

Development of a Magnetically Levitating Flywheel Generator

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Abstract. The energy sector has been at a crossroads for a rather long period of time when it comes to storage and use of its energy. The purpose of this study is to build a system that can store and disseminate energy in a simple and affordable way, which can be improved with more research with this study serving as a foundation. For this study, energy generation and even control engineering was integrated with the field of material science by evaluating the energy storage in the said material. After the completion of the bearing system, the flywheel levitated at about 20mm above the assembly area and it spins for a relatively long period of about 25s by producing a kinetic energy of 35J at an rpm of 320. This newly developed alternative way of generating electricity by using kinetic energy produces 10v of electricity. This study provides an insight of magnetism in bearing systems for the next evolution of renewable energy.

1 Introduction

The limitations of both renewable and non-renewable energy bring about the need for a third alternative for power generations such as self-sustaining generators. These are generators which would in theory can use the energy added to its systems initially to then fuel itself and thus effectively creates a “perpetual motion machine”. Now unfortunately in the current age of science and technology there have been no advancement to such a degree that allow for the breakdown of the laws of physics, but we can try to create a system which can act as such if only for a short period of time, a kind of “Pseudo-perpetual motion machine” if you will. Power is not always available in most developing nation which can be detrimental in many cases. It would be advantageous to have a turbine which could run on nothing more that kinetic energy while giving the added benefits of having next to no noise and no fumes or dangerous emissions.

A flywheel is a body that could store kinetic energy imparted to it by an external force. In this sense it is a mechanical storage device which can emulate the storage of electrical energy by converting it instead to mechanical energy. The input energy for a Flywheel energy storage system is usually drawn from an electrical source coming from the grid or any other source of electrical energy. As more energy is imparted into a flywheel it speeds up as it stores more energy and slows down when it loses the said energy[1], [2]. Although, the existing lithium-ion battery has a high energy density but high cost in term of power capacity

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and less power density. These features make it popular in applications that requires high energy and overall weight consideration, such as in electronics and automobiles. In order to avoid friction loss, magnetic bearing systems are often incorporated with most energy storage flywheels, which makes the device store save energy over a long period of time at a very high efficiency[3]. A study projected that in the year 2030, li-ion batteries would show great advantage over other source of energy[4]. However, flywheel energy storage systems are still very efficient and competitive for most applications that requires frequent charge/discharge at many cycles. There is less environmental pollution with flywheels when compared with other alternatives, since it contains no chemicals, this feature give flywheel energy storage system advantages for the use of electrical grid to smoothing power output and to ensure an improved efficiency in terms of power distribution from renewable energy sources[5]. Most UPS, power pulsation and hybrid vehicles also implement flywheel energy storage system due its faster response time and the high-power density features

Several review papers address different aspects of FESS research[6][7]. Many have focused on its application in renewable energies [5], especially in power smoothing for wind turbines[8][9]. In a typical FESS system rotating flywheel is driven by an electrical motor-generator performing the interchange of electrical energy to mechanical energy, and vice versa where it is needed.

The aim of this project is to research and build a turbine powered by Kinetic energy to produce voltages ranging from 10 volts or higher. Flywheel turbine that is held magnetically locked in a static position allowing it to move freely without being affected by contact forces will be built, and the system that can regulate and generate electric current which can be stored in a battery will be ensured. Lastly this study aims to incorporate an embedded system capable of regulating multiple parameters of the system in order to ensure smooth running of the turbine. The schematic for this developed device will be presented and explained in detail.

2 Methodology

The design calculation and construction of various components of the device such as the Flywheel, Shaft, Magnetic bearing assembly, alternator magnet array, winding array are presented in this section.

2.1 Design and Assembly of Rotor

The rotor consists of two slices of aluminum with spaces cut in them for the neodymium magnets to lie as seen in Figure 1.

