piezoelectric energy conversion is that some piezoelectric materials become electrically polarized when subjected to mechanical strain. The degree of polarization is proportional to the applied strain. This property is used to direct the conversion of vibrations into a voltage output by using a piezoelectric material.

Some magnetostrictive materials offer an even better capability with regard to energy harvesting compared to piezoelectric materials.

The advantages are ultra-high energy conversion efficiency and high power density.

The basis of electrostatic energy convertor is the variable capacitor. A variable capacitance structure is driven by mechanical vibrations and oscillates between a maximum and a minimum capacitance. If the charge on the capacitor is constrained, the voltage will increase as the capacitance decreases. If the voltage across the capacitor is constrained, charges will move from the capacitor to a storage device or to the load as the capacitance decreases. In either case, mechanical kinetic energy is converted to electrical energy.

The electromagnetic mechanism employs electromagnetic induction arising from the relative motion of the magnetic flux gradient and a conductor (the Faraday's law). According to the fundamentals of electromagnetism "The induced electromotive force (EMF) in any closed circuit is equal to the time rate of change of the magnetic flux through the circuit". So the main principle here is to let a magnet to move freely within a coil by using the force of vibration. As the magnet moves within the coil it causes a change in flux through the coil and according to Faraday's law this will generate a voltage in the coil.

The majority of recent developments of devices for converting vibration into voltage are focused in Piezoelectric and electromagnetic energy conversion generators.

In the present project, we have used the design of electromagnetic energy conversion generators.

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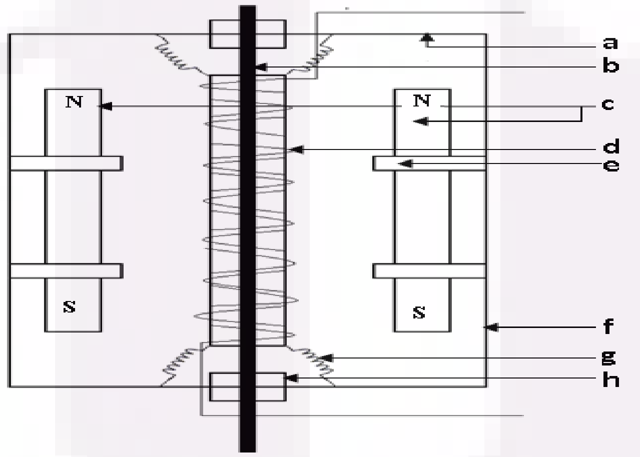
2.2 Structure of the generator

The structure of the electromagnetic generator is symmetrical. A theoretical block diagram of it is shown in figure 2.1. The structure consists 6 Alinico bar Magnet circling a copper coil at equal distance within a cylindrical Aluminium housing.



(a)Plastic plates stabilizing the induction coil within the magnetic field, (b)Axial rod, (c)Magnets,(d) Induction Coil, (e)Magnet holders, (f)Metallic cylinder, (g)Springs & strings holding the coil allowing up & down movement during vibration, (h) Obturators

Fig. 2.1 Inner Diagram Of The induction generator

The magnets are arranged such that there North poles are upward and South Pole is down ward. The coil is in between supported along an axis by 6 springs thus it can move freely.

2.3 Design and dimension of the Induction generator:

The generator is constructed using an alluminium sheet with dimension 160 x 160 x 3 mm. The system consists 6 Alinico bar magnet surrounding a coil with equal distance. To prepare this system first the alluminium sheet is prepared (Fig. 2.2). Then the magnets are placed on it at 15 mm distance from each and at 44 mm distance from each end.

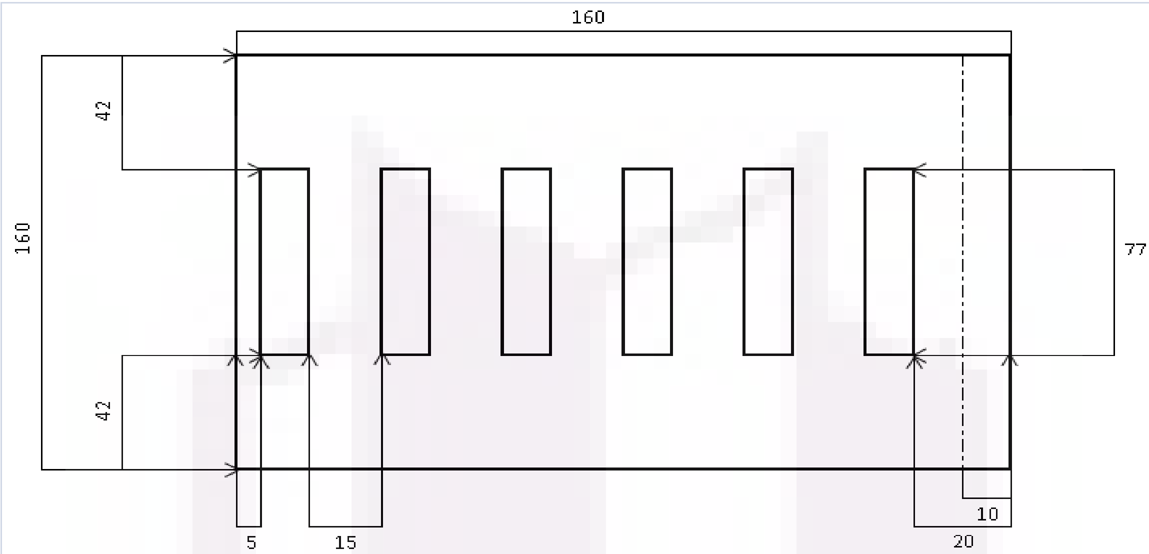


Fig. 2.2 Design and dimension of the Induction generator

As per as the design each magnet acquires 10 mm width wise and each placed 15 mm apart. The last 10 mm space of the sheet (width wise) is left for riveting purpose, which makes the useful space as 160 x 150 mm.

