MICRO POWER-GENERATION BY FLYWHEEL MULTIPLICATION OF OFF GRID SYSTEM

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A Project and Thesis submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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APPROVAL LETTER

This thesis report titled **"**Micro Power-Generation by Flywheel Multiplication of Off Grid System**",** submitted by Nitish Ranjan Mondol ID: 163-33-350, to the Department of Electrical and Electronic Engineering, Daffodil International University has been recognized as a partial supplement to the Under Graduate science phase of electrical and electronic engineering and confirmed as its style and material. The presentation has been held on 9th January 2020.

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Dedicated

to

Beloved My Parents

and

Teachers

DECLARATION

Here I, declare that this thesis is based on the results we receive. The work materials found by other researchers are referred by reference. This thesis is submitted to Daffodil International University for achieving B.Sc. degree of Electrical and electronics engineering. This thesis has not been fully submitted for any degree prior to the degree.

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TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLE

ACRONYMS

FESS- Flywheel Energy Storage System

ESS- Energy Storage Systems

ToU- Time of Use

UPS- Uninterruptible Force Supplies

FES- Flywheel Energy Storage

PMA- Permanent Magnet Alternator

RPM- Revolution Per Minute

PSC- Permanent Split Capacitor

MW- Mega Watt

KW- Kilo Watt

KE- Kinetic Energy

AC- Alternate Current

DC- Direct Current

SMB- Superconducting Magnetic Bearing

MSC- Machine Side Converter

GSC- Generator Side Converter

ABSTRACT

Micro power generation by flywheel multiplication, which is a kind of Flywheel Energy Storage Systems (FEGS) provide a means for improving the efficiency of electrical systems when there are imbalances between supply and demand. Additionally, they are a key element for improving the stability and quality of electrical networks. They add flexibility into the electrical system by mitigating the supply intermittency, recently made worse by an increased penetration of renewable generation. One energy storage technology now arousing great interest is the flywheel energy storage systems (FESS), since this technology can offer many advantages as an energy storage solution over the alternatives. Flywheels have attributes of a high cycle life, long operational life, high round-trip efficiency, high power density, low environmental impact, and can store mega joule (MJ) levels of energy with no upper limit when configured in banks. This paper presents a critical review of (FESS) in regards to its main components and applications, an approach not captured in earlier reviews. Additionally, earlier reviews do not include the most recent literature in this fast-moving Fifield. A description of the flywheel structure and its main components is provided, and different types of electric machines, power electronics converter topologies, and bearing systems for use in flywheel storage systems are discussed. The main applications of FESS are explained and commercially available flywheel prototypes for each application are described.

The paper concludes with recommendations for future research.

Keywords: energy storage systems (ESS); flywheel energy storage systems (FESS); power electronics converters; power quality improvement

CHAPTER 1

INTRIDUCTION

1.1 Background

The flywheel as a method for vitality stockpiling has existed for a huge number of years as one of the soonest mechanical vitality stockpiling frameworks. For instance, the potter's wheel was utilized as a rotatory article utilizing the flywheel impact to keep up its vitality under its very own inactivity. Flywheel applications were performed by comparable rotating objects, for example, the water wheel, machine, hand factories, and other revolving objects worked by individuals and creatures. These turning wheels from the medieval times don't vary from those utilized in the nineteenth or even twentieth hundreds of years. In the eighteenth century, the two significant improvements were metals supplanting wood in machine developments and the utilization of flywheels in steam motors. Advancements in cast iron and the generation of iron brought about the creation of flywheels in one complete piece, with more prominent snapshot of latency for a similar space. The word 'flywheel' showed up toward the start of the modern upheaval (to be specific in 1784). At the time, flywheels were utilized on steam motor pontoons and trains and as vitality aggregators in production lines. In nineteenth century, because of the improvements in cast iron and cast steel, huge flywheels with bended spokes were fabricated. The initial three-wheeled vehicle was worked by Benz in 1885 and can be named for instance. After some time, a few shapes and plans have been executed, however significant improvements came in the mid twentieth century, when rotor shapes and rotational anxieties were completely dissected, and flywheels were considered as potential vitality stockpiling frameworks. An early case of a flywheel framework utilized in transport was the Gyrobus, fueled by a 1500 kg flywheel, delivered in

Switzerland during the 1950s. During the 1960s and 1970s, FESS were proposed for electric vehicles, stationary force back up, and space missions. In the next years, fiber composite rotors were manufactured and tried. During the 1980s, moderately low-speed attractive course began to show up.

In spite of significant improvements during their beginning periods, the usage of flywheels has not been huge and has declined with the advancement of the electric network. Be that as it may, because of the ongoing upgrades in materials, attractive heading, power hardware, and the presentation of fast electric machines, FESS have been built up as a strong alternative for vitality stockpiling applications.

A flywheel stores vitality that depends on the pivoting mass guideline. It is a mechanical stockpiling gadget which copies the capacity of electrical vitality by changing over it to mechanical vitality. The vitality in a flywheel is put away as rotational dynamic vitality. The info vitality to the FESS is typically drawn from an electrical source originating from the matrix or some other wellspring of electrical vitality. The flywheel accelerates as it stores vitality and backs off when it is releasing, to convey the gathered vitality. The pivoting flywheel is driven by an electrical engine generator (MG) playing out the trade of electrical vitality to mechanical vitality, and the other way around. The flywheel and MG are coaxially associated, showing that controlling the MG empowers control of the flywheel

1.2 Significance of the study

Energy storage systems (ESS) can be utilized to adjust electrical energy organic market. The procedure includes changing over and putting away electrical energy from an accessible source into another type of energy, which can be changed over go into electrical energy when required. The types of energy storage transformation can be compound, mechanical, warm, or attractive. ESS empower power to be delivered when it is required and put away when the age surpasses the interest. Storage is valuable when there is a low interest, low age cost, or when the accessible energy sources are irregular. Simultaneously, put away energy can be devoured on occasion of popularity, high age cost, or when no elective age is accessible. Energy request keeps on expanding, as requested by the family units and businesses with high development rates in BRIC and creating nations. This has prompted increments in energy costs and conventional energy age strategies are less ready to adjust, worsening the issues because of market deregulation, power quality issues, and weights to confine carbon dioxide outflows. Sustainable power sources (RES) and potential appropriated age (DG) are considered as enhancements or substitutions for customary age techniques [3]; in any case, there are significant difficulties related with energy supply originating from renewables, because of their discontinuous nature over a scope of timescales. When RES are providing energy, there might be low interest, however when the energy is requested, it might surpass RES energy generation. Additionally, there are month to month, regular, and yearly changes in RES supply, as their accessibility is constantly liable to climate conditions. Then again, the energy request contrasts every now and then, which doesn't really coordinate the irregularities of RES, along these lines making dependability issues. Along these lines, ESS are a fundamental need to total customary producing plants so as to satisfy an over the top need, and supplement irregular RES for their combination into the electrical system.

As a partner to the present electrical system, there is a popularity for dependable, practical, durable, and naturally solid energy storage systems to help an assortment of energy storage applications. With progresses in materials innovation, orientation, and force gadgets, the innovation of flywheels for energy storage has essentially created.

The most widely recognized utilizations of flywheels in electrical energy storage are for uninterruptible force supplies (UPS) and force quality improvement. For these applications, the electrochemical battery is exceptionally befuddled and experiences a deficient cycle life, since the quantity of cycles every day is normally excessively high. The creators note this isn't really valid for some UPS with profoundly solid matrices, so storage is only occasionally called upon. Especially for power quality improvement, electrical aggravations are visit however short, with most by far of them going on for under 5s.

Such aggravations are adequately overseen by flywheels and offer an improvement over batteries considering the quick reaction time and longer life cycle of the previous. Indeed, even with one cycle a day, an electrochemical battery is probably not going to keep going for even 10 years under these conditions (3650 cycles). This must be accomplished if the profundity of release is kept low and the battery is painstakingly overseen, both electrically and thermally. It additionally requires determining an energy storage limit two to multiple times the necessary limit, to diminish the profundity of release, therefore prompting a greater expense.

Super capacitors have been tried for these sorts of utilizations; be that as it may, with pretty much a similar capital expense as flywheels, their operational lifetime is generally low (coming to as long as 12 years).

To utilize such a framework and limit its ability so as to lessen the cost, it is increasingly valuable for the storage framework to be utilized all the time, to consider the time moving of interest and to encourage into the lattice on occasion of appeal. Enthusiasm for this new worldview of how energy is utilized will be enormously improved once Time of Use (ToU) taxes are set up.

Various surveys of flywheel storage systems have been exhibited by a few papers in the writing. An examination of energy storage innovations is made in, where a numerical and graphical audit shows the upgrades and issues related with FESS. A near examination of energy storage advancements for high force applications is completed in and a review of FESS for power framework applications is given. FESS is quickly audited in and a review of some past tasks is exhibited, be that as it may, such sources offer a shortage of data. The creators of spotlight on the improvements of engine generator (M-G) for FESS, where the regular electrical machines utilized with flywheels, alongside their control, is accounted for. A survey and reenactment of FESS for a detached breeze power framework is introduced. This survey adopts an alternate strategy from prior work and especially gets on extremely ongoing writing in what is a quickly creating subject.

This paper centers around the portrayal and uses of FESS, giving a diagram of some business ventures for every application. A significant number of the above papers have given surveys of FESS, yet what is absent in the writing is an exhaustive audit of FESS with a depiction of the applications which are economically accessible. Following the presentation, a depiction of FESS is exhibited. The principle segments of FESS, including the rotor, electrical machine, course, and flywheel regulation are examined in subtleties and The paper finishes up with proposals for future research.

1.3 Problem Statement and Motivation of the Study

Notwithstanding of the plenteous force energy storage assets, numerous networks still live without access to power either from the utility matrix or free sustainable power source produced power. There is a test to supply power to the populace in view of two reasons. To start with, there is no enough force age to satisfy the present force request. Second, regardless of whether there is sufficient force age, establishment of matrix framework to every town is trying because of their geological areas and financial limitations. Energizing these remote regions by expanding transmission lines from the utility network to these provincial networks is very work and time serious as needs be capital concentrated. Certain essential administrations that ought to be given to specific network are power, water supply, correspondence, transportation; Health care and training are some compulsory requirements for any network to heighten out of neediness. Along these lines supply of solid power is essential to provide food this all administrations. The interest just as the energy misuse is ascending in Our nation. To satisfy the consistently expanding request of the nation, the force age framework needs to grow to abuse the sustainable sources. FESS are the potential methods for power creating for country remote regions. The stock of modest power from sustainable power sources as principle wellsprings of intensity creation has direct collaboration with neediness mitigation in the country.

Regularly ladies contribute their occasions to get water, to gather kindling, to cook nourishment for the entire family and different exercises, moreover, the cooking is encouraged indoor which results an indoor contamination presenting to various illnesses, this conceivably influences the wellbeing of ladies and youngsters as they remain longer there, other than the rest of the family unit individuals from the family. In view of the asset of sustainable power source patterns it has, it is the convenient requirement for the provincial occupants to provide food a dependable power access in the everyday exercises, moreover, to upgrade industrialized cultivating, little and small scale undertakings. Accordingly, power has become the heart for the manageable improvement of the country's economy.

1.4 Objectives of the Study

The main target of this thesis work is to design an off grid flywheel energy storage system that can generate and provide cost effective electricity to those who are in need of electricity. The objectives of this thesis are:

- Estimating electricity loads required for domestic uses, commercial sectors and community services like, primary school were determined.
- optimizing the FESS to be applied to rural areas via flywheel, Pulley, Permanent Magnet Alternator, Induction Motor, Controllers, and batteries.
- Analyzing the sensitivity of the power system.
- To improve the quality of life of the people of the village through the FESS system in the rural areas.
- Reduce the use of power generation fuels.
- Working to meet the growing demand for electricity.
- Outlines conclusions and recommendations.

1.5 Methodology of the Study

The Flywheel energy storage framework coordinates quantities of intensity create parts, for example, flywheel, Pulley, Permanent Magnet Alternator, Induction Motor, Controllers, and batteries. The criteria of choosing the best half and half energy part mix for a proposed site depends on the exchange off between cost, supportability, development of innovation, proficiency and least utilization of fuel. The strategies applied in this investigation are recorded underneath:

- The different off grid system were studied
- FESS Optimization Model for Electric storage tools has been used to design the off grid power system.
- Microsoft office excel
- Different scenarios to select techno-economic flywheel energy storage system architect

CHAPTER 2

BACKGROUND OF THE STUDY

2.1 Country Background

Geography

Figure 2.1: Geography of Bangladesh at night

Figure 2.2: Geography of Bangladesh

The over-dependence on coal originates from broadly acknowledged reasoning that coal is the least expensive alternative for power, with renewables ordinarily expelled as uncompetitive. This has curbed the standpoint for wind and sustainable power source in the locale, regardless of huge and to a great extent undiscovered potential. The International Energy Agency (IEA), for example, predicts that coal will hold its prevailing situation in the energy blend and record for very nearly 40 percent of the development in essential energy request somewhere in the range of 2017 and 2040.

