TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.3, March 2014, pp. 1751 ~ 1757
DOI: http://dx.doi.org/10.11591/telkomnika.v12i3.4540

Design of Asynchronous Motor Soft Starting and Saving Energy Control Based on PLC

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Abstract

For Asynchronous motor starting current impact is large, efficiency of running at light load is low. An energy-saving controller was designed with the PLC (Programmable Controller) as the core. It could realize the soft start and the energy saving control of motor when motor light run. The experimental results showed that: the energy-saving controller had the characteristics of stable starting, flexible parameter adjustment, energy saving effect obviously when motor light run.

Keywords: *asynchronous motor, soft starter, PLC, energy saving running*

1. Introduction

AC asynchronous motor is one of the most important driving equipment in the production of industry and agriculture, and an important pillar of the national economy construction equipment, Which has been widely used because of its advantages of low cost, simple structure, small maintenance workload, high reliability [1-4]. But at the same time, energy consumption of motor is also main sources of the production and processing enterprises, but direct starting asynchronous motor current and mechanical impact is too large, the service life of its own and dragging equipment will have an impact, large voltage drop of the grid will affect the power grid and other equipment running, in addition, in the process of the motor's running power energy consumption directly affects the economic benefit of enterprise. Therefore, improving and optimization of start-up and operation of the motor control system have very important realistic meaning.

2. The Composition and Working Principle of the System Energy Saving Controller Based on PLC

The main circuit of electronic soft starter model generally adopts thyristor voltage regulator circuit, voltage regulator circuit is composed of six thyristors, connected to the three-phase power supply circuit of the motor in series. When the microcomputer control system of starter receives the starting instruction, then execute relevant calculation, exports the trigger pulse signal of thyristor. By controlling the thyristor conduction angle, the starter regulates output voltage according to the design pattern, controls start process of motor. When the starting process is completed, short-circuit all the thyristors using contactor, the motor directly put into the power grid, in order to avoid the thyristor unnecessarily working for a long time, also in order to reduce unnecessary power loss.

For the motor with light load and no-load running, can choose to have the soft starter is put into operation, to achieve the energy-saving motor light running, As shown in Figure 1, operation mode of the motor can be decided according to the change of power factor. The motor load rate is high, because the higher power factor($\cos\varphi$), short-circuit all the thyristor module using contactor. When the motor load rate is small (i.e. motor at light load and no-load running), because the low power factor ($\cos\varphi$), the PLC controller outputs a control signal for the bypass contactor disconnect, at the same time, outputs control corresponding voltage to the thyristor module, the thyristor module is put into operation in the larger trigger control angle, at this time, the motor running at lower voltage. When the load was increased, the power factor is also gradually increased, while increased to a certain value, the PLC controller outputs control

Received August 24, 2013; Revised September 28, 2013; Accepted October 7, 2013

sign, the thyristor module exit operation, put into the bypass contactor. The function Can been set in programming, which is when the thyristor module just put into operation, quits detection and control action of the power factor, after the soft starting process is completed, input power factor control.

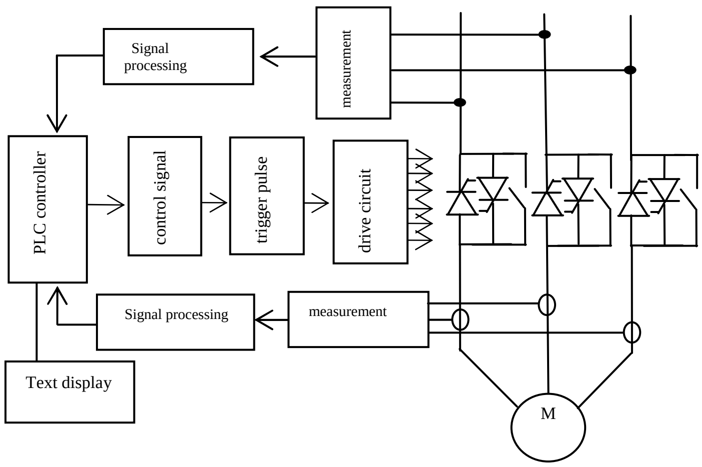

Figure 1. Principle of Control System

3. Soft Start Control of Asynchronous Motor

It is can been seen by the mechanical characteristics of AC motor [5-6], the motor starting torque is small, and about 1~2 times of the motor rated torque. It can be seen that the starting current of the electric motor is higher 5~7 times of rated current. Both inconformity, it is indicated that the motor power factor is very low when motor starts.

