Design and Analysis of Flywheel Energy Storage System for Power Electronic Interface

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ABSTRACT

Storage of energy is necessary in many applications because energy may be needed when the source is not available. Sometime the energy demand may exhibit some peaks where the supply energy may be uniform in character. Energy can be stored in many ways. It is seen that kinetic energy storage in flywheel provides the highest specific energy compared to any other alternative source. Especially when the flywheels are made with composite materials they provide very high efficiency. In this paper design of flywheel has been done using finite element analysis (Ansys 12.0) for various materials and the comparative results are presented. The results are useful in selecting the flywheel for power electronic interface.

Keyword: Flywheel energy storage, Efficiency, Composite materials, FEA, Comparison.

INTRODUCTION

Flywheel technology is old and effective method for storage. Earlier stages, flywheel energy storage was proposed for electric vehicles and for stationary power backup. After the fiber composite rotors, the magnetic bearings started to appear in 1980s. The potential for using flywheels as electric energy storage has long been established by extensive research. The storage capacity of the flywheel is high compared to the existing conventional storage methods. Moreover, the flywheel has so many advantages which include high power density, no capacity degradation, less periodic maintenance, short recharge time, etc. The major disadvantage of the flywheel reported in the literature is its high initial installation cost. The developments and progresses in materials, magnetic bearings and power electronic circuits make the flywheels a competitive choice for a number of energy storage applications. Further the progress in power devices facilitates the use of flywheel at high power with compact size. The following modifications in the conventional flywheel make it more effective in terms of performance of storing the kinetic energy.

- Use of composite materials for making the rotor of flywheel.
- Use of magnetic bearings instead of mechanical bearings.

The modifications improve the rotational velocity and hence the storing capacity. Because the energy stored is proportional to the square of the speed but only linearly proportional to the mass. In this paper, a comparative analysis have been carried out in the design materials namely gray cast iron and S-glass epoxy using finite element analysis (FEA).

Flywheel in Storage Systems with Power Converters: The burning of fossil fuels, such as coal, oil and gas to produce heat, electricity and in transport produces greenhouse gases (GHG) including carbon dioxide and methane. They cause global warming. Considering today's energy scenario, the importance of the use of renewable energy becomes more important. In principle, energy can always be converted from one form to another. In actual practice, however, there will be some forms that will be preferred due to cost-effectiveness. Electrical energy conversion is most preferable because of its advantages. All renewable energy sources can be converted to electricity. Fig. 1 shows the block diagram of the general renewable energy conversion into electrical energy for driving the day-to-day appliance.

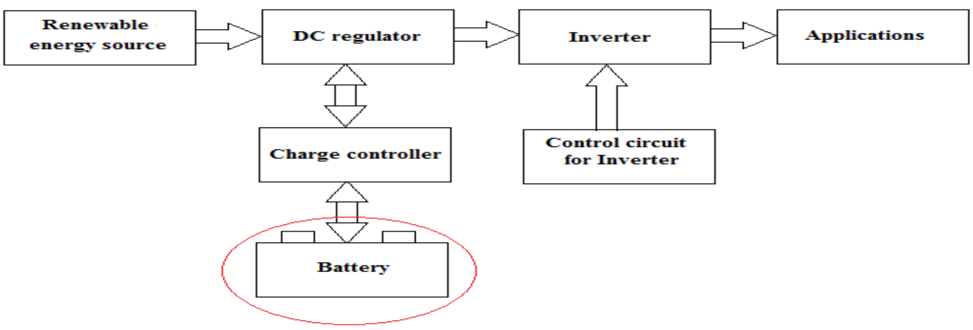

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Figure.1.Block Diagram of Renewable Energy Conversion System

The major problem in the renewable energy conversion system is the storage device as the sources are intermittent in nature. Commonly used storage systems are batteries where there is lot of problems faced mainly the cost, life, maintenance and periodic replacement. Energy storage systems are rapidly emerging technology that can ensure a stable supply of electricity and also to balance peak load demand. As the share of variable renewable increases in energy systems, the potential role of energy storage systems become more critical. The most energy efficient energy storage device is the flywheel storage. The most important advantage of flywheel is that the time delay during charging and discharging is very low. Power is available instantaneously and very high power output can be given out for a short period of time. Other energy storage methods such as pumped hydro or compressed air have the disadvantage of higher time delay in converting mechanical energy to electrical energy. When the power demand is immediate flywheel is viable source.

In electromechanical systems, the kinetic energy of a moving mass stores electrical energy. The most prevalent type of mass in an electromechanical storage system is a rotating mass, or flywheel. Like electrochemical batteries, flywheels must be part of a fully integrated system that includes sophisticated solid-state power conversion devices, monitors, controls, climate controls, utility and user interface equipment, safety devices and transportation features to be useful in electric power applications.

