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3 Phase Synchronous Motor Speed Control System Using PID Control

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Abstract

Synchronous motor is an alternating current (AC) motor that operates with the prime mover as the initial rotation of the rotor until the rotational speed is equal to the rotational speed of the imaginary poles on the stator. In its application a 3-phase synchronous motor needs to be set in advance so that the resulting speed is stable. In this big task of Electric Motor Control, a speed experiment was carried out on a 3-phase synchronous motor using Mathlab simulation with Siemens motor specifications, namely 50 Hz, 400 V with 16kVA power and 1500 RPM rotational speed using Proportional Integral Differential (PID) control to control the speed of a 3-phase synchronous motor so that it is more stable. From the calculations that have been carried out and the PID tuning that has been carried out, the results show that the PID control can control the motor so as to produce a more stable and efficient speed in the industry.

Keywords: Synchronous, Motor, Rotation Speed, Control, Proportional Integral Differential (PID).

1. Introduction

Synchronous motor is an Alternating Current (AC) motor that operates with the prime mover as the initial turning on the rotor until the rotational speed is equal to the rotational speed of the imaginary poles on the stator. The rotation of the synchronous motor occurs due to the magnetic attraction between the imaginary poles that rotate in the stator. Synchronous motors based on their usefulness are defined as motors that get input from electric power to produce rotation [1], [2]. Synchronous motors are also useful for improving the system power factor [3]. When the excitation of the synchronous motor is set in such a way that it exceeds the nominal current, the motor will work at the leading power factor and act as a capacitor by supplying reactive power to the system [4].

In its application a 3 phase synchronous motor needs to be set in advance so that the resulting speed is stable. There are various methods that can be applied to control the speed of a 3 phase synchronous motor, one of which uses PID control. In this big task of Electric Motor Control, a speed experiment was carried out on a 3-phase synchronous motor using Matlab simulation with Siemens motor specifications, namely 50 Hz, 400 V with 16kVA power and 1500 RPM rotational speed using PID control to control the speed of the 3 phase synchronous motor so that it is more stable.

2. Research Method

The methodology that is used as a reference in the preparation of this big task report is described through a flow chart which is the steps in solving the problems that will be discussed. The flow chart of this task completion framework is shown in the following Figure 1.

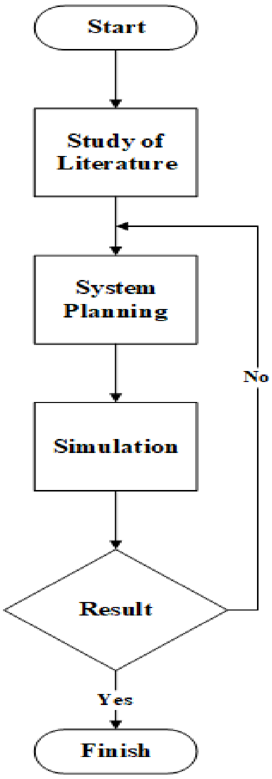

Figure 1. Methodology Flow Diagram

2.2 System Planning

2.1. Study of Literature

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A literature study is carried out which is the collection of information from journals related to the problems to be discussed. Literature study was conducted to find out the theory related to the problems that occurred as a reference material in the discussion of the big task. The following is a literature study that is used as a reference in research.

Three-phase synchronous motor is an alternating current (AC) electric motor whose rotor rotation is synchronous with the speed of the stator rotating field. This motor operates on a three-phase voltage source connected to the armature coil in the stator. In addition to getting a three-phase voltage supply, synchronous motors also get excitation current/field current from a direct current (DC) source in the field coil in the rotor. Synchronous motor in operation cannot perform self-starting. Therefore, a three-phase synchronous motor requires a prime mover to rotate the rotor to its synchronous rotational speed [5].

