DESIGN OF HYBRID POWER SYSTEM FOR RUBBER-TYRED GANTRY CRANES

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INTRODUCTION

The Rubber-Tyred Gantry (RTG) crane is hoisting equipment which is usually used in ports that consist of induction motors as hoist motors. It is powered up by a diesel generator and used to move shipping containers in port terminals from one location to another. The diesel generator is sized according to the hoist motor because the hoist requires the highest amount of electrical power (both peak and steady state). Although the hoisting period lasts only a few seconds, the generator must be able to support the peak power needed. The effect is excessive fuel consumption during peak power and in idle mode. The diesel generator meets peak power demands by consuming a large amount of fuel during each lift event.

However, most RTG cranes are operated inefficiently owing to high fuel costs. One of the reasons for the RTG crane's poor operation efficiency is that the equipment is operated at a constant speed during the vertical lift even though the load or real vertical lift changes. Another reason for poor operation efficiency is that when the container is lowered, the regenerated energy created by controlling the hoist motor is directed to resistor banks and dissipated as heat. If suitable energy storage was in place, this wasted energy could be recovered and stored and could be utilized for the next lift.

This research study has proposed the potential solution of hybridizing the Energy Storage System (ESS) for the RTG crane based on the combined energy storage devices. The strategy is to use a small battery as the primary energy source and another storage device that assists the battery during high power peaks and fluctuations. The battery and the secondary energy storage device act together to store large amounts of energy and handle a high-power surge during high acceleration and regenerative braking operation.

This research aims to develop a new hybrid model for RTG crane power supply using a battery and supercapacitor which use regenerative energy efficiently. Quasi Z-source inverter (QZSI) topology is used as an alternative to the conventional voltage source inverter and this new topology gained attention in motor drive systems[1]. The proposed system is modeled in MATLAB software and tested the waveforms for 15 kW rating Induction motor.

METHODOLOGY

The complete proposed block diagram is shown in figure 1.

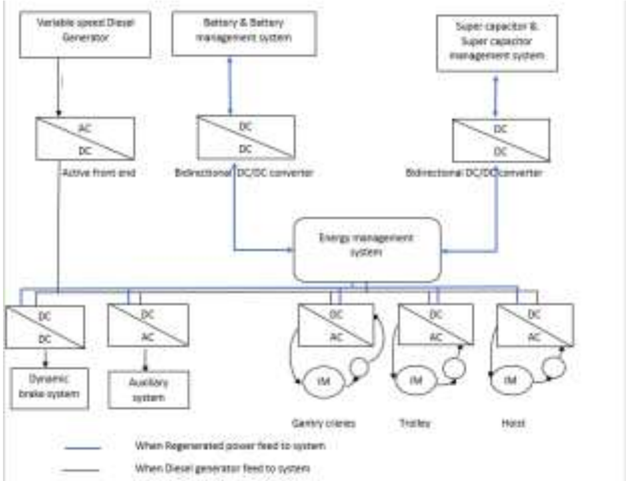

Figure 1: Block diagram for the proposed system

The Li-ion battery bank and supercapacitor bank are connected to the DC link through DC/DC converters and the output of the diesel generator is fed to an Active Front End (AFE) unit, which connects to the DC link. The AFE converter is used to control the output power of variable speed diesel generator ([2] and [3]). Three-leg interleaved DC/DC converter is used to interface the supercapacitor bank and Li-ion battery bank to the DC bus. These converters exhibit several advantages against conventional bi-directional DC/DC converters such as low current ripple, wide input/output voltage range, high power density, modular architecture, and high efficiency ([4] to [9]). The hoist motor, trolley motor, gantry motors, and the auxiliary system get their energy from the DC link through variable frequency drives and constant voltage constant frequency converter, respectively.

