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Comparative analysis of current control of PMSM drive for PID and PI controllers

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ABSTRACT
The permanent magnet synchronous motor is that type of brushless magnet motor in which windings of the motor are sinusoidally distributed and generate sinusoidal emf.These motors have numerous advantages over other methods such as improved efficiency, faster dynamic response, less maintenance, improved power factor. To achieve desired level of performance, it requires suitable speed and current controller design. In this paper, a comparative study has been made between PID and PI controllers.

Keywords-*PMSM,PID and PI Controller*

I. INTRODUCTION

In all vector control strategies of ac drives typically two closed loop, current control and speed control loop are used. Speed controllers are used in speed controller loops to obtain a magnitude of reference torque to obtain the desired (reference) speed [7]. Speed controller compares the actual speed, speed obtained from speed sensor of the motor and reference speed to generate reference torque value. The reference speed is passed through speed ramp block which limits the rising and falling rate or speed signal [1][2]. The actual speed is passed through a low pass filter to filter out speed transients and then compared with actual speed. Industrial controllers can be classified according to their controlling action such as proportional controller, PI controller,PID controller etc.Type of controller to be used must be decided depending upon nature of plant and operating condition such as safety, cost, avaiblity, reliability, accuracy and size.

II. PROPOTIONAL –INTEGRAL-DERIVATIVE CONTROLLERS

PID controllers are the most widely-used type of controller for industrial applications. They are structurally simple and exhibit robust performance over a wide range of operating conditions. In the absence of the complete knowledge of the process these types of controllers are the most efficient of choices. The three main parameters involved are Proportional (P), Integral (I) and Derivative (D). The proportional part is responsible for following the desired set-point, while the integral and derivative part account for the accumulation of past errors and the rate of change of error in the process respectively. For the PID controller shown in figure 1, Output of the PID controller is given by

$$U(t) = K_p e(t) + K_i \int e(t)\, dt + K_d \frac{de(t)}{dt} \quad (1)$$

Where,

Error, e(t) =Set point- Plant output(Process Variable)

K_p = proportional gain, K_i = integral gain, K_d = derivative gain

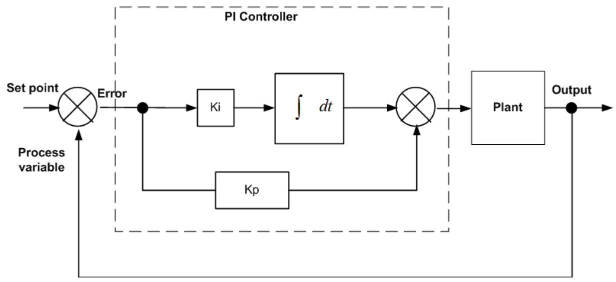


Figure 1. PID controller

In discrete control, the proportional control is implemented by a proportional constant K. For the implementation of integral control in discrete mode, bilinear –transformation integration is used. The transfer function of this PID controller is

Simplifying the above transfer function

$$D(z) = K\left[1 + \frac{1}{T_i}\frac{T_s(z+1)}{2(z-1)} + \frac{T_d}{T_s}\frac{z-1}{z}\right] \quad (2)$$

Where K is the constant.

Speed controller compares the actual speed obtained from speed sensor of motor & the reference speed to generate reference torque value. The reference speed is passed through speed ramp block, which limits the rising & falling rate of the speed signal, as shown in Figure 2. The actual speed converted in electrical rad/sec, is passed through low pass filter to filter out speed transients & then compared with actual speed.

The error signal is then passed through typical proportional-integral-derivative controller (PID controller). The torque signal so obtained, is passed through torque limiter which limits the maximum & minimum value of torque signal. Thus a reference torque signal is generated.

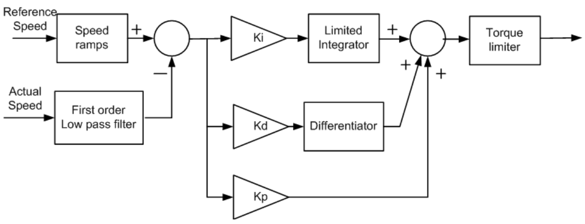


Figure 2. Block diagram schematic of PID speed controller implemented in simulation.

