Research on Structure for Flywheel Energy Storage System in Long Lifetime UPS

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ABSTRACT
This paper establishes the flywheel energy storage organization (FESS) in a long lifetime uninterruptible power supply. The Flywheel Energy Storage (FES) system has emerged as one of the best options. This paper presents a conceptual study and illustrations of FES units. After brief introduction to the FES system and its theory of operation, the paper focuses on the important role of the FES system in enhancing the operation of the distribution network. Supported by illustrated circuits, the FES system in the improvement of the power quality of the network. A flywheel energy storage technology was ended, with a special focus on the progress in automotive applications. In order to improve the efficiency and lifetime, then it discusses a newly proposed design of the FES system that emerged recently, which includes the use of Superconducting Magnetic Bearings (SMB) and Permanent Magnetic Bearings (PMB). In conclusion, the paper analyzes the FES systems great potentials that could be exploited in improving the reliability of the electrical system.

Keywords: Energy storage; Flywheel; bearings, power system quality, power system reliability, design of flywheel

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I. INTRODUCTION
Flywheel energy storage systems (FESS) store electric energy in terms of the kinetic energy of a rotating flywheel, and convert this kinetic energy into electric energy when necessary. A FESS is a viable technology for energy storage because it is environmentally safe, can sustain infinite charge/discharge cycles, and has higher power-to-weight ratio than chemical batteries [1]. FESSs commonly use active magnetic bearings (AMBs) for contact-free operation to maximize the efficiency of the system the most important trade-off sin a flywheel energy storage system is between high power or high energy. A high-power application is relatively simple seen from a flywheel design perspective. A standard high-power electric machine is fitted with some extra weight to sustain the power for a long enough time. A focus on high energy means that thereimums on the mechanical properties of the rotor put limits on the power transfer units or suspension. Energy requirements on the mechanical properties of the rotor put limits on the power transfer units or suspension. Energy flywheels are a main area of research, since this opens up possibilities for new end applications. The UPS necessitate the energy buffer such as electric doublecapacitors (EDLCs), batteries, or flywheels as the UPS has to supply the power to load until an emergency generator begin. Table I shows the description of each energy storage strategy. The battery can accomplish a high energy density at low cost, though, one of the trouble in the battery energy storage is the short life time. In meticulous, the lifetime taking place the ambient and the number of charge and discharge time. In addition, the battery cannot manage with speedy charge and discharge owing to the large internal resistance in the battery. On the other hand, an EDLC has a high charge and discharge efficiency. Besides, the rapid charge and discharge are probable because the internal resistance is extremely small. Though, similar to the battery, the lifetime is decreased rapidly owing to the authority of the ambient temperature [1]. On the other hand, flywheel energy storage systems (FESS) has subsequent advantages compared to chemical batteries
(i) Environmental friendly,
(ii) Low maintenance cost,
(iii) Long lifetime due to no chemical structure, and
(iv) The charge and discharge characteristic of high cycle are excellent. For these reason, the flywheel has attracted attention as an energy storage system [2-8].
The flywheel motor of FESS is becoming large power capacity. For quick charge and discharge, and compactness of structure, the rotor of flywheel is mounted onto the flywheel body. The gap between rotor and stator is relatively large, so the vibration of the rotor axe centre will affect the electromagnetic field parameters. On the contrary, the change of the electromagnetic field parameters will affect the dynamic characteristics of the rotor. As a result, the electromechanical coupling vibration will occur for the interaction of electromagnetic and mechanical parameters of the FESS, and will furthermore affect the rotor dynamic performance, and bring self-excited vibration. We can say that the electromechanical coupling vibration not only decreases the system stability, but also leads to disastrous accidents. In addition, there are many other features that make flywheel storage systems a promising solution for future energy needs. These features include pollution-free operation with a maximum amount of stored energy, which is mainly affected by the weight and shape of the rotor, and the high efficiency of the storage process including the efficiency of the energy conversion. Based on the extended