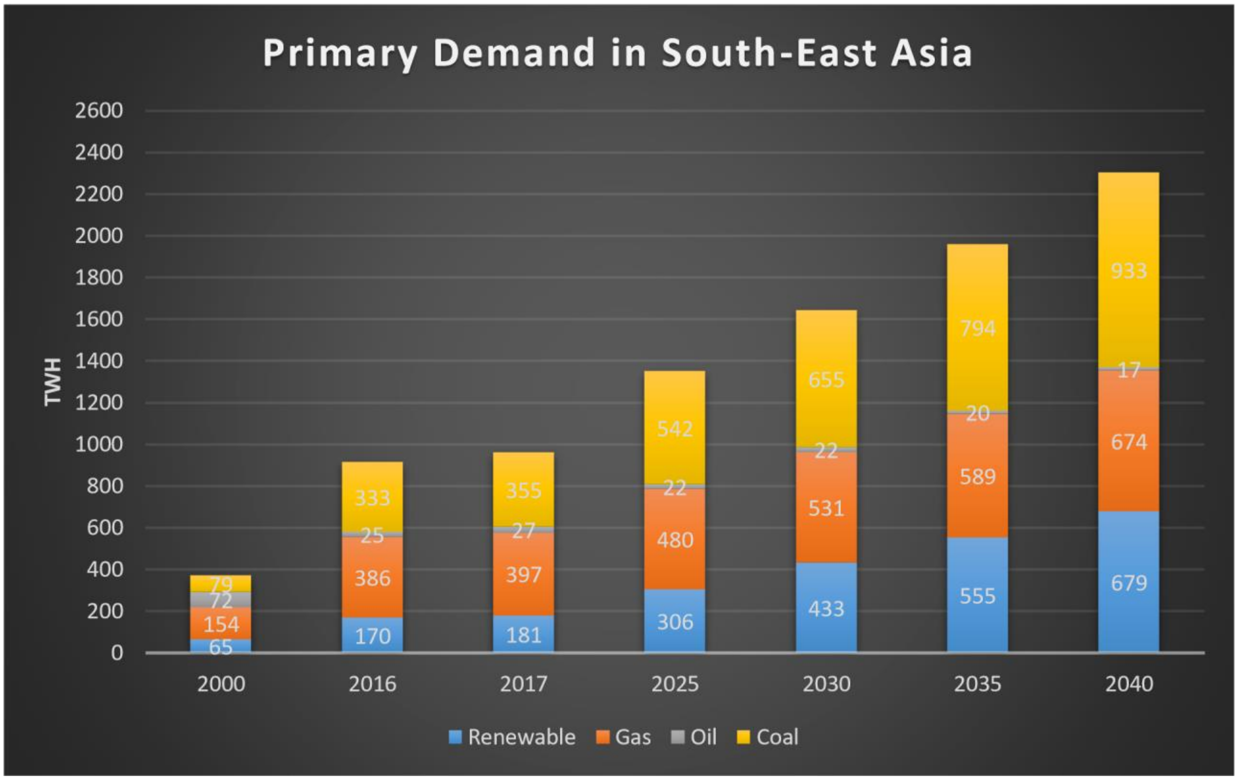


Figure 2.4: Primary Demand in South-East Asia

Table 2.1: Electricity Consumption per Capita: In South-East Asia

Country	KWh per person	Year
Singapure	7954	2018
Malaysia	4304	2018
India	877	2018
Indonesia	812	2018
Sri Lanka	561	2018
Bangladesh	336	2018

CHAPTER 3

OVERVIEW OF THE ENERGY GENERATED SYSTEM

3.1 System Components

Flywheel energy storage systems (FESS) utilize electric energy input which is put away as motor energy. Active energy can be depicted as "energy of movement," for this situation the movement of a turning mass, called a rotor. The rotor turns in an about frictionless fenced in area. At the point when momentary reinforcement power is required in light of the fact that utility force varies or is lost, the inactivity enables the rotor to keep turning and the subsequent motor energy is changed over to power. Most present day high-speed flywheel energy storage systems comprise of a gigantic turning chamber (an edge connected to a pole) that is upheld on a stator – the stationary piece of an electric generator – by attractively suspended direction. To look after proficiency, the flywheel framework is worked in a vacuum to decrease drag. The flywheel is associated with an engine generator that communicates with the utility network through cutting edge power gadgets.

Flywheel energy storage (FES) works by quickening a rotor (flywheel) to a fast and keeping up the energy in the framework as rotational energy. At the point when energy is separated from the framework, the flywheel's rotational speed is decreased as an outcome of the guideline of protection of energy; adding energy to the framework correspondingly brings about a speed up the flywheel. Most FES systems use power to quicken and decelerate the flywheel, yet gadgets that legitimately utilize mechanical energy are being created.

Propelled FES systems have rotors made of high quality carbon-fiber composites, suspended by attractive direction, and turning at speeds from 20,000 to more than 50,000 rpm in a vacuum fenced in area. Such flywheels can come up to speed in only minutes – arriving at their energy limit considerably more rapidly than some different types of storage.

Class	Example application to the micro scale
Thermal energy storage	Solar energy is used to heat water, which can be used for cooking, and bathing applications.
Chemical energy storage	Batteries or fuel cells can be used to store excess electricity produced by PV panels during the day time for use at night.
Electrical energy storage	Capacitors can be used to store electrical charges inside electrical appliances for short periods of time.
Gravitational energy storage	Water is pumped up a hill using excess electrical energy, and can be harvested by letting that water flow down the hill again, through a turbine that converts the energy from the flow of water into mechanical or electrical energy.
Kinetic energy storage	Flywheels store kinetic energy through their spinning disks. Flywheel systems can last a long time (decades) and store a large amount of energy, but are expensive compared to battery technology, for instance, due to needing a vacuum to reduce spinning resistance.

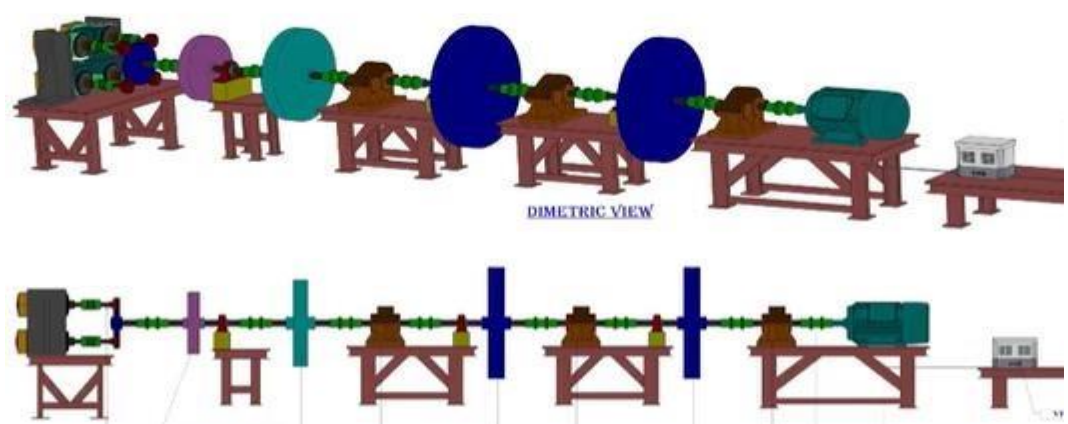


Figure 3.1: Dimetric view of flywheelenergy storage .

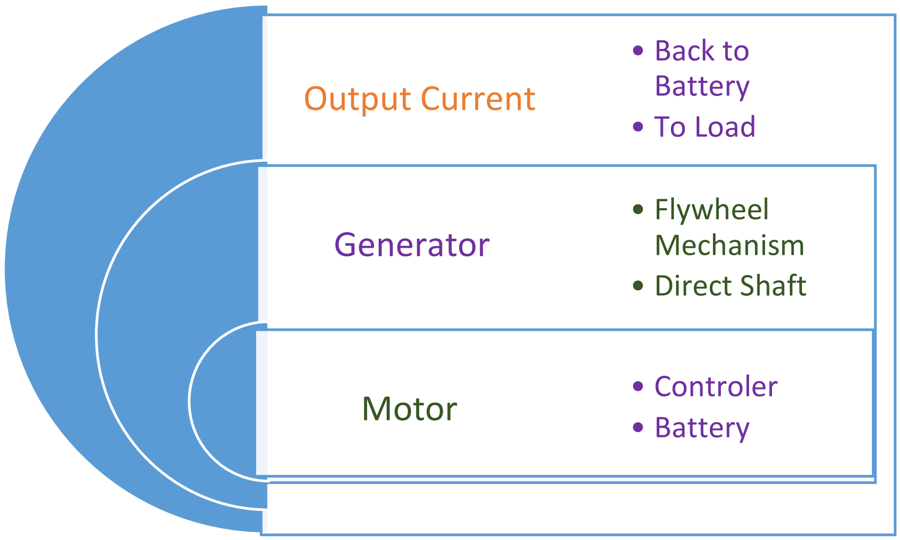


Figure 3.2: Connecting system each other with Flywheel Multiplication systems

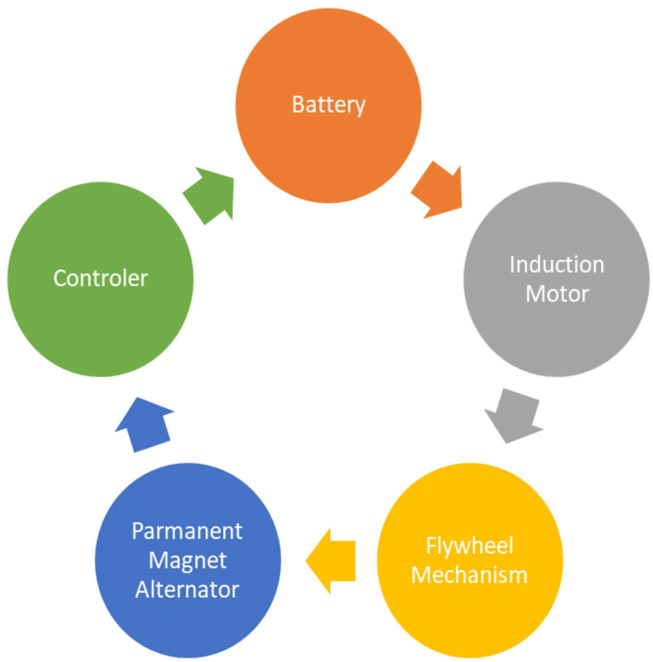


Figure 3.3: Circle Diagram of Flywheel Multiplication Systems

3.2 Main Components of FESS (Flywheel Energy Storage System)

- AC Induction Motor
- Pulley
- Flywheel
- Permanent Magnet Alternator
- Controller
- Battery

3.2.1 AC Induction Motor

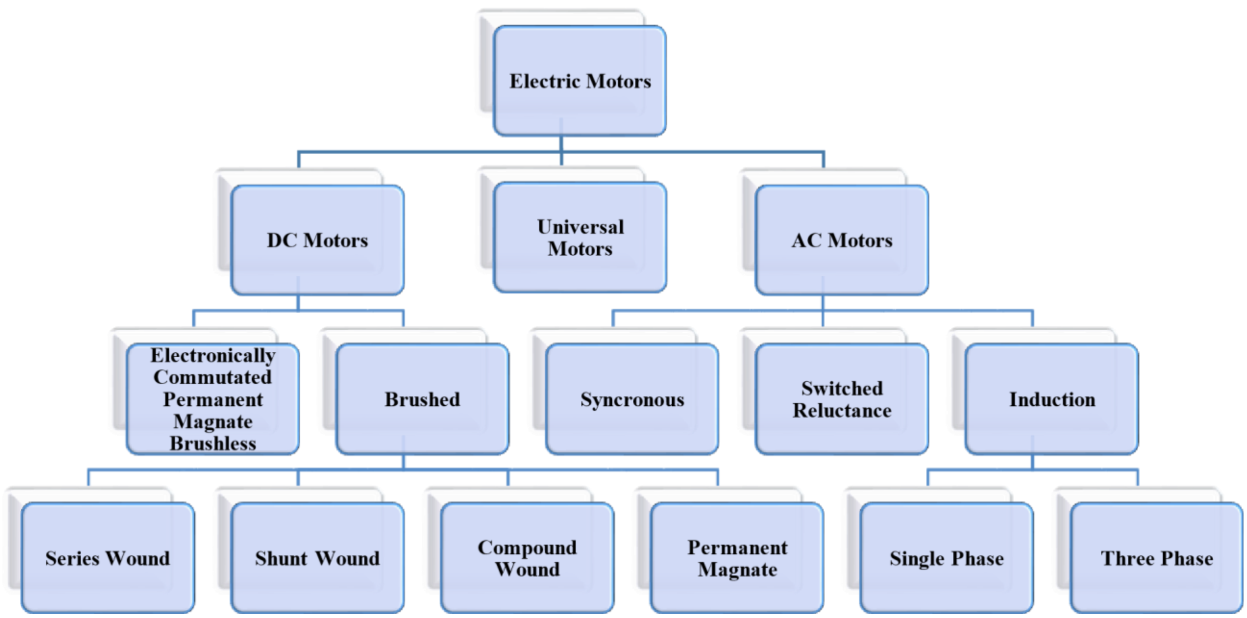


Figure 3.4: Classification of Electric Motors Slip:

On the off chance that the rotor of a squirrel confine engine was to run at the genuine synchronous speed, the transition in the rotor at some random spot on the rotor would not change, and no current would be made in the squirrel confine. Therefore, standard squirrel-confine engines run at somewhere in the range of several RPM slower than synchronous speed. Since the pivoting field (or proportional throbbing field) viably turns quicker than the rotor, it could be said to slip past the outside of the rotor. The distinction between synchronous speed and genuine speed is called slip, and stacking the engine builds the measure of slip as the engine backs off somewhat. Indeed, even with no heap, inner mechanical misfortunes keep the slip from being zero.