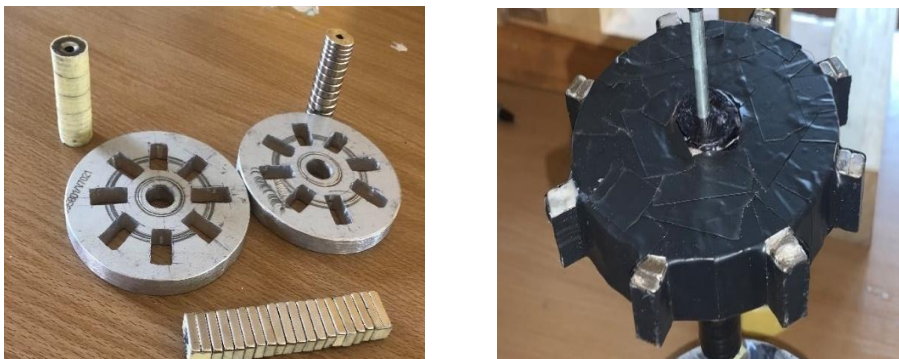


Figure 1: Rotor Assembly

Diameter of Rotors, $d_o = 100mm$
 Thickness of rotors, $h = 10mm$
 Magnet Dimensions = $20 \times 10 \times 5 mm$
 Density of Neodymium = $7.5 \times 10^{-6} kg/mm^3$

$$\begin{aligned} \text{Volume of Rotors} &= \pi h(r_o^2 - r_i^2) \\ &= \pi \times 10 \times (50^2 - 8^2) \\ &= 76529.1970 mm^3 \end{aligned}$$

$$\begin{aligned} \text{For the two slices, the total volume} &= 2 \times 76529.1970 \\ &= 153058.3940 mm^3 \end{aligned}$$

$$\begin{aligned} \text{Total Volume of Magnets} &= 1000 \times 16 \\ &= 16000 mm^3 \end{aligned}$$

$$\begin{aligned} \text{Mass of Magnets} &= 16000 \times 7.5 \times 10^{-6} \\ &= 0.12 kg \end{aligned}$$

$$\begin{aligned} \text{Volume of Vacant Rotor Cylinders} &= 153058.3940 - 16000 \\ &= 137058.394 mm^3 \end{aligned}$$

$$\begin{aligned} \text{Mass of Vacant Rotor Cylinders} &= 137058.398 \times 2.7 \times 10^{-6} \\ &= 0.37kg \end{aligned}$$

$$\begin{aligned} \text{Total Weight of Rotor} &= 0.37 + 0.12 \\ &= 0.49 kg \end{aligned}$$

2.2 Design and Assembly of Shaft:

There are two (2) shafts in the Layout of the system, one which will hold the flywheel and another which will hold the “Driver Magnet”. Thus, Design of Shaft is to be calculated in order to find the proper shaft diameter which would withstand the load easily and to ensure the maximum energy is transferred with minimum loss. As the body in question is not restricted or bound at any end, there is no torsional stress but only that of bending.

$$\text{Yield strength} = 1.65474N/mm^2,$$

$$\text{Length of the shaft } L = 400mm$$

$$\text{Density of the shaft} = 7.84 \times 10^{-6} kg/mm^3$$

For this engine, the flywheel is fixed/assembled on the shaft along with the alternator configuration and 2 sets of 8 ring neodymium magnets combined to form part of the magnetic bearing system on set distances to form the shaft assembly as seen in Figure 2a & 2b.

2.3 Design of Flywheel:

This study is centered toward the generation of energy by using the kinetic energy as well as using magnetic energy to keep motion continuous. Thus, a flywheel of mass 1.5kg was chosen, that can utilize the gravitational energy and give a successful output. The density of Aluminum = $2.7 \times 10^{-6} kg/mm^3$ [10], Outer Diameter of cylinder, $d_o = 153 mm$, Inner Diameter of cylinder, $d_i = 16 mm$, and Thickness of cylinder, $h = 30 mm$. Hence;

$$\text{Volume of Flywheel, } V = \text{Volume of Outer Cylinder} - \text{Volume of Inner Cylinder}$$

$$\begin{aligned} V &= (\pi r_o^2 h) - (\pi r_i^2 h) \\ &= \pi h(r_o^2 - r_i^2) \\ &= \pi \times 30 \times (76.5^2 - 8^2) \\ &= 545529.710 mm^3 \end{aligned}$$

