SCR SWITCHED CAPACITOR VAR COMPENSATION

INTRODUCTION

In AC systems cos φ is defined as the relationship between the active power (P) and apparent power (S). In an electric installation where all the connected equipment behaves as a resistive loads (owens, lightbulbs, etc.) all the consumed apparent power is active, then cos φ =1. But, in industrial installations, it is common the use of inductive loads (motors, transformers, etc). In those cases appears a phase shift between voltage and current waveforms (cos φ <1) which implies a reactive power (Q) consumption.

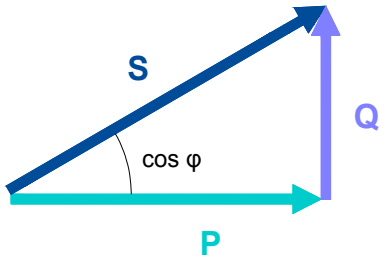


figure 1: power phase diagram.

$$\cos\varphi = \frac{P}{S} \qquad S = \sqrt{3}\cdot U_F \cdot I_L \qquad P = \sqrt{3}\cdot U_F \cdot I_L \cdot \cos\varphi \qquad Q = \sqrt{3}\cdot U_F \cdot I_L \cdot \sin\varphi$$

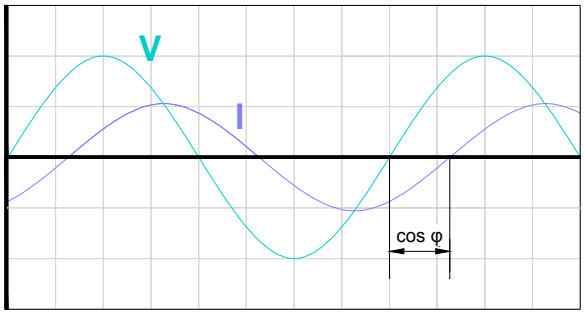


figure 2: phase shift between current and voltage waveforms.

Reactive power consumption affects generating equipment, making the supply station transformers operates in an increased operation mode than needed. Furthermore electric companies also penalize on invoices the reactive power consumption. Bringing the cos φ compensation a money saving.

Knowing the value of inductive reactance is possible to compensate the cos φ of our facility by means of adding an equivalent capacitive reactance (capacitors).

With the inductive reactive power (Q) of our load we can calculate the nominal capacity we must connect to each phase in order to compensate the reactive power. If we are working in a delta scheme (figure 3).

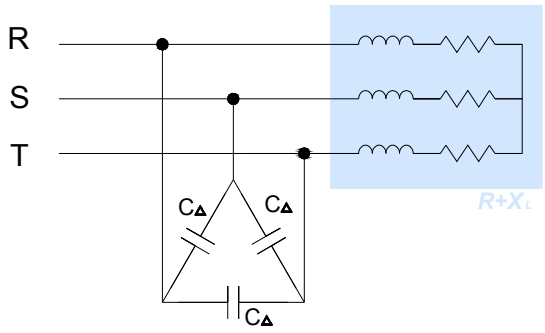


figure 3: delta connected capacitor bank.

$$C_\Delta = \frac{3\cdot Q}{U_F^2 \cdot \omega}$$

or in a wye scheme (figure 4).

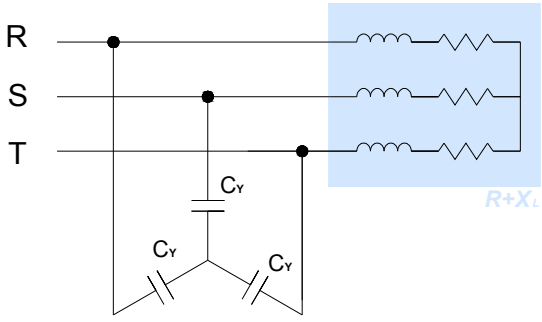


figure 4: wye connected capacitor bank.

$$C_Y = \frac{9\cdot Q}{U_F^2 \cdot \omega}$$

Please note that the voltage which stands a wye connected capacitor ($U_F/\sqrt{3}$) is less than the delta connected capacitor (U_F) but instead the needed capacitance is 3 times greater.

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APPLICATION NOTE

CAPACITOR BANK DYNAMIC CONNECTION

However it is very likely that the cos φ of our facility varies thorough the day because machines connection/disconnection, start and stop engine, etc. A cos φ change implies a variation in our capacitor bank, a way to do that is to measure the phase shift and act with contactors in order to switch on or off capacitor groups. These contactors can be static (semiconductor) or electromechanical The second one have several drawbacks: delayed switching between the switch signal and the proper switch (tricky to synchronize with the power mains) and also due its mechanical behavior, rebounds occur in the contact which is a source of electrical noise and contact (and device) degradation.