The speed of the AC engine is resolved fundamentally by the recurrence of the AC supply and the quantity of posts in the stator twisting, as per the connection:

$$N_S = \frac{120F}{P}$$

where

Ns= Synchronous speed, in revolutions per minute

F= AC power frequency

P= Number of poles per phase winding

Genuine RPM for an acceptance engine will be not as much as this determined synchronous speed by a sum known as slip, that increments with the torque created. With no heap, the speed will be near synchronous. At the point when stacked, standard engines have between 2–3% slip, unique engines may have up to 7% slip, and a class of engines known as torque engines are appraised to work at 100% slip (0 RPM/full slow down). The slip of the AC motor is calculated by:

S= (Ns- Nr)/Ns

Where,

Nr = Rotational speed, in revolutions per minute.

S = Normalized Slip, 0 to 1.

For instance, an average four-shaft engine running on 60 Hz may have a nameplate rating of 1725 RPM at full burden, while its determined speed is 1800 RPM. The speed in this sort of engine has generally been adjusted by having extra arrangements of loops or posts in the engine that can be turned on and off to change the speed of attractive field revolution. In any case, improvements in power gadgets imply that the recurrence of the force supply can likewise now be fluctuated to give a smoother control of the engine speed.

This sort of rotor is the fundamental equipment for acceptance controllers, which is an exemption of the utilization of pivoting attractive field as unadulterated electrical (not electromechanical) application.

Single-phase induction motor:

Single-stage engines don't have a special turning attractive field like multi-stage engines. The field interchanges (turns around extremity) between post combines and can be seen as two fields pivoting in inverse ways. They require an auxiliary attractive field that makes the rotor move a particular way. Subsequent to beginning, the substituting stator field is in relative turn with the rotor. A few strategies are regularly utilized:

Shaded-pole motor:

A typical single-stage engine is the concealed post engine and is utilized in gadgets requiring low beginning, for example, electric fans, little siphons, or little family machines. In this engine, little single-turn copper "concealing loops" make the moving attractive field. Some portion of each post is circled by a copper curl or tie; the actuated current in the lash restricts the difference in motion through the loop. This causes a period slack in the transition going through the concealing loop, with the goal that the greatest field force moves higher over the shaft face on each cycle. This delivers a low level pivoting attractive field which is sufficiently huge to turn both the rotor and its connected burden. As the rotor gets a move on the torque develops to its full level as the essential attractive field is pivoting comparative with the turning rotor.

A reversible concealed post engine was made by Barber-Colman quite a few years back. It had a solitary field curl, and two chief posts, each split most of the way to make two sets of shafts. Every one of these four "half-shafts" conveyed a curl, and the loops of slantingly inverse half-posts were associated with a couple of terminals. One terminal of each pair was normal, so just three terminals were required on the whole.

The engine would not begin with the terminals open; interfacing the regular to one other made the engine run one way, and associating basic to the next made it run the other way. These engines were utilized in modern and logical gadgets.

An unordinary, flexible speed, low-torque concealed shaft engine could be found in rush hour gridlock light and publicizing lighting controllers. The shaft faces were parallel and generally near one another, with the plate focused between them, something like the circle in a watthour meter. Each post face was part, and had a concealing loop on one section; the concealing curls were on the parts that confronted one another.

Applying AC to the curl made a field that advanced in the hole between the shafts. The plane of the stator center was around digressive to a nonexistent hover on the circle, so the voyaging attractive field hauled the plate and caused it to pivot.

The stator was mounted on a rotate so it could be situated for the ideal speed and afterward braced in position. Setting the posts closer to the focal point of the circle made it run quicker, and toward the edge, more slow.

Split-phase motor:

Another normal single-stage AC engine is the part stage acceptance engine, ordinarily utilized in significant machines, for example, climate control systems and garments dryers. Contrasted with the concealed shaft engine, these engines give a lot more noteworthy beginning torque.

A split-stage engine has an optional startup winding that is 90 electrical degrees to the primary twisting, constantly focused legitimately between the shafts of the fundamental winding, and associated with the principle twisting by a lot of electrical contacts. The loops of this winding are twisted with less turns of littler wire than the primary twisting, so it has a lower inductance and higher opposition. The situation of the winding makes a little stage move between the motion of the fundamental winding and the transition of the beginning winding, making the rotor turn. At the point when the speed of the engine is adequate to defeat the dormancy of the heap, the contacts are opened naturally by a diffusive switch or electric hand-off. The heading of revolution is controlled by the association between the fundamental winding and the beginning circuit. In applications where the engine requires a fixed pivot, one finish of the beginning circuit is for all time associated with the primary twisting, with the contacts making the association at the opposite end.

Capacitor start motor Schematic of a capacitor start motor:

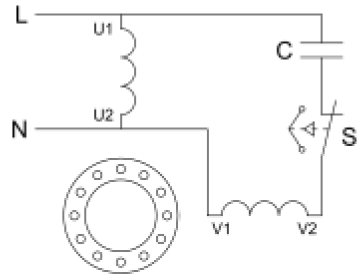


Figure 3.5: Schematic of capacitor start motor

A capacitor turns over engine is a part stage enlistment engine with a beginning capacitor embedded in arrangement with the startup winding, making a LC circuit which delivers a more prominent stage move (thus, a lot more noteworthy beginning torque) than both split-stage and concealed shaft engines.

Resistance start motor:

A resistance start motor is a split-phase induction motor with a starter inserted in series with the startup winding, creating reactance. This added starter provides assistance in the starting and initial direction of rotation. The start winding is made mainly of thin wire with fewer turns to make it high resistive and less inductive. The main winding is made with thicker wire with larger number of turns which makes it less resistive and more inductive.

Permanent-split capacitor motor:

Another variety is the changeless part capacitor (or PSC) engine. Otherwise called a capacitor-run engine, this sort of engine utilizes a non-captivated capacitor with a high voltage rating to produce an electrical stage move between the run and start windings. PSC engines are the predominant sort of split-stage engine in Europe and a significant part of the world, yet in North America, they are most as often as possible utilized in factor torque applications (like blowers, fans, and siphons) and different situations where variable paces are wanted.

A capacitor with a moderately low capacitance, and generally high voltage rating, is associated in arrangement with the beginning winding and stays in the circuit during the whole run cycle. Like other split phase engines, the fundamental winding is utilized with a littler beginning winding, and pivot is changed by turning around the association between the primary winding and the beginning circuit, or by having extremity of principle winding exchanged while start winding is constantly associated with a capacitor. There are huge contrasts, nonetheless; the utilization of a speed delicate outward switch necessitates that other split-stage engines must work at, or near, max throttle. PSC engines may work inside a wide scope of velocities, much lower than the engine's electrical speed. Additionally, for applications like programmed entryway openers that require the engine to invert pivot regularly, the utilization of a component necessitates that an engine should ease back to a close to stop before contact with the beginning winding is restored. The 'perpetual' association with the capacitor in a PSC engine implies that changing revolution is immediate.

Three-stage engines can be changed over to PSC engines by making basic two windings and interfacing the third by means of a capacitor to go about as a beginning winding. In any case, the force rating should be at any rate half bigger than for a practically identical single-stage engine because of an unused winding.

3.2.2 Pulley

We are well in progress in finding out about basic machines and building the antiquated Egyptian pyramids that we have been employed as specialists to plan and develop. Presently, we will go further into our comprehension of pulleys to check whether we can utilize this information to help make our work simpler.

A pulley is a straightforward machine comprising of a string folded over a wheel (now and again with a notch) with one finish of the string appended to an article and the opposite end connected to an individual or an engine. Pulleys may appear to be straightforward, yet they can give an incredible mechanical preferred position so lifting undertakings might be done effectively.

Engineering Connection:

Specialists are specialists at abusing the upsides of straightforward machines in a wide range of genuine applications that advantage society. They consolidate the mechanical bit of leeway of pulleys into their plan of numerous advanced structures, machines, items and apparatuses, for example, cranes, lifts, flagpoles, zip lines, engines, bike rings/chains, garments lines, water well can/rope, rock climbing gadgets, window blinds and sail/angling vessels. Utilizing various pulleys related to engines and gadgets, engineers make complex present day gadgets that perform a lot of work for next to no power.

Different Types of Pulley:

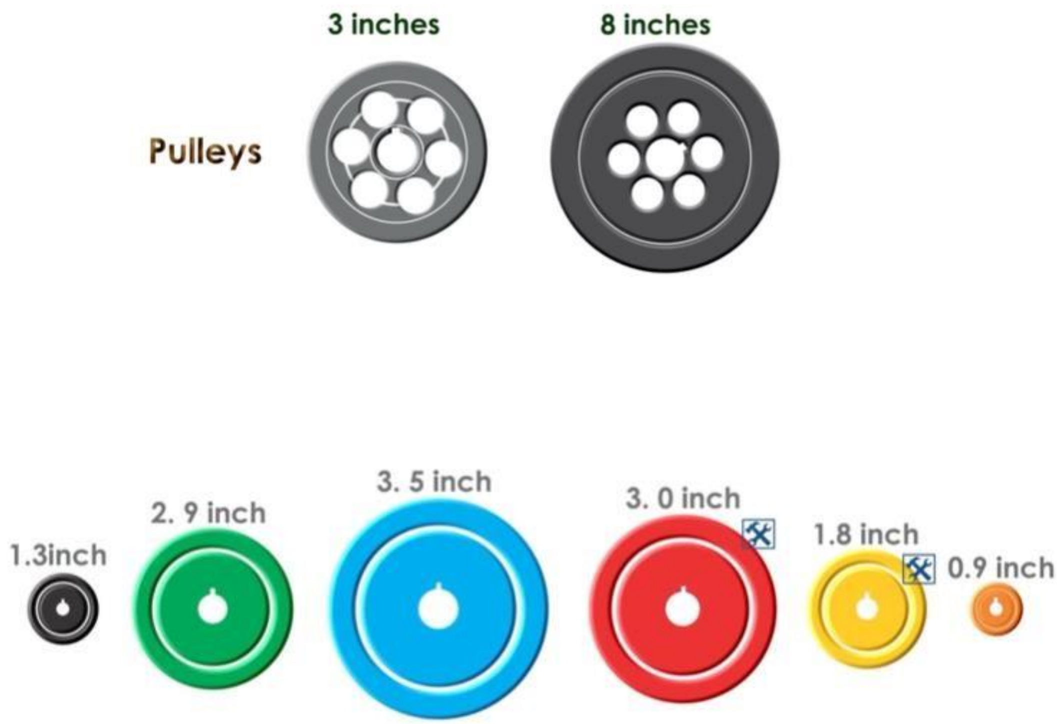


Figure 3.6: Different size of pulley

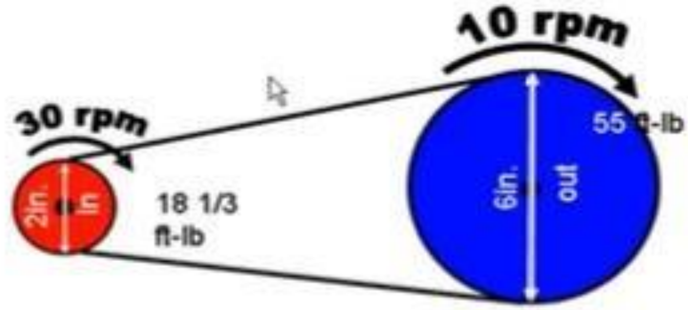
Figure 3.7: Three steps pulley

Pulley and Belt Systems:

Equation:

$$\frac{d_{out}}{d_{in}} = \frac{\omega_{in}}{\omega_{out}} = \frac{\tau_{out}}{\tau_{in}}$$

$$\frac{6in.}{2in.} \qquad \frac{30rpm}{10rpm} \qquad \frac{55\,ft-lb}{18\frac{1}{3}\,ft-lb}$$



Where,

d = diameter

ω = angular velocity (speed)

τ = torqe

Coefficient Fluctuation of Speed (φ):

