Flywheel Energy Storage in Electrical System Integrates Renewable Energy Sources

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Abstract

The Flywheel Energy Storage System (FESS) is a new storage technology and has many advantages over traditional energy storage methods. This paper presents an integrated solution of FESS with wind and solar power systems working in micro-grids to improve the quality of wind and solar power supplied to the grid. The results of modeling and simulation in Matlab - Simulink have shown that the wind and solar power system integrated FESS can overcome the energy fluctuations of wind and solar power to provide a less changing energy for the grid.

Keywords: *Flywheel Energy Storage System, Solar Power, Wind Power, Micro-grid*

I. INTRODUCTION

The renewable energy source in general, the wind and solar power in particular are clean energy, they do not cause environmental pollution, Vietnam has great potential in the use of wind energy and solar energy. However, in order to harvest and use effectively, reduce pollutant emissions, especially CO_2, is the object of research for many countries.

Integrated wind and solar system allows to integrate power from many different sources that have been transform to electrical power and merged together into direct current and use directly for DC load or going through power electronics converter and turned into alternating current and use directly for AC load or linked to the national grid or the micro-grid [1],[2]. This system is flexible in installation and using and it is an indispensable part of smart grid.

Figure 1 shows the diagram about the function of the integrated wind and solar system grid linked. The advantages of this system is the cost of electricity production process is very low, a single wind, solar generator system can work substantial for over 20 years with low budget. Compared to a solar-powered system or just using wind energy, the solar and wind integrated system is more stable. This is a clean energy source, does not create pollutants, does not consume fossil raw materials, completely friendly to the environment. In the context of rising prices for electricity and fossil fuels, installing an integrated solar and wind power system can be a great solution, especially in areas with difficulties in transmitting power.

The integrated system of renewable energy sources offers many benefits and is environmentally friendly. However, this network also has limitations that must be overcome, which is the instability of the sources: solar energy (depending on the heat radiation flow of the sun) [1], [2], wind power (depends on wind speed). It is these dependencies that can cause sudden fluctuations, significantly affecting the stability of power generation sources (capacity, voltage, etc.) Leading to the instability of micro grids. Therefore, stabilizing voltage and micro-grid capacity requires an energy storage system (ESS) to maintain a balance between electricity demand and supply [3], [8].

In this paper, an energy storage flywheel (FESS) system is proposed to be used to stabilize the power quality of the integrated wind and solar power systems. The next section presents the structure and components of FESS, the principle of controlling them in the system include wind and solar power, the results of simulating the energy charge / discharge of FESS on Matlab-Simulink, and the final section is the conclusions and future works.

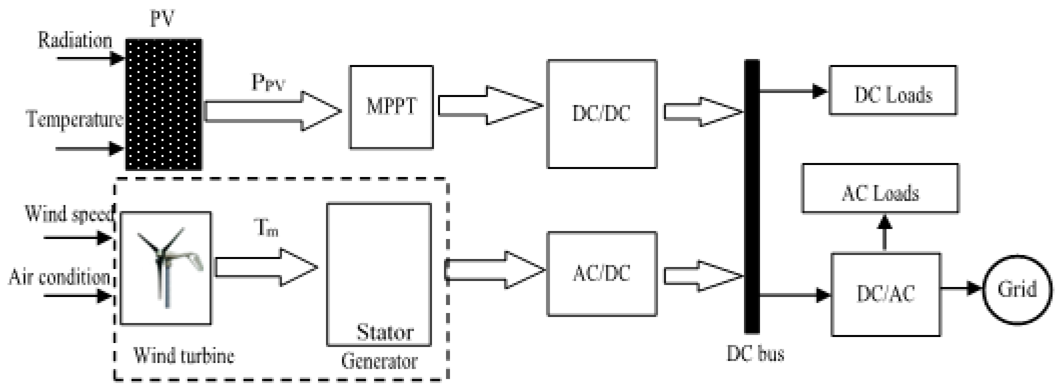

Fig. 1: Functional block diagram of integrated system of wind power and solar power

II. FLYWHEEL ENERGY STORAGE SYSTEM

Flywheel energy storage system (FESS) is an efficient storage, regulate and energy saving technology. In the FESS system, energy is stored in the flywheel in the form of kinetic energy of the rotating unit and emitted according to system requirements.

The main components of an energy storage flywheel are shown in Figure 2 [5],[8].