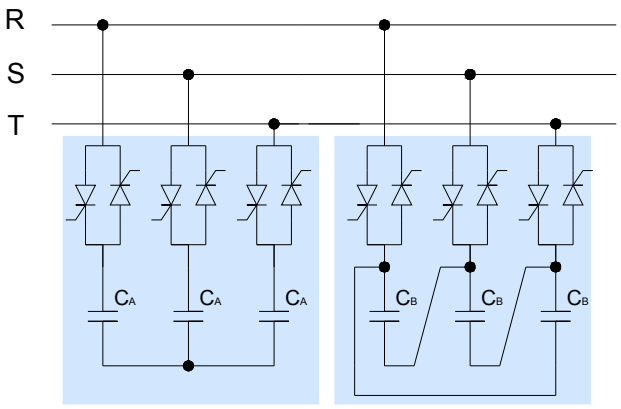


figure 5: connection using SCRs of a capacitor bank in wye (a) and delta (b) schemes.

Although the capacitive reactive power consumption is not penalized, to have more capacity than the strictly necessary connected in the network, is an unnecessary power consumption.

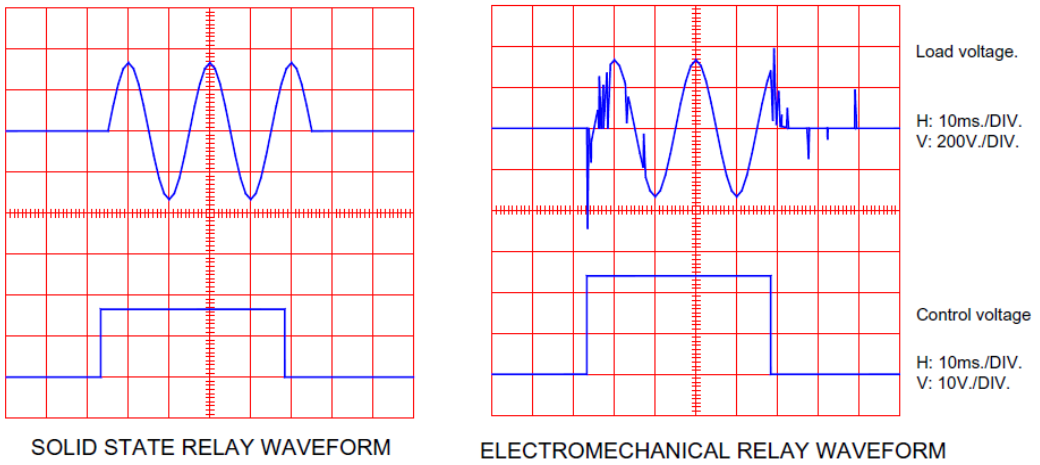


figure 6: Solid state vs. electromechanical relay waveforms.

ZERO-CROSS SWITCH STATIC CONTACTOR

Using the zero-cross switching cards SC018, SC024 and SC030 it is possible to make a simple galvanic isolated estatic contactor controlling two SCRs in antiparallel (W1C configuration). Model choosing depends of the mains working voltage and the capacitor configuration:

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datasheet	U working [V]	U max [V_{pk}]
SC018	400	1800
SC024	480	2400
SC030	690	3000

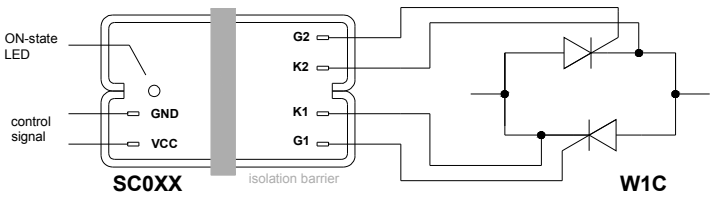


figure 7: zero-switch static relay with an SC0XX card.

When a switching signal is applied to card's input control, the SCRs will switch when the voltage across its terminals crosses the 0 V. The switch off is produced naturally when the control signal is off and the direct current flowing through SCRs extinguishes.