Φ = variation of speed/mean speed

Variation of speed = $\omega_{\max} - \omega_{min}$

$\omega_{mean} = \frac{\omega_{max}+\omega_{min}}{2}$

Coefficient Fluctuation of Energy:

$$\boldsymbol{\beta = \frac{Greatest\ Fluctuation\ in\ Energy}{Work\ Done\ per\ revoloution(W)}}$$

$$\boldsymbol{\beta W = Greatest\ Fluctuation\ in\ Energy}$$

$$\beta W = Maximum\ KE - Minimum\ KE$$

$$\beta W = \frac{1}{2} I\omega_{max^2} - \frac{1}{2} I\omega_{min^2}$$

Determination of Greatest Fluctuation of Energy

$$\beta W = \frac{1}{2} I(\omega_{max^2} - \omega_{min^2})$$

$$\beta W = \frac{1}{2} I (\omega_{max} - \omega_{min}) (\omega_{max} + \omega_{min})$$

$$\beta W = \frac{1}{2} I\phi\omega_{mean}(2\omega_{mean})$$

$$\beta W = I\phi\, \omega_{mean^2}$$

Table 3.1: Reading of pulley, A

SL. No	RPM	Time taken to supply energy $T_{in}(s)$	Time taken to consume energy T_{out}(s)	Efficiency %
1	1901	21.33	5.46	74.40
2	1928	21.02	6.02	71.36
3	1932	21.27	6.79	68.07
Average	1920.33	21.20	6.09	71.27

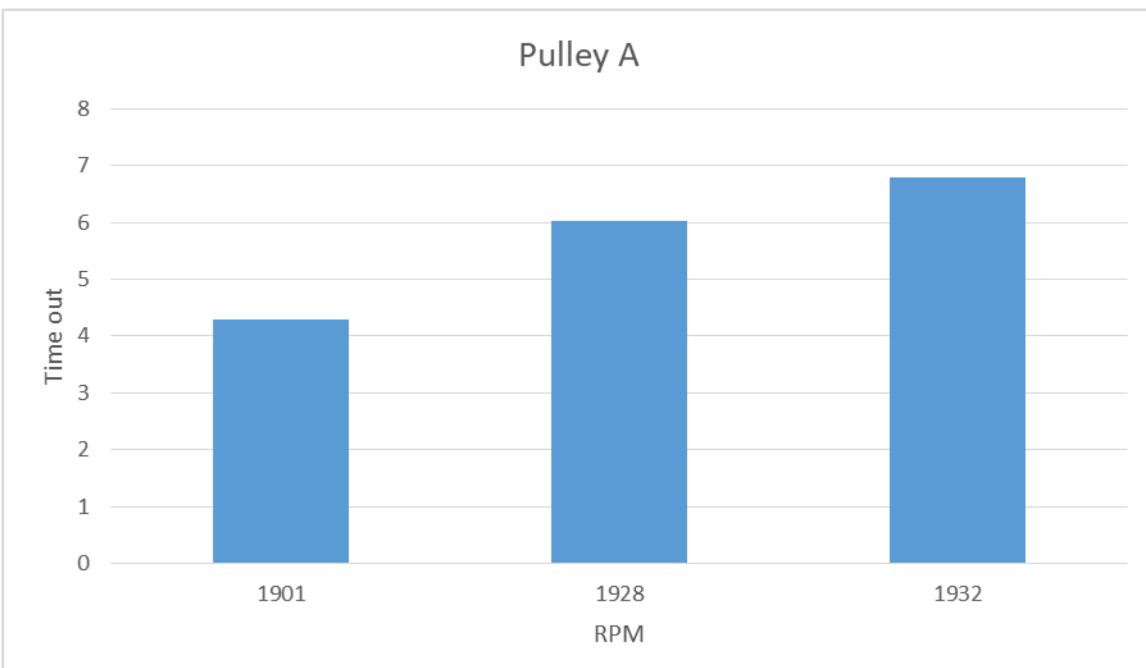


Figure 3.8: Graph pulley A result

Table 3.2: Table of pulley B

SL. No	RPM	Time taken to supply energy $T_{in}(s)$	Time taken to consume energy T_{out} (s)	Efficiency %
1	1362	21.82	4.55	79.14
2	1382	21.87	4.61	78.92
3	1315	22.03	4.88	77.84
Average	1353	21.90	4.68	78.63

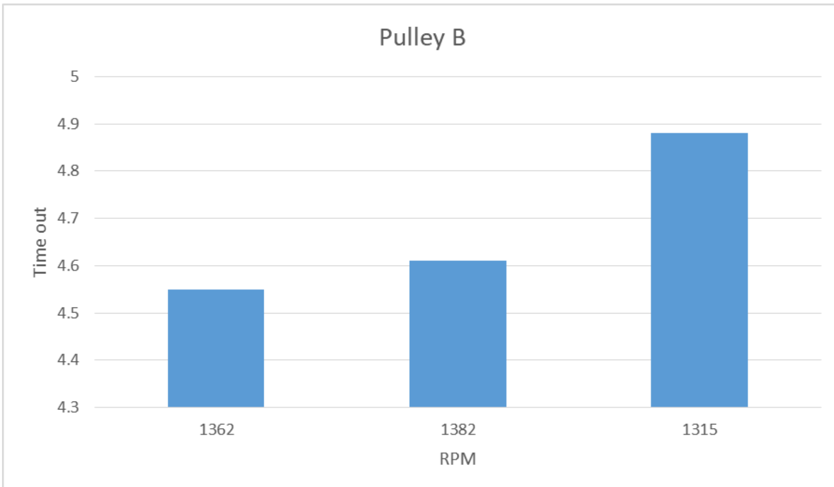


Figure 3.9: Graph of pulley B result

Table 3.3: Reading of pulley C

SL. No	RPM	Time taken to supply energy $T_{in}(s)$	Time taken to consume energy T_{out} (s)	Efficiency %
1	1167	20.52	3.95	80.75
2	1156	21.31	4	81.22
3	1156	20.90	3.48	79.54
Average	1159.67	20.91	3.81	80.50

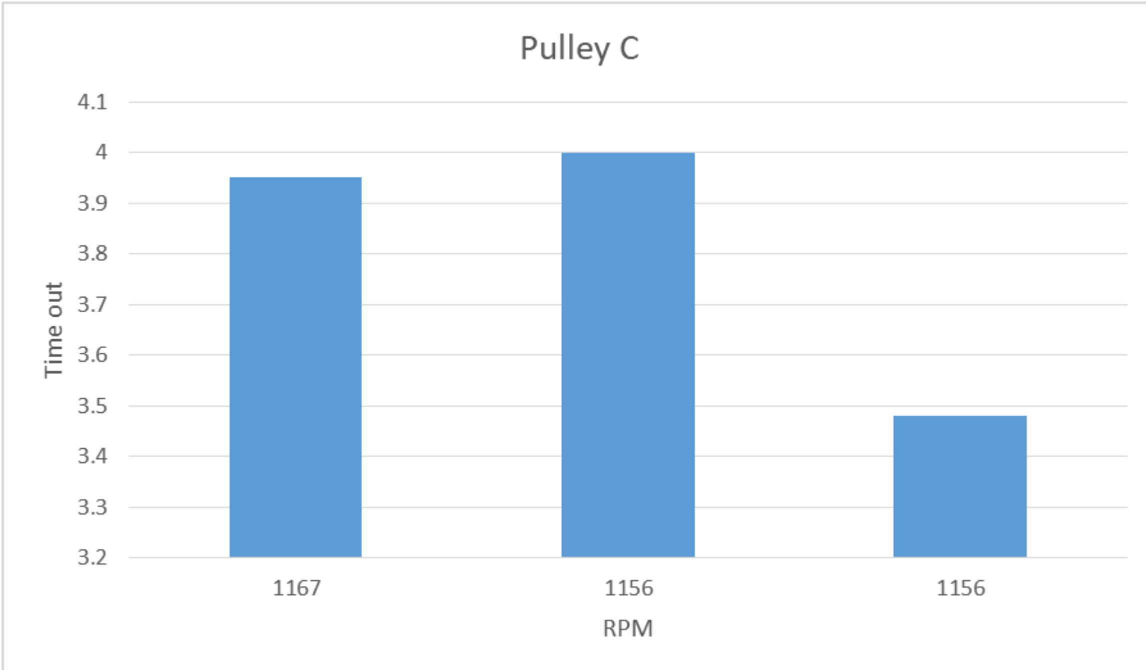


Figure 3.10: Graph of pulley C result

While looking this table it very well may be reasoned that bigger the measurement of the pulley will bring about lesser RPM and break and the other way around. In such a case that the breadth of the pulley is expanded, it will set aside more effort to finish insurgency which will upset the RPM just as break of flywheel.

3.2.3 Flywheel:

A flywheel is an extremely substantial wheel, in the past a huge spoked wheel with an overwhelming metal edge however now more normally produced using a carbon-fiber composite material, with a littler round and hollow structure that is just about a quarter as overwhelming. In the two cases the rule is the equivalent – it needs critical power to set the wheel turning, and the equivalent to prevent it from turning. As it were, it has high precise force.

The outcome is that at high speeds it can store a ton of dynamic energy, which makes it a mechanical battery. That is, it stores energy as active energy as opposed to as compound energy as does a regular electrical battery.

Hypothetically, the flywheel ought to have the option to both store and concentrate energy rapidly, and discharge it, both at high speeds and with no point of confinement on the complete number of cycles conceivable in its lifetime. In any case, their cost, weight, and energy thickness have been conventional worries with flywheels.

These are being tended to with propels in materials sciences and turning framework structure. Natural concerns are likewise driving examination into flywheel energy storage systems (FESS).

Flywheels are regularly enormous and substantial in light of the fact that they can store more energy that way. Then again, littler and lighter wheels are likewise utilized by and large since they can turn a lot quicker and hence substantially more active energy is created along these lines. In this way there are various sizes and states of flywheel. With the accessibility of present day lightweight composites and pottery, flywheels are currently generally littler and ready to turn at high speeds.

Flywheel Working Process

The FESS is comprised of a substantial pivoting part, the flywheel, with an electric engine/generator. The inbuilt engine utilizes electrical capacity to turn at high speeds to set the flywheel turning at its working rate. This outcome in the storage of motor energy. At the point when energy is required, the engine capacities as a generator, in light of the fact that the flywheel moves rotational energy to it. This is changed over go into electrical energy, subsequently finishing the cycle.

As the flywheel turns quicker, it encounters more noteworthy power and in this manner stores more energy.

Flywheels are in this way demonstrating enormous guarantee in the field of energy storage systems intended to supplant the average lead-corrosive batteries.

For a flywheel, dynamic energy is determined with respect to a turning object, as

$E = ½Iω2$

Where,

E-is Kinetic energy.

I-is the snapshot of latency, which relies upon the genuine mass and the area of that mass from the turning focus the more remote it is the higher the snapshot of idleness becomes.

ω-is the rakish speed of the flywheel.

In this manner the best flywheel as far as snapshot of idleness could be one which is bigger, spoked and lightweight, yet with a substantial edge of metal. In the event that the edge is twice as overwhelming as the first, this would store twofold the energy that a lighter edge would, yet the mechanical confinements increment correspondingly. Then again, multiplying the pace of turning yields double the precise speed, which implies the energy put away is quadrupled.

Flywheels turn on orientation which require appropriate oil to limit frictional powers. Air opposition should likewise be decreased to as meager as could reasonably be expected. Consequently, the most recent advancement in flywheels is mounting them on low-erosion heading inside fixed metal chambers, or surprisingly better, drifting them on superconducting magnets which maintains a strategic distance from contact totally and putting them inside vacuum chambers to evade air haul also.

The FESS is equipped for creating a few MW of intensity for brief periods. Flywheels are most appropriate to create high force yields of 100 KW to 2 MW over a brief time of 12-60 seconds. The pinnacle yield, at 125 KW for 16 seconds, is adequate to give 2 MW to one second.

There are two fundamental flywheel setups. In one sort the flywheel is connected to the pole and both pivot together. This is named an ordinary rotor. The other kind comprises of a flywheel turning around a pole which doesn't move, likewise got a back to front rotor.

The Configuration

The engine/generator is commonly a perpetual magnet-based machine in light of the fact that these have higher efficiencies and are littler for some random force rating. They likewise have lower rotor misfortunes and winding inductances, making them increasingly useful in a vacuum working condition and fit to the fast energy move commonplace of flywheel applications.

The energy storage itself is performed utilizing a three-stage IGBT-based PWM inverter/rectifier arrangement.

Attractive course is made out of lasting magnets that utilization appalling power to keep the flywheel's weight suspended, while it is balanced out with the utilization of electromagnets. The high temperature superconducting attractive direction are favored here as they consequently position the flywheel without requiring electrical force or a situating control framework.

An outside inductor is likewise important on the grounds that when utilized in arrangement with the machine in charging mode, the all-out consonant bending is diminished to inside typical range. The lasting magnets would somehow or another offer low inductances which increment the THD and cause higher force misfortunes and expanded temperature.

The FESS has three working modes, the charging mode, the backup mode, and the releasing mode.

3.2.4 Permanent Magnet Alternator

A Permanent magnet alternator (in like manner called PMA, never-ending magnet generator, PMG or magneto) relies upon the appealing field made by a constant magnet to change over mechanical essentialness into electrical power. It can deliver AC, with which it can control the whole engine and charge the battery.

In this article, we will focus on the normal structure of a constant magnet structure and give a short introduction to its working standard.