Therefore, the mass, M is given as,

$$M = \text{Density} \times \text{Volume}$$

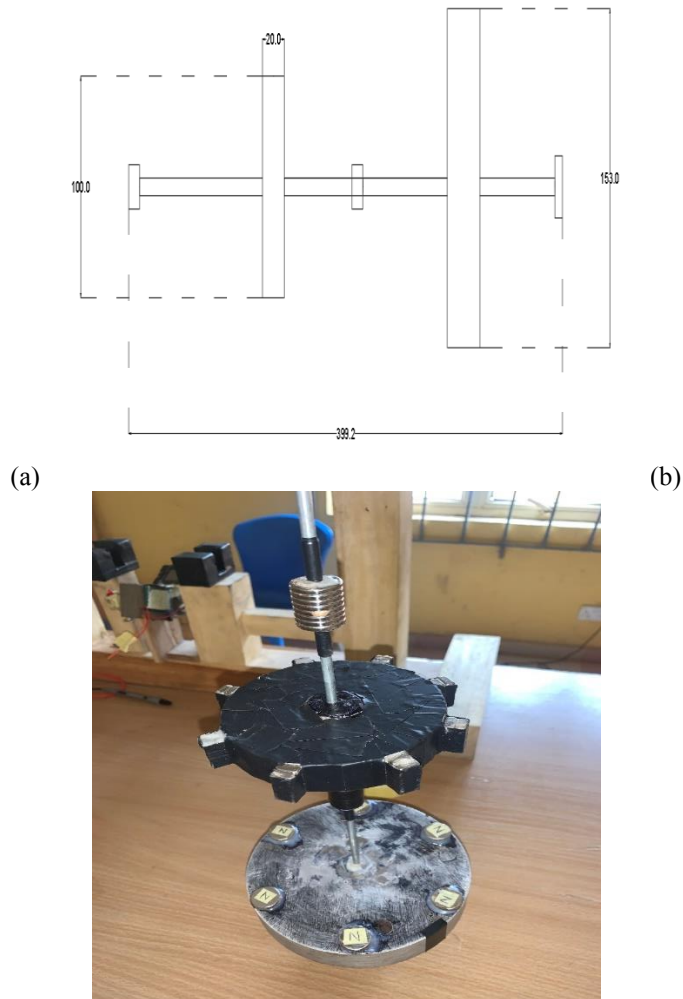


Figure 2: (a) Isometric view of the Shaft, (b) Complete Shaft Assembly

$$\begin{aligned} &= 2.7 \times 10^{-6} \times 545529.710 \\ &= 1.4729 \text{ kg} \sim 1.5 \text{ kg} \end{aligned}$$

2.4 Design of Frame:

The frame is the component that holds all the weight and a stable vibration must be ensured. For this purpose, it needs to be made of sturdy materials but also be lightweight wherever possible. The frame is constructed with hardwood, which is naturally sturdy in order to negate vibrations that may occur due to the rotation of the shaft it holds. It holds other members/links on it using wood and nails along with other techniques such as tenon etc. its dimension and assembly is shown in Figure 3.

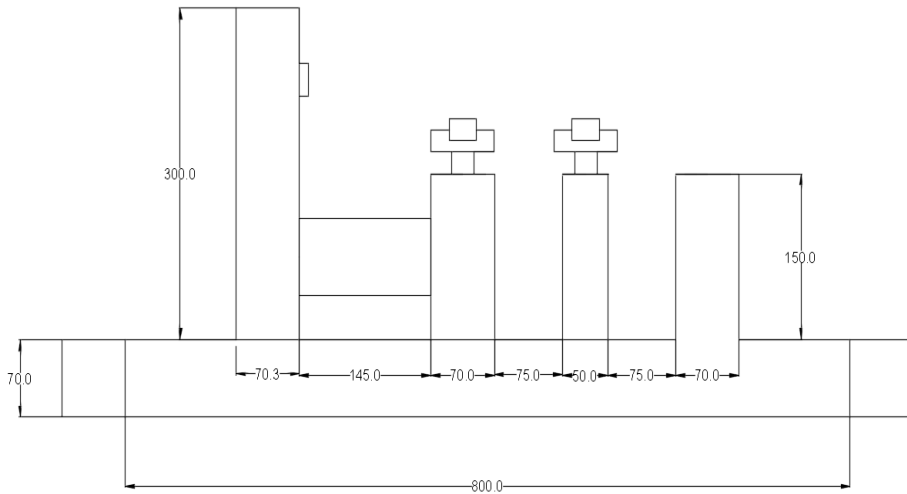


Figure 3: Frame Assembly

2.5 Design of Alternator and the Driver electromagnet Configuration:

As this is where the energy generation takes place, the energy output and current generated in the coil would be calculated for this specification. Also, the electromagnet configuration is an important system as it is required to add energy back into the system when needed in order to keep its momentum. It comprises of a number of different components all coming together to make the system working harmoniously.

