PEDAL POWER ENERGY HARVESTING

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by

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

AC	Alternating Current
DC	Direct Current
EH	Energy Harvesting
TEG	Thermal Electric generator
AGS	Automation Generating System
LPMSG	Linear Permanent Magnet Synchronous Generator
PMG	Permanent Magnet Generator
BLDC	Brushless Direct Current
PMDC	Permanent Magnet Direct Current
ISEA	International Sports Engineering Association
LCD	Liquid Crystal Display
RPM	Revolution Per Minute

PENUAIAN TENAGA KUASA KAYUHAN

ABSTRAK

Tenaga yang boleh diperbaharui memainkan peranan penting dalam mengurangkan pelepasan gas rumah hijau seperti bio bahan api, solar, dan angin. Tenaga ini bersih dan menguntungkan, tetapi hanya terletak di kawasan terpencil sahaja. Contohnya, pada hari-hari mendung atau ketika fenomena bencana berlaku pengunaan panel solar bukanlah cara yang efisien untuk menuai tenaga dan menyebabkan di mana mangsa bencana tidak dapat memperoleh tenaga elektrik. Tenaga yang sedia ada terus digunakan oleh pengguna sehingga habis. Oleh itu, projek ini mencadangkan menjana kuasa elektrik sendiri dengan basikal semasa keadaan kecemasan berlaku. Projek ini telah diilhamkan berdasarkan Taufan Maria yang menghancurkan bandar kecil di pergunungan pusat Puerto Rico, di mana taufan memutuskan talian kuasa di seluruh kawasan itu. Penukaran tenaga makanan kepada tenaga mekanikal luaran semasa aktiviti fizikal mempunyai kecekapan dalam julat 2.6 - 6.5%, bergantung kepada jenis aktiviti fizikal yang dilakukan. Daripada pelbagai teknik pemulihan tenaga yang wujud, generasi tenaga mengayuh basikal menunjukkan julat yang paling besar untuk pemulihan berskala besar. Tenaga kinetik yang dihasilkan oleh gerakan mengayuh basikal menghasilkan sejumlah besar voltan sehingga 15V hingga 30V. Walau bagaimanapun, disebabkan voltan keluaran yang dihasilkan oleh penjana adalah terlalu besar, pengawal voltan perlu dimasukkan untuk mengawal selia voltan yang dijana oleh penjana arus terus magnet tetap ke paras voltan dan arus tertentu supaya ia dapat digunakan dengan mudah untuk mengecas bateri tanpa merosakkannya. Arduino Mega digunakan untuk mengawal kelajuan kayuhan dan voltan di hasilkan,serta memutuskan bekalan apabila bateri

dicas penuh. Akhirnya, kesan kelajuan kayuhan yang berbeza dan pengeluaran elektrik juga disiasat. Pada akhir kajian ini, didapati bahawa kelajuan basikal yang perlahan memberikan kecekapan yang tinggi untuk menuai tenaga, tetapi ia mengambil masa yang panjang untuk mengisi penuh bateri. Jumlah kuasa yang dihasilkan pada keadaan ini ialah 7.392W. Jumlah tenaga ini cukup untuk mengecas telefon bimbit, menyalakan lampu LED dan kipas berkuasa rendah semasa keadaan kecemasan.

PEDAL POWER ENERGY HARVESTING

ABSTRACT

Renewable energy plays an important role in reducing greenhouse gas emissions such as biofuels, solar, and wind. They are favorable and located in remote area. For example, on cloudy days or when any disaster phenomenon occurs solar is not an efficient way to harvest energy and leads to where the victim of the disaster cannot reach for electricity. The temporary energy keeps used by the user until it's drain out. Therefore, this project proposes generate our own power by cycling during emergency situation happened. This project was inspired based on Hurricane Maria which devastated the small town in the mountains of central Puerto Rico, where the hurricane downed power lines throughout the area. The conversion of food energy to external mechanical energy during physical activity has efficiencies in the range of 2.6 - 6.5%, depending on the type of physical activity being performed. Out of the variety of energy recovery techniques that exist, pedal motion electricity generation shows the most promise for large-scale recovery. The voltage produced is up to 15V to 30V. However, due to that output voltage produce by the generator is more than battery charging requirement, a voltage regulator is need to be included to regulate the voltage generated by permanent magnet direct current generator to a certain voltage and current level so it can be readily use to charge up the battery without harm it. An Arduino Mega is used as controller to isolate the speed and voltage in order to control the cut off voltage when the battery is full. In the end, the effect of different speed of pedaling on electrical production is also investigated. In the end of this research, it is found that slow cycling speed gives high efficiency to harvest energy, but took long time to full charge the

battery. The amount of power generated at this condition was 7.392W. This amount of energy enough to charge up mobile phone, light up low power LED light and fan during emergency situation.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Energy is defined as the ability of a physical system to do work or ability move or elicit change in matter. However, existence of energy is unnecessary available of work. Energy exists in several type such as heat energy which related with temperature, kinetic or mechanical energy is energy produce by motion, light energy which form from photons, potential energy due to an object position, electrical energy from the movement of charge particles, chemicals energy which be able to absorbed or released energy be chemical reaction and other forms of energy which can be classified as renewable or nonrenewable energy[1].

As mentioned above, nonrenewable energy is a source of energy that will run out in certain duration because it will replenish in a short period of time. The most of nonrenewable energy source that discovered by scientist is fossil fuel which contain coal, petroleum and natural gas. According to statistic, more than 66% of electricity generated by the whole world from fossil fuel and another 8% from nuclear energy. Even though fossil fuels are the main source to produce electricity to the whole world due to inexpensive to extract and easily can be stored, piped or shipped anywhere in the world, it is harmful to environment when its burned. Fossil fuel release carbon dioxide and toxic gases to atmosphere during combustion process or called greenhouse effect which lead air pollution to the earth[2].

