SCOPE OF FLYWHEEL ENERGY STORAGE SYSTEM IN FITNESS CENTERS OF PAKISTAN AS A BACK-UP ENERGY SUPPLY

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ABSTRACT

The paper presents a review on how mechanical energy that is wasted during exercise in fitness centers and gymnasiums can be stored and utilized in creating a backup energy through Flywheel Energy Storage (FES) system for uninterrupted power supply. For a country like Pakistan where load shedding is a reality, this kind of a set up will help not only to create a backup energy supply but eventually also help in energy conservation and reduction of electricity bills of the fitness centers. The case study reviews the scope of a Flywheel Energy Storage (FES) system incorporated in cycling machines in fitness centers. Study revealed that for a small set up of fitness center comprising of five cycling machines, energy of 2.547 KWh could be generated using the FES system. This energy can be used to light the bulbs of the set up. Hence, after conducting the study it is concluded that it is feasible to incorporate FES system in fitness centers of Pakistan as it has great potential to be used as a suitable back up energy supply.

Keywords: *Energy Storage System, Flywheel ESS, Energy Utilization & Back-up Energy Supply*

INTRODUCTION

Energy Storage Systems are now a renowned system to store and retrieve energy especially for back up supply (Cheng, Sabah & Wu, 2017). Out of the many Energy Storage Systems, FES is gaining more and more popularity due to its immense advantages. A FES system is designed using a flywheel, differential sprocket system, generator and inverter which converts kinetic energy stored to electrical energy to provide back up energy supply. Flywheel is used to store kinetic energy during cycling in gymnasiums while speed is varied using sprocket differential gears. Converting wasted mechanical energy to electrical energy can be used as a back up energy supply. The amount of energy generated is calculated and the results suggest the scope for using this technology in gymnasiums of Pakistan. Pakistan has been facing severe energy crisis for more than a decade now. Not much has been done to cater the increasing energy demands resulting in prolonged hours of load shedding. According to Energy Experts Group constituted by Economic Advisory Council in 2009 in Pakistan, it is estimated that the energy demand for Pakistan by the end of 2030 will increase by 64% (Zeeshan, 2013).

Hence, energy conservation and utilization of wasted energy is a necessity for the country. This will not only save energy but eventually also result in deceasing electricity bills for the required set-up. Currently in Pakistan, battery based back up energy supply is mostly used. This system requires frequent maintenance but is cost effective as compared to other options available. Solar energy back up system is also used on a very small scale. Energy Storage System is necessary for renewable sources in order to stabilize output (Ogata, Matsue & Yamashita, 2016). However, it is not very popular due to its cost and maintenance issues. Flywheel energy storage system is a concept that is still new to the local market in Pakistan and the scope and potential of it to be used commonly in residential or small business set up is yet to be explored properly. The characteristics of flywheel like high cycle life, environmental friendliness, high efficiency and low maintenance makes it a favorable option for back up systems to be considered for small scale set ups.

LITERATURE REVIEW

Flywheel is a simple device for storing energy in rotating mass. A flywheel stores mechanical energy to electrical energy by means of an electrical machine with a bidirectional power converter (Sebastian & Pena, 2012). However, the true scope and potential of a flywheel system still remains undiscovered (Takahashi, Kitade & Morita, 2012). It is only since the development of high strength materials and magnetic bearings that this technology has gained a lot of attention. Exploration of high strength materials and magnetic bearings has allowed designers to reach high operating speeds, hence yield more kinetic energy (Liu & Jiang, 2007). Using magnetic bearings has made it possible to reach high operating speeds providing cleaner, faster and more efficient bearing equipment and that to at the extreme temperatures (Hebner, Beno & Walls, 2007). Most Flywheel Energy Storage (FES) systems use electricity to accelerate and decelerate the flywheel, but devices that directly use mechanical energy are being developed (Bolund, Bernhoff & Leijon, 2007).

Advanced Flywheel Energy Storage systems comprise of rotors made of high strength carbon-fibre composites, suspended by magnetic bearings, spinning at speeds from 20,000 to over 50,000 rpm in a vacuum enclosure. Such flywheels can come up to speed in a matter of minutes reaching their energy capacity much more quickly than some other form of storage (Brian & Fabien, 2007). Renewable energy sources and potential distributed generation are considered great supplements and replacements, however, these also have great challenges associated with them (Hajipaschalis, Poullikkas & Efthimiou, 2009). The capacities of FES device is extraordinary and so is its unique design. Where, a traditional lead-acid cell battery, used in heavy-duty power applications stores energy at a density of 30-40 watt-hours per kilogram (enough to power a 100 watt bulb for 20 minutes); a flywheel based battery can reach densities 3-4 times higher around 100-130 watt-hour per kilogram (Fabien, 2007). Unlike battery, flywheel is also known for storing and discharging all energy quickly and that too without getting damaged.

