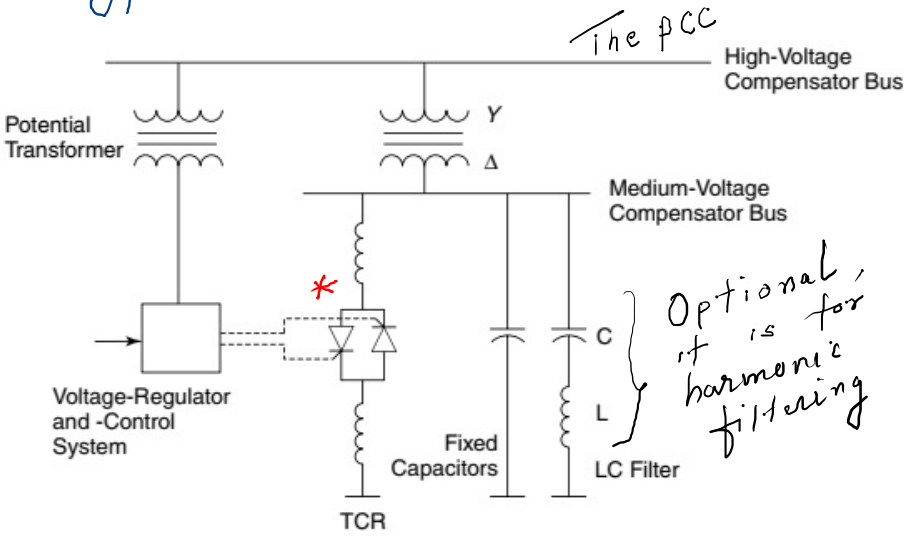
The Fixed Capacitor - Thyristor Controlled Reactor (FC-TCR)
Static VAr Generator and Its Control

A Typical FC-TCR based SVC System



A 1-line diagram of a TCR compensator with fixed-shunt capacitors.

* A single Thyristor used in FACTS controllers can block 4 to 9 kV, and carry 3000 – 6000 A forward current. 10 to 20 such units are connected in a series string to raise blocking voltage capability and many such strings are connected in parallel to increase current carrying capability.

Operation of a TCR

E You can use the following as Text books for this portion.

1. Understanding FACTS by Hingorani & Gyugyi, Section 5.2
2. Thyristor-based FACTS Controllers for Electrical Transmission Systems by R. Mohan & Rajiv K Varma IEEE Press, Wiley Interscience Section 3.4

