Automatic Control of Thyristor Controlled Series Capacitor (TCSC)

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ABSTRACT

There are two types of FACTS controllers viz. series and shunt. Series compensation reduces the transmission line reactance in order to improve Power Flow through it, while shunt compensation improves the Voltage profile.

Among the FACTS devices, the TCSC controller has tremendous capability of giving the best results in terms of performance. This paper develops the control algorithm for automatic control for the developed working model of TCSC. This paper investigates the effects of TCSC on synchronous stability and voltage stability improvement. Stability of the System has been assessed using P-δ and P-V Curves. The experimental test results shows the improvement in both synchronous and voltage stability margins.

KEYWORDS : TCSC Controller, Design of small scale TCSC Model, Variable Series Compensation, FACTS Controllers, Single Machine Two bus System, Radial system model, Voltage Stability, P-V Curves and Power System voltage Stability.

I. INTRODUCTION

A power system is a network of electrical components used to supply, transmit and use electric power. The interconnected power system is known as the grid and can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating centres to the load centres and the distribution system that feeds the power to nearby homes and industries.

There are many losses while transmitting the power from generation stations to load centres. The focus is more on the occurrence of different kinds of instability. Voltage stability requirements and different techniques to improve the stability like the fixed compensation techniques and the dynamic compensation techniques. FACTS controllers which are the dynamic compensating devices which can be g used for better results.

In this paper, series compensation of TCSC (thyristor controlled series capacitor) is used. Closed loop control is achieved with the use of microcontroller. The firing angle control of TCR is obtained with the observation of the error voltages. P-V curves have been drawn with and without TCSC controller.

A power system is stable if it returns to a steady-state or equilibrium operating condition following a disturbance. This criterion shall hold true for all loading conditions and generation schedules under normal operating conditions; following either the loss of any power plant, or for the most severe network faults. In the planning and operation of a power system it is important to consider the potential emergence of a variety of stability problems.

Angle stability mainly involves the dynamics of generators and their associated control systems. Angle stability can be further categorized into transient stability and small signal or steady-state stability. Frequency stability is closely related to angle stability.
Voltage stability mainly involves the dynamic characteristics of loads and reactive power. Voltage Collapse is perhaps the most widely recognized form of voltage instability.

II. POWER SYSTEM STABILITY

II.1 CLASSIFICATION OF STABILITY

The stability of an interconnected power system is its ability to return to its normal or stable operation after having been subjected to some form of disturbance. The tendency of synchronous machine to develop forces so as to maintain synchronism and equilibrium is called stability. The stability limit represents the maximum stead state power flow possible when the synchronous machine is operating with stability. There are two forms of stability. One is synchronous stability and other is voltage stability. Synchronous stability can be assessed by using P-δ curve and voltage stability can be estimated using P-V curve as explained below.

II.2 SYNCHRONOUS STABILITY INDEX

P-δ curve

The relation between input power and the load angle is called power angle characteristics. The equation is given by, $P = EV\sin\delta / X$. The steady state stability limit is EV/X and it occurs at 90^o

II.3 VOLTAGE STABILITY INDEX

P-V curve

As the power transfer increases, the voltage at the receiving end decreases. Finally, the critical or nose point is reached. It is the point at which the system reactive power is out of use. The curve between the variation of bus voltages with loading factor is called as P-V curve or 'Nose' curve. PV curves are used to determine the loading margin of the power system. The margin between the voltage collapse point and the operating point is the available voltage stability margin.

III. SERIES COMPENSATION

A capacitive reactance compensator which consists of series capacitor bank shunted by a thyristor controlled reactor in order to provide a smoothly variable series capacitance reactance

III.1 Uncompensated Transmission Lines

Today's Interconnected Power Network is very large and has many lines, perhaps most of the lines are uncompensated leads to more reactive power losses subsequently poor voltage regulation. Some times it may leads to voltage instability and subsequently Collapse due to disturbances, sudden variations of load and contingencies. The main reason for the Voltage Collapse is due to lack of reactive power in the heavily stressed systems, Generator reactive power limits, the load characteristics, the action of the voltage control devices.