2.4 Final Diagram of the induction generator:

The sheet, after planting the magnets and fixing them with the help of holders is bend and shaped as a cylinder (Fig 2) with height 160mm and diameter 48 mm.

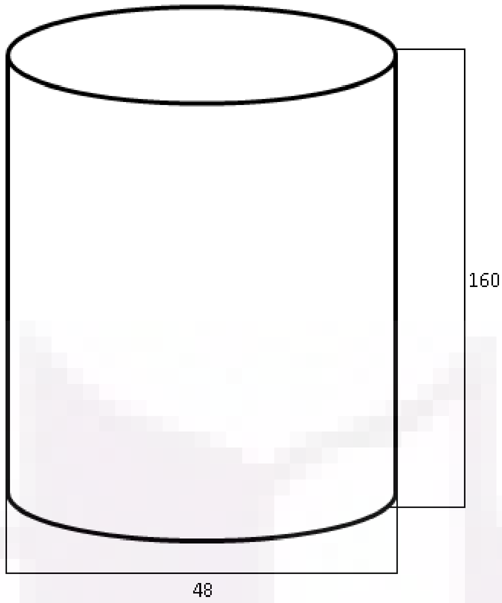


Fig 2.3 Final Diagram of the induction generator

The system works on the principle of linear magnetic induction, on Faraday's Law of electro magnetism. Which is "The induced electromotive force (EMF) in any closed circuit is equal to the time rate of change of the magnetic flux through the circuit."

Fig 2.4 Photograph of the generator

2.5 EQUATION GOVERNING THE BEHAVIOR OF THE GENERATOR:

E=-n ∂Φ / ∂t Assuming B as the flux density and A as the area of the coil we have,

Φ = $\int \vec{B} \cdot dA$ **hence E=-n∂/ ∂t** $\int \vec{B} \cdot dA$

2.6 WORKING OF THE GENERATOR:

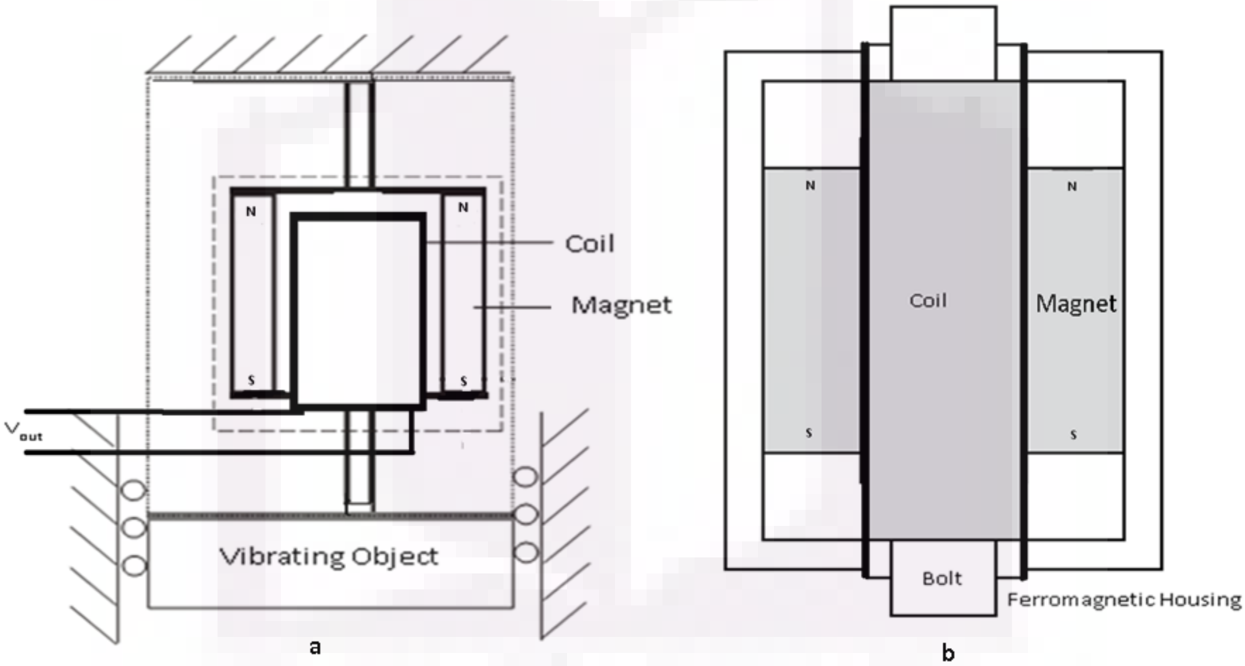


Fig 2.5 Block Diagram of the Induction generator

—The Vibration gives an upward thrust to the generator.

—The coil systems move upward while the magnet remains fixed.

—As the coil reaches its maximum height it comes down by its own weight.

2.7 Formulation

This structure is based on Faraday's Law of electro magnetism. The magnet-system produces a magnetic field of flux density B in the coil. As the magnet system move along the axis it induces an electric field in the coil around it. Which is $E=-N\,\partial\Phi/\partial t$. where Φ is the flux in weber.