Figure 3.11: Permanent Magnet Alternator

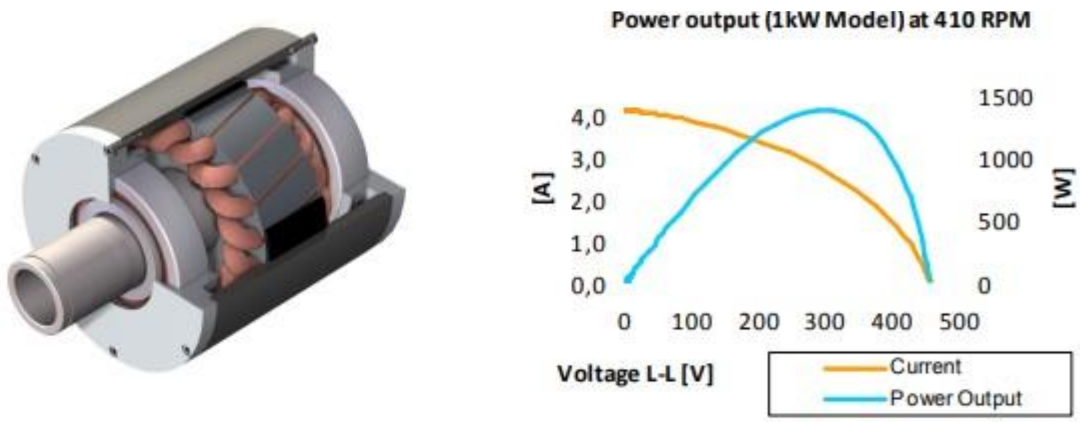


Figure 3.12: Simulation of Permanent Magnet Alternator

A cutting edge alternator contains both moving and stationary circles of wire. In the alternator, nevertheless, the moving circle, called the rotor, uses current gave through slip rings to create a moving field. Power is removed from the stationary field circles.

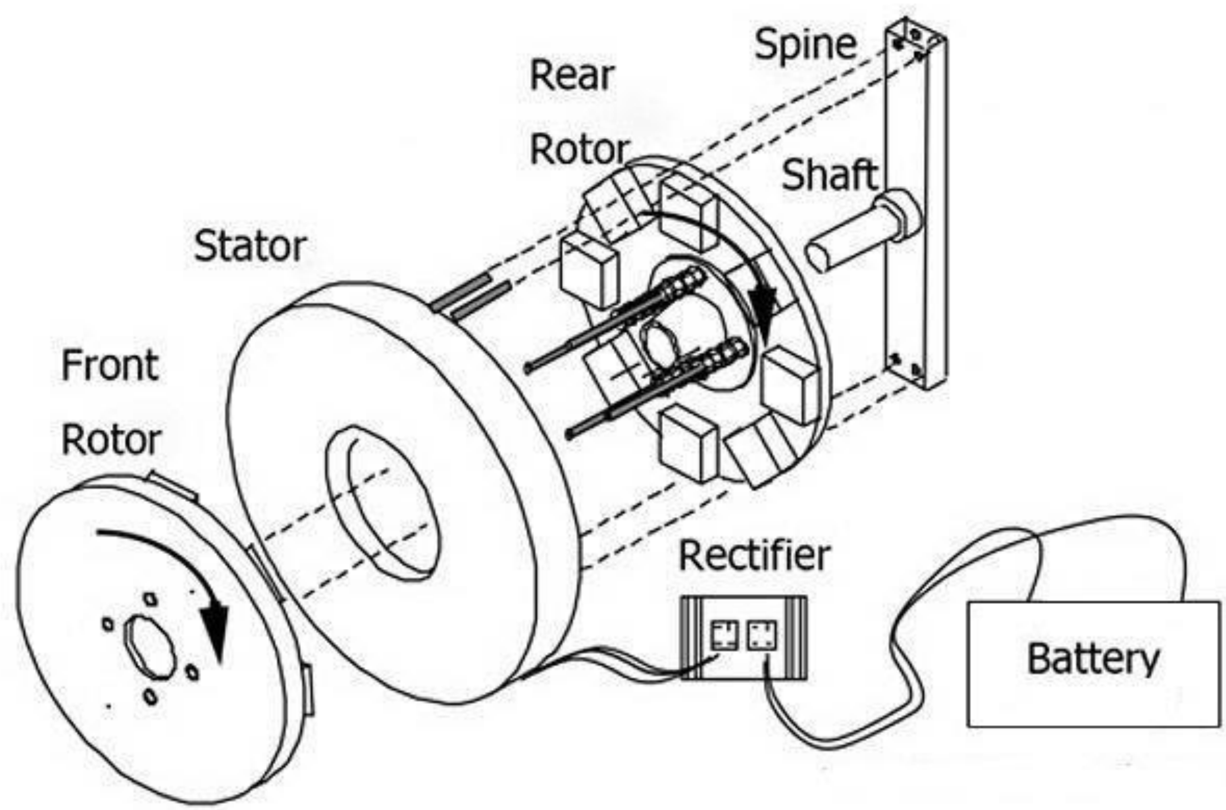


Figure 3.13: Schematic Design of Permanent Magnet Alternator

- The stator contains six circles of copper wire cast in fiberglass pitch. It is mounted onto the spine and doesn't move.
- The magnet rotors are mounted on heading turning on the shaft. There're two rotors: the back one behind the stator and the front one apparently, which are related by the long studs experiencing an opening in the stator.
- The sharp edges are mounted on comparable studs. They will drive the magnet rotors to turn and go through the twists. During this system, the electric power is made.
- The rectifier is mounted on an aluminum and ldquo; heatsink and rdquo; to keep cool. The copper wire moves the made AC power.

3.2.5 Battery

The battery is the core of the electrical framework. It is a significant energy storage gadget and is the generally broadly utilized as auxiliary storage cell. Without it the car motor can't be turned over with turning over engine. Be that as it may, it isn't just utilized in vehicle fields yet additionally in different fields where power storage instrument is constantly required. It is a force storage component which discharges a progression of electron through an outer circuit. In this framework, substance energy is changed over into electrical energy because of responses happening between the cathode materials and electrolytic arrangement or electrolyte. This thought of electro-concoction energy storage started with logical examinations concerning power. In 1789, while leading an analysis Luigi Galvani saw that the legs of frog started to jerk when they came into contact with two unique sorts of material [1]. From this perception, electrochemical cell was created and after that battery comprising of at least two electrochemical cells was found. At that point the improvement of battery has done step by step. Chiefly, the improvements have occurred in essential material of development of battery. In present the protection among positive and negative cathode and external layers are made of hard elastic, PVC and so forth. The watery electrolyte arrangement contains in a holder which is made of plastics, glass, elastic or PVC. In present days, electrolyte arrangement has likewise created. These days' glue type electrolyte, for example, ammonium chloride is utilizing in a portion of the batteries rather than fluid corrosive arrangement. Those sorts of batteries are called dry cell battery. Be that as it may, the utilization of dry cell batteries has not yet spread enough. Then again, wet cell batteries have tremendous application and require more consideration. Along these lines, our fundamental concern is about support of wet cell batteries.

In present days, wet cell batteries are created economically by various organizations for autos and different purposes. They set the existence time of the battery as per their employments. The existence cycle of the battery relies upon the nature of battery as well as upkeep of battery done by the clients. Truth be told, the lifecycle generally relies on how appropriately the battery is kept up. The vast majority of the batteries can't finish its monetary life because of the absence of cognizant about the best possible upkeep procedure of battery. In the event that the battery is appropriately kept up, at that point the lifecycle just as administration rating of battery will increment from which buyer can be profited monetarily. In this way, the significance of legitimate support of battery can't be dismissed.

Importance

Battery is a delicate electric gadget. It is basic that batteries are appropriately kept up to guarantee unwavering quality. Under perfect working and support conditions, this could stretch out battery life to seven or eight years. It isn't strange to discover a few batteries to play out this well. On the off chance that you have issues that create in fifth or 6th year of the battery life, it is profoundly impossible that significant fixes could be advocated. It is astute to consider five to six years as the typical life expectancy. Under five years could show operational maltreatment or poor support chiefly. Moreover, as indicated by the statics of Hamko Battery Industry Ltd., a battery can serve up to 7-8 years, when support rate is 100%. In any case, it will serve just up to 3-4 years, when the support rate is half or normal. Be that as it may, if the support rate is beneath half or the battery isn't kept up in any way, it will just satisfy its guarantee life or not. the histogram, acquired from the statics of Hamko Battery Industry Ltd. speaks to the significance of keeping up a battery to build its financial life.

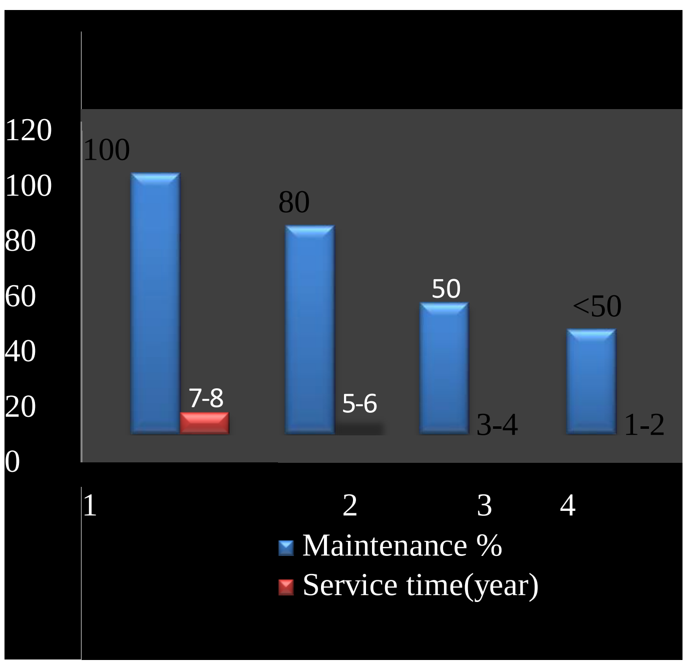


Figure 3.14: Relation of service time of battery with maintenance rate

There are various issues happened in the battery because of the absence of upkeep. Undercharging or cheating issues are usually happened because of the absence of legitimate upkeep of battery. In the event that charging of battery isn't taken care of or kept up appropriately, it can lessen the battery limit in everyday exercises. Undercharging not just diminishes the battery limit in everyday work exercises, however motivations unusual sulfation prompting further decrease of limit and early cell disappointment. Cheating makes pointless utility cost, however will make high temperatures and over gassing bringing about untimely cell disappointment. Battery issues are additionally happened because of the inappropriate watering process. In the event that watering isn't done appropriately in time and battery electrolyte level is permitted to drop significantly, the gas volume inside the battery becomes proportionately bringing about an expanded measure of combustible gas blend. Any outside or interior sparkle may bring about an oxyhydrogen blast. Moreover, the plates are never again secured by the electrolyte and may erode which may cause extreme disappointment of the battery. Once more, overwatering causes flood of electrolyte arrangement. As times goes on water is included and in the long run the electrolyte arrangement turns out to be progressively weaken, thus, low gravity readings and lost battery limit. Moreover, outside erosion, and grounds are quickened, expanding issues with the forklift hardware and somewhat, influencing the life span of the battery. Moreover, numerous battery issues are brought about by free or eroded associations which are the aftereffects of absence of legitimate consideration of battery. Be that as it may, the best possible keeping up of the battery consistently guarantees legitimate charging, appropriate watering and appropriate consideration of the battery. It keeps the battery liberated from all issues and guarantees long existence of the battery. It additionally keeps the consistency in battery execution.

In this way, the significance of legitimate battery upkeep is past any inquiry.

Figure 3.15: Battery regularly maintained

Figure 3.16: Wasted batteries due to lack of maintenance

Way of Maintaining Battery

Proper way of battery maintenance means an approach combining preventive with predictive and corrective battery maintenance procedures i.e. there are three ways of maintaining battery:

1. Preventive battery maintenance: It is a procedure of increasing battery reliability by taking action to prevent accelerated deterioration.
2. Predictive battery maintenance: It is a procedure of measuring changes in battery conditions and allowing trend analysis to predict the health and expected economic life of the battery.
3. Corrective battery maintenance: It is a procedure of providing remedies to faults or problems that have been detected.

Preventive Battery Maintenance

Preventive battery maintenance process includes watering, ventilation, charging and caring. If those processes are maintained properly, then it can be possible to keep the battery away from all problems or failures.

a) Watering

The main reason of battery needs water is loss of electrolyte for which electrolysis is responsible. Other reasons are evaporation from internally generated heat, heavy work load, unavoidable heat, mismatched batteries and charging equipment, use of batteries without a sufficient cool down period. Those reasons can be avoided but need of water due to the loss of electrolyte cannot be avoided. As battery is charged, a small quantity of water in the electrolyte is broken down into hydrogen and oxygen. So, it is necessary to fill up water into the battery after a particular time. Whole watering process is given below:

1. Before starting the charging cycle, each individual cell should be visually checked to assure that the electrolyte level is at least above the separator protector.
2. If the electrolyte level is below the separator protector, sufficient water should be added to bring the level above the protector.
3. Overwatering should be avoided and distilled water must be used.
4. Once electrolyte levels and temperatures are deemed satisfactory, the charging cycle may be initiated.

b) Ventilation

Proper ventilation is required for batteries because of gasification. Generated gas during electrolysis in battery should have enough space for escaping. If it is not done, there may be occurred explosion by generated gas. For this purpose, vent cap can be used in battery. It increases safety in poorly-ventilated area. It is advantageous over all other ventilation system. It only provides escape path for harmful and unnecessary gases and helps to prevent steam from escaping. It condenses the steam into water which in turn helps to reduce watering intervals. But vent caps should always be kept tight and gas vent should always be kept opened. Any missing or worn vent plug gaskets should be replaced. The room in which batteries are kept should also have proper ventilation system so that gases have enough space for escaping from the room.