All these factors may lead to

- Limiting the Power Transfer capability of Un-compensated Lines
- May exceed the Line Limits subsequently line outages and may cause the cascading outages
- voltage instability and voltage collapse which may leads to partial blackout or sometime total blackout

III.2 Compensated transmission lines

When compensated transmission lines are involved, the required reactive power by the lines will be supplied or absorbed by the compensating devices which may be placed in series and/or in parallel with the transmission lines. The result of using the compensating devices is that the voltage instability does not occur. There are various types of compensating devices to be used according to the requirement like the shunt compensation and the series compensation.

FACTS controllers are the compensation devices which have gained very high importance as they are variable compensation devices.

IV THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

A capacitive reactance compensator which consists of series capacitor bank shunted by a thyristor controlled reactor in order to provide a smoothly variable series capacitive reactance

IV.1 OBJECTIVES

Shunt compensation is ineffective in controlling the actual transmitted power, which at a defined transmission voltage, is ultimately determined by the series line impedance and the angle between the voltages of line

- It is always recognized that ac power transmission over long lines was primarily limited by the series reactive impedance of the line.
- Series Compensators are quite affective to Improve Voltage Stability, Transient Stability, and Power Oscillation Damping and also to Mitigate SSR and Power Quality Problems.
- For the same level of compensation the Series Compensator size is quiet small compared to the shunt compensator perhaps the degree of series compensation is limited due to SSR and FR Problems.

IV.2 OPERATION OF TCSC

A TCSC is a series-controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range. From the system viewpoint, the principle of variable-series compensation is simply to increase the fundamental-frequency voltage across an fixed capacitor (FC) in a series compensated line through appropriate variation of the firing angle, α. A simple understanding of TCSC functioning can be obtained by analyzing the behaviour of a variable inductor connected in parallel with an FC. The equivalent impedance, Zeq, of this *LC* combination is expressed as

The impedance of the FC alone, however, is given by $-j(l/\omega C)$.

If $\omega C - (l/\omega L) > 0$ or, in other words, $\omega L > (1/\omega C)$, the reactance of the FC is less than that of the parallel-connected variable reactor and that this combination provides a variable-capacitive reactance are both implied.

If $\omega C - (1/\omega L) = 0$, a resonance develops that results in an infinite-capacitive impedance-an obviously unacceptable condition.

If, however, $\omega C - (1/\omega L) < 0$, the *LC* combination provides inductance above the value of the fixed inductor. This situation corresponds to the inductive-mode of the TCSC operation.

In the variable-capacitance mode of the TCSC, as the inductive reactance of the variable inductor is increased, the equivalent-capacitive reactance is gradually decreased. The minimum equivalent-capacitive reactance is obtained for extremely large inductive reactance or when the variable inductor is open-circuited, in which the value is equal to the reactance of the FC itself.

IV.3 IMPROVEMENT OF SYSTEM STABILITY LIMIT USING TCSC

Providing fixed-series compensation on the parallel path to augment power-transfer capability appears to be a feasible solution, but it may increase the total system losses. Therefore, it is advantageous to install a TCSC in transmission paths, which can adapt its series-compensation level to the instantaneous system requirements and provide a lower loss alternative to fixed-series compensation. The series compensation provided by the TCSC can be adjusted rapidly ensure specified magnitudes of power flow along designated transmission line. This condition is evident from the TCSC's effectively, that is, ability to change its power flow as a function of its capacitive-reactance setting:

$P = V_1 V_2 \sin\delta / X$ (1)

Where *P* = the power flow from bus 1 to bus 2.
V_1, V_2 = the voltage magnitudes of buses 1 and 2, respectively
X_l = the line-inductive reactance, X_c = the controlled TCSC reactance combined with fixed-series capacitor Reactance.
δ=the difference in the voltage angles of buses 1,2. This change in transmitted power is further accomplished with minimal influence on the voltage of interconnecting buses, as it introduces voltage in quadrature. The freedom to locate a TCSC almost anywhere in line is a significant advantage.
Power-flow control does not necessitate the high-speed operation of power flow control devices. Hence discrete control through a TSSC may also be adequate in certain situations. However, the TCSC cannot reverse the power flow in a line, unlike HVDC controllers and phase shifters.