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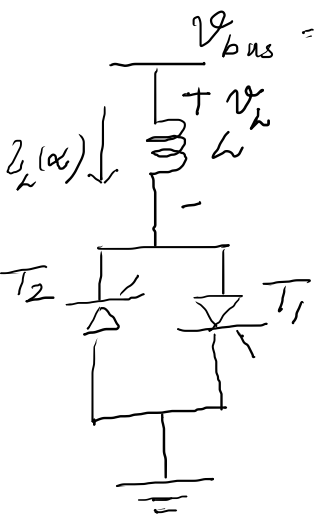
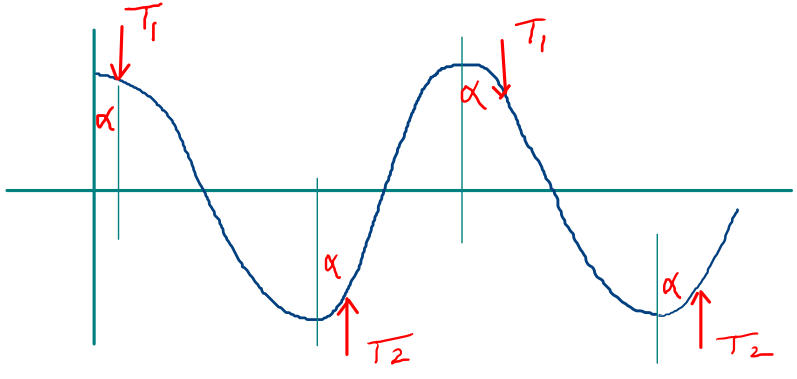
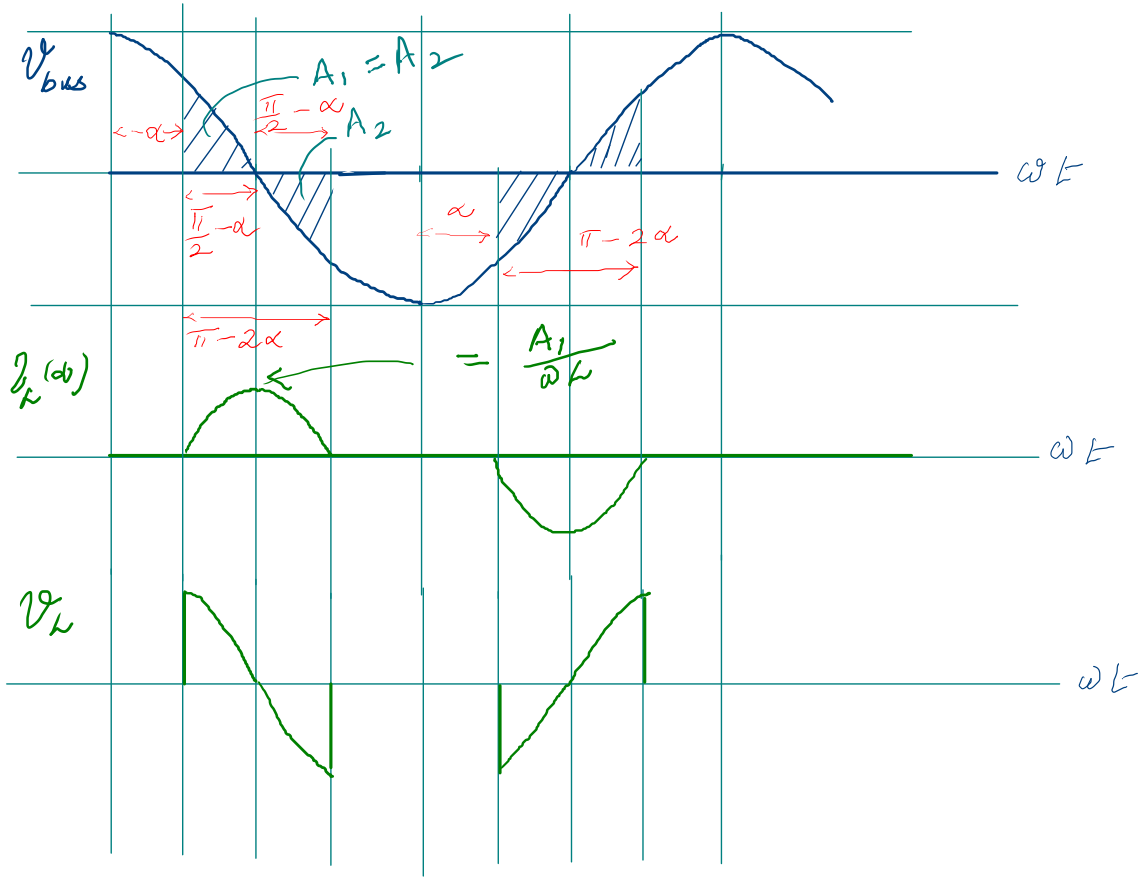
A Single-phase TCR Unit

$v_{bus} = V_m \cos \omega t$



Firing angle of T_1 is α degrees after the peak position of voltage in +ve half-cycle and firing angle of T_2 is α degrees after the peak of voltage in -ve half-cycle.