The hybrid energy storage system proposed in this research consists of a supercapacitor(SC) connected in parallel with capacitor C1 through a bidirectional DC-DC converter (refer to figure 2). The idea is, that the battery is connected to the input of QZSI as the primary source of the inverter to supply power for the electrical motor, while simultaneously, the super-capacitor functions as backup energy storage to supply transient power during peak load demand [10]. The battery delivers the partial amount of power demand (discharges and charges) that is required through the bidirectional QZSI topology, and the SC is triggered to operate when necessary, to supply or accept (discharges and charges) excess peak power through the bidirectional DC-DC converter. This helps to limit the battery current stress. The SC is equipped with the bidirectional DC-DC converter in parallel to the capacitor C1, where the bidirectional DC-DC converter is used to control the power flowing in and out (charging and discharging) to and from the SC ([11] and [12]).

Figure 2, figure 3, and figure 4 show the flow of power and the mode of operation between the battery a primary energy source, the supercapacitor as secondary energy storage, and the induction motor.

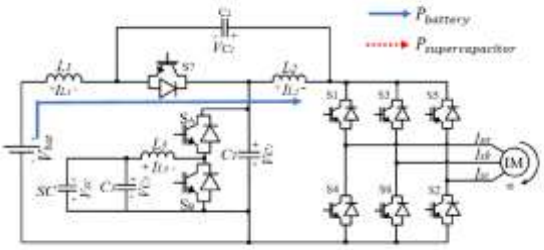

Figure 2: Power flow of battery and supercapacitor storage to IM drive Mode 1 (Standby mode)

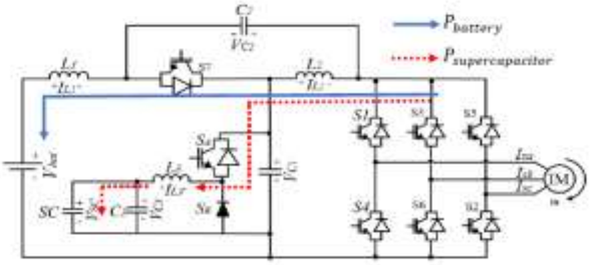

Figure 3: Power flow of battery and supercapacitor storage to IM drive Mode 2 (Charging)

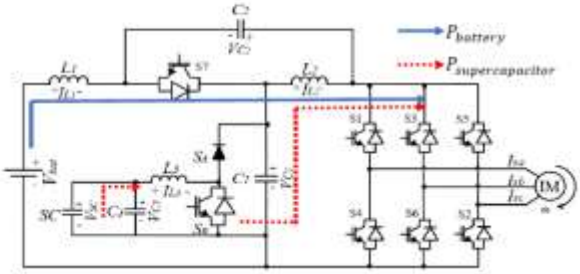

Figure 4: Power flow of battery and supercapacitor storage to IM drive Mode 2 (Discharge)

SYSTEM MODELLING

The Proposed system is modeled and simulated in a MATLAB simulation environment and the model is represented in figure 5.

