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Improving the Quality of Solar Power in the Micro-Grids

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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. In this paper, we present an integrated solution of FESS with solar power systems working in micro-grids to improve the quality of solar power supplied to the grid. The results of modeling and simulation on Matlab - Simulink software have shown that the solar power system integrated FESS can overcome the energy fluctuations of solar power to provide a less changing energy for the grid.

Keywords: FESS, flywheel energy storage system, solar power, micro grid

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I. INTRODUCTION

Solar energy is a clean and endless energy source that nature bestows on people. Since ancient times, people have taken advantages of this energy source to serve themselves from solar cookers, solar water heaters, ... Nowadays, there are many solar power plants with medium scale and large national grid connection or buildings using solar power at household scale. Solar energy with outstanding advantages such as infinite reserves, does not cause climate change and does not affect bad impacts on the environment, is attracting the attention of many countries around the world. Currently many countries in the world have taken specific steps to gradually replace traditional fossil energy sources with renewable energy sources in which the sun is an appropriate choice. The main direction for exploiting and using renewable energy is to turn them into electricity into the national grid or mix with each other to form a local grid (grid) [1], [2].

Although there are many advantages, solar power has the disadvantage of continuously fluctuating according to the solar radiation intensity, day, night and season [3], thus affecting the quality of the grid and calculation and continuous power supply. Especially for micro grid, this abnormal fluctuation can lead to grid failure or net collapse. To overcome this drawback, an energy storage system (ESS) is required to maintain the balance between power supply and demand. This process involves converting and storing electromagnetic energy from an existing source into another form of energy and they can be converted into electricity when needed. The form of storage energy conversion may be mechanical, thermal or magnetic chemistry. Storage allows power to be released when needed and stored when production exceeds demand. Storage can be at times of low demand, low production costs or when intermittent energy sources are available. At the same time, energy storage can be consumed at times of high demand, high production costs or when there is no available source.

An energy storage technology that is attracting great interest is the flywheel energy storage system (FESS) [4], [5], [6]. This storage technology has many advantages compared to other storage solutions such as high life cycle, high energy storage density, can store unlimited energy, low operating costs. But they have the disadvantage that the discharge time is quite short. They are effectively applied to smoothing the capacity of renewable energy power systems to work independently or work in microarrays.

In this paper we propose a solar power system with integrated energy storage flywheel (Fig.1). A built-in induction machine can work in generator mode or engine mode to convert energy from mechanical to electrical and vice versa to stabilize the power of the solar power system. Integrated FESS provided for micro mesh. The next section of the paper presents the operating principle of FESS, building the control system structure and simulating the charging-discharging operation of the energy storage flywheel system.

II. OPERATION OF FESS IN MICRO GRID

Considering grid connected solar power system with integrated energy storage flywheel with block diagram described in Fig1.[4]. The energy flywheel in a rotating block is made of composite material placed in a hollow cylinder lifted by the magnetic field to minimize friction between the shaft and the base. The flywheel shaft connects to the rotor shaft of the motor which is designed to operate at high speed and minimize friction, they can operate in engine mode or in generator mode.

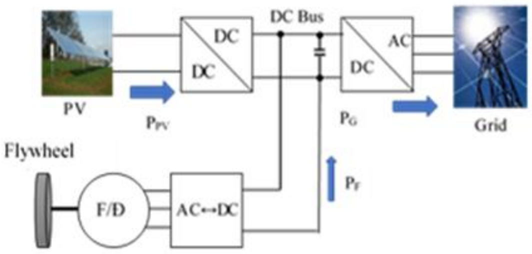

Fig.1. Grid connected PV systems with integrated fess

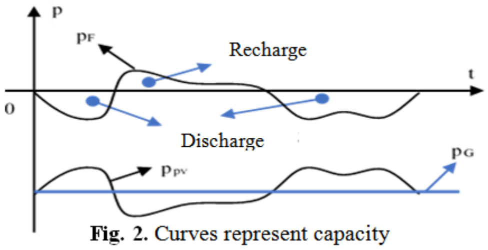

Fig. 2. Curves represent capacity

The operating principle of FESS can be summarized as follows: Under normal working conditions the electric machine in the flywheel works in engine mode, the flywheel performs energy storage in the form of kinetic energy. On the other hand, when there is an abnormal oscillation at the source or load, the electric machine in the flywheel acts as a generator providing the additional energy needed to stabilize the system. During the discharge process the speed of the flywheel decreases gradually, leading to a constantly changing voltage frequency. In order to maintain the voltage frequency generated by the flywheel generator, it is necessary to use a working power electronic converter in rectifier mode to turn a frequency-changing power into DC power and and an electronic power converter working in reverse mode to convert DC electric energy into sinusoidal AC voltage connected to the grid.