The internal operation of the card is as follows: The switching of the SCRs is made by connecting the anode to the gate (through a resistor) This method ensures correct firing of the thyristor, as the trigger energy obtained from the same power circuit. And it is also very robust, no additional power supply required, just a simple trigger signal with a maximum consumption of 30 mA.

The connection of capacitor banks in the zero-cross voltage, minimizes the initial current peak which causes variation of voltage across the capacitor, extending its life and preventing voltage drops occur in the network due to wiring inductances.

TOPOLOGIES

As we have seen, the capacitors can be connected in different ways in three-phase installations. We can even choose to have a phase always connected while we control the other two. Here are some options:

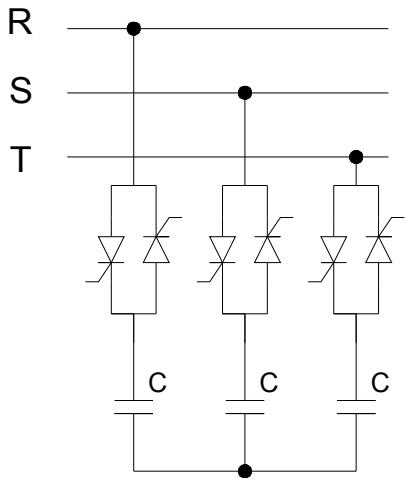


figure 8: W3C contactor, wye connected capacitors.

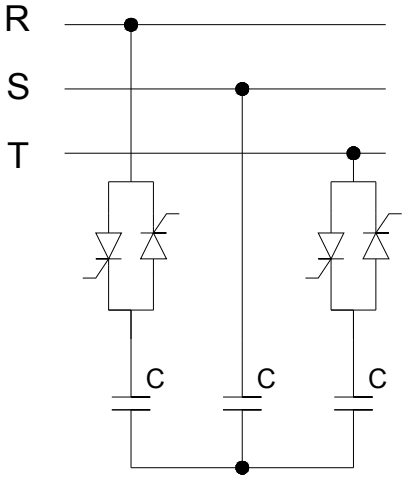


figure 9: W3.2C contactor, wye connected capacitors.

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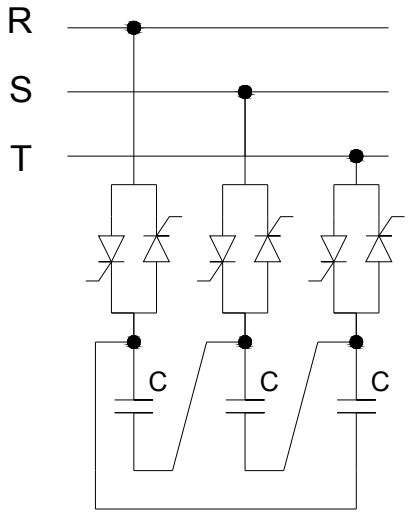


figure 10: W3C contactors, delta connected capacitors.

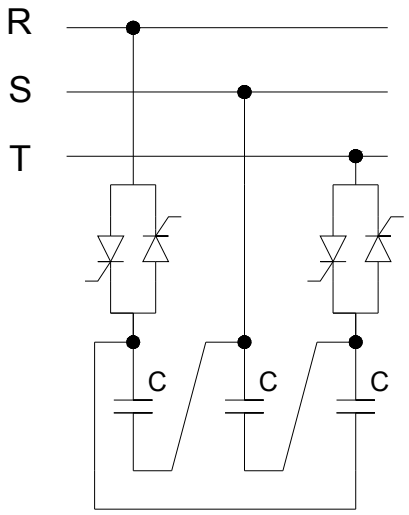


figure 11: contactors W3.2C , delta connected capacitors.

W3.2C configuration in front of W3C represents a cost saving, since it requires only two contactors per bank.

The drawback, you can't use a wye connection with neutral because one of the capacitors will allways be connected.

We must also consider the voltage drop in each thyristor group when turned off. In all of them the voltage across SCRs will be $U_{F,}$ The SCR choice should be made taking into account the maximum voltage difference if the capacitors are not discharged quickly enough:

$$U_{PK} = 2 \cdot \sqrt{2} \cdot U_F$$

Then, for a three phase mains with 230 V_{AC} between phases, U_{PK} = 650 V, a 1200 V_{RRM} thyristor is recommended.

Following the same procedure:

400 V_{AC} → U_{PK}=1131V, 1600 V_{RRM} or 1800 V_{RRM} SCR.
480 V_{AC} → U_{PK}=1357V, 2200 V_{RRM} SCR.
690 V_{AC} → U_{PK}=1951V, 3300 V_{RRM} SCR.

