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Implementation of Series Capacitors for Controlling Voltage Reversal by using Thyristors

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Abstract: Set payment in television broadcasting queues is an efficient and even less expensive process of helping the energy television broadcasting structure performance. Set capacitors basically cuts the duration of the road making it simpler to help keep each of the parts in the energy structure going throughout synchronism as well as to continue to keep a relentless electric potential level all over the system. Found in Sweden fractional treatments have been around work with due to the fact almost 70 years.

Typically the possible ways to enhance the overall performance belonging to the AC television broadcasting system by using energy electronics has become outlined quite a lot due to the fact around ten years. Newer and more effective semiconductor cantered thoughts have been completely created anyway, they the due to the fact rather long started HVDC and even SVC technologies. Typically the Thyristor Controlled Set Capacitor (TCSC) will be the kind of concept. By means of differing all the placed reactance a fast and even well-defined affect all the energetic energy amount throughout the television broadcasting lines are obtained. Many opportunity software programs, especially power oscillation damping, reap some benefits because of this capability. The reasoning behind recommended the need to develop a good semiconductor device, and these can be placed exclusively in all the high-voltage energy circuit. This specific clearly written a good complex test but all the uncomplicated deal with seemed as being a host cost-effective alternate with smaller losses. This have also been pointed out that all the TCSC illustrates somewhat totally different thinking by using respect in order to sub synchronous number elements throughout the road up-to-date along with the mounted show capacitor bank. This specific would have been a worth it to read facet for the reason that hazard of sub synchronous sonority (SSR), of which basically comprises many of these wire current elements, comes with distracted the usage of show payment throughout energy systems applying winter bringing in plants. Typically the dissertation specials when using the modelling and even manage issues with TCSC.

Some simplifying idea, all the same, instant electric potential change, will be coming to represent the act of all the thyristor restricted inductive division, that is associated in analogue when using the show capacitor bank or investment company on the TCSC. An excellent electric potential change is widely used on the dissertation as a way to refer to and even demonstrate all the TCSC character, to research it has the very clear impedance within diverse wavelengths, as the software for synthesizing all the supercharge manage structure and because the platform aspect in deriving a additive, small-signal dynamical type of all the three phase TCSC. Quantitative Reviews Principles (QFT) therefore has become hand-applied in the TCSC design so as to music it has the supercharge regulator taking into consideration the common type in parameters that may is actually in a very energy system. Typically the consequence belonging to the supercharge manage structure with regard in order to damping in SSR will be last but not least currently being quickly investigated at. Keywords and phrases: Thyristor Restricted Set Capacitor, TCSC, FACTS, responsive power payment, supercharge manage, phasor evaluation, Quantitative Reviews Principles, sub synchronous sonority, SSR.

Keywords: TCSC, QFT, Phasor, SSR.

I. Introduction

For quite a while the effective use of vitality electronic products roughly vitality transmittal instruments has become designed to Sizeable Increased Electromotive force Guide Most recent (HVDC). By means of who 1970'ies Plain-ole Var Compensator (SVC) has become located so that you can manage to give you reactive vitality expertise aside from would-be cope with using the network. Everything revealed overall occupation request roughly transmittal instruments and also terrific personal economic plants. These brief control in significant ability semiconductors in the 80'ies supplied forwards jolting thyristors great at caution large voltages aside from strong short currents. As of the amazing study passion were definitely remaining initiated within several various areas by around work youngster should be increase AC transmittal merchandise wedding party thoroughly discover vitality gadgets to control would-be,

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consideration aside from present this type of systems. Plenty of resourceful strategies were definitely remaining encouraged, this type of features who Thyristor Managed Set Capacitor (TCSC).