Maximum delay in obeying a firing angle change command = $T/2$ sec

The Fixed Capacitor - Thyristor Controlled Reactor (FC-TCR) Static VAr Generator and Its Control

$I_{LF}(\alpha)$ = amplitude of fundamental

$$= \frac{V_m}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right)$$

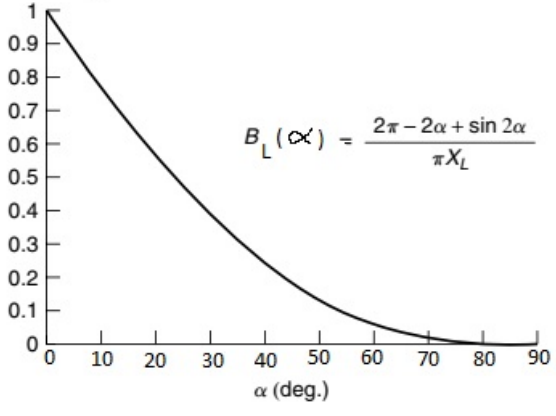
with α in radians.

Susceptance at fundamental frequency $\triangleq B_L(\alpha)$

$$\therefore B_L(\alpha) = \frac{1}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right)$$

Range of α = 0 to 90° and α is measured from 90° position on sine wave.

$\omega L \times B_L(\alpha)$

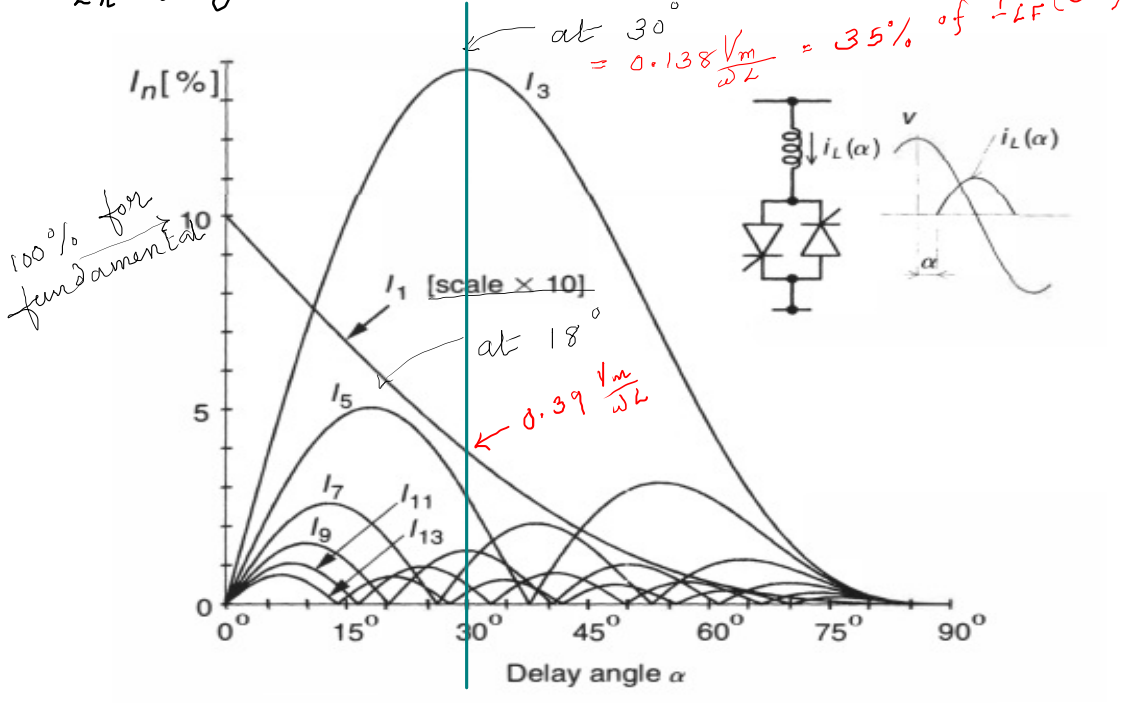


$I_{Ln}(\alpha)$ = amplitude of n^{th} harmonic

$$= \frac{V_m}{\omega L}\frac{4}{\pi}\left\{\frac{\sin\alpha\cos n\alpha - n\cos\alpha\sin n\alpha}{n(n^2-1)}\right\}$$