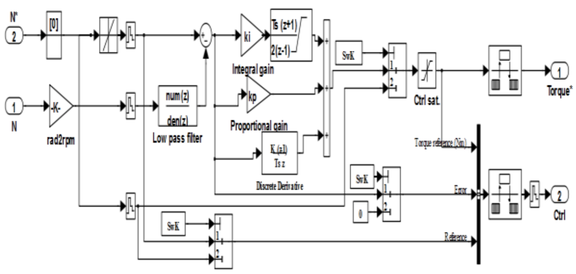


Figure 3. Simulink model of PID speed controller

III. SIMULATION RESULTS OF PID SPEED CONTROLLER

The main aim of the simulation study of this control strategy, vector control with PID speed controller is to check the performance which states the effectiveness of the control strategy. The speed response, the stator current waveforms and torque ripples are considered as the main performance parameters that are checked here.

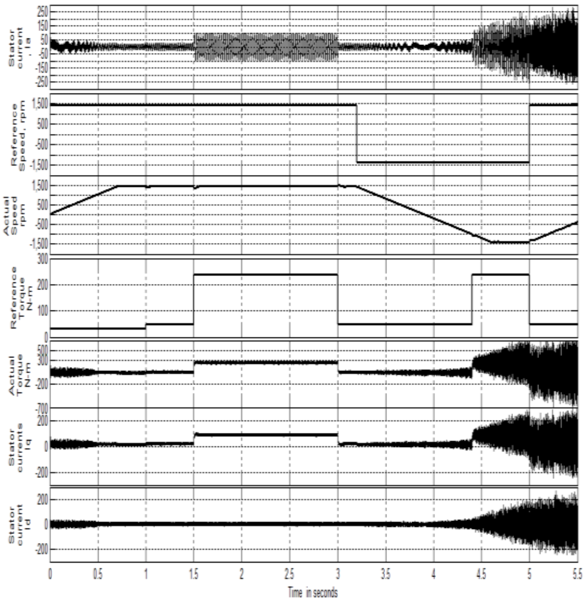


Figure 4. Simulation results of vector control of PMSM with PID speed controller.

The system built in MATLAB for a PMSM drive system has been tested for starting, load perturbations and speed reversals. The Figure 4 shows simulation results of the quantities actual and reference speed, the stator current I_a, actual and reference torque and stator currents in rotor frame of reference I_{dq} during vector control of PMSM using PID controller.

The actual speed follows reference speed as per the speed controller settings and motor parameters. The rate of rise or fall of speed can be altered but the final response of the drive also depends on torque saturation settings of speed controller (PID controller) of the motor.

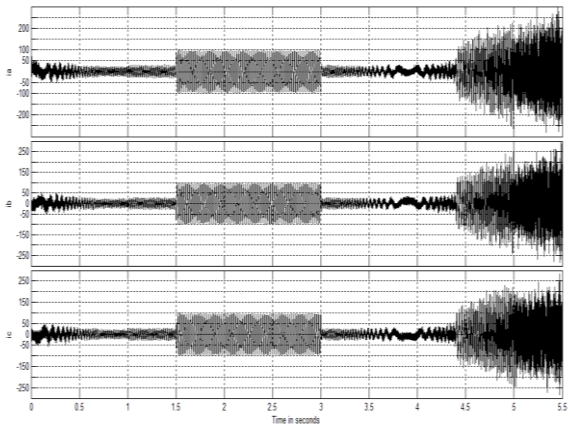


Figure 5 : stator current waveforms i_{abc} during vector control.

As the step of the speed (difference between previous speed at which motor is running and the reference value) is more, the settling time increases. In other words, actual speed reaches at the desired level with delay. A short duration dip in the speed occurs at the time of increase in the load or a sharp rise in the speed is observed during decrease in the load but their duration is too small. Hence it has been observed , PID controller shows poor performance when load is increased during deceleration. When load is abruptly increased during negative reference speed region, due slower response of PID controller, the electromagnetic torque requirement increases steeply showing heavy ripples in torque and stator currents.