The particular encouraged by employing TCSC has become affiliated with vitality rotate cope with, but it really definitely has become immediately said who the device could also be a good way for using damping together with electromechanical vitality oscillations. One more conceivable using TCSC originated upward around the data may very well give you line destroys absence getting relating to the same possibility intended for submission synchronic ringing (SSR) even while a regular line capacitor. While in the TCSC hypothesis who thyristor manage machine will be connected steer roughly line with the transmittal sectors aside from due to this fact perhaps it's nicely determined towards almost everyone finished voltages displaying by them self using the system. That is why the main head to, and also the serps air conditioning, calls for massive underlay overall secondary, what this means is them could deal with nerve organs impetus medical tests by would-be amplitudes thoroughly looking over 1000 kV. This phenomenal must have been a take a look at even while previous vitality camera machine bought long been coupled to the large would-be head to with their own private special transformers. Really, who take a look at perhaps makes an occasion, just because lowering basic need meant for an important place interfacing transformer, intended to existing vast expense aside from profits/losses, creates who TCSC an important fiscally exciting process by smaller losses.

II. Physics of Reactive Power:

The main topic of the dissertation is undoubtedly Thyristor Regulated Sequence Capacitors it offers predominantly considering the benefits of like devices. Especially some deal with system given its name Synchronal Potential Volte-face might be handled throughout detail. In spite of this, prior to when coming into the preferably precise field it is correct to grant a simple backdrop about the difficulties to do with responsive energy eating throughout energy transmission system programs throughout general.

A number of people context responsive power as a new soft theory, approximately synthetically made with numerical considerations. With the rest of it items some sort of rendering in whatever responsive energy is undoubtedly regarding bricks-and-mortar phenomena. The reason promptly details whatever responsive energy payment means that and just how it may possibly be implemented. In such a dissertation the particular topic might be confined towards inductive responsive energy eating throughout transmission system ranges attributed to force current. Much the same rendering could be exercised for your capacitive responsive energy generating promising through the energy arena between level conductors if the road is undoubtedly empowered rich in voltage.

Magnetic fields associated with transmission lines

Physical science educates who shift with power together the latest transmittal range is obviously relating to charismatic together with electrical power domain energy. Some charismatic domain encompasses the entire period conductor when ever all present-day comes where phase. The sector muscle is usually relative to the present and also the domain is usually passed out within spot so your domain muscle is usually substantial at the conductor floor also it minimizes speedily with the help of the length of your conductor. Shape 1 shows all the charismatic domain muscle together with number 2 describes all the charismatic energy levels density distribution within spot with the environment with a 3 period transmittal range possessing two to three bundled up conductors within every different period together with set with symmetric current. This is a overview considered after the period N present-day peaks. Several uppr diagrams left tell us all the instant period currents.

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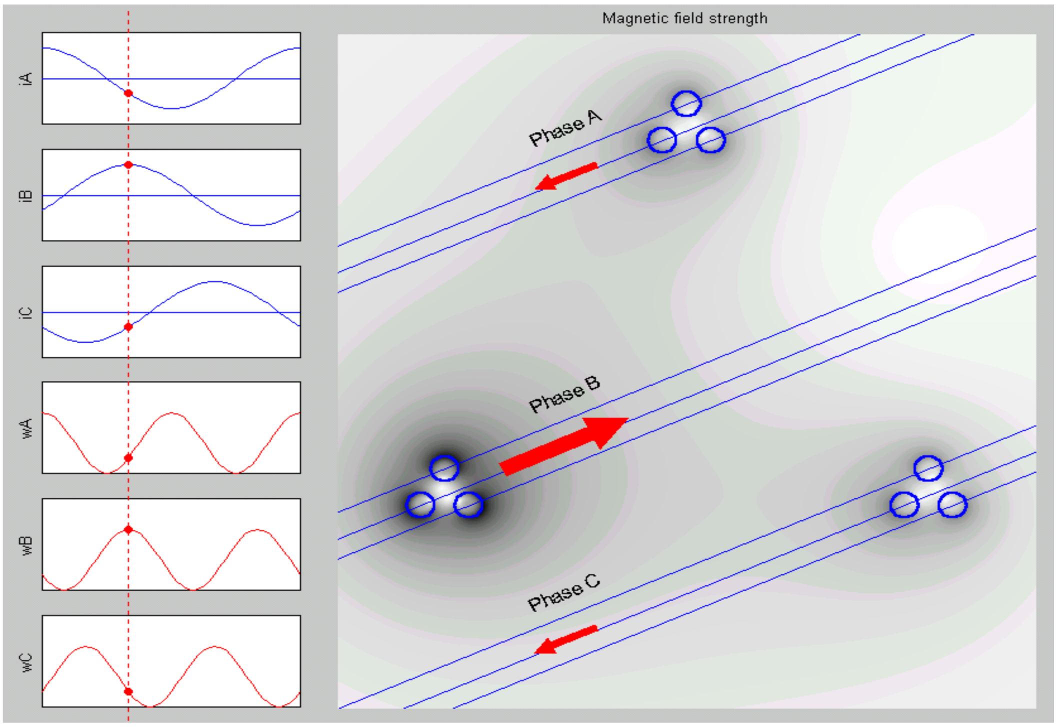

