A Review of the Impact of TCSC Device on the Protection of Transmission Line

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Abstract- In this paper presents a analysis of the impact of TCSC on the protection of transmission lines. 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. Distance relays are used for fault detection on transmission lines by measuring the apparent impedance at the relay location. The impedance is compared with preset values (zones) to determine fault location and direction. TCSC is a series compensation device. It consists of a capacitor in series with the line, controlled by thyristors (via a thyristor-controlled reactor, TCR).

INTRODUCTION

The TCSC is considered as a dynamical device and its transient process is modeled in order to have the response to disturbances based on its own control strategy. It is shown that not only the TCSC affects the protection of its line, but also the protection of adjacent lines would experience problems [5]. The analysis is done first analytically by using simple models, then the power system and the protective relays are simulated in detail by Real Time Digital Simulator (RTDS). Finally, the simulation results are validated by using a commercial relay. As power system dynamics changes, many sub-systems are affected, including the protective systems. Therefore, it is essential to study effects of FACTS devices on the protective systems, especially the distance protection, which is the main protective device at EHV and HV levels. Unlike power system parameters, the controlling parameters of FACTS devices could affect the measured impedance even in the absence of the fault resistance [8-10].

In the presence of FACTS devices, the conventional distance characteristic such as Mho and Quadrilateral are greatly subjected to mal- operation in the form of over-reaching or under-
reaching the fault point. Therefore, the conventional characteristics might not provide the protective functions satisfactorily in the presence of FACTS devices [11] [12]. The measured impedance at the relaying point is the basis of the distance protection operation. There are several factors affecting the measured impedance at the relaying point. Some of these factors are related to the power system parameters prior to the fault instance, which can be categorized into two groups [1-3]. First group is the structural conditions, represented by the short circuit levels at the transmission line ends, whereas the second group is the operational conditions, represented by the line load angle and the voltage magnitude ratio at the line ends. In addition to the power system parameters, the fault resistance, in the single-phase to ground faults, could greatly influence the measured impedance, in such a way that for zero fault resistance, the power system parameters do not affect the measured impedance. In other words, power system parameters affect the measured impedance only in the presence of the fault resistance, and as the fault resistance increases, the impact of power system parameters becomes more severe [4][6]. In today's power system, there are some difficulties for constructing new transmission lines, because of the limited resources and environmental restrictions.

Midpoint Voltage Regulation for Line Segmentation: Consider the simple two bus machine transmission model in which an ultimate Var compensator is connected at the center of transmission line, as shown in Figure1 (a). For simplicity, the line is represented by the series line inductance. The compensator is represented by a sinusoidal ac voltage source, in-phase with the midpoint voltage, Vm, and with an amplitude equal to that of the sending- and receiving-end voltages must be such that Vm=Vs =Vr= V.

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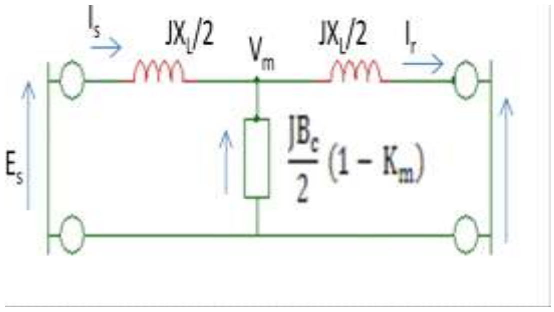

Figure 1. Transmission line with midpoint line compensation.

- **Line Segmentation:**

The shunt compensator at the midpoint effectively divides the transmission line into two shorter segments, each with half the total impedance.

- **Reactive Power Exchange:**

The compensator exchanges reactive power at the midpoint to regulate the voltage.

- **Long Transmission Lines:**

It is most useful for long transmission lines where the voltage drops are substantial.

TCSC steady-state model

The Thyristor-Controlled Series Capacitor (TCSC) consists of a series capacitor in parallel with a Thyristor-Controlled Reactor (TCR). The TCR uses a pair of back-to-back thyristors to control the current flowing through an inductor, allowing the TCSC to function as a variable reactance. By varying the thyristor firing angle, the TCSC can smoothly and rapidly adjust its impedance, influencing power flow and enhancing stability in transmission lines. Fig. 2 shows a TCSC module with different protective elements [11]. Basically, it comprises a series capacitor (C), in parallel with a Thyristor Controlled Reactor (TCR) (Ls). A metal oxide varistor (MOV), essentially a nonlinear resistor, is connected across the series capacitor to prevent the occurrence of high capacitor over voltages. Not only does the MOV limit the voltage across the capacitor, but it allows the capacitor to remain in the circuit even during fault conditions and helps improve the transient stability. A circuit breaker is also installed across the TCSC module to bypass it if a severe fault or equipment malfunction occurs[7]. A current limiting inductor, L_d, is incorporated in the circuit to restrict both the magnitude and the frequency of the capacitor current during the capacitor bypass operation.