Table: Characteristic of Each Storage Devices.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Flywheel</th>
<th>EBL</th>
<th>Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy storage/ion</td>
<td>Kinetic</td>
<td>Ion transfer</td>
<td>Chemical reaction</td>
</tr>
<tr>
<td>Charge &amp; Discharge of short period</td>
<td>Fast</td>
<td>Fast</td>
<td>slow</td>
</tr>
<tr>
<td>Temperature characteristic</td>
<td>Excellent</td>
<td>Limited by temperature</td>
<td>Limited by temperature</td>
</tr>
<tr>
<td>Energy density</td>
<td>good</td>
<td>good</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

The flywheel motor of FESS is placed inside a vacuum containment to eliminate any frictionless that might be caused by the air and suspended by bearings for stable operation. Then, depending on the need of the grid, the kinetic energy is transferred either in or out of the flywheel which is connected to a machine that works as either the motor or generator. In the motor mode, electric energy supplied to the stator winding is converted into torque and applied to the rotor, causing it to spin faster and thus gaining kinetic energy. While in the generator mode, the kinetic energy stored in the rotor would apply torque which is converted to the needed amount of electric energy. Fig. 1 shows the basic layout.

II. PRINCIPLE OF OPERATION

A flywheel stores energy in a rotating mass. Depending on the inertia and speed of the rotating mass, a given amount of kinetic energy is stored as rotational energy. The main idea is that the flywheel
IV. FLYWHEEL TECHNICAL CONSIDERATIONS

According to Boland (2007) the concept of having the kinetic energy stored in a spinning mass is not a new one. A great deal of research has been conducted on this topic over several decades, specifically focusing on the flywheel units and the methods to improve their efficiency and means of operation [3]. The following aspects have always been associated with the design and work of any flywheel energy system: high-Speed Permanent Magnet Motor Generator.

The VDC systems’ motor generator design utilizes specialized rare earth magnets to minimize rotor heating and maximize efficiency and reliability. This type of motor design allows the system to cycle quickly without overheating and can therefore be used in difficult applications with high cycling and long life requirements. The motor generator is rotated at speeds up to 36,750 RPM, where the flywheel system is at a fully charged state. During discharge, the rotor speed decreases to a minimum speed, typically 10,000-12,000 RPM. This speed range is called the discharge range and can be adjusted for more energy or higher cycling depending on the application. The rotor assembly of the flywheel operates in a vacuum provided by an external pump. By removing air from the rotating area of the motor, all wind age losses from the system are eliminated, increasing electrical efficiency.

A- MAGNETIC BEARINGS AND CONTROLS

Magnetic bearings allow the motor assembly to rotate at very high speeds with no physical contact to stationary components, thereby taking advantage of the high efficiencies obtainable with high-speed rotation. Magnetic bearings levitate the rotating assembly through the force of a magnetic field, and the upper and lower magnetic bearings provide five axes of support, which include the axial and radial support. The Vycon magnetic bearing design is based on a combination of permanent magnets, which provides a bias field in the gap, and controlled electromagnets, which provide the adjustment and centering of the rotor assembly. To minimize bearing power requirements and losses, the flywheel is vertically oriented, thereby only requiring the axial bearing axes to support the full rotor weight. The position of the rotor assembly is controlled by the magnetic bearing controller (MBC), which feeds rotor position information from position sensors next to the magnetic bearing actuator.

The MBC contains a digital controller, sensor inputs and current amplifiers that monitor and control the position of the flywheel rotor via a five axes active magnetic bearing system. The controller in turn adjusts the current into each coil to reposition the rotor within an allowable orbit. The rotor position signals are fed to the control module, which runs a digital filter compensation program to produce a command signal for each current amplifier. The current amplifiers provide the drive current to the actuators of each axis, thereby applying the forces on the rotor that maintains the desired flywheel rotor position. The patented magnetic bearing technology eliminates virtually all maintenance, including the need to replace or repack lubricant for a mechanical bearing system. As a result, VDC energy storage systems have a 20-year life with no bearing maintenance.

