Mitigation Of Sub Synchronous Resonance (Ssr) Oscillations By Using Thyrister Controlled Series Capacitor (Tcsc).

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Abstract :

The proposed series capacitive compensation scheme is effective in damping power swing as well as sub synchronous resonance oscillations. The combination of fixed series capacitor and TCSC is termed as a Hybrid technique. A "hybrid" series capacitive compensation scheme in damping power system oscillations effectiveness is described in this paper. The compensation of three-phases is done separately, two-phases are done by fixed series capacitor, and third phase is compensated by TCSC in series with fixed capacitor. The advantage of proposed technique is damping power system oscillations for various system conditions. The performance of proposed technique is verified by simulation design in MATLAB/simulink software.

Key words :

FACTS controllers, hybrid series compensation, power system stability, series compensation, thyristor controlled series capacitor (TCSC).

I.Introduction

Flexible AC Transmission Systems (FACTS) technology provides unprecedented way for controlling transmission grids and increasing transmission capacity [1]. FACTS Controllers provide the flexibility of controlling both real and reactive power which could result in an excellent capability for improving power system dynamics. A problem of interest in the power industry in which FACTS controllers could play a major role is the mitigation of Sub Synchronous Resonance (SSR) oscillations [2]. SSR is a dynamic phenomenon in the power system which has certain special characteristics. Series capacitive compensation is the potential risk of sub synchronous resonance (SSR), where electrical energy is exchanged with a generator shaft system in a growing manner which may result in damage of the turbine-generator shaft system. Therefore, mitigating SSR has been and continues to be a subject of research and development aiming to develop effective SSR counter measures. The recently proposed phase imbalanced series capacitive compensation concept has been shown to be effective in enhancing power system dynamics as it has the potential of damping power swing as well as sub synchronous resonance oscillations [3].

A phase imbalanced capacitive compensation is a "hybrid" series compensation scheme, where the series capacitive compensation in one phase is created using a single-phase TCSC in series with a fixed capacitor (Cc), and the other two phases are compensated by fixed series capacitors (C). The schematic diagram of the hybrid series compensation scheme is shown in fig.1. The TCSC control is initially set such that its equivalent compensations at the power frequency combined with the fixed capacitor yield a resultant compensation equal to the other two phases. Thus, the phase balance is maintained at the power frequency while at any other frequency, a phase imbalance is created. To further enhance power oscillations damping, the TCSC is equipped with a supplementary controller.

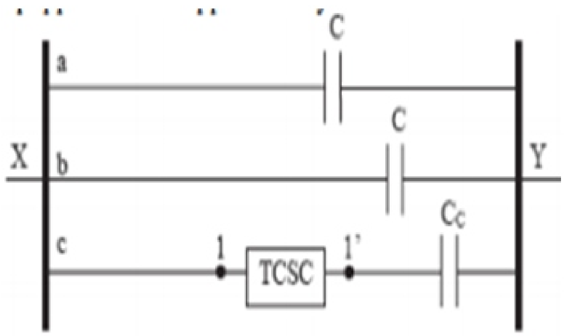


Fig.1. schematic diagram of the hybrid series compensation scheme.

The phase imbalance of the proposed scheme can be explained mathematically as follows:

1)At the power frequency, the series reactances between buses X and Y, in Fig.1, in phases a, b, and c is given by:

$$X_a = X_b = \frac{1}{jw_o c} \qquad -(1)$$

$$X_c = \frac{1}{jw_o c} - jX_{TCSCo} \qquad -(2)$$

Here

$-jX_{TCSCo}$ Is the effective capacitive reactance of the TCSC at the power frequency such that $X_a = X_b = X_c$.

2) During any other frequency

$$X_c = \frac{1}{jw_o c} - jX_{TCSCo} - j\Delta X_{TCSC} \qquad - (3)$$

Here

ΔX_{TCSC} - The change in capacitive reactance of the TCSC due to action of TCSC supplementary controller.

This paper is organized as follows; In Section2, the proposed test power system model is resented. Section 3 describes the designing of single–phase TCSC. In section 4 the simulation results are described. Finally, in section 5 the conclusion is presented

I.Test Power System Model:

To demonstrate the effectiveness of the proposed model in power system oscillations damping, the system shown in Fig.3 is adopted as a test model. It consists of three large generating stations (G1, G2 and G3) supplying two load centers (S1 and S2) through five 500 kV transmission lines. The two double-circuit transmission lines L1 andL2 are series compensated with fixed capacitor banks located at the middle of the lines. The compensation degree of L1 and L2 is 50%. The compensation degree is defined as the ratio (XC/XL)* 100% for fixed capacitor compensated phases and (XCc+XTCSC)/XL* 100% for the hybrid compensated phase.