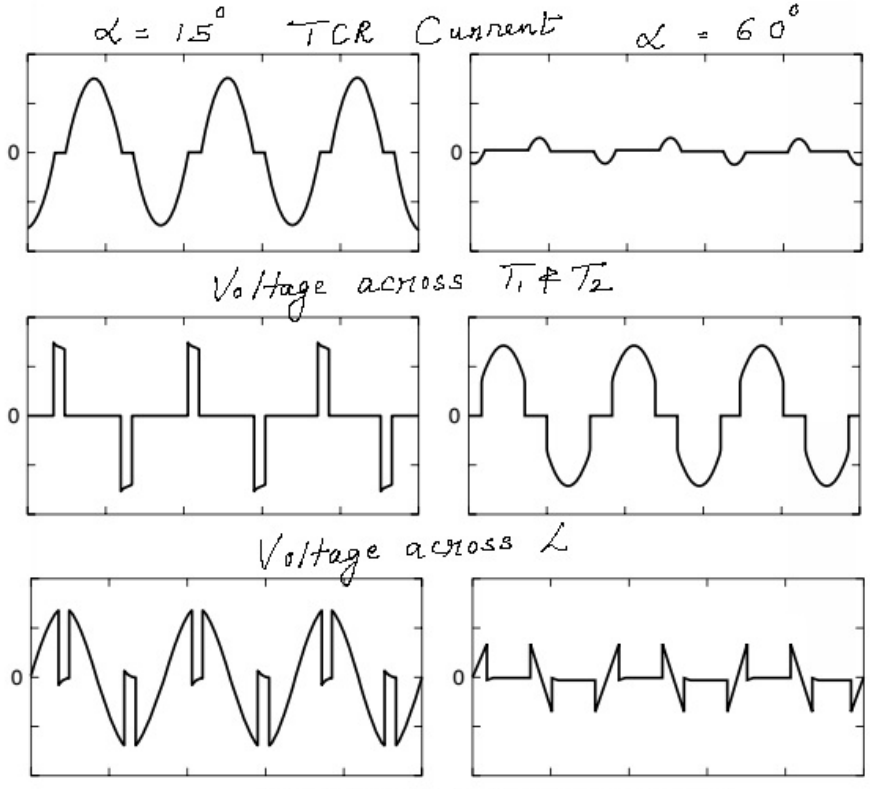
for odd n and $n \neq 1$

$I_{Ln}(\alpha)$ goes to a max when $n\alpha = 90°$



Amplitudes of the harmonic components in the current of the TCR versus the delay angle α.

The Fixed Capacitor - Thyristor Controlled Reactor (FC-TCR) Static VAr Generator and Its Control



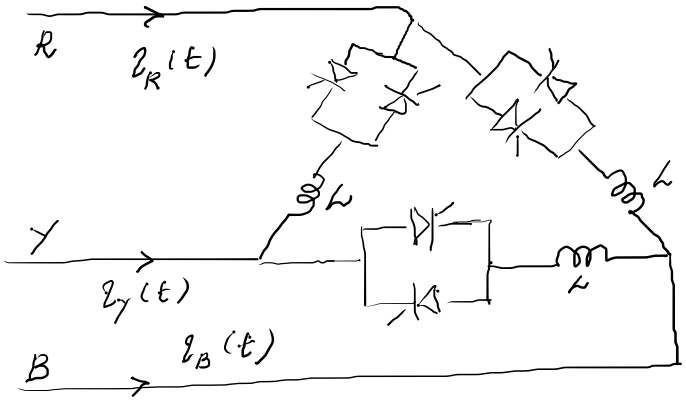
Current and voltages for different α in a TCR.

- Can there be even order harmonics ?