Figure 3.17: Vent cap of battery

c) Charging

The purpose of charging a battery is to put back the energy that has been removed. A battery that is not properly charged will deliver sub-standard performance and display a shorter life span. Overcharging, undercharging and over discharging are always harmful for the battery. The plates suffer greatly when over discharged. Voltage per cell should not be allowed to drop below 1.75 volts [3]. So, proper charging is necessary for standard performance and longer life span of battery. Whole charging process is given below:

1. The battery should not be discharged more than 80% of its A.H. capacity. So, the battery should be charged when the discharge rate is 80% [2].
2. The battery should be charged only after a visual inspection. Never attempt to charge the battery with a damaged case or low electrolyte levels.
3. A state-of-charge test should be performed before charging.
4. Always connect the positive terminal of the battery charger to the positive cell of the battery and the negative terminal of the battery charger to the negative cell of the battery.
5. Unplug the charger or turn it off before disconnecting the terminals at the battery. It should be done when the battery is fully charged.
6. Periodic testing of the battery and charger are necessary.

Table 3.4: The method of charging batteries that are fully discharged [4]

Reserve Capacity Rating	**Slow Charge**	**Fast Charge**
80 minutes or less	15 hours @ 3 amps	2.5 hours @ 20 amps
80 to 125 minutes	21 hours @ 4 amps	3.75 hours @ 20 amps
125 to 170 minutes	22 hours @ 5 amps	5 hours @ 20 amps
170 to 250 minutes	23 hours @ 6 amps	7.5 hours @ 10 amps
Above 250 minutes	24 hours @ 10 amps	6 hours @ 40 amps

CHAPTER 4

TECHNICAL ASPECT OF THE SYSTEM

4.1 Structure and Components of FESS

FESS comprises of a turning rotor, MG, orientation, a force hardware interface, and control of lodging, which are talked about in detail in the accompanying subsections. An ordinary flywheel framework appropriate for ground-based force is schematically.

4.1.1. Flywheel Rotor

The stored energy in a flywheel is determined by the rotor shape and material. It is linearly proportional to the moment of inertia and the square of its angular velocity, as shown in Equation (1):

$$E = \frac{1}{2} I\omega^2$$

where E is the stored kinetic energy, I is the moment of inertia, and ω is the angular velocity. The useful energy of a flywheel within a speed range of minimum speed (ω_{min}) and maximum speed (ω_{max}) can be obtained by:

$$E = \frac{1}{2} I({\omega_{max}}^2 - {\omega_{min}}^2) = \frac{1}{2} I{\omega_{max}}^2\left(1 - \frac{{\omega_{min}}^2}{{\omega_{max}}^2}\right) \quad (2)$$

Typically, an electrically driven flywheel normally operates between (ω_{min}) and (ω_{max}), to avoid too great a voltage variation and to limit the maximum MG torque for a given power rating. The moment of inertia is a function of the mass of the rotor and the rotor shape factor. Flywheels are often built as solid or hollow cylinders, ranging from short and disc-type, to long and drum-type. For a solid cylinder or disc-type flywheel, the moment of inertia is given by:

$$I = \frac{1}{2} mr^2 \quad (3)$$

where m is the rotor mass and r is the outer radius. For a hollow cylinder flywheel of outer radius b and inner radius a, as shown in Figure 2, the moment of inertia is:

$$I = \frac{1}{2} m\left(b^2 - a^2\right) \quad (4)$$

For a flywheel with length h and mass density ρ, the moment of inertia is determined by:

$$I = \frac{1}{2}\pi\rho h\left(b^4 - a^4\right) \quad (5)$$

Thus:

$$E = \frac{1}{4}\pi\rho h\omega^2\left(b^4 - a^4\right)$$

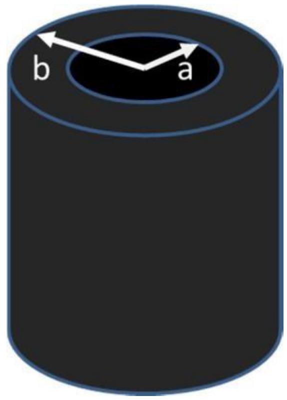


Figure 4.1: Hollow cylinder flywheel.

The maximum speed limit at which a flywheel may operate is determined by the strength of the rotor material, called tensile strength σ. A suitable safety margin must be maintained, to keep the stress experienced by the rotor below the strength of the rotor material. The maximum stress of a thin rotating ring is given by:

$\sigma_{max} = \rho r^2 \omega^2$ where σ is the maximum stress and ρ is the density of the flywheel material. More complex equations are available for different rotor geometries, but the maximum stress is always proportional to ρ, and the square of peripheral speed, equal to *r*ω. The effect of rotor geometries can be accommodated by introducing a shape factor *K*. The maximum specific energy and energy density are then given by:

$$\frac{E}{m} = K\frac{\sigma_{max}}{\rho}\left[\frac{J}{kg}\right]$$

$$\frac{E}{V} = K\sigma_{max}\left[\frac{J}{m^3}\right]$$

Conditions (8) and (9) show that the particular (vitality per mass unit) and vitality thickness (vitality per volume unit) of the flywheel are reliant on its shape, communicated as shape factor K. The state of a flywheel is a significant factor for deciding the flywheel speed limit, and thus, the most extreme vitality that can be put away. The shape factor K is an estimation of flywheel material usage. Figure 4.2 shows the estimations of K for the most well-known sorts of flywheel geometries.

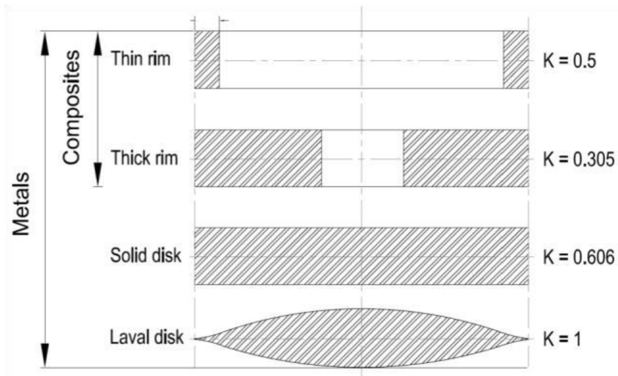


Figure 4.2: Different flywheel cross sections.

As per Equation (1), the put-away vitality of a flywheel can be enhanced by either speeding up (ω) or expanding the snapshot of latency (I). This permits two decisions for FESS: low-speed FESS (regularly up to 10,000 rpm) and rapid FESS (up to 100,000 rpm). Low-speed flywheels are normally made of heavier metallic material and are bolstered by either mechanical or attractive course. Rapid flywheels, for the most part, utilize light yet solid composite materials and commonly require attractive courses. The cost of rapid flywheels can be up to multiple times higher than the expense of low-speed flywheels, as indicated by the creators note that the expense of a flywheel framework is administered by the structure of the entire framework, not the rotor, even though this center component may direct the plan of different components in the framework, consequently the absolute expense. Another class of middle of the road speed flywheels, profiting by the minimal effort of steel materials however an adequately high vitality thickness, is likewise being created, in light of the utilization of overlaid steel. This can offer minimal effort, yet also minimized, choices.

Electric Machine

As clarified already, the electrical machine or incorporated MG is coupled to the flywheel, to empower the vitality change and charging procedure of the flywheel. The machine, going about as an engine, charges the flywheel by quickening it and drawing electrical vitality from the source. The put-away vitality on the flywheel is removed by a similar machine, going about as a generator, and subsequently, the flywheel is backed off during release. Regular electrical machines utilized in FESS are the acceptance machine (IM), lasting magnet machine (PM), and variable hesitant machine (VRM).

An IM is utilized for high force applications because of its toughness, higher torque, and minimal effort [18]. The speed restrictions, complex control, and higher support necessities are the fundamental issues with IMs. The squirrel confine type can be a more affordable choice for moderate reaction applications. A doubly-bolstered acceptance machine (DFIM) has as of late been utilized in FESS applications, because of its adaptable control and lower power transformation rating, permitting relieved force hardware estimating. An IM is broadly utilized in wind turbine applications to empower the force smoothing of windage frameworks.

A VRM is extremely hearty and has low lingering misfortunes and a wide speed run. It has a more straightforward control instrument than IMs with regards to fast activities. On the drawback, it has a low force factor and low force thickness, just as high torque swells. Both exchanged hesitance and synchronous hesitance types are applied in rapid FESS applications.

A PM is a most regularly utilized machine for FESS on account of its higher effectiveness, high force thickness, and low rotor misfortunes. It is generally utilized in rapid applications because of the speed restrictions of IMs, and the torque wave, vibration, and clamor of VRMs. The issue with a PM is its sitting misfortunes because of the stator swirl's current misfortunes, its significant expense, and its low elasticity [18]. A brushless dc machine (BLDCM), perpetual magnet synchronous machine (PMSM), and Halbach cluster machine (HAM) are the fundamental kinds of PM machines utilized in FESS applications [20]. An examination between IMs, VRMs, and PMs is displayed in Table 1. Concerning the evaluation of explicit force, the creators in [18] seem to have distorted the distributed qualities. As far as we can tell, contingent upon the rotor speed, the particular intensity of an IM and VRM would associate with half of that of the PM and not the enormous distinction is appeared in [18]. Further investigation of the first writing reports that the particular force thickness of PM synchronous machines is roughly 1.2 kW/kg.

Table 4.1: Comparison of electrical machines suitable for use in FESS.

Machine	**Asynchronous**	**Variable Reluctance**	**Permanent Magnet Synchronous**
Power	High	Medium and low	Medium and low
Specific power Rotor losses	Medium (~0.7 kW/kg) Copper and iron	Medium (~0.7 kW/kg) Iron due to slots	High (~1.2 kW/kg) Very low
Spinning losses	Removable by annulling flux	Removable by annulling flux	Non-removable, static flux
Efficiency	High (93.4%)	High (93%)	Very high (95.5%)
Control	Vector control	Synchronous: Vector Control. Switched: DSP	Sinusoidal: Vector control. Trapezoidal: DSP
Size	1.8 L/kW	2.6 L/kW	2.3 L/kW
Tensile strength	Medium	Medium	Low
Torque ripple	Medium (7.3%)	High (24%)	Medium (10%)
Maximum/base speed	Medium (>3)	High (>4)	Low (<2)
Demagnetization	No	No	Yes
Cost	Low	Low	Low
Advantages	Low cost	Robustness of temperature overheat	Low loss, high efficiency
	Simple manufacture	Overcurrent capability	High power density

	Technology-matured	Excitation coil can repeat adjustment	High load density
	Adjustable power factor	Lower loss at starting torque	High torque density
	No demagnetization	Easy to dissipate heat	Small volume, light quality
	High energy storage	Lower loss, higher efficiency	low rotor resistance loss
	No running loss	High power density	No field winding loss
			Flexible shape and size
			Simple control mode
			High reliability
Disadvantages	High slip ratio of rotor	Complex structure	poor robustness of temperature
	Limited speed	Difficult to manufacture	Demagnetization
	Larger volume	Low power factor	High cost
	Low power to quality ratio	Torque ripple, vibration and noise	Materials fragile
	High losses, low efficiency	More outlet from machine	Difficult air gap flux-
		Difficult to regulate speed	field adjustment

To exploit the two PMs and VRMs, half breed PM hesitance machines have as of late been created. Other whimsical machine types for FESS are exhibited in [20] and the most recent improvements of MG for FESS are talked about in [19].

In flywheel estimating, a most extreme measure of vitality stockpiling is focused on inside the specialized furthest reaches of the material and gear picked. The mechanical quality of the material, the greatest speed of the engine/generator, framework misfortunes, and physical measurements are the most significant plan parameters.

In voltage guideline of a space station was accomplished by utilizing a vitality stockpiling gyrator. The force originating from the sun based boards feed the heap and the spinner during the period where the satellite sees the sun. This is known as the "charging stage" of the whirligig. In the charging mode, the engine quickens, arrives at the appraised speed, and keeps on turning at this speed. The motor vitality put away in the whirligig in this mode is changed over back to electrical vitality to supply the heap in the period called the "release period", during which sun powered vitality isn't accessible for the satellite. In this mode, the line voltage guideline is additionally accomplished by the whirligig. Between the charging and releasing periods, there is a change period called "charge decrease", in which sunlight based vitality is at a low level and just a modest quantity of vitality can be gotten from sun powered boards. In this mode, the whirligig is likewise responsible for line voltage guideline.

