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Dynamic Analysis of TCSC on Distance Protection Relay & Its Mitigation

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Abstract: ***The basic operation principle of distance relay is based on the fact that the line impedance is fairly constant with respect to the line length. However, the implementation of FACTS controllers in power system transmission for enhancing the power system controllability and stability have introduced new power system issues in the field of power system protection that must be considered and analyzed. Some of the concerns include the rapid changes in line impedance and the transients introduced by the fault occurrence and the associated control action of the FACTS Controllers. The presence of the FACTS devices in the faulted loop introduces changes to the line parameters seen by the distance relay. The effect of FACTS device would affect both the steady state and transient characteristics of the apparent impedance seen by distance relays due to the fast response time of FACTS Controllers with respect to that of the protective devices.***

Keyword: *Power system protection, TCSC, Zones, Distance Relay.*

I. INTRODUCTION

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 parameters becomes more severe [4]. In today's power system, there are some difficulties for constructing new transmission lines, because of the limited resources and environmental restrictions. This leads to interdiction of double circuit lines and compensated lines by FACTS devices in to the power systems. In the case of the double-circuit lines, because of the low distance of the conductors of two circuits, two circuits affect each other mutually [5]. On the other hand, recently FACTS devices are introduced to the power systems to increase the transmitting capacity of the lines and provide the optimum utilization of the system capability. It is well documented in the literature that the introduction of FACTS devices in power systems has a great influence on their dynamics [6-7]. 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]. It is well-known that FACTS series devices such as Thyristor Control Series Capacitor (TCSC) are used to improve the power transfer capability of long transmission lines. These series connected FACTS devices inject a series voltage with the line and change the line impedance, cause the impedance seen by distance relay to be lower or higher than the actual line impedance and the distance relay either over reaches or under reaches.

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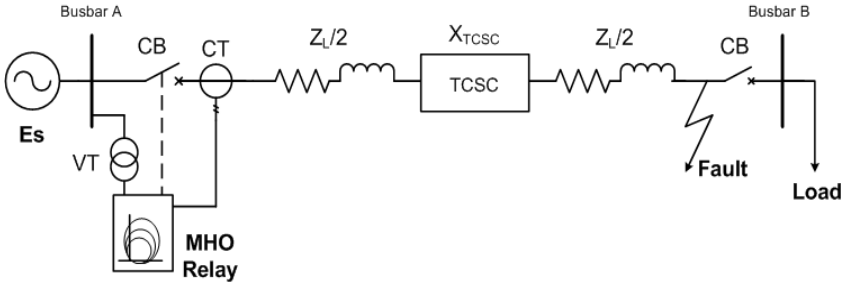


Figure.1. Transmission line with midpoint line compensation.

II. PRACTICAL TCSC MODEL AND MODES OF OPERATION IN STEADY STATE

A. *TCSC Model*

Fig.2 shows a TCSC module with different protective elements. 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. 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.

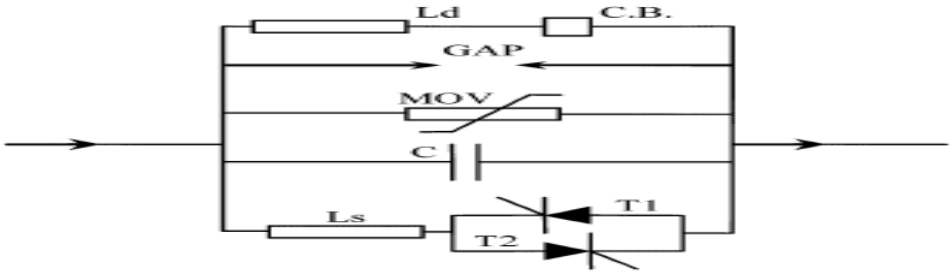


Fig. 2. Practical TCSC module.

B. *TCSC Modes of Operation in Steady State*

In normal operating conditions, there are four modes of operation used in Steady State are as follows:

A. *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. In this mode, the TCSC performs like a fixed series capacitor.

