

## Automatic Reactive Power Control Using FC-TCR

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### Abstract

*A fixed capacitor-thyristor controlled reactor (FC-TCR) type of power factor compensator with different series R-L load is analyzed using an approximate circuit. The variation of reactive power and power factor before and after compensation is examined. The simulation is carried out in PSIM software for 3-phase 440 volt. The close loop control is possible for different load condition. Automatic firing angle is adjusted such that minimum VAR taken from the supply & power factor is maintain near to unity.*

### Keywords

*$\alpha$  -Firing angle, TCR- Thyristor Controlled Reactor SVC – Static VAR Compensator, FC – Fix Capacitor APFC – Automatic Power Factor Correction*

### 1. Introduction

The power demand is increasing day by day as the industrial load is increasing. Majority of loads are inductive in nature in the industries. So they consume reactive power which will affect the generation of the plant. To give this additional power we need to increase generation or increase KVA rating of the transformer. This is very costly solution. The optimum solution is to provide this additional reactive power from the load side only. In this case we don't need to increase the KVA rating of the transformer so cost will not increase & additional  $I^2R$  losses will also eliminated. This type of compensation is called load compensation. Load compensation is generally provided by shunt compensating device which is connected in parallel to the load. There are different types of shunt compensation device. These devices also called SVC (static var compensator). In this inductor or

capacitor is controlled with the help of power electronic devices like Thyristor, IGBT, MOSFET etc. There are some important types of svc are explained below:

#### A. SVC

##### 1. TSC (Thyristor Switched Capacitor)

It is a capacitor switched using thyristor. Systems of this type consist of one or more cooperating three-phase sections of TSC, where each section includes capacitors, thyristor switches that are switched on or off depending on the total reactive power supplied by the entire device.

##### 2. TSR or TCR

TSR and TCR are systems with induction components only. They consist of a TSR (Thyristor Switched Reactor) or TCR (Thyristor Controlled Reactor) section; TSR includes thyristor switched reactors, whereas TCR are reactors with thyristor controlled induction. A TSR-type compensator is composed of several three-phase TSR sections whose thyristor switches are switched on or off (discrete control) depending on reactive power that is to be received by the entire device from the system. A TCR-type compensator has a similar structure, but the basic difference between these devices lies in the fact that TSR has no ability to provide smooth control of inductance.

##### 3. TCR-FC

These devices consist of two types of components. The first one is a TCR module that receives reactive power, and the second is FC (Fixed Capacitor), which include also higher harmonic filters. They are an essential element when it comes to the work of TCR. FC is a source of reactive power.

##### 4. TCR-TSC-FC

These compensators consist of three groups of components. The first group consists of thyristor controlled reactors. The second group consists of TSC, which is the primary source of reactive power. The third group is higher harmonic filter (treated as fixed capacities – FC), which are an additional source of reactive power. Their presence in this system is necessary due to the need to eliminate the interferences caused by TCR. However, additional

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filters that do not come from the same compensator and can eliminate other interferences can be used.

### 5. TSR-TSC

Compensators of this type consist of two groups of elements. The first group consists of thyristor switched inductors, while the second group consists of TSC. The system may provide only discrete control.[3] Apart from this FC-TCR is the cost effective solution. We can also use the other combination according to load requirement & cost. If cost is not concern than TSC-TCR is best option.

TCR is controlled by two methods- Phase Angle Control & Integral angle control. According to application we have to decide which method is best suitable.[1-2]. Nowadays electric power companies getting stricter about tariff and also they give penalty for having low power factor. So each company keeps maintaining their power factor as high as possible. Generally APFC panels are used in industries to compensate reactive power. They provide step wise reactive power control not in a smooth manner. FC-TCR gives smooth control of reactive power. Generally APFC panels are used in 2 steps. For e.g. 75 KVAR load we can design 25 KVAR & 50 KVAR APFC panel. When load is 50 KVAR we can switch on the 50 KVAR group same for 25kvar. Suppose we have 50 KVAR reactive power requirements throughout whole day. Among them 40 KVAR is fix means load is on and off & remaining 10 KVAR load is variable means it can vary frequently. In this case we can use 40 KVAR APFC panel & for 10 KVAR load we can use FC-TCR. So we can get perfect reactive power control.