The total installed capacity and peak load of the system are 4500 MVA and 3833 MVA respectively. Shunt capacitors are installed at buses 4 and 5 to maintain their voltages within 1±0.05 p.u. Two loading profiles designated as Load Profiles A and B are considered in the investigations of this paper. In Load Profile A, S1 = 1400 + j200 MVA and S2 = 2400 + j300 MVA while in Load Profile B, S1 = 2000 + j200 MVA and S2 = 1800 + j300 MVA. The power flow results for the bus voltages and the line real power flows of the system for these two loading profiles are shown in the Appendix. The EMTPRV is used as the simulation study tool.

II.Designing Of Single –Phase Tcsc:

The single-phase TCSC is modeled in the EMTPRV as a single module using an ideal thyristor pair and an RC snubber circuit as shown in Fig. 2. A Phase Locked Loop (PLL) is used to extract phase information of the fundamental frequency line current, which will be used to synchronize TCSC operation. The thyristor gating control is based on the Synchronous Voltage Reversal (SVR) technique [4]-[6].

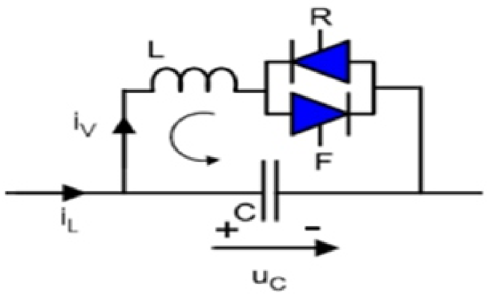


Fig.2. TCSC main circuit

The TCSC impedance is measured in terms of a boost factor kB, which is the ratio of the apparent reactance of the TCSC seen from the line to the physical reactance of the TCSC capacitor bank.

A positive value of kB is considered for capacitive operation. A low-pass filter based estimation algorithm is used to estimate the voltage and the current phases. A boost measurement block performs complex impedance calculations for the boost factor of the TCSC as:

kB = Imag[V^C / I^C]/ XCTCSC

Here

V^C and I^C are the estimated phase voltage and current and

XCTCSC is the capacitive reactance of the TCSC capacitor branch at the fundamental frequency.

A proportional-integral (PI) control based boost level controller is implemented to control the TCSC boost level to the desired value by adjusting the instant of the expected capacitor voltage zero crossing. The integral part of the controller helps in removing the steady state errors. The controller parameters were determined by performing repeated time domain simulations for the different operating conditions. This algorithm uses the difference between the actual boost level and the reference boost level (err) shown in Fig.4 as an objective function.

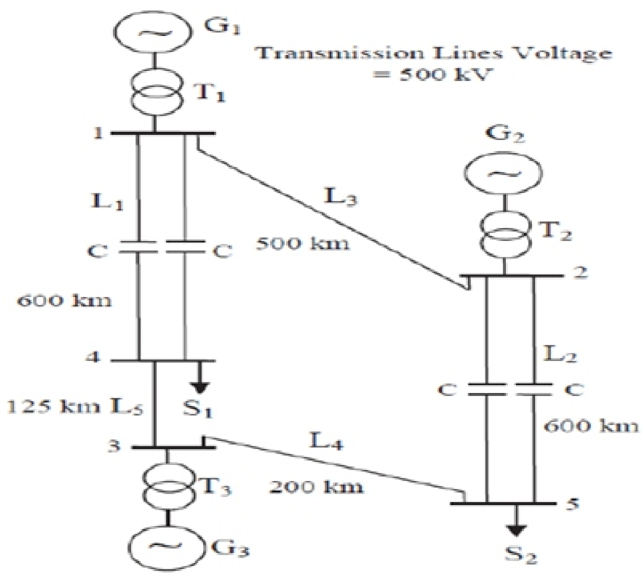


Fig.3. test model of power system.

The algorithm starts with arbitrary initial values for the control parameters and calculates the values of the objective function each time. The control parameters are incremented for the next iteration and the procedure is repeated until the objective function approaches a minimum value (below a threshold value). The procedure described above is widely used by industry for tuning of controller parameters.