The construction of a synchronous motor is not much different from a three-phase induction motor, and is exactly the same as the construction of a generator, only the difference is in the direction of the power flow. In a synchronous motor there are several components as follows [6]:

a. Stator

   The stator consists of a generator body made of steel which functions to protect the inside of the generator, the terminal box and the name plate on the generator. The stator core is made of ferromagnetic material which is layered and there are grooves where the stator windings are placed.

b. Rotor

   There are two types of rotors commonly used in synchronous motor construction, namely:

   i. Cylindrical rotor: the cylindrical type rotor is usually used for motors with high speed requirements between 1500-3000 RPM and the number of poles on this type of rotor is usually only two or four.

   ii. Silent rotor: silent type rotor is usually for low speed requirements, which is around 100-150 RPM.

c. Axis

   Axis is the main component in the electric motor that acts as the shaft where the various equipment that must be used is attached.

d. Bearing

   Bearing have functions to make a smooth rotation in the electric motor.

e. Brush

   In electric motor, a copper brush that serves to connect DC current to the rotor. The position of this brush is attached to the main rotor, so there will be friction that conducts electric current in the same direction on an ongoing basis.

f. Slip ring

   Slip ring is a light metal that surrounds the shaft. The slip ring is one of the components that functions to connect the DC supply to the rotor.

Control PID is one of the controls that has been widely used in industrial applications because of its simple structure, it can be seen that the simple mathematics of PID control is as Equation (1).

$$u(t) = k_p[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d \frac{de_t}{dt}] \qquad (1)$$

Where u(t) is the control value calculated by the PID controller, Kp is the proportional coefficient, Ti is the time constant integral and Td is the time constant differential. The functions of these three elements are:

a. Proportional: Describes the deviation signal e(t) of the proportional control system. when the e(t) signal is present, the PID controller produces an immediate control effect to reduce the drift.

b. Integral: used to eliminate static errors and improve system stability.

c. Differential: Reflects changes in signal deviation, introduces a correction signal before the deviation of the signal value becomes larger and speeds up system response to reduce timing.

Therefore, designing a PID controller mainly means specifying three parameters, as well as how to configure all three PID parameters (Kp, Ki, Kd). The block diagram of the control system can be shown in Figure 2 [7].

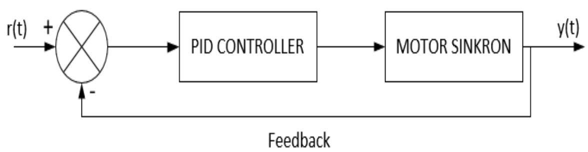

Figure 2. PID Control System

Synchronous machines have armature coils on the stator and field coils on the rotor. The armature coil is shaped the same as an induction machine, while the field coil of a synchronous machine can be in the form of a shoe pole (salient) or a pole with an even air gap (cylindrical rotor). Direct current (DC) to produce flux in the field coil is supplied to the rotor through the rings. When the armature coil is connected to a three-phase voltage source, it creates a rotating field in the stator. The rotor field pole which is given a direct current amplifier gets a pull from the stator rotating field pole so that it also rotates at the same speed (synchronous). In terms of the interaction of two magnetic fields, the coupling produced by a synchronous motor is a function of the coupling angle [8].

At zero load, the axis of the rotating field pole coincides with the axis of the field coil. Each additional load makes the motor field "lag" briefly from the stator field, in the form of a coupling angle, then rotates at the same speed again. The maximum load is reached when the coupling angle is 90o. The addition of a further load resulting in a loss of coupling and motor strength is called a loss of synchronization [9], [10], [11].

2.2 System Planning

System design used to design and find out the specification as well as the tools and materials needed to make three-phase synchronous motor speed control system.

2.3 System Testing

Simulation testing was carried out using MATLAB software. Testing are carried out to determine the performance of the system that has been designed and obtain data which will be analyzed further.

2.4 Analysis and discussion

Data analysis is done by do the calculations, then making comparisons and processing data to get some conclusions.