The engine/generator unit is the most basic part of flywheel vitality stockpiling frameworks. In this manner, its determination and control configuration should be done first. Ordinarily, perpetual magnet AC synchronous engines are the essential decision in applications because of their high productivity and brushless structure. In the writing, sensorless procedures have been recommended to decrease the equipment necessities and dispose of the restrictions forced by sensors [8–10].

Even though there are a few research extends about these methods, the strategy isn't sufficiently experienced to use in space applications.
Due to their superior and minimal effort, brushless DC engines can likewise be utilized in flywheel vitality stockpiling gadgets that are broadly utilized in persistent vitality frameworks.

Rapid flywheel structure and examinations of the misfortunes of a flywheel were introduced in the attractive bearing was proposed to lessen the mechanical misfortunes and it was accounted for that wind age misfortunes can be disregarded if vacuum lodging is utilized. The effectiveness of the flywheel at the most extreme speed was given as 95.98% yet the vitality productivity (full circle proficiency) was not given.

A low-speed smaller scale flywheel vitality stockpiling framework was planned in [13]. The uninvolved attractive bearing was proposed to suspend the rotor with no mechanical contact with the stator. It was accounted for that to accomplish high proficiency; the framework was worked under a vacuum domain. In any case, the framework productivity was not given in this paper either.

An audit of flywheel-based vitality stockpiling frameworks was exhibited in [14]. Every one of the parts (engine, bearing, lodging, wheel, power converter) of a flywheel was assessed. To diminish misfortunes, attractive bearing and vacuum lodging must be utilized. Under vacuum conditions (ignoring wind age misfortunes) and without mechanical misfortunes (by utilizing attractive bearing), the flywheel effectiveness was given at around 90%–95%.

In this paper estimating a flywheel vitality stockpiling unit is pointed. To begin with, parametric conditions to be utilized in the plan are gotten from the vitality equalization of the framework. At that point, segment choice is made, and parameters that influence the vitality balance are resolved. At last, framework estimating is done utilizing these parameters.

4.1.2 Bearings

The mechanical heading is precluded in a fast flywheel vitality stockpiling frameworks because of the grinding, misfortunes, and requirement for grease. So attractive orientation is profoundly utilized due to the capacity to work at rapid with no misfortunes, with high accuracy and have a long lifetime. As per the control rule, the attractive bearing can be separated into latent attractive bearing (PMB), dynamic attractive bearing (AMB) and mixture attractive bearing (HMB). Uninvolved attractive bearing contains changeless magnets on the two sides, on the stationary and turning rings, for this situation, it needn't bother with control or force, however, the principle disservice of PMB is the trouble to accomplish stable levitation every which way because of Earnshaw's hypothesis which suggests that accomplishing stable static levitation by utilizing fixed magnets is incomprehensible, as outlined in condition (10).

$$K_{ax} + 2K_{Rad} \leq 0 \qquad (10)$$

Where K_{ax} is the axial suspension stiffness, K_{Rad} is the radial suspension stiffness, and multiplication of 2 is due to the two dimensions of radial space.

It can be seen, that if the axial suspension is stable $K_{ax} > 0$, that led to $K_{Rad} < 0$ which is unstable, and the opposite is true. To overcome this issue many methods are used such as using passive magnetic bearing for axial suspension and active magnetic bearing for radial suspension, or to use superconducting magnetic bearing (SMB) which operates in critical temperature. The working principle of active magnetic bearing is based on electromagnetic forces to maintain the rotor position, so it requires a controller and position sensor as depicted.

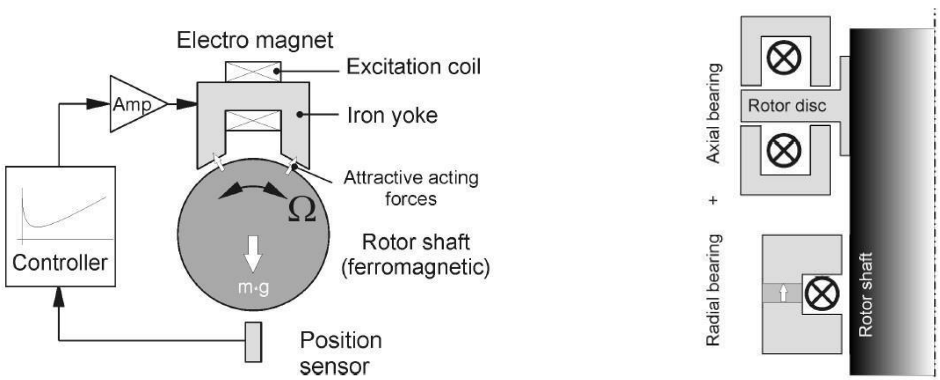


Figure 4.3: left: Active magnetic bearing structure. Right: Axial and radial bearing

As indicated by load support, attractive heading can be isolated into hub bearing (push) and spiral bearing (Journal), and to keep up stable levitation, the flywheel stockpiling framework requires two diary course and one push bearing as delineated in figure 6. For mixture attractive bearing, it is produced using a mix of detached attractive bearing and dynamic attractive bearing.

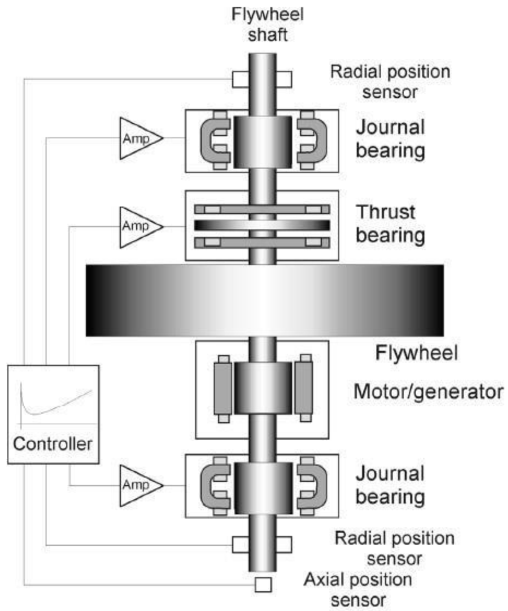


Figure 4.4: Flywheel with bearing system

4.2 Housing

One of the fundamental misfortunes of the flywheel stockpiling framework is the streamlined drag misfortune (windage misfortune), so to limit the misfortunes, the flywheel framework is put in a vacuum chamber or low-thickness gases, for example, helium, these methodologies require outer vacuum siphon and complex cooling framework. The alluring weight of the flywheel chamber is between 10−1 hPa *to* 10−3 hPa and even less, to accomplish this weight, the vane rotational siphon is utilized, and for pressure lower than 10−3 hPa turbo siphon is added to the vacuum framework. For security reasons the load is made of thick steel and introduced underground, in the event of any disappointments, there will be two boundaries to forestall any harms.

Terminal voltage *(V)*

The engine alternator will be controlled from the vehicle's DC transport and the RMS estimation of the line-to-impartial terminal voltage must surpass this voltage. In this plan, the terminal voltage will be fixed at the transport voltage. Picking a particular voltage may seem to compel the plan, however as the models will illustrate, this doesn't put any limitations on ideal machine determination. The terminal voltage of an engine can be changed to any discretionary incentive without changing the applicable plan qualities. A terminal voltage of 155 V was utilized in this proposition. The goal of the plan is to discover a machine that meets these presentation prerequisites and shows the most alluring exhibition in the accompanying qualities.

Rotor eddy current loss *(Pr)*

This recollects the cost of the copper and magnets for the machine. Other machine costs, for instance, collecting will add to the total machine cost, in any case, they are not obligated to depend on a general sense upon structure parameters and are expelled.

Material cost *(Ct)*

This remembers the expense of the copper and magnets for the machine. Other machine costs, for example, assembling will add to the absolute machine cost, however, they are not liable to rely fundamentally upon structure parameters and are dismissed.

Material weight *(wt)*

Electrical efficiency *(Effj)* The prevail electrical misfortunes in the machine are Ohmic and vortex flows misfortunes in the armature wires. Rotor misfortunes, however a significant trait, are irrelevant in the effectiveness figuring.

4.3 Power Converter

The primary piece of intensity change in the flywheel vitality stockpiling framework is the Bidirectional converter which works as a force interface between the lattice and the engine/generator blend and empowers the ability to stream in the two bearings as portrayed.

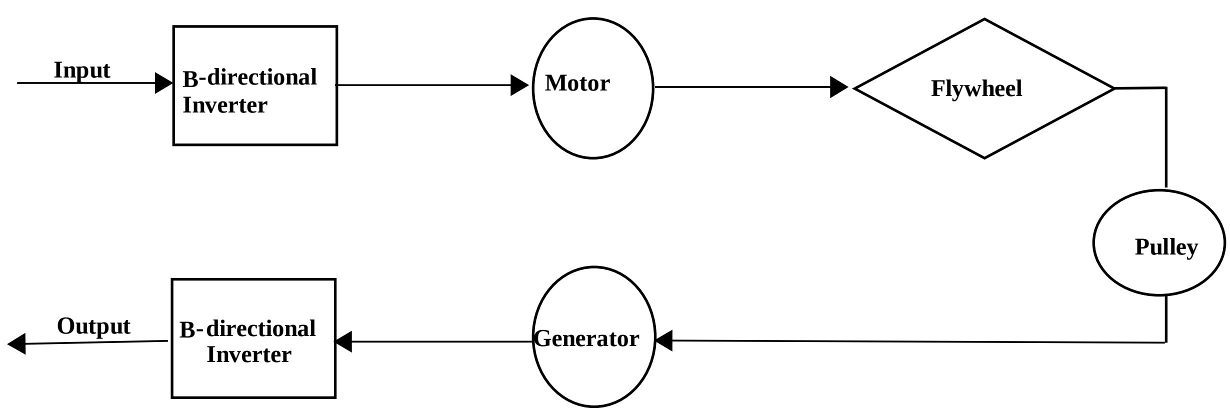


Figure 4.5: The flow of power in flywheel converter

The working standard of bi-directional converter depends on AC-DC-AC topology, it changes over the AC power into DC and afterward from DC to AC, this gives the capacity to control the recurrence and voltage, so bi-directional converter can be isolated into three sections: machine side converter (MSC), DC connection and matrix side converter (GSC).

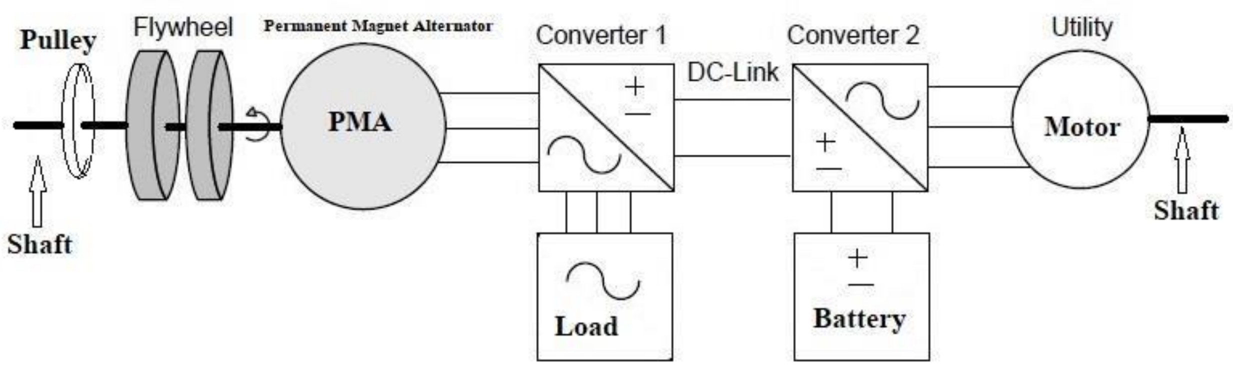


Figure 4.6: Machine and grid side converters

DC link also gives the possibility to connect multiple flywheel systems in parallel for high power storage demand.

The working activity of the converter contains three modes: charging mode, backup mode and releasing mode. During the charging mode, the network side converter functions as a rectifier, while the engine side converter fills in as an inverter quickening the flywheel when the flywheel arrives at the necessary speed the converter is set to reserve mode. The releasing mode prompts the contrary activity the engine side converter fills in as a rectifier while the framework side converter functions as an inverter to infuse the necessary vitality to the lattice, this makes the flywheel delayed down, one of the methods used to forestall voltage vacillation is to include help converter in the DC interface, to guarantee stable DC voltage level as appeared.