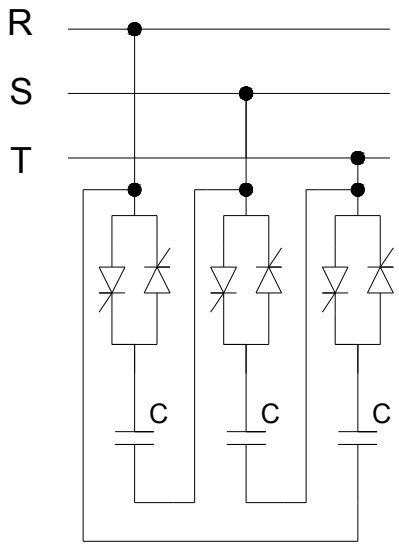


figure 12: inside delta contactors.

Another phenomena also appears when shooting contactors sequentially during its zero-cross, and is that in the instant a contact is closed (in W3.2C) or 2 closing contacts (in W3C) and before the final closing, the branches leading directly affect the other creating phase changes in voltage across the contactor and floating branch conduction (please see figure 13).

All of these effects are undesirable and can be avoided using the configuration **inside delta contactors** (figure 14).

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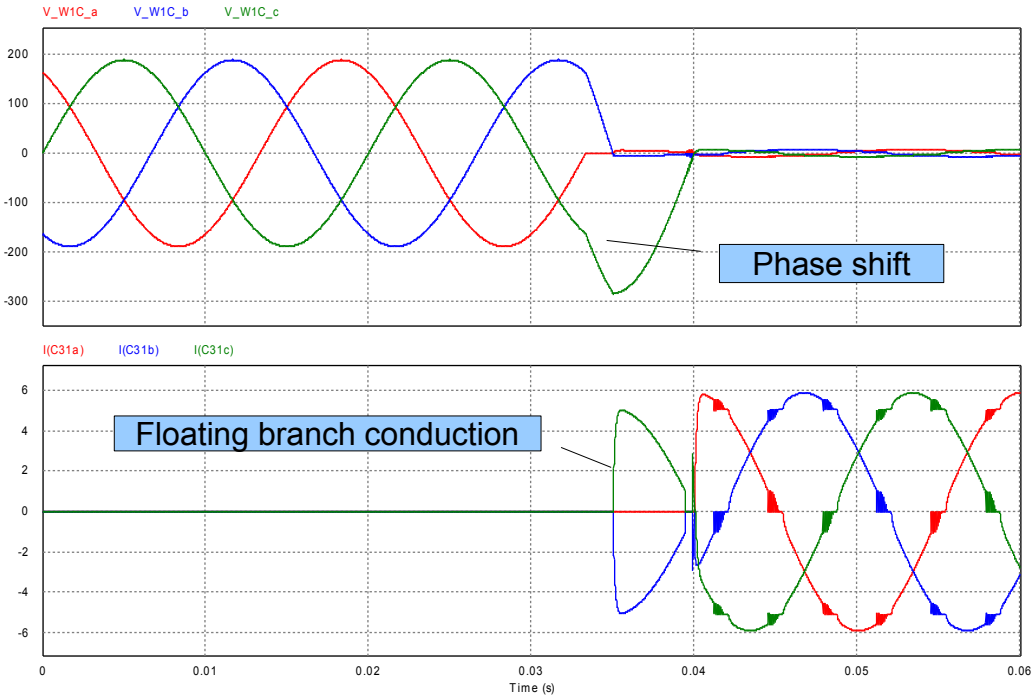


figure 13: contactor voltage (up) and current flowing through capacitiors (down) wye W3C topology.