IV.4 ADVANTAGES OF TCSC

Use of thyristor control in series capacitors potentially offers the following little-mentioned advantages:

- Rapid, continuous control of the transmission-line reactance
- Dynamic control of power flow in selected transmission lines within the network to enable optimal power-flow conditions
- Damping of the power swings from local and inter-area oscillations.
- Suppression of sub synchronous oscillations. At sub synchronous frequencies, the TCSC presents an inherently resistive-inductive reactance. The sub synchronous oscillations cannot be sustained in this situation and consequently get damped.

V DESIGN CRITERION OF TCSC

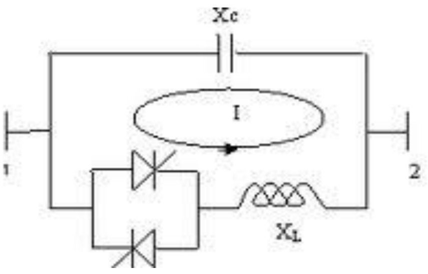

Fig.1 TCSC

Consider the Line reactance of the transmission line in per unit system.For 50% compensation, the value of the capacitor in the TCSC will be 50% of the line reactance. Now for capacitive compensation, the value of inductive reactance must be greater than capacitive reactance, that is, $X_l > X_c$

$X_{tcsc} = (X_l * X_c) / (X_l - X_c)$ (2)

Total reactance of the line with TCSC is

$X = X_l - X_{tcsc}$ (3)

$Q_{tcsc} = (I_c * I_c * X_c) - (I_{tcr} * I_{tcr} * X_l)$ (4)

The variation of reactive power demand with load variations are obtained as

Now, if Q_{dmin} = minimum reactive power demand
Q_{dmax} = maximum reactive power demand

$Q_{tcsc} = Q_{dmax} - Q_{dmin}$ (5)

$Q_{ref} = Q_1 = 1$ p.u (corresponding to voltage value of 1 p.u)

$V = V_{ref} = 1.0$ p.u

$Q_c = Q_{max} - Q_{ref}$ (6)

$Q_{tcr}(\alpha) = Q_{ref} - Q_{min}$ (7)

$Q_{tcsc} = Q_c - Q_{tcr}(\alpha)$

Therefore

$I_{tcr} * I_{tcr} * X_l = I_c * I_c * X_c - Q_{tcsc}$ (8)

Hence $X_l = (I_c * I_c * X_c - Q_{tcsc}) / I_{tcr} * I_{tcr}$ (9)

This is how the value of the inductive reactance in the TCSC circuit is calculated.

V.1 MODEL DESIGN

The design criterion for the present case to find the value of capacitance and inductance of a TCSC controller is based on the net reactance of the transmission line and power flow control through it. SMTB Test System is developed in the laboratory with a transmission line model of 0.2 p.u reactance. The design of TCSC is based on line reactance value, in the present case the compensation is limited to 50%. Hence take the fixed capacitive reactance value equal to 0.1 p.u, Take the value of X_C as 0.1 p.u

Line reactance is 61.1Ω

Actual X_C= % of compensation * line reactance
=0.5*61.1=30.55Ω

$X_C = 1/2\pi fC$

$C = 1/2\pi X_C = 1/2\pi*50*30.55$ (10)

C = 0.1mF

In the above circuit X_C is in parallel with X_l

$Q_C = 150^2/30.55 = 735$ Var (11)

$Q_{TCR} = 735 - 240 = 495$ Var

$Q_{TCR} = 495 = 150^2 / X_L$

Therefore, $X_L = 45.45\Omega$ (12)

$X_L = 2\pi fL$

L = 144mHenries (13)

Practical Design:

L = 150mH
C=1 KVAR

The above ratings are chosen based on the availability.

VI CASE STUDY: TEST RESULTS

SMTB system without TCSC

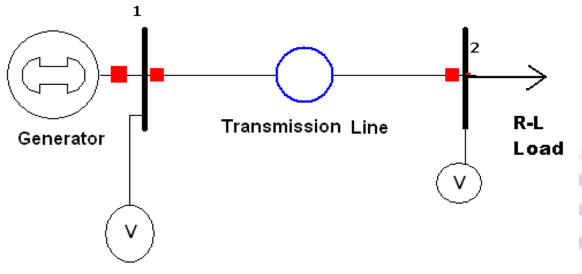

Fig.2 SMTB system without TCSC

CASE 1

This case is considered when the infinite bus is feeding the load through a line without any compensation.