B. *Bypass mode*

If the thyristor valve is triggered continuously it will remains conducting all the time and the TCSC behave like a parallel connection of the series capacitor bank with the inductor in the thyristor valve. 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 ranges, 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.

C. *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. It causes a capacitor voltage that adds to the voltage caused by the line current. This is the normal

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operating mode of TCSC.

D. 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. The poor waveform and the high valve stress make the inductive boost mode less attractive for steady state operation.

III. TCSC MODES OF OPERATION DURING FAULT

During a fault different modes of operation could occur that incorporates the TCSC protection equipments. These modes are as follows:

The common operating modes used are steady state and fault conditions i.e 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 not need. During each mode the impedance seen by the relay differs significantly. For example, in steady state, the capacitive boost mode is the common mode for TCSC, so a considerable portion of the line inductance is compensated by the TCSC capacitive effect. In bypass mode, the impedance seen by the relay is the impedance of fault path plus the inductive impedance of the parallel circuit of capacitor and inductor of the TSR branch. In TCSC design requirements are tabulated and clearly mentioned that the purchaser should specify the required sequences of faults, dynamic overload, temporary overload, and continuous currents for the TCSC bank, and also the power system fault currents, the type of bypass mode that can be occurring during internal and external faults, and the desired post-fault control mode, reactance range, and voltage across the TCSC bank.

A. 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.

B. 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. This condition is usually very short but may be repeated several times during the fault period. The impedance of the TCSC would be the parallel combination of the capacitor and the MOV in a lower resistance mode. The relay would overreach but differently from the previous case without MOV operation.

C. Blocked Mode

In some cases, for neglect the 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. 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.

D. 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.

E. Circuit Breaker Bypass

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

IV. 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

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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.

A. 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.

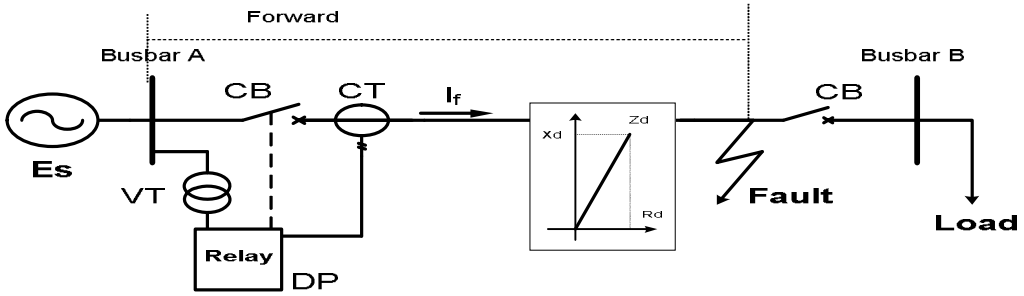


Fig. 3. Distance protection in the presence of fault.

B. 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*.

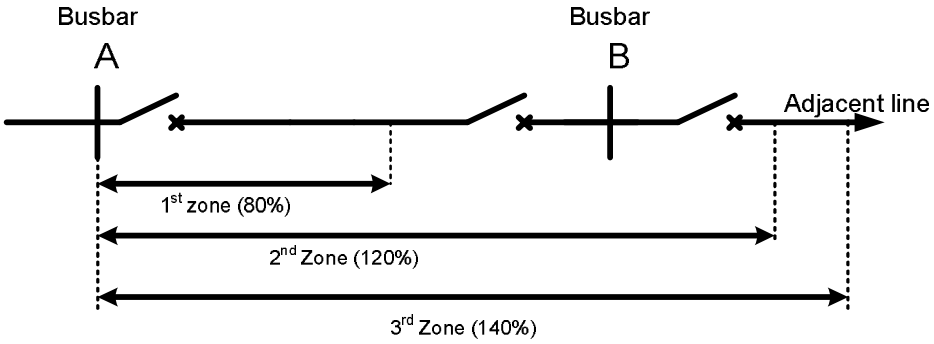


Fig. 4. Settings zones of the distance protection.