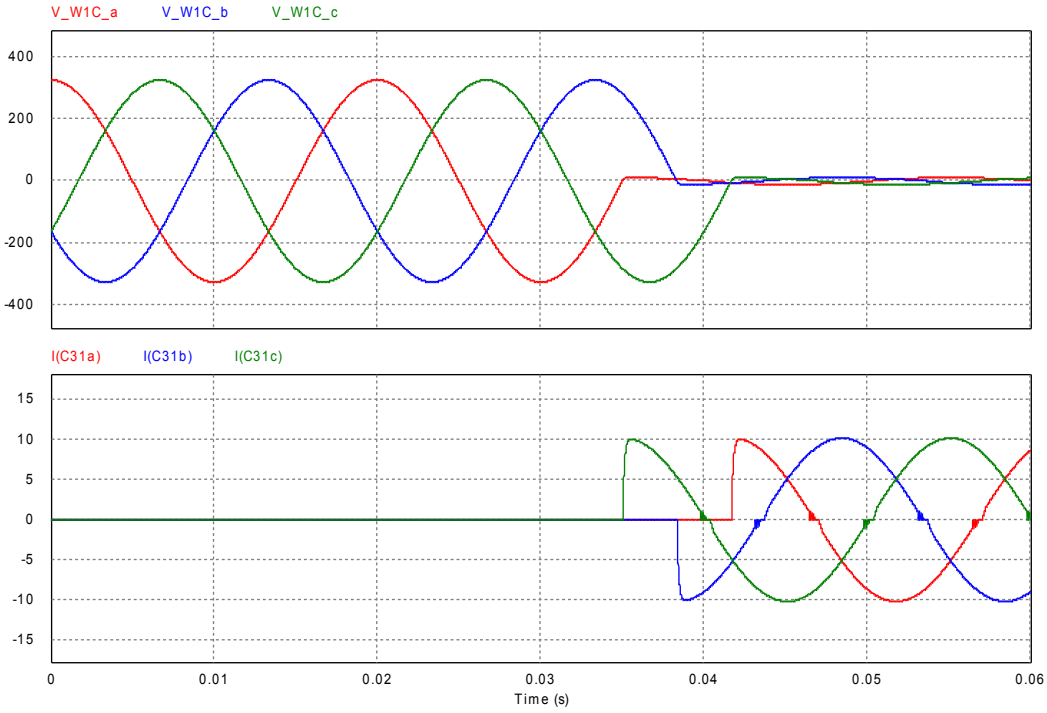


figure 14: contactor voltage (up) and current flowing through capacitiors (down) inside delta contactors topology.

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MOUNTING RECOMMENDATIONS

Fuses:
They are essential to protect the installation. They must be connected in series with each contactor to better match the current value of the fuse with the branch that protects. Connecting a single fuse with several branches (with banks with a lot of branches and capacitors) makes it necessary to increase the current of the fuse leading a less effective protection.

Inductance ballast:
Inductive reactances should be connected with the branches of the capacitor banks when we have nonlinear loads in our facility. Nonlinear loads produces harmonics (multiple frequency of the mains). A bank of capacitors is a purely capacitive load of low impedance for high frequency currents and these currents can cause overheating of the capacitor and premature aging. In addition to putting a capacitor, along with the rest of the circuit inductance, can lead the circuit into resonance with one of the harmonics and cause a catastrophic failure. Put properly calculated ballasts banks softens these effects.

Choosing thyristors:
First, you must take into account the voltage criteria described before in topologies paragraph. Then we must bear in mind that a thyristor with a higher current value also have a higher latching and maintenance currents, this delays the triggering for low working currents, can also be more noisy or even will be impossible to trigger on. (figure 15).

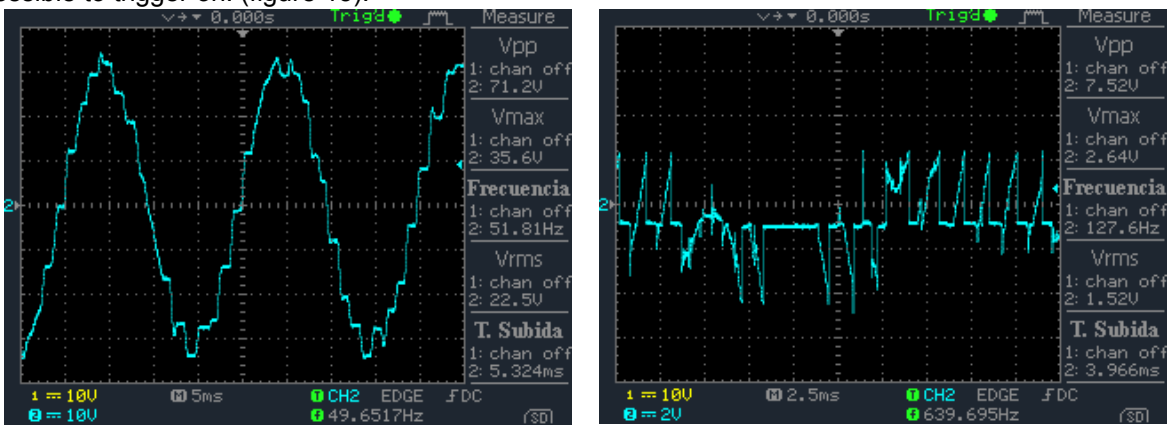


figure 15: capacitor voltage (left) and contactor voltage (right) for a deficient triggering due a lack of current.

