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Automatic control of synchronous motor using PI controller for improving power factor

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Abstract

This paper proposes a method to improve power factor of electrical system by automatically controlling the synchronous motor. The PI control methodology is proposed for controlling the synchronous motor in order to excite rotor field with constant power factor. The PI control scheme is managed by using LabVIEW program on computer. Moreover the data acquisition card (DAQ USB-6009) is used for connection between the software and hardware. The results showed that the responses of the PI controller which tuned by Ziegler-Nichols have the ripple problem of the field current control. The problem is solved by using the Ziegler-Nichols method worked together with the trial and error method. The performance of the Ziegler-Nichols method worked together with the trial and error was highly satisfactory in order to optimize an operating point of synchronous motor control to improve power factor automatically.

Keywords: PI controller, synchronous motor, power factor

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1. Introduction

Generally an inductive load is a main problem for electrical system. Characteristically it has a low power factor, also it is requires as either the generators or distribution systems to pass reactive current with implicated power losses and excessive voltage drops [1]. In electrical power system, power factor (PF) correction has conventionally been understood in terms of adding capacitive bank to offset the effect of an inductive load. However many failures for using capacitive bank might occur for example harmonic currents, high ambient temperatures and poor ventilation. Also an initial capacitor bank is recently increased dramatically in terms of adding automatic equipment for serving effective PF correction. Theoretically a synchronous condenser can be applied for PF correction appropriately [2, 3, 4], also its maintenance cost is lower than the maintenance cost of capacitor bank. For synchronous motor, the traditional method of power factor correction has the unsuitable parameter of controller. Generally, the controller design must be in a condition of stability of system. The response may not be enough to meet demand such as the speed of access to the set point. The controller tuning is a major opportunity to increase the stability of power factor improvement. Therefore the suitable parameter of controller makes an important feature of the power factor improvement in the excitation control and can increase system inflexibility and operational reliability.

Fundamentally for operating synchronous machines is required essentially to excite synchronous rotor field. Also constant voltage control has been recommended [5] for controlling synchronous rotor field which is proposed to keep constant bus voltage. If the bus voltage is higher than the reference value, the excitation control will enforce the machine to decrease production of reactive power. On the other hand, if the bus voltage down, the control will enforce the machine to increase production of reactive power [5].

2. Materials and methods

For this paper, the PI control methodology is proposed for controlling the synchronous motor in order to excite rotor field with constant power factor.

2.1 Synchronous motor

For this paper a main purpose is alternatively an idea for using the PI controller as tool for controlling to DC excitation of synchronous motor in order to correcting power factor. Therefore the synchronous motor can be controlled for either producing or absorbing reactive power. For example Figure 1 shows corresponding reactive power versus DC rotor field current which is similar to V curve [6].

2.2 PI controller

Principally the block diagram of PI control system can be displayed as Figure 2. A PI controller consists of two parts, a proportional (P) element and an integral (I) element which connected in parallel. All of element take the error as input. Kp and Ki are the

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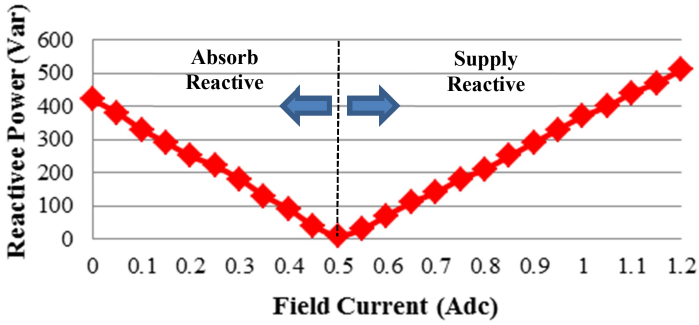

