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Energy Recovery System for a Universal Robot UR5

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1. Universal robots

In the field of industrial robotics, one of the challenges currently faced on the road to greener manufacturing is excessive power consumption. This paper analyses the possibility of implementing an energy recovery system in a UR5 robot arm from Universal Robots.

This would replace the currently used system of energy eater modules, a collection of parallel braking resistors.

To serve as a platform for developing these systems, a permanent magnet synchronous motor (PMSM) from the base joint of a UR5 has been donated by Universal Robots. Figure to the right shows the final lab setup.

2. Energy Recovery System

To be able to transfer the energy to the supercapacitors and back again, a buck-boost converter is introduced. This is controlled with a single PWM signal, since it is operated as a synchronous buck-boost converter. To design a controller which outputs a duty cycle, the equations that describe the averaged system are established.

Algebraic Equations

$$i_{ps} = \begin{cases} \dfrac{v_{ps} - v_{C,el}}{R_{ps}} & if\ v_{ps} \geq v_{C,el} \\ 0 & if\ v_{ps} \geq v_{C,el} \end{cases}$$

$$v_{C,el} = v_o$$

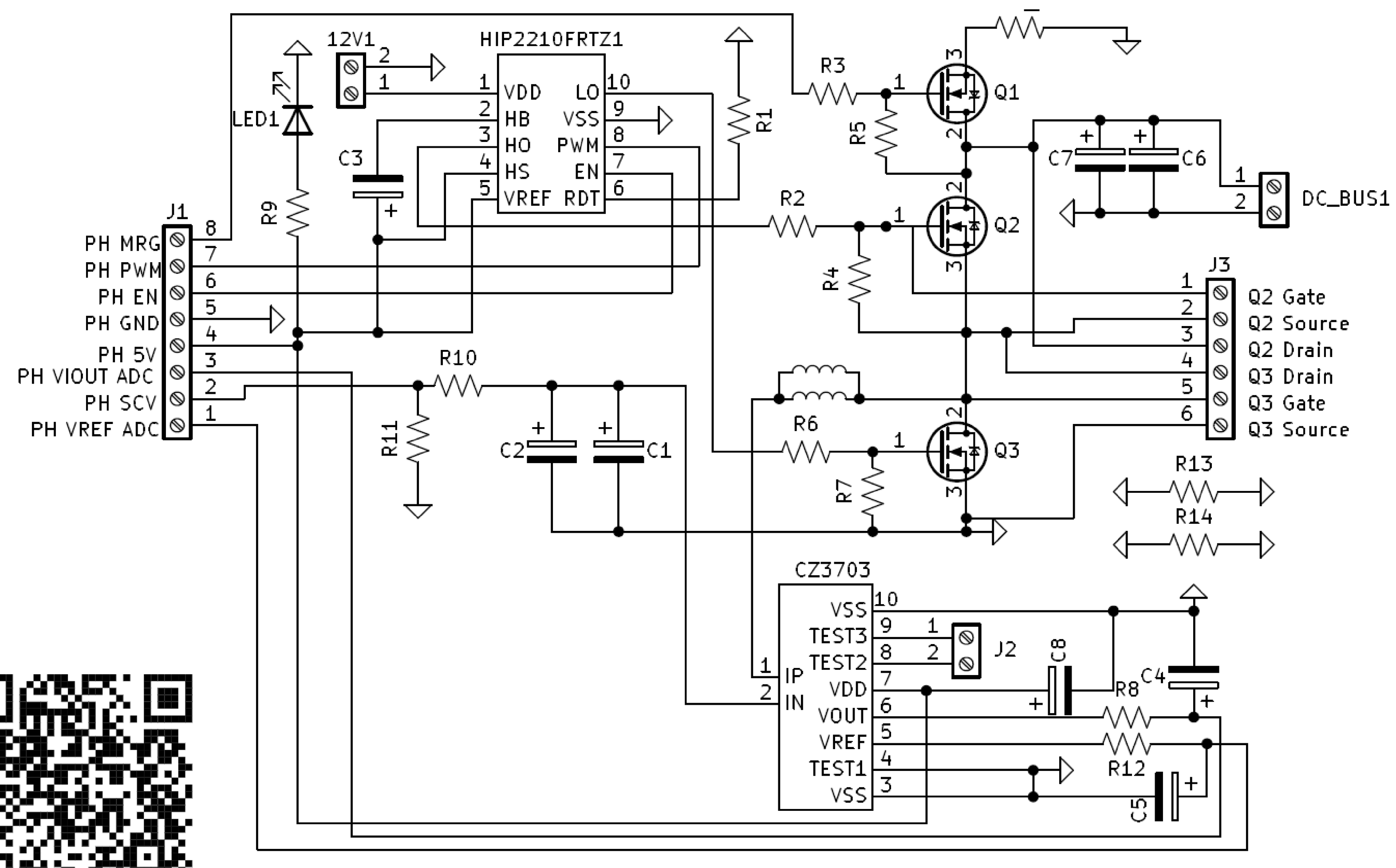
Differential Equations

$$\frac{di_L}{dt} = \frac{1}{L}\left(Dv_{C,el} - R_{tot} i_L - v_{C,su}\right)$$

$$\frac{dv_{C,su}}{dt} = \frac{1}{C_{su}} i_L$$

$$\frac{dv_{C,el}}{dt} = \frac{1}{C_{el}}\left(i_{ps} - Di_L - \frac{P_{motor}}{v_o}\right)$$

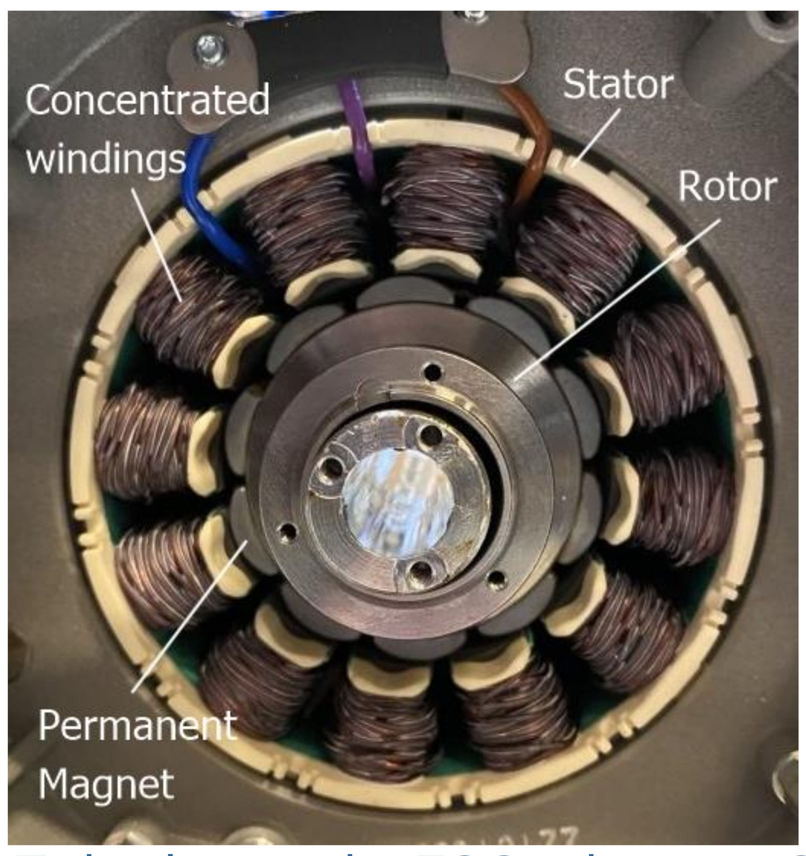
From here, linearisation is done in order to design a linear controller. The control scheme resulted in cascaded loops, with the inductor current as the inner state and the different voltages as the outer state. After designing the different controllers in the scheme, they were then discretised to realise it on the microcontroller. To run the buck-boost in synchronous mode and read the states, a MOSFET driver and a hall effect current sensor are added to the system. The final schematic of the PCB is visualised below.



