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Analysis of the Impact of TCSC Device on the Protection of Transmission Line

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Abstract - The Thyristor Controlled Series Capacitor (TCSC) is a type of Flexible AC Transmission System (FACTS) device used in power systems to dynamically control power flow and enhance system stability. However, its operation significantly affects distance protection, especially the apparent impedance measured by distance relays during faults. The simulation results show that distance relays overreach & getting unwanted trip signals and to overcome this impact further mitigation techniques are also discussed. Modern energy transmission system suffers from high voltage drop and reduced power transfer capability due to enormous load, therefore flexible AC transmission system TCSC devices are used to improve the power transfer capability of long transmission lines.

Key Words: TCSC System, THD, Power Quality, Damping, Power Flow, Reactance, Stability, Security, Transmission Line, Voltage Profile

INTRODUCTION

A Thyristor Controlled Series Capacitor (TCSC) is a flexible power electronics device that enhances transmission line performance by dynamically adjusting series capacitive reactance.[1] It comprises a fixed series capacitor in parallel with a thyristor-controlled reactor (TCR), allowing control of the line's impedance via the thyristor's firing angle[5]. There is rapid growth in the demand of electrical power due to increase in the industrial and domestic load. Power demand is greater than the power generation. The solution is installation of new power stations and construction of more transmission lines. This may not be practicable or desirable due to many reasons like heavy cost, large time consumption and environment issues. Adjusting the reactance parameter of the transmission line improve the power flow profile of the power system. There is huge competition in the electricity market and this give scope to increase the capacity of power transmission of existing facilities By modulating its reactance, the TCSC improves power system stability, increases power transfer capability, and dampens oscillations, making it a valuable tool for modern grids. Power systems have to be planned, projected, constructed, commissioned and operated in such a way to enable a safe, reliable and economic supply of the load. As power system demand growth increased gradually, while the expansion of power generating stations and transmission lines are limited due to the limited resources and environmental aspects[2]. Therefore, some of the transmission lines get overloaded and introduce new problems with related to voltage profile, power system stability, power flow.

Flexible AC Transmission Systems (FACTS) have all the capability that grid operators need to meet the challenges presented by the fast-changing energy market[3]. It is a new technology using power electronics for controlling the parameters and structures of power systems to optimize the transmission flow, reduce energy losses, and increase the transient/dynamic stability of the system.

REVIEW OF LITERATURE

Based on Various FACTS Devices - This classification is based on the simulation and comparison of results using various FACTS devices. Simulink model for uncompensated power system has been developed and then simulated using various different FACTS controllers has been done [4]. Simulation results showing real power and reactive power variation with change in the value of TCSC capacitance were plotted. The major devices from the FACTS family discussed were STATCOM, TCSC, FC-TCR, UPFC, SSSC

Based on Single Phase Representation of TCSC using Pulse Generator Pulse generator has been used for giving the firing pulses for analyzing the thyristor, capacitor current, capacitor voltage. For proper working of TCSC in capacitive and inductive mode appropriate pulses should be given.

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FACTS AND DISTANCE PROTECTION

The AC transmission system has various limits classified as static limits and dynamic limits. These inherent power systems limits restrict the power transaction, which lead to the underutilization of the existing transmission resources. Traditionally, fixed or mechanically switched shunt and series capacitors [6][7], reactors and synchronous generators were being used to solve much of the problem. However, there are restrictions as to the use of these conventional devices. Desired performance was not being able to achieve effectively. Wear and tear in the mechanical components and slow response were the heart of the problems.

TYPES OF FACTS CONTROLLERS

Flexible AC Transmission Systems (FACTS) devices control power flow in AC networks and are categorized by their compensation approach: Series Compensation, Shunt Compensation, and Combined (Series-Shunt) Compensation. Key examples include the Thyristor Controlled Series Capacitor (TCSC) and Static Synchronous Series Compensator (SSSC) for series control, the Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM) for shunt control, and the Unified Power Flow Controller (UPFC) for combined control.