Figure 1 Variation of stator reactive power with rotor field current

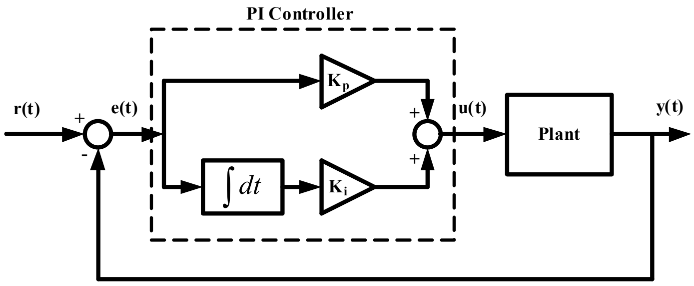

Figure 2 Block diagram of the PI control system

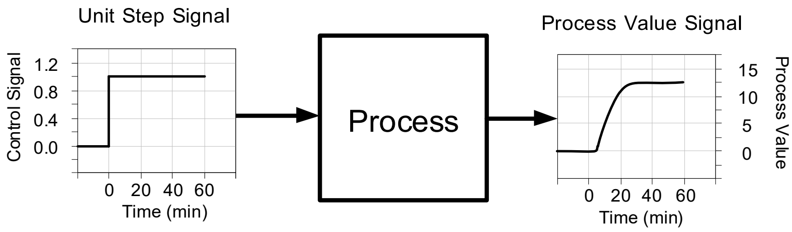

Figure 3 Block diagram of the experiment find parameters of PID controllers

expansion ratios of proportional and integral elements respectively. Also the formula of PI control can be generally shown as the equation (1) [7, 8, 9, 10]. Normally P control is proportional to the error signal which is a direct response to the error signal generated by system. The larger proportional gain is the cause of the larger changes of response to the error, and thus affects the speed of response which the controller can respond to changes in the system. And I control is highly effective at increasing the response time of a system control along with eliminating the steady-state error associated with proportional control. For adjusting the parameters of the PI controller, the Ziegler-Nichols method is recommended as simple and effective [11, 12, 13]. Usually main parameter of PI controller can be calculated for using the response of process which operates to enter the unit step input signal to the process steps shown in Figure 3. Figure 4 shows the response of the process from start to respond to the steady state in Figure 4.

$$u(t) = K_p e(t) + K_i \int e(t)dt \qquad (1)$$

where *u(t)* is control signal, *e(t)* is error of the process, *y(t)* is output signal of the controlled system and *r(t)* is reference signal.

From Figure 4 shows the response of the process which can calculate both the R (expansion rate) and L (the dead time). Also it can calculate the value of parameter R from equation (2). Then the main parameters either value or gain of P and PI control can be calculated as shown in Table 1.

$$R = \left(\frac{y1 - y0}{Control\ Signal\ Value} \right) \div \tau \qquad (2)$$

where $y1$ is the steady state value and $y0$ is the initial state value.

