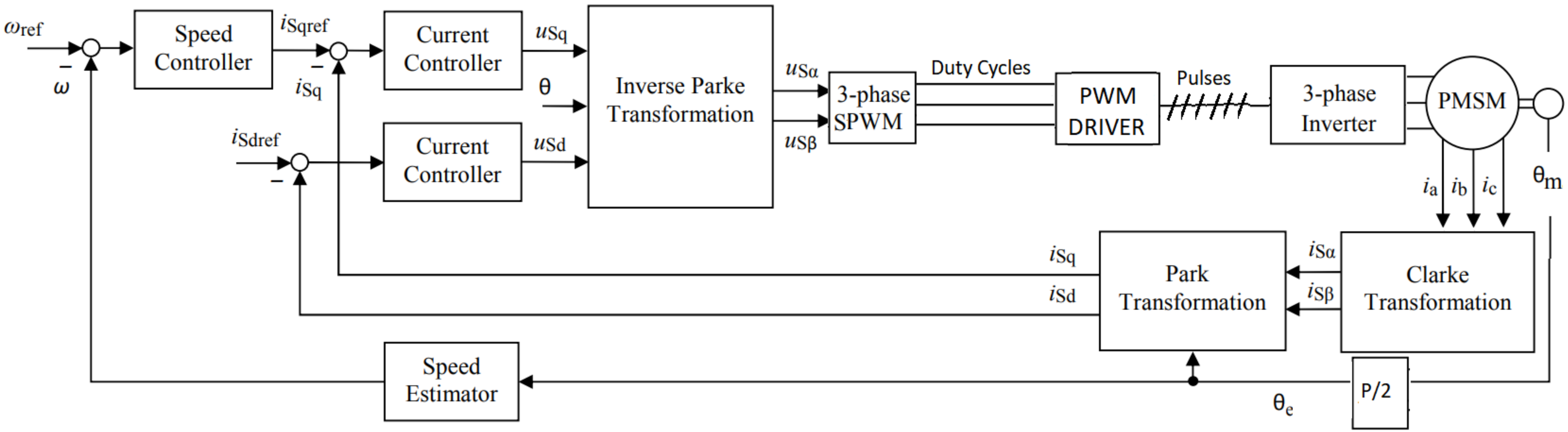
FOC Architecture- Overview



PMSM MATHEMATICAL MODEL

$$v_{sd} = R_s i_{sd} + L_{sd}\frac{di_{sd}}{dt} - \omega_r L_{sq} i_{sq} \qquad (1)$$

$$v_{sq} = R_s i_{sq} + L_{sq}\frac{di_{sq}}{dt} + \omega_r \left(L_{sd} i_{sd} + \Psi\right) \qquad (2)$$

$$\omega_r = P\omega_m \qquad (3)$$

where

ψ_{sd}, ψ_{sq}, v_{sd}, v_{sq}, i_{sd} and i_{sq} are respectively the motor fluxes, voltages and currents

ω_r is the electrical angular speed,

Γ_e is the electromagnetic torque,

Ψ is the flux of the permanent magnet

P is the number of pole pairs.

R_s is the stator resistance

L_{sd} and L_{sq} are the stator inductance in d-q axes

$$J\frac{d\omega_m}{dt} = \Gamma_e - \Gamma_l - B\omega_m \qquad (4)$$

$$\Gamma_e = \frac{3}{2}P\left(\psi_{sd} i_{sq} - \psi_{sq} i_{sd}\right) \qquad (5)$$