The trip delay is not possible for faults surely on the line. It is the role of measurement in the first zone, set at 80% of the reactance of the line. It triggers instantaneous. The trip must be ordered online for failure is the role of other zone settled more than 100% of the line, which then over flows to the first zone line adjacent to the position facing. The outbreak, called 2nd and 3rd stage, must be selectively controlled the 1st stage. The trip time *t1*, *t2* and *t3* correspond to these four zones of operation and interval of different selective Δ*t* is indicated in figure 5.

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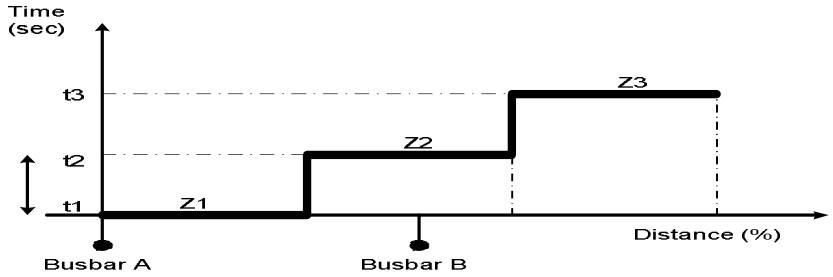


Fig. 5.Time selectivity for the distance protection

C. Representation of Impedance Protection

We place relay side DP, the impedance of the relay is invariant whatever the type of fault: the characteristic is fixed. The relationship between it and the voltage, current is invariant, fixed by the constructor. However, the relationship between the impedance measurement and the direct impedance may vary with the type of fault if the relationship is strictly used in the corresponding for fault, direct representation of the impedance may change depending on the type fault. Four types of characteristics of the curve $X = f(R)$ is: MHO, quadrilateral, polygonal and elliptical, but the relay digital is based on two types first.

V. IMPACT OF TCSC IMPEDANCE ON MHO IMPEDANCE CHARACTERISTICS OF DISTANCE RELAY

The operating principle of distance protection is based on measuring the voltage and current at the measuring point. A graphical representation of a mho characteristic is shown in Fig. 6. If the TCSC operates in inductive mode measured, Z_2 is the impedance measured by the relay. If the TCSC operate in capacitive mode, Z_1 is the measured impedance by the relay and over reach problem is occurred.

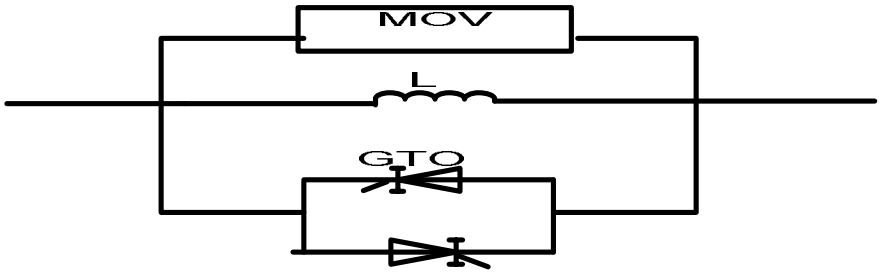


Fig. 6. Configuration of solid state FCL

VI. SIMULATION RESULT

A. TCSC Results in Steady State Condition

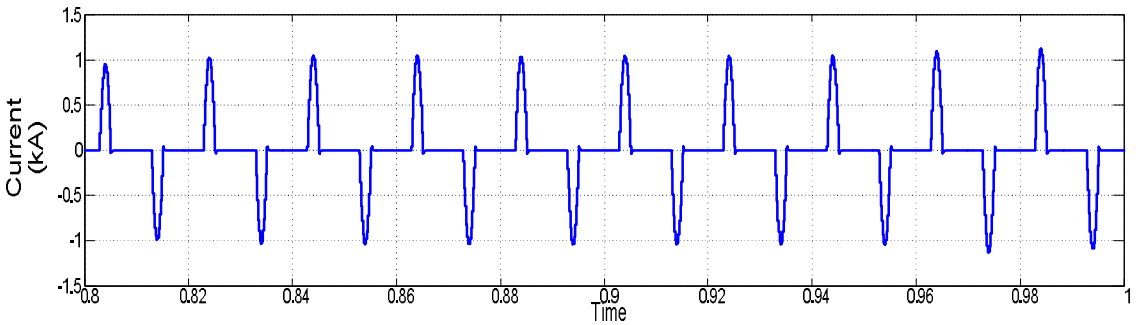


Fig.7. (a)