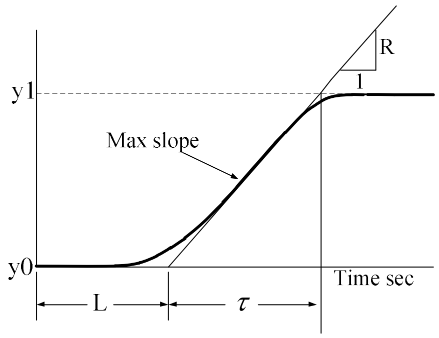

Figure 4 Reaction curve of process

Table 1 Parameters of the controller by Ziegler-Nichols method

Controller	K_p	K_i	K_d
P	1/RL	-	-
PI	0.9/RL	K_p/3.3L	-
PID	1.2/RL	K_p/2L	0.5K_pL

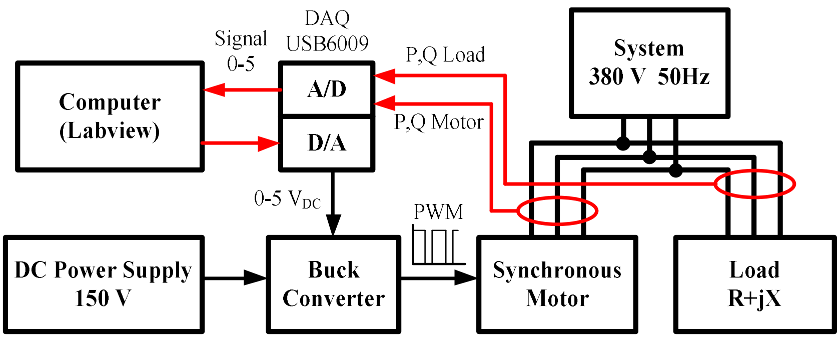

Figure 5 Block diagram of the experimental connection

Table 2 Parameters of synchronous machine

Parameters	Rate
Power	0.8 kW
Voltage (Δ/Y)	220/380 V(AC)
Current (Δ/Y)	2.6/1.5 A(AC)
Field voltage	220 V(DC)
Field current	1.6 A(DC)
Speed	1500 rpm

3. Experiment setup

In experimental work, Figure 5 shows a block diagram of the experimental connection. A synchronous motor is selected on a machine laboratory which has particular parameters as shown in Table 2. The fixed RL load is 31W+j41VAR. The output of the DC power supply can generate 150 VDC to the buck converter which also creates PWM waveform to the rotor field coil of synchronous motor [14]. Moreover the data acquisition card (DAQ USB-6009) is used for connection between the software and hardware. Technically the data acquisition card has 14 bits resolution for A/D and 12 bits resolution for D/A. Also a control program (LabVIEW) is used to simulate the PI controller [15]. Moreover for metering power factor, power meter is applied for measuring either the active power or the reactive power in both RL load and synchronous machine. Figure 6 shows this laboratory measurement scene.

Figure 6 Laboratory measurement scene

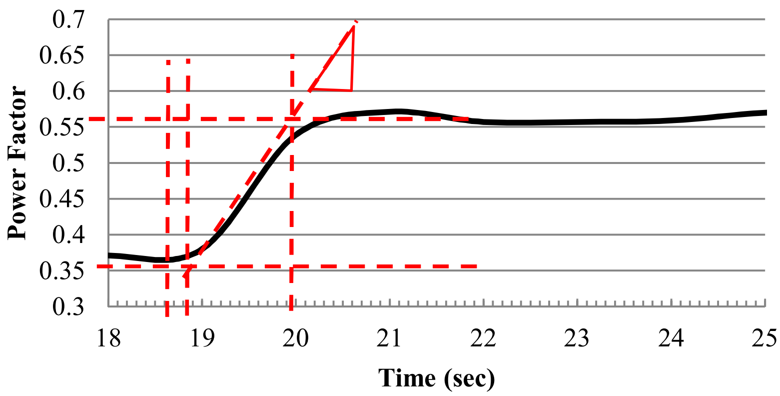

Figure 7 Response of the open loop control system

Table 3 Parameter of PI Controller

Controller	K_p	K_i
PI	0.371	0.562

4. Results and discussion

In this step, the main parameters of PI controller is estimated by the response of the process from start to respond to the steady state as shows in Figure 7. Since control signal input is 1.5, the parameters of the PI controller can show in Table 3.

Secondly for experiment control in order to controlling with the conventional PI, the synchronous motor was operated by the conventional PI controller which gets by Ziegler-Nichols method. Initially the objective power factor is fixed as 0.85. Since the synchronous motor is operated for constant power factor, it can be seen that the resultant output of the conventional PI controller is always obtained ripple at steady state response as shown in Figure 8. It can be finalised that the response to the target in quick time, however the steady state response is oscillated. Moreover the control target (0.85 PF) is unstable regularly. Typically the gain of this controller may be too high value. For solving this problem, a method of trial and error can be applied together with the original Ziegler-Nichols method in order to minimize responding ripple and oscillation. By the PI controller parameters from the Ziegler-Nichols method is the default and then adjusted by trial and error method. The first step for tuning parameters, K_p will increase and decrease at each 25% by using the gain in Table 4. It can show response of adjusting K_p in Figure 9.