Formula for both Energy stored in a flywheel, “K.E” and Inertia, “I” are as follows

$$K.E = \frac{1}{2} i \omega^2, \quad I = \frac{1}{2} m r^2$$

For the inertia of the Flywheel and rotor, we have

$$I = \left(\frac{1}{2} \times (1.4729) \times 0.0685\right) + \left(\frac{1}{2} \times (0.4982) \times 0.042\right) \\ = 0.06091 \text{ kg/m}^2$$

After getting this, we then insert this into the equation for kinetic energy

$$K.E = \frac{1}{2} \times 0.06091 \times \omega^2 \\ = 0.03045 \omega^2$$

This will serve as the relationship model for speed and kinetic energy of the flywheel.

The winding is built using the remains from a used transformer as shown in Figure 4, while salvaging the iron core. The windings inside were replaced with new ones of different diameter or gauges. The transformers were cut out from the “I” and “E” configuration to form the winding.

The winding is able to magnify the changing magnet field emanating from the rotor. The change in the magnet fields/flux then induces current into the coil. The stator winding has 3000 turns in total of copper enameled winding with a resistance of 556Ω, and made of 32 standard wire gauge which is built on the core of a transformer to enhance the magnetic field and thus increase the output generated in order for energy generation at lower rpm values.

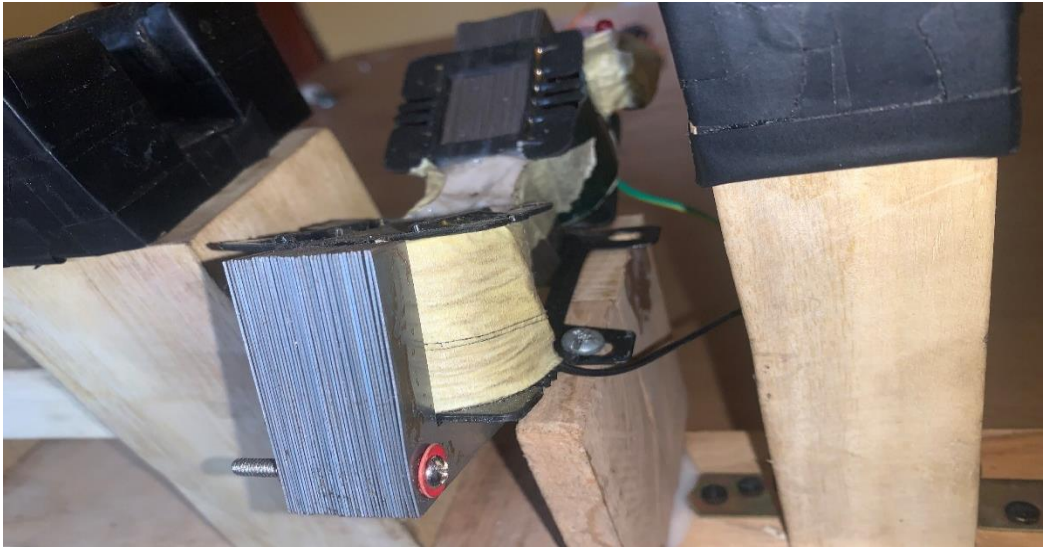


Figure 4: Stator Winding

2.6 Design of the Control System

The Arduino microcontroller was chosen for its ability to used input and give out instructions to multiple components and or devices to create a controlled system with the use of little power. It accomplishes this by employing its core CPU to evaluate data received from its I/O peripherals. Another important component incorporated to the system is the hall effect sensor, which gives the microcontroller the values it needs to carry out its operations. The KY-035 sensor operates by sensing the magnitude of a magnet in close proximity to it and giving a signal to the user as it does as shown in Figure 5. It has an output current of 10mA and supply voltage of 5V, with an operation temperature ranging from 40 to 100°C[11].