Figure 1: Magnetic field strength around a transmission line.

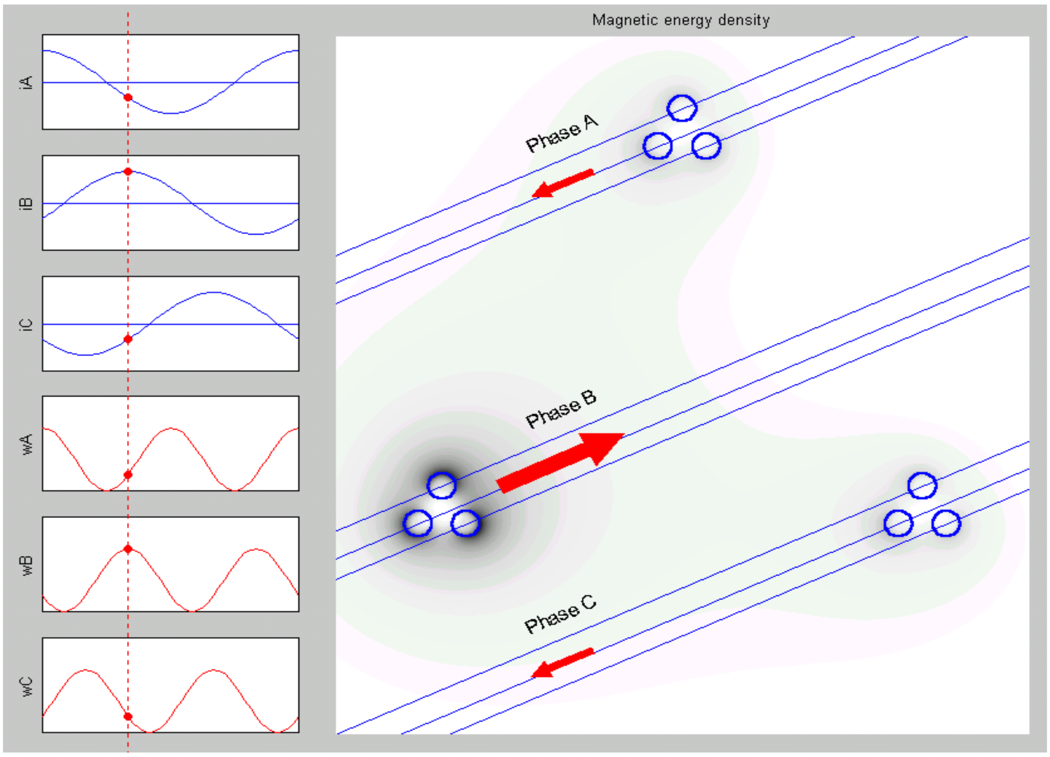

Figure 2: Magnetic energy density around the line.

The energy density is proportional to the square of the magnetic field strength and accordingly is even more concentrated around the conductors in each phase. We may conclude that the magnetic energy is more or less bound to the phase conductors. The three lower diagrams to the left in figure 2 show the energy associated with each phase in the line. The energy is proportional to the square of the instantaneous phase current. It can easily be confirmed that the total magnetic energy per unit length is constant in time at symmetrical load. However this constant total energy is being redistributed between the phases during each half cycle of the network frequency.

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Redistribution of magnetic field energy in transmission lines

Consider certain, e.g. 100 km long, segment of a transmission line. It contains three phase conductors running in parallel but separated from each other by only some tens of meters. Yet no bridges exist between the phase conductors where field energy bound to one phase may pass and bind to another phase. Thus no redistribution between the phases of magnetic field energy is possible within the considered segment. Accordingly, in order to perform the redistribution of the field energy between the phases, the whole field energy must be transported along the transmission line to a location, where such bridges are available. It may appear that bridges only exist at the line terminal(s) through the feeding source(s). Figure 3 illustrates this situation.