In Figure 9 since K_p is reduced, the ripple of the response is lower. Moreover 25% of K_p is the best experimental. Also the next step for tuning parameters, K_i will increase and decrease at each 25% by using the gain in Table 5. It can show response of adjusting K_i in Figure 10. It can be found that reducing the K_i could increase the rise time of the response and increasing the K_i could increase the overshoot of the response by the best experimental value adjustment is K_i 100%.

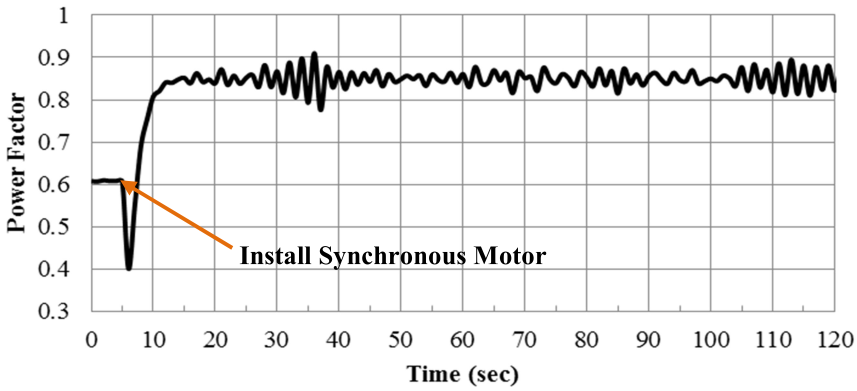

Figure 8 Results of controlling power factor by the PI controller which tuned by Ziegler-Nichols method

Table 4 Parameter of PI controller by adjusting K_p

Controller	K_p	K_i
K_p 25%	0.093	0.562
K_p 50%	0.186	0.562
K_p 75%	0.278	0.562
K_p 100%	0.371	0.562
K_p 125%	0.464	0.562
K_p 150%	0.557	0.562

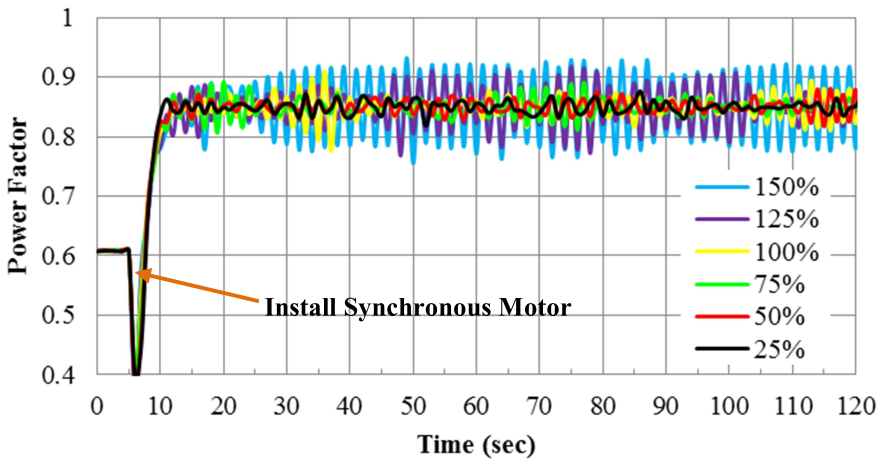

Figure 9 Results of controlling power factor by adjusting K_p

Table 5 Parameter of PI controller by adjusting K_i

Controller	K_p	K_i
K_i 25%	0.093	0.141
K_i 50%	0.093	0.281
K_i 75%	0.093	0.422
K_i 100%	0.093	0.562
K_i 125%	0.093	0.703
K_i 150%	0.093	0.843