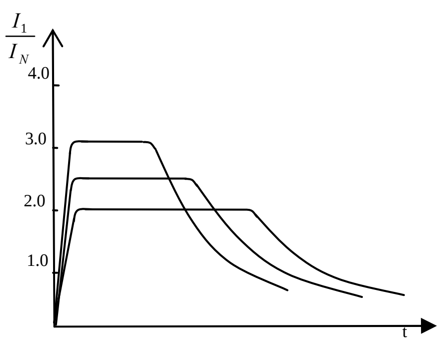

Figure 2. Asynchronous Motor Starting Process and the Current Impact

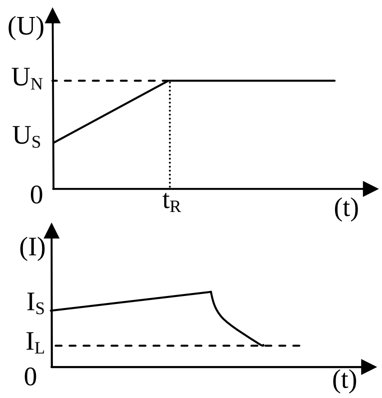

Figure 3. Voltage Slope Soft Starting Mode

This is because the electric energy consumption is concentrated in the establishment of the motor magnetic field when starting. Soft starting method can not only realize no impact and smoothly starting motor, but also to adjust the parameters of the starting process of motor according to the load characteristics, such as the limiting value, the starting time, as shown in Figure 2; in addition, the soft starter can realize many kinds of protection function. This is fundamentally solves the disadvantages of the traditional starting method [7].

The main control mode of soft starting have two categories: the first is the voltage and current type, such as the starting current, voltage ramp start; the second is the torque control, torque control, torque with such as start jumping control start. The most commonly used is the soft start by limiting current and the soft start by controlling voltage ramp.

3.1. Soft Starting by Limiting

Current-limiting soft-starting control mode is mainly used for light load starting, as shown in Figure 1, when the motor is started, the output voltage soft starter increased rapidly from 0, until the output current reaches the current limit value (Im). When (I < Im),increased voltage to the rated value, the motor speed gradually speed up.

3.2. The Soft Start Through Voltage Ramp Control

The ramp voltage start control mode for heavy load starting, as shown in Figure 3, by controlling the voltage of the motor end (i.e. voltage according to a certain slope gradually increase), starting current of the motor is limited (Far less than the full pressure start), at the same time, the motor speed is gradually increased, achieved soft start of motor.

From Figure 3 we can also see that there is static friction torque of load, so early in a given voltage, a sudden voltage or the starting voltage (about 25%~75% adjustable); Since the voltage according to a slope increased, this is called a ramp voltage.By applying a threshold voltage (less than the rated voltage) and the ramp voltage, it limit the starting current. After given ramp time t_R, reaches the rated voltage U_N. The current is limited to relatively small range, then current gradually increased according to the load torque demand until the starting process is finished, current reduced to a load current I_L. Voltage slope soft starting mode limits starting current, and provides initial starting torque, achieves the start of motor smoothly. And with the changes of the static torque, the starting voltage (U_S) can also be free to adjust. According to the size of load moment of inertia, the ramp time (t_R) can also be free to adjust.

4. Energy-saving Running of AC Asynchronous Motor

4.1. Analysis of Asynchronous Motor Energy Efficiency

The efficiency of motors is:

$$\eta = \frac{P_2}{P_1} = \frac{P_2}{P_2 + \sum p} \tag{1}$$

Where, P_1 —The input electric power (kW);

P_2 —Axis output power (kW);

η —efficiency;

$\sum P$ —The total loss when the motor is running (kW)

Use the following formula to express Total loss of three-phase asynchronous motor.

$$\sum P = P_{Cus} + P_{Fe} + P_{Cur} + P_{mech} + P_s \tag{2}$$

Where P_{Fe} —Basic iron loss (kW)

P_{Cus} —The stator copper loss (kW)

P_{Cur} —Copper loss of rotor (kW)

P_{mech} —Mechanical loss (kW)

P_s —Stray loss (kW)