In order to counter the problems of resource depletion and pollution, renewable energy sources are used as alternative way to harness energy due to its regeneration properties which mean it will not run out. Biofuel, biomass, geothermal, hydropower, solar energy, tidal power, wave power, and wind power are types of sources of renewable energy that found by researcher. The most important role of the type of energy to reduce greenhouse gas emission. About 15% of U.S. electricity generation was from renewable energy sources in 2016. However, this kind of energy is more expensive to harvest and to use because of depend on region areas itself and not always available[3].

Recently the human energy harvesting has increasingly gaining attention from the researchers. Besides, on average human body consume about 1300 kcal per day. Adult female consume about 1500 kcal per day while adult male consumes about 1600 to 1800 kcal per day which mean about 5.44 MJ to 7.53MJ consume per day[4]. Some of this energy used for human body system for survival purpose and the others energy are just wasted and turn into fat which is not only wasted but give negative side effect to human health. This wasted energy can be changed to electrical energy which give more beneficial to human itself.

There are several human activities that could burn out unwanted calories such as walking, running and cycling. From those activity, cycling with regular training 2-3 times per week has a maximum power output of 250-400W, while a world class cyclist generates up to 600W[5]. Therefore, pedaling or cycling is suitable to be harvested into electrical energy.

1.2 Problem Statement

Although renewable energy plays an important role in reducing greenhouse gas emissions such as biofuels, solar, and wind, they are favorable and located in remote area. For example, on cloudy days or when disaster phenomenon occurs solar is not an efficient way to harvest energy and leads to where the victim cannot reach for electricity. The temporary energy keeps used by the user until it's drain out. In order to avoid this situation, occur, we generate our own power by cycling during emergency situation happened. During cycling, energy transfer from human to circular motion on rear tire of the bicycle through the use of a foot pedal and crank system. In some developing countries are using pedal powered tools. Although this is a relatively slow method, it is clean energy. Pedal technology is nearly perfect with 97% efficiency. Using your own power helps you understand the amount of energy you use, reduce your ecological footprint and help you burn some calories. Almost every house has at least one bicycle at their home. The cycling power can be used to charge phones, process food, and pump water.

1.3 Objectives of Research

Stated below are the objectives of the project:

1) To design and build a prototype which is be able to test the generator electrical energy output power by cycling the bicycle at two variation of speed.
2) To study the required voltage and current needed to store it to the 12-volt lead acid battery and method of voltage regulation from the generator.
3) To measure time taken and required energy by human to charge 12-volt lead acid battery.

1.4 Limitation of Research

This research will focus on harvesting the electrical energy from cycling. The electrical energy produced by generator will be investigated and analyzed. However, it need to be regulated before go to energy storage phase which is in my case is 12-volt lead acid battery. In order to charge up lead acid battery, voltage and current regulation circuit will be built. An Arduino Mega will be use as controller to measure speed and control the cut off voltage when the battery is full. Double pole double throw double throw switch (DPDT) is use to switching from charging mode to discharge mode by using invertor as output. The output power for the energy harvester to power up electrical devices such as to charging phone, power up table fan or light for night time.

1.5 Thesis Outline

This thesis contains of five chapters which are organized as following:

Chapter 1 describes the background of this project and importance of study. The main idea or reason behind this project carry out, objectives of the project and scope of research are also included.

Chapter 2 discusses on different types of human power harvesting technology that has been conducted by previous researchers. The type energy harvester, low and high power energy harvester, working principle of generator, operation of bicycle and energy storage management.

Chapter 3 describes the methodology that need to be done in this research. The process involved and the circuitry used in this research will be explained in detail.

Chapter 4 shows the result obtained from this research. The results are analyzed and discussed in this chapter.

Chapter 5 concludes the research done and further improvement and suggestion about this research are proposed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses on various benefits and technique of human power energy harvesting that have been conducted by previous researchers such as harvesting energy from the body temperature and kinetic movement such as walking, shaking motion and working principle of bicycle and power storage. Besides, the permanent magnet generator working principle and type of generator also described in this chapter. Lastly, fundamental of energy efficiency and the prediction of energy efficient pedal forces in cycling are also include in this chapter.

2.2 Human Power Energy Harvesting

Renewable energy has brought about significant attentions to the whole word due to its benefits which to reduce pollution and at the same time provide sustainable clean source of energy. As mentioned before, the most common types of renewable energy are solar, wind, and tidal. Although renewable energy has huge advantage than non-renewable energy, there is energy resources that very close to us has not been recognized which is human power. In theoretical investigation of the benefits of human powered product by Hyunjae Daniel Shin [6], he discovered there are two kind of benefits, first is the direct benefit which include financial and second is the environmental benefits and intangible benefits which cover the health and behavior scope of benefits. This shows the win-win situation where human powered energy not only provide clean environment but give advantages to human itself[7].

2.2.1 Low Power Energy Harvesting

In 2017, wearable energy harvesting from body to battery was proposed by Michele Magno [8] as solution to overcome short lifetime of wearable devices. Although its challenging due to strict constraints in term of size, weight and cost, he managed to present the taxonomy of technology, architecture and design trade-off for efficient energy harvesting (EH) system for wearable devices. The main idea are to use kinetic and thermal EH from the human body and pump to control circuit before supply to load or storage from his discussion as shown in Figure 2.1.

