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Quasi-Z-Source inverter with hybrid energy storage for IM drive system

Masitah Muhammad*, Zulhani Rasin, Auzani Jidin, Azziddin Mohamad Razali

Centre for Robotics and Industrial Automation (CeRIA), Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: zulhani@utem.edu.my

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ABSTRACT – This paper investigates on the newly proposed hybrid energy storage system on quasi-Z-source inverter (qZSI) for the induction motor (IM) drive system. The objectives are to reduce the current stress on the battery with supercapacitor hybrid energy storage based on bidirectional DC/DC converter. The performance of the field-oriented control (FOC) for IM drive and proposed method of hybrid energy storage system during acceleration/regenerative braking is evaluated by time-domain simulation in MATLAB/Simulink environment. The results verify the benefit of qZSI converter and proposed method works satisfactorily according to the requirement to reduce the battery current stress, thus increasing the efficiency of the overall system

1. INTRODUCTION

As the electrical vehicle (EV) is operating in various condition including high power transient during the acceleration and regenerative braking, it requires the energy storage system (ESS) to function as an energy buffer and backup for the system [1]. The effect of transient power during high speed operation, due to the regenerative braking of the motor may cause an enormous damage to the battery due to its low power density. The supercapacitor (SC) on the other side has a higher power density, and capable of charge/discharge at faster rate. In order to utilize the supercapacitor to its maximum, the DC/DC converter must have an efficient control of the power flow, which can further improve the system. On the inverter/drive side, quasi-Z-source inverter (qZSI) topology has gained attention as an alternative to boost the DC bus voltage [2-3] and overcomes the output voltage constraints of the conventional drives. Moreover, the qZSI also demonstrates fault-tolerant capabilities to shoot-through faults and voltage sags [4]. This work proposes on the new method of installing a secondary energy storage to realize hybrid energy storage system (HESS) based on battery and SC for the qZSI fed motor drive system.

2. METHODOLOGY

Figure 1 shows the overall block diagram of the qZSI based IM drive system with hybrid energy storage. The battery as a primary energy source, while supercapacitor as a secondary energy source connected in parallel to capacitor C_1 via a bidirectional DC-DC converter. The diode in qZSI is replaced with IGBT switch S_7 to enable a bidirectional power flow from/into the battery. The bidirectional DC-DC converter functions as a boost/buck converter during forward/braking operation. A dSpace1104 microcontroller platform is used to process the measured signals and producing the switching signals. Table 1 and Table 2 show the parameters values and specification of the overall system.

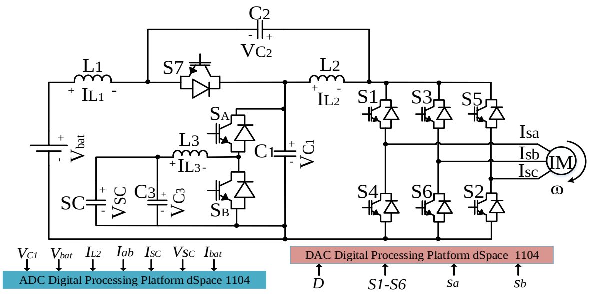


Figure 1 qZSI based IM drive with hybrid energy storage.

Table 1 qZSI and energy storage system parameters.

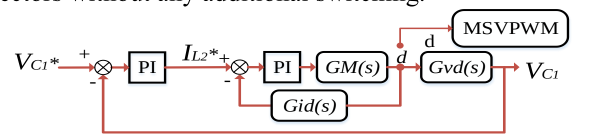
Parameters	Values
Battery Capacity	Lead acid 30units x 12V (nominal 360V,42 Ah)
Supercapacitor	400F, 134 units x 2.7V
Bidirectional DC-DC Converter	L_3 = 10 mH, C_3 = 220 uF
Switching Freq.	10 kHz
qZSI network	$L_1 = L_2$ = 4.7 mH, $C_1 = C_2$ = 1000 uF

Table 2 Induction Motor (IM) parameters.

