Methods of Computation of Optimal PID Controller Parameters for Vector Control of Induction Motors.

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***Abstract*- In this paper, method of computing Proportional, Integral and Derivative (PID) controller parameters for vector control of induction motor is proposed. The proposed method computes optimal parameters for current loop, flux loop, and speed loop as function of required settling time and motor parameters. Simulation results show robustness of the proposed method to system parameters variations.**

Keywords: *Optimal Control, PID, Field oriented control of induction motor.*

I. INTRODUCTION

In vector control of ac machines, the field-oriented vector control of induction motor requires the speed control, torque control and flux control loop. These control loops required the computation of Proportional, Integral (PI) control parameters to be selected such that current, flux, and speed tracks the desired value in fast time [1]. Usually the PI parameters are chosen arbitrary or by trail and error method to achieved the desired system performance. Many servo motion control applications do not fully utilize all three parameters of the PID controller. Instead, only the proportional and derivative gains are used. Proportional gain adjustments vary the bandwidth to meet the settling time specification. Derivative gain adjustments vary the system response to meet overshoot requirements. Increasing derivative gain will reduce the control signal magnitude when the error rate is high, thereby reducing or eliminating overshoot [2]. Integral gain is normally only used to reduce steady state error caused by friction, gravity, etc. However, the misapplication of integral gain can cause stability problems.

The method we proposed in this paper will state clearly how the PI parameter is computed based on the system parameters and the close-loop performance requirements by specifying the settling time as the only system performance requirements.

Construction and operating principles of induction motors incorporate generation of a revolving field in the stator and torque production in the rotor. The characteristic of induction motor can be explained in steady-state and transient state by modeling the equivalent transformation of 3-phase model into synchronous or stationary model. Usually in induction motor control it is convenient to design the control system base on synchronous frame because the motor variables (speed, currents and fluxes) attain constant values at steady state, unlike in stationary frame where the motor variables varied with time which is not convenient for design of control system.

The AC induction motor is a workhorse of most of industrial and residential motor application due to their simple construction and durability. Although the AC induction motors are designed to operate at a constant input voltage and frequency, but advance in solid state and digital processing and microprocessor technology had made it possible to effectively vary input frequency of the motor via Pulse Width Modulation (PWM) Techniques.

II. INDUCTION MOTOR MODEL

To simplified the analysis and control design for induction motor, transformation techniques is usually employed to transform the induction motor variables (voltage, current and torque) from the three phase into its equivalent model either in stationary frame or synchronous frame. The three phase model of induction motor is transform into stationary two orthogonal phase using Clark transform shown in figure (1). The model of induction motor in stationary frame is not suitable for control design because the motor variable varied with time at steady-state. Thus, there is a need for transformation of the motor variables into a frame whereby the motor variables act as dc component (time-invariant) at steady state [1]. This requirement is achieved through transformation of stationary from variable into frame called synchronous from using what known as Park transform. This transformation is shown in figure (2).

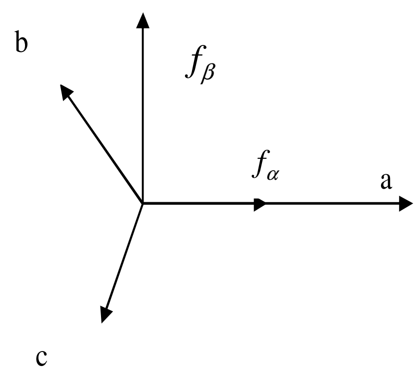

Figure 1. 3-phase transformation to stationary frame

The model of squirrel cage induction motor in the rotating or synchronous frame is given by [1-4], [8]

$$\begin{aligned}
u_{ds} &= R_s i_{ds} + \frac{d\lambda_{ds}}{dt} - \omega\lambda_{qs} \\
u_{qs} &= R_s i_{qs} + \frac{d\lambda_{qs}}{dt} + \omega\lambda_{ds} \\
0 &= R_r i_{dr} + \frac{d\lambda_{dr}}{dt} - (\omega - \omega_r)\lambda_{qr} \\
0 &= R_r i_{qr} + \frac{d\lambda_{qr}}{dt} + (\omega - \omega_r)\lambda_{dr}
\end{aligned} \tag{1}$$

$$\begin{aligned}
\lambda_{ds} &= L_s i_{ds} + L_m i_{dr} \\
\lambda_{qs} &= L_s i_{qs} + L_m i_{qr} \\
\lambda_{dr} &= L_r i_{dr} + L_m i_{ds} \\
\lambda_{qr} &= L_r i_{qr} + L_m i_{qr}
\end{aligned} \tag{2}$$

The torque developed induction motor is given by [3]

$$T_d = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left(\lambda_{dr} i_{qs} - \lambda_{qr} i_{ds}\right) \tag{3}$$

The mechanical model of induction motor is given by

$$J\frac{d\omega_r}{dt} + B\omega_r = \frac{P}{2}\left(T_d - T_L\right) \tag{4}$$

Where

u_{ds}, u_{qs} d-axis and q-axis input voltage respectively

R_s, R_r Stator and rotor resistance respectively

L_s, L_r, L_m Stator, rotor and mutual inductance inductance

$\lambda_{ds}, \lambda_{qs}$ Stator d-axis and q-axis fluxes

$\lambda_{qr}, \lambda_{qr}$ Rotor d-axis and q-axis fluxes

i_{ds}, i_{qs} Stator d-axis and q-axis currents

i_{dr}, i_{qr} Rotor d-axis and q-axis currents.

