Design of Low Power Intelligent Compound Switch for Reactive Power Compensation Based on Single-chip ATMEGA16L

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Abstract—This paper presents a kind of low power capacitance casting-chipping compound switch for reactive power compensation (RPC) equipment based on single-chip ATMEGA16L. Difficulties exist in RPC equipment design because there are problems of big surging and slow reaction when the contactor applied alone, and there are problems of big power consumption and low capability of the anti-interference when power electronic device applied alone. The proposed RPC equipment uses the parallel connection of thyristor and magnetic latching relay as the main loop switch. The switching process based on the concerted action between the magnetic latching relay and thyristor. The thyristor works only under the condition of voltage zero-cross. When the equipment switched on, the electric current is undertaken by the magnetic latching relay alone. This equipment has the advantages of low surging current, low power consumption, strong capability of anti-interference to harmonic and quick reaction of compensation. It can successfully achieve in the trouble shooting, trouble removal and trouble indicating. In the tests of switching 30Kvar capacitance, the surging current was 1.1 times of the peak of stable current. Good performance of this equipment is shown in the volume production and the application.

Keywords: Reactive power compensation; Compound switch; Thyristor; Magnetic latching relay; ATMEGA16L

I. INTRODUCTION

With the development of modern industry, many shock loading appeared on the worksites. The shock loading will cause many problems such as voltage flickering of power grids, network loss, reduction of power factor, and so on. Lack of effective measure will affect not only the secure and economical operation of the electrical power system, but also the proper operation of the electrical equipment and it will damage the equipment under serious condition. The technique of RPC is an effective way to solve this problem. In China, three methods of capacitor switching are used in RPC: (1) Common contactor. The most serious problem of it is that it causes high surging current, and it has other drawbacks such as generating spark at the touch point, ruining the contactor, shortening the operational lifespan of the capacitor, affecting the proper operation of other electrical devices by the interference of power grid impulse, and so on. (2) Special contactor with pre-cast resistance. This kind of contactor has bigger size, and it still don’t solve the problem of high surging current and it is easy to be damaged as common contactor. Moreover, the phenomenon of resistance damaged by heat occurs frequently. (3) Thyristor solid-state relay. It could realize zero-cross switching and it is a kind of desirable device for capacitance’s casting-chipping. But it still has some problems, for example, thyristor will affect the proper switching of the capacitance due to the interference caused by harmonic in power network and affect the proper operation of SSR due to the temperature rise caused by huge break-over power consumption.

In recent years, many researches indicate that compound switch is an effective solution for capacitance switching. The general approach is to use the parallel connection of thyristor and magnetic latching relay to realize the capacitance switching. Compound switch have the advantages of thyristor zero-cross switching, zero power consumption while relay closed, and it is easy to miniaturize and long range centralized control. Generally, compound switch can be divided into single-phase compensation and three-phase compensation, which have the similar principle.

This paper presents a kind of single-phase compensation compound switch based on single-chip ATMEGA16L. The paper is organized as follows. In section II, the power consumption of the reactive power compensation switch is analyzed in detail. In section III, the overall design of the circuit is given out. In section IV, low power consumption design is given out. In section V, the design of software flow is given out. The results and concluding remarks are discussed in section VI.

II. POWER CONSUMPTION ANALYSIS OF REACTIVE POWER COMPENSATION Switch

Generally, power consumption of switches can be divided into main circuit consumption and control circuit consumption. Because of the difference between ON-OFF states, the power consumption should be discussed separately. In this part, we will analyze the switch
power consumption of different kinds of switches with 30Kvar capacitance. Every phase break-over current is 45A, and it is zero when it is cut-off. Every mechanical touch-point resistance is 0.8Ω (ignoring the affection of temperature variation to resistance), break-over voltage drop of thyristor is 1.0V.

(1) Common contactor. Power consumption of the main circuit on cut-off state is zero as well as the control circuit. Thus, the total consumption on cut-off state is zero. When it turns to break-over state, the power consumption of three contactors in the main circuit is about 4.8W, consumption of the control coil is 15W in general. Therefore, the total power consumption on break-over state is about 20W.