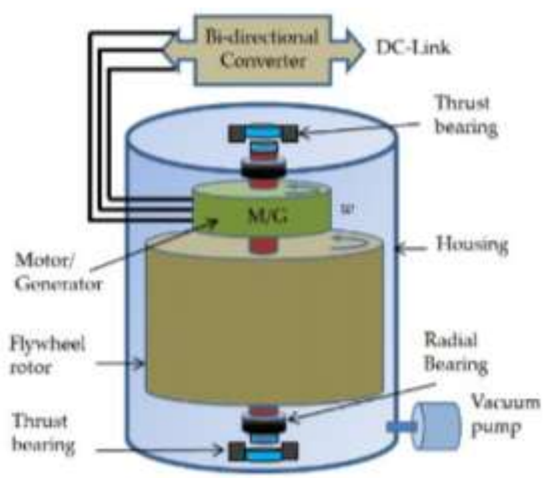

Fig. 2: Structure and components of FESS

The energy storage flywheel is usually designed to operate at high speed to achieve the highest energy storage density. The flywheel of the first generation is made of steel with mechanical bearings, so the speed is not high (only about 6000 rpm). Thanks to the improvements of the flywheel material and the technology of the active magnetic bearing, it has made important advances in the energy storage technology of the flywheel up to 60,000 rpm (10 times bigger than the first flywheel).

In the FESS system, not only the rotor rotates at high speed, but also the position of the rotor must be precisely controlled in the middle and not in contact with the stator, so the rotor's oscillation is as small as possible. Magnetic bearing is a supporting device used at high speed with characteristics such as frictionless operation, no need to lubricate grease, no noise, no pollution, no environmental pollution, long lifespan.

The energy stored in the flywheel in the form of kinetic energy is calculated according to the formula [6]:

$$W = \frac{1}{2} J \omega^2$$

Where

- W is the energy stored in the flywheel in the form of kinetic energy (Jul);
- J is the moment of inertia (kgm^2), $J = k.M.R^2$ with M is the mass (kg), R is the radius (m), k is the inertial constant depending on the physical shape and structure of the flywheel;
- ω is the angular velocity (rad/sec).

In the flywheel has an integrated rotor of an electric machine can work in generator mode or engine mode to convert energy from mechanical energy to electricity and vice versa. There are many types of generators used for flywheel systems, such as permanent magnet generators, induction machines, etc.

The operation of the flywheel can be summarized as: when there is too much power the flywheel performs charging, it acts like an electric motor, different from conventional electric motor, the motor used in flywheel has huge inertia torque and very high rotation speed. On the other hand, when there is an abnormal oscillation at the source or load the flywheel acts as a generator providing the power needed to keep the system stable. During the process of discharging the energy, the speed of the flywheel decreases gradually resulting in a constantly changing frequency of the voltage. In order to maintain the frequency of voltage generated by the flywheel's generator, we need to use a power electronic converter working in rectifier mode so that the sea of electricity changes frequency into a DC power and a power electronics inverter works in inverter mode to convert DC electric energy into sinusoidal alternating voltage connected to the grid.

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III. THE OPERATION PRINCIPLE OF FESS IN A WIND-SOLAR ENERGY SYSTEM

The most common structure of the energy storage flywheel system is shown in Figure 3 and 4. In Figure 3, the converter 1 and converter 2 are bidirectional converters. In discharge mode, converter 1 works as a rectifier, converter 2 works as an inverter. In charge mode converter 1 works in inverter mode and converter 2 in rectifier mode. Figure 4 has the same working principle as Figure 3 but using Multi-stage flywheels, they are connected via a DC bus. Multi-stage flywheel systems can provide higher energy storage capacity than single-stage flywheel systems.