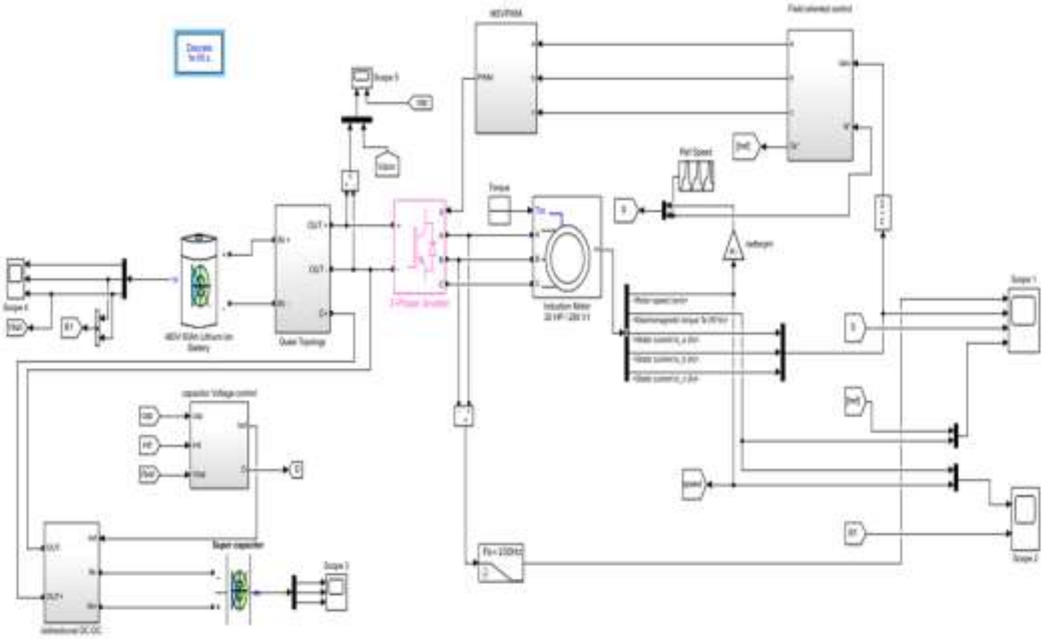

Figure 5: Block diagram for the proposed system

Table 1 provides the specifications for parameters used in the simulation. The data is collected from real RTG crane specifications used in the port terminal.

Table 1: Specification parameters of the overall system for the simulation

System item	Simulation parameters		
Battery capacity	Lithium ion 13 units * 36V (Nominal 480V .136Ah)		
Super capacitor storage unit	400F 178 units*2.7V = 480V		
Bidirectional converter network	L_3 = 10 mH	C_3 = 220 μF	
QZSI network	$L_1 = L_2$ = 4.7 mH	$C_1 = C_2$ = 1000μF	
Switching frequency	10 kHz		
DC link voltage	C_1 control at 640V	V_{DC} 800-1200V_{Peak}	ST d:0.2-0.3
Induction motor	15 kW		
	Rated voltage	480 V_{L-L}	
	Rated current	31.5 A	
	Rated speed	1450 rpm	
	Inertia (J)	0.102 kgm^2	
	Viscous fiction (B)	0.009541 Nm rad^{-1}	
	Stator inductance (L_s),	L_s = 0.065181 H	Lr=0.065181H
	Stator resistance (R_s),	R_s = 0.2147Ω	R_r = 0.2205Ω
	Mutual inductance (L_m)	0.06419H	
	Rated frequency	50Hz	

RESULTS AND DISCUSSION

This section presents and discusses the results obtained via simulation to verify the proposed hybrid energy storage system's effectiveness of the drive system for the QZSI fed IM. The simulation result is separated into two sections which are motoring operation and regenerative operation mode.

4.1 Motoring (acceleration) of 15 kW motor with load

Figure 6 shows the results for speed, stator current, and torque control of the motor for the case of motoring with a load.

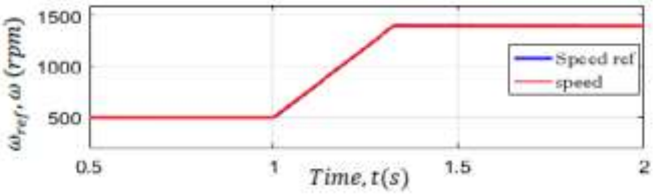

Figure 6. a: control during motoring mode for the motor to the change in motor speed (Scope 1)

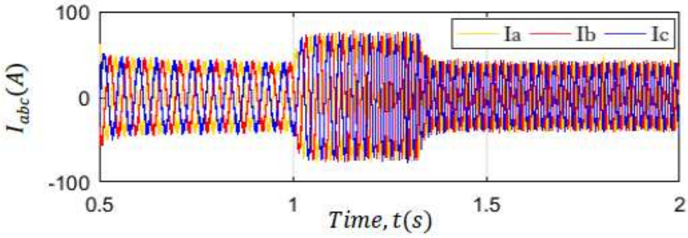

Figure 6.b: The current flowing to the motor stator during motoring of IM (scope 1)