Yes, if the α value in +ve and −ve half-cycles are different. In that case $i_L(\alpha)$ will contain a DC component also.

Control of Harmonics in a 3Ø TCR

1. Delta Connection.



Assumptions -

- The value of L in three legs are equal
- Thyristors are fired with same firing delay α
- 3Ø symmetry is maintained accurately in firing.
- Line voltages are balanced

Then, triplen harmonic currents circulate in Δ and WILL NOT BE present in $i_R(t)$, $i_Y(t)$ and $i_B(t)$.

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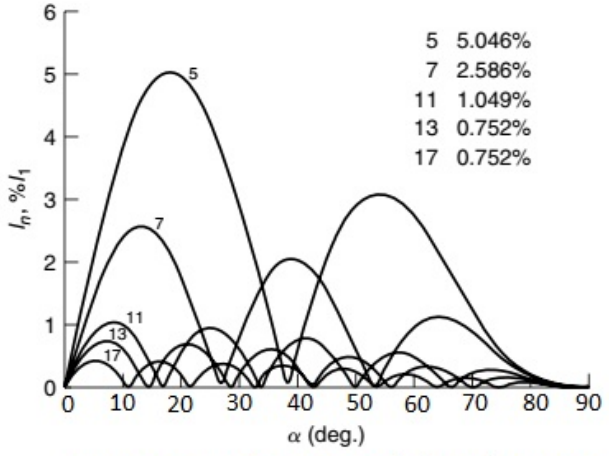
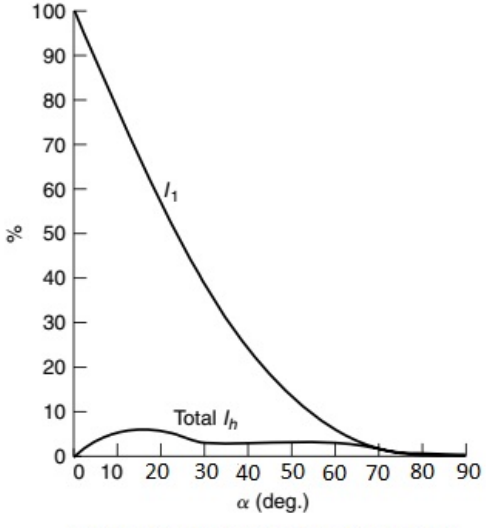


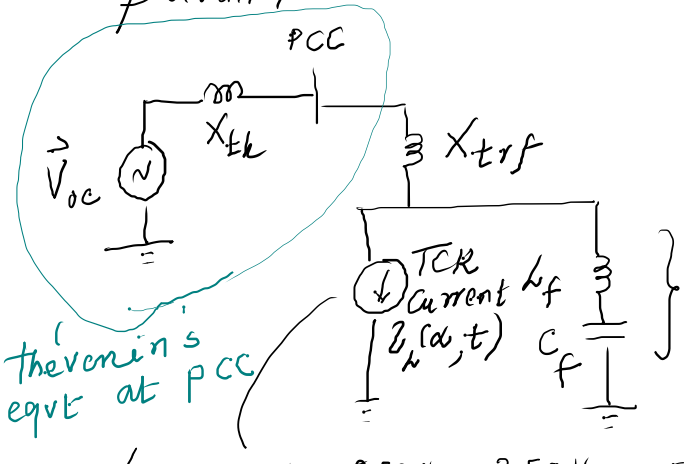
Harmonics in a Delta-Connected Three-phase TCR Unit



Fundamental RMS and Total Harmonic RMS Current in a Delta-Connected Three-phase TCR

But if firing in 3 legs are not exactly at 120° or if the supply voltage is unbalanced (in amplitude or in phase or in both), the triplen harmonics will flow in the lines.

- Use passive Tuned Harmonic filters in parallel to TCR.



has 50 Hz, 250 Hz, 350 Hz ---- Current components

Problem: One tuned structure per harmonic order to be cancelled will be needed.