Assuming l is the length of the coil. ∂x is the distance the coil moves after each thrust and ∂t is the time taken to reach ∂x (Assumed to be 1 since the distance is very small)

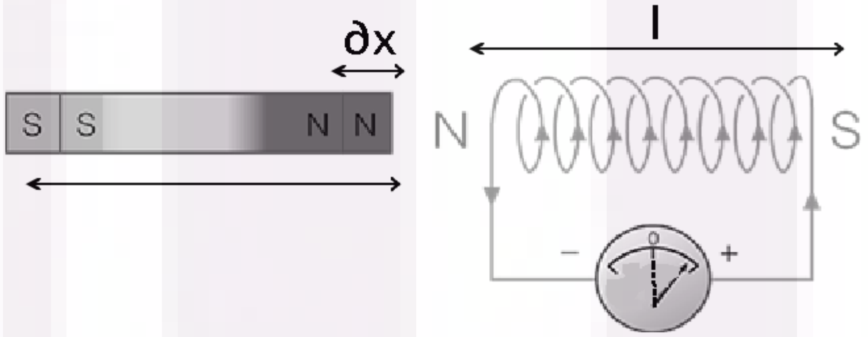


Fig 2.6 basic principle of induction generator working

$\partial x= (F-Mg)/2M$ [where M is the total mass of the generator, F is the upward thrust by vibration]

Using Faraday's Law we have

$E=-N\partial q/\partial t$ [Taking ∂t as 1 that is calculating for unit time]

$E=-N\partial q$

$E=-N\Phi\, lv^*\, \partial x$ [L is the length of the coil, V is velocity of the magnet and ∂x **is** the distance travelled]

$E=-N\Phi\, lv(F-Mg)/2M$

$E=-N\Phi\, l((F-Mg)/M)^2/2$

$E=-N\Phi\, l(a/M)^2/2$ **[a=(F-Mg)]**

Chapter 3

Wind power generator

3.1Theoretical Background

Wind energy is a very popular source of alternate energy in current times. It is basically the kinetic energy of the moving air. This energy is used for human civilization for a long time.

The basis of using wind energy is to use the kinetic energy of wind to spin a shaft. It converts the force of the wind into turning force acting on the rotor blades. The rotation of the shaft is used to drive a turbine which generates electric energy.

3.2 Working principle of wind turbine:

Rotor blades act like airfoils. An airfoil is a structure around which air flows creating lift. Rotor blades have a special shape so that when the wind passes over them, it moves faster over one side. According to Bernoulli's Principle increased air velocity produces decreased pressure. Hence when the wind blows there is a pocket of low pressure formed on the downwind side of the blade. The blade is pulled toward the low pressure making the rotor turn. This is called lift. The lift force is stronger than the force, known as drag, acting on the front side of the blade. The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity. In wind turbine design, the objective is to have a high lift-to-drag ratio. This is accomplished by twisting the blades. The blades are twisted so that the wind hits them at the correct angle of attack. This twist is known a pitch.

3.3 Wind speed and energy:

The amount of energy that can be captured from the wind is exponentially proportional to the speed of the wind. If a windmill were perfectly efficient, the power generated is approximately equal to:

P (watts) = 1/2 D (air density) x A (swept area) x V^3 (wind velocity)

Therefore, if wind speed is doubled, the power in the wind increases by a factor of eight, i.e. 2 x 2 x 2. In reality, because of Betz's Limit it doesn't have such affect.

3.4 Betz Law:

Betz's law is a theory about the maximum possible energy to be derived from a wind turbine developed in 1919 by the German physicist Albert Betz. According to this law "no turbine can capture more than 59.3 percent of the kinetic energy in wind." It is also called as Betz Limit. This limit is the cause of the very nature of wind turbines themselves.

Wind turbines extract energy by slowing down the wind. For a wind turbine to be 100% efficient it would need to stop 100% of the wind - but then the rotor would have to be a solid disk and it would not turn and no kinetic energy would be converted. On the other extreme, a wind turbine had just one rotor blade, most of the wind passing through the area swept by the turbine blade would miss the blade completely and so the kinetic energy would be kept by the wind.

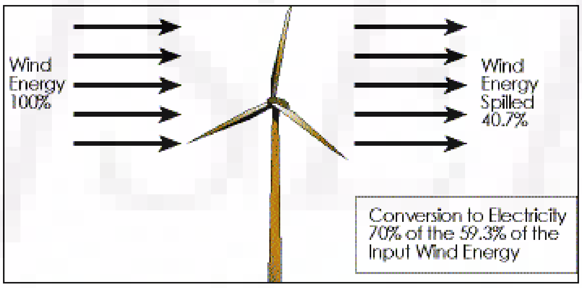


Fig 3.1 Wind flow and wastage (Betz's Law)[26]

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). After taking engineering requirements of a wind turbine - strength and durability into account the real world limit is well below the *Betz Limit* with values of 0.35-0.45. Taking other ineffiencies in a complete wind turbine system like the generator, bearings, power transmission and so on - only 10-30% of the power of the wind is converted into usable electricity.

3.5 Structure of a wind turbine:

A wind turbine consist the following parts.