$$\psi_{sd} = L_{sd} i_{sd} + \Psi \qquad (6)$$

$$\psi_{sq} = L_{sq} i_{sq} \qquad (7)$$

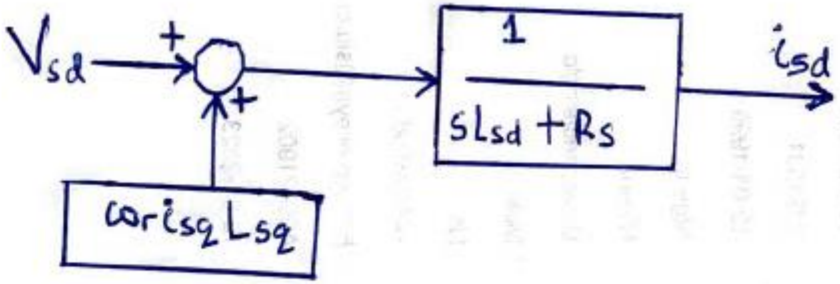
J is the inertia of the motor and coupled load,

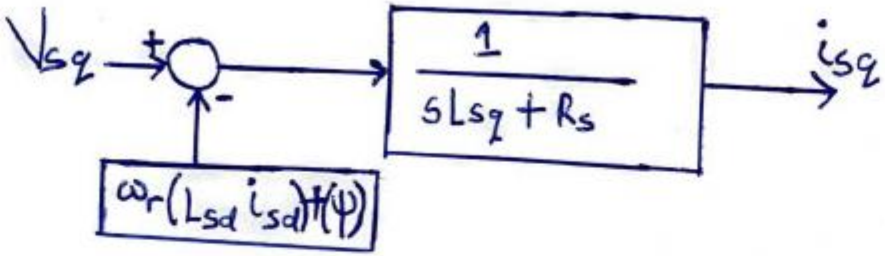
Γ_l is the load torque,

B is the friction coefficient

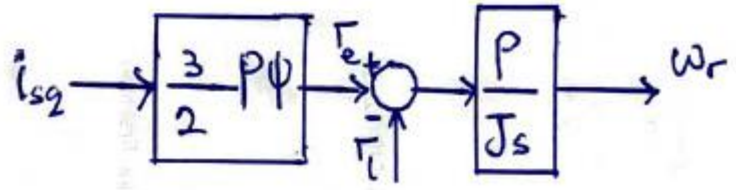
ω_m is the mechanical angular speed.

Electrical Equation Block Diagram (dq-axis)