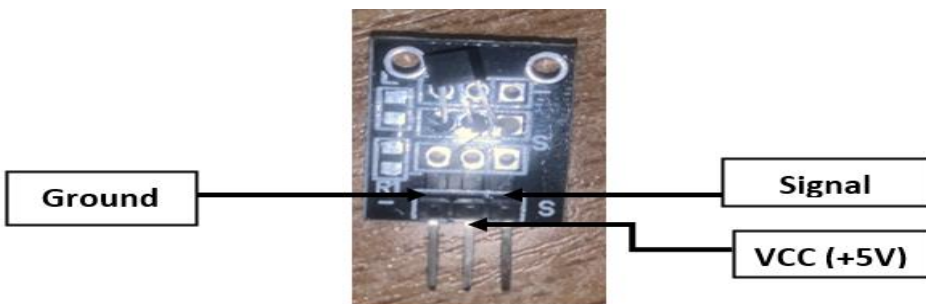


Figure 5: KY-035 Hall Effect Sensor

The 5v relay chosen has a maximum contact voltage of 250VAC with a current of 70mA when relay is active and a Quiescent current of 2mA As shown in Figure 6. Relays is an electromechanical device that uses an electric current to open or close the contacts of a

switch, in this case it closes and open the gate to the output of the flywheel which will then power the coil.