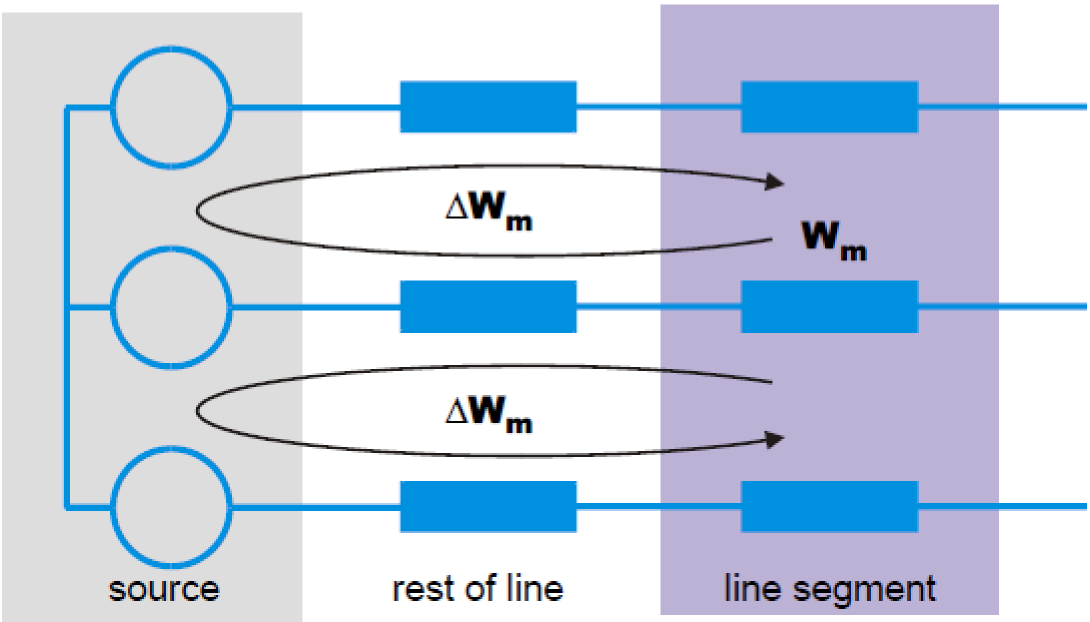

Figure 3: Redistribution of magnetic field energy.

In fact it can be concluded that in a long transmission line the field energy will have to be transported hundreds of kilometers in order to be redistributed to its neighbor phase conductor which runs some tens of meters away. And this transport is effectuated twice per cycle of the network frequency. When the line current is high and/or when the transmission line is long a large portion of the driving source voltage is necessary to accomplish the redistribution of field energy and therefore a voltage drop occurs along the line. The constant of nature *μ0=1.26 mH/km* implies that each conductor in an overhead transmission line exhibits an inductance in the range of *1 mH/km*. The magnetic energy associated with each phase conductor illustrated in figure 2 then peaks at *wm=2.2 kJ/km* when the line carries *1500 A rms*. This figure translates to a reactive power consumption in the line of *QL=3ωNwm=2.1(2.5) Mvar/km* at *50 (60) Hz.* It appears that the reactive power consumption in the transmission line is considerable for lines having a length of some hundred kilometers. Further the reactive power consumption is proportional to the square of the load current, thereby limiting the practically useful line current rating to a few kilo amperes.

Reactive power compensation

The discussion above indicates that any means that substitutes the need for transport of field energy will improve the performance of the transmission system. There are two obvious principles, which can be applied to do this.