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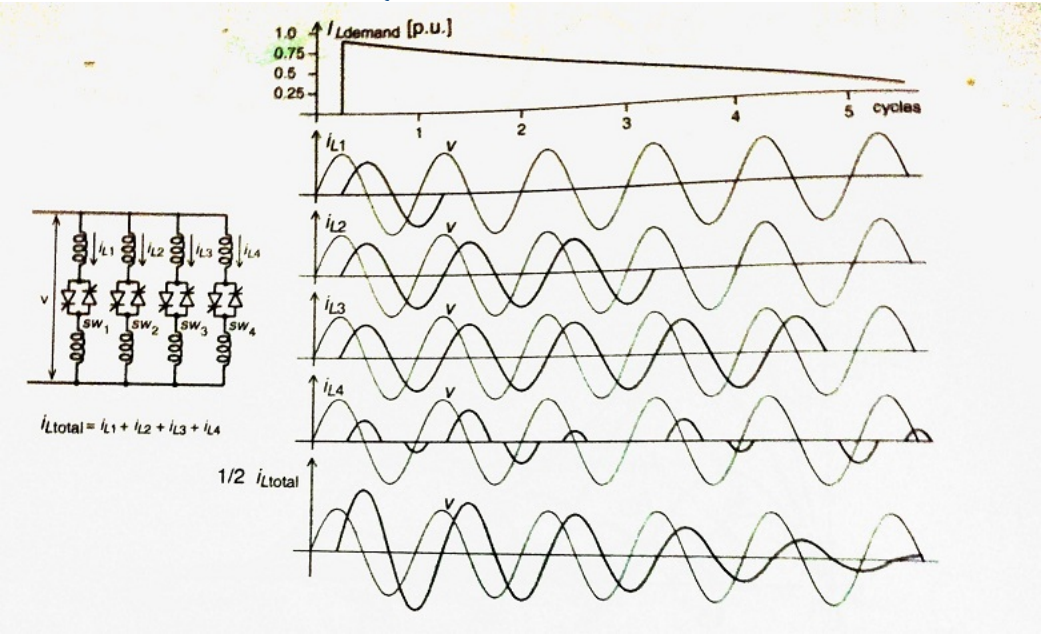
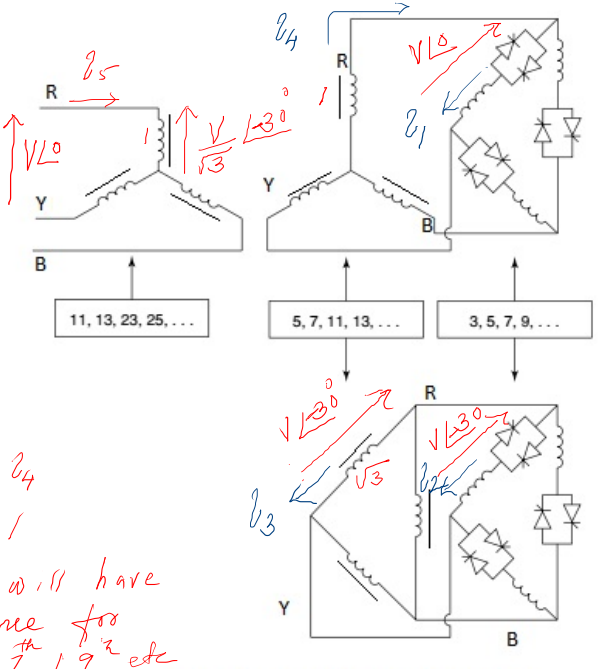
- Use Segmented TCR
  Total required TCR rating is distributed equally among 'n' smaller units.



