# A Novel DTC-based Control Method of Flywheel System to Improve Fault-Ride Through Capability of the Microgrids

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## Abstract

This paper proposes a new control method for Flywheel Energy Storage System (FESS) to guarantee a Fault-Ride Through (FRT) capability of the sensitive microgrids like big data centers. The proposed method has been developed towards a twofold aim: regulating constant common DC-bus voltage, during serious voltage dips caused by the grid-side electrical faults and also keeping a constant charge current during normal operation of the grid. The proposed FESS is coupled with Permanent Magnet Synchronous Machine (PMSM). The speed sensorless Direct Torque Control (DTC) technique has been developed for PMSM control and the Extended Kalman Filter (EKF) is used to estimate the rotor position and consequently the rotor speed. The main contributions of the overall control method are: (i) the decoupled disturbance control at discharge mode copes with sudden load change disturbances; (ii) the DTC provides fast and precise torque response; (iii) the real time speed estimation by the EKF increases the speed and the accuracy of the overall control system; (iv) the proposed FESS can be easily replaced by the Battery Energy Storage System (BESS).
The proposed system and the corresponding control method are verified in MATLAB/Simulink environment. The simulation results confirm the effectiveness of the proposed control method.

## 1 INTRODUCTION

The term microgrid is used to refer to a smaller part of the power grid where production and consumption are controlled together but independently from the rest of the grid [1]-[2]. The microgrid reliability, from the viewpoint of the customer, contains the absence of long and short interruptions, for instance, during dips [3].

To ensure the sensitive microgrid reliability, it could be connected to the main grid through the common DC-bus voltage which is supported by an adequate energy storage system during grid-side electrical faults, which may result in a voltage drop at common DC-bus [4].

This paper proposes a flywheel energy storage system (FESS) as an energy storage system. The proposed FESS is coupled with a Permanent Magnet Synchronous Machine (PMSM) to allow for bidirectional power flow. Speed sensorless Direct Torque Control (DTC) is proposed for PMSM control and an Extended Kalman Filter (EKF) is used to estimate the real time rotor position and speed. A diode rectifier is used to interface the FESS to the grid. The block diagram of the proposed system is shown in Fig. 1. In normal grid-connected operation of the microgrid the flywheel is in charge mode. During serious voltage dips, the flywheel control system moves to the discharge mode and targets at keeping constant common DC bus.

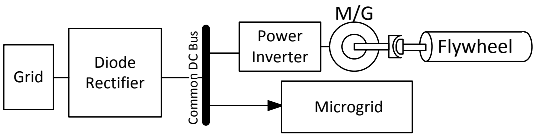

**Fig. 1** The block diagram of the proposed system.

## 2 PROPOSED CONTROL METHOD

The proposed control method consists of two main modes: charge and discharge modes. In both modes, the command inverter current and then the command $dq$-stator currents are derived to keep constant charging current at charge mode and the constant DC bus voltage at discharge mode [3]. The DTC enables direct control of electromagnetic torque of the PMSM and consequently the inverter current. In the proposed DTC scheme, an EKF is used to estimate the real-time motor speed [4].

### 2.1 Charge Control Mode

In charge control mode, the control system aims at providing constant charging current for the flywheel system. To this end, the power relations between inverter current and the flywheel system are derived [3]. The electrical power, at the terminal of the inverter is:

$$P_{dc} = i_{inv} \times v_{dc} \tag{1}$$

Ignoring the power losses in the inverter, $P_{dc}$ is equal to the electrical power ($P_{elec}$) at the terminals of the motor/generator. The electrical power is a function of electrical torque and rotor mechanical speed as follow:

$$i_{inv} = \frac{\tau_e \times \omega_{rmech}}{v_{dc}} \tag{2}$$

The electrical torque can be also obtained from stator $dq$-currents, in rotor reference frame, $(i_{qs}^r, i_{ds}^r)$ as:

$$\tau_e = \frac{3}{2}\frac{P}{2}\left[\left(L_d i_{ds}^r + \lambda_{af}\right) i_{qs}^r + \left(L_q i_{qs}^r\right) i_{ds}^r\right] \tag{3}$$

where $P$ is the number of poles, $\lambda_{af}$ is the induced flux linkage and, $L_d, L_q$ are $dq$-axis rotor inductances.

To provide a linear control system, between the electrical motor torque and the q-axis current, the command $d$-axis current is set at zero, $i_{ds}^{r*} = 0$. Thereby, (3) changes to:

$$\tau_e = \frac{3}{2}\frac{P}{2}\lambda_{af} i_{qs}^r \tag{4}$$

Finally, substituting (4) in (2), and manipulating the obtained equation, the motor current is obtained as a function of the inverter current:

$$i_{qs}^{r*} = i_{inv}^* \frac{3\,\lambda_{af}\omega_r}{2v_{dc}} \tag{5}$$

where $\omega_r$ is an electrical rotor speed. The overall scheme of the charge/discharge control modes is shown in Fig. 2.