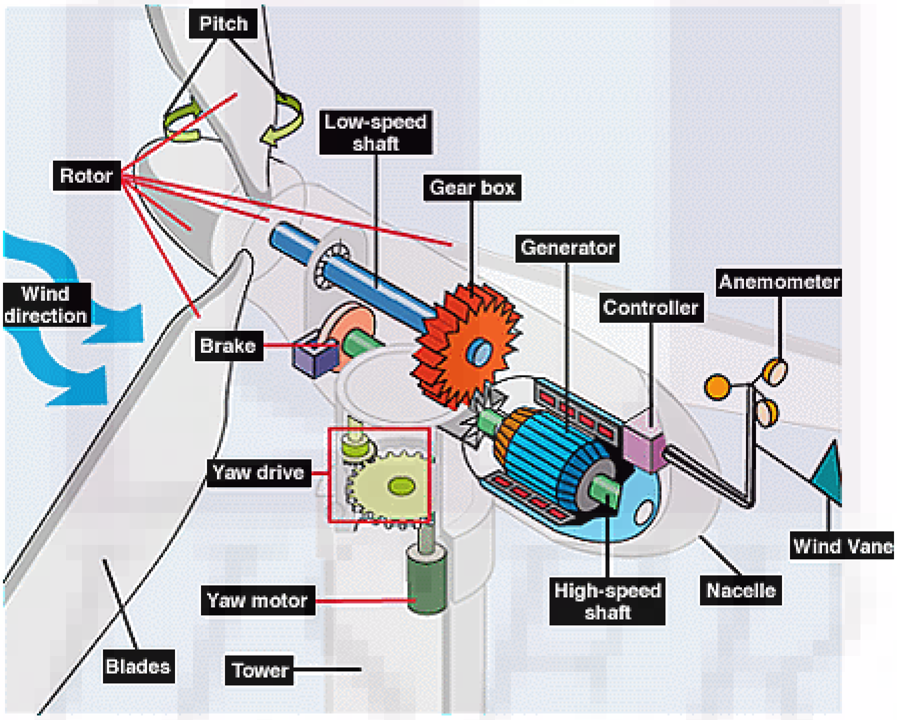


Fig 3.2 Parts of a General Wind Turbine[27]

3.5.1 Rotor: The hub and the blades together are referred to as the rotor. Wind turns the blades which turn the drive shaft. The total area covered by the rotor is known as the Swept Area.

3.5.2 Shaft: Two different shafts turn the generator. One is used for low speeds while another is used in high speeds.

3.5.3 Generator: The generator is what converts the turning motion of wind turbines blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity

3.6 Structure of the proposed turbine developed in the present project:

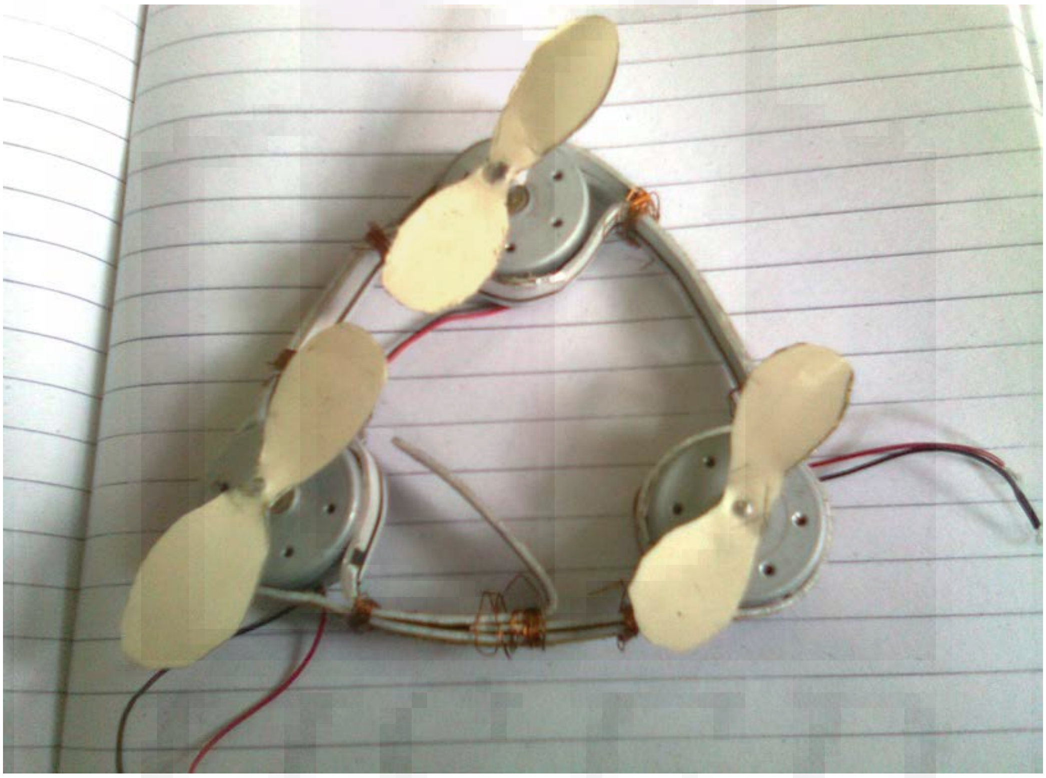


Fig 3.3 Real Life Picture of wind turbine designed by the project

The turbine designed in this project is based on the property of dc motor that when the shaft of a dc motor is rotated then it produces voltage like a generator. This model uses 3 dc motor which are connected with blades to make them rotate when wind flow towards them. As the blades rotate they cause the shaft of the dc motor to rotate as well. Since the dc motor works as a reverse generator as the shaft rotates it cause the coil inside the motor to rotate within a magnetic field and produces electricity (as per Fig 3.4).