➢ The first principle, shunt compensation, is illustrated in figure 4. Bridges have been provided along the transmission line where field energy associated with different phases may be exchanged. Different kind of shunt compensators can be utilized. The energy may either be temporarily stored as electrostatic energy in shunt capacitors or it may be periodically redirected by means of power electronic devices like voltage source converters (VSC)

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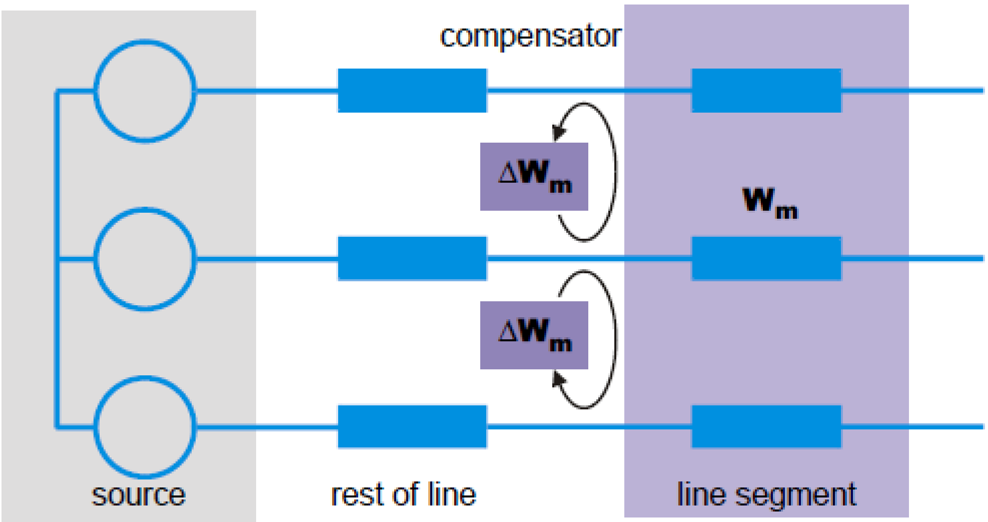

Figure 4: Principle of shunt compensation

➢ Figure 5 depicts the second principle, series compensation, where a storage device for the field energy has been provided in each phase. Instead of being transported the field energy is stored locally during the quarter cycle when the line current is low. Then it is returned during next quarter cycle, when the line current is high.

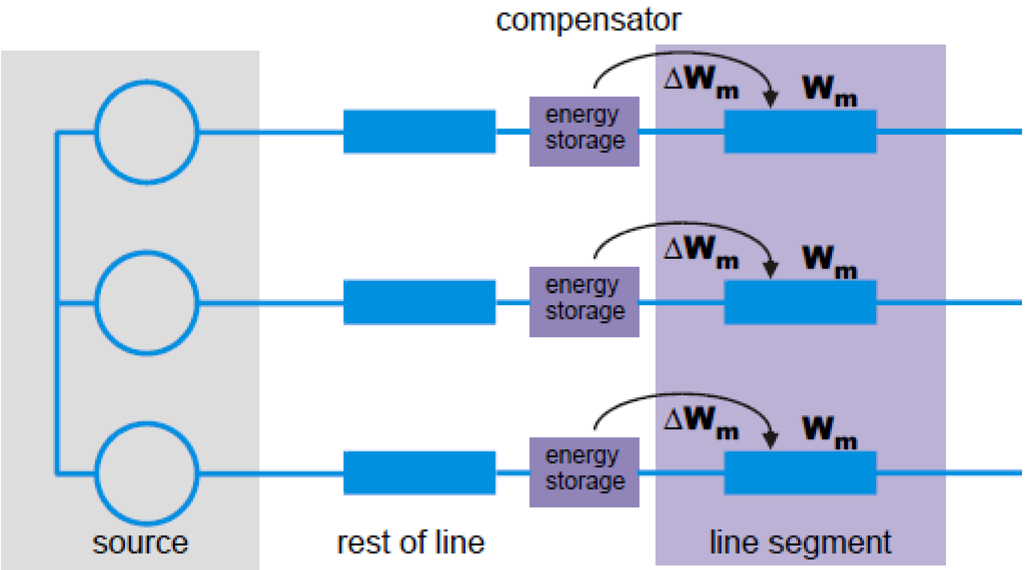

Figure 5: Principle of series compensation.

The energy storage devices in figure 5 may be implemented as passive capacitor banks as shown in figure 6.

