MODERN OPTOELECTRONIC DEVICES

FOR POWER ELECTRONICS

S. Voloshin, S. Arhipov

Continue*.

Stability of the thyristor optorelays to dU/dt and dI/dt. The quick voltage increasing in output of close relay may be due to the following factors:

- Supplying to voltage to the load circuit in a phase which close to 90°;
- Appearing of transients in load circuit;
- Occurrence of switching voltage surges because of phase shift between current and voltage at current value lower than thyristor holding current in electrical circuit with inductive load.

Surges can lead to unauthorized opening of thyristor relay outputs at increasing dU/dt of some critical value. For unsymmetrical thyristors stability to dU/dt is characterized of a critical rate of voltage rise in close state $(dU/dt)_{cr}$, or static dU/dt. Appearing of static dU/dt due to the presence of stray capacitance anode-managing electrode, and current through this capacitance is proportional to dU/dt and can be exceeded current unlocking thyristor.

Triac together with $(dU/dt)_{kp}$ is characterized of a critical rate of change of switching voltage $(dU/dt)_{sw}$. Action $(dU/dt)_{sw}$ due to the presence of an electric residue in the triac material after previous switching. This charge at sufficiently quick increasing of reverse voltage facilitates the switching of the triac in opposite direction at absence of control signal. Thus, controlling is lost. The value of electric residue depends on peak current before switching and current zero-crossing rate $(dI/dt)_{sw}$. At small values of these quantities stability of triacs increase and $(dU/dt)_{cr}$ starts to be determined that is extremely higher than $(dU/dt)_{sw}$.

Self-starting of a relay because of random surges in load circuit may not be influenced any negative impact on some types of loads (for example, heaters), since during half-power frequency relay is switched off. However for such loads as electromotor valve winding, self-starting shutdown is unacceptable. Moreover unauthorized thyristor switch can be lead to disastrous effects in reverse systems (interphase closure) and in systems with capabilities in loads (supercurrents of condensers' charges). Also it's impossible to admit of loss of controlling and on inductive loads too.

To eliminate an unauthorized optorelay switch on is used some steps, main step of them is to shunt the relay output with a damping circuit RC. Herewith increasing of C leads to decrease of dU/dt, and R serves to current limit at discharging of a capacitor and decreasing of emission transition. Usually for specific load values C and R find experimentally starting from values that is counted using approximate methods.

Let's look at one of the methods – resonant one. With inductive load L_n resonant circuit frequency L_n must meet condition

$f_p < \dfrac{(dU/dt)_{cr}}{2pU}$, where U – line surge.

Since $f_p = \dfrac{1}{2pLC}$ then $C > \dfrac{1}{(2p\mathrm{fp})^2 L_n}$.

If we take cosj as a power factor of the load, then surge value will be $U=U_a$ *sinj, where U_a – the amplitude of the voltage in the line.

Hereof: $C > \frac{U_a^{\,2}\sin^2 j}{(dU/dt)^2{}_{cr}L_n}$.

For a chain with the specified values of voltage and current U_n and I_n we have

$X_L = \frac{U_N}{I_N}\sin j$ and $X_L = 2pfL$,

then $L = \frac{U_H \sin j}{2pfI_H}$ and $C > \frac{4pfU_N I_N}{(dU/dt)^2{}_{cr}}\sin j$.

For assessing of the value R will view a ratio for about 30-% emission transition (attenuation constant 0.5). In nominal values terms $(dU/dt)_{cr}$ will get

$$R = \frac{(dU/dt)_{cr}}{2pfI_N}.$$

There is one more method to increase relay stability to speed surges – insertion in the load chain of a delay reactor which is an inductance element in core with high permeability and square hysteresis loop. At operating load currents the reactor is in saturation mode, that's it does not affect the current. At decreasing of current the reactor "is restored" contributed to the circuit high inductivity. It slows down the speed of current change and, in particular, holds the repeated application of reverse voltage helping the thyristor locking. It should be noted that decreasing the speed of current increasing on initial stage of thyristor switch on, the reactor contributes to the uniform distribution of current density the crystal protecting the thyristor of devastating impact of high values dI/dt that lead to local heating up the crystal fields above allowable values because of high current density.