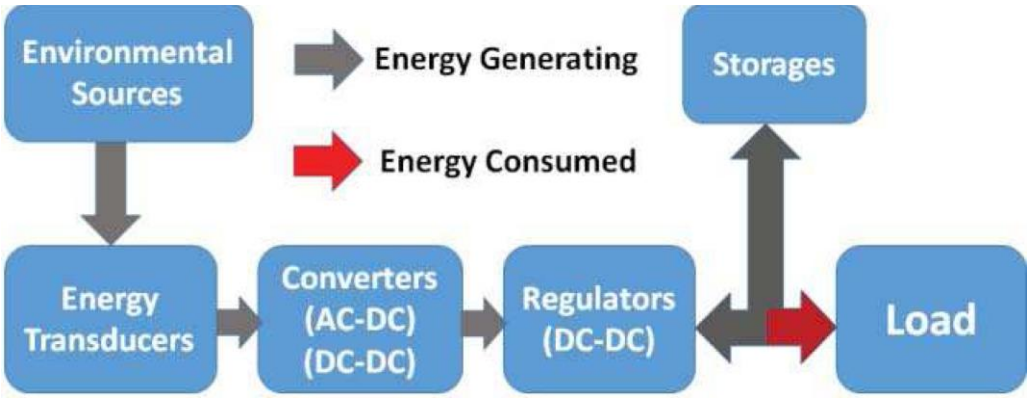

Figure 2.1 : Block diagram of a generic system with energy harvesting [8].

In terms of thermal energy harvesting, he proposed thermal electric generator (TEG) to generate energy. TEG is a module can be modeled as a temperature gradient dependent voltage source and an internal resistance as shown in Figure 2.2 [9].

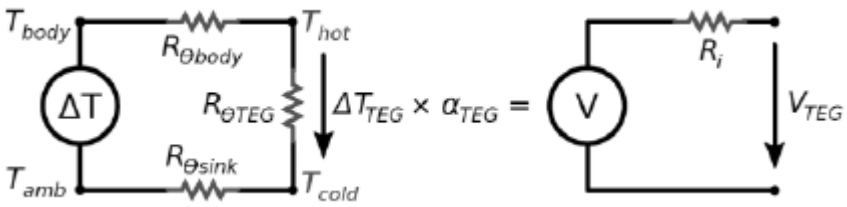

Figure 2.2: Model of the thermal and electrical characteristics of a TEG module for an on-body harvesting scenario.[8]

Where for the kinetic energy harvesting, the most popular way to extract the energy from human body is using electromagnetic oscillating rotational generators. Popular Japanese watch company Seiko is the first company using Automation Generating System (AGS) in their watch. AGS is self-winding mechanism was used in watches under the Kinetic brand. The design consisted of a rotating pendulum mass, a gearbox train (ratio 1: 100) and a small permanent magnet generator Figure 2.3.

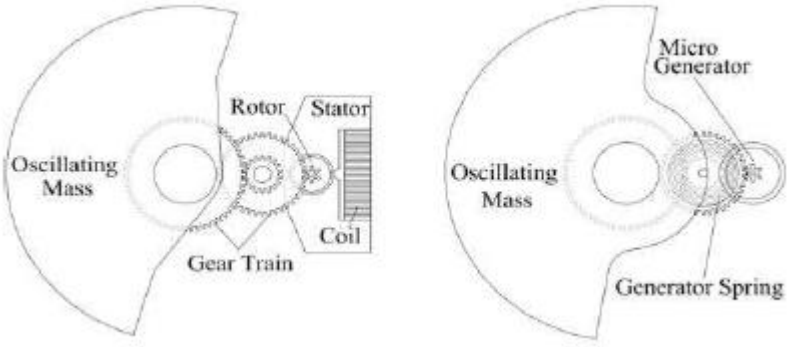

Figure 2.3: Oscillating rotational generators from commercial wristwatches; Seiko AGS[10] and ETA Autoquartz (right) [8].

Another way to harvest energy from human body by using piezoelectric. The human EH technique discovered by Shenck and Paradiso [11]. According to them, the human energy can be extracted from walking by mounted piezoelectric material at bottom of the shoes.

However, they spotted a difficulty to harvest energy at varying frequencies, which significantly limits utility in real wearable application scenarios.

In 2013, M. H. Mohammadi and M. Poshtan has designed a handheld linear PM synchronous generator which can charge small scale electrical devices such as mobile phone. The experiment relies on faraday's law for induction in Equation (2.1).

$$e = -Nd\emptyset/dt \tag{2.1}$$

To increase the induced energy, they focused on creating the maximum possible number of turns using copper wires of small diameter, usually less than 0.1 mm in thickness. The selection of permanent magnet material is based on the maximum flux density in order to produce maximum energy base on Table 2.1.

Table 2.1: Comparison of magnetic material properties.

Material	*Br* (mT)	*Hc*	*BHmax* (kJ/m^3)	Density (kg/m^3)	Max Working Temp. (℃)
Ceramic	100	High	26	4980	250
Alnico	130	Low	42	7200	550
SmCo (2:17)	350	High	208	8400	300
NdFeB (N38H)	450	High	306	7470	120

In their research, different number of turns and diameter sizes of wire are tested with five different NdFeB N48H grade magnet direction. Two linear permanent magnet

synchronous generator (LPMSG) prototype are made to compare the power generation as shown in Figure 2.4 and Table 2.2.