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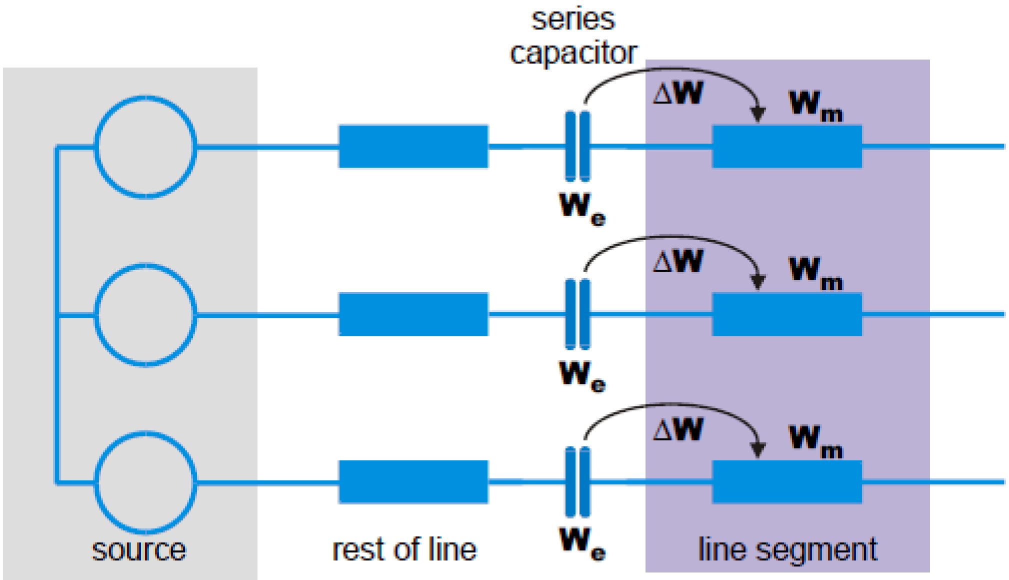

Figure 6: Passive capacitor bank as temporary energy storage.

The voltage across the capacitor opposes the movement of the magnetic energy along the transmission line, which reduces the voltage drop. Let the line current be sinusoidal

$$i(t) = \hat{I}_L \cos \omega_N t \qquad (2\text{-}1)$$

Then the capacitor voltage is

$$u_C(t) = \hat{U}_C \sin \omega_N t$$
$$\hat{U}_C = \frac{\hat{I}_L}{\omega_N C} \qquad (2\text{-}2)$$

The energies then become

$$w_m = \frac{L\hat{I}_L^2 \cos^2 \omega_N t}{2} = \frac{L\hat{I}_L^2}{4}(1+\cos 2\omega_N t)$$
$$w_e = \frac{C\hat{U}_C^2 \sin^2 \omega_N t}{2} = \frac{C\hat{U}_C^2}{4}(1-\cos 2\omega_N t) \qquad (2\text{-}3)$$

The opposite signs of the time-varying term in the magnetic and electrostatic energies indicate that compensation really comes about. Further the proportionality between the line current amplitude and the capacitor voltage amplitude indicates that the compensation is self regulating.

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III. Methods and Results: Topology, Parameters, Notation

In our analysis we shall first look at the waveforms in steady state operation. In this study we consider the simple main circuit according to figure 7.