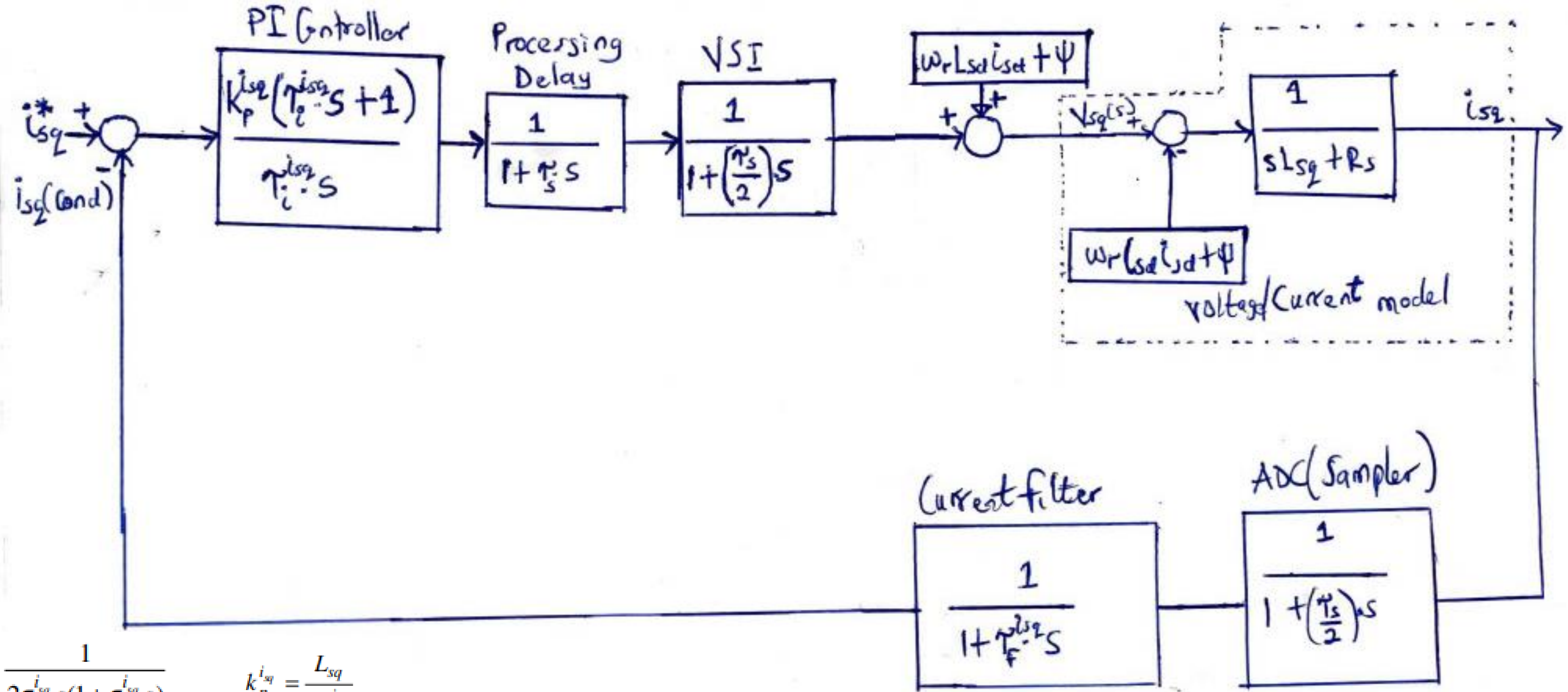




Mechanical Equation Block Diagram



Controller Parameterization - Iq Current loop



$$G_{open}^{i_{sq}}(s) = \frac{1}{2\tau_{\Sigma}^{i_{sq}}\, s(1+\tau_{\Sigma}^{i_{sq}}\, s)}$$