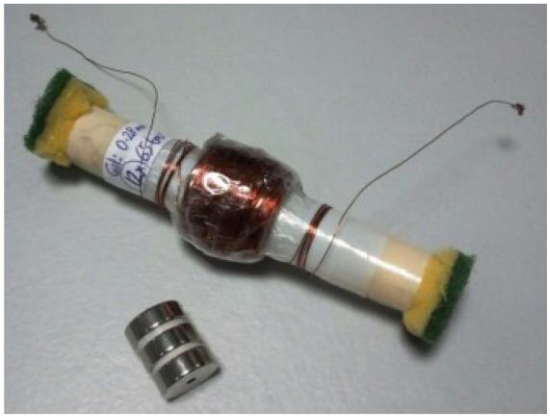

Figure 2.4: Designed LPMSG Prototype 2 with 0.28mm Diameter Solenoid.

Table 2.2: Prototype Power Generation Comparison.

Prototype	Mass (g)	Power Generated (mW)	Power Mass Density (mW/g)
1	56	140	2.5
2	150	1600	10.7

Research about wearable energy harvester for human motion is conducted by Jiahong Lin and Huicong Liu [12]. They used rotational movement instead of linear movement. The same type of magnet which is NdFeB is used in their experiment. Their design mainly consists of a casing, a cover, a stator, a rotor, and wound coils Figure 2.5 and 2.6. The stator and rotor are both made of NdFeB magnet. The cylindrical stator magnet is fixed in the center of the casing, and the disk-shaped rotor magnet is attached on the edge of the stator by magnetic attractive force. Without assembling any shaft or bearing structure, the stator and rotor magnets formed a higher pair have theoretical line contact. It enables the rotor magnet

easily rotate around the center stator magnet at low frequency vibration and avoids unnecessary surface friction.

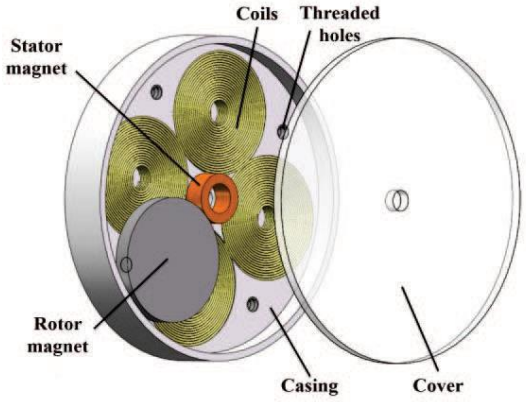

Figure 2.5: 3-D schematic view of the designed energy harvester[12].

Figure 2.6:The fabricated prototype of the energy harvester with a wristwatch for size comparison[12].

Based on the results, the harvester shows a good performance in EH. When running at 8 km/h by using a pair of magnetic stator and rotor, the measured maximum Vpp is 1.92 V and corresponding power density obtained is 0.2 mW/cm3 [12].

2.2.2 High Power Energy Harvesting

In order to power up high power devices, high power generator need to be choose. In 2016, Méndez-Gayol and his research group from University of Oviedo in Spain proposed a research about working in a smart grid for a sustainable gym[13], where all the electric energy generated by sport machines, is injected into the grid. People who come to the gym not only burn their calories but give power to gym as well[14]. They used permanents magnets generators (PMG) mounted to bicycle to mimic gym training bicycle that will produce three phase AC voltage and rectify it to DC voltage. Before it be injected to the grid it need to be boosted and convert backed to high ac voltage. Some of the energy produced is used to light up the gym itself as shown in Figure 2.7 [15].

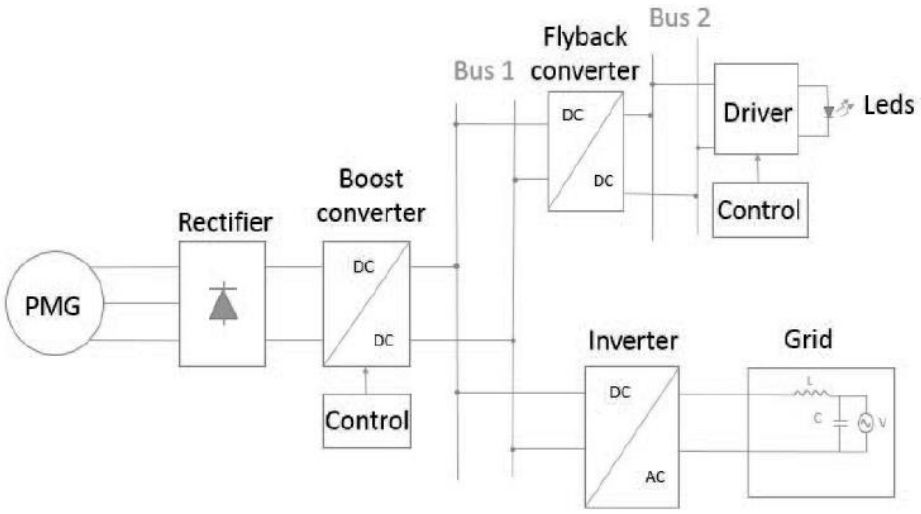

Figure 2.7: Block diagram of the smart grid[15].

In their research they use different values of load and speed to determine value of current draw and power produce by the generator while pedaling.

In 2015, Swati.M. Mudaliar used similar method as Méndez-Gayol to harvest energy which is using bicycle pedal system[16]. In her experiment she compared two types of generator which are brushless dc (BLDC) and permanent magnet dc (PMDC) generator output power by fixing the output load with 75 ohms 8-watt resistance. Then, five persons with non-athlete background and different weight variation to generate the energy. The result shows that BLDC is more efficient to generate energy than PMDC but she did not mention voltage and speed rate of both generators in her research Table 2.3.

Table 2.3: Observation table [13].