Parameters IM	Values
Rated voltage and current	360V, 3.5 A
Rated speed	1450 rpm
Rated frequency	50 Hz
Inertia (J), Friction factor (B)	J = 0.02 kgm^2, B = 0.001 Nm/rad
Stator and Rotor inductance	L_s = 0.3252 H, L_r = 0.244 H
Mutual inductance	L_m = 0.3117 H
No. pole pair	2
Stator and Rotor resistance	R_s = 3.45 Ω, R_r = 3.4 Ω

2.1 Field Oriented Control of IM and Dual loop Capacitor Voltage Control of qZSI

A dual loop capacitor voltage control is applied in this work by controlling the capacitor C_1 voltage at a fixed value to keep a balance power transfer between the energy source and the IM drive [4]. As shown in Figure 2(a), PI controller is used to control V_{C1} and inductor current I_{L2} to produce the shoot-through duty ratio d. On the motor drive side, the field-oriented control (FOC) is applied to the induction motor aims at obtaining a decoupled control of the machine flux and torque by referring the (α,β) machine model to a rotating (d,q) reference frame aligned on the rotor flux vector whose magnitude and position are provided by a flux estimator. The block diagram of the FOC is shown in Figure 2(b) with d-axis component of the stator current vector controls the flux, while the q-axis current component controls the speed. The current control forms an inner loop of the control system, receiving the reference current values from the outer flux and torque/speed control loop. The modified carrier based SVPWM (MSVPWM) is used to produce the switching signals with the shoot-through time *d* is placed during zero vectors without any additional switching.



(a) Dual-loop Control of Capacitor Voltage

(b) Field Oriented Control (FOC)

Figure 2 (a) dual-loop control of capacitor voltage control; (b) FOC.

2.2 Current control of the hybrid energy storage during charge/discharge

The reference signal I_{L2}* represented as α in Figure 3 is sent to the bidirectional DC-DC converter as a reference signal I_{sc}* to control the supercapacitor current during the buck/boost operation to reduce the current flowing in/out to/from the battery.

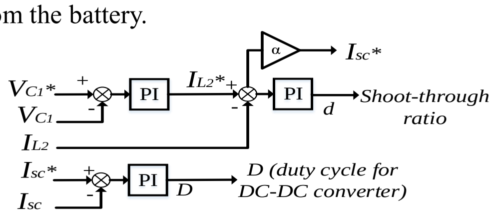


Figure 3 Control of supercapacitor current.

3. RESULT AND DISCUSSION

The effectiveness of proposed hybrid energy storage method in qZSI for the IM drive system is verified via MATLAB/Simulink software. Figure 4 (top) shows the speed transient changes from 500rpm to 1400rpm at t=1s (motoring) and from 1400rpm to 0rpm at t=1.7s (regenerative). The FOC functions satisfactorily to control the speed of the IM with the stator current increases and decreases proportionally with the speed as shown in the middle. From the bottom figure which compares the battery current with and without the SC, it is shown that the SC helps to reduce the stress of the battery current during motoring and regenerative braking. During the acceleration and regenerative braking, I_{bat} without SC reaches peak of 5A while with the SC, I_{bat} peaks approximately at 2A, reducing I_{bat} to half. The dual-loop capacitor voltage control works effectively as shown in Figure 5 (top) as the V_{C1} is maintained at 500V while I_{L2} follows the reference current in middle figure, and the DC link voltage is indirectly maintained at 640V in the bottom.

4. CONCLUSION

A qZSI fed IM drive system with a new method of installing supercapacitor as a secondary energy source to realize a battery/supercapacitor HESS has been proposed. Based on the simulation results, the proposed method works satisfactorily according to the requirement and helps to reduce the battery current stress, thus increasing the efficiency of the overall system.

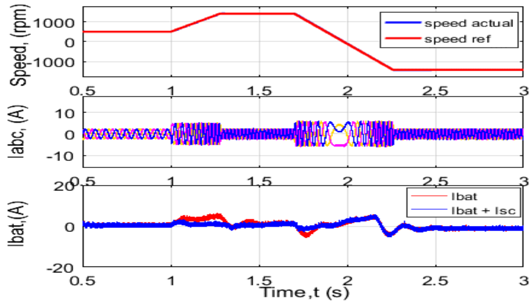


Figure 4 Speed of IM (top); stator current (mid) at various speed; comparison of battery current I_{bat} with and without ESS (bottom).

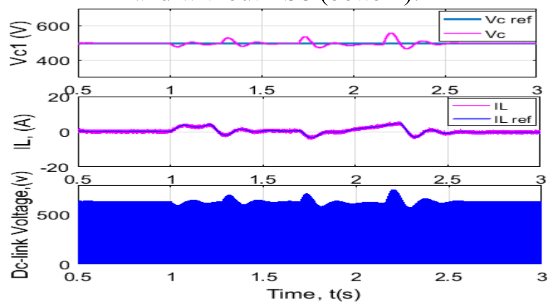


Figure 5 The capcitor voltage, V_{C1} (top); the inductor current I_{L2} (mid); the DC link voltage (bottom).

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