It is important to adjust the SCR nominal slightly upwards the working current will circulate through them. But not oversize too much it if there is no cause.

Delta connected capacitors $$I_{WIC} = U_F \cdot \omega \cdot C$$

Wye connected capacitors $$I_{WIC} = \frac{U_F}{\sqrt{3}} \cdot \omega \cdot C$$

Delta-wye combinations
Sometimes for large banks of capacitors is much more cost effective to have only one capacitance value and combine wye connected groups with delta connected groups, or even wye-delta associations, in order to obtain different values for different capacity and adjust the power factor correction. However it has the disadvantage that the previously mentioned effects of phase shift and floating branch conduction can be magnified.

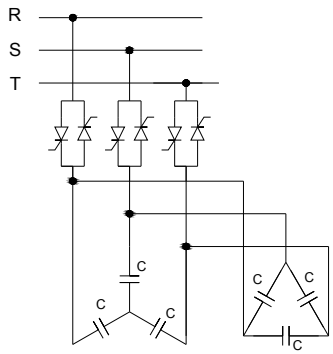


figure 16: delta-wye combinations.

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Combinations with electromechanic relays
You can combine the use of electromechanical relays with static relay where is contemplated that the added noise produced by electromechanical relays do not affect the proper operation of static contactors and other circuit elements. It is much more advisable to use a single type of relays, preferably static ones.

Discharge resistors
It should connect a discharge resistors in each capacitor of the capacitor bank. These resistors ensure that the capacitor is fully discharged when starting the contactor and discharged quickly when it is open again.

RECOMMENDED APPLICATION CIRCUIT

For all that described before in this document the following is the application circuit recommended by Rectificadores GUASCH, S.A. as a reactive compensation with a capacitor bank.

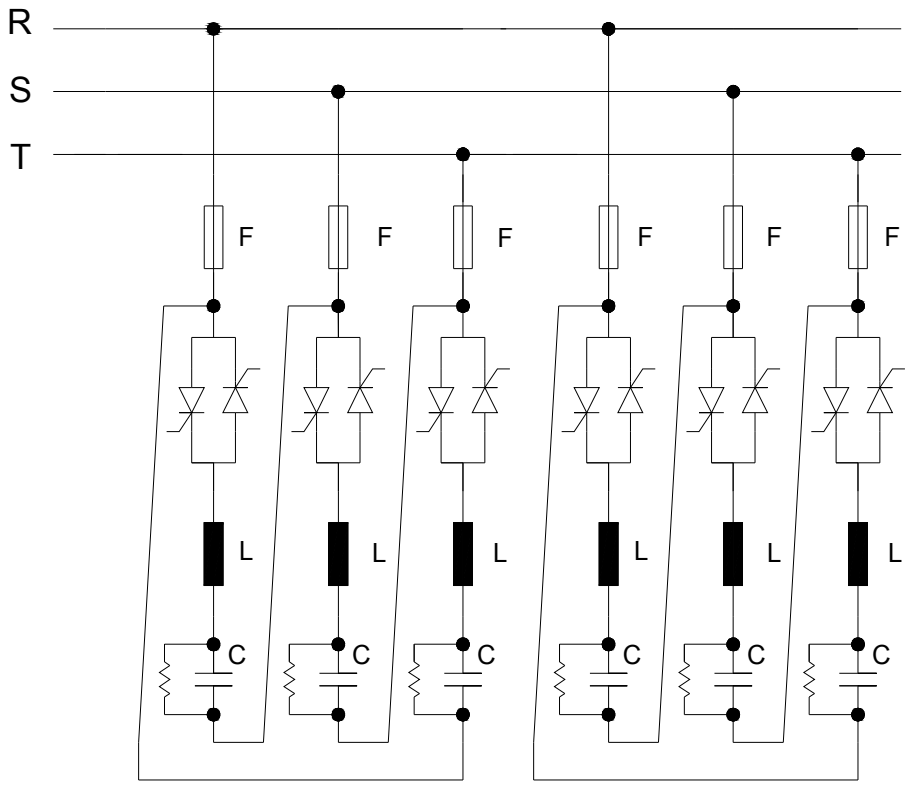


figure 17: Recommended application circuit for VAR compensation.

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