CASE 2

Generator feeding the load through Transmission Line Model with TCSC.

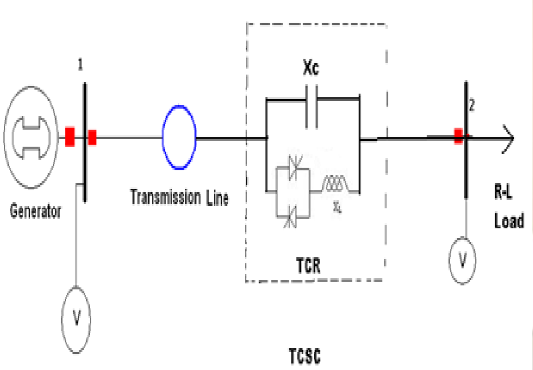

Fig.3 SMTB system without TCSC

VI.1 Automatic Control Circuit for TCSC

Voltage regulation is provided by means of a closed-loop controller. TCSC control circuit consists following blocks, such as step down/up transformer, rectifier bridge circuit, active power filter, voltage regulator, PI controller, gate pulse generating unit (i.e. firing unit). Figure illustrates a TCSC including the operational concept.

TCSC with automatic control circuit

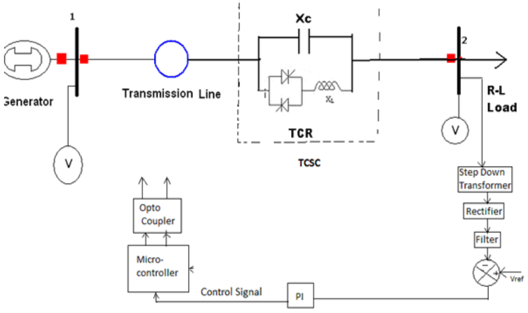

Fig.4 SMTB system with automatic control of TCSC

Fig.5. Control circuit of TCSC

VI.1 Data acquisition for single phase system

According to the previous section, the overall arrangement data acquisition for single phase system is shown by the block diagram in the fig.6

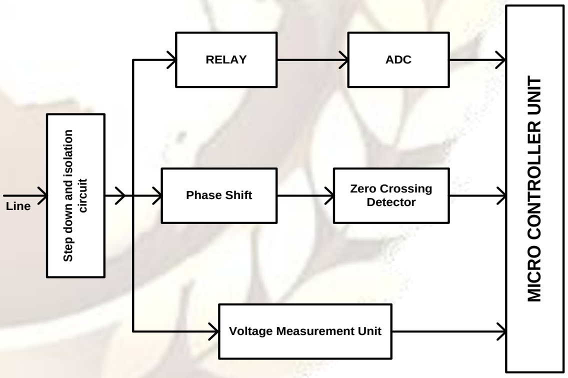

Fig.6 Block Diagram of the Data acquisition system

The fundamental requirement is that the voltage to be measured must be stepped down by factors that would not render the measured values inaccurate and hence unreliable. An analog to digital converter is added in order to facilitate an instantaneous reading of the phase voltages by the microcontroller. The zero crossing detector permits the detection of negative and positive half-waves and hence reading the peak of the corresponding half wave. V. Control System Elements The microcontroller, which is used as part of the control system in voltage balancer, must be able to respond to the analog electrical quantities. The analog electrical quantities (i.e. Voltage) is to be converted into digital values suitable for the microcontroller by using an ADC converter. The block diagram of the completed control system is shown in fig.6

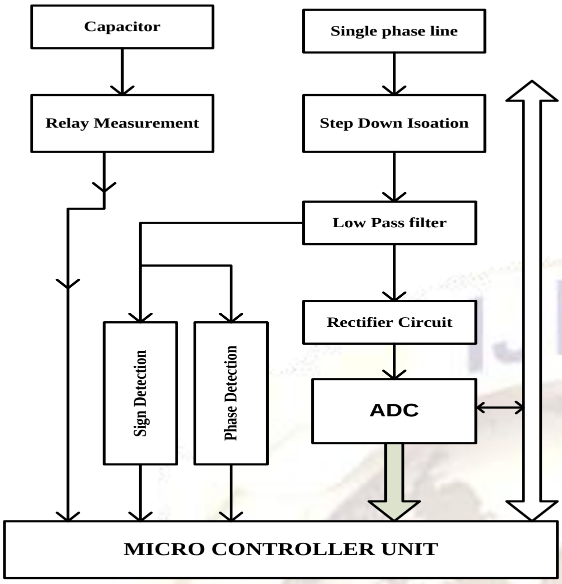

Fig.7 Control System Architecture

The control scheme implemented for TCSC topology works as follows:

- The amplitude of the bus voltage V is measured and filtered.
- Then it is compared against the voltage reference V_{ref}.