2.5 Conclusions

Conclusions is the result of testing, as well as the analysis that has been done. To get conclusions, analysis data was needed. Based on the analysis carried out, several results are then drawn which are refers to conclusions.

2.6 System Planning

2.6.1 System Block Diagram

The block diagram the PID method shows in Fig. 3 of a three-phase synchronous motor speed control system in Figure 3.

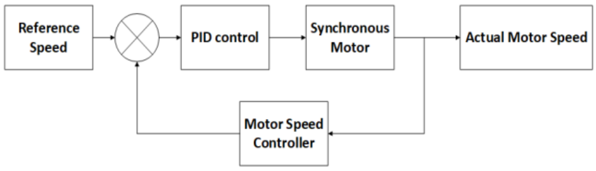

Figure 3. Block Diagram System

The input of this system is the reference speed of the synchronous motor to be controlled. The reference voltage is then regulated by the PID control which in turn regulates the speed of the synchronous motor. Then the result or the output of this system is the rotor speed which has been adjusted according to the needs with PID control.

2.6.2 Motor Spesification

The specifications of the motor used in this large task refer to the specifications of the motor in the industry, namely the Siemens 1LE10, which can be seen in the Table 1.

Table 1. Three-Phase Synchronous Motor Specifications

Parameter	Value	Unit
Rated Output	0,12 – 18,5	kW
No. of poles	2, 4, dan 6	poles
Voltage	400	V
Frequency	50	Hz
RPM	1500	rpm

2.6.3 System Circuit

There is a series of systems designed in Mathlab software. The following below is a picture of the circuit that has been made in Figure 4.

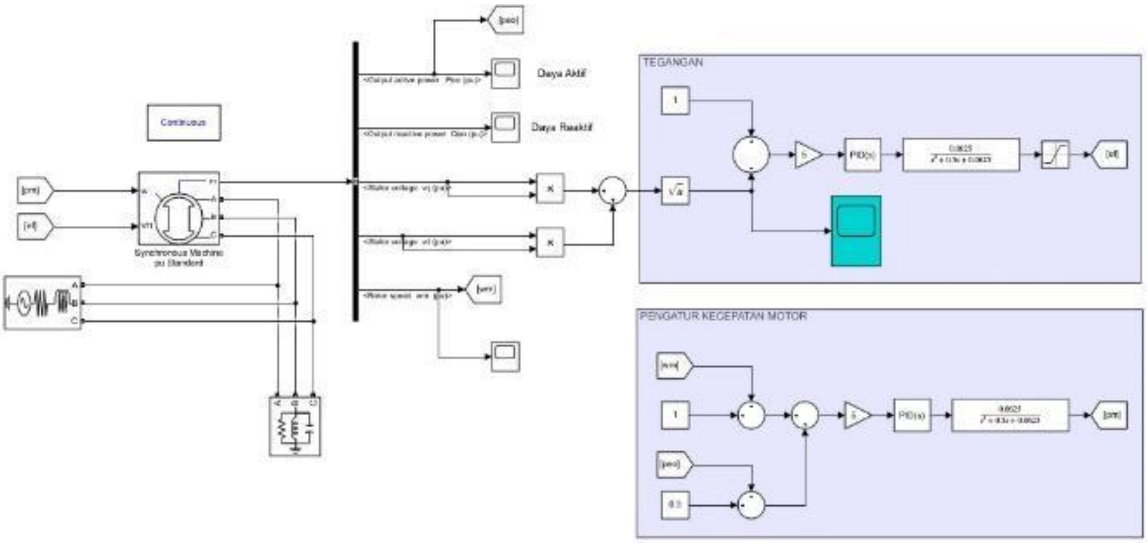

Figure 4. System Circuit

2.6.4 Calculations

As for manual calculations to find the value of Kp, Ki, and Kd on the SIMULINK PID block. Here's the math that has been calculated as Equation (2).

$$\frac{C(s)}{R(s)} = \frac{K\omega n^2}{S^2+\xi\omega n.S+\omega n^2} \quad (2)$$

Where K is gain, ξ is damping ratio, and ωn is undamped address frequency.

