A New Composite Switch for Low Voltage Equipment Control

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Abstract—Many electrical devices need fast and frequent on and off control which require reliable and long life switches instead of traditional AC contactors, solid state relay. A new composite switch design is presented for the equipments with multiple circuits should be controlled. Based on thermal analysis of bidirectional triode thyristor and magnetic latching relay simulation, the cooling fins could be removed and up to 50 channels could be integrated and encapsulated in a package. The new design also provide RS-232, Modbus and direct link ports for external control which could cut down the cost and simplify the control circuit complexity. The new composite switch is suitable for reactive power compensation and smart distribution network control.

Keywords—Composite Switch; Magnetic-latching Relay; Bidirectional Triode Thyristor; Multiple Circuit Control

I. INTRODUCTION

In order to cut down line-loss and improve power factor, auto reactive power compensation devices are usually equipped on the low voltage side in a 10kV substation, low voltage capacitor unit is one of the best choice. Besides the control unit, switches is the most important element which determines the reliability and lifetime of the compensation equipment.

![Switches used in reactive power compensation](image)

Fig. 1 Switches used in reactive power compensation

Traditionally, AC contactor is widely used as the control actuator to switch-in and cut-off the capacitors (as shown in Fig.1(a)). However, because the phase angle at which AC contactor actuating could not be regulated precisely, electric arc sometimes is produced, which burns the contact head and destroys the contactor. Solid state relay (SSR) is a non contact switch that can solve this problem, however, it needs very big cooling fins and cooling fans to protect SSR from over heat. On the other side, SSR consumes energy and produces harmonic current during the whole operation period[1~3].

In recent years, a composite switch provides a better choice in which a relay connect with a SCR in parallel (as shown in Fig.1(b)). It is endowed both the advantages of large current contractors and power electronic elements. The composite switch could reduce or eliminate the electric arc produced by the switch operation during switch-in and cut-off process with the aid of power electronics. After the relay finishes the operation, power electronics will be shutoff so that no power and no harmonics are produced during the steady operation period. By way of searching voltage zero cross point, in accordance with relay control, the lifetime of switch could be lengthen greatly.

![Integrated Composite Switches used in reactive power compensation](image)

Fig. 2 Integrated Composite Switches used in reactive power compensation

In many conditions, reactive power compensation, for example, there are up to tens of capacitor sets should be controlled in a single compensation panel, so tens of composite switch must be installed in a it to satisfy the need of capacitor control. Obviously, this is of high cost and
engineering complexity. A integrated type of the composite switch is proposed in which one the control unit, communication port, current and voltage sensing, signal conditioning circuit, etc., are shared by all composite switches. These can not only reduce the cost, but also reduce the space needed for switch installation.

II. MAIN ELEMENTS SELECTION

There are three major kinds of elements used in the composite switch which are bidirectional triode thyristor, magnetic latching relay and control unit. Their selection and control are of great importance in the integrated composite switch design.

A. Bidirectional Triode Thyristor

Bidirectional triode thyristor is also named as triac which approximately equivalent to two silicon-controlled rectifiers joined in inverse parallel and with their gates connected together. Bidirectional triode thyristor can conduct current in either direction when it is triggered and thus doesn't have polarity. It can be triggered by a positive or a negative voltage signal. Once triggered, the component could conduct continuously until the current through it drops below a certain threshold value, the holding current, such as at the end of a half-cycle of alternating current. This makes the triac a very convenient component for AC control.

For practical application of a composite switch, the rated capacity of a bidirectional triode thyristor should be roughly equal to that of a magnetic latching relay. For low voltage compensation capacitors connected in ' Δ ' way, its line to line voltage is 400V, and its rated current is about 50A. So BTA100, 1200V triac is selected considering the security margin which could meet the need about 25kVA load.

B. Magnetic latching Relay

Magnetic latching relay is a kind of switch with a permanent magnet steel inside. Once a magnetic latching relay transit into on or off state, no maintaining power is needed to keep it with the help of the permanent magnet. So a pulse signal is used instead of a continuously voltage signal. Some magnetic latching relays have two windings-set winding and reset winding which are used to turn the contacts into on/off steady states separately. But for large capacity devices, magnetic latching relay of single winding is preferred[4].

A control circuit is given as shown in Fig. 3 in which only \( n+1 \) lines is needed to carry out \( n \) switches on and off control.

For example, if the \( i \)-th circuit is to be turned on, the \( i \)-th contact of relay \( Ci \) is closed at first and one lead of the winding of \( i \)-th magnetic latching relay \( Ri \) is connected to ground line GND, then \( Ps \) is closed so that the other lead of the winding \( Ri \) is connected to the positive voltage source. Once the winding of relay \( Ri \) get the energy, its contact \( Rmi \) will be closed and switch in the corresponding load.

In the analysis, GRT508B-80A, which is widely used in intelligent smart meters, is chosen. In a composite switch, because a triac is always connected in parallel with it during the operation period, its actual allowable current should be much larger than the rated value.

C. Control Unit

Control block diagram is shown above in Fig4. For a 15 circuits control, there are about 75 I/O pins needed for a MCU, including 15 ports for triggering triacs, 30 ports for turning on/off magnetic switches, 15 ports for monitoring the current of each circuits and 3 ports for monitoring voltage.

TMS320LF2407A is a member of the TMS320C24x generation of digital signal processor (DSP) controller that offers the enhanced architectural design for low-cost, low-power, and high-performance processing capabilities. Several advanced peripherals, optimized for motion control applications, have been integrated to provide a true single-chip DSP controller.