To analyze the activity and thereby see the effect of energy storage flywheel on the system as shown in Figure 1, assumed that the p_{pv} is the power from the solar power supplied to the grid, this capacity often change constantly according to environmental conditions [2]; p_f is the capacity of the flywheel system; p_g is the pumping capacity into the grid, so that the grid works stably, this capacity needs to be fixed (p_g = const)

$$p_f = p_g - p_{pv} \tag{1}$$

The curves represent power types is shown in Figure 2. From the expression (1) and Figure 2 we could see that the capacity of FESS varies according to the capacity fluctuation of renewable energy sources. FESS will charge energy when $p_f > 0$ and discharge energy to replenish the system energy when $p_f < 0$. The curve representing the quantity p_f is used as a reference quantity to control the operation of FESS.

III. OPERATION CONTROL OF FESS

3.1. Structure diagram of the control system

From Figure 1, it's needed to control the operation of the flywheel system so that when there is a fluctuation of solar energy, the total capacity of the solar power system and the flywheel system pumped through at least change, it needs to be maintained:

$$p_{pv} + p_f = p_g \approx \text{const} \tag{2}$$

FESS control diagram is shown in Figure 3. The converter is a bilateral converter.

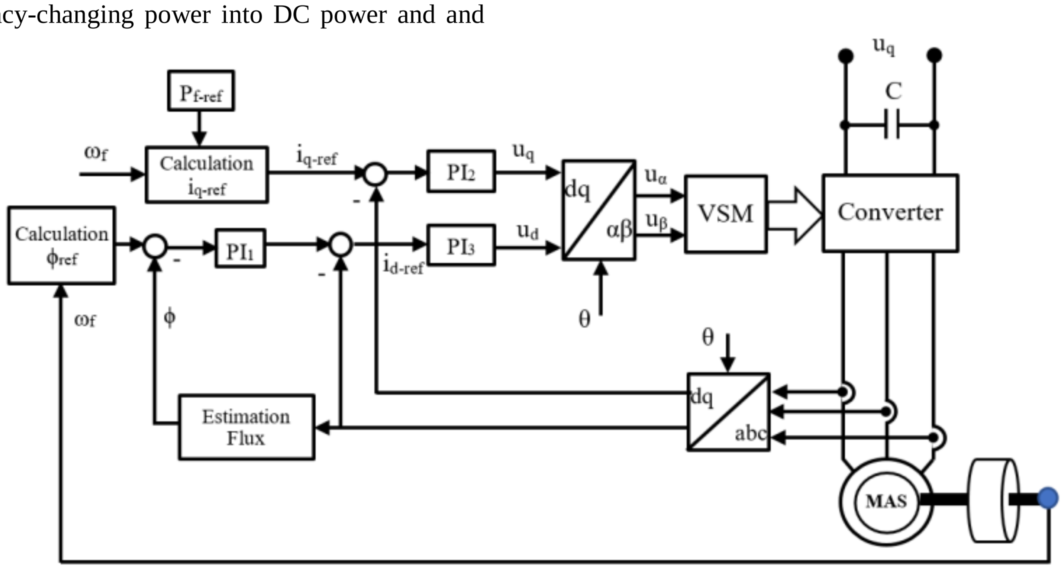

Figure 3. FESS control diagram

The relationship between capacity and energy stored in flywheel is determined by:

$$P_F = \frac{dE_F}{dt} \quad (3)$$

P_F (W): the maximum power can be supplied by the retention system (equal to the rated capacity of the integrated asynchronous machine in the flywheel); E_F is stored energy (J). The relationship between energy, moment of inertia and rotation speed of the flywheel

$$\frac{dE_F}{dt} = \frac{1}{2} J_F \frac{d\omega_F^2}{dt} \quad (4)$$

ωF (rad / s) is the angular speed of the flywheel; JF [kg.m2] is the moment of inertia of flywheel, we have:

$$P_F = \frac{1}{2} J_F \frac{d\omega_F^2}{dt} \quad (5)$$

In differential form: $P_F = \frac{1}{2} J_F \frac{\Delta\omega_F^2}{\Delta t}$

$$P_F \Delta t = \frac{1}{2} J_F \Delta\omega_F^2 \quad (6)$$

$$J_F = \frac{2P_F\Delta t}{\Delta\omega_F^2} = \frac{2P_F\Delta t}{\omega_{F\max}^2 - \omega_{F\min}^2} \quad (7)$$