Peddler	Weight of person (kg)	Duration of cycling (min)	Average RPM BLDC	Average RPM PMDC	Average watts (BLDC)	Average watts (PMDC)
PERSON 1	40	5	257.1	408.548	0.2374	0.0187
PERSON 2	57	5	346.875	613	0.6436	0.0419
PERSON 3	65	5	360.363	568.363	0.5650	0.0378
PERSON 4	72	5	398.125	541.2	0.6833	0.0343
PERSON 5	80	5	461.63	665.466	0.8885	0.0521

2.3 Working Principle Permanent Magnet Direct Current Generator

Permanent magnet direct current machine can be used as motor or as generator as the construction between both of them are the same. When current is injected to the PMDC machine it become motor to move mechanical load, or the PMDC machine driven mechanically it will generate output voltage. There are two typical DC generators construction which are shunt wound DC generator and series wound DC generator as shown

in Figure 2.8. The weakness of this generator is self-excited which cause a small changes of the load current, the output voltage will have severe changes too.

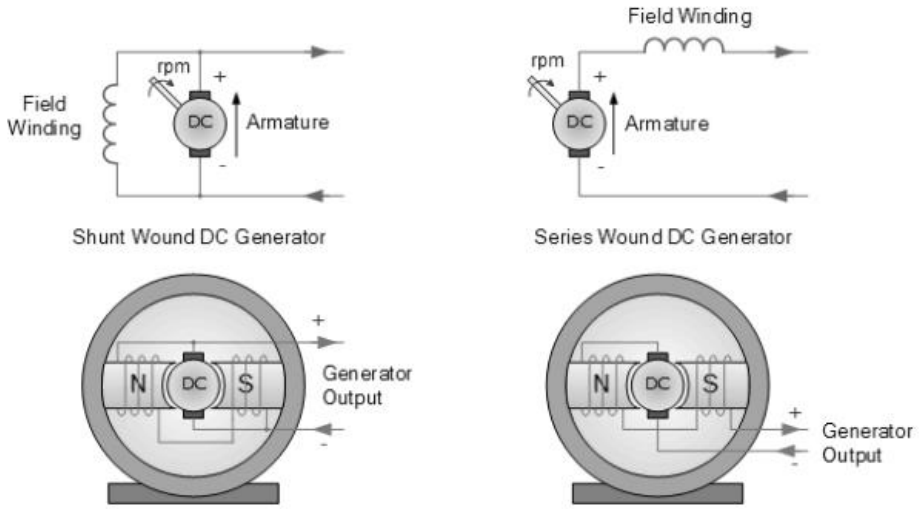

Figure 2.8: DC Generator Construction. (left) Shunt wound DC Generator (right) Series wound DC generator.

To counter the weakness, self-power field winding called separately excited DC generator but its need power to generate power as in Figure 2.9. Replacing field winding with permanent magnet is one of the way.

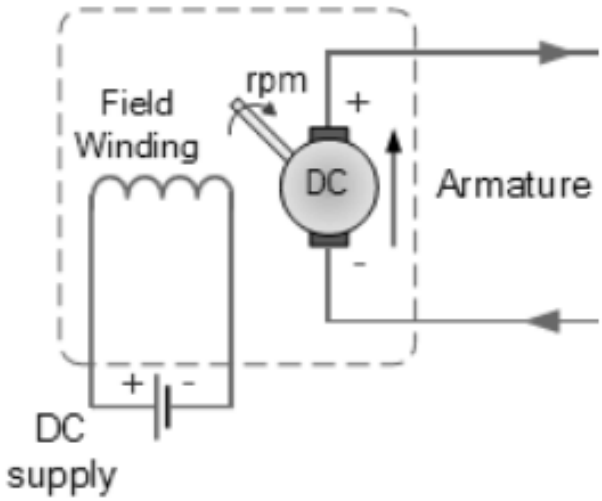

Figure 2.9: Separately Excited DC Generator.

The PMDC generator can be considered as a separately excited DC brushed motor with a constant magnetic flux. When PMDC machine is used as generator, the motor need to drive a lot faster than it rated speed to produce near to rated motor voltage. The low rpm DC machine is more suitable to make as DC generator. The main advantage of permanent DC generator is its respond very quickly on change of speed of the rotor because of the strong stator field is always constant and generally lighter than wound stator machine. Besides, it's give better efficiency because of there is no field winding and coil losses.

There are three factors that affect DC voltage generated by PMDC generator. First, the magnetic field develop on the stator itself. Its depend on its size of the generator and strength of the magnet used which is depend on the type of the magnet used. Secondly, the number of turn or loop of wire on the armature which affect the generation of DC voltage. The more the winding on armature the higher the output voltage. In term of the wire use for loop, the larger the diameter of the wire used the higher current produced. Lastly, the rotational speed of armature is proportional to the output voltage and is generally linear.

2.4 Principle Operation of Bicycle

Too improve the cycling performance, several technical solutions have been developed such as elliptic chain rings, pedal-crank systems with varying lengths or independent crank arms. The effect of these system is small. Franz Höchtl and his research team [17] studied the prediction of energy efficient pedal forces in cycling using musculoskeletal simulation models .

In his experiment, a task to maximize pedaling efficiency by apply force to the crank on certain angle was given to the athlete Figure 2.10. The result from the experiment showed the most efficient way to pedal a bicycle is by apply force on sector 2 with contribution of 90% efficiency overall crank rotation with only 35% efficiency.