DSP LF2407A has 144 pins in which 41 pins are digital I/O. By way of expansion and multiplexing, LF2407 could meet the need of this application.

III. THERMAL ANALYSIS OF TRIAC

Bidirectional triode thyristor is the most important component in the device and is also the most vulnerable one to current and voltage surge. Without cooling fins, the heat produced during the turn on/off process must be well controlled very carefully so that the temperature will not exceeds the permitted 125℃.

In the research, triac only works during the turn-on and turn-off process to protect the magnetic relay from burning down which occupy only very short time. It can be assumed that the heat produced in these periods is totally radiated out completely and does not affect the next cycle.
A. Simulation Model

A simulation model is built on Cyber platform which mainly focuses on the thermal analysis of the bidirectional triode thyristor. The thermal resistor and thermal capacitance are set according to the datasheet of the triac and considered in function below.

\[ temp_j = temp + pwrd \times rth_{eff} \]  

(1)

where \( temp \) is the circumstance temperature, \( pwrd \) is the triac power loss, \( temp_j \) is the temperature and \( rth_{eff} \) is the thermal resistance which is set as 0.00587 J/℃.

In the model, a Triac is connected in parallel with a magnetic latching relay MLS as shown in Fig.5. The current through the triac and the voltage over it are multiplied to produce the power which indicates the power loss in the triac, and its temperature. The signal for MLS control is created from two separate ones by logic gate circuits.

B. Results Analysis of Turn-on Process

In the very beginning, both the triac and magnetic latching relay are at off (open) state. Firstly, triac is turned on. 10ms later, the winding of magnetic latching relay is switched in and its main contacts are closed. After 20ms, when magnetic latching relay (its contacts) is stable, triac is then turned off. During the 30ms, power loss is produced and the temperature rises from environmental value to 119℃. Even it is very hot, it still below the permitted temperature.

C. Results Analysis of Turn-off Process

When the magnetic latching relay should be turned off, the triac should be turned on at first. After the triac is triggered for 5ms, the magnetic latching relay is turned off. 20ms later, when magnetic latching relay (its contacts) is stable, triac can be turned off. During the 25ms, the temperature of triac rises from environmental value to 252.3℃ which much higher than its permitted temperature.

For the off time of triac is very long, its temperature will return to the environmental.

IV. CONTROL SYSTEM DESIGN

The kernel part of composite switch design is to coordinate the control of triac and magnetic switch, especially there are up to 30 circuits should be controlled precisely.

A. Triac Control

In theory, the voltage between the source and the capacitor at the moment should be equal so as to minimize the impact to the triacs[5,6]. Assume that the bus voltage is

\[ U_s (t) = U_m \sin (\omega t + \alpha) \]  

(2)

and the residual voltage over the capacitor is \( U_{co} \), neglecting the voltage drop of the triac during turning on, by means of Laplace transform, then there is

\[ U (s) = \frac{[LS + 1/C_s]}{s} I (s) + U_{co}/s \]  

(3)
In which U(s) and I(s) are the terminal voltage and branch current after the transformation. According to equation (3), α should be zero in order to eliminate the oscillation during the triac turning on period.

In many cases, it is quite difficult to make sure that the voltage over the capacitor equals to peak value of power source voltage. The voltage between the two main terminal of triac is measured to show if it is the right time to turn on the triac that no serious impact will appear.

B. Magnetic-latching Relay Control

As illustrated in Fig.3 above, the magnetic latching relay is turned on or off by connect it winding to positive or negative source. At the starting point of the composite switch, the initial state of I/Os are not definite which will lead to the contacts Ps and Pn close at the same time. A logic IC BL8023 is adopted to drive the magnetic latching relay which solves the problem[7].

![Fig.8 BL8023 Structure for Magnetic latching Relay Control](image)

C. Zero-crossing Point Detection

The triac should be turned on and off around voltage zero crossing point to reduce the voltage stress dV/dt. The heat produced by triac can be reduced as well.

![Fig.9 Zero-crossing Detection Using LM393](image)

A voltage zero-crossing detection circuit is illustrated in Fig.9, in which LM393 is comparator. When the voltage of input signal is higher than the set threshold, LM393 outputs high level and send a interrupt signal to MCU through optoelectronic isolator TP521. A small threshold is helpful in reducing oscillation risk and get a stable interrupt signal.

D. Other Circuits

For saving the I/O ports, a shifting register 74LS164 is used in coordination with data state latch 74LS373 that consist a switch-in and switch-off module. Up to 72 sets capacitors connected in single phase or 24 sets connected in three phase could be controlled. At the control of Clock signal, the state word is moved into register through series data bus and then latch out in parallel[8].

X5045 is powerful IC that can monitor the source and also has power-on reset, power-off salvage, watch-dog functions. Keyboard has four keys that used for setting, checking parameters, such as the threshold of current and voltage, capacity of a capacitor, clock, electricity, etc. MAX202 is a dual channel communication IC used for communicating with its upper control unit.

V. CONCLUSIONS

By means of integrating tens of composite switch in one package, their sensing circuits, controller units, signal conditioning circuits and communication port could be simplified greatly and the cost is cut down. Furthermore, The design accelerates the response of mechanical switches and eliminates the oscillation and surging at the same time. The lifetime of capacitors is lengthen significantly.

The integrated composite switch can also be used as the smart switch in the distribution network.

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