QR code links to video of lab setup running with FOC

3. AC – Motor

A model of the PMSM was constructed on the basis of electrical motor working principles. In addition, a FOC scheme based on cascaded PI control loops was formulated to allow for user-issued speed commands. The figure below is an annotated picture of the PMSM. The governing PMSM differential and algebraic equations in the synchronously rotating dq-reference frame are seen to the right:



Electrical Model

$$v_{dq} = R_s i_{dq} + \frac{d\lambda_{dq}}{dt} + \begin{bmatrix} -\omega_e \lambda_q \\ \omega_e \lambda_d \end{bmatrix}$$

$$\lambda_d = L_s i_d + \lambda_{pm}$$

$$\lambda_q = L_s i_q$$

$$T_e = \frac{3}{2}\frac{p}{2}\lambda_{pm} i_q$$

$$\omega_e = \frac{p}{2}\omega_r$$

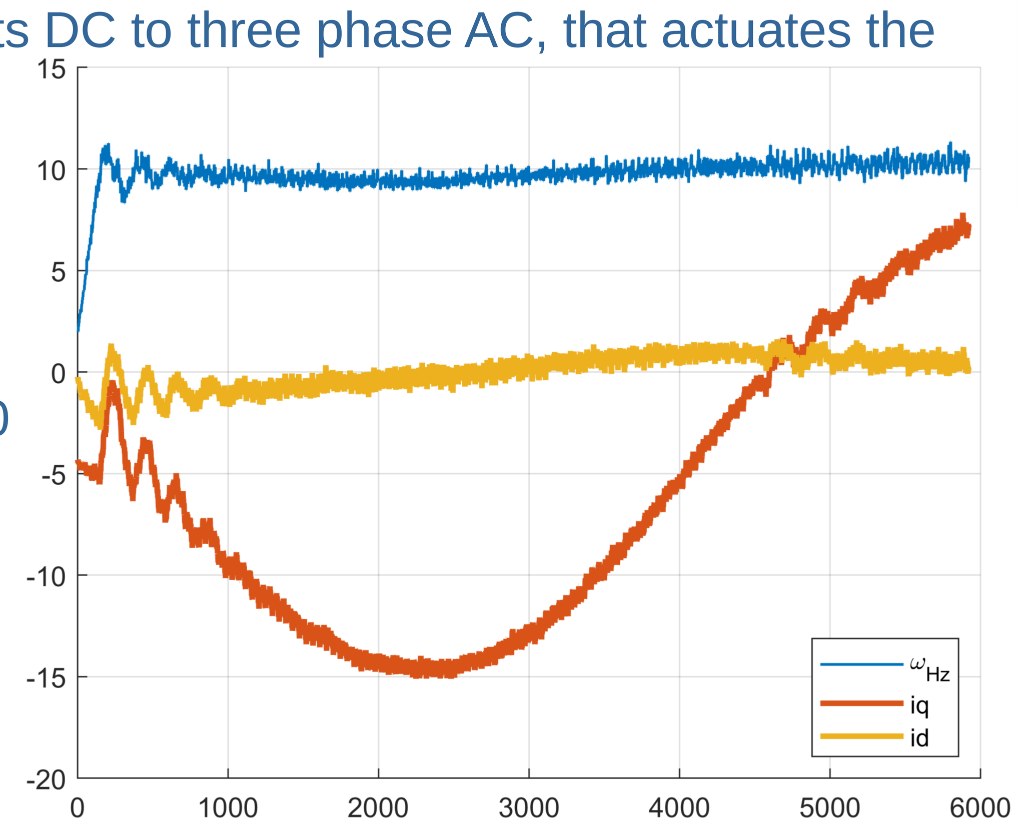
Mechanical Model

$$J\frac{d\omega_r}{dt} = T_e - T_L - B\omega_r - C_f \mathrm{sgn}(\omega_r)$$

To implement the FOC scheme, a C program is developed for the STM32 microprocessor. This features sampling of the three phase currents, DC-bus voltage and differential encoder. These states are fed through the FOC algorithm and then through SVPWM.

The SVPWM algorithm determines the duty cycles for three channel complementary PWM. These PWM signals drive the six MOSFETs, which converts DC to three phase AC, that actuates the PMSM.

A 10 Hz velocity step is examined to the right. The i_d current remains about zero, while the velocity remains about 10 Hz. The i_q flips sign, which implies that the generated torque also flips, and therefore goes from using power to generating power.



4. Conclusions

The Energy Recovery System design was finalised, and the module constructed, but not examined.

Control of the PMSMs i_q, i_d and ω states were achieved at low-velocity steps. Steps greater than 15 Hz, had an increase in the i_d steady-state error, why further tuning is expected for future work.

Finally, the two developed control systems should be implemented and examined conjointly, as this allows for regenerative braking

Acknowledgement

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