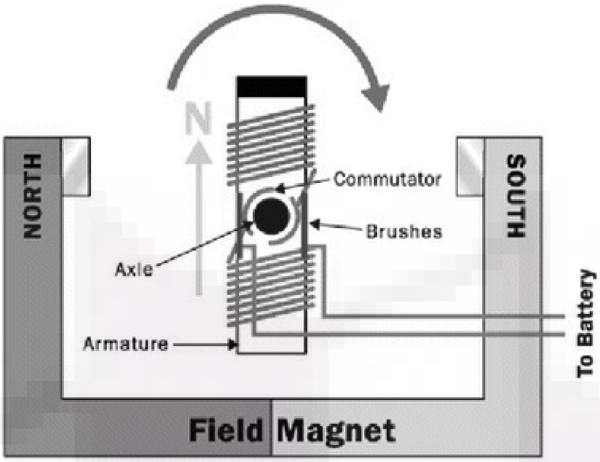


Fig 3.4 Inside of a DC motor

Wind Turbine:

The turbine is constructed using alluminium strips of width 7 mm and thickness 2mm. First, an Equilateral triangle is prepared with those strips with arm length 9cm each. Then 3 dc motor (Rf-300fc) is fixed at the 3 corner of the triangle using aluminium strips of same dimension (Fig 3.5).

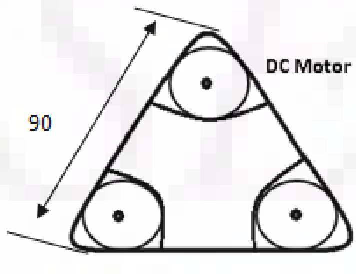


Fig 3.5 basic diagram of the turbine

The blades of the turbine are made from alluminium foil with thickness 0.2-0.3 mm. each blade is 80 mm long and shaped to rotate as wind pass them (Fig 3.6).

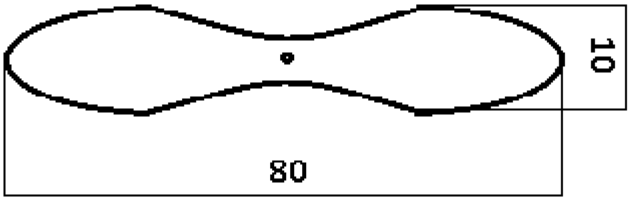


Fig 3.6 Blade diagram and dimension

The blades are fixed on the dc motors with the help of glue. The final structure is as per figure 3.7 and figure 3.3 .

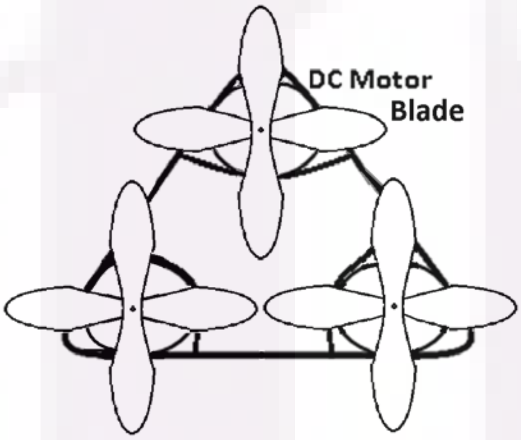


Fig 3.7 Final Structure of Wind turbine

For a wind turbine the amount of power available is determined by the equation:

3.7 Equation governing the behavior of the wind turbine generator

$w = rAv^3/2$ where w is power, r is air density, A is the rotor area, and v is the wind speed.

As we know that only 10-30% of total power is available or can be captured hence

w_{act}=w*0.1 w_{act} is the actual power obtained from the turbine

when this power will be applied on the shaft, the shaft will rotate in speed

$\omega = w_{act}/T$ where ω is the rotating speed of the shaft in rad/sec and T is the minimum torque required for the motor.

$\omega_{rpm} = \omega * 60/2\pi$

the DC motor used in this project as depicted in Fig 3.8, are of RF-300FA-12350 with specification

MODEL		VOLTAGE		NO LOAD		AT MAXIMUM EFFICIENCY					STALL		
		OPERATING RANGE	NOMINAL	SPEED	CURRENT	SPEED	CURRENT	TORQUE		OUTPUT	TORQUE		CURRENT
			V	r/min	A	r/min	A	mN·m	g·cm	W	mN·m	g·cm	A
RF-300FA	12350	1.5 - 6.0	3	3500	0.022	2830	0.093	0.48	4.9	0.14	2.51	26	0.39

Fig 3.8 Specification Of Dc Motor

Also the output of the system is taken across a load resistance R_l hence

$V_{o/p} = (w_{act}/R_l)$^.5

$I_{o/p} = w_{act}/V_{o/p}$

Chapter 4

Experiment Tests

The devices are all tested manually to verify that they can produce some amount of voltage. Due to unavailability of resource systematic testing could not be done. As no suitable shaker was available the systematic test of the Induction Generator not properly done instead the possible result of the induction generator is shown using MATLAB and the device is . Also because of the lack of blower and setup the wind turbine could not be tested properly. However the wind turbine is tested using Mouth Blow, Table Fan and in vehicle at different speeds.

4.1 Induction Generator

The induction generator could not be tested due to lack of instruments and set up. Some tests were made on cycle and a MATLAB programming with a vibration profile of an almost equal mass in a train is done. Both tables are given below.