B- BI-DIRECTIONAL POWER CONVERTER

The power module is an Insulated Gate Bipolar Transistor based bi-directional direct current (DC) to alternating current (AC) or AC to DC device. During the charging or motoring state, it acts like an Uninterruptible Power Source (UPS) inverter, and the power module converts DC from the UPS to 3-phase AC that is applied to the stator and spins the flywheel. While it is discharging or generating, it acts like a UPS rectifier; the power module converts the 3-phase AC from the flywheel motor-generator to a regulated DC.

C-POWER ELECTRONICS

The energy conversion in a FESS is accomplished by the electrical machine and a bi-directional power converter. The power electronic converter topologies that can be used for FESS applications are DC-AC, AC-AC, and AC-DC-AC, or a combination of these. The switching devices of the power converters are selected based on their operational characteristics and application. These include a bipolar junction transistor (BJT), metal oxide semiconductor field effect transistor (MOSFET), insulated gate bipolar transistor (IGBT), and thyristor (SCR, GTO, MCT). The commonly used switches are a silicon controlled rectifier (SCR), gate turn off thyristor (GTO), and IGBT. SCR and GTO have been traditionally used for variable frequency power converters. However, IGBT has been greatly adopted in recent years, due to its higher power capability and higher switching frequencies [9].
V. BASIC DESIGN APPROACH

There are two approaches in designing a flywheel unit: The first stage is to obtain the amount of energy• required for the desired degree of smoothing in addition to the moment of inertia needed to absorb that determined energy. The second stage is to define the flywheel• geometry, which caters to the required moment of inertia in a reasonably sized package. A. Design Parameters

There are many parameters to be considered in the design of the flywheel energy unit: 1) Speed fluctuation the speed fluctuation is defined as the change in the shaft speed during a cycle, given by the following equation:

$$F_l = W_{\text{max}} - W_{\text{min}}$$

Coefficient of speed fluctuation. The coefficient of speed fluctuation is one of the parameters set by the designer. The smaller this chosen value, the larger the flywheel would be and the greater the cost and weight to be added to the system. However the smaller coefficient would result in the smoother operation of the flywheel energy unit. The coefficient can be found by the following equation:

$$C_f = W_{\text{max}} - W_{\text{min}} / W$$

Where\(W\): the nominal angular velocity.

The typical value of \(C_f\) is set to be between 0.01 up to 0.05 for precision machinery work. 3) Design equations

The kinetic energy in a rotating machine is given by

$$E_k = \frac{1}{2} I w^2$$

The kinetic energy in any system could thus be found from

$$E_k = E_1 - E_2$$

$$E_k = \frac{1}{2} I (2wavg) (Cfwavg)$$

$$E_1 - E_2 = Cfwavg$$

The above equation can also be used to obtain an appropriate flywheel inertia \(I_m\) corresponding to the known energy exchange \(E_k\) at a specific value of coefficient \(C_f\).

A- FLYWHEEL ENERGY DESIGN USING SMB AND PMB

The Flywheel energy storage approach is currently considered as one of the most successful figures of energy storage, and many attempts have been made to improve this technology. Among these latest developments is the use of a superconducting magnetic bearing (SMB) together with a permanent magnetic bearing (PMB). According to Komori (2011) this approach has resulted in higher energy storage compared with conventional flywheel systems, and would lead to reduced overall costs and cooling costs. One of the main issues in operating the flywheel system is the large vibration transmitted to the rotor during operation, causing difficulties in controlling the speed of the rotation. The purpose of this specific design, using SMB and PMB, is to support the rotor in the flywheel system; the main function of the SMB is to suppress the vibrations in the rotor, while the PMB passively controls and maintains the position of the rotor [7].