IV. PROPOTIONAL INTEGRAL CONTROLLERS

In control engineering, a PI Controller (proportional-integral controller) is a feedback controller which drives the plant to be controlled by a weighted sum of the error (difference between the output and desired set-point) and the integral of that value. It is a special case of the PID controller in which the derivative (D) part of the error is not used.The PI controller is mathematically denoted as

$$U(t) = K_p e(t) + K_i \int e(t)\, dt \quad (3)$$

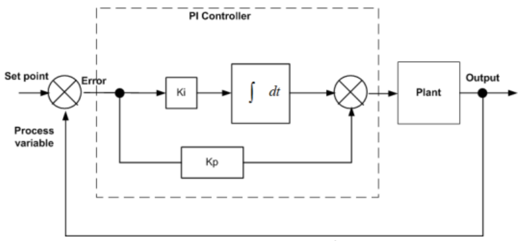


Figure 6. Block diagram of PI controller

The control strategy for vector control of PMSM is shown in Figure 7. The speed control loop uses a PI regulator to produce the flux and torque references for the vector control block[4]. The vector control block computes the three reference motor line currents corresponding to the flux and torque references and then feeds the motor with these currents using a three-phase current regulator. One of the most widely used controllers in the design of continuous data control system is the proportional integral derivative (PID) controller. But this PID controller is avoided because differentiation can be problematic when input command is step[5][6] .If applied properly, the PI controller can be used to improve the steady-state performance by increasing the type of the system and at the same time, improve the relative stability.

In discrete control, the proportional control is implemented by a proportional constant K_p. For the implementation of integral control in discrete mode, bilinear –transformation integration is used. The transfer function of this PI controller is

$$D(z) = \frac{(2K_p + K_i T_s)z + (K_{i.} T_s - 2K_p)}{2(z-1)} \quad (4)$$

K_i is the integral constant.

Simplifying the above transfer function

$$D(z) = K_p + K_i \frac{T_s(z+1)}{2(z-1)} \quad (5)$$

Speed controller compares the actual speed obtained from speed sensor of motor & the reference speed to generate reference torque value. The reference speed is passed through speed ramp block, which limits the rising & falling rate of the speed signal, as shown in Figure 4.9. The actual speed converted in electrical rad/sec, is passed through low pass filter to filter out speed transients & then compared with actual speed[8]. The error signal is then passed through typical proportional & integral controller (PI controller). The torque signal so obtained, is passed through torque limiter which limits the maximum & minimum value of torque signal. Thus a reference torque signal is generated[9].

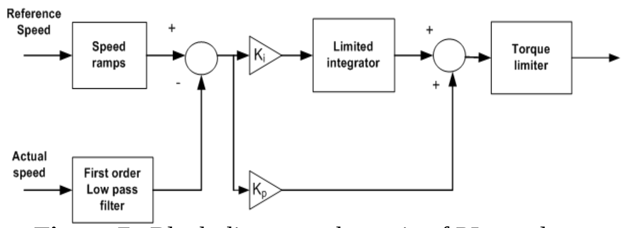


Figure 7. Block diagram schematic of PI speed controller

The Simulink realisation of the above model is shown in Figure8.

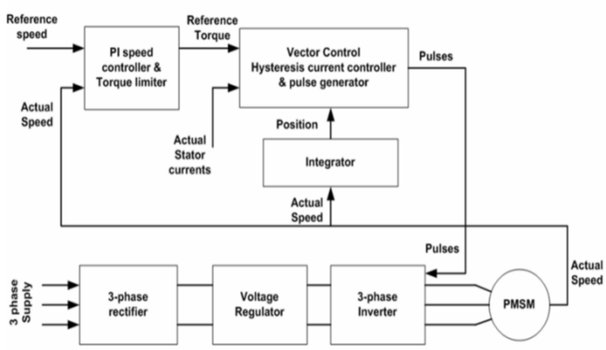


Figure 8. Block diagram schematic model of PI controller

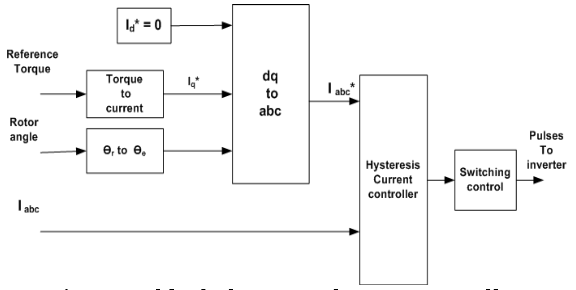


Figure 9. block diagram of vector controller

The Simulink model of the vector controller is shown in Figure 10[7]. Since vector control to be performed is below base speed the d-axis current reference (i_d*) is kept zero, whereas q-axis current reference (i_q*) is obtained from reference torque value. These two currents are then converted stator frame of reference (i_{abc}*) to compare it with actual stator currents (i_{abc}).