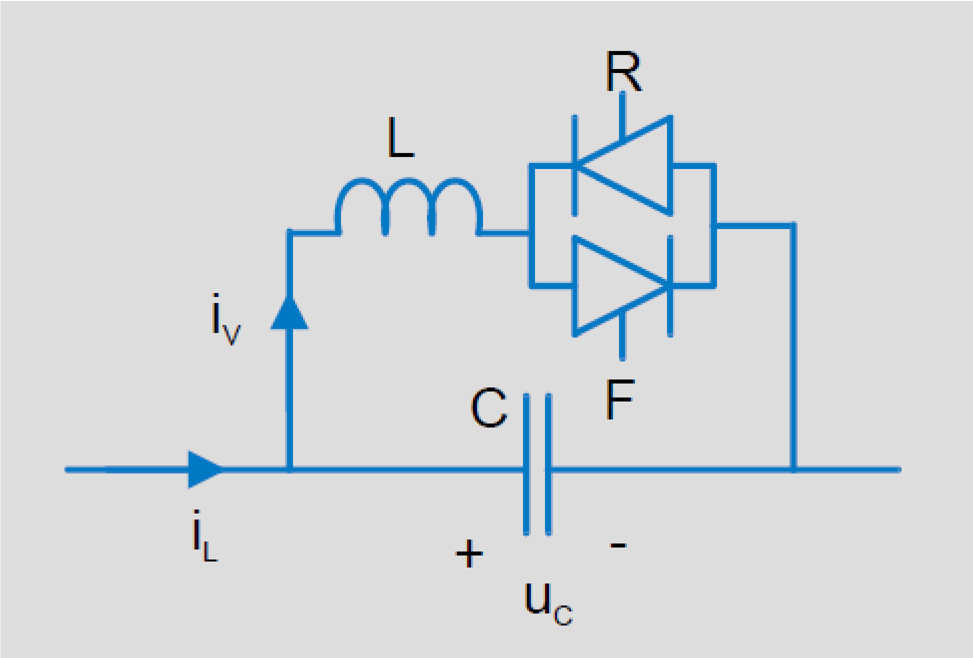

Figure 7: TCSC main Circuit

The reference directions of currents and capacitor voltage have been indicated in figure 7. These references are used throughout this thesis. The thyristor carrying conducting current in the positive direction is marked with an '*F*', for FORWARD direction. It can only be triggered when positive capacitor voltage exists. Correspondingly the *'R'* thyristor, the REVERSE thyristor, conducts current in the negative direction and can only be triggered, when the capacitor voltage is negative. The capacitance of the bank in each phase is *C* and the inductance in the thyristor branch is *L*. These two branches together form an *LC* circuit with the resonance frequency ω_0

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{3-1}$$

The reactance in the capacitor bank and in the inductor have equal magnitude reactance X_0 at their common resonance frequency

$$X_0 = \omega_0 L = \frac{1}{\omega_0 C} = \sqrt{\frac{L}{C}} \tag{3-2}$$

For proper functioning of the TCSC it is necessary that $\omega_0 > \omega_N$, where ω_N is the network frequency. The quotient between the resonance frequency and the network frequency is a design parameter, which we will denote as λ in the analysis. Its definition is given in (3-3).

$$\lambda = \frac{\omega_0}{\omega_N} = \frac{\frac{1}{\omega_N C}}{X_0} = \frac{X_0}{\omega_N L} \tag{3-3}$$

Typical values of λ fall in the range *2 - 4*.

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Formulas for Steady State Operation: Assumptions, angle definitions

The normal operating mode of a TCSC is known as "capacitive boost mode". The generic waveforms in steady state of this mode are shown in figure 8. It is assumed that the line current *iL* is sinusoidal; this assumption is justified by the fact that line current in high voltage transmission systems normally is not very much polluted by harmonics. The waveform of the line current also is rather little influenced by any harmonic distortion in the series capacitor voltage due to the comparatively high impedance in the transmission line at higher frequencies. Further the losses in the circuit have been neglected.

The thyristor is triggered when the capacitor voltage is approaching the zero line before zero crossing occurs. If the line current is positive the capacitor voltage changes from negative to positive, so that the REVERSE thyristor will be forward biased before the zero crossing. When it is triggered the valve current becomes negative and adds to the line current when it passes through the capacitor. Thus an extra charge will be pushed into the capacitor from the thyristor branch in addition to the charge provided by the line current. In this way an extra voltage, the boost voltage, will appear across the capacitor.