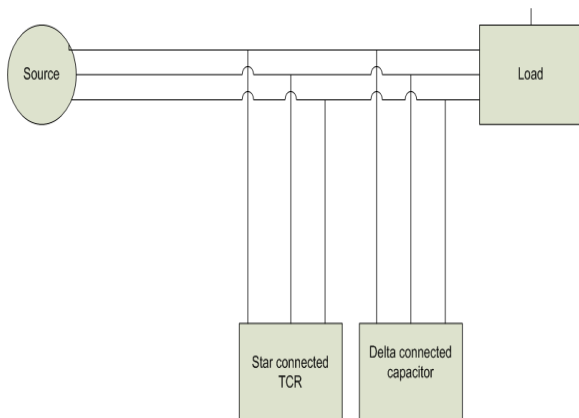


Figure 1: Block Diagram Of FC-TCR

Normally FC TCR is used for HT side above 11kV. Here we are going to use FC TCR at 440 V LT side

for 10 KVA. For this we use delta connected capacitor bank & star connected TCR (thyristor controlled reactor). Here LT side delta connected capacitor bank easily available so we can easily use it. Reactors are generally star connected controlled by thyristors.

## 2. Theory

The current in a TCR can be continuously varied from zero (corresponding to zero conduction angle) to maximum (corresponding to conduction angle of  $180^\circ$ ) by phase control in which the firing angle  $\alpha$  (with respect to the zero crossing of the voltage) is varied from  $180^\circ$  to  $90^\circ$ . [4] Here phase control technique is used to control the thyristor. In this thyristors are switched on at zero crossing of voltage in each cycle. Here the thyristor controlled reactor are controlled in terms of alpha angle range from  $90^\circ$  to  $180^\circ$  because in inductor current starts  $90^\circ$  lagging from voltage waveform. Generally TCR is not controlled by integral angle control because it may cause problem of saturation by continuously on the TCR for a long time. Integral control is used only resistive loads.

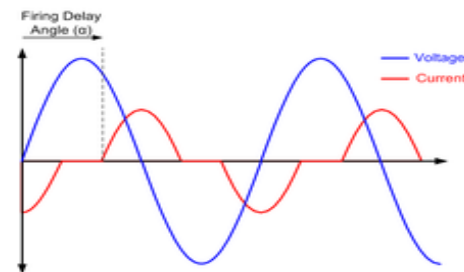


Figure 2: Waveform Of V & I In TCR

The instantaneous current  $i_{TCR}$  over half a cycle is given by

$$i_{TCR} = (\sqrt{2} V) / X_L (\cos \alpha - \cos \omega t) \dots \dots (1)$$

Here V= Rms Voltage

$X_L$ = inductive reactance

$\alpha$ = Firing (Delay) angle

The relation between the fundamental component of the reactor current and the phase-shift angle  $\alpha$  is given by

$$I_1 = V_{rms} / \Pi \omega L (2\Pi - 2\alpha + \sin(2\alpha)) \dots \dots (2)$$

We get the value of current in terms of alpha (firing angle).

### 3. Simulation

Here simulation is based on different 0-10 KVAR load. E.g. 1KVAR, 2KVAR ...10KVAR. For each load it's equivalent R & L and load angle is shown in the Table:1. Now for any load capacitor will continuously provide fix 10KVAR reactive power, so we have to compensate this by switching on the TCR, otherwise over compensation will occur. Here the reactive power of the load measured by  $3 * V * I * \sin \alpha$ . So logic is that Q of load is subtracted from the Q of capacitor, so remaining Q will be required from the TCR. To get this Q from TCR we have to adjust alpha. After that total reactive power of star connected TCR  $= 3 * V * I$  To match this both value we rotate one loop in which alpha is continuously vary from  $90^\circ - 180^\circ$  by 0.01 incremental steps.

The loop will stop at particular value of alpha when both the value of Q will be matched & at that time alpha angle freeze. One look up table is made from 0 to 10 kvar loads by trail and error methso,also alpha angle at which minimum reactive power is maintain & at the same time PF is 0.99 all the time. Here this value of TCR current is fundamental component . So here we cannot directly measure the TCR current, the direct measurement of current has harmonic content because as alpha varies continuously. So FFT block is used whose output gives the peak of fundamental value of the TCR current, but we want rms value so dived this by 1.414 so we get rms value.[5].