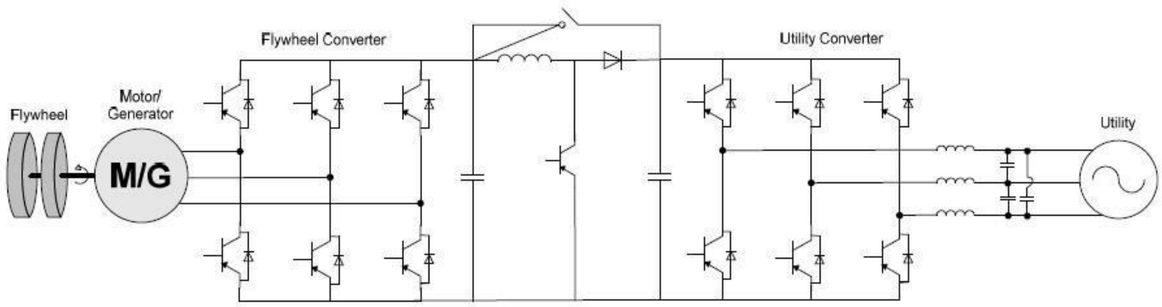


Figure 4.7: Flywheel converter with boost converter in the DC link

Sizing of flywheel energy storage device

Before beginning a nitty-gritty framework structure, the plan necessities should be characterized. The capacity gadget must give the necessary vitality to satellite subsystems during the dull period in the circle. In this paper, the forced necessity of the S-band transmitter of the BilSat satellite is utilized as the beginning stage of the structure. This bit of gear devours 23 W during information move [15]. Since the dim period is around 30 min for low earth circle satellites, the vitality utilization for this gadget is determined to be 11.5 Wh for the most pessimistic scenario, accepting that the exchange is constant.

The structure should have an iterative procedure and every one of the parameters is subject to one another. The beginning stage of the structure is the estimation of the active vitality put away in the wheel of the engine/generator unit while it is pivoting at the most extreme speed. This worth is given in Eq. (1).

$$E_{tot} = \frac{1}{2} J \omega_{\max}^2 \tag{1}$$

The principle capacity of the flywheel in the application is disposition control and accordingly, its speed should be over a base for every single working condition with the end goal that the base force esteem is accomplished. Flywheel speed can be changed between this base speed and the greatest speed. The contrast between the vitality sums at these two velocities is the vitality that can be usable by the framework. This distinction is characterized as the profundity of release (DD).

$$E_{diff} = \frac{1}{2} J \left(\omega_{\max}^2 - \omega_{\min}^2\right) \tag{2}$$

Eq. (1) is valid for a lossless system. The effective energy amount can also be found by incorporating the round-trip efficiency (η) in the equations.

$$E_{eff} = \eta \frac{1}{2} J \left(\omega_{\max}^2 - \omega_{\min}^2\right) = \eta \, E_{diff} \tag{3}$$

The full circle proficiency utilized in Eq. (3) is characterized to be the proportion of the vitality recouped during the generator activity to the vitality provided during the engine (putting away) activity. Full circle proficiency esteem shifts relying upon the activity speed interims.

Since the momentary effectiveness will be differing for variable burden and activity conditions, the speed interim should be resolved first. The fundamental condition to begin the procedure is the electromechanical torque condition. During the engine activity:

$$T_{em} = J \frac{d\omega}{dt} + B\,\omega + T_L \tag{4}$$

The torque equation during the discharge (generator) interval is given as follows:

$$J \frac{d\omega}{dt} = T_{em} + T_L + B\omega \tag{5}$$

As is evident in this condition, the vitality stream is switched, and the source currently is the putaway vitality. It ought to likewise be noticed that the breeze age misfortunes are not overlooked here since the exploratory set-up will at present have them, in spite of the fact that they are required to be zero out of a genuine space application. The heap torque, then again, is zero since there isn't such a heap in the framework.

The framework full circle effectiveness between any double cross moments can be modified as follows by utilizing the way that vitality is the time-essential of intensity, and force is equivalent to torque times the speed.

$$\eta = \frac{E_e}{E_{diff}} = \frac{\int_{t1}^{t2} T_{em} \omega \, dt}{\frac{1}{2} J(\omega_{\max}^2 - \omega_{\min}^2)} \tag{6}$$

Friction losses in the flywheel systems can be reduced by using either magnetic bearings or oilless bearings. Although there is no load to oppose in the system, windage losses in systems without sufficient vacuum levels and disturbance torques for various reasons still exist.

System design

Exactness metal balls have been utilized in the structured framework and every one of the prerequisites will be resolved dependent on this. Because of this decision, mechanical grinding misfortunes should be considered in the plan.

As there are numerous questions, it is necessitated that a portion of the parameter esteems are picked and the rest are determined. The inactivity of the flywheel has been taken as 0.008 kgm2. The heaviness of the framework currently relies upon this incentive just as material determination and mechanical structure. Aluminum material has been utilized as the material to assemble the flywheel. In the end, a circle molded flywheel of 20 cm in breadth and 2 kg in weight was acquired. Figure 1 shows the strong work of the flywheel plan.

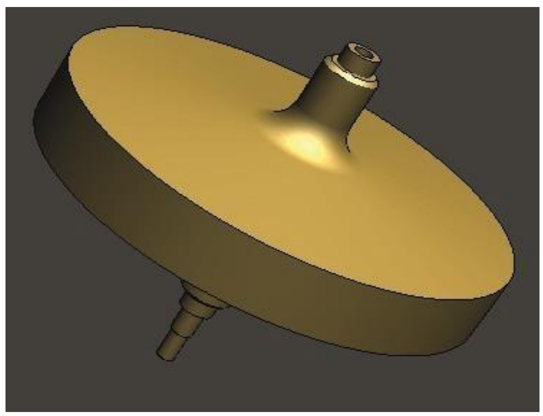


Figure 4.8: Solid work of the flywheel design.

As stated earlier, a minimum value of the angular momentum exists for the attitude control system. This value is H_{min} = 0.4 Nms for the satellite used in the design. Minimum speed of the operation is obtained now by using these values.

$$H_{\min} \leq J\,\omega_{\min} \Rightarrow \omega_{\min} \geq (0.4\ Nms)/(0.008\ kg.m^2) = 50\ rad/s = 477.46\ RPM$$

In spite of the fact that this worth will ensure the activity of the frame of mind framework, the voltage produced at this speed by the flywheel will be little to control the transport. Along these lines, the incentive for the base speed was picked to be 5000 rpm. Then again, the base speed isn't picked greater than 5000 rpm to keep the profundity of release as large as would be prudent.

It isn't appropriate to characterize a particular productivity for the generator because of variable speed activity. Along these lines, it would be a superior way to deal with utilize the vitality balance condition (Eq. (7)) to decide the activity speed interim.

$$\begin{aligned} \tfrac{1}{2}J(\omega_{\max}^2 - \omega_{\min}^2) &= \int_{t1}^{t2} T_{em}\omega dt + \int_{t1}^{t2} B\omega^2 dt \\ &= \int_{t1}^{t2} T_{em}\omega dt + \int_{t1}^{t2} P_{fr} dt + \int_{t1}^{t2} P_{wind} dt \end{aligned} \tag{7}$$

Speed variety in the generator method of activity is direct just if the heap is steady. Be that as it may, the heap is never consistent in light of the speed-subordinate misfortunes. This is particularly valid for the ground model because of the windage misfortunes. Then again, accepting a consistent burden disentangles the plan. A multiplier is acquainted in the controller with make up for this blunder.

CHAPTER 5

SOCIO-ECONOMIC ASPECT OF THE SYSTEM

Through constant perception and conduction of research works, utility specialists and field engineers have ventured into a choice that, the urban, just as rustic clients of Bangladesh, must be increasingly cautious and genuine while they utilize electric capacity to guarantee the most extreme productivity and the age of greatest income. They've additionally said that the complete interest insufficiencies can be gotten together by placing new ages into the matrix as well as by guaranteeing the efficient utilization of current force supply. The force conveyance system of Bangladesh will appreciate every one of the offices and advantages of Grid expressed above if and if the present framework is significantly adjusted to a circulation framework. Subsequently, the present issues like arranged burden shedding because of exorbitant interest than supply and moderate nature of provided force will be illuminated.

5.1 Benefits of Smart Power Distribution

Some major benefits of smart distribution system for Bangladesh are:

A. Reliable Power Supply

Force slice because of unforeseen issues is a typical occurrence in Bangladesh. With oneself recuperating and quick exchanging attributes of FESS, the flaws can without much of a stretch be found and cleared naturally. It decreases blackout time and other related expenses. Thus, receptive force backing and voltage profile support can likewise be overseen.

B. Distributed Energy Resources

FESS is an across the board and understood subject today for power age and progressively is getting well known. It will diminish the popularity of pressure from the off-framework. Utilizing a battery reinforcement framework, the vitality can be utilized in the evening time as well. Indeed, for better execution as far as specialized and money related perspective, the AC electric apparatuses rather than DC machines can be introduced in urban territory homes and business places.

misfortunes will be decreased. The sensors will respond rapidly enough to gauge any surprising exercises in the off-network.

F. Electricity Market

This activity will make a degree to make the present power to showcase a deregulated market. In this way, new challenges, business, and research territories will be made.

G. Load Shifting and Switching

Burden moving and power steering system will be simpler and programmed because of mechanized elements of off Grid. The Supervisory Control and Data Acquisition System will be an incredible assistance in such a manner.

H. Economic Benefit

The previously mentioned reasons decrease the additional speculation and upkeep cost that could be expected to introduce additional force age and dissemination offices, which implies less monetary venture and common works. These reserve funds might be used to additionally improve the current framework.

I. Digitization

Steps to actualize Smart Grid by the Govt. of Bangladesh will be a solid way to deal with making a "Digital Bangladesh". The legislature has proclaimed the "Vision 2021" which focuses on the foundation of a creative and present-day nation by 2021 through successful utilization of data and correspondence innovation - a "Digital Bangladesh" [6].

The clients need a solid, modest and quality force supply in a domain cordial way. Thinking about all the specialized, practical, topographical, ecological and social perspectives, it tends to be expressed that the savvy dispersion framework is an inescapable decision for Bangladesh.

5.2 Financial Aspect of the System

One of the impediments of flywheel innovation is the significant expense of innovation contrasted and others like batteries. In any case, it has been seen that the achievement of these gadgets is shown and they bring about helpful when exceptional applications, conditions, imperatives are on the table.

Since one of the most significant objectives in the advancement of a flywheel is to accomplish an aggressive cost, an incredible exertion is vital too since it relies upon the particular states of the application that is considered.

- Prototype cost
- Identification of the relative weight in the total cost of the device.
- Identification of the fixed and variable costs.

There is some building cost that thinks about the plan of the gadget. Here there may be incorporated mechanical plan, electromagnetic structure, electronic structure, and control programming. While thinking about the manufacture, some exceptional devices must be created for unique methodology. Those expenses are just required once and in this way considered as fixed expenses once. In the end, some improvement can be applied to the underlying plan and that would be traduced in a variable building cost yet for this first exercise won't consider.

CHAPTER 6

CONCLUSION AND RECOMMENDATIO

6.1 Recommendation

Although the flywheel is perhaps the most punctual type of vitality stockpiling, minimal, solid, low support flywheels have just become accessible moderately as of late. The numbers delivered have been little, and the utilization of progressively outlandish materials and their handling, for example, carbon fiber composites, have kept the expense at around multiple times higher than steel flywheels [10,18]. New, inventive plans dependent on steel conquer the worry about wellbeing for exceptionally focused on rotors, which would now be able to work at a lot higher tip speeds than was viewed as safe for solid steel rotors [88]. Steel has the advantage that the material and preparing courses are settled and comprehended to the stockpile base which is as of now there, for minimal effort producing at all basic clump sizes of 10 s to 1000 s. Steel is effectively recyclable in contrast with batteries, even though reusing won't be accomplished for a considerable length of time given a compelling limitless schedule life and cycle life of numerous 10 s of thousands.

Another worry identifies with the charge holding capacity of flywheels since the misfortunes in right now accessible flywheels are high. These misfortunes are mechanical (drag, bearing, rubbing), electrical (hysteresis, swirl flow, copper), and influence converter-related (exchanging and conduction) [89]. If flywheel misfortunes can be kept to around 10%–20% once-over per 24 h, given the accessible advancements and the lower rates of the steel flywheel, the likelihood for these applications is surely encouraging. The vacuum required for this isn't unduly high and will be held by methods for a hermetically fixed framework, just requiring periodic re-siphoning. Most of the weight can be suspended on detached attractive direction, with unavoidable misfortunes in the delicately stacked metal ball framework being admirably inside the 20% run down misfortune recompense. The rest of the misfortune is the electromagnetic drag in the generator and this relies upon the plan. Since a flywheel for this obligation is probably going to have an electrical machine of kW rating like the kWh rating, numerically, the electromagnetic drag of a well-planned framework can likewise be kept inside the misfortune spending plan.

6.2 Conclusions

This paper has introduced a basic audit of FESS regarding its fundamental segments and applications. The structure and segments of the flywheel are presented and the primary sorts for electric machines, power gadgets, and bearing frameworks for flywheel stockpiling frameworks are depicted in detail. The fundamental uses of FESS in power quality improvement, uninterruptible force supply, transportation, sustainable power source frameworks, and vitality stockpiling are clarified, and some monetarily accessible flywheel stockpiling models, alongside their activity under every application, are likewise referenced. FESS offers one of a kind attributes of an extremely high cycle and schedule life and is the best innovation for applications that request these necessities. A powerful ability, moment reaction, and simplicity of reusing are extra key favorable circumstances. Given the interest for ESS is extending considerably, and that FESS has these extraordinary qualities, the future for FESS stays extremely splendid, even in when the expense of Li-particle and other science battery innovation keeps on diminishing. Future work will incorporate the definite demonstrating and examination of a flywheel framework for reinforcement force and lattice bolster applications.

Conflicts of Interest: The authors declare has no conflict of interest.

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