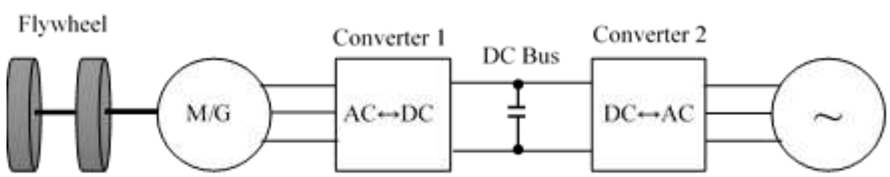

Fig 3: The structure of energy storage flywheel grid linked 1 level

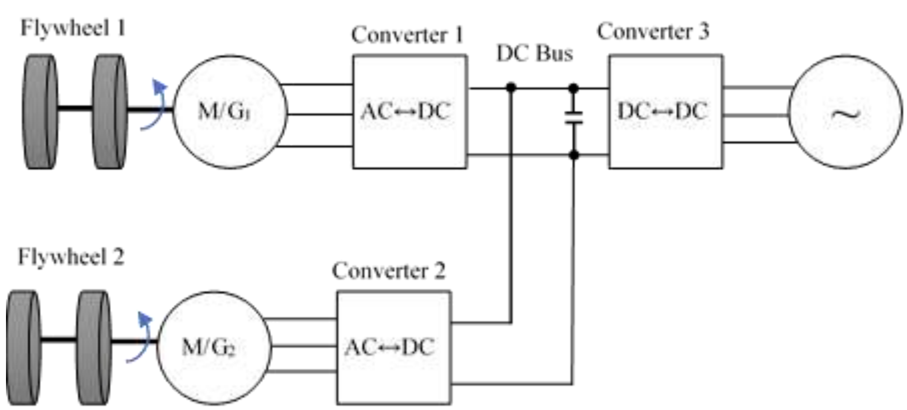

Fig 4: The structure of energy storage flywheel grid linked 2 levels

Figure 5 shows a wind and solar power system with a built-in energy storage flywheel system. The electrical power of the flywheel system is integrated into the system's DC bus using a bidirectional DC-AC converter.

To analyze the activity and thereby see the effect of the energy storage flywheel on the hybrid system as shown in Figure 5, we assume that P_1 is the power from renewable energy sources (wind, solar) supply to the grid.

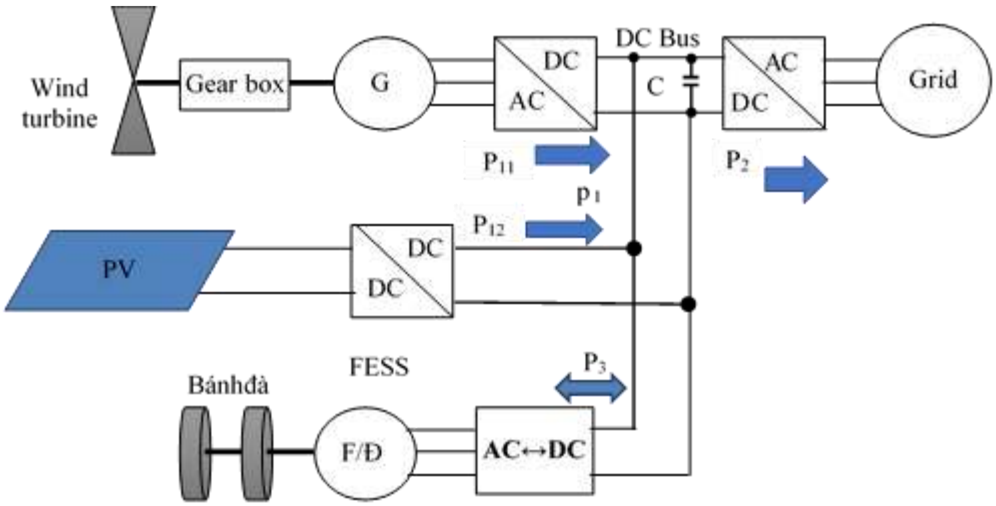

Fig 5: Solar power system and wind power system integrated FESS

$$P_1 = P_{11} + P_{12} \quad (1)$$

Where, the P11 is the power supplied by the wind turbine, P_{12} is the power supplied by the solar power system. P1 power often changes continuously and randomly according to environmental conditions [5], [6]; P_2 is the power supply system for the grid, P_3 is the power of the flywheel system Because the capacity of renewable energy sources (P_1) is constantly changing, in order to keep P_2 constant, the power of the flywheel system must change, we also have:

$$P_3 = P_2 - P_1 \quad (2)$$

Equation (2) shows that the power of FESS fluctuates according to the variation of capacity of renewable energy source.

IV. CONTROLLING THE FLYWHEEL ENERGY STORAGE SYSTEM

From the above analysis, we draw the control task set out here to control the operation of FESS to keep the pumped power into the grid unchanged when there is a fluctuation of capacity of power generation system using renewable energy.