(2) Special contactor with pre-cast resistance. Contactor power consumption of the main circuit on cut-off state is zero, pre-cast resistance power consumption is 1W for per phase, and control power consumption is zero. Thus, the total power consumption on cut-off state is 3W. On break-over state, the power consumption of three contactors in the main circuit is about 4.8W, the power consumption of the pre-cast resistance goes down to zero and the power consumption of the control coil is 15W in general. Therefore, the total power consumption on break-over state is about 20W.

(3) Thyristor solid-state relay. The thyristor power consumption of the main circuit on cut-off state reaches to zero, the resistance power consumption of buffer circuit is 1W for per phase, and the power consumption of the control circuit is about 2W. Therefore, the total power consumption on cut-off state is 5W. On break-over state, every thyristor is with voltage drop 1.0V, 45A electric current, and 45W power consumption. The RPC of buffer circuit goes to zero, Zero power consumption of control coil and the power consumption of the control circuit is 2W. Therefore, the total power consumption of the break-over state is about 137W.

(4) Compound switch. On cut-off state, the contactor power consumption is zero. The RPC of the thyristor buffer circuit is 1W for per phase and the power consumption of the control circuit is about 2W. Therefore, the total power consumption on cut-off state is 5W. On break-over state, current flow pass the contactors of the relay and the power consumption of the three contactors is 4.8W. Because no current flows pass the thyristor, so its power consumption is zero. The resistance power consumption of the buffer circuit goes down to zero, zero power consumption of control coil and the power consumption of the control circuit is 2W. Therefore, the total power consumption on break-over state is about 7W.

III. OVERALL DESIGN OF THE CIRCUIT

A. The block diagram of circuit

As shown in Fig.1, the circuit used the single-chip ATMEGA16L produced by Atmel. ATMEGA16L is a high-performance, 8-bit microcontroller with advanced RISC architecture, 44-lead TQFP, 32 programmable I/O lines and 16K program store. It has many advantages, such as wide-range voltage working ability, anti-interference, speed reaction, low-power consumption, high drive, stable performance, and so on. In this system, it is responsible for voltage detection, phase sequence detection, zero-cross detection, operational instructions and the drive control of the magnetic latching relay and thyristor.

![Fig.1. The block diagram of circuit](image)

The main circuit consists of two parts, one of them controls trigger thyristor, another controls the ON-OFF of the magnetic latching relay.

B. Control principle

When single-chip receives the casting-chipping signal, the signal will pass through contactor voltage zero-cross detection. It will be isolated and amplified, and make the thyristor break-over at the zero-cross point. Then the magnetic latching relay will be closed by intelligent decision of the program to realize correct switching of the capacitance. After that, most current will pass through the contactor of the magnetic latching relay and achieve in zero power consumption (the loss of the thyristor account to from several dozens to over a hundred watt when it break-over). When remove the signal, the single-chip will send a trigger pulse to thyristor and make it a break-over, then cut off the layer and stop the pulse sending to make sure the thyristor will cut off automatically at current zero-cross.

IV. LOW POWER CONSUMPTION DESIGN

A. Main circuit of compound switch

The main circuit of compound switch contains: capacitance (group) C, the absorbing circuit that composed by R0 and C0 to protect SCR, the switching contactor of the magnetic latching relay (S1), pulse isolation transformer (T1). SCR will be break-over when pulse trigger pass though T1. Because thyristor is break-over
only at the switching moment (several dozens of milliseconds) and capacitance is cut-off after casting-chipping. Because the power consumption is very slow, extra radiator is not needed. After capacitance is cast, there is no current pass through the coil of the magnetic latching relay and the power consumption only exists at the contactor resistance, which is about 1W power consumption for per contactor. When capacitance is chipped, the power consumption of the magnetic latching relay is zero.

B. Single-chip controller selection

ATMEGA16L is one of AVR® 8-bit Microcontroller with some characteristics as high-performance, low-power, and so on. It could work properly at the voltage range from 2.7～6.0V, the current under working condition is 1.5mA. MCU could work at the idle mode and power-down mode. In the power-down mode, the working current without watchdog circuit could reach to 1uA. In addition, the I/O buffers of ATMEGA16L could absorb 20mA current with powerful drive ability.

Due to its advantages of low working voltage, low power consumption, rich peripheral interfaces, rich pins and its powerful drive ability, fast working speed and stable performance, now ATMEGA16L is widely used in many fields, such as instrument, meter industries, industrial control, and so on.