Today flywheels are used as supplementary uninterrupted power supply storage at several industries world over (Bolund et al, 2007). Hence, it is more likely being considered for power back up applications (Emadi, Bernhoff & Leijon, 2005). This advantage as well as its long life span and minimal maintenance makes FES system greatly suitable for storing mechanical energy wasted in gymnasiums by people during their exercise sessions on machines like thread mills, cycling, etc.

According to a study conducted by the BBC, Pakistan's fitness industry is one section of the economy that has not been affected by recessions or political instability; in fact it is booming (Fareeha, 2011). With the changing life styles, and increasing amount of gymnasiums in cities of Pakistan like Karachi and Lahore, it is high time work should be done to recover wasted energy. Hence, Energy Conservation Gymnasiums should be introduced which will not only benefit the fitness centers by saving up energy (which can easily be used as back up energy to power fans and lights) but in the long run will also help in overall electricity cost reduction.

With the draining energy resources and increasing human demand steps for optimization of energy usage has become a need (Zeeshan, 2013). Work needs to be done not only in conservation of energy but reusing wasted energy also. These setups will help immensely in using wasted energy on treadmills and cycling machines to be conserved by a setup that requires low maintenance and is also long lasting. Today the wheel seems poised to bring about another such change, and though the impact this time might not alter civilization as we know it, it may yet prove to be revolutionary (Abrahamsson, 2014).

RESEARCH METHODOLOGY

FES system is incorporated on a cycling machine. FES system houses a flywheel rotor mounted on bearings connected to a motor. Flywheel, made of steel, is rotated with the help of human kinetic energy via paddle of a cycling machine. The rotation of the flywheel gives the revolutions per minute (rpm) which helps to calculate its angular speed. Moment of inertia is also calculated which in turn is used to calculate the useful energy of flywheel. A differential sprocket is used to vary speed of the cycle and vary energy output. The flywheel is connected to an electric motor which converts mechanical energy stored by flywheel to electrical energy using an inverter. This electrical energy is then used as back up energy to light bulbs and fan. System is made to run and storage capacity is calculated through stored kinetic energy. Results are repeated for different cycling machines to verify results.

CREO Model of FES System

Figure 1

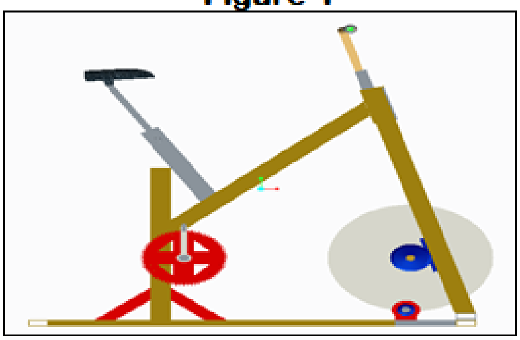
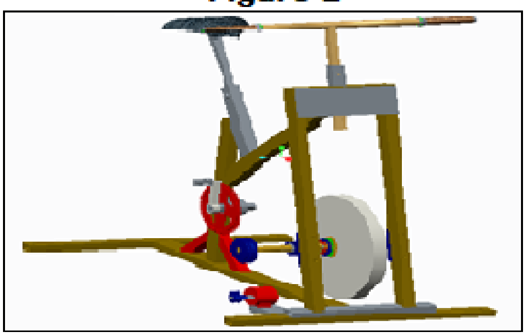


Figure 2



Calculations for Flywheel Energy Storage System for a Cycling Machine

Energy Stored by Flywheel:

Flywheel diameter= 20 in
Flywheel pulley diameter= 6 in
Flywheel mass=25 kg
Generator RPM= 480 rpm
Flywheel RPM=80 rpm
Generator shaft diameter=1 in
Moment of Inertia of Flywheel:

$I = Kmr^2$ ……… (1)

$= 1 . 25. (0.254)^2$

$= 1.613$ kgm^2

Angular speed of Flywheel

$w = \frac{2\pi N}{60}$ ………….. (2)

=6.284. 80/60

=8.38 rad/s

Kinetic Energy Stored By Flywheel

$K.E = \frac{1}{2} I\, w^2$ …….. (3)