Specialty of operation for inductive load. DC relay operation for inductive load with loss of relay management because of changing of switching voltage dU/dt is accompanied more types of effects. So, at switching off the relay (at load circuit breaking) danger is load self-inductance voltage. Besides protection methods of failure of the relay because of overvoltage that shown in section 3*, it's possible to protect by addition a unipolar relay to half bridge scheme. When switching the legs of bridges to the diodes VD1 and VD2, external ones, with quick recovery or built into the VT1 and VT2, and at switching VT1 load current is closed with a loop that created VD2 and power supply, etc.

Fig. 1 Half-bridge protection scheme at work for inductive load.

Inductive load shunting with a diode is allowable only at not big energy values W_L saved in load. It's defined by the formula

$$W_L = \frac{L_N * I_N^{\ 2}}{2}$$

and limited by permissible pulse power the used diode.

Big increase of allowable value W_L can get at switching the diode and resistor to chain (Fig. 2). In this case should be satisfied conditions

$$R < \frac{U_{relay} - E}{I_N} \qquad \text{and} \qquad P_R > \frac{L_N * I_N^{\ 2}}{2} * f_{com},$$

Where U_{RELAY} - maximum allowable voltage at the relay, E – voltage load, I_N – load current, P_R – resistor power, f_{COMM} – average switching frequency relay. Time constant of current decay in load is equal to L_N/R.

Self-inductance voltage that appear at switching off don't affect the operation of thyristor relays because load opening circuit is when load current close to zero. For relay such type there is danger of current overload for the following reasons:

- asymmetry of switching output thyristors (triacs) that leads to appearance to a current constant and saturation of the core and hence to appearance of currents.
- core saturation at relay switching in a intersection of the voltage point.

In its turn the switch asymmetry can be a result of:

- asymmetry of conductor angles because of big controlled currents (threshold) difference of different polarity;
- asymmetry of conductor angles at wrong phase pulse relay controlling;
- partial (half-wave) opening of the relay at most quickly crossing of reverse voltage "permission switching window" (for relay with switch controlling of voltage through zero)for thyristor switch or because of small control current.

In the first case relay can't be used with inductive loads, in the second case – solution is obvious, in the third case – we should decrease the change of switching voltage dU/dt that described the methods above and provide sufficient input current.

At pure inductive loads with saturating ferromagnetic cores such as contactors or transformers, the relay when it's connected can go into saturation. Switching the relay with voltage transition through zero-is the worst one. Multicycle strating currents can exceed the rated value by many times. For such loads the rated starting conditions – is switch the relay in its maximum voltage or soft start with small initial angles of conduction.

Operation specialties for capacitive load related to appearance of big starting current in the chain (I >> $C\frac{dU}{dt}$) with high dI/dt or with appearance of overload in the relay because of residual voltage in the capacitance. Overcurrents are possible both in AC circuit and in DC circuit, however for protection against these currents are used different methods in these circuits. In DC circuit with given supply voltage U_0 current amplitude at switching can be valued (ignoring the active resistance of the circuit) using the formula

$$I = C\frac{U_0}{D_t},$$

where Dt – switch relay time. When working with high-speed relays that have Dt >>10^{-6} sec, the current can be extremely high. For example, at C = 10 µF and U_0 = 100 V we will get I >> 10^3 A.

To limit the starting current we can use a current-limiting resistor or inductivity in load circuit. In last case the starting current would have oscillatory character.