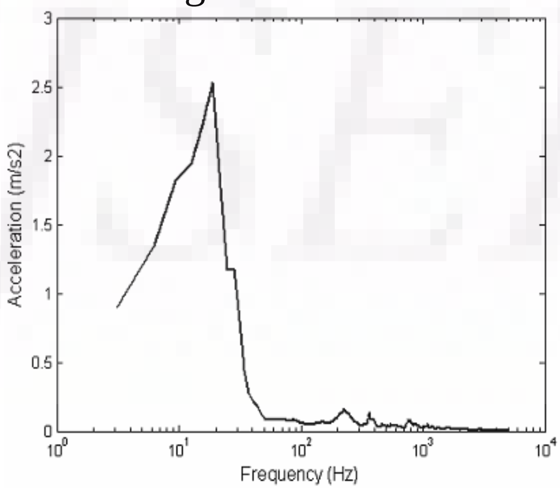


Fig 4.1 Vibration Profile of a 500gm mass in a train running in an average speed of 40 Km/hr

4.1.1 Table showing effect of acceleration on power output in MATLAB output

This table is made up with the help of the data obtained from the following vibration profile.

Table 4.1.1Voltage produced due to vibration of the induction generator(mv) in MATLAB

SL. NO.	Acceleration (m/s^2)	Voltage (mV)
1	1	8.8163
2	1.1	10.6678
3	1.2	12.6955
4	1.3	14.8996
5	1.4	17.28
6	1.5	19.8367
7	1.6	22.3698
8	1.7	25.4792
9	1.8	28.5649
10	1.9	31.8269
11	2	35.2653
12	2.1	38.88
13	2.2	42.671
14	2.3	46.6384
15	2.4	50.782
16	2.5	55.102

4.1.2 Power output of induction generator generated in a Bicycle.

This data is obtained by attaching the generator to a bicycle and running it through a road for 15 min.

Table 4.1.2Voltage produced due to vibration of the induction generator(mv) in a cycle

SL. NO.	Road Condition	Voltage (mv)
1	Bitumen Road	0
2	Clay Track	0.4-0.6
3	Country Track	0.4-0.5
4	Worn Trail	0.8-1.2
5	Forest Trail	1.2-1.5
6	-	-
7	-	-
8	-	-
9	-	-
10	-	-

4.2 Wind turbine

4.2.1 Power output of wind turbine generated from the Mouth blow

During experimental set up, we frequently used mouth blow to move the blades of the wind turbine, in order to test the power generation. We found that, as the force and velocity of blow changes by the voluntary effort of the human subject, the power generation changes in a controlled and predicted pattern.

Mouth blow by an adult human subject is basically an act of expiration of air from the lung. Regarding this, there are three standard volume quantifications,

Tidal volume: This is the volume of air expired or exhaled by the human subject by normal voluntary effort, after a normal inspiration. This is amounting to 500 ml, exhaled within 1 to 2 seconds.

Expiratory capacity: This is the volume of air expired or exhaled by the human subject by forced voluntary effort, after a normal inspiration. This is amounting to 1000 ml, exhaled within 1 to 2 seconds.

Vital Capacity: This is the volume of air expired or exhaled by the human subject by forced voluntary effort, after a maximum effort of inspiration. This is amounting to 4000 ml, exhaled within 3 to 4 seconds, out of which about 3000 ml is exhaled within 2 seconds.

Table 4.2.1Voltage, Current produced due to movement of different blades of the rotor (mV, mA)

	Blade A		Blade B		Blade C	
MODEl-1						
Application of Tidal volume	0	0	0	0	1	0.1
Application of Expiratory capacity	18	4	22	5	1	0.1
Application of Vital Capacity	315	44	323	45	150	24
Model-2						
Application of Tidal volume	0	0	0	0	0	0
Application of Expiratory capacity	3	0.2	1	0.01	0	0
Application of Vital Capacity	250	33	267	37	112	18

4.2.2 Power output of wind turbine generated from the Table Fan

This set of data is taken using a table fan with 3 variable speed setting as High, Medium and Low.

Table 4.2.2Voltage, Current produced due to movement of different blades of the rotor and by the whole system

Wind Turbine Test with Table Fan								
Model – 1								
SL NO.	**A**		**B**		**C**		**ALL**	
	Voltage	**Current**	**Voltage**	**Current**	**Voltage**	**Current**	**Voltage**	**Current**
1	23 mv	3.7 ma	60 mv	11 ma	20 mv	3.1 mA	80-98mV	11-16mA
2	98-103 mv	17 ma	130 mv	24 ma	80 mv	8.9 ma	0.5-.7 V	39-48mA
3	180-230mv	26-34 ma	280-310 mv	37 ma	160 mv	23-25 ma	1.2-1.5 V	90-95 mA
Model – 2								
SL NO.	**A**		**B**		**C**		**ALL**	
	Voltage	**Current**	**Voltage**	**Current**	**Voltage**	**Current**	**Voltage**	**Current**
1	30-40 mv	2-3.4 ma	30-40 mv	6-7 ma	10-12 mv	1-2 ma	8-9 mv	0.5-1 ma
2	120-125 mv	15-16 ma	130-140 ma	16-18 ma	53-60 mv	8-10 ma	.8-1 v	36-38 ma
3	220 mv	30 ma	220-270 mv	32-34 ma	90-105 mv	14-18 ma	1.5-2 v	70-78 ma

4.2.3 Power output of wind turbine generated in a car at variable speed

The test of the turbine is done in car. The main principle behind this test is that assuming the general wind speed is zero or ignorable the speed of the backlash wind would be equal to the speed of the car.