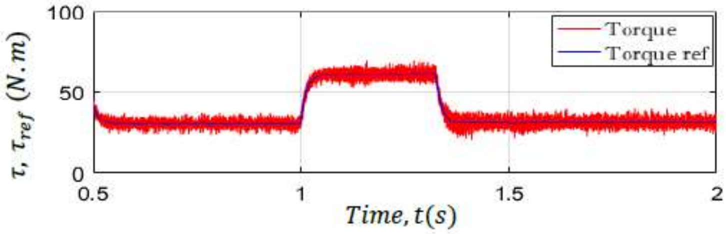

Figure 6. c: Torque control of the motor during motoring of IM (scope 1)

Figure 7 shows the battery current I_{bat}, supercapacitor current $I_{sc,}$ and supercapacitor voltage V_{sc} results for the case of motoring.

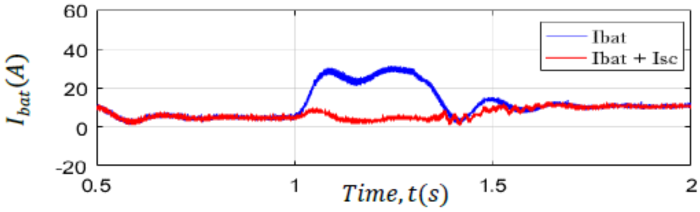

Figure 7.a: Comparison of battery current I_{bat} with and without the engagement of supercapacitor

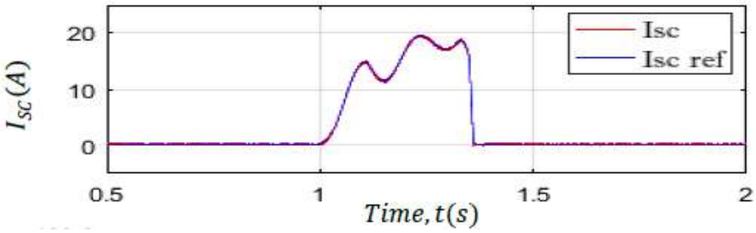

Figure 7.b: Control of supercapacitor current I_{sc} during motoring (Scope 3)

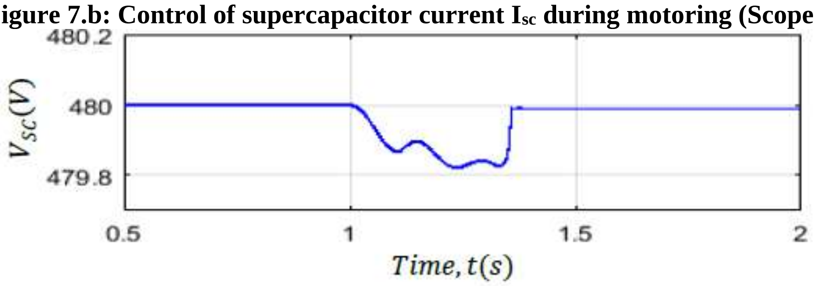

Figure 7.c: Change in the supercapacitor V_{sc} during motoring (Scope 3)

4.2 Regenerative braking of 15 kW motor with load

Figure 8 shows the simulation results for speed, three-phase stators current, and torque control of the motor for the case of regenerative braking with the load.

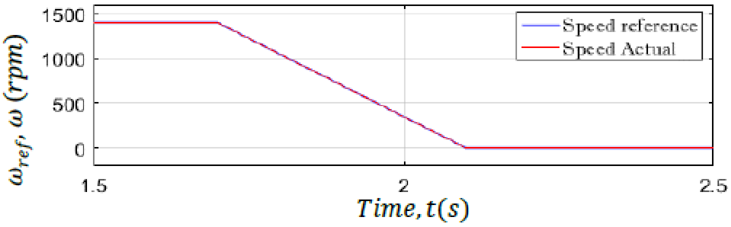

Figure 8. a: control during deceleration mode for the motor to change in motor speed