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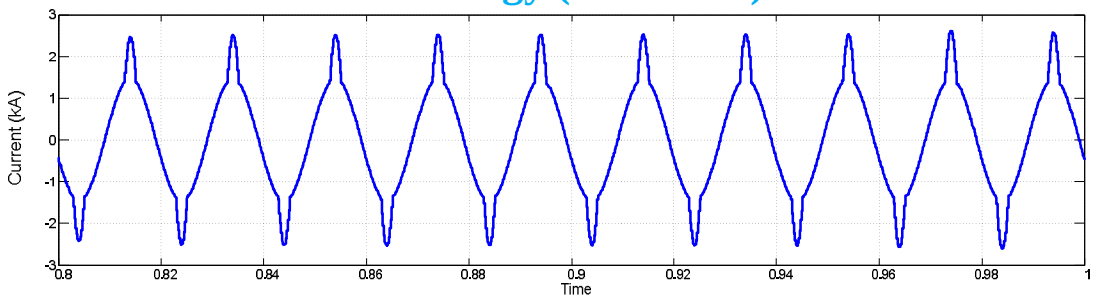


Fig. 7. (b)

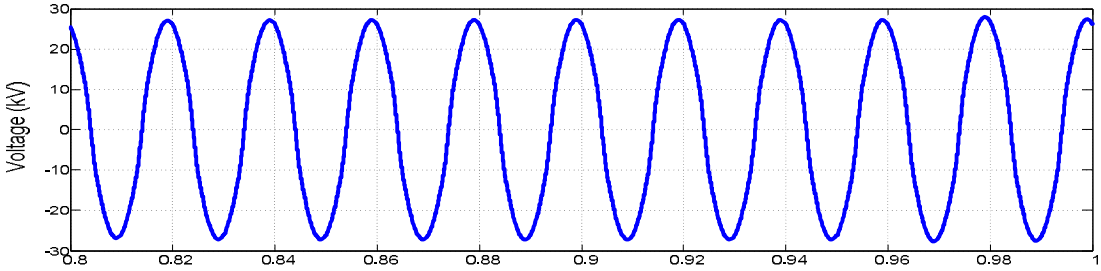


Fig.7. (c)

Fig.7. TCSC results in steady state condition (a) TCR current,(b) Capacitor current, (c) Voltage across capacitor.

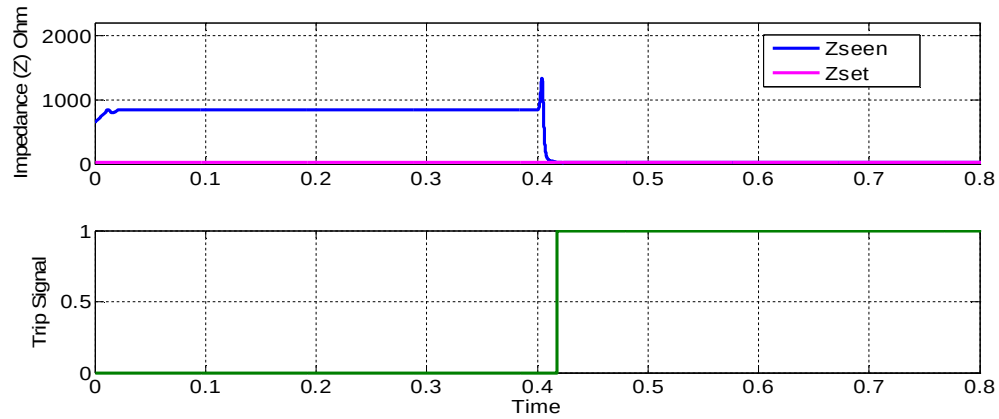


Fig. 8 (a)