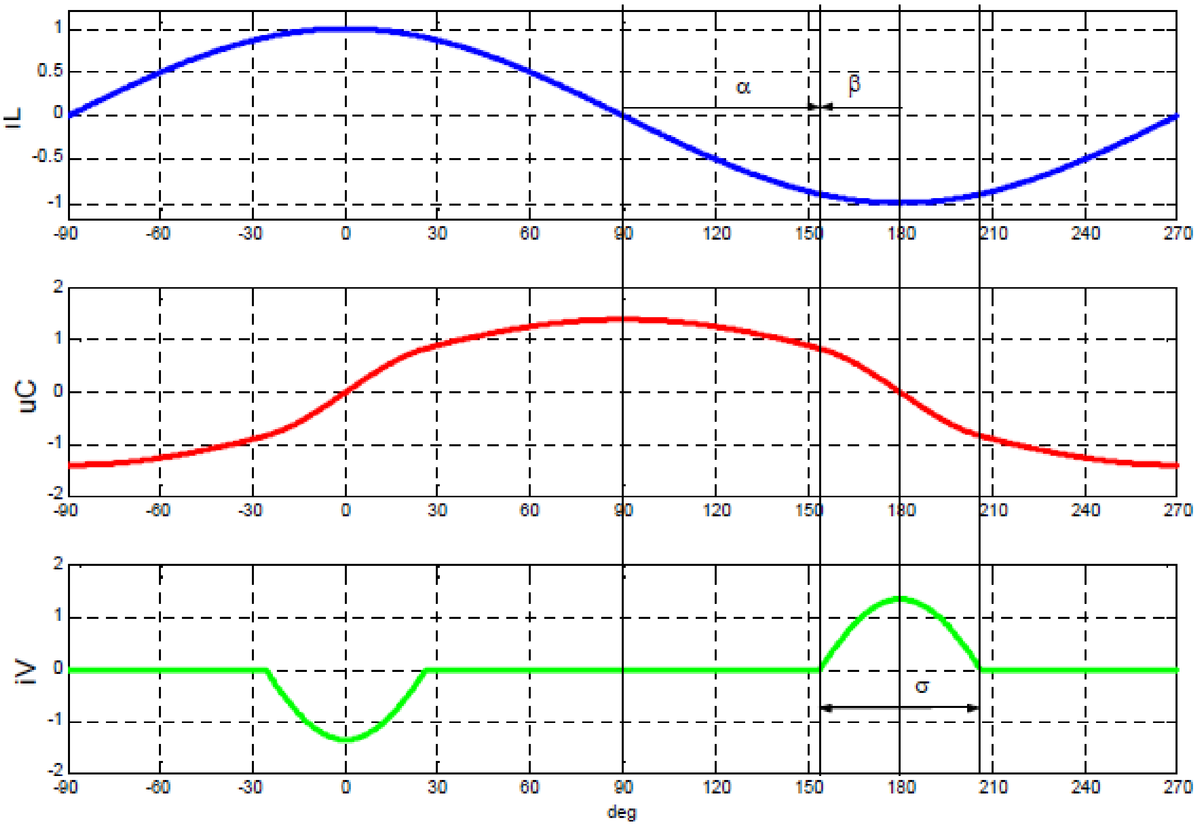

Figure 8: Generic waveforms for TCSC operating in capacitive boost mode.

In the study of steady state conditions the thyristor trigger angle α (shown in figure 8) can be used as the control parameter. Like in other line-commutated converters α is referred to the earliest instant when forward voltage appears across the thyristor. In capacitive mode operation the trigger angles is around 140-180°. Often it is more practical to use the control angle β (shown in figure 8). It is related to α by the expression

$$\alpha = \pi - \beta \qquad (3\text{-}4)$$

Also the conduction angle σ (shown in figure 8) appears in formulas in the literature about TCSC. Obviously

$$\sigma = 2\beta \qquad (3\text{-}5)$$

It should be noted that, although the definition of α was referred to the zero crossing of the capacitor **voltage**, in practice the phase information to be used for synchronization is always derived from the line **current**, i.e. the angle used in practice is rather α-π/2, which is also shown in the figure.

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IV. CONCLUSION

It has been shown above that the model derived in this chapter provides some very interesting results with respect to the conditions for SSR when series compensation is provided partly or totally by means of TCSC. The use of the SVR scheme has some important advantages over conventional direct control of the firing angle of the thyristors

- The electrical damping is mainly determined by the inherent characteristics obtained by using the SVR algorithm to determine the thyristor firing instants
- The tuning of the regulators and synchronization system then becomes less critical for the SSR behaviour
- Linear controllers can be used in the boost regulator minimizing the dependence of parameters
- The characteristics of the TCSC behaviour with respect to SSR to a large extent is independent of the boost factor
- The TCSC can provide adequate SSR behaviour even when it operates with low boost factor

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