It is well know that the motor efficiency is very high at rated load [8], the power factor is about 0.7~0.9, its efficiency is about 80%. But when the load decreases, the index is down, especially when the load drops to the rated load below 30%, fall even more. Because if the voltage is constant and the motor load change, the excitation current which is proportional to the voltage is basically unchanged, the reactive power(Q) which is drawed by motor from the electrical power grid is also unchanged. But the active power absorbed by the motor is decreased with the decrease of load, Copper loss is smaller (assuming rotor impedance is constant), while the iron loss is almost constant. In general, the total loss (=copper loss (active power loss) + iron loss (reactive loss)) is decreased, the reactive power loss does not fall, therefore, the power factor of the motor at no load and light load is low. In addition to the variable loss which is proportional to the load current is reduced, the efficiency of the motor is also greatly reduced.

4.2. Analysis of Light-load Energy-saving Running of Motor

For full load or overload running motor, reducing the terminal voltage will cause serious consequence, along with reduce of supply voltage, the motor flux and EMF decreases, Basic iron loss will decline. But at the same time, motor torque which is changed with the square of the voltage drops rapidly until less than the load torque, the motor can only rely on the increase of slip rated; only improve the electromagnetic torque in order to balance the load torque. At the same time, increase of angle between stator and rotor voltage Increasing the slip ratio, cause the rotor current is increased, at the same time, angle between stator and rotor voltage is increased, resulting in increase of the stator current, So that the stator and rotor copper loss increase value greatly exceeds the iron loss decrease value, the motor winding temperature rise will increase, efficiency will decrease, even will cause motor burnout accident.

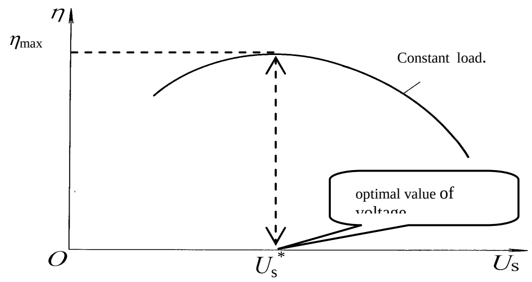

Figure 4. Efficiency Curve and Optimal Voltage

But for the motor running with light load, the situation is different, when reducing the load at the same time, decrease the motor terminal voltage, the excitation current will decrease, reactive power will decrease, thus the power factor will improve. When motor light load running, the motor of the actual slip ratio greatly less than rated value. Rotor current is small, when in the step-down running, rotor current increased numerical is restricted. On the other hand, due to the voltage reduction, the excitation current is reduced, decreasing reactive power, so that the no-load current and iron loss are reduced, in this case, the total losses of the motor can be reduced, the stator temperature rise is reduced, the running efficiency is improved. Also can improve the power factor, achieve the purpose of saving electric energy.

Thus, economic running of the motor has great relation with motor load rate and reasonable matching of working voltage.

In order to reduce the energy consumption of the motor light running, only trying to low iron loss, that is dropping the air-gap magnetic flux (ϕ_g).

$$\phi_g \infty \frac{E_g}{\omega} \tag{3}$$

By the formula 3, ϕ_g is associated with air-gap potential(Eg), namely, only by reducing the voltage applied to the stator, just can reduce the air gap flux, improving power factor, Then reduce the magnetizing current and copper consumption, but also reduce the iron loss, achieve the purpose of energy saving. But if too much lower voltage and flux, it can been seen by $T_e = K_T \phi_m I_r^{'} \cos\varphi_r$ [5], rotor current Ir’ will increase, while the stator current (Is) may increase, The decrease of iron loss will be filled by increased copper loss, efficiency is reduced. So the light-load energy-saving has an optimal voltage value, when the load torque is certain, For each output power (or load coefficient β), There must be an optimum adjustment pressure coefficient ($K_{um} = U_s^* / U_N$), The highest efficiency at the moment, as shown in Figure 4, the optimum voltage coefficient can be determined by the following formula [9].

$$K_{um} = 4\sqrt{\frac{\beta^2(\Sigma p_N - P_0)}{K \Sigma P_N}} \tag{4}$$

Where P_0 —Motor no-load power (kW)

ΣP_N —Active power loss of the motor at rated load (kW);

K —Calculation coefficient, $K = (P_0 - P_{mech}) / \Sigma P_N$;

β —Load coefficient, $\beta = P_2 / P_N$

4.3. Analysis of Energy-saving Effect of Energy-saving Running

Energy-saving running effect of reduce voltage is related with load rate, also with the load duration, pole pair of motor, motor slip ratio. This paper mainly analyzes the relationship between light load energy saving effect and load rate.