=0.5. 1.613. (70.2)

=56.6 J

Therefore, in 1 second, 56.6 J is produced.
In 3hrs, power produced is = 3 (10800) (56.6)
=1833.84 KJ

Hence If 5 cycling machines are functional for 3 hrs,
Power produced is=5*1833.84=9169.2 KJ
As 1 KJ= 0.27778Wh (Watt.hour)
Therefore, Power produced by 5 cycling machines for 3 hrs =2.547KWh

Differential Sprocket System

Diameters of differential sprockets used are: 2.1in, 2.5in, 2.9in and 3.1 in
For the first Sprocket:
d=9 in, N=14 rpm

$N_1 d_1 = N_2 d_2$ ………. (4)

$N_1 = \frac{2.1}{9} * 80$

N_1 = 18.66 rpm

Similarly, for other sprockets
For d=2.5, then N=22.2 rpm.
For d=2.9, then N=25.8 rpm.
For d=3.3, then N=29.3 rpm.

Design of Shaft (Steel)

Applying ASME Code to find $\tau_{\text{permissible}}$
As, yield stress S_{yt} = 240MPa
$\tau\ permissible\ = 0.3 * S\ yt$ ……… (5)
=0.3*240=72MPa
τ = 0.75*72 =54MPa
For generator, I = 7 A & V = 12 V
Power (generator) $P = V.I$ ….. (6)
= 12*7= 84W
$P= \frac{2\pi NT}{60}$ …………….. (7)
Torque, $T = \frac{P*60}{2\pi N}$ ……… (8)
$T=\frac{84*60}{6.28*50}$
T=16.050 N.m

FINDINGS

An FES system is designed for a small-scale fitness center. A fitness center is assumed to be fully working for at least 3 hours per day. Along with other machines, five cycling machines are assumed to be operational. An FES system incorporated in all five machines. Kinetic energy stored by the flywheel which is then converted to electrical energy through generator is calculated to be 1833 KJ per cycling machine. Hence, for five cycling machine, the total stored energy available is 9169 KJ which is equivalent to 2.547 KWh.

DISCUSSION

The following calculations assures that FES system can be used as a back up energy supply to light bulbs and fan. Therefore, flywheel energy storage system holds a lot of scope in providing uninterrupted power supply as it requires less maintenance and is environmental friendly. FES system in fitness centers are also suitable as it has long operational life, high efficiency as well as high power density. The cost is also market competitive in the long run. The FES system in a fitness center will not only provide back up energy but also eventually reduce electricity bills in the long run. The performance of FES system can further improve with involvement of magnetic bearings, better flywheel material made of high tensile strength or by increasing flywheel speed by increasing moment of inertia. Further work in this area will yield far more energy, which can meet even greater energy requirements.

Set-up Cost and Feasibility

The material used for flywheel is steel. Cost of the whole FES system set up was around 15,000 Pakistani Rupees per unit including the paddling system, flywheel, generator, battery storage, sprockets, bearings, etc. This cost was estimated after a thorough local market survey. The number of machines determine the number of unit used. For an average small size gymnasium with 5 cycling machines and other machines, at least 5 units of FES will be required. This will cost approximately 75,000 Pakistani Rupees. Compared to other back-up systems in the market, the cost is slightly high compared to uninterrupted power supply (UPS) but cheaper than solar back-up power supply. However, unlike other systems available, FES system has high durability and very low maintenance thus saving money in the long run. For larger and improved set up, the cost would increase if high strength flywheel material was used or if number of flywheel was increased; however, it would also lead to better performance and more energy output would be possible.

Limitation

The electrical losses like eddy currents, mechanical losses like drag and friction in bearings and losses during power conversion like switching and conduction influence the results.

CONCLUSION

The case study shows that incorporating a FES system in cycling machine of fitness centers has great scope and potential for providing back up energy. The material with which FESS had been made is easily available in the local market at a reasonable price. The energy stored and generated is 2.547KWh over a duration of three hours by five cycling machines. This energy can further be improved with usage of better flywheel material with better tensile strength, use of magnetic bearings and housing the flywheel in vacuum. Although, including these changes are also costly but energy gained will be far greater as done in this case study. FES systems is a modern yet simple method, which has very high scope in the market for a lot of applications one of them being the back up energy for fitness centers. With the changing lifestyle and diets, increase of fitness centers provide an opportunity to utilize the wasted energy to a better use. In a country like Pakistan, where load shedding is a living reality, such solutions can provide great relief for small business and encourage further opportunities to explore FESS in similar applications.

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