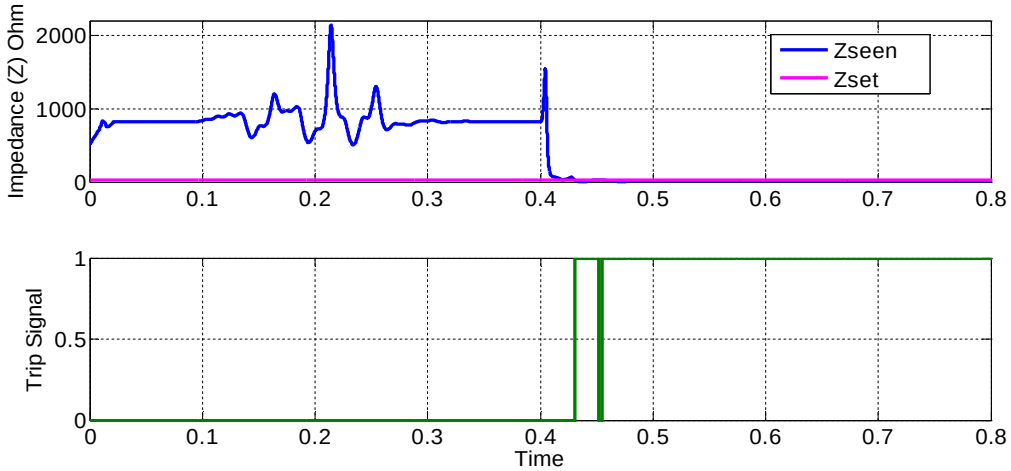


Fig. 8 (b)

Fig. 8 (a) & 8 (b) Impedance seen by relay and trip signal without & with TCSC *L-G FAULT AT 65 KM.*

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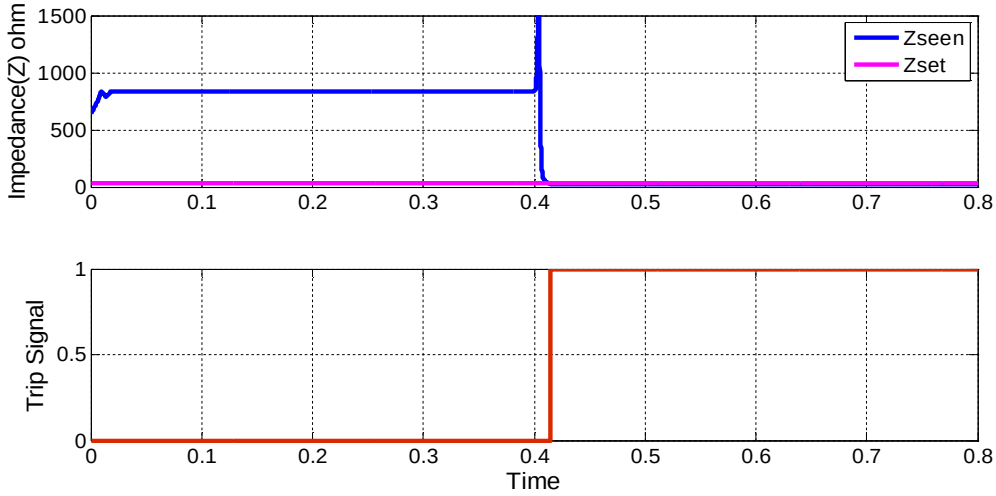


Fig. 9 (a)