Table 4.2.3Voltage, Current produced due to movement of the whole system

Velocity(Km/hr)	Voltage(V)		Current(A)	
	Model-1	Model-2	Model-1	Model-2
10	0	0	0	0
15	0	0	0	0
20	0	0	0	0
25	12 mv	1 ma	0	0
30	28 mv	3 ma	0	0
35	41 mv	5 ma	30 mv	6 ma
40	59 mv	6 ma	37 mv	6 ma
45	70 mv	7 ma	42 mv	7 ma
50	92 mv	9 ma	53 mv	10 ma
55	124 mv	14 ma	60 mv	10 ma
60	157 mv	24 ma	88 mv	15 ma
65	-	-	-	-
70	-	-	-	-
75	-	-	-	-
80	-	-	-	-

Data of the output voltage and currents, obtained from the above test from Model 1 and Model 2 of the wind turbine generator, and as shown in the Table 4.2.3 were processed by Curve fitting tool in

MATLAB platform. Curves were drawn putting voltage (mv) and Current (ma) in the Y axis, against the velocity of the moving vehicle in X axis. All the curves were fitted in Cubic Polynomial function, with reasonable degree of fitness. Equations obtained with corresponding coefficients, as presented in Table 4.2.4 to 4.2.7 and Figure 4.2 to 4.5.

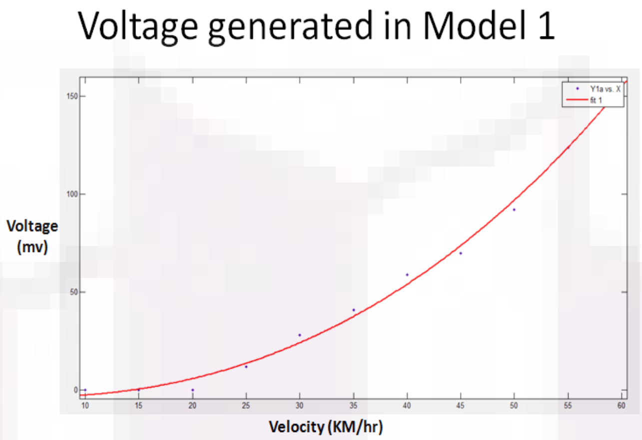


Fig 4.2 Voltage Generated in Model 1

Table 4.2.4 Equation of the Cubic Polynomial Curve obtained from the voltage generated in the wind turbine model 1

Linear model Poly3: f(x) = p1*x^3 + p2*x^2 + p3*x + p4 Coefficients (with 95% confidence bounds): p1 = 0.0002704 (-0.0008041, 0.001345) p2 = 0.03324 (-0.0805, 0.147) p3 = -0.3427 (-3.962, 3.277) p4 = -2.727 (-36.16, 30.71) Goodness of fit: SSE: 139.5 R-square: 0.9951 Adjusted R-square: 0.993 RMSE: 4.464

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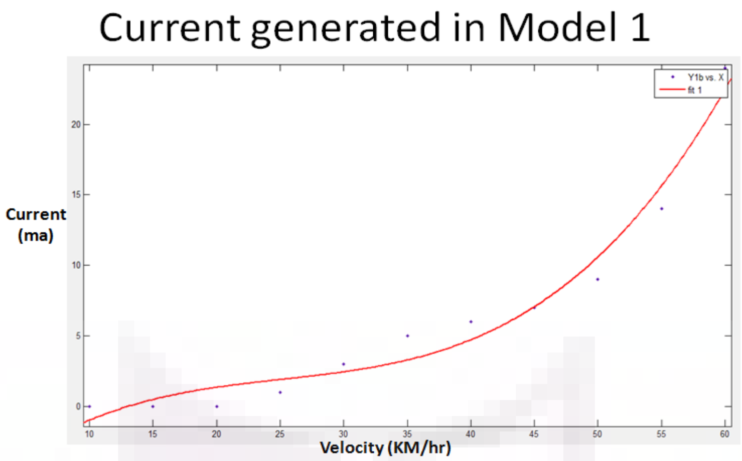

Fig 4.3 Current Generated in Model 1

Table 4.2.5 Equation of the Cubic Polynomial Curve obtained from the current generated in the wind turbine model 1

Linear model Poly3:
    f(x) = p1*x^3 + p2*x^2 + p3*x + p4
Coefficients (with 95% confidence bounds):
    p1 = 0.0004009 (3.426e-005, 0.0007676)
    p2 = -0.03016 (-0.06898, 0.008651)
    p3 = 0.8559 (-0.3794, 2.091)
    p4 = -6.909 (-18.32, 4.5)
Goodness of fit:
  SSE: 16.25
  R-square: 0.9699
  Adjusted R-square: 0.957
  RMSE: 1.523

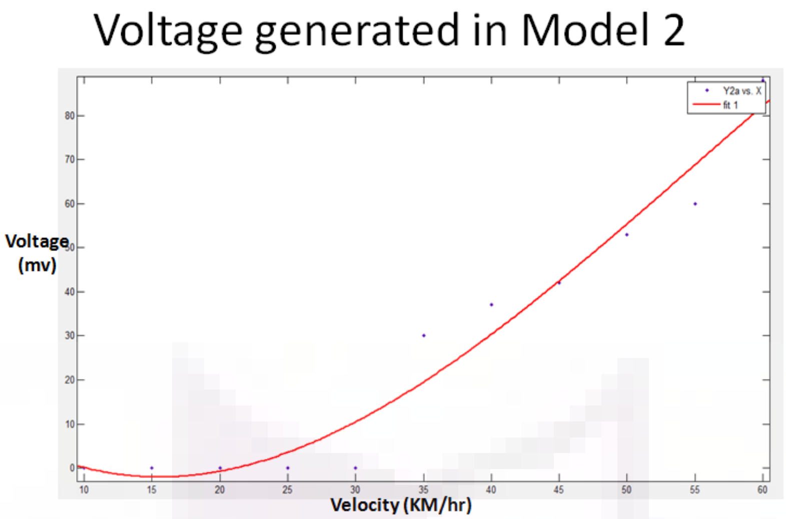

Fig 4.4 Voltage Generated in Model 2

Table 4.2.6 Equation of the Cubic Polynomial Curve obtained from the voltage generated in the wind turbine model 2