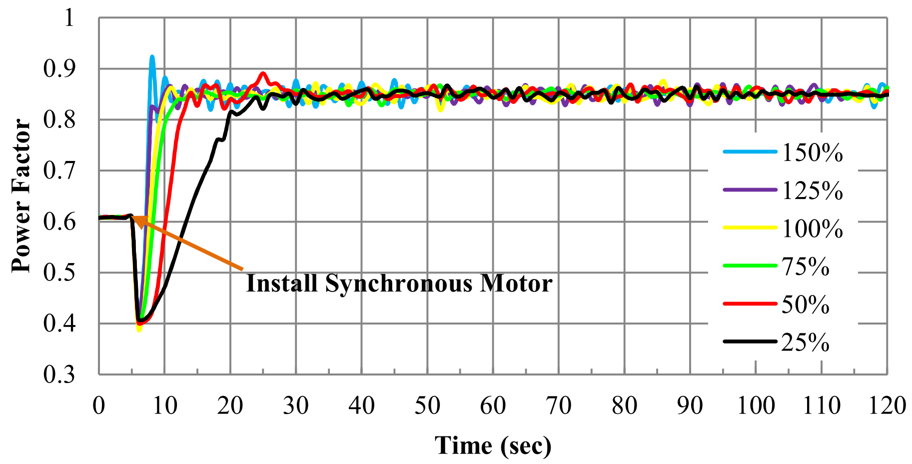

Figure 10 Results of controlling power factor by adjusting K_i

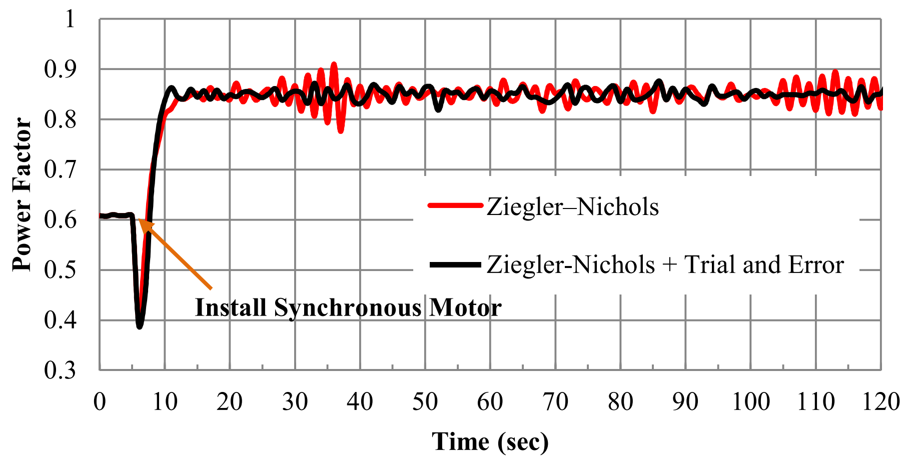

Figure 11 Comparison results of controlling power factor

Figure 11 show comparison results of the synchronous motor that was operated by the PI controller two methods for example the sole Ziegler-Nichols method and Ziegler-Nichols worked together with the trial and error method. Since constant 0.85 PF is fixed, the resultant output of the Ziegler-Nichols worked together with the trial and error method can solve ripple at steady state response. However for the PI controller from the Ziegler-Nichols worked together with the trial and error method, their oscillation occurs at steady state response.

5. Conclusions

The PI control technique, for the rotor excitation of the synchronous motor, has been presented in this paper. The results showed that the system which controlled by the PI controller that tuned by Ziegler-Nichols technique is always obtained ripple at steady state response. Moreover the control target is unstable regularly. For solving this problem, a method of trial and error can be applied together with the original Ziegler-Nichols method, the ripple problems of the excitation control is reduced remarkably. The Ziegler-Nichols combine trial and error technique is a likely method for improving the control performances of the excitation control.

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