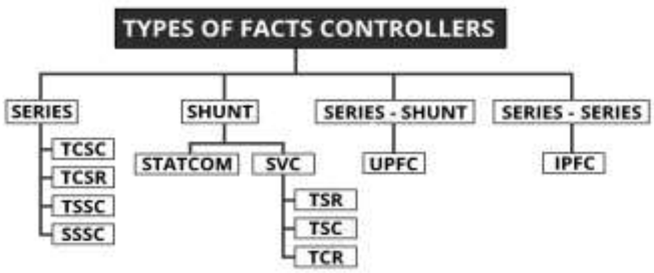

Fig. 1.1: Types of FACTS Controllers

Types of Flexible AC Transmission System

Static Var Compensator

Static Var Compensator is the most primitive and first generation of FACTS controllers[8]. Electric Power Research Institute (EPRI) brings this technology to the market three decade ago. This compensator consists of a fast thyristor switch controlling a reactor and/or shunt capacitor bank, to provide dynamic shunt compensation.

Thyristor Controlled Series Capacitor

Thyristor Controlled Series Capacitor (TCSC) is a later member of the first generation of FACTS devices, that uses silicon controlled rectifiers to manage a capacitor bank connected in series with a line. TCSC allows utility to transfer more power further on a particular line[9].

Static Synchronous Compensator- Static Synchronous Compensator (STATCOM) is the second generation of FACTS controllers that has a very promising future application.

Static Series Synchronous Compensator- Static Series Synchronous Compensator (SSSC) is a complementary second-generation FACTS controller, which is simply a series version of STATCOM. Static Series Synchronous Compensator (SSSC) consists of a voltage source inverter connected in series through a coupling transformer to the transmission line.

Unified Power Flow Controller- Combining the STATCOM and the SSSC into a single device with a common control system represents the third generation of FACTS known as Unified Power Flow Controller (UPFC).

Thyristor Controlled Series Capacitor (TCSC)- Thyristor Controlled Series Capacitor (TCSC) consists of a series compensating capacitor shunted by a thyristor controlled reactor (TCR). TCSC is one of the Flexible AC Transmission Systems (FACTS) devices which is used for all mentioned purposed.

OPERATION OF TCSC

TCSC is consisted as a series compensating capacitor (C) shunted by a thyristor controlled reactor (TCR) as shown in Figure which is placed series in transmission

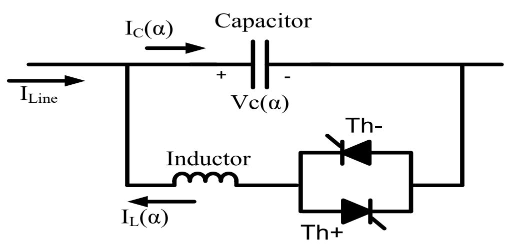

Fig. 1.2: Schematic diagram of TCSC

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TCSC has four operation modes: Blocking, Bypass, Capacitive and Inductive mode. TCSC impedance consists of capacitor and inductor reactance as equation (6) where $jX_L(\alpha)$ is reactance of the inductive branch and depends on the firing angle (α) of thyristors. The four mode operations are made by this angle.

$$jX_{TCSC} = \frac{jX_L(\alpha)*(-jX_C)}{jX_L(\alpha)+(-jX_C)}$$

Blocking Mode Operation - If thyristors are off during the each period, The TCSC impedance will be equal to capacitance reactance XC. It is obvious that TCSC will be like a series capacitor and will have all effects of series capacitor in the transmission line. The firing angle of the thyristor is 90 degree in this mode.

Bypass Mode Operation - When two anti-parallel thyristors are on in all time that they have turning on condition, TCSC will operate in Bypass mode. Thyristors conduct 180 degree in each cycle. The inductance of TCR branch is in circuit always and TCSC impedance is equal to equation in this case.

$$jX_{TCSC} = -\frac{X_L*X_C}{X_L-X_C}$$

3Capacitive and Inductive Mode Operation - If the firing angle of the thyristors is greater than zero and smaller than 90 degree, The Impedance of TCR branch in fundamental frequency will be equal to equation that α is firing delay angle respect to zero crossing of the line current. σ is conducting angle and is equal to σ = 2π-α.

$$X_L(\alpha) = X_L \frac{\pi}{\pi-2\alpha-\sin(2\alpha)}, \; X_L \leq X_L(\alpha) \leq \infty$$