- Use TCR in 12-pulse arrangement
  $6(2k-1) \pm 1$ with $k = 1, 2, 3 \ldots$ order harmonic current amplitudes go to 0 in the primary – 5, 7, 17, 19, 29, 31, 41, 43 ... etc disappear
  11, 13, 23, 25, ... etc present



$I_5 = I_3 + I_4$
(These will have 180° difference for 5th, 7th, 17th, 19th etc

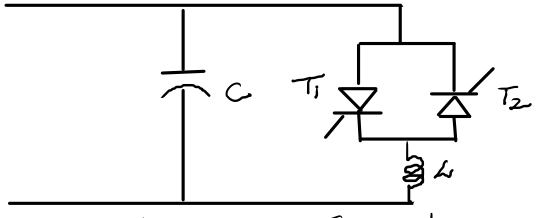
5th harmonic in I_4 leads 5th h in I_1 by 30° (remember, 5th h is of -ve phase sequence)

5th harmonic in I_2 (which is same as I_3) has 150° extra lag (compared to 5th harmonic in I_1)

A TCR in 12-Pulse Arrangement

The Fixed Capacitor - Thyristor Controlled Reactor (FC-TCR) Static VAr Generator and Its Control

Reactive Power Capability and Loss Behaviour of FC-TCR SVG



Susceptance = $jB_c = j\omega C$

Susceptance = $-jB_L = -j\frac{1}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right)$

$\frac{1}{\omega L}$ is usually $> \omega C$ and hence when $\alpha = 0$ FC-TCR takes lagging reactive power of value $V^2\left(\frac{1}{\omega L} - \omega C\right)$ and when $\alpha = 90^\circ$ it takes leading reactive power of $V^2(\omega C)$ where V is system voltage in pu.

Rating is based on nominal voltage and nominal voltage in pu is taken as 1 pu.

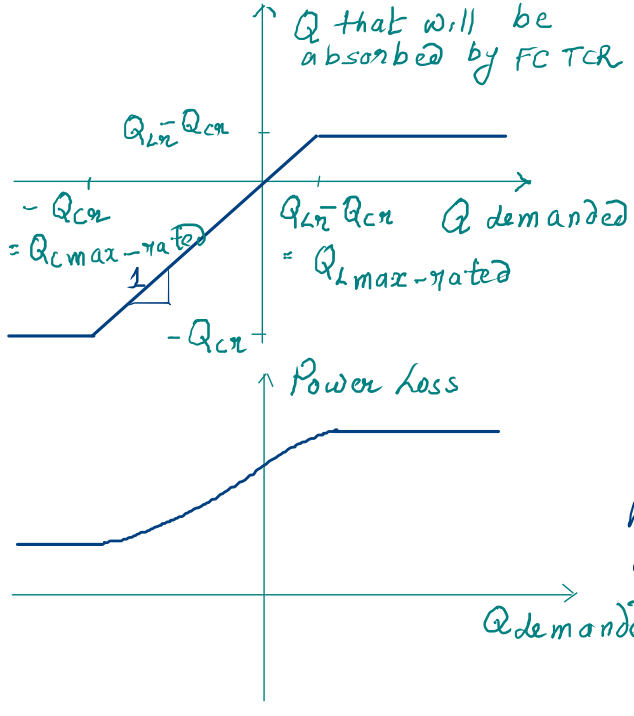
So $Q_{Lmax} = \left(\frac{1}{X_L} - \frac{1}{X_C}\right)$ where X_L & X_C are in pu

and $Q_{cmax} = \frac{1}{X_C}$; X_C in pu.

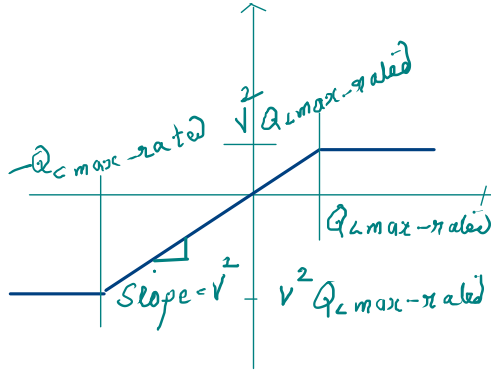
Rating of C, $Q_{cr} = Q_{cmax}$ pu

Rating of L, $Q_{Lr} = (Q_{cmax} + Q_{Lmax})$ pu.