$$k_p^{i_{sq}} = \frac{L_{sq}}{2\tau_{\Sigma}^{i_{sq}}}$$

$$G_{close}^{i_{sq}}(s) = \frac{1}{1+2\tau_{\Sigma}^{i_{sq}}\, s}$$

$$k_i^{i_{sq}} = \frac{k_p^{i_{sq}}}{\tau_i^{i_{sq}}}$$

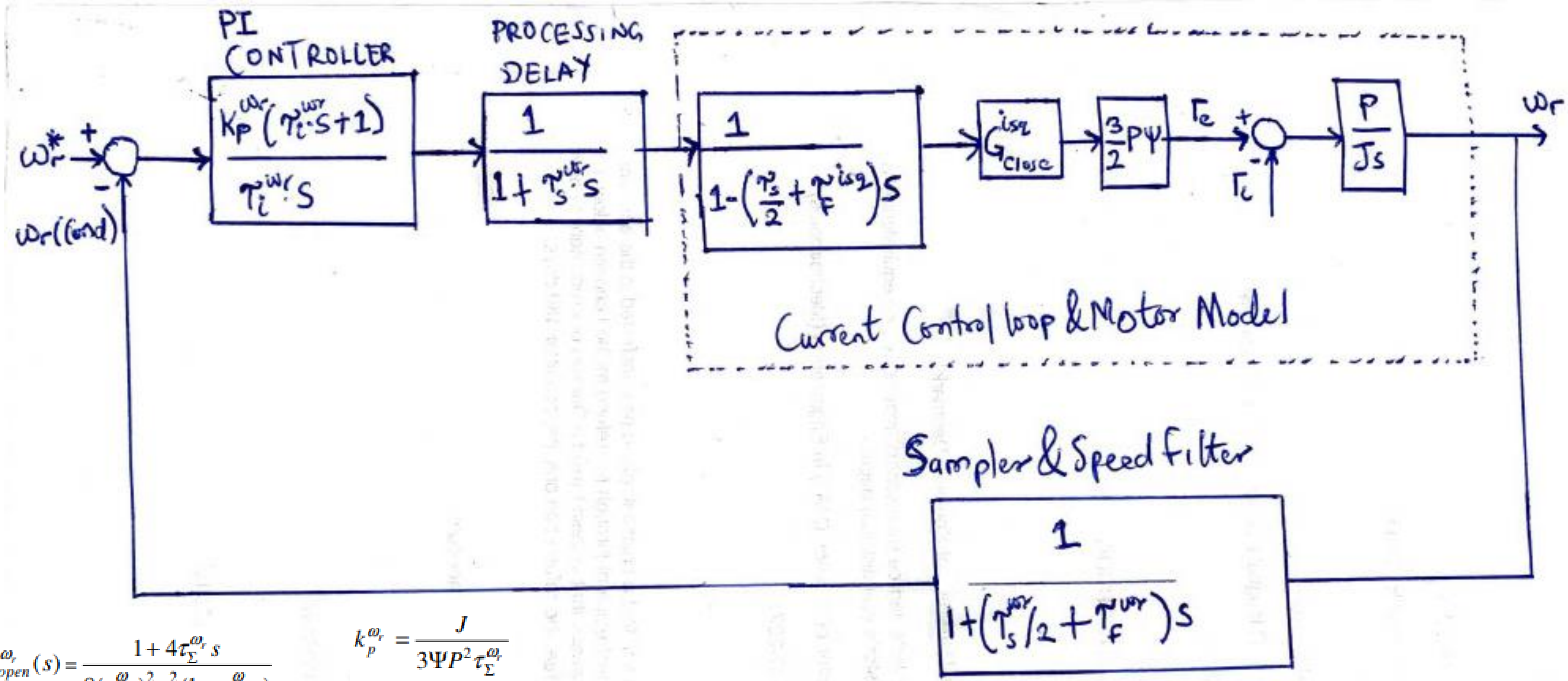
$$\tau_{\Sigma}^{i_{sq}} = 2\tau_s + \tau_f^{i_{sq}}$$

$$\tau_i^{i_{sq}} = \frac{L_{sq}}{R_s}$$

Controller Parameterization - Id Current loop

- Same method as used for Iq
- Replace q-axis inductance with d-axis inductance.

Controller Parameterization - Speed loop



$$G_{open}^{\omega_r}(s) = \frac{1 + 4\tau_{\Sigma}^{\omega_r} s}{8(\tau_{\Sigma}^{\omega_r})^2 s^2 (1 + \tau_{\Sigma}^{\omega_r} s)}$$

$$\tau_{\Sigma}^{\omega_r} = \frac{3}{2}\tau_s^{\omega_r} + \tau_f^{\omega_r} + 2\tau_{\Sigma}^{i_{sq}} - \tau_f^{i_{sq}} - \frac{\tau_s}{2}$$

$$k_p^{\omega_r} = \frac{J}{3\Psi P^2 \tau_{\Sigma}^{\omega_r}}$$

$$k_i^{\omega_r} = \frac{k_p^{\omega_r}}{\tau_i^{\omega_r}}$$

$$\tau_i^{\omega_r} = 4\tau_{\Sigma}^{\omega_r}$$

References

[1]. B. Zigmund, A. Terlizzi, X.T. Garcia, R. Pavlanin and L.Salvatore, Experimental evaluation of PI tuning techniques for field-oriented control of permanent magnet synchronous motors, Advances in Electrical and Electronic Engineering, 14, 114-119.

[2] Umland, J. W., & Safiuddin, M. (n.d.). Magnitude and symmetric optimum criterion for the design of linear control systems-what is it and does it compare with the others? Conference Record of the 1988 IEEE Industry Applications Society Annual Meeting. doi:10.1109/ias.1988.25302

Let’s run the Simulation!