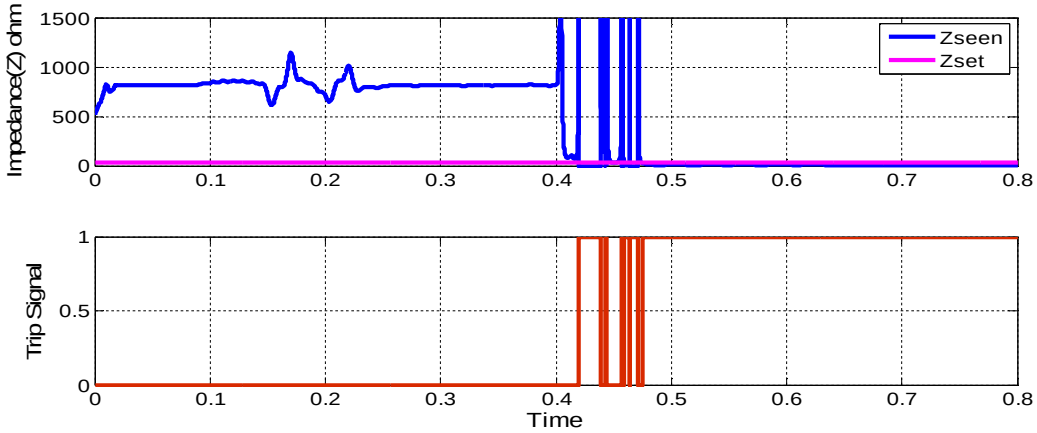


Fig. 9 (b)

Fig. 9 (a) & 9 (b) Impedance seen by relay and trip signal without & with TCSC *L-L-L-G FAULT AT 65 KM.*

Simulation results (fault at 65 km)

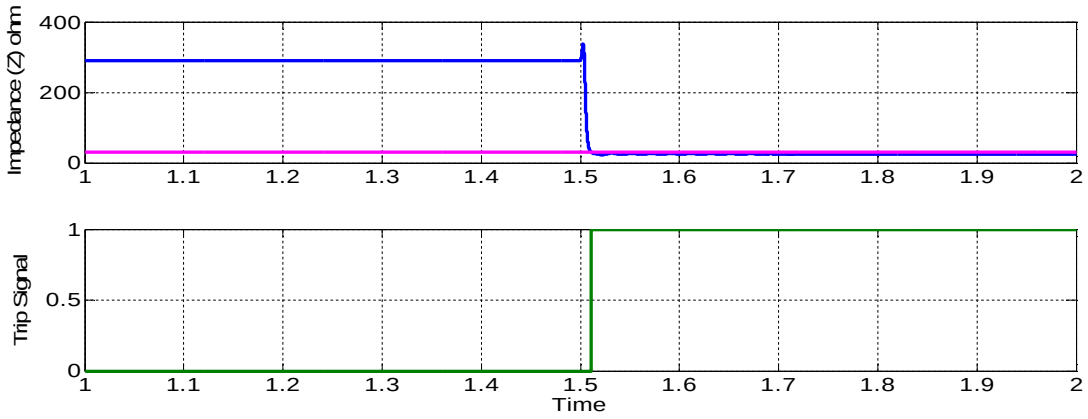


Fig.10 (a). Simulation results without TCSC (fault at 65 km)

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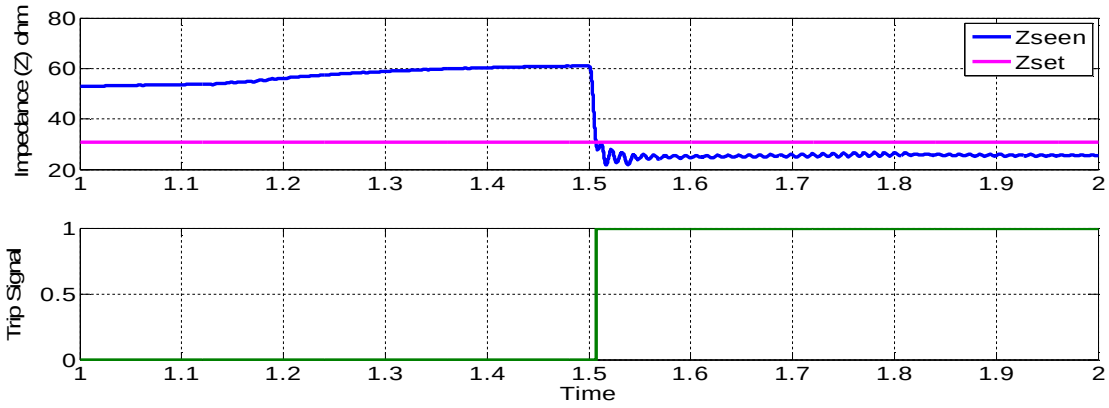