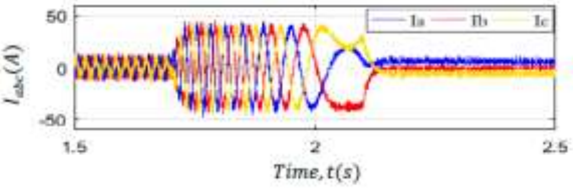

Figure 8.b: The current flowing to the motor stator during deceleration of IM (scope 1)

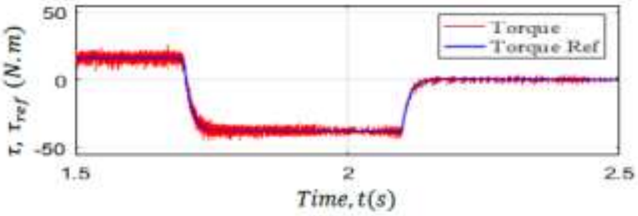

Figure 8. c: Torque control of the motor during deceleration of IM (scope 1)

Figure 9 shows the corresponding results for battery current I_{bat}, supercapacitor current I_{sc}, and supercapacitor voltage V_{sc} control for the case of braking with the load.

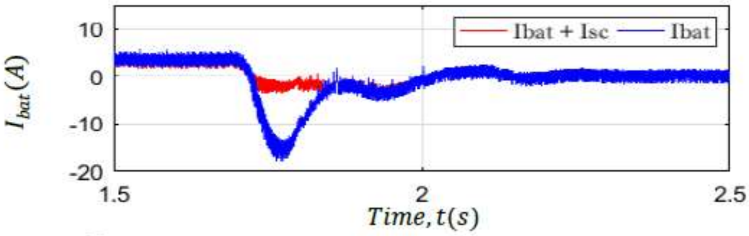

Figure 9.a: Comparison of battery current I_{bat} with and without the engagement of Super-capacitor (Scope 5)

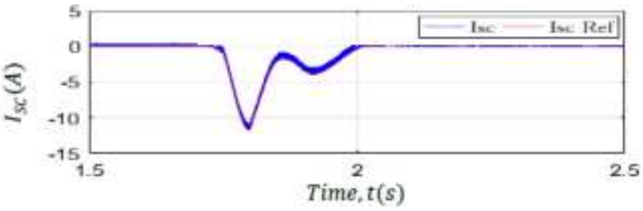

Figure 9. b: Control of supercapacitor current I_{sc} during regenerative braking (Scope 3)

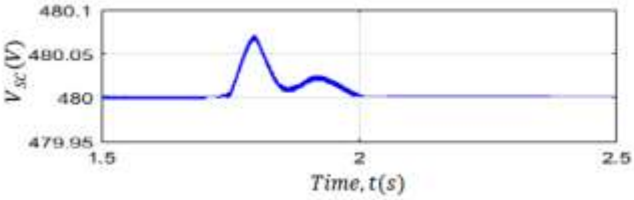

Figure 9. c: Change in the supercapacitor Vsc during regenerative braking (Scope 3)

CONCLUSIONS

This research proposed a new battery and supercapacitor hybrid energy storage method for the QZSI-fed induction motor drive system. The battery acts as the primary power source and the supercapacitor is interfaced to the inverter via a bidirectional DC-DC converter to one of the capacitors in the impedance network of the QZSI.

The main objective of the research was to identify the availability of potential regenerative energy and proposed hybrid energy storage for the effective use of regenerative energy for the next lift. With the proposed battery and supercapacitor hybrid energy storage method, the flow of power within the drive system is efficiently controlled. The battery current stress is reduced, contributing to prolonging its life cycle and a longer run of the RTG.

RECOMMENDATIONS AND FUTURE WORKS

Several recommendations for future work to further improve the QZSI with hybrid ESS for IM drives performances are discussed here. The proposed energy storage method uses a simply fixed power distribution between the battery and supercapacitor during the transient operation. This can be further improved with a variable power distribution method algorithm for better motor drive performance.

Future work may also include the evaluation of system power losses so that a better comparison can be made with the currently used conventional VSI and the QZSI. Experimenting with a higher power rating in a real environment may help to identify issues with the proposed system and rectify those in the practical implementations.

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