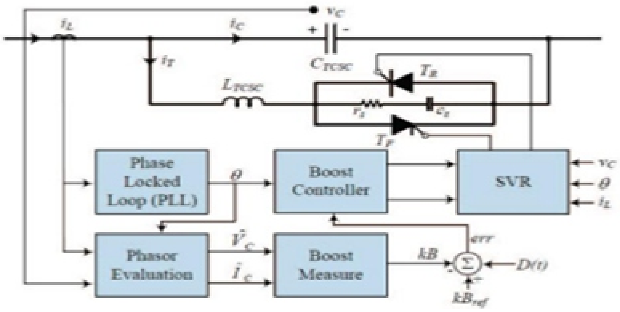


Fig.4. Block diagram of TCSC controller.

The supplemental signal generated from m-stage lead-lag compensation based controller is represented by D(t) in fig.4. As the real power flow in the transmission line is proportional to the inverse of the total line reactance, the power swing damping can be achieved by properly modulating the apparent TCSC reactance through this controller.

The supplemental controller input (stabilizing) signals could be local (e.g. real power flows) or remote (e.g. load angles or speed deviations of remote generators). If a wide-area network of Synchronized Phasor Measurement (SPM) units is available, then the remote signals can be downloaded at the controller in real time without delay. Local signals are generally preferred over remote signals as they are more reliable since they do not depend on communications.

In Fig. 5, kBref is the TCSC boost level set point. The Synchronous Voltage Reversal block solves for angle γ from the non-linear relation,

uCZ = XoiLM [λγ – tan(λγ)]

Here uCZ is the estimated capacitor voltage at the desired instant when the capacitor voltage zero crossing occurs,

iLM is the measured value of the line current iL, Xo is the TCSC capacitor reactance at the TCSC resonance frequency,

λ is the ratio between the TCSC resonance frequency and the system fundamental frequency and

γ is the angle difference between the firing time and the voltage zero-crossing.

The value of γ is used to calculate the exact firing instants of the individual thyristors.

III.Simulation Results:

This section demonstrates the capability of the proposed hybrid series compensation scheme in power system oscillations damping.

For this purpose, the scheme is assumed to be placed in the test scheme replacing the fixed series capacitive compensation in L1 and L2. Moreover, it is assumed that each TCSC provides 50% of the total capacitive compensation and the disturbance is a three cycles, three-phase fault at bus 4. Furthermore, the performance of the scheme is compared with only fixed capacitor compensation (fixed C).

Fixed compensation:

In this test four different combinations of stabilizing signals are examined (see table 1) in order to determine the combination that would result in the best system transient time responses. The final results of the time-domain simulation studies (controllers tuning) are shown in Fig. 7 which illustrates the generator load angles, measured with respect to generator 1 load angle, during and after fault clearing. The simulation model for fixed TCSC compensation is shown in fig.5.

combination	TCSC in L1	TCSC in L2
1	δ_{21}	δ_{21}
2	δ_{31}	δ_{21}
3	δ_{31}	P_{L2}
4	P_{L1}	δ_{21}

Table 1:

It can also be seen from Fig. 8 that the best damping of the relative load angle responses are achieved with the δ21- δ21 combination. The second best damped responses are obtained with the δ31-δ21 combination. These results should be expected due to the direct relationship between the relative load angles and the generators that yield the problem. It can also be seen from Fig. 9 that the worst damped responses are obtained with PL1- δ21combination which results also in the increase of the first swings.

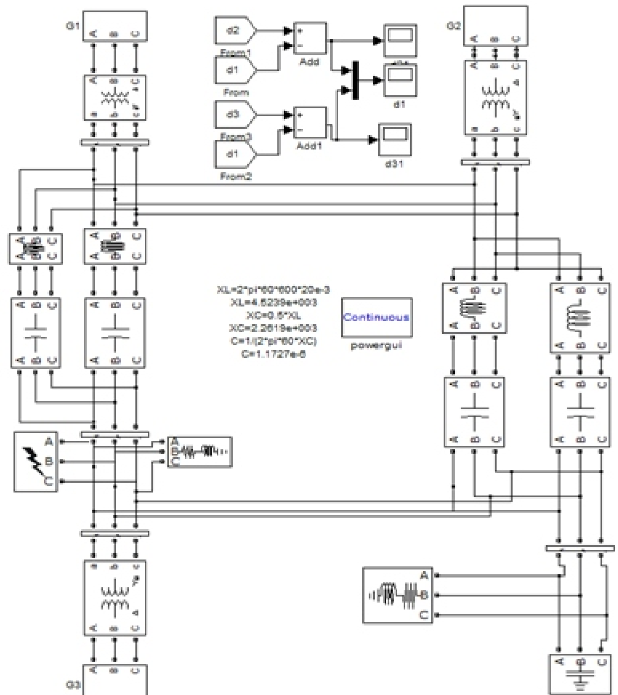


Fig.5. simulation model of fixed TCSC compensation technique

Hybrid TCSC compensation:

In this case, δ21 is used as the supplementary controllers stabilizing signal. Fig.9 illustrates the generator load angles, measured with respect to generator 1 load angle, during and after fault clearing. It can be seen from Fig.9 that, at this loading profile, the hybrid single-phase TCSC scheme provides to system oscillations compared to fixed capacitor compensation. It is observed, however, that there is a slight increase in the first swing of δ21.
In another case Any of the four signals, δ21, δ31, PL1 and PL2 contains the system's two natural modes of oscillations and can be used to add damping to these modes as it has been demonstrated in Test Case I. it is a dual channel controller, in this The sum of two properly selected signals, however, should result in a more effective damping.

The reason is that the two natural modes of oscillations are, in general, not in phase. A dual-channel controller would adjust separately the gain and phase of each mode of oscillations and, thus, provides a better damping. The results shows that the best and second best damped responses are obtained with δ21 PL1 and δ31 PL2 the generator load angles, measured with respect to generator1 load angle, during and after fault clearing.

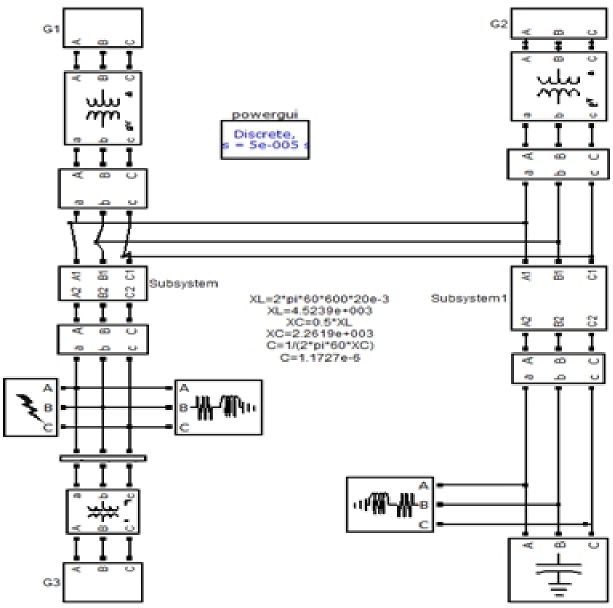
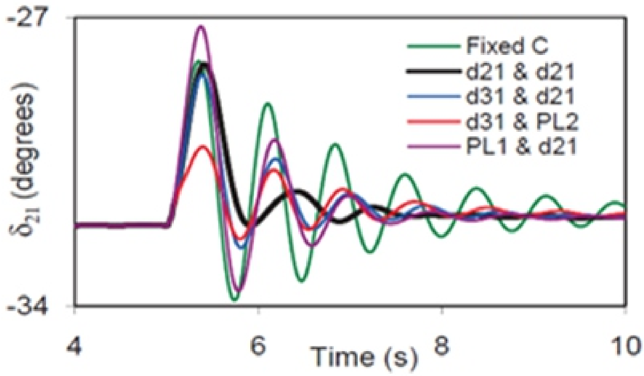


Fig.6. simulation model of hybrid TCSC compensation technique.



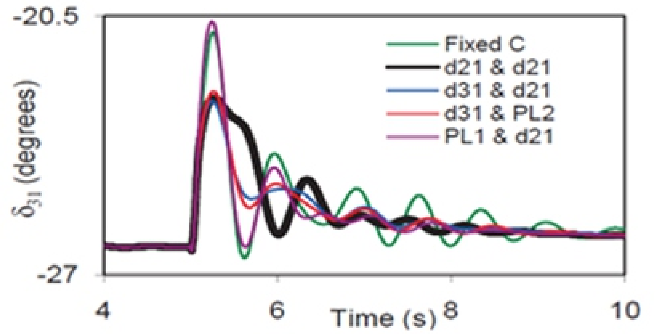


Fig.7. Generator load angles, measured with respect to generator 1 load angle, during and after clearing a three-phase fault at bus 4 (Load Profile A).