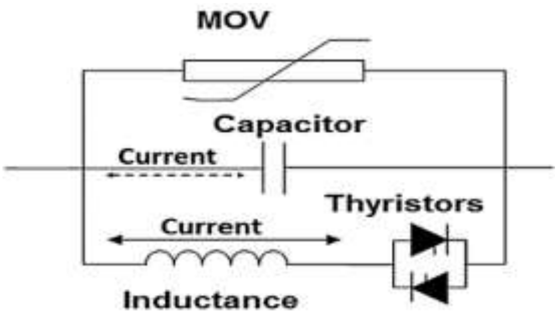

Figure 2. TCSC module.

TCSC Modes of Operation in Steady State

In normal operating conditions, there are four modes of operation; blocking mode; bypass mode; capacitive boost mode; and inductive boost mode [1].

Blocking mode: When the thyristor valve is not triggered and the thyristors are kept in non- conducting state the TCSC is operating in blocking mode. The line current passes only through the capacitor bank. In this mode, the TCSC performs like a fixed series capacitor.

Bypass mode: If the thyristor valve is triggered continuously the valve stays conducting all the time and the TCSC behaves like a parallel connection of the series capacitor bank with the inductor in the thyristor valve[9]. In this mode, the resulting voltage in the steady state across the TCSC is inductive and the valve current is somewhat bigger than the line current due to the current generation in the capacitor bank. For practical TCSC's with ratio between 0.1 to 0.3 range, the capacitor voltage at a given line current is much lower in bypass than in blocking mode. Therefore, the bypass mode is utilized as a means to reduce the capacitor stress during faults.

Capacitive boost mode: If a trigger is supplied to the thyristor having forward voltage just before the capacitor voltage crosses the zero line a capacitor discharge current pulse will circulate thorough the parallel inductive branch. The discharge current pulse adds to the line current through the capacitor bank.

Inductive boost mode: In this condition the circulating current in the thyristor branch is bigger than the line current. In this mode, large thyristor currents result and further the capacitor voltage waveform is very much distorted from its sinusoidal shape. The peak voltage appears close to the turn on [12]. The poor waveform and the high valve stress make the inductive boost mode less attractive for steady state operation.

TCSC MODES DURING FAULT

During a fault, a Thyristor Controlled Series Capacitor (TCSC) transitions through several operational and protective modes to protect its internal components and the wider power system. The specific sequence of modes depends on the severity of the fault current [10].
These modes are as follows:

- TCSC bypass operation with/without MOV;

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- Capacitive boost mode with/without MOV;
- Inductive boost mode with/without MOV;
- Blocked mode with/without MOV conduction;
- Circuit breaker bypass.

The operating modes that are common in steady state and fault conditions are bypass mode, blocked mode, capacitive boost mode and inductive boost mode without MOV conduction.

TCSC bypass mode with MOV - conduction is improbable, since bypass mode decreases the capacitor voltage considerably, and the MOV operation is not necessary. During each mode the impedance seen by the relay differs significantly.

***Capacitive Boost Mode without MOV* -** When the fault current is low, no transition from capacitive boost mode takes place. In this case a significant compensation exists, so the conventional distance relay overreaches considerably. This condition usually occurs when the fault is in the adjacent lines [11].

Capacitive Boost Mode with MOV - In this case, MOV operates for decreasing the voltage across the capacitor. The MOV is fast enough to conduct and reset within a half-cycle. The MOV would not short out the capacitor as the circuit breaker would.

***Blocked Mode* -** In some cases, for avoiding over current of the thyristors or the capacitor caused by the fluctuation of the firing angle under conditions that the voltage phase of the capacitor changes suddenly, the thyristors would be blocked. In this case, the line is compensated by the capacitor only [09]. Distance relay overreaches less than the capacitive boost mode. This case might be accompanied by MOV operation. This case is different from Capacitive Boost Mode from the capacitance (or degree of overreaching) point of view.

***TCSC Bypass Operation* -** If the fault current is relatively high, then the MOV operation is not enough to decrease the capacitor voltage, so the TCSC goes to bypass mode. In this case, the distance relay would under each due to the reactor of the TCR.

Circuit Breaker Bypass - If the fault is not cleared within a certain time (primary protection failure) then the TCSC transits to circuit breaker by pass mode. Since the series reactor in the circuit breaker circuit is very small, the relay experiences the normal situation. This conditionis used only for back-up protection.