Fig. 10 (b). Simulation results with TCSC (fault at 65 km)

D. Simulation results (fault beyond reach)

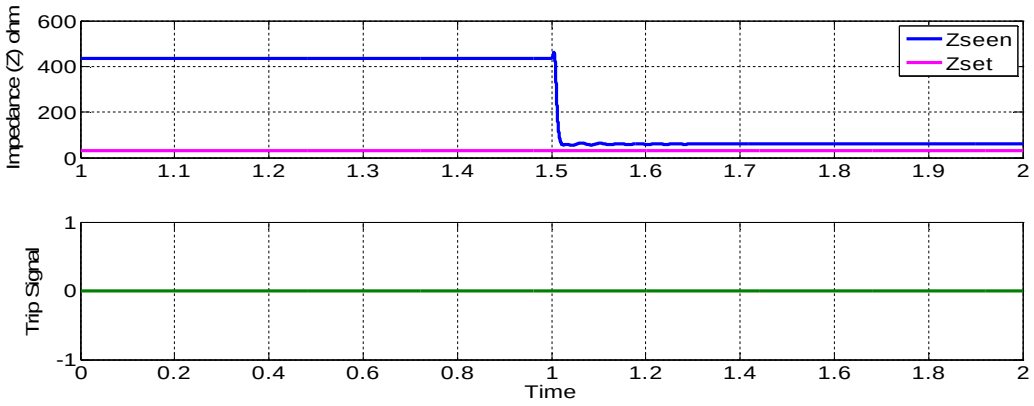


Fig.11 (a) Simulation results without TCSC (fault beyond reach).

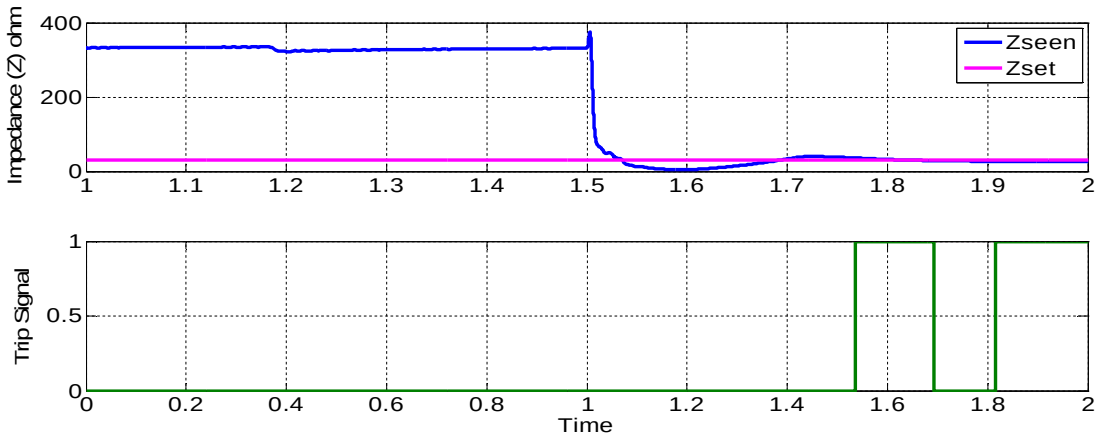


Fig.11 (b) Simulation results with TCSC (fault beyond reach).