B-DESCRIPTION OF THE DESIGN

Fig. 4 shows a schematic description of the flywheel energy storage system using a SMB and a PMB. It should be noted that the SMB is placed into the top of the flywheel’s rotor, while the PMB is set at the top of the flywheel rotor. This is because the damping effect of the SMB is effective if it is placed in the lower side of the rotor, while PMB has no damping effect [8]. The flywheel is constructed so that the centre of gravity is lower than the centre of the supporting point. Thus, the centre of gravity still lies in the centre position of the upper magnet of the SMB part, which would give the system more inertia and make it more stable under both rotating and non-rotating condition [7].

Fig. 4 Shows a schematic description of the flywheel energy storage system using a SMB and a PMB

VI. THE LATEST DEVELOPMENT OF THE MOTOR/GENERATOR FOR THE FES SYSTEM

2016 :Yali the Motor/Generator is the core dynamic component for the FES system. So far, except for very few applications of special or new structure motors such as synchronous homopolar machines, disc-type motors, printed circuit windings, three types of motors have been widely used, including the Induction Motor, the RM and the PMM [11]. A. Induction Motor/Generator (IM/G) 1996: Researchers in Japan developed a 0.2kWh, 16500rpm FES device with IM/G, which first used high strength carbon fiber for the flywheel and was capable of preferable stability at high speed. In August of 1996, a 5500kWh, 74,000kg, 4m diameter FES system which used a doubly-fed IM/G rated 26.5MVA, with 12 poles and 90% for line frequency regulation on a 132kV bus was installed and commissioned at the Chujowansubstation.

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Flywheel storage energy system is not a new technology; though, the bottomless interest in applying its principle in power system applications has been really increasing in the recent decades. In addition, research has been applied to develop the great feature the FES can offer, which primarily exposed in power excellence improvement and improvement of the network dependability and stability. In addition, advancements in the design of the flywheel energy units, composite materials, and power electronics devices have powerfully presented the FES technology as vulnerable option to the electromechanical batteries, especially that FES system have the description of storing and releasing energy in very fast time with very high operational efficiency. Besides, Flywheels are now used intensively in many applications related to power system such as telecommunications, utilities load levelling, and even in some additional applications in satellite engineering as well. In addition, it has been concentrated lately in distribution sectors of electrical power. Most of the distribution networks are exposed to voltage dips problems, and FES system, associated with its power electronics converters, offer effective compensation for the network. Moreover, many researchers have started conducting studies to evaluate the high possibility of having FES systems with intermittent power system sources such as wind and solar systems. This paper tried to demonstrate the excellence of applying its principle in power system applications has been really increasing in the recent decades. In addition, research has been applied to develop the great feature the FES can offer, which primarily exposed in power excellence improvement and improvement of the network dependability and stability. In addition, advancements in the design of the flywheel energy units, composite materials, and power electronics devices have powerfully presented the FES technology as vulnerable option to the electromechanical batteries, especially that FES system have the description of storing and releasing energy in very fast time with very high operational efficiency. Besides, Flywheels are now used intensively in many applications related to power system such as telecommunications, utilities load levelling, and even in some additional applications in satellite engineering as well. In addition, it has been concentrated lately in distribution sectors of electrical power. Most of the distribution networks are exposed to voltage dips problems, and FES system, associated with its power electronics converters, offer effective compensation for the network. Moreover, many researchers have started conducting studies to evaluate the high possibility of having FES systems with intermittent power system sources such as wind and solar systems. This paper tried to demonstrate the
The concept of many technical papers on FES systems. After illustrating the basic functioning design and way of work, this paper described the position of the FES systems in the control of reactive power and power quality in distribution network. Behind that, a brief basic design and lately design of flywheels using SMB and PMB have been illustrated in some feature. The paper concluded with the recent developments in flywheels industry that can offer the FES systems in the future to be great solution to solve the power system reliability problems in the lowvoltage distribution network.

REFERENCES


