MODIFIED SETTING NUMERICAL DISTANCE PROTECTION OF POWER TRANSMISSION LINE IN PRESENCE TCSC USING IEC 62850 COMMUNICATION PROTOCOL

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Abstract: This paper presents a study of the performance of numerical distance relay for a 400 kV electrical transmission line compensated by series Flexible AC Transmission System (FACTS) i.e. Thyristor Controlled Series Capacitor (TCSC) is connected in the middle of the transmission line and can be used in voltage mode control or reactive power injection mode, and damping of power system oscillations in high power transfer levels. IEC 61850 is a new international standard for communication networks and systems in substations that defines different message types based on their transfer time requirements. In IEC 61850 based Substation Automation systems (SAS). The effect of the TCSC on the measured impedance at the relaying point is investigated. The setting zones protection deals with the absence and presence of TCSC using IEC 61850 communication protocol for two stations i.e. Principal station and TCSC station with proposed scheme for tele-protection for studies the effects of TCSC insertion on the total impedance of a transmission line protected by MHO distance relay and the modified setting zone protection in capacitive and inductive mode for three forward zones (Z_1, Z_2 and Z_3) have been investigated in order to prevent circuit breaker nuisance tripping to improve the performances of distance relay protection.

Keywords: *Numerical Distance Relay, Setting Zones, TCSC, Tele-Protection, Substation Automation System, IEC 61850 Communication Protocol.*

I. INTRODUCTION

Power electronic techniques offer a promising approach for fast and flexible control of AC power network. The flexible AC transmission system (FACTS) is been used for controlling power flow in transmission system and for enhancing power quality and reliability at the distribution level. However, because of the added complexity due to the interaction of FACTS devices with the transmission system, the transients superimposed on the power frequency, voltage and current waveforms (particularly under faults) can be significantly different from those systems not employing FACTS devices and it will result in rapid changes in system parameters such as line impedance and power angle [1]. TCSC is one of the most widely used FACTS devices. It is based on a voltage source convert and can inject an almost sinusoidal current with variable magnitude and in quadrature with the connecting line voltage. It is widely used at the mid-point of a transmission line or heavy load area to maintain the connecting point voltage by supplying or absorbing reactive power into the electrical power system [2]. Because of the presence of TCSC devices in a fault loop, the voltage and current signals at relay point will be affected in both steady and transient state.

This impact will affect the performance of exiting protection methods, such as distance relay. Some research has been done on the performance of the distance relay for a transmission system with different FACTS devices. The work in [3] has presented the analytical results based on steady-steady model of STATCOM, and has studied the impact of STATCOM on distance relay at different load levels. In [4], the voltage-source model of FACTS devices is used to study the impact of FACTS on the tripping boundaries of distance relay. The work in [5] shows that TCSC has a big influence on the MHO characteristic, reactance and direction and makes protection region unstable. The study in [6] demonstrates that the presence of FACTS devices on a transmission line will affect the trip boundary of distance relay. Moreover both the FACTS device parameters and its location have impact on the trip boundary. In [7] the analytical and simulation results of the measured impedance at the relaying point of transmission line incorporating STATCOM are calculated using PSCAD/EMTC package. The effect of different types of TCSC on distance protection of transmission lines has been reported for general research on the influence of TCSC on the protection of transmission lines [8-11] and in [12] is study the impact on communication-aided distance protection schemes and its mitigation.

In existing substation protection systems, voltages and currents at different points of the substation are measured and scaled down using voltage and current transformers. The outputs of these transformers which are analog signals

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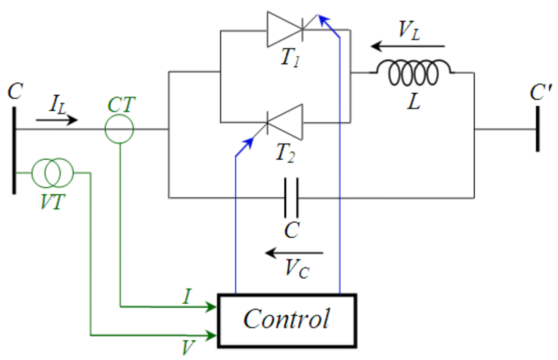
are connected to different protective relays through hardwired cables. Measured signals are processed in protective relays using various protection functions to detect any fault or abnormal condition in the substation. Appropriate commands (e.g., trip or block signals) are issued through hardwired cables to open or close a circuit breaker or to inform other protective relays, in substation protection systems based on IEC61850, instrument transformers are connected to intelligent electronic devices (IEDs) through a communication network called process bus, which includes merging units (MUs) and Ethernet switches.