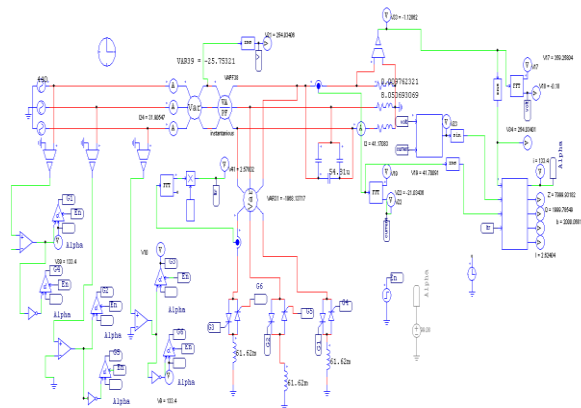


Figure 3: Simulation Circuit

Make this current value as label and given to simplified c block. In this the current is measure by

above equation continuously & at the same time reactive power is also measured by  $3 * V * I$ .

$$z = 3 * V * I * \sin \alpha;$$

$$b = 10000 - Z;$$

When this value is matched with b value the alpha angle is fixed & it will be displayed at the first output of the c block. According to this value the triggering pulse is given to the thyristors of TCR.

Table 1: Table Shows the Value of Equivalent R & L from Q (Reactive Power)

Q(KVAR)	R in Ohm	L in Henry	Alpha Angle
1	27.104	0.1232493	94.3
2	20.49882	0.014499918	99.08
3	16.38154	0.014221073	103.55
4	13.60132	0.013324249	108.44
5	11.616	0.01232493	113.6
6	10.12677	0.011376858	119.25
7	8.971707	0.010521282	125.6
8	8.050693	0.009762321	133.19
9	7.299672	0.009092161	143.41
10	6.675862	0.008499952	180

Alpha angle ( $\alpha$ ) is adjusted in such a way that minimum VAR is taken from the source & power factor is maintained to 0.999. The above result is obtained by simulation in PSIM software. Here we get  $\alpha = 119.47^\circ$  by the logic which is near equal to  $119.25^\circ$ .

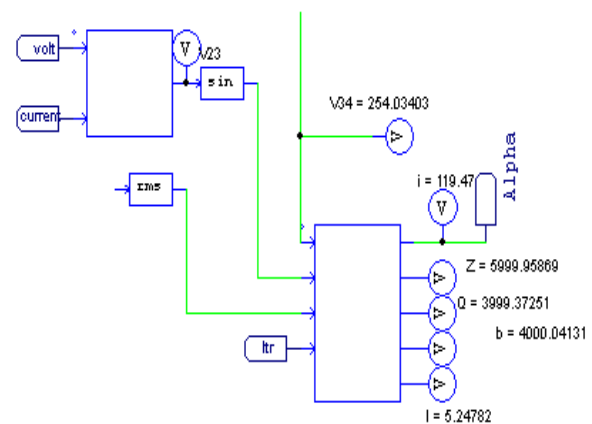


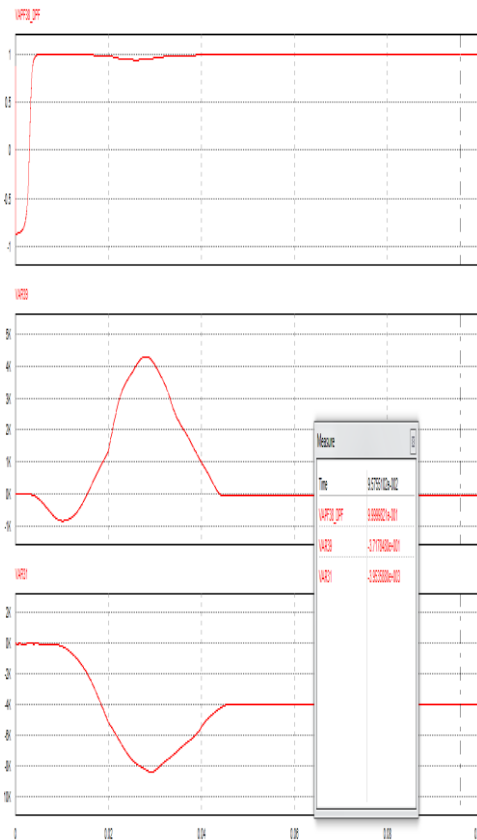
Figure 4: Logic Blocks

Let us take example of 6 Kvar load. It can easily measured by calculation as seen in above figure. The value of z shows load var, after that Q shows the value measured by the equation & b shows the value after subtraction from the KVAR value given by capacitor which is 10000 is this case. When this