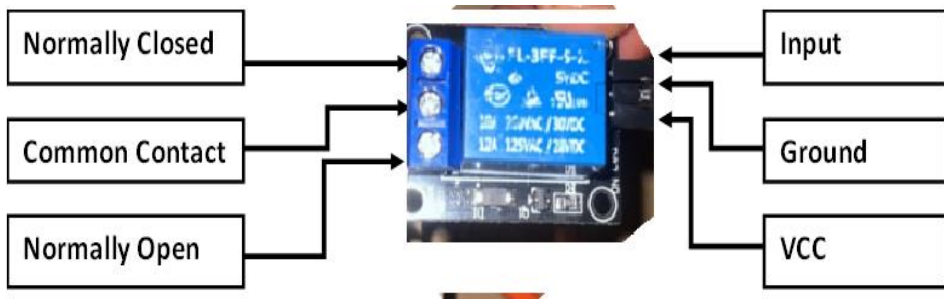


Figure 6: 5v Relay

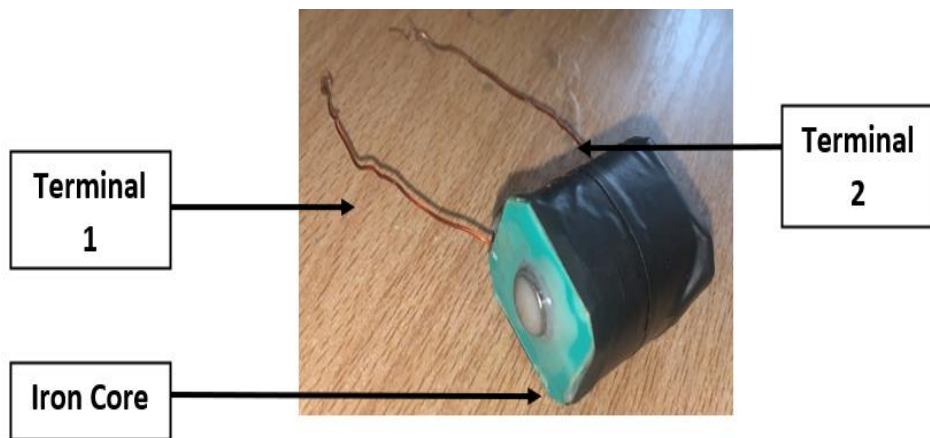


Figure 7: Wound Coil

The solenoid is a component connected to the relay in which voltage will flow to energize it creating the magnetic field needed to move the flywheel. It was built in order to fit in between the magnets on the flywheel so as to more efficiently push the magnets when powered by the relay. It was made by winding a length of enameled copper wiring on an iron bolt, the bolt was then cut to fit in the winding and also act as the poles for the magnetic field as shown in Figure 7. It has 200 turns in total of copper enameled wiring with a resistance of 2.2Ω , which comprises of 21 standard wire guage and implement a supply current of greater than 100mA. The control system is set up in a number of ways and to simplify the process in the chart in Figure 8. The system is built to sense the magnetic field of the magnets on the flywheel and send a value of "1" or "0" back to the Arduino, depending on the users selected key on the remote the Arduino then send a signal to the relay allowing power from the flywheel into the solenoid, this will then create a magnetic field which will then propel the flywheel in short burst giving it acceleration in a given direction. By using the remote control, the speed of the frequency as which the coil is energized is controlled which will then control the speed of the flywheel to one of three (3) set values.

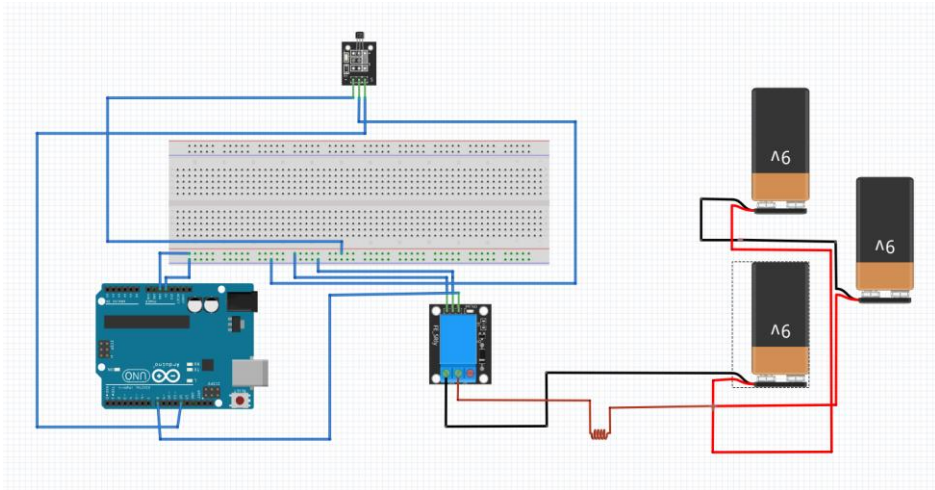


Figure 8: Schematic Diagram of control system

The flywheel is connected to a shaft that transmits its rotational energy to the alternator rotor. The alternator array is made of two slides of aluminum plates that are fitted with magnets which will induce current into windings located between them. The current induced in the windings (coils) will then be deposited in a battery after rectification. Some of this energy will be used to move a motor which will spin the flywheel further with the aid of a control system and a magnetic gear system, keeping the system moving. The energy generation process begins when the operator imbues the flywheel with rotational energy, after the rotational speed of the flywheel reaches a “threshold” speed and the specified energy levels are reached the energy collected instantaneously by the coils will be fed to the electrical hub. In this electrical hub the volts of electricity are separated by the control unit in which a portion is saved to a battery and the other is sent to a motor located on the frame. This motor located above the flywheel vertically and in front of it horizontally will then spin a magnet which is magnetically linked to the magnets on the flywheel thus adding energy back into the system keeping the system in motion until it is turned off by the operator. The control system will then be used to vary the speed depending on the user’s needs.

3. Result and Discussion

The generator after it was designed and built was tested on various parameters such as, Rotational speed, Ac voltage, Dc voltage, Time of revolution, Time after stator induction, Flywheel levitation. After the acquisition of the tools and the connections made wherever needed, actions were taken to make sure the values and results were gotten correctly. The flywheel was then spun by hand after which the tachometer was used as well as the values on the multimeter taken down before being tabulated. The values to be calculated were done carefully as shown in Table 1. The information was collated into different graphs for analysis purposes.