According to the literature [10], Saving active power of step-down running can be calculated as follows:

$$\Delta P = (\Sigma P_N - P_0)\beta^2(1 - 1/K_u^{\ 2}) + K \Sigma P_N(1 - K_u^2) \tag{5}$$

Saving reactive power of step-down running can be calculated as follows:

$$\Delta Q = (Q_N - Q_0)\beta^2(1 - 1/K_u^{\ 2}) + Q_0 \Sigma P_N(1 - K_u^2) \tag{6}$$

Where, Q_0 —the reactive power at no-load (kWAR)

Q_N —The reactive power at rated load (kWAR)

Saving the total equivalent active power of step-down running.

$$\Delta P^` = \Delta P + K_Q \Delta Q \tag{7}$$

Where, K_Q —reactive power economic equivalent (kW/Kwar).

The saving rate σ is:

$$\sigma = \frac{\Delta P^`}{P_1^` + \Delta P^`} \times 100\% \tag{8}$$

Where $P_1^`$ —Active power input of step-down running (kW)

At light load, reduce the motor terminal voltage can increase power factor. Power factor of light load reduce voltage running is relate with voltage regulation coefficient and load rate, may be determined by the formula 9:

$$\cos\varphi = \frac{\cos\varphi_N}{\sqrt{1 + 3(k_0 k_u)^2(1/\beta^2 - 1)/(3 - k_u)^2}} \tag{9}$$

Where, K_0 —the ratio of rated no-load current and rated current;

$\cos\varphi_N$ —Motor rated power factor

5. Energy Saving Effect Test of Light Load Reduce Voltage Running of Motor

PLC of the energy saving control system is S7-200CPU224XP, text display is TD400C(To replace the traditional keyboard and display panel),Motor is Y100L1-40 series 4 pole motor, power equal 2.2kW, Load of testing system is DC generator, Experiment debugging on the system, the experimental data are shown in Table 1.

Table 1. The Experimental Data of Different Load Rate

Load rate	With/without energy-saving running	Voltage (V)	Power (W)	Speed (r/min)	$\cos\varphi$	Efficiency η(%)	The saving rate (%)
10	without	385	335	1487	0.21	51	
	With	195	217	1485	0.42	63	35.2
15	without	384	415	1482	0.33	57	
	With	210.5	304	1478	0.48	73	26.7
25	without	384	587	1476	0.51	65	
	With	253.5	490	1475	0.65	79	20
30	without	383	712	1472	0.66	68	
	With	272.5	603	1471	0.80	81	15.3
40	without	381	1005	1472	0.69	75	
	With	295	943	1471	0.81	84	6.2
51	without	380	1167	1471	0.70	81	
	With	315	1141	1469	0.83	85	2.2

It is seen from Table 1, with the decrease of load rate, the running efficiency of motor can be improved gradually, the power factor increased more significantly. The experimental results show that, motor load rate is greater than 0.5, energy-saving effect is not obvious; When load rate is in 0.3~0.5 between, efficiency changes is little, but the power factor is improved obviously, there is a certain energy-saving effect; The load ratio is below 0.3, energy-saving effect is remarkable, motor efficiency and power factor are both improved. The energy-saving operation scheme can make the induction motor under different load showed higher efficiency, and improve the power factor.

6. Conclusion

In this paper, Energy-saving control system is designed based on programmable controller (PLC) and thyristor, control system can realize the motor soft starting and energy saving running control, it has a variety of protection. PLC measure current and voltage, calculate power factor value, and then control of AC asynchronous motor soft starting and light-load energy-saving running according to the power factor. Not only ensure smooth starting, reducing the impact to power grid, but also realize the light-load energy-saving running of AC asynchronous motor. After the test, when the motor is no-load or light load, energy-saving effect is remarkable, especially suitable for short full load or long time no-load.

Acknowledgements

This work was supported by Natural Science Foundation of Hunan province (10JJ9012), science and technology project of Hunan province (2011GK3057).

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