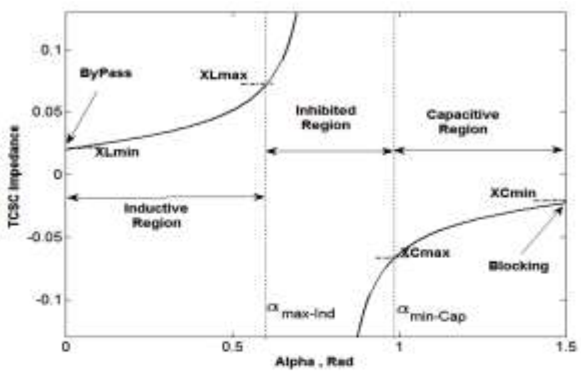

Fig. 1.3: Mode Operations of TCSC

Changing of TCSC impedance is very fast near the αresonance and sensitivity to the firing angle is high. Therefore, an inhibited region is defined between capacitive and inductive area. This area is shown in Figure 2 between and. αmin-Cap − αmax-Ind

Control Strategy for TCSC

Open-loop Control- The open-loop control scheme is the simplest method for TCSC, in which firing delay angle as is obtained directly from the reactance order X_{ref} using the steady state nonlinear algebraic relationship between them. Fig. depicts the diagram of open-loop control scheme.

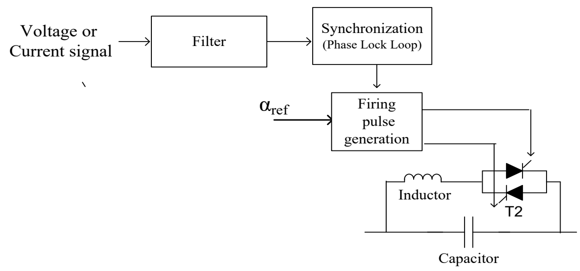

Fig.1.4: TCSC open-loop control methodology

The capacitor voltage is measured and filtered to get the fundamental frequency components[10]. The synchronizing signal originating from the voltage signal through PLL supplies the timing reference pulse for thyristors. Then according to the firing angle reference αref ,the trig pulse is generated and sent to the appropriate thyristor.

Closed -loop Control - In addition to open-loop control, closed-loop control scheme is another common control method in automation control area.

Constant 1Impedance (CI)- The closed-loop constant impedance control is similar to the open-loop control; the only difference between them is the feedback link, which is not adopted in the open-loop control.

Constant Current (CC)- The constant current control choose the steady operation current as the reference signal, then the difference of the reference and the measured variable after normalization is entered to the PI controller.

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***Constant Power (CP)* -** A typical structure for constant power control scheme, choosing active power as the control variable. The reference value of power is the desired value of the compensated line.

TCSC Modes During Fault

- Capacitive Boost Mode without MOV
- Capacitive Boost Mode with MOV
- Blocked Mode
- TCSC Bypass Operation
- Circuit Breaker Bypass.

MODELING AND SIMULATION RESULTS

This project implements a new approach based on fault impedance calculation technique to measure fault impedance at the relay point and also implementation of mho relay to investigate the impact of Thyristor Controlled Series Capacitor on the distance protection scheme. Further, the mitigation techniques are also discussed.

In order to investigate the applicability of proposed network system, the single line schematic diagram of the system under study, with the equivalent circuit of Thyristor Controlled Series Capacitor (TCSC) in the mid-point of the line with the positive and zero sequence networks are shown in fig. (the negative sequence is similar to the positive one and is omitted). The two systems are connected with 500kV transmission lines with500 kV, 60Hz transmission lines which angle difference between them is δ = 300. The positive and negative sequence line impedance is 0.0185+j0.3766 ohm/km, and the zero sequence transmission line impedance is 0.3618+j1.2277 ohm/km[11]. The power system model is shown in Fig.The system is simulated using MATLAB/Simulink software. The transmission line is modeled as an equivalent pi-section in MATLAB library, the total line length is about 300km having a three equal section of 100km.

Basic Network System

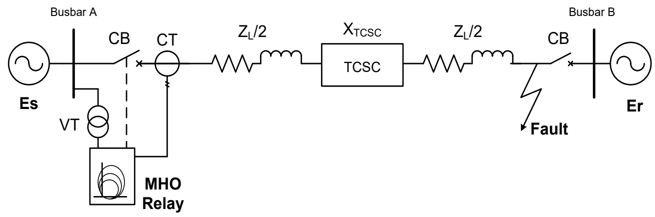

Fig. 1.5: Basic equivalent network used for simulation (TCSC in the middle).