In which ω_{Fmax} and ω_{Fmin} are maximum and minimum rotation speed of flywheel (rad/s). The state equations of three-phase asynchronous machines in the reference system (dq) are described by (8).

$$\frac{d}{dt}\begin{bmatrix}\phi_{dr}\\ \phi_{qr}\\ i_{ds}\\ i_{qs}\end{bmatrix} = \begin{bmatrix} \frac{-R_r}{L_r} & (\omega_s - p\omega_F) & \frac{MR_r}{L_r} & 0 \\ (\omega_s - p\omega_F) & \frac{-R_r}{L_r} & 0 & \frac{MR_r}{L_r} \\ \frac{MR_r}{\sigma L_s L_r^2} & \frac{Mp\omega_F}{\sigma L_s L_r} & \frac{-R_{sr}}{\sigma L_s} & \omega_s \\ -\frac{Mp\omega_F}{\sigma L_s L_r} & \frac{MR_r}{\sigma L_s L_r^2} & -\omega_s & \frac{-R_{sr}}{\sigma L_s} \end{bmatrix} \begin{bmatrix}\phi_{dr}\\ \phi_{qr}\\ i_{ds}\\ i_{qs}\end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \end{bmatrix} \begin{bmatrix} u_{ds} \\ u_{qs} \end{bmatrix} \quad (8)$$

$$R_{sr} = R_s + \frac{M^2}{L_r^2} R_r \quad ; \; \sigma = 1 - \frac{M^2}{L_s L_r}$$

In which: R_s, R_r are stator and rotor phase resistors; L_s, L_r are stator and rotor phase inductors; M is mutual inductance; u_{ds}, u_{qs} are perpendicular components of stator voltage; i_{ds}, i_{qs} are perpendicular components of stator current; Φ_{dr}, Φ_{qr} are perpendicular components of the rotor flux; p is the number of polar pairs; ω_s is the rotational speed of the stator magnetic field.

Control the electric machine in the FESS system according to the VSM method (Vector Space Model). The assumption is:

$$\phi_{dr} = \phi; \;\; \phi_{qr} = 0 \quad (9)$$

State equations system (8) becomes:

$$\frac{d}{dt}\begin{bmatrix}\phi_{dr}\\ i_{ds}\\ i_{qs}\end{bmatrix}=\begin{bmatrix}\frac{-R_r}{L_r} & \frac{MR_r}{L_r} & 0\\ \frac{MR_r}{\sigma L_s L_r^2} & \frac{-R_{sr}}{\sigma L_s} & \omega_s\\ -\frac{Mp\omega_F}{\sigma L_s L_r} & -\omega_s & \frac{-R_{sr}}{\sigma L_s}\end{bmatrix}\begin{bmatrix}\phi_{dr}\\ i_{ds}\\ i_{qs}\end{bmatrix}+\begin{bmatrix}0 & 0\\ \frac{1}{\sigma L_s} & 0\\ 0 & \frac{1}{\sigma L_s}\end{bmatrix}\begin{bmatrix}u_{ds}\\ u_{qs}\end{bmatrix} \quad (10)$$

Reference magnetic flux is determined by the expression:

$$\phi_{f-ref}=\begin{cases}\phi_{rn} \quad \text{khi } |\omega_f|\le\omega_{fn}\\ \phi_{rn}\frac{\omega_{fn}}{|\omega_f|} \quad \text{khi } |\omega_f|>\omega_{fn}\end{cases} \quad (11)$$

$$\phi_{rn}=\frac{L_r}{M}\phi_{sn} \quad (12)$$

ϕ_{rn} is the rated flux of the rotor; ϕ_{sn} is the rated flux of the stator

$$\phi_{sn}=\sqrt{3}\frac{u_s}{\omega_s} \quad (13)$$

u_s is the rms value of stator phase voltage; (rms: root mean square)
ω_s the angular speed of grid voltage that equal to 314.16 rad/s

$$\phi_{rn}=\sqrt{3}\frac{L_r}{M}\frac{u_s}{\omega_s} \quad (14)$$

Reference stator current is determined by

$$i_{ds-ref}=PI\left(\phi_{r-ref}-\phi_{r-est}\right) \quad (15)$$

PI is the rule to adjust the integral rate. The estimated value of the rotor flux is

$$\phi_{dr-est}=\frac{M}{1+\frac{L_r}{R_r}s}i_{ds} \qquad \text{(s: Laplace operator)} \quad (16)$$