VII. CONCLUSION

A comprehensive analysis of the impact of TCSC on the protection 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

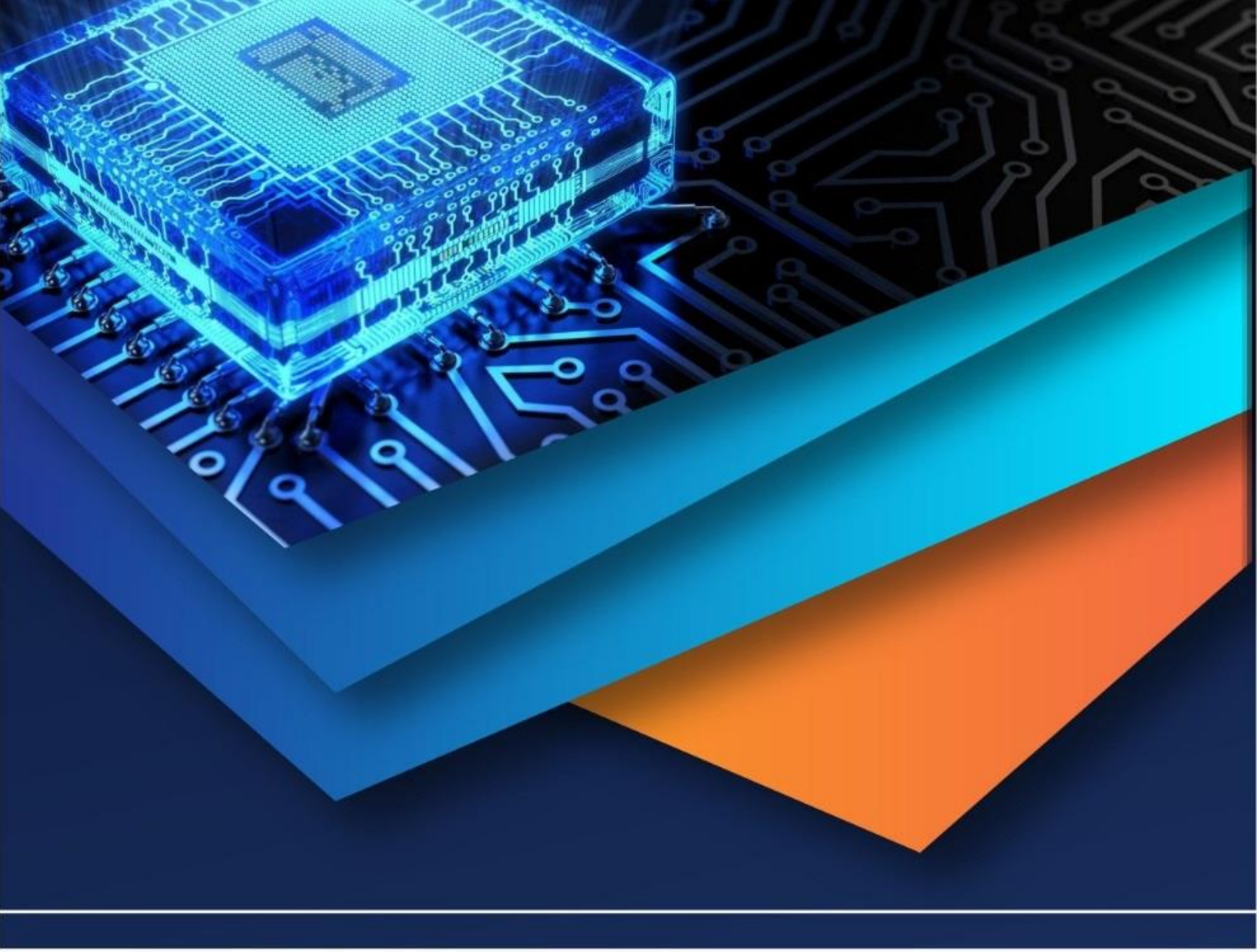
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another can create serious problems for the conventional relays like forward overreach, reverse overreach, miss coordination in primary and back-up protection, directional malfunction and adverse effect on distance schemes. As shown in this paper, in the presence of TCSC the relay coordination encounters 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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