values are same, alpha angle is become fix, here  $\alpha=119.47^\circ$ . The last value gives the fundamental component of TCR current which is measured by the previous equation. The first three inputs are volt,  $\sin \square$  & current which are used to measure the reactive power of load. The last input is the fundamental current of TCR which is not necessary to take. As shown in waveform of power factor, VAR taken from source side & VAR given by TCR.

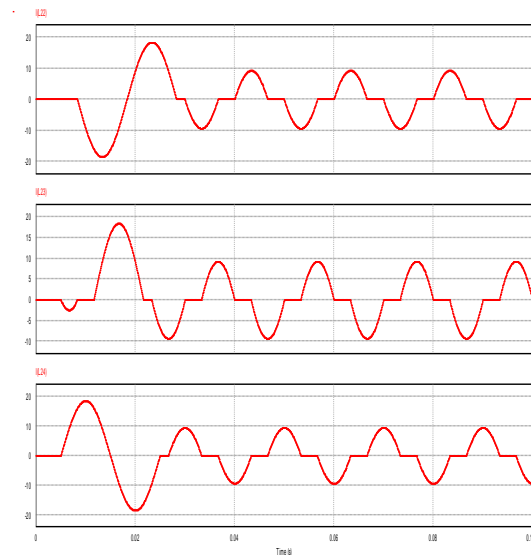
#### 4. Results

Following waveform shows value after compensation. Load is 6 KVAR & after compensation we get 37 VAR leading as seen from the second waveform indicated as VAR 39. Our capacitor gives 10 KVAR continuously, 4 KVAR is additional so we have to absorb this additional KVAR by TCR. From the last waveform indicated as VAR 31, we can see TCR absorb the 3953 var. first waveform shows the power factor 0.9999.



**Figure 5: Waveform of PF & VAR**

Following figure shows the waveform of current flowing to the TCR at  $\alpha=119.47^\circ$ .



**Figure 6: Waveform of TCR Current at  $119^\circ$**

#### 5. Conclusion

With the help of close loop control of FC-TCR firing angle is automatically adjusted with the variation of load. We can easily analyze the required firing angle ( $\alpha$ ) for any kind of equivalent R-L load of particular reactive power. One can do harmonic analyses from the current waveform by showing that if any harmonic is present, we can design particular harmonic filter for that. Here in this case harmonic is very less below 5%.So no needs to design any filter.

#### 6. Future Work

Hardware implementation of FC-TCR can be done for small industry. Till now it used for H.T. (above 440V) side, it is also used at L.T.(440V) side. One can go towards TSC-TCR simulation, So that some amount of capacitors is switched on directly as per variable step by step load increases. This capacitor is selected based on load schedule for e.g. from 10 am to 11 am particular requirement load is 20 kvar then after 11 am 5 KVAR load drops & again after 2 pm 30 KVAR load requirement is there. The most fluctuating load is 25 to 30 KVAR. So for particular this case one can design four number of 5 KVAR capacitor means total 20 KVAR APFC panel so in this capacitor are switched on & off as per load

requirement & it will provide reactive power compensation. Now only 10KVAR load is remaining (20-30 KVAR). One can design 10 KVAR FC-TCR for this. So it will give smooth steeples reactive power compensation.

### References

- [1] Al Roman & Adam Heiligenstein, CHROMALOX TRAINING Manual- SCR Power Theory Traning Manual. ISO9001, 2002.
- [2] Control Concepts, inc.” What You Should Know About SCR Power Controllers”, Nocross, GA USA, 2002.
- [3] Robert Kowalak / Gdańsk Robert Małkowski / Gdańsk,University of Technology[pg.13-20] Shunt Compensator As Controlled Reactive Power Sources, 2013.
- [4] Facts Controllers In Power Transmission And Distribution by K. R. Padiyar, New Age International (P) Limited ISBN (13): New Delhi, ISBN (13): 978-81-224-2541-3, 2007.
- [5] Psim help – Powersim software [9.0].



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