The set power (reference) of the asynchronous machine is determined by formula (1). From that, the reference electromagnetic torque can be calculated 17

$$M_{r-ref}=\frac{P_{f-ref}}{\omega_f} \quad (17)$$

We define the voltages modulated by the converter in the reference system (dq) and apply to the asynchronous electric stator by the following formula:

$$\begin{bmatrix}u_{ds}\\ u_{qs}\end{bmatrix}=\frac{U}{2}\begin{bmatrix}u_{d-reg}\\ u_{q-reg}\end{bmatrix} \quad (18)$$

With u_{d-reg} and u_{q-reg} is the controlling voltage in the reference system (dq).
The converter modulation current is determined by the expression below

$$i_{m-mac}=\frac{1}{2}\begin{bmatrix}u_{d-reg} & u_{q-reg}\end{bmatrix}\begin{bmatrix}i_{ds}\\ i_{qs}\end{bmatrix} \quad (19)$$

The control of the converter is drawn from the equation

$$u_{d-reg}=\frac{2}{U}v_{ds-ref};\; u_{q-reg}=\frac{2}{U}v_{qs-ref} \quad (20)$$

3.2. Simulation results

In order to illustrate the operation of the FESS system in compensating for the lack of energy of the grid caused by sudden change of solar power capacity, we conduct system simulation in Matlab-Simulink as after:

Suppose that the solar power system + FESS needs to provide a stable power for micro grid (P_{grid}); The capacity of the solar power system (P_{pv}) always fluctuates around P_{grid} value, the reference power to control FESS's operation is:

$$P_{ref} = P_{wheel} = P_{grid} - P_{pv} \quad (21)$$

Simulation parameters are as follows:
- Moment of inertia of flywheel: $J_f = 150kgm^2$
- The integrated asynchronous electric machines in flywheels with a capacity of 50 kW; Number of bipolar: p = 2; Stator resistor: $R_s = 0.05\Omega$; Rotor resistance: $R_r = 0{,}043\Omega$; Stator inductance: $L_s = 40.7.10^{-3H}$; Rotor inductance: $L_r = 40.1.10^{-3}H$; Mutual inductance between stator and rotor: $M = 40.10^{-3}H$.
- Initial velocity of flywheel: 1500 rpm (157 rad/s) and reference power equal to the rated power of the asynchronous motor (50kW)

The simulation results are shown on Fig.4 to Fig.8. In which: Fig. 4 is shown the speed of the integrated electric motor in the flywheel; Fig. 5 is shown the reference magnetic flux and the actual magnetic flux of the electrical motor connected to the flywheel; Fig. 6 pointed out the reference power, which meets the transceiver power of the integrated asynchronous electric machines corresponding to P_{pv}; Fig. 7 is illustrated the reference power, responsive transceiver power of FESS and the total power of the PV-FESS system pumped into the micro-grid. Fig. 8 demonstrated the phase A voltage and its current from 2.91s to 3.23s.

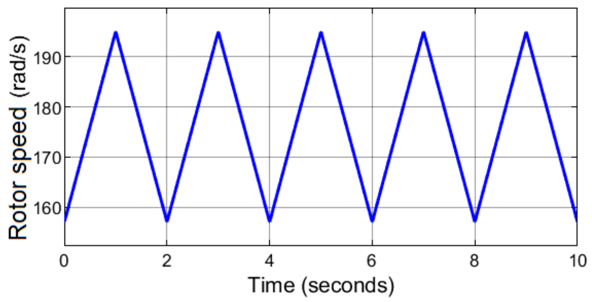

Fig. 4. The speed of the integrated electric motor in the flywheel

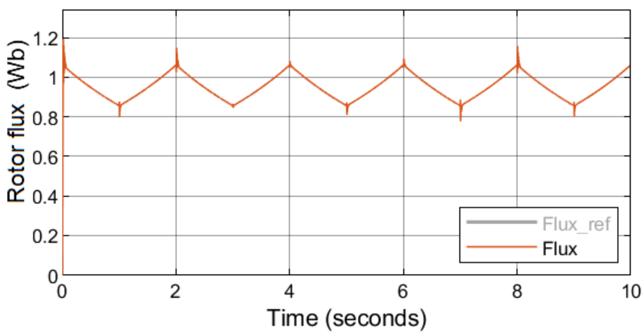

Fig. 5. The reference magnetic flux and the actual magnetic flux of the electrical motor connected to the flywheel