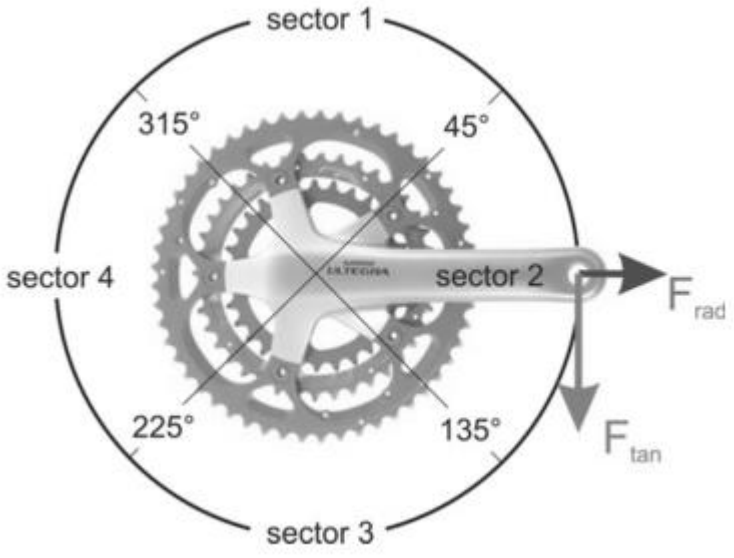

Figure 2.10: Tangential and radial forces applied on the right pedal, used for the calculation of Index of Efficiency[17].

2.5 Energy Storage Management

Lead-acid batteries are constructed with two electrodes. The positive electrode which is the anode is made from a lead antimony alloy with lead (IV) oxide pressed into it while the negative electrode which is the cathode is made from pure lead and both electrodes are immersed in sulphuric acid. When the battery is discharged, water is produced, diluting the acid and reducing its specific gravity. While in charging process the sulphuric acid is produced and the specific gravity of the electrolyte increases [18, 19].

2.5.1 Storage Capacity

The capacity of a battery is usually expressed as a number of ampere-hours (Ah). One ampere-hour is the amount charge delivered when a current of one ampere is delivered for one hour. Since the capacity of lead-acid batteries depend on the rate at which they are discharged a discharge rate is also set[20].

2.5.2 State of Charge

There are two main methods for determining the state of charge for lead-acid batteries which are terminal voltage and specific gravity. The terminal voltage method determines by the open circuit voltage when no current flowing. If the voltage is measured with the charging current flowing it will be increased by the voltage drop across the internal resistance. While in discharging state the measured voltage will drop due to the internal resistance of the cell Table 2.4. Another method to determine state of charge is specific gravity method. This method is recommended to the battery which is not sealed and a hydrometer can get into the battery [21].

Table 2.4: The approximate battery and cell voltages for various states of charge [16].

State of Charge(approx.,)	12 Volt Battery	Volt per Cell
100%	12.70	2.12
90%	12.50	2.08
80%	12.42	2.07
70%	12.32	2.05
60%	12.20	2.03
50%	12.06	2.01
40%	11.90	1.98
30%	11.75	1.96
20%	11.58	1.93
10%	11.31	1.89
0%	10.50	1.75

The charging voltage must be higher than the battery voltage for current to flow into the battery [20]. There are two basic ways to charge a lead-acid battery from an uninterrupted supply which are constant voltage charge and constant current charge. A constant voltage is applied across the battery terminals. As the voltage of the battery increases the charging current tapers off but his method requires simple equipment but it not recommended. While the constant current charge, an adjustable voltage source or a variable resistor maintains a constant current flows into the battery. Thus it requires a sophisticated charge controller circuit.

2.6 Summary

There are various types of kinetic energy harvester has been research and invented in the past few years. Each harvester has its own working principle. The research about human kinetic energy harvesting discussed in the previous section is summarized in Table 2.5.

Table 2.2: Previous Work on Human Energy Harvesting.

Authors	Types of motion/source	Type of transducer used/working principle	Output obtained from the technique used
Michele Magno[8]	Body temperature	thermal energy	Power density produce 25µW/cm^2
E. M. Y. P. D. Mitcheson[22]	Hand swing	electromagnetic oscillating rotational generators.	Output power at 55Hz and 14.9 ms^{-2} in the range of 0.61µW at 18mV
Shenck and Paradiso[11]	Walking	piezoelectric	Output power at 299Hz and 4.9ms^{-2} in the range of 3.981µW at 4.5V
M. H. Mohammadi and M. Poshtan[23]	Shaking	PM synchronous generator	LPM SG tube with a 2cm packed 0.28mm wire solenoid of about 975 turns with triple ring magnets and two sponges at either end produced 729mW
Jiahong Lin and Huicong Liu[12]	Running	Rotational/swing movement of PM	power density of 0.2 mW/cm^3 at 1.29V produced after 8 km/h running
Méndez-Gayol[15]	Pedaling	permanents magnets generators	with the load of 100 ohms the power produce in the range of 2.6W to 102.2W from 925.3 rpm to 6122.6 rpm
Swati.M. Mudaliar**[**16]	Pedaling	BLDC and PMDC generator	By 5 minutes cycling and from range of 40 kg to 80 kg participant weight and 75-ohm load -Power produce by BLDC is 0.2374W to 0.8885W -power produce by PMDC is 0.0187W to 0.0521W

This study will be focuses in details about factor that can affect the amount of electrical energy produced by cycling motion. Factors such as human body weight and speed of cycling will be investigated. Both technique and method applied by previous researcher will be used as the basis of the study. PMDC generator is used as transducer and the output of the generator on speed and amount of load will be investigated. The research on time taken and energy used to full charge the 12V lead acid battery will also be studied and analyzed to ease the further investigation on pedal power energy harvesting capability.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter presents and explains the methodology on the pedal power energy harvesting. Figure 3.1 shows the flow of the methodology of this study.