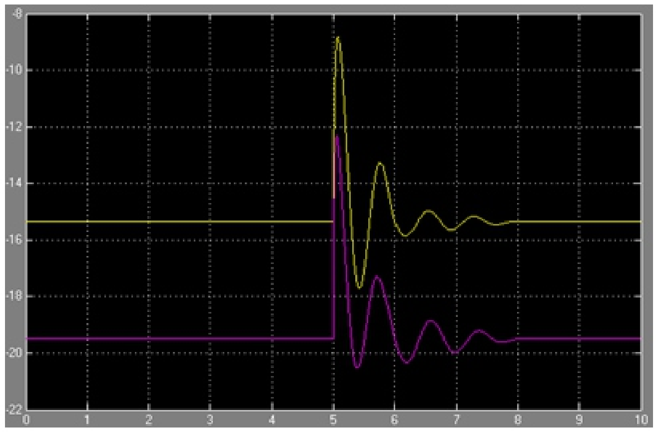
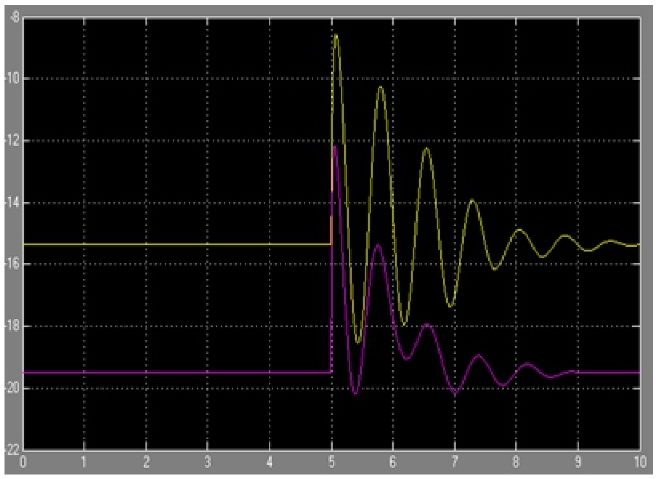
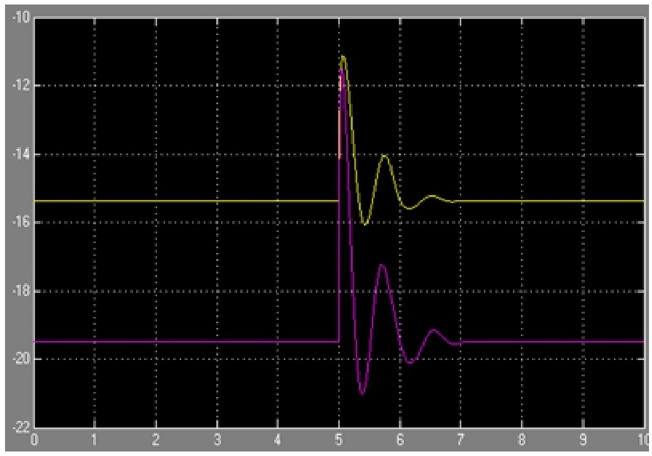


Fig.8. Generator load angles, measured with respect to generator 1load angle, during and after clearing a three-phase fault at bus 4.





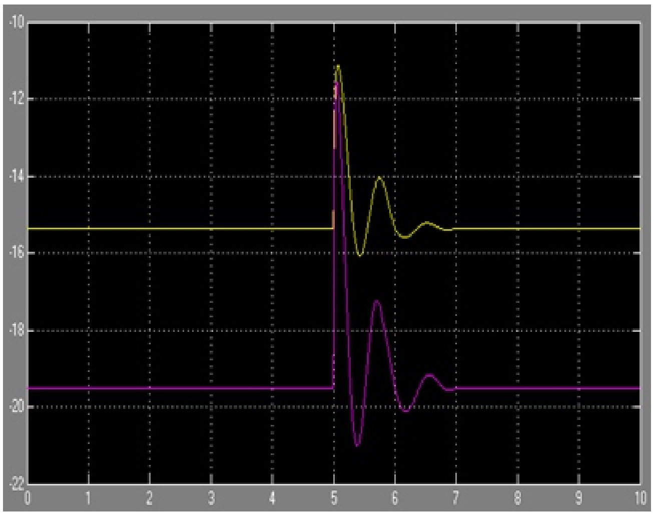


Fig.9.Generator load angles, measured with respect to generator 1 load angle, during and after clearing a three-phase fault at bus 4 (Load Profile B, dual-channel controller).

IV.Conclusion:

A new hybrid series capacitive compensation technique in damping power system oscillations is presented in this paper. The TCSC controller is used for the compensation, TCSC controller is operated at two conditions, and they are hybrid and fixed compensations. A proportional-integral (PI) control based boost level controller is implemented to control the TCSC boost level to the desired value by adjusting the instant of the expected capacitor voltage zero crossing. A Phase Locked Loop (PLL) is used to extract phase information of the fundamental frequency line current. The model power system is described in this paper for studying of Damping Power System Oscillations. The performance characteristics of the proposed TCSC technique are verified by model in MATLAB/simulink software.

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