Future electric substations are expected to be heavily dependant on intelligent electronic devices (IEDs) which operate on communication protocols such as IEEE 802.3 (Ethernet) based IEC 61850. For applications IEC 61850 international communication protocol in power system researcher in [12] proposes the use of an intrusion detection system (IDS) tailored to counter the threats to an IEC 61850 automated substation based upon simulated attacks on IEDs, in [14] implementation and testing of directional comparison bus protection based on IEC 61850 process bus and in Packet Scheduling of generic object oriented substation event (GOOSE) messages in IEC 61850 based substation IED for substation automation systems (SAS) is study in [15] and control and automation of electrical power system substation using IEC 61850 communication in [16].

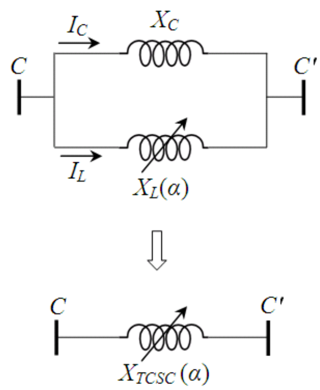
In this paper, the impacts of TCSC on the setting zones protection for numerical distance relay in a transmission system using IEC 61850 communication protocols applied to two station automation (principal busbar and TCSC) are investigated.

II. POWER TRANSMISSION LINE WITH TCSC

Series connected FACTS devices TCSC are usually utilized to regulate the voltage at their connection point. The model of these devices and their general model are presented in this section. The compensator TCSC mounted on figure 1.a is a type of series FACTS compensators. It consists of a capacitance (*C*) connected in parallel with an inductance (*L*) controlled by a valve mounted in anti-parallel thyristors conventional (T_1 and T_2) and controlled by an angle of extinction (α) is varied between 90° and 180°.



(a)



(b)

Figure 1. Transmission line on presence TCSC system. a). Mounting, b). Apparent reactance.

This compensator injected in the transmission line a variable reactance (X_{TCSC}) indicated by figure 1.b. Its value is function of the reactance of the line X_L where the device is located. The apparent reactance X_{TCSC} is defined by the following equation [10-12],[17]:

$$X_{TCSC}(\alpha) = X_C \,//\, X_L(\alpha) = \frac{X_C . X_L(\alpha)}{X_C + X_L(\alpha)} \qquad (1)$$

The expression of X_{TCSC} is directly related to the angle α, which was varied, following the above equation:

$$X_L(\alpha) = X_{L\max}\left[\frac{\pi}{\pi - 2\alpha - \sin(2\alpha)}\right] \qquad (2)$$

Where,

$$X_{L\max} = L.\omega \qquad (3)$$

$$X_C = \frac{1}{C.\omega} \qquad (4)$$

A part of the equation (2), final the equation (1) becomes:

$$X_{TCSC}(\alpha) = \frac{X_C . X_L\left[\frac{\pi}{\pi - 2\alpha - \sin(2\alpha)}\right]}{X_C + X_L\left[\frac{\pi}{\pi - 2\alpha - \sin(2\alpha)}\right]} \qquad (5)$$

The curve of X_{TCSC} as a function of α is divided into three different regions : inductive, capacitive, and resonance, is summarized in the following figure.

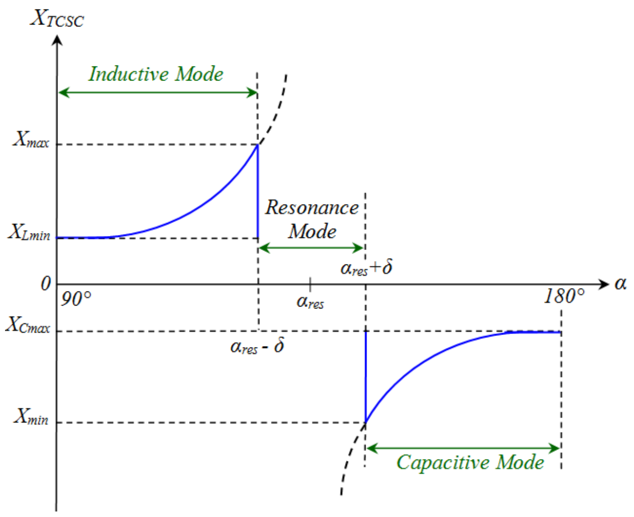


Figure 2. Characteristic curve $X_{TCSC} = f(\alpha)$.