Linear model Poly3: f(x) = p1*x^3 + p2*x^2 + p3*x + p4 Coefficients (with 95% confidence bounds): p1 = -0.000575 (-0.002389, 0.00124) p2 = 0.09497 (-0.09711, 0.287) p3 = -2.533 (-8.646, 3.58) p4 = 16.52 (-39.94, 72.97) Goodness of fit: SSE: 397.9 R-square: 0.9579 Adjusted R-square: 0.9399 RMSE: 7.539

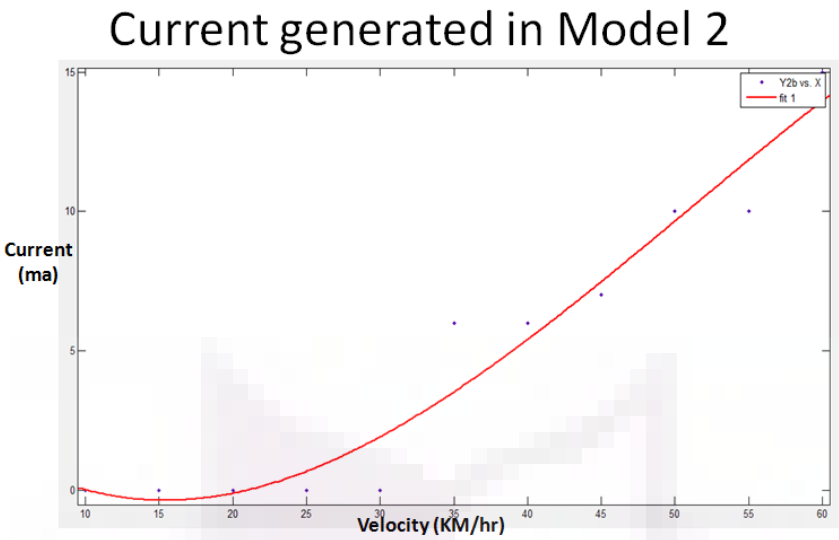

Fig 4.5 Current Generated in Model 2

Table 4.2.7 Equation of the Cubic Polynomial Curve obtained from the current generated in the wind turbine model 2

Linear model Poly3:
f(x) = p1*x^3 + p2*x^2 + p3*x + p4
Coefficients (with 95% confidence bounds):
p1 = -0.0001166 (-0.0004758, 0.0002427)
p2 = 0.01779 (-0.02024, 0.05581)
p3 = -0.4648 (-1.675, 0.7454)
p4 = 3 (-8.177, 14.18)
Goodness of fit:
SSE: 15.59
R-square: 0.9445
Adjusted R-square: 0.9207
RMSE: 1.493

The results presented as above show a stable and reasonably predictable outcome in terms of voltage and current output in the wind turbine generator. The 4 coefficients of the cubic polynomial function may be correlated with the different factors influencing the generator output.

Chapter 5

5.1 Conclusion In the present project, an electromagnetic induction generator and a small scale wind turbine are designed and modeled to utilize the vibration and wind backlash generated during machine operation as a means of energy harvest.

The generalized equation were also developed for electromagnetic induction generator using vibration as a source and small scale wind turbine generator using backlash wind as a source.

Both these small devices are tested and are found to produce controlled electric power. Curves and equations generated from the data obtained from the output voltage and current are found to be correlated satisfactorily with the expected values.

5.2 Limitations

1) The magnets used in the model of electromagnetic induction generator were not of appropriate quality and specification, leading to unsatisfactory energy output.
2) The model of electromagnetic induction generator is to be developed to respond to different levels and amplitudes of vibrations, by suitable modification of the springs and suspensions.

3) Appropriated and high quality chemically insulated cables should be used to prevent short circuiting of the armature coil with the magnet and magnet holders.
4) The design and the making of the blades of the small scale wind turbine model must be improved to achieve uniform output voltage by the same quantity of blow.
5) The developed model of electromagnetic induction generator was tested only in the controlled laboratory conditions. A programmed simulation was also conducted. However, a real time data in the practical field condition could not be obtained.

5.3 Future scope

1) With overcoming of the limitations as afore-mentioned, it is possible to achieve,
   a. A predictable and satisfactory energy output
   b. Response to different levels and amplitudes of vibrations.
   c. Uniform output voltage by the turbine in response to same quantity of wind blow.

2) Energy harvested from the above sources may be utilized by appropriate instrumentation and miniaturization to power the commonly used wireless devices.
3) The output voltage or the current produced by the wind turbine in response to mouth blowing by human respiratory effort may be correlated with the human lung function in health and in disease states.

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APPENDIX-A

MATLAB program for the vibration test.

```
Q=.08;
M=.7;
l=.054;
N=2000;
a=[1 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2 2.1 2.2 2.3 2.4 2.5 2.4 2.3 2.2
2.1 2 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1 .9 .8 .7 .6 .5 .4 .3 .2 .1]
for i=1:40
e(i)=(N*Q*l*(a(i)/M)^2)/2
end
plot(a,e)
```