### 2.2 Discharge Control Mode

In discharge control mode, the command inverter current is determined based on the DC bus voltage error.

To cope with a sudden disturbance imposed to the system (e.g. a load change), a Decoupled Disturbance (DD) controller is added [3]. The rectifier current $i_{rec}$ is added directly to the PI controller output as DD control signal.

The detailed structure of the proposed discharge control mode is also shown in Block 2 in Fig. 2.

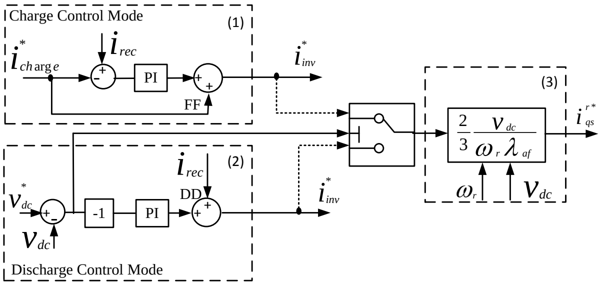

**Fig. 2** The overall scheme of the charge/discharge control modes.

## 3 SIMULATION RESULTS

To verify the performance of the proposed control method the proposed system is studied during a voltage dip caused by a balanced fault in the grid whereas the load change disturbance is also imposed during fault occurrence. The part of the simulation results are shown in Fig. 3 and Fig. 4.

The system is initially in charge mode, where the initial rotor speed is set to 1256.65 rad/s. The flywheel is charging at constant current 22.12 $A$ for three seconds. At time $t = 3$ s a balanced electrical fault occurs in the grid and lasts until t=6 s. Further, at time t=4 s, the load increases from 9.6 kW (13.9 A) to 20.7 kW (29.9 A).

The three-phase voltage waveforms are shown in left-side subplot of Fig. 3.

As a result of voltage dip, the DC voltage drops below the threshold value; therefore, the control system moves to the discharge mode. The regulated DC bus voltage is shown in right-side subplot of the Fig. 3. The disturbance decoupled (DD) control part, limits the disturbances in DC bus voltage, at t= 4 s, when a sudden load change is imposed.

The rotor speed estimated by the EKF is shown in left-side subplot of the Fig. 4. During first three seconds, the flywheel is in charge mode, thus the flywheel speed is increased to 1264.4 rad/s and the stored energy in flywheel increases from 3.8 MJ to 3.843 MJ. At t=3 s, because of the fault occurrence causing a dip at the main-grid side of the rectifier, the flywheel control moves to the discharge mode. The flywheel speed decreases to 1262.78 rad/s at t=4 s. At t=4 s, because of the sudden load change, the rate of speed reduction is increased and the speed decreases to 1255.6 rad/s at t=6 s.

When the electrical fault is cleared the flywheel moves back to the charge mode. The flywheel speed is increased to 1260.63 rad/s at t=8 s.

The electrical machine phase current is shown in time domain in right-side subplot of the Fig. 4.

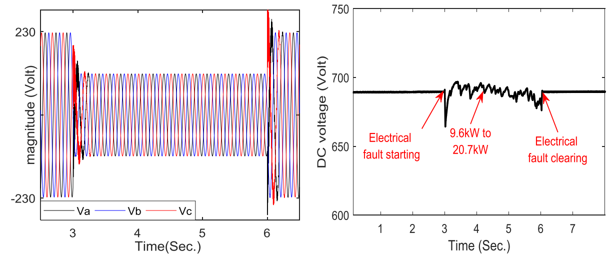

**Fig. 3** Waveforms of synthetic voltage dip (left-side) and the regulated DC-link voltage, $V_{dc}$ (right-side).

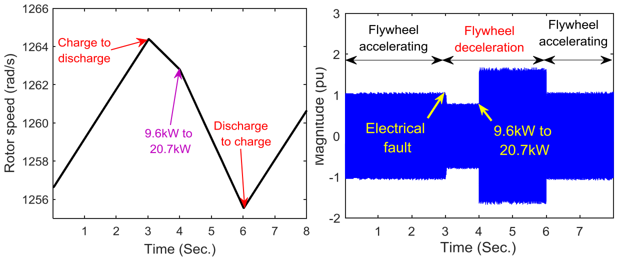

**Fig. 4** Estimated rotor speed using EKF (left-side) and motor phase currents (right-side).

## 4 REFERENCES

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