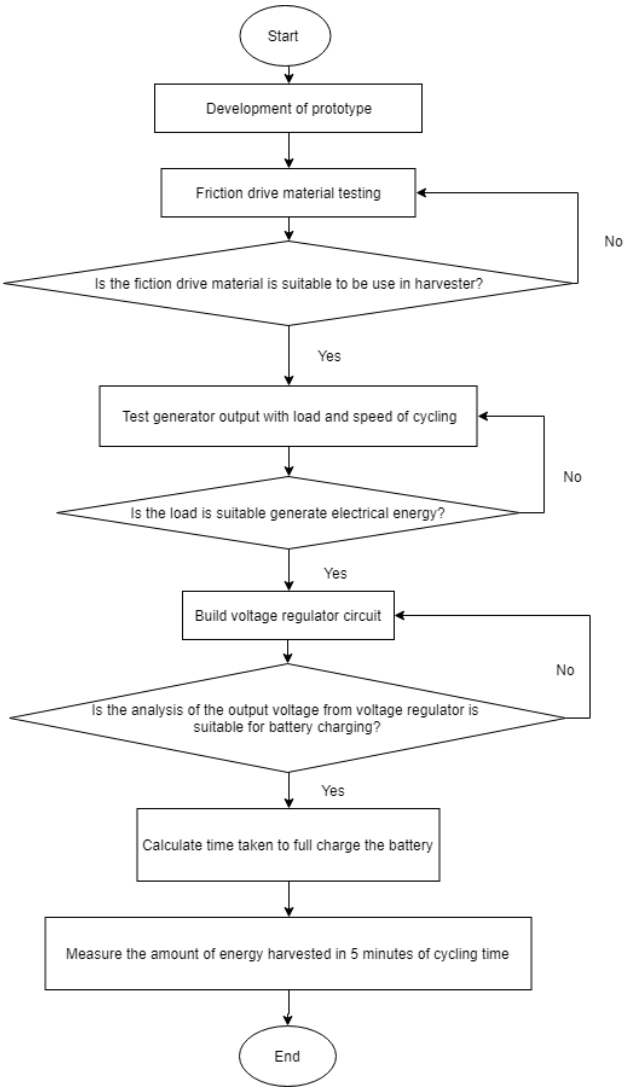

Figure 3.1: Flowchart of methodology.

Initially, the prototype need to be built to mount PMDC generator and the friction drive system so it can be test. The material for friction drive need to be chosen before full test because there are heat and force involve with the system. After suitable material was selected, the test on generator was carried out. Since the output of the generator is proportional to the speed and load, speed and load test need to be held and the data are collected to analyze the raw output of the generator.

Then the regulator circuit was built in order to regulate the voltage generated by the generator. So, the voltage is suitable for charging the lead acid battery. After suitable output voltage was determined, the controller circuit was built for safety purpose which will isolate the voltage of the battery and the speed of the generator. It will cut off the power input to the battery when the battery is full and at minimum state to avoid over charge and discharge which can harm the battery itself. Finally, test charge will be held to record the time taken and calculate the energy needed to full charge the battery by different speed of cycled.

3.2 Component Selection

In this section, several components were selected to build a harvester such as PMDC generator, Arduino, switch relay, voltage regulator and rechargeable lead acid battery. Figure 3.2 shows the block diagram of the harvester and components needed. The PMDC generator was used to convert the kinetic energy into electrical energy. The Arduino will be used to isolate the voltage of the battery, cut off the power input to the battery when the battery is full and at minimum state to avoid over charge and discharge which can harm the battery itself isolate the speed of generator too. The regulator was use to regulate the voltage to

requirement voltage for charging the battery. Lastly, the rechargeable battery is used to prove this harvester can store the energy produce to the battery.

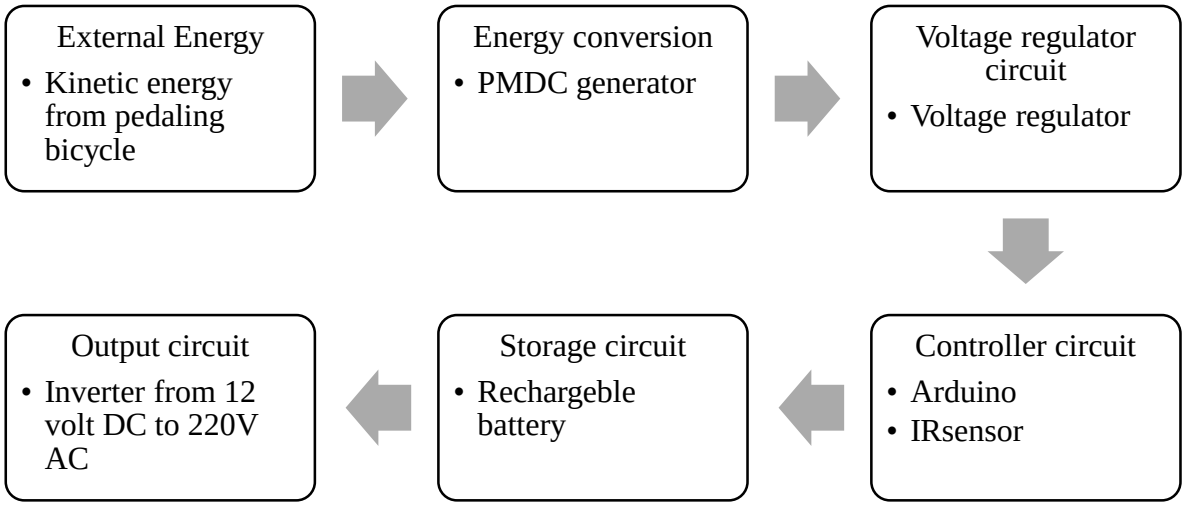

Figure 3.2: Block diagram of harvester and the component needed.