Most flywheel energy systems accelerate and decelerate using electrical energy. Today, most of the research efforts are being spent on improving energy storage capability of flywheels to deliver high power at transfer times, lasting longer than the conventional battery powered technologies. The performance of flywheel can be attributed to three main parameters namely material strength, geometry and rotational speed. The material strength directly determines the kinetic energy level that could be produced combined with high rotor speed which leads to the improvement of specific energy. Improvement in flywheel with increased speed of 20000 to 50000 rpm can be achieved using composites, suspended with magnetic bearings in vacuum. Also the flywheel systems have longer lifetime with no maintenance. The energy density of flywheel is very high in the order of 105 W-h to 128 W-h. The mechanical efficiency 97% can be achieved by using flywheel with magnetic bearings. The energy densities of flywheel using composite material are ten times than that of lead acid batteries.

Basic components of flywheel energy storage systems are:

Flywheel: Heart of the system providing a 20 year life with no maintenance.

Master controller: Monitors output demand and controls the various subsystems including charging and discharging of flywheel.

Magnetic bearing controller: Controls the position of flywheel rotor.

Bi-directional power converter

Vacuum pump: Reduces windage losses thus resulting in increased electrical efficiency.

Power electronics used with flywheel helps to take power from the flywheel to the grid if at the grid side, the voltage generated by the inverter leads the grid voltage. The reverse will happen for the power to flow from the grid to the flywheel. On the flywheel side, power will flow into the flywheel when the inverter phase angle leads the shaft angle and vice versa. Phase angles of both side inverters should be so controlled that the power output from the flywheel is equal to the process of FEA involves three stages namely,

- Preprocessing
- Meshing
- Post processing

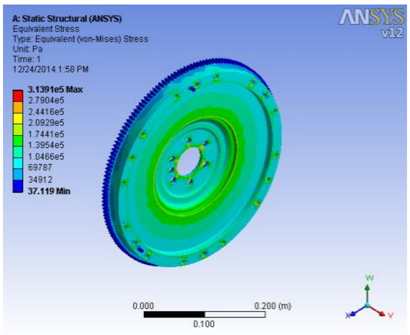
FEA model is described to achieve a better understanding of the mesh type, mesh size and boundary conditions applied to complete an effective FEA model. In this paper, the flywheel is designed in solid works (IGS file) and imported to ANSYS 12.0 for analysis. Mapped mesh analysis have been done for two materials namely gray cast iron and S-glass epoxy for comparing the stored energy capacity.

Meshing using ANSYS: Meshing is done using smart mesh since it does not have any restrictions. Modeling Assumptions:

- The material is isotropic.
- Vibration effects are ignored.
- Steady state conditions.

- There is rigid connection on the drive shaft with no keyway for notch effects and no chamfering

The flywheel is meshed using Edge2, then by using the ANSYS12.0, the maximum equivalent von misses stress and the total deformations are computed. Then in the structural analysis the maximum equivalent (von-misses) stresses, normal stresses, shear stresses and total deformation at loading conditions are shown in Fig. 3 for two materials.



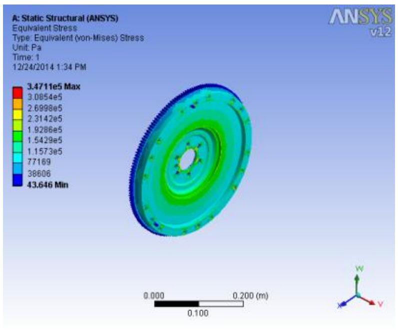


Figure.3. Meshing and Stress analysis for gray cast iron and S-glass epoxy

The following modifications in the conventional flywheel make it more effective in terms of performance of storing the kinetic energy.

- Using a composite material for the flywheel material
- Reduction of weight which improves the kinetic energy as the speed increases
- Specific energy increases as the weight of the material decreases for the same dimensions

Comparative Analysis of Storage Capacity: Energy stored by a flywheel is proportional to moment of inertia (I) and the square of its angular velocity (ω).

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

Where,

$$I = \rho \times v \times r^2 \quad (2)$$

ρ = Rim density (kg/m^3); v = rim volume (m^3) and r = radius (m).

To calculate the weight of the flywheel for the above said two materials, the dimensions are obtained in solid works for the same size of flywheel. The obtained parameters are listed in Table 1.

Table.1.Comparision of flywheel materials

Parameters	Type of material	
	Gray cast iron	**S-Glass epoxy**
Radius , r (m)	0.504	0.504
Volume, v (m^3)	0.128	0.128
Rim density (kg/m^3)	7510	1590
Calculated specific Energy (kJ/kg)	0.097	0.485

From the above table, it is observed that the density of the S-glass epoxy material based flywheel is lesser than that of gray cast iron based flywheel. Hence the weight of the flywheel is reduced. The calculated mass for gray cast iron based flywheel is 60 kg and that of S-glass epoxy based flywheel is 11.9 kg. Moreover, the energy storage capacity of the later material is 0.388 kJ/kg.

Inference: Using the composite material for the flywheel reduces the amount of material used for flywheel and hence the overall efficiency of the flywheel has been improved.

CONCLUSION

In this paper, the importance of flywheel storage systems has been discussed. To improve the efficiency of the flywheel, different composite materials have been tried and analyzed the performance using finite element analysis. It is found that the mass of the flywheel has been reduced for the same dimensions. Since the weight directly affects the specific energy, better performance has Obtained when the composite material is used for the construction of flywheel. Further research can be extended in the area of flywheel materials.

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