The voltage difference between the two signals is processed by a PI controller which causes a corresponding change in the firing angle α. The value provided by the PI controller is used as the input to the TCR firing control unit.

Laboratory Setup of SMTB Test System

This case is considered when the generator is feeding the load through a line. To estimate the stability of the system, the P-V curves have been drawn for the SMTB test system without and with TCSC.

Fig.8 Lab setup of SMTB system with TCSC

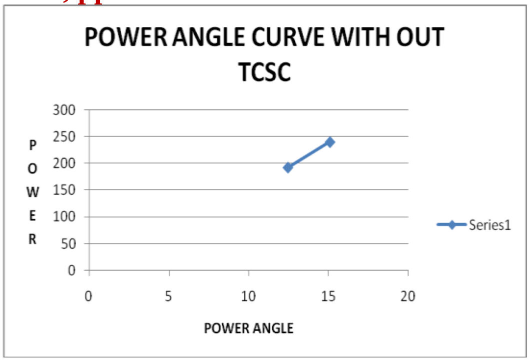

Fig.9 P-δ Curve without TCSC

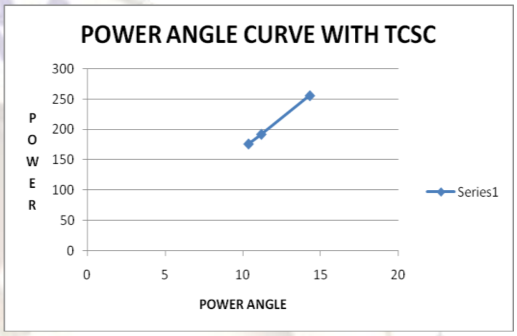

Fig.10 P-δ Curve with TCSC

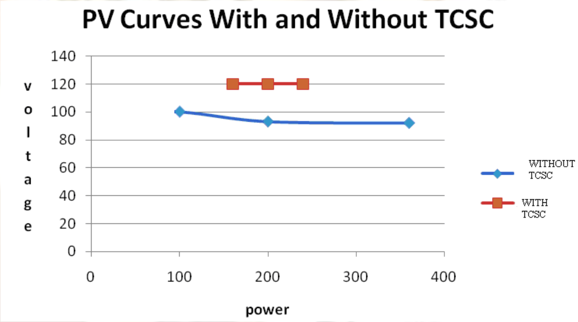

Fig.11 P-V Curves with and without TCSC

The SMTB test system with a source feeding the RL load through a transmission line model and tested with and without TCSC. PV curves have been drawn for both the cases. The system stability has been assessed with PV curves. The results shows that improvement in the stability margin. Series capacitive compensation is thus used to reduce the series reactive impedance to minimize receiving end voltage variation and the possibility of voltage collapse. It is also observed that the compensation by using this technique i.e TCSC is faster when compared to other compensating techniques such as mechanical switching and synchronous condensers.

CONCLUSIONS

The results shows that there is improvement in the both synchronous and voltage stability margins, when TCSC is connected in the test system. Series capacitive compensation is thus used to reduce the series reactive impedance to minimize receiving end voltage variation and the possibility of voltage collapse and it can improve power flow capability of the line. It is also observed that the compensation by using this technique i.e TCSC is more effective than other compensating techniques such as mechanical switching capacitors and synchronous condensers.

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NOMENCLATURE

α is the Firing Angle
TCR : Thyristor Controlled Reactor
I_{TCR} is the Current through TCR
V_{TCR} is the voltage across TCR
PI : Proportional and Integral
SMTB: Single Machine and Two Bus
TCSC: Thyristor Controlled Series Capacitor
P-V: Power – voltage
P-δ : Power – Load Angle
B_{TCSC} : Net susceptance of TCSC

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