Reactive Capability curve at Nominal Voltage of 1 pu



Reactive Capability Curve at System Voltage V pu



∴ Suitable when average capacitive demand is high (as in PF Correction) and not suitable when it is low as in dynamic compensation in Power Transmission System.

The Fixed Capacitor - Thyristor Controlled Reactor (FC-TCR) Static VAr Generator and Its Control

Internal Control of FC-TCR SVG

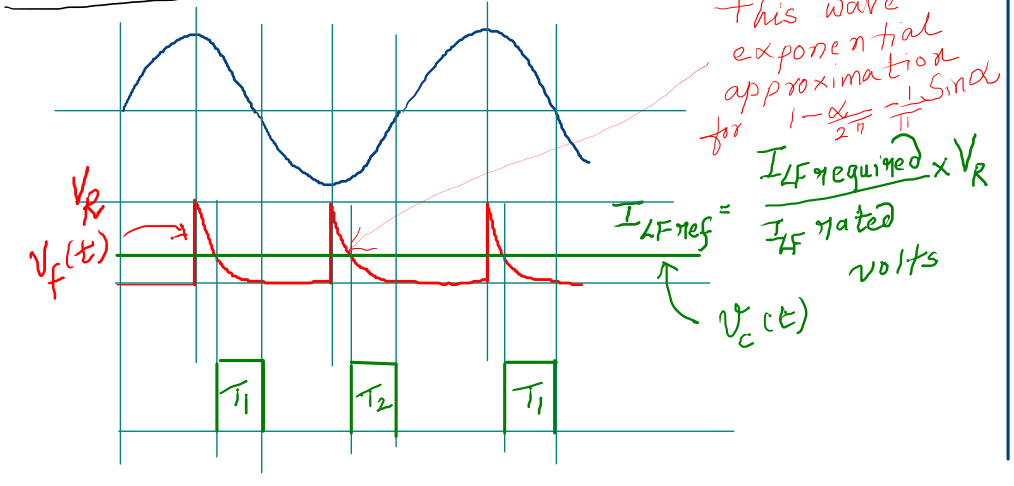
A Single TCR unit is assumed.

Input — is the value of I_{LF} desired, represented by a suitable DC control voltage.

Assumption — Nominal voltage = 1 pu.

Let V_R (say 5V) be the voltage used to represent maximum lagging current possible from TCR (when $\alpha = 0$). It will be equal to rating of L in pu.

Strategy to get firing positions

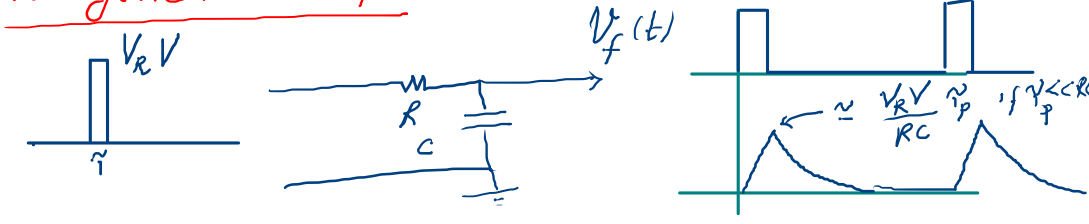


Problem — When $V \neq 1$ pu, actual I_{LF} realised will be $V \times I_{LF\,required}$

Solution — Make peak of $v_f(t) \propto V$.

But then $v_c(t)$ has to be limited (i.e saturated at) at slightly less than $V \times V_R$ (V in pu, V_R is the voltage needed to represent rated current from TCR)

To generate $v_f(t)$



Take $\tilde{\tau}_p = 0.1$ ms Then RC can be 1 ms.

Let $V_R = 5V$.

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