Table 1. Table of Test Values

Angular Speed (RPM)	Angular Speed (rad/s)	Avg Stopping Time (t)	AC Voltage (V1)	DC Voltage (V2)	Percentage Loss (%)	Kinetic Energy (J)
91.00	9.53	11.44	2.91	1.83	37.11	2.77
125.00	13.09	12.79	4.22	2.58	38.86	5.22
127.00	13.30	15.70	4.47	2.61	41.61	5.39
182.00	19.06	17.21	5.21	3.56	31.67	11.06
243.00	25.45	19.81	6.91	4.54	34.30	19.72
273.00	28.59	20.90	7.47	5.19	30.52	24.89
320.00	33.51	24.58	8.29	6.02	27.38	34.20

3.1 Kinetic Energy and DC voltage

Using the Data from the table 1, after plotting the values on a graph, it is shown that the DC voltage induced into the stator is directly proportional to the kinetic energy imbued into the flywheel and as such with increase in the power able to be transferred to it, the voltage output as well as the current will increase exponentially as seen in the Figure 9.

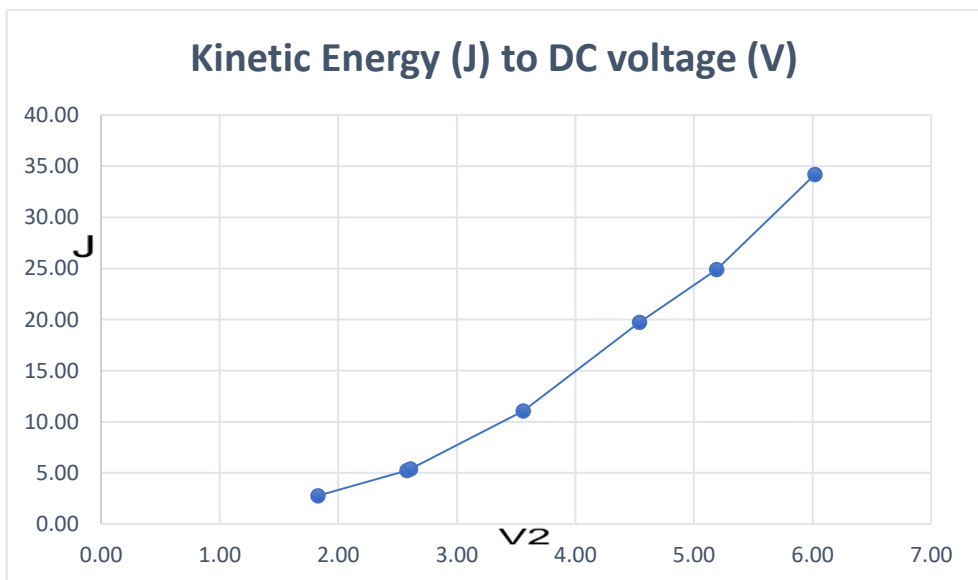


Figure 9: Chart of Kinetic Energy to Voltage

3.2 Variation of Voltages to the Angular Speed.

Similar to the DC voltage, the AC voltage also progresses linearly with respect to the angular speed as shown in Figure 10, but seems to progress faster than its direct counterpart, although the percentage losses in the voltage seems to suggest enough time the voltages will coincide which would be a very novel finding, as suggested by a similar study[12].

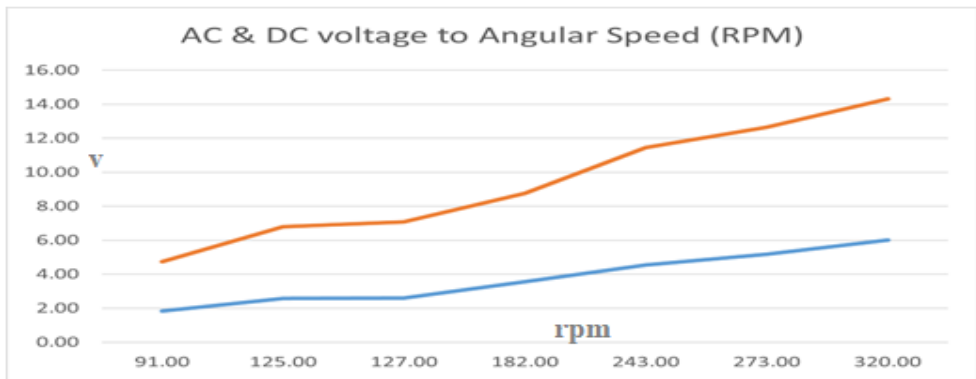


Figure 10: Figure of voltages to Angular speed.