ω, ω_r Reference frame and rotor electrical angular speed.

J, B Motor inertia and biscus friction coefficient

T_d, T_L, P Developed torque, Load Torque, and number of poles

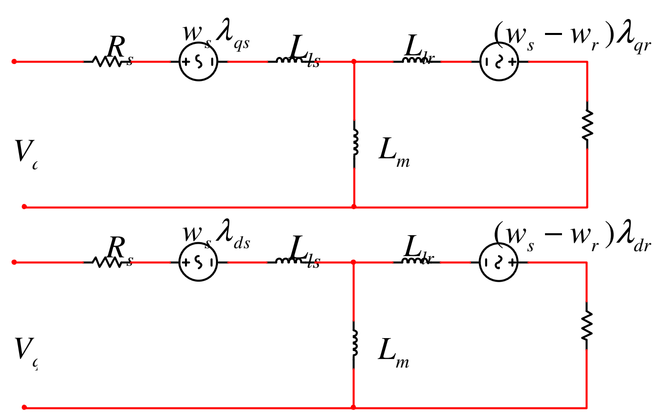

Figure 2. Induction motor model in synchronous frame

III. OPTIMAL PID PARAMETERS COMPUTATION METHOD

Looking at the mechanical model equation of the motor equation (4), it is clear that this equation is a first order system. Transforming equation (4) into s-domain, yield the first system of the form

$$\omega_r(s) = \frac{k_m}{(\tau_m s + 1)}(T_d - T_L) \qquad (5)$$

Where the mechanical time constant $\tau_m = \frac{J}{B}$,

and gain $k_m = \frac{P}{2B}$.

The equation in (5) has a settling time of about $5\tau_m$. The characteristic equation of the closed-loop system shown in figure (3) is given by

$$\frac{wr}{wr^*} = \frac{k_m k_p s + k_m k_i}{\tau_m s^2 + (1 + k_m k_p)s + k_m k_i} \qquad (6)$$

Assume the above closed-loop equation (6) has a first order system given by

$$\frac{w_r}{w_r *} = \frac{1}{\tau_c s + 1} \qquad (7)$$

Where τ_c is a time constant of the closed-loop system.

Equating equation (6) and equation (7), yield the following PI controller parameters:

$$k_p = \frac{\tau_m}{k_m \tau_c}, \qquad k_i = \frac{1}{k_m \tau_c} \qquad (8)$$

The equation (8) above compute the PI controller parameter as function of plant time constant, dc gain and require closed-loop time constant. Since the settling time of first order system is approximately five times of its time constant, therefore, equation (8) can be written as function of the required settling time as follows

$$k_p = \frac{5\tau_m}{k_m \tau_s}, \qquad k_i = \frac{5}{k_m \tau_s} \qquad (9)$$

Where τ_s is a settling time of the closed loop system.

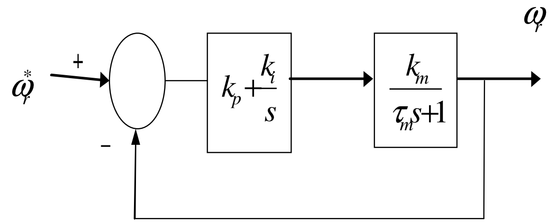

Figure 3. Speed control loop

III. THE FIELD ORIENTATION PRINCIPLE

The field orientation concept implies that the current components supplied to the machine should be oriented in such a manner as to isolate the component of stator current magnetizing the machine (flux component) from the torque producing component. This can be accomplished by choosing the reference frame speed ω*e* to be the instantaneous speed of the rotor flux linkage vector and locking its phase such that the rotor flux is entirely in the *d*–axis (now equivalent to the flux or magnetizing axis), resulting in the mathematical constraint [1-2],[4].

$$\lambda_{qr} = 0 \qquad (10)$$

The torque generating current component (i_{sq}) is calculated as a function of the required motor torque and the motor field. The reference current $i_{sq\mathrm{ref}}$ is proportional to the torque-to-field ratio. The torque is calculated in turn as a function of the difference between the reference speed and the actual speed of the motor.