Start:

$$\frac{K}{S(S+0.5)}$$

ξ = 0.5

ωn = 3 rad/s

Open Loop Pole:

S = 0

S + 0.5 = 0

S = -0.5

Break in away:

$$\Sigma\frac{1}{d.z} = \Sigma\frac{1}{d.p}$$

$$0 = \frac{1}{S-(-0.5)} + \frac{1}{S-(0)}$$

$$0 = \frac{1}{S+0.5} + \frac{1}{S}$$

$$= \frac{1}{S(S+0.5)}$$

S = -0.25

Close Loop:

$$\frac{C(s)}{R(s)} = \frac{AB}{1+AB} = \frac{\frac{K}{S(S+0.5)}.1}{1+\frac{K}{S(S+0.5)}.1}$$

Start:

K = 0

$S^2 + 0.5S \neq 0$

$$\frac{K}{K+S(S+0.5)}$$

$= S^2 + 0.5S + K$

K = 0.0625

System Transfer Function in Figure 5.

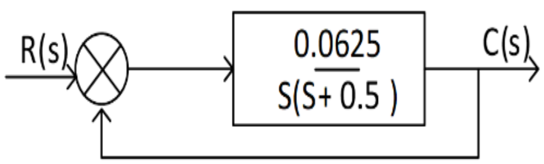

Figure 5. System Transfer Function

S = -0.5

RC Close Loop Analysis:

$$\frac{C(s)}{R(s)} = \frac{\frac{0.0625}{S(S+0.25)}}{1+\frac{0.0625}{S(S+0.5)}.1}$$

$$= \frac{0.0625}{S(S+0.5)+0.0625}$$

$$= \frac{0.0625}{S^2+0.5S+0.0625}$$

Polynomial:

$S^2 + 2\xi\omega nS + \omega n^2$

$S^2 + 0.5S + 0.0625$

New K = 5

T = 10

$$\frac{0.0625}{S(S+0.5)}$$

$$\frac{C(s)}{R(s)} = \frac{0.0625}{S^2+0.5S+0.0625}$$

$\omega n^2 = 0.0625$

$\omega n = \sqrt{0.0625}$

$\omega n = 0.25$

$0.5 = 2\xi\omega n$

$0.5 = 2\xi(0.25)$

$\frac{0.5}{0.25} = \xi$

$2 = \xi$

Determine Kp, Ki, and Kd:

$$Kp = \frac{2\xi\omega nT-1}{K} = \frac{2(2)(0.25)(10)-1}{5} = 1.8$$

$$Ki = \frac{\omega n^2 T}{K} = \frac{(0.25)^2(10)}{5} = 0.125$$

$$Kd = \omega n\sqrt{1-\xi^2} = (0.25)\sqrt{1-(2^2)}$$

$= 0.25\sqrt{1-4}$

$= 0.25(\sqrt{-3})$

$= 0.25\sqrt{3}$

$= 0.43$

3. Result and Discussion

3.1. Simulation Result Without Using PID Control

Here's a graph of RPM on a synchronous motor without using PID as a feedback controller that's shown in Figure 6.

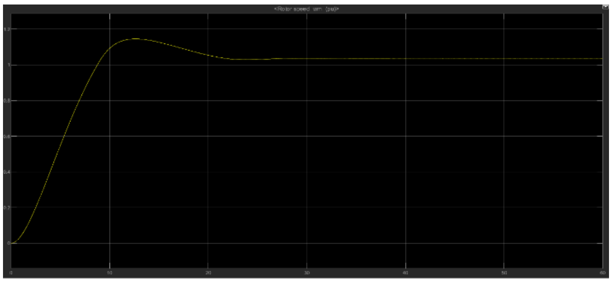

Figure 6. RPM Graph Results on Synchronous Motors Without using PID

In Figure 6, it can be seen that there is an overshoot or signal and function that exceeds the target which is quite large. The occurrence of a large enough overshoot results in a decrease in the working quality of a 3-phase synchronous motor, therefore the overshoot needs to be reduced. In addition, the graph shows that the rise time has only occurred in 10 seconds.