TCSC CONTROL STRUCTURE

General structure of TCSC controller is represented in Fig. The controller is implemented in MATLAB using Simpower control blocks. The TCSC controller is based on proportional-integral (PI) regulator. The derivative components controller feedback is compared with reference value and applied to the controller.

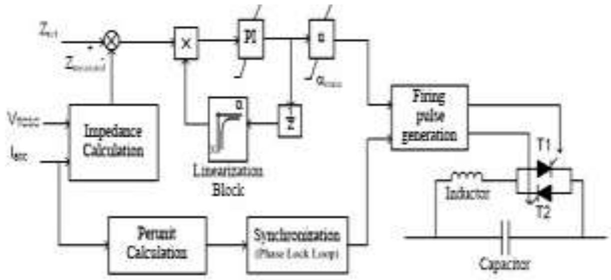

Fig. 1.6. TCSC closed-loop constant reactance control methodology

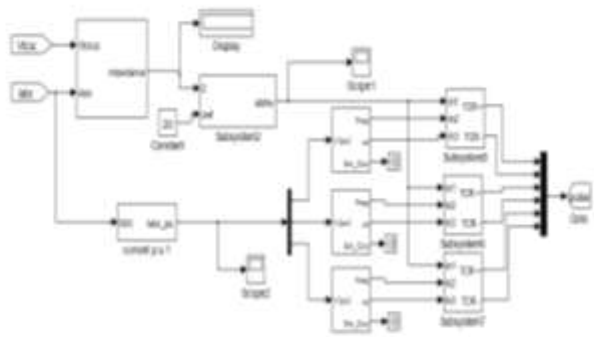

Fig. 1.7: Simulation of Control Strategy for TCSC

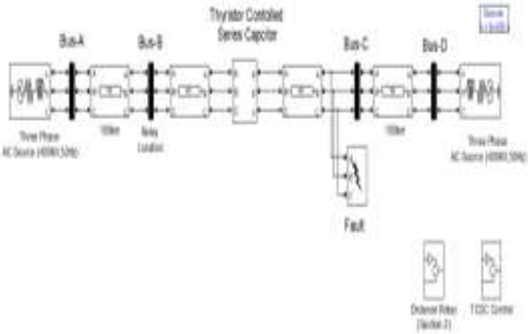

Fig. 1.8: Simulation of Proposed Network System

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SIMULATION RESULT

TCSC Results in Steady State Condition - The fig. shows the TCSC behaviour in steady state condition. When α is between 600 and 900, the equivalent impedance is capacitive. For the general analysis the capacitive boost mode is considered. In the steady state condition, the waveform shows (a) TCR current, (b) Capacitive Current, (c) Voltage across capacitor.

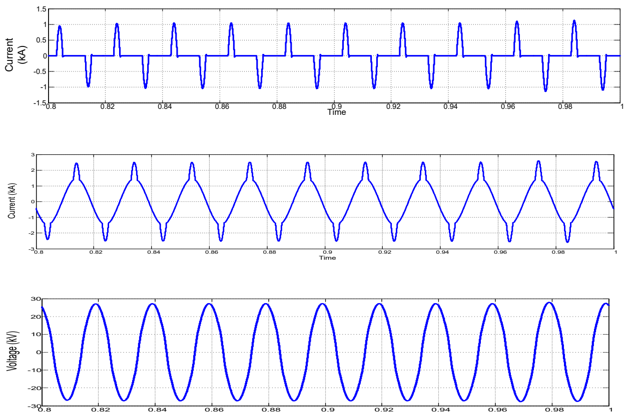

Fig. 1.9: TCSC result in steady state (a) TCR current, (b) Capacitor current,(c) Voltage across capacitor

TCSC Results in Fault Condition (Fault at 0.88 sec)

As the fault occurred at 0.88sec, the TCSC switched its capacitive boost mode to inductive mode. In this mode, TCSC limits the fault current. While the fault occurred in the system the fig shows the TCSC behaviour of the waveform (a)TCR current, (b)Capacitive current, (c)Voltage across TCSC capacitor.