3.3 Kinetic Energy to Stopping Time

Due to having lowered friction due to the hybrid system, the flywheel was able to spin for longer and using a stop-watch to measure the time between start of the rotation and its end, the values were tabulated and it can be seen that all values increased with respect to the kinetic energy given to the system as shown in Figure 11.

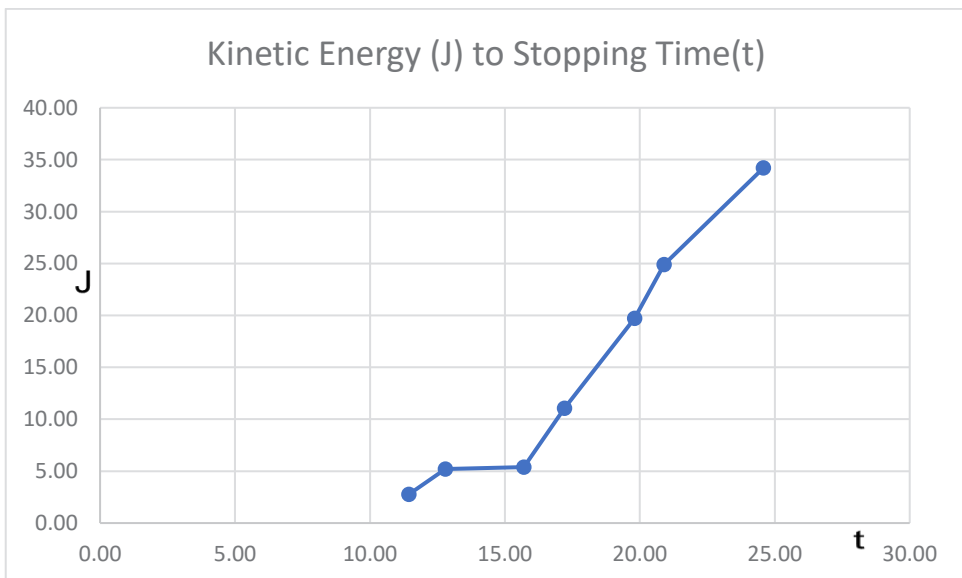


Figure 11: Chart of Kinetic Energy against Stopping Time

3.5 Comparison Between Flywheel and Batteries

The developed flywheel storage system is compared with the existing Valve regulated lead acid batteries and it shows great advantages in many aspects as presented in Table 2.

Table 2: Comparison between flywheel and Batteries

Category	Flywheel (7075 Aluminium)	Batteries
Maintenance	Limited	Extensive
Power Efficiency	93%	86%
Total energy storage weight for 1MW (kg)	3,213	14,760
Hazardous Material	None	yes
Total embedded carbon (CO2/kg)	6,785	16,750
Average Operating temperature	40 °	25 °
Embedded carbon emission (CO2/kg)	2.23	1.14
Total life cycle embedded carbon (CO2/kg)	6.785	67,002
Power Density (W/kg)	117	35
Life Expectancy	20years	5years

Conclusion

The aim of this study is to discover alternative ways of generating electricity by using kinetic energy as a case study, as such, the main aim of the project, which was to generate 10v of electricity was attained. The flywheel storage system technology is an interdisciplinary, complex subject that involves mechanical, electrical, and magnetic subsystems. This paper presents in detail the working principle of flywheel which stores the energy in the form of kinetic energy by rotating spinning the rotor of the flywheel, the flywheel rotor is made from materials exhibiting high tensile strength in order to withstand and ensure high rotational speed. Additionally, the shape of the rotor is a factor to be considered which affects the overall energy density of the flywheel. The combination of the motor and the generator helps in the power conversion for charging and discharging of the flywheel.

The flywheel is connected to a shaft that transmits its rotational energy to the alternator rotor. The alternator array is made of two slides of aluminum plates that are fitted with magnets which will induce current into windings located between them. The current induced in the windings (coils) will then be deposited in a battery after rectification. Some of this energy will be used to move a motor which will spin the flywheel further with the aid of a control system and a magnetic gear system, keeping the system moving.

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