III. NUMERICAL DISTANCE PROTECTION: PRINCIPAL AND SETTING ZONES

Since the impedance of a transmission line is proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring the impedance of a line up to a predetermined point (the reach point). Such a relay is described as a distance relay and is designed to operate only for faults occurring between the relay location and the selected reach point thus giving discrimination for faults that may occur in different line sections [18-19].

The basic principle of distance protection involves the division of the voltage at the relaying point by the measured current. The apparent impedance so calculated is compared with the reach point impedance. If the measured impedance is less than the reach point impedance, it is assumed that a fault exists on the line between the relay and the reach point is shows in figure 3.

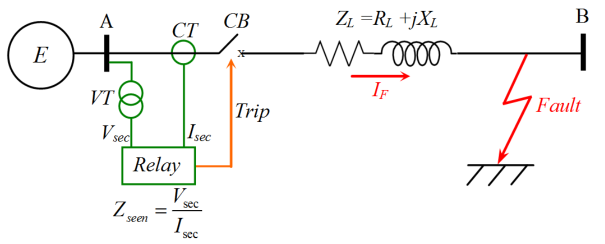


Figure 3. Principle of operation of distance protection.

A). Selectivity Protection

Time selectivity protection is given by the staggered trip time depending on the distance between measurement point and the fault [18-19]. Following the philosophy of setting the distance protection in Sonelgaz group, three zones (Z_1, Z_2 and Z_3) are considered [20].

The first zone covers about 80% of the protected transmission line AB and trips the circuit breaker in t_1. The second zone extends to 100% of the protected line AB and 20% of the adjacent line and trips circuit breaker in the t_2 while the third zone extends to 100% of the protected line AB+40% of the adjacent line and trips the circuit breaker in the t_3 as indicated in figure 4.

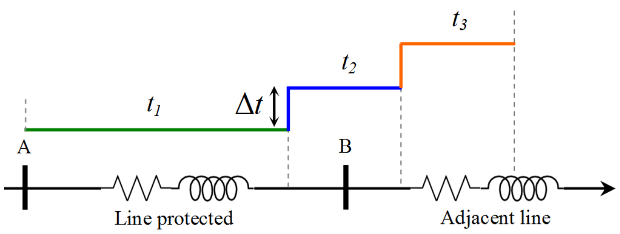


Figure 4. Selectivity of distance protection.

B). Setting of Distance Zone

Line impedances are proportional to the line lengths and this property is used to calculate the distance from the relay location to the fault. The relay, however, is fed with the current and voltage measured signals from the primary system via CT and VT transformers. Therefore, the secondary measured value by relay is used for the setting and is obtained by the following expression:

$$Z_{seen} = Z_T.l = \left[\left(R_L + jX_L\right).l\right].\left(k_{VT}/k_{CT}\right) \qquad (6)$$

The setting zone of distance zone for transmission line is indicated by figure 5.

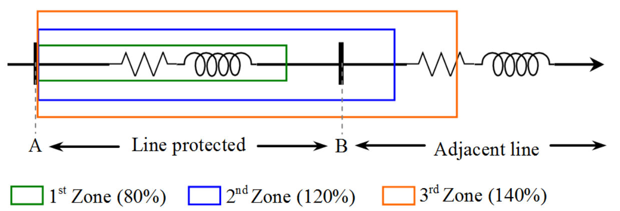


Figure 5. Settings zones of distance protection.

The setting zones for protected electrical transmission line without series FACTS i.e. TCSC is:

$$Z_1 = R_1 + jX_1 = 80\%Z_{AB} = 0{,}8.(R_{AB} + jX_{AB}) \qquad (7)$$

$$Z_2 = R_2 + jX_2 = R_{AB} + jX_{AB} + 0{,}2.(R_{BC} + jX_{BC}) \qquad (8)$$

$$Z_3 = R_3 + jX_3 = R_{AB} + jX_{AB} + 0{,}4.(R_{BC} + jX_{BC}) \qquad (9)$$

The impedance total of transmission line AB and BC measured by distance relay is:

$$Z_{AB} = K_Z.Z_{L-AB} = K_{VT}/K_{CT}\; Z_{L-AB} \qquad (10)$$

$$Z_{BC} = K_Z.Z_{L-BC} = K_{VT}/K_{CT}\; Z_{L-BC} \qquad (11)$$

Where, Z_{L-AB} and Z_{L-BC} is real total impedance of line AB and BC respectively. K_{VT} and K_{CT} is ratio of voltage and current respectively. The characteristic curves X (R) for MHO distance relay are represented in figure 6.