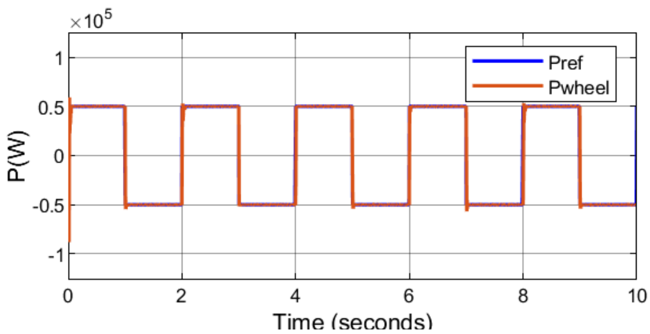

Fig. 6. The responsive power of the FESS

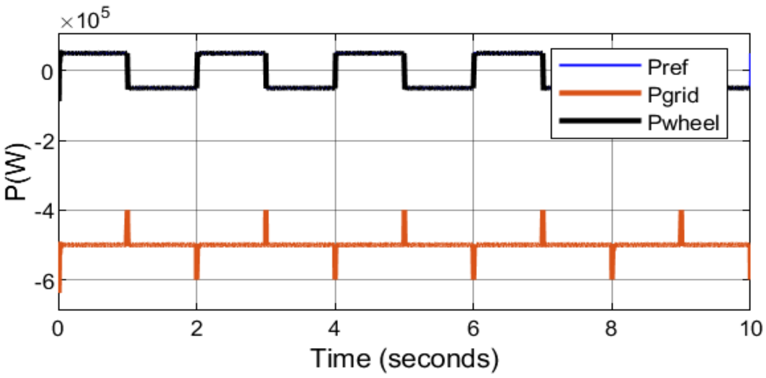

Fig. 7. The reference power, responsive transceiver power of FESS and the total power of the PV-FESS system pumped into the micro-grid

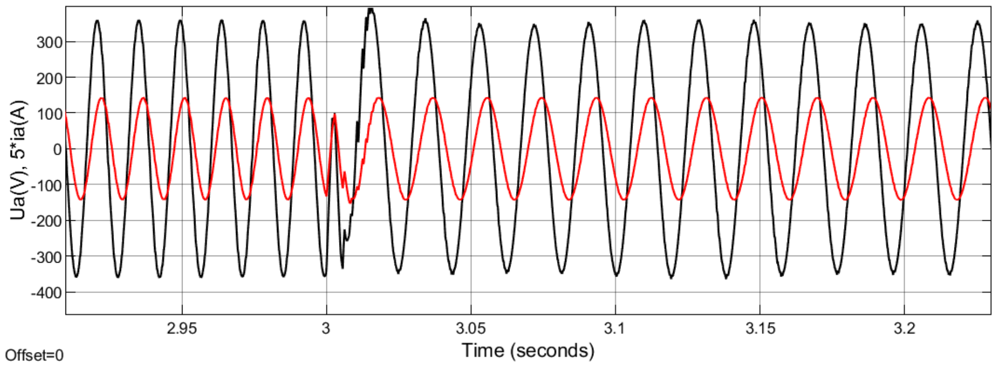

Fig. 8. The phase A voltage and its current from 2.91s to 3.23s

Comment: The simulation results above show that when the photovoltaic battery capacity oscillates in the period from 0 to 1 second the flywheel speed comes from the original value (157 rad/s) accelerated to 195 rad/s. During this time the motor works in motor mode (positive power). In the period of 1 second to 2 seconds, the flywheel speed decreased from 195rad/s to 157rad/s, the electric motor worked in transmitter mode (negative power), the energy stored in flywheel in kinetic form is compensated for the lost energy of the battery. Likewise in the remaining period. As a result, we have the total capacity of PV-FFSS system pumped into the net almost unchanged. We also get the same results for the PV power changed.

IV. CONCLUSION

The energy storage flywheel system has many advantages compared to traditional energy storage technologies (batteries,...) such as high energy storage density, which can store unlimited energy reserves, high life cycle, low operating cost. The integration of FESS in the solar power system allows maintaining the stability of the solar power supplied to the grid. The simulation results showed the correctness and feasibility of the proposed solution. This system can be used to "smooth" and balance the energy supply and demand in renewable energy systems that work independently or connected to micro-grid. The next research problem is to build an experimental model to test and improve the proposed results.

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