From equation (2) we find that to inject into the grid the least volatile power, the reference power to control the operation of FESS is determined as:

$$P_{ref} = P_3 = P_2 - P_1 \quad (3)$$

If the reference power is positive, there is an excess of energy stored as kinetic energy and the machine in FESS works as an electric motor. In the opposite case, the asynchronous machine in FESS works as a generator to provide power, offsetting the volatility of P1. FESS system block diagram is shown in Figure 5. The circuit consists of an asynchronous machine connected to the flywheel, a 2-sided power converter (AC-DC) connecting between IM and DC-bus. Diagram of the control structure of FESS system is shown in Figure 6 [2], [3]. In the reference signal diagram Pref is determined by the equation (3)

V. SIMULATION RESULTS

To clearly see the operation of the flywheel system in compensating the abnormal energy shortage generated by wind and solar power systems, we simulated the system in Matlab-Simulink with simulated scenarios and parameters.

1. SIMULATED SCENARIOS

In normal working state, the capacity of the solar power system + wind provides enough capacity to maintain a stable working state of the system

P1 = P2.

Assuming that due to the abnormal fluctuations of the solar radiation, or the speed wind, energy they provide to the grid is short of 50kW in a 10-second period, the FESS will discharge energy to make up for that.

$$P_3 = P_2 - P_1 = 50kW \quad (4)$$

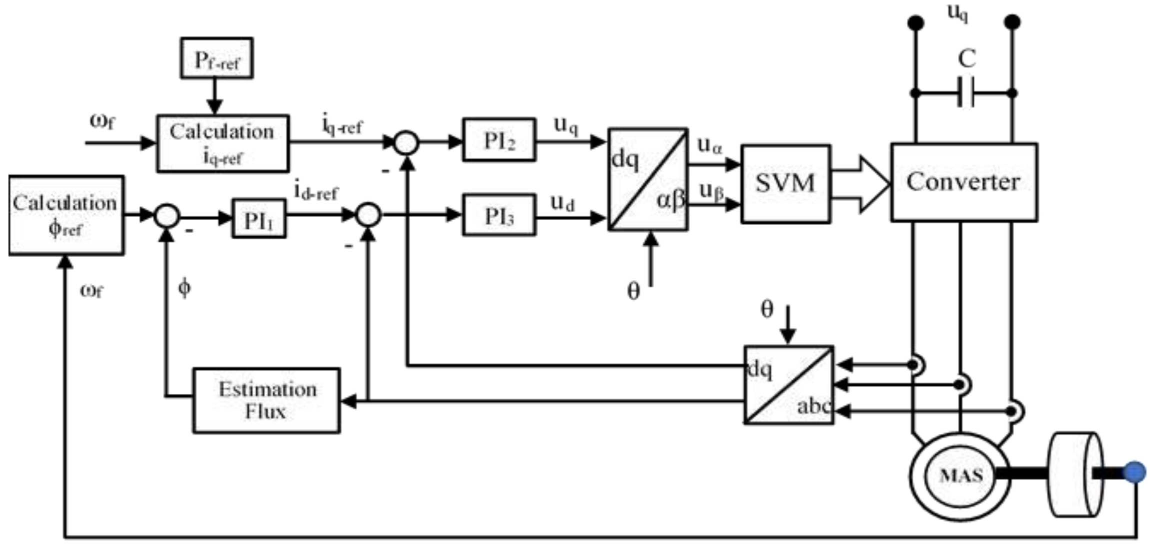

Fig. 6. FESS's control diagram

2. SIMULATED PARAMETER

- Moment of flywheel inertia: $J_f = 150kg/m^2$
- Asynchronous machines connected to the flywheel have the following parameters:

- Power of electric machine connected to flywheel: $P_f = 50kW$
- Pole pair number: p = 2
- Stator resistance: $R_s = 0.05\Omega$
- Rotor resistance: $R_r = 0.043\Omega$
- Stator inductance: $L_s = 40{,}7.10^{-3}H$
- Inductance rotor: $L_r = 40{,}1.10^{-3}H$
- Inductance between stator and rotor: $M = 40.10^{-3}H$
- Simulation time in 10s.
- P_2 = 500kW = const: the energy that the wind-solar system provides to the grid (need to keep unchanged)
- Renewable energy is injected into the grid (always changing) $P_1 = 500 + 50\sin 2t$ kW.
- The energy exchanged with FESS: $P_3 = P_2 - P_1 = -50\sin 2t$ kW (P3 is used as a reference signal to control FESS)

The characteristics of P_1, P_2 and P_3 are shown in Figure 7. The simulation results are shown in the figures from Figure 8 to Figure 10. Where, Figure 8 is the speed of electric machine, Figure 9 is the reference power and power response of FESS. Figure 10 is the reference power, power response and the total power injected into the grid.