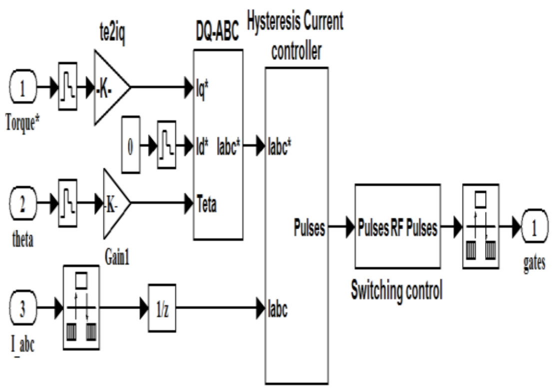


Figure 10. Simulink model of vector controller

V. PERFORMANCE ANALYSIS OF VECTOR CONTROLLED PMSM DRIVE

The system built in MATLAB for a PMSM drive system has been tested for starting, load perturbations and speed reversals. The Figure 11 shows simulation results of the quantities actual and reference speed, the stator current I_a, actual and reference torque, stator currents in rotor frame of reference I_{dq} and the DC link voltage during vector control of PMSM[12][13].

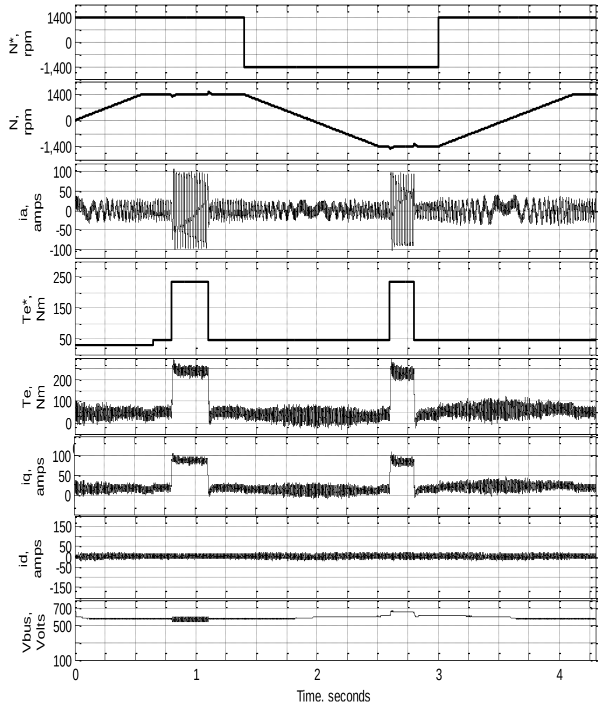
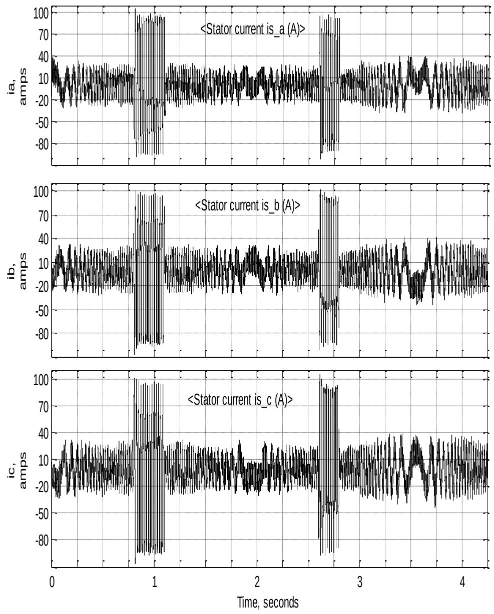


Figure 11. Simulation results of vector control of PMSM with PID speed controller.

Figure 11 simulation result of vector controlled PMSM

The rate of rise or fall of speed can be altered but the final response of the drive also depends on torque saturation settings of speed controller (PI controller) of the motor[10][11]. The torque saturation settings decide the currents flowing through the devices.

As the step of the speed (difference between previous speed at which motor is running and the reference value) is more, the settling time increases[14][16]. In other words, actual speed reaches at the desired level with delay. A short duration dip in the speed occurs at the time of increase in the load or a sharp rise in the speed is observed during decrease in the load but their duration is too small[15].



VI. CONCLUSION

The performance of developed model of PMSM drive is found to work satisfactorily with the developed PI controller in transient as well as steady state. The result shows that the wide range of speed can be can be covered in vector control. The response of vector control for PMSM drive with PI speed controller is observed to be good for load perturbation and transient condition instead of PID controller.

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