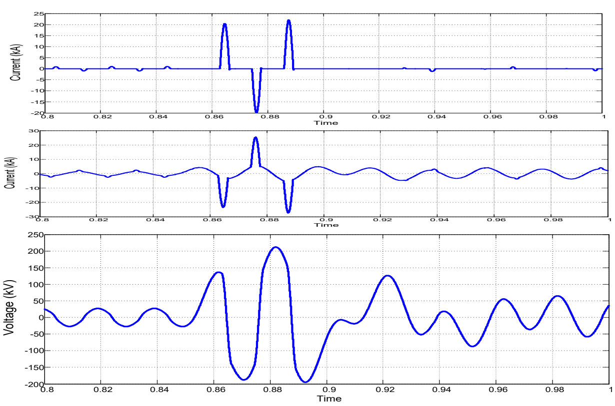

Fig. 1.10: TCSC result in fault condition (a) TCR current, (b) Capacitor current, (c) Voltage across capacitor

New Proposed Method to Mitigate the TCSC Impact

Modified Input Signals to Relay: When TCSC inserted in transmission lines, the overall impedance of transmission line get reduced and XL i.e. impedance seen by the relay changes as verified earlier[12]. Also the earlier proposed system has its own drawback such as elements cost increases, switching loses increases, reliability reduces etc. To overcome this new technique is proposed with modified input signals to the relay and results are also verified.

The simulation model and respective results are shown below

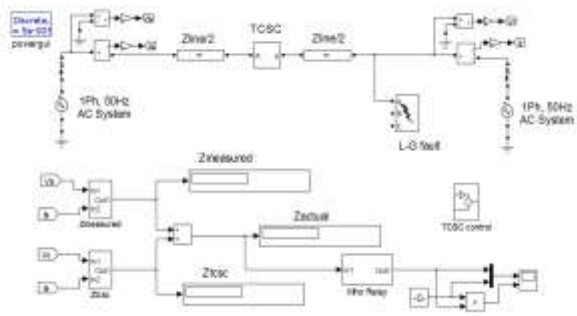

Fig 1.11: Simulation model of new proposed scheme

Simulation Results of New Proposed Method

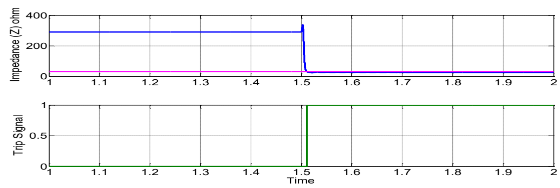

Fig 1.12: Simulation results without TCSC (fault at 65 km).

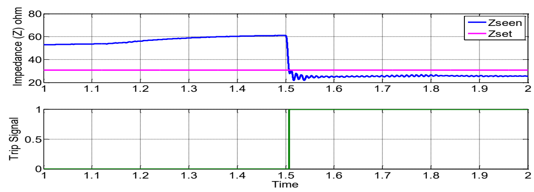

Fig 1.13: Simulation results with TCSC (fault at 65 km).

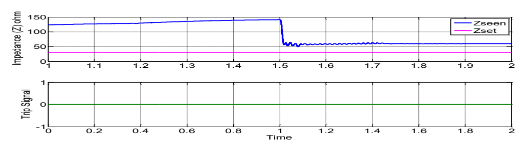

Fig 1.14: Simulation results with new proposed mitigation scheme TCSC (fault beyond reach).

Parameters	Values
Length	100 km
Positive-sequence Impedance Positive-sequence Parallel capacitive reactance	0.0185+j0.3766 Ω/km 0.22789 MΩkm
Zero-sequence Impedance Zero-sequence Parallel capacitive reactance	0.3618+j1.2277 Ω/km 0.34513 MΩkm
TCSC Components	
TCSC main Capacitor	203µF
TCR inductance	7.76mH
MOV reference voltage	338 KV
MOV reference current	10 KA

CONCLUSION

In this project, the effect of TCSC on the protective zone is studied. The simulation results show clearly the impact of TCSC on MHO distance relay performance. The impedance Zseen is influenced by the injected voltage VTCSC of the TCSC. Since deviation of the measured impedance is not constant, because of the varying parameters of the injected reactance by TCSC. The proposed work presents mitigation techniques with the modification of signals input to the mho relay i.e. modification of relay. In addition used of FCL is also proposed as one of the mitigation technique. In order to increase the total system protection performance and avoid unwanted tripping of circuit breaker in the presence of series FACTS devices compensator on electrical transmission lines care must be taken. For specified system, setting for different protection zones can be achieved based on the proposed setting principles.

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