3.2. Simulation result with PID Control

Manual calculations were carried out to find the value of Kp, Ki, Kd for PID and obtained a value as shown in Figure 7 which was then entered into the simulation to see the resulting output.

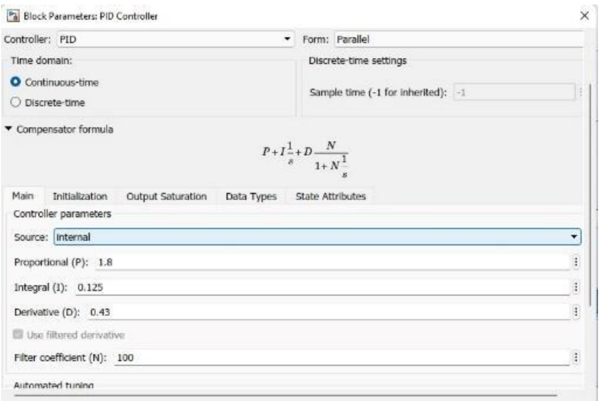

Figure 7. Input Data Kp Ki Kd According to Calculations

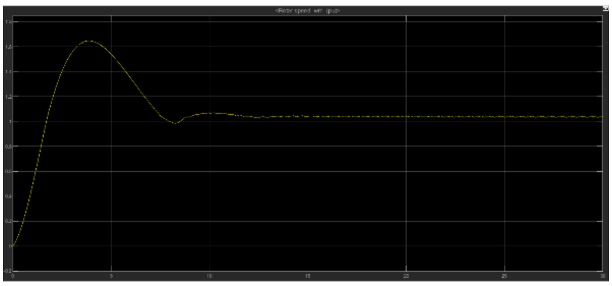

Figure 8. RPM Graph Result on Synchronous Motors using PID Calculations

Figure 8 is the resulting graph. It can be seen that the required rise time is faster, but there are still overshoots and large errors. So it is necessary to do PID tuning to refine the resulting output.

3.3. Simulation Result using PID Tuning Control

Here are the results of the PID tuning back after doing the calculations. Manual calculations are carried out to approximate the PID tuning, after the calculation, the calculation is used as a reference as the value of the new PID approximation. Figure 9 below is the result of the new PID tuning on a 3-phase synchronous motor.

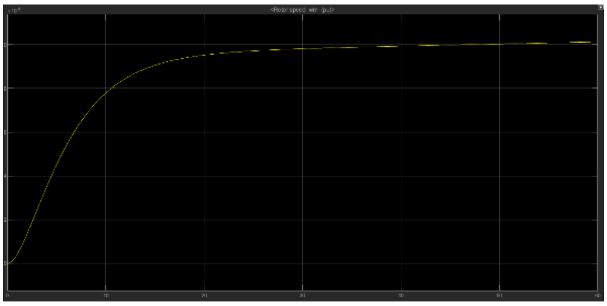

Figure 9. Graph Result using Tuning PID

The graph in figure 9 shows that the overshoot and error in the three-phase synchronous motor signal has been reduced and the resulting signal is getting better.

Conclusion

The conclusion from the simulation that has been carried out is, in three-phase motor speed control can be used to idealize the output signal from the motor speed so that the motor can work or rotate many times better than without PID control system. In applying PID to a three-phase synchronous motor, manual calculations are required which are then tested using Mathlab simulations. Furthermore, PID tuning is done again which is to get even better output results. PID control can controlled the speed of a three-phase synchronous motor.

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