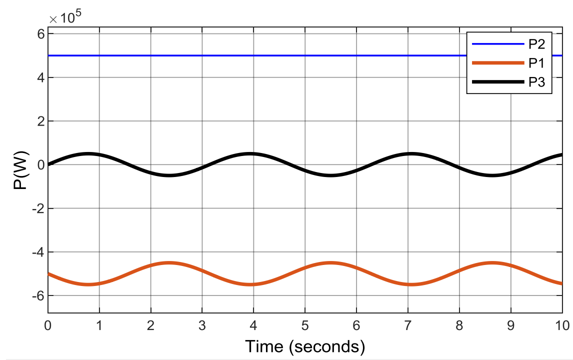

Fig. 7: P_1, P_2 and P_3

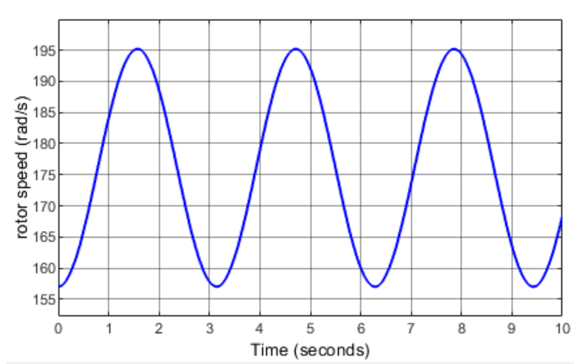

Fig. 8: The speed of electric machine

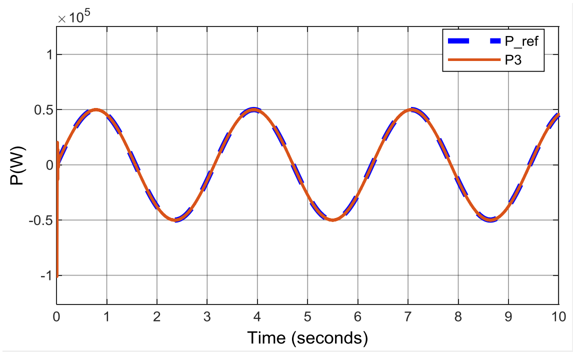

Fig. 9: Reference power and power response of FESS

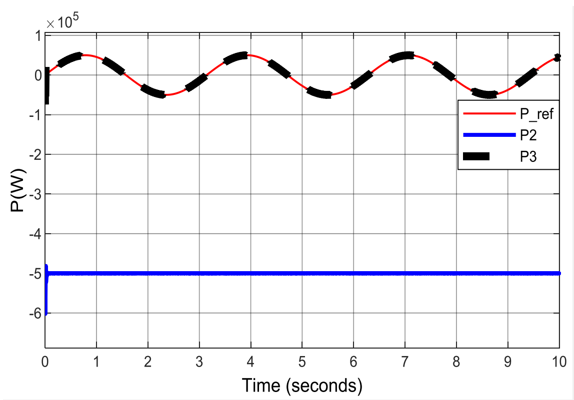

Fig. 10: The reference power, power response and the total power

Comment: The above simulation results show that in the period of 0 sec to 1.67 sec the electric machine in FESS works as an electric motor, it increases the speed of 1.57 rad/sec to 195.3 rad/sec. FESS performs charging. Next from 1.67sec to 3.14sec the machine acts as a generator, its speed decreasing from 195.3rad/sec to 1.57rad/sec. At this time the energy of FESS is compensated for the shortage of the Wind-solar power system. In the way similar with the remaining time. As a result, the total capacity of the wind-solar power system and FESS injected into the grid is maintained almost unchanged.

VI. CONCLUSION

The energy storage flywheel system has many advantages compared to traditional energy storage technologies (cells, batteries, ...) Such as high energy storage density, can store an unlimited energy amount, high life cycle, low operating costs. The integration of FESS of wind and solar power systems allows to maintain the stability of wind and solar power. The simulation results have shown the correctness and feasibility of the proposed solution. This system can be used to "smooth" and balance energy supply and demand in renewable energy systems that work independently or connected to the micro grid. The next research issue is to develop an experimental model to test and finalize the proposed results.

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