DISTANCE PROTECTION:

PRINCIPLES AND MODELING –

Distance relay is so called because it is based on an electrical measure of distance along a transmission line to a fault. The distance along the transmission line is directly proportional to the series electrical impedance of the transmission line. Impedance is defined as the ratio of voltage to current. Therefore, distance protection measures distance to a fault by means of a measured voltage to measured current ratio computation.

Measurement Principle –

The numerical distance relay uses to locate a fault on a distance measurement between the fault and the point where it is installed. It is determined through a measurement of Xd which ranges from 0.33 to 0.42 Ω per kilometre depending on the type of high-voltage line. This measure must be of a directed character. By taking into account the reactive part of the impedance Zd between the fault point and the relay, can liberate the distance measurement from the RF. In the presence of a fault as shown in figure 3.

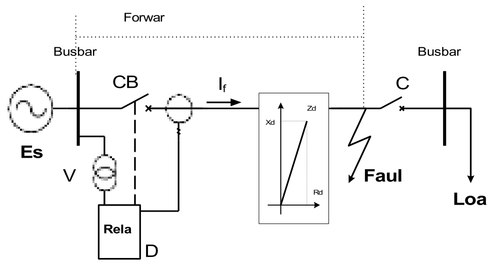

Figure 3. Distance protection in the presence of fault.

Relation between Time-Distance - Time selectivity protection is given by the staggered trip time depending on the distance between measurement point and the fault. Following the philosophy of setting the distance protection in Sonelgaz group, three zones (Z1, Z2 and Z3) have to be chosen as shown in figure 4. The 1st zone covers about 80% the protected line AB and tripped circuit breaker in t1, the 2nd zone extends 100% of the line protected AB+20% of the adjacent line is shorter and tripped circuit breaker in the t2, the 3rd zone extends of 100% of the line protected AB+40% of the adjacent line is longer and tripped the circuit breaker in the t3.

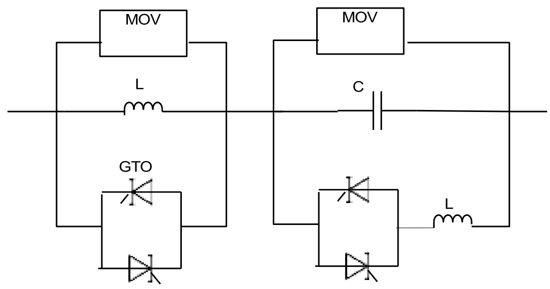

Fig. 4. Settings zones of the distance protection.

FAULT CURRENT LIMITER

FCL is placed in series with line and limits the amplitude of the fault current to a predefined value [1] and [2]. General configuration of used FCL is shown in Fig. This device is composed of two parallel branches, one consists of a pair of Gate Turn Off thyristors (GTO) and the second has a current limiting reactance. In the steady state operation of system, the GTO conducts continuously. When a fault current bigger than a reference value, GTOs are turned off and the fault current passes through the limiting reactance. GTOs will be fired again when the fault current is lower than the predefined value.

FCL impedance depends on firing angle and TCSC on measured impedance in second zone of distance relay (Fig.). When fault occurs the FCL will be inserted into the networks which increase the impedance. In the fault condition, firing angle of the FCL will be generated considering the conducting angle of TCSC. The amount of line impedance compensation factor defines firing angle of TCSC and this angle does not change during fault.

As a consequence, FCL in the proposed method does not need to measure TCSC firing angle during fault, so no delay will introduce into the protection system. Hence, the FCL inserts the proper value of impedance to minimize the effect of TCSC on over reach problem of the distance relay. The control schematic of FCL is shown in Fig.

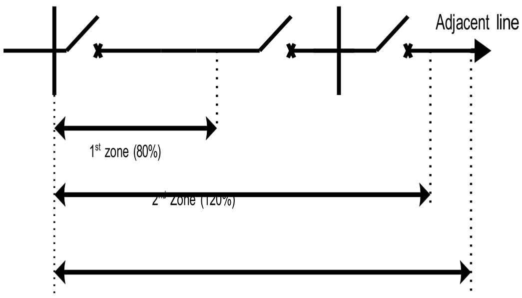

Fig.5. TCSC equipped with FCL

problem using FCL. However, this method does not have any effect on under reach problem of distance protection due to TCSC.

CONCLUSION

A comprehensive analysis of the impact of TCSC on the pro-tection of transmission lines during system disturbances is presented. The results indicate that TCSC dynamics have a significant impact on the power system protection and its transition from a mode to another can create serious problems for the conventional relays like forward overreach, reverse overreach, miscoordination in primary and back-up protection, directional malfunction and adverse effect on distance schemes. As shown in this paper, in the presence of TCSC the relay coordination encounter problems. A novel method is presented to minimize the over reach problem using FCL. However, this method does not have any effect on under reach problem of distance protection due to TCSC.

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