C. Drive circuit of magnetic latching relay

Shown as Fig.2, the drive circuit of magnetic latching relay mainly consists of triodes Q1, Q2 and the coil of magnetic latching relay. The condition of the contactor could be changed only when a reverse voltage pulse is put on the coil due to the existence of the strong magnetic force in magnetic latching relay. A new type of magnetic latching relay with center tap is used in our circuit. The coil center tap of the magnetic latching relay connects with +12V power supply and the other two ports of the coil connect with the control switch respectively.

When Q1 is single-pulse break-over and Q2 is cut-off, the condition of the relay is closed (open); When Q2 is single-pulse break-over and Q1 is cut-off, the condition of the relay is open (closed). C1 could provide enough power to prevent the magnetic latching relay affecting the power resource. It only needs several decades of milliseconds of pulse current on the coil to make the contactor close or open and needs no current to maintain the situation. Therefore, it could reduce the power consumption of the system effectively in the application.

V. Design of software flow

The main progresses of the software flow are introduced in following:

(1) Casting-chipping—when circuit receive the control signal from the power factor controller, the single-chip controller will send out pulse at the moment of SCR voltage zero-cross, to make the SCR break through, plug the capacitance in the power network stably and maintain the situation. Next, the single-chip controller will send out control signal of magnetic latching relay and make it break-over. At that time, the resistance value is very small (generally under 1mΩ), and the most current of the main circuit could be separated to the relay contactor by thyristor, to make it working with the thyristor switch in the parallel connection. Finally, the thyristor trigger signal is removed, and the whole current is undertaken by the magnetic latching relay alone and the circuit work stably.

(2) Cut-off—when CPU receive the capacitance cutting signal, it will send out thyristor trigger pulse at first, a part of the separated current will pass through the thyristor and make the SCR working with magnetic latching relay in the parallel connection. Then the magnetic latching relay will be cut off and the thyristor undertake the connection current of the capacitance and the power network in short time. Finally, the trigger signal of the thyristor is cut off and the thyristor will be cut off automatically at the moment of current zero-cross.

The sequential waveform is shown in Fig.3. Form the Fig.3, we can see that: (1) The time of the SCR trigger time is bigger than ΔT. (2) The voltage of the compound switch S1 reduced from 1V to zero because of the relay break through. (3) No matter what condition the magnetic latching relay is in (On or OFF), SCR is always in the condition of pulse trigger break-over. So, the main contactor of S1 doesn’t generate the electric arc, the operational lifespan of the magnetic latching relay and the capacitance is prolonged. Meanwhile, it eliminates the arc disturbance in the circuit and makes the whole system more safe and reliable.

The main program will initialize the condition of the voltage, phase sequence and the switch, set the flag bit, then determine if there is casting-chipping signal or not and do some operate by the different states. Fault will be removed automatically when it turn out, and if it can not be removed automatically, the switch will not cast, then indicate the trouble, which build up a close-loop control.
VI. RESULT ANALYSIS AND CONCLUSION

A. Result analysis

After repeated experiments and improvements and one month test on the worksite, the experimental device was examined by the Hangzhou electric power industrial compensate devices’ performance test center. Its appearance, essential security, affection of the power resource, protect function, power consumption, high and low temperature, temperature rise, casting-chipping function are all satisfied the requirements and the standards. In the test, surging current got further effective control through many times debugs of the zero-cross detection. Surging current of the three-phase separate compensation controller cannot be observed and the surging current of the three-phase joint compensation controller was 1.1-1.2 times the peak of stable current. The observation of the oscilloscope is shown in Fig.4.

B. Conclusion

This paper introduced a design of low power intelligent compound switch for reactive power compensation based on single-chip ATMEGA16L, including the control principle, the circuit and the software flow. The device could automatically realize the zero-cross switching of the thyristor, and the current will only pass through the contactor of the magnetic latching relay to improve the anti-interference ability of the device. And its small contactor resistance volume and huge contactor capacity reduce the total power consumption dramatically. The device has many advantages such as low surging current, low power consumption, strong anti-interference ability, good performance, and so on. At present, type 10-40Kvar of this kind of device are already put into mass production and have good performance in many places such as low voltage electric substation, power station, power house of small and medium-sized enterprises.

REFERENCES