3.2.1 Design of Prototype

The prototype is designed with SolidWorks software due to make the harvester portable and convenient to the user. The design consists of bicycle rear tire stand with ribs ① to make it sturdy and can handle the weight of the cyclist, adjustable base with hinge ② and threaded screw ③ to engage the friction shaft from the generator to the rear tire of the bicycle ④ as shown in Figure 3.3. It is made of wood to minimize the total weight. Several bracket and screw are used to assemble the prototype. In order to hang the rear tire of the bicycle to the prototype shaft with threaded hole ⑤ is use to extend the length of the original shaft. Figure 3.4 shows the energy flow from human to the friction drive shaft.

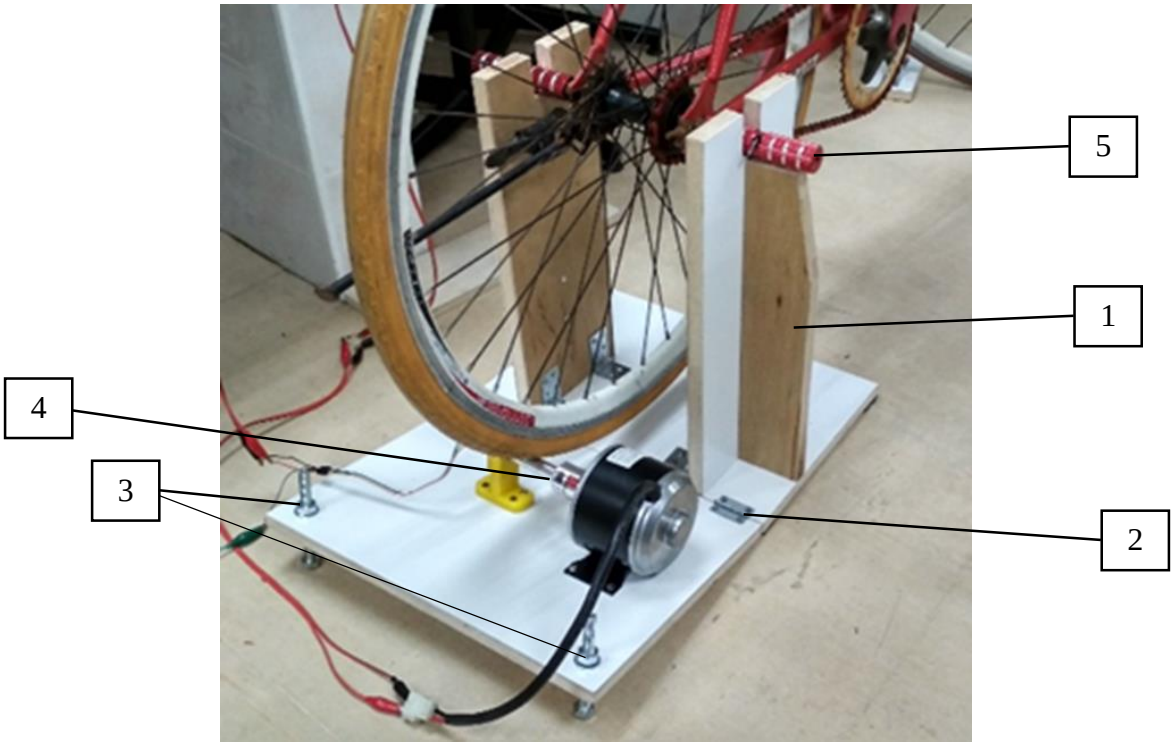

Figure 3.3: Prototype of pedal power energy harvesting.

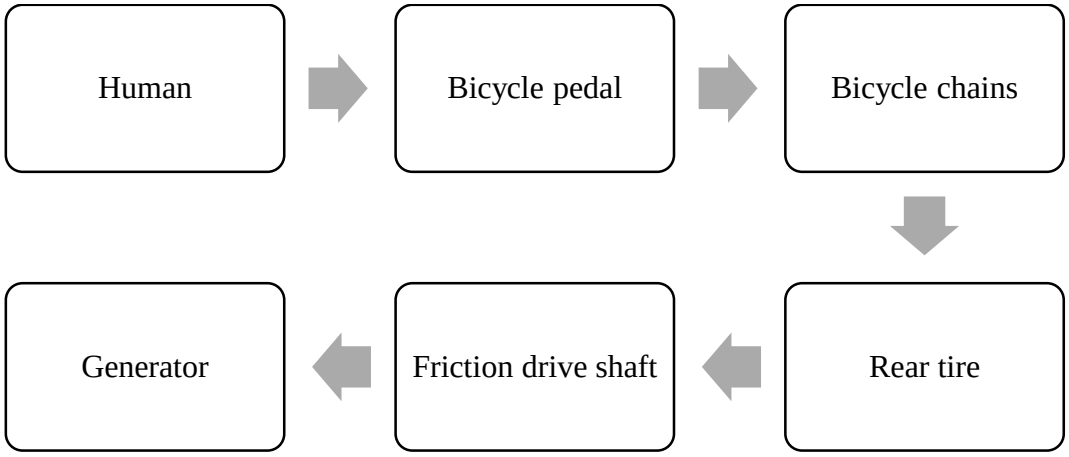

Figure 3.4: Flow of energy transfer from human to friction drive shaft.