In the case of indirect rotor field orientation, the flux orientation is calculated by integrating the stator angular frequency (11). The slip angular frequency is estimated as shown by equation (13) which is derived from the basic equations governing the rotor circuit (12). In (13) it is implicit that the rotor flux amplitude is constant due to very good current controllers providing very fast (ideally instantaneous) dynamic response. Parameter detuning leads to a loss of rotor field orientation and to a deterioration of the system dynamic response [2]. The rotor time constant *Tr* specially should be updated through an estimator.

$$\theta(t) = \int_0^t (\omega_{slp} + \omega_r)dt = \int_0^t \omega dt \qquad (11)$$

$$0 = R_r i_{qr} + \omega_{slp}\lambda_{dr} + \frac{d\lambda_{qr}}{dt} = R_r i_{qr} + \omega_{slp}\lambda_{dr} = R_r i_{qr} + \omega_{slp}\lambda_r \qquad (12)$$

$$0 = R_r i_{dr} - \omega_{slp}\lambda_{qr} + \frac{d}{dt}\lambda_{dr}$$

$$\omega_{slp} = -\frac{R_r i_{dr}}{\lambda_r} = \frac{L_m R_r}{L_r \lambda_r} . i_{qs} \qquad (13)$$

IV. SPACE VECTOR PWM TECHNIQUE

Space Vector PWM (SVPWM) is a special technique of determining the switching sequence of the upper three power transistors of a three-phase voltage source inverter (VSI). It generates less harmonic distortion in the output voltages or current in the windings of the motor load. SVPWM provides more efficient use of the dc bus voltage, in comparison with the direct sinusoidal modulation technique [1].

VI. RESULT DISCUSSIONS

The performance of the proposed controller were investigated by setting the required settling time of 0.2 seconds and the desired speed of 200 rad/sec. As it is clear from the resulted motor speed (figure (5)) that the motor speed converge to desired speed without overshoot. It is also clear from figure (4) in comparison to open-loop response shown in figure (4), that the significant ripple available in open-loop case is almost disappear in the case of using the proposed controller.

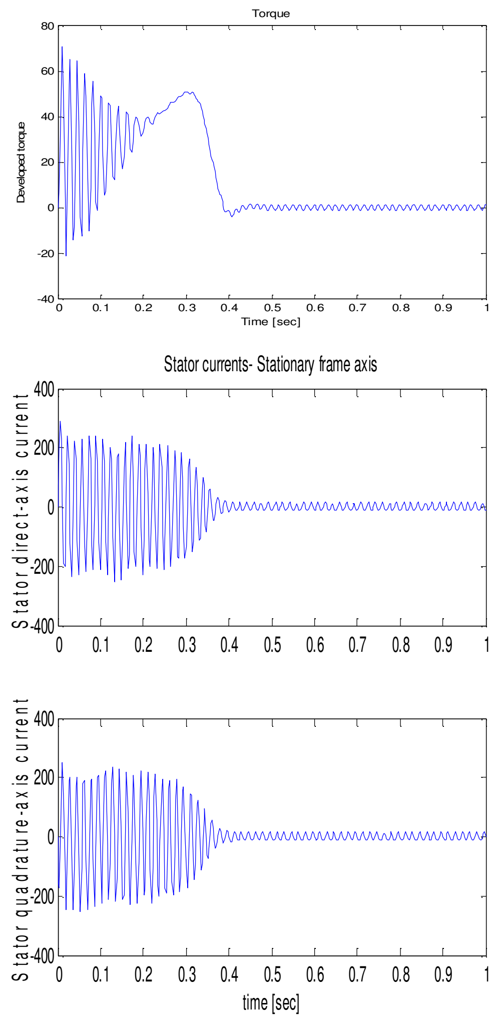

Figure 4. Open-loop response of induction motor

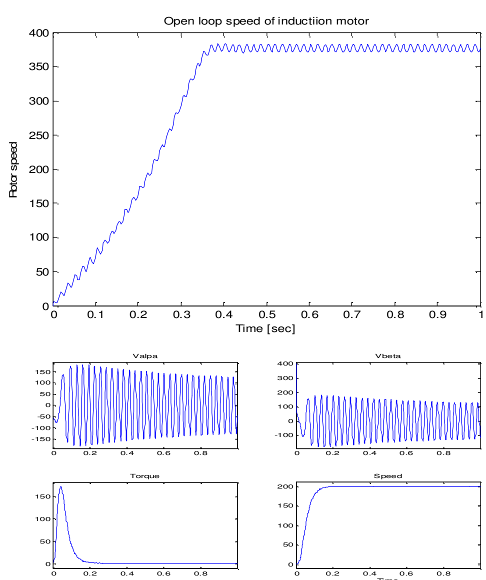

Figure 5. Closed-loop performance.

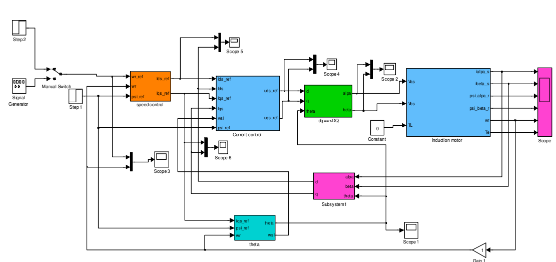

Figure 6. Induction motor control system block diagram

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