In AC circuits with relay that use thyristors current peaks appears in the next cases:

- when voltage phase unlike the zero in the moment when the relay is switched on.
  This case a one-time pulse current appears that is proportion to the amplitude of the voltage in the line in the moment of switching;
- when switching voltage of thyristor relay outputs unlike the zero, this leads to periodic current steps at voltage crossing of zero (when the relay is switched on).
  When the relay working with capacitive load without a control of the voltage transition through zero a one-time current pulse in a switching moment can be unacceptably large. In particular, with a value of capacity about 100 µF (such an order of capacity in phase correction systems), nominal voltage 380 V and switching time of thyristor about 10^{-6} sec. value of current for worst case is

$$I = \frac{10^{-4} * 380}{10^{-6}} = 38 * 10^{3} \text{ A.}$$

From the relation C *D_t /I we obtain the pulse current time

$$D_t = \frac{10^{-4} * 5 * 10^{2}}{5 * 10^{4}} = 10^{-6} \text{ sec.}$$

In real conditions because of resistance and inductivity of circuit current amplitude is less and time is higher than the estimated values. Anyway, current value exceeds the allowable peak current of thyristor leads up to the pulse time. Besides, such current surges create large electromagnetic interference.

A large decrease of pulse current amplitude at switching can be achieved by using a relay with controlling the phase transition through zero. Herewith voltage of prohibited switch should be as lower zero as it can. With a value of this voltage 10 V, according to the evaluated equation, the current will be equal 10^3 A, but real value – about hundreds amperes. It's quite acceptable when short duration pulse is. If it's necessary more suppression of the surge current then a small inductance (~ 10 µH) can be in series connected. It follows that with capacitive loads can be only used the relay with a control of phase transition through zero (like TM).

Periodic current surges in amplitude in each half-cycle of operating frequency depend on the value of switch relay output voltage. Alongside with interferences and local heating of the crystal such surges can lead to degradation some types of condensers because of expansion of the spectral composition of the current by them. Switching relay voltage determines the driver's circuit of power thyristors that for the relay of general purpose consists a protective resistor ($U_{sw\ on}$ ~ R*I_{ctr}, where R – protective resistor, I_{contr} – unlocking current of control circuit). Purpose of the resistor – is current protection of the driver on working on inductive load. When working on capacitive load can be removed and it reduces the switching voltage to 3-4 V. “Proton-Impuls”, CJSC produces the special relays (like TMK) for condensing loads with normalization values $U_{SW\ ON}$ = 4 V and U_{block} = 10 V. It’s not recommended to use these relays when working on inductive load. When working with active loads its use is acceptable.

Let’s consider the voltage in relay output when working on capacitive load. When switch deenergizing on relay input the output thyristor is switched off when the current is close to zero. When this happens condenser current on amplitude the voltage is equal to mains voltage. Next half-cycle the voltage in the line change the sign and in closed relay output is the sum of voltages and capacitor, and value of the sum achieves the double amplitude of the voltage. Thus, in the case of capacitive load the maximum allowable voltage of used relay must exceed the relay voltage not less than twice that work with active and inductive load.

In single-phase circuit is permissible to use two relays with outputs are connected in series and normal maximum allowable voltage. Hereby it’s necessary to call for the equalizing the voltage on them with resistors and varistors. More complex case is a three-phase system (fig. 1) used for compensation of phase shift in the networks. Here in each interphase chain is used two series-connected thyristors, therefore after switching off the sum of resudual capacitive voltages and phase voltages will be distributed between them, i.e. they may have normal maximum allowable voltage (380 V for voltage 380 V). However, there is a nuance that demands the considering. As a rule the condensers C1 –C3 are shunted with a high-impedance dumping resistors and if they have a time to discharge then there are no problems. When the discharge resistors are absent or for a small period of time between switching-on condenser voltage does not have a time to discharge and add up with line voltage. As far as in the thyristor switching-on process always at first are open two of them, and in some milliseconds – the third one, than during these milliseconds the total voltage will be applied to it. Varistor which shounts this thyristor takes the overvoltage and probably will dissipate the excess energy of the capacitor. It’s necessary the energy not to be too high for the varistor taking into account the switching frequency.