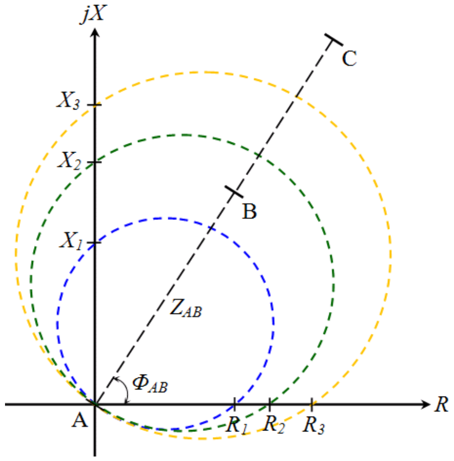


Figure 6. Characteristic curves of MHO distance relay.

The presence of TCSC systems in a reactor (X_{TCSC}) is a direct influence on the total impedance of the line protected (Z_{AB}), especially against the reactance X_{AB} and no influence on the resistance R_{AB}, the new setting zones for protected transmission line with TCSC connected at midline are:

$$Z_1 = 80\% Z_{AB} = 0,8.\left[R_{AB} + jX_{AB} + jX_{TCSC}(\alpha)\right] \quad (12)$$

$$Z_2 = R_{AB} + jX_{AB} + jX_{TCSC}(\alpha) + 0,2.(R_{BC} + jX_{BC}) \quad (13)$$

$$Z_3 = R_{AB} + jX_{AB} + jX_{TCSC}(\alpha) + 0,4.(R_{BC} + jX_{BC}) \quad (14)$$

C). Numerical distance relay

Numerical distance protection relays have changed dramatically in the last two decades from simple single function distance protection relays into multifunctional IEDs with primary transmission line protection functions based on classical or advanced operating principles. Several groups of functions are identified: Basic transmission line fault protection, advanced protection schemes, abnormal system conditions detection, automation, monitoring, and Analysis and fault recorder.

The main purpose of any multifunctional distance protection IED is to detect and clear as quickly as possible short circuit faults that can damage substation equipment or create conditions that adversely affect system stability or sensitive loads. This is achieved through the use of instantaneous distance elements or communications based protection schemes [21]. The distance elements can be simple or complex, with different operating characteristic, with or without directional supervision. The functions in the distance relay have a hierarchy that needs to be considered for the testing of the device (see figure 7). First of all, the secondary currents and voltages that are applied to the distance protection relay are filtered and processed in the analog input module and provide instantaneous sampled values to the internal digital data bus of the IED.

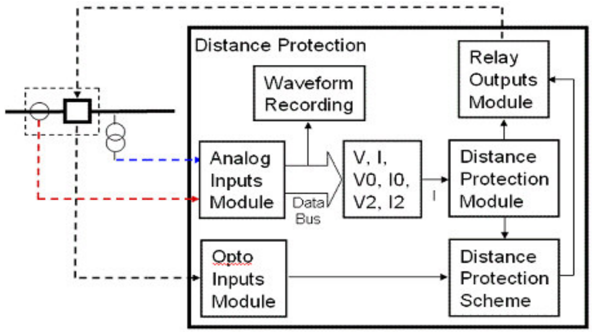


Figure 7. Numerical distance protection block diagram.

When a protection element detects an abnormal condition, it may operate and issue a trip command to clear a fault. It may also interact with other protection elements in an advanced distance protection scheme used for acceleration or adaptation of the relay to change configuration or system conditions.

IV. PRINCIPAL AND TOPOLOGY OF IEC 61850

Since 2003, automation systems based on IEC 61850 have been under construction and some of them have been in operation. Utilities and industrial electricity consumers have been benefitting from the standard worldwide.

This paper describes the implementation of the standard with focus on the components, network topology, electromagnetic compatibility and certification of conformity. The current projects and operating systems are surveyed and the statistics indicating the acceptance of this standard is illustrated [22-25].

A). Principle

IEC 61850 enables control, protection and monitoring devices to communicate with each other without protocol convertors in substations. It also safeguards the investment of owners of substation automation systems in an environment in which communication technology changes rapidly. Since becoming international standard in 2005, it has increasingly gained acceptance from the utilities and industrial electricity.

IEC 61850 is expected to be more widely applied as evident from the considerable number of installations with compliant equipment under construction and in operation. Both utilities and industrial electricity consumers have full confidence on this standard and show no hesitation in adopting it in important substations and industrial plant demanding high reliability.

B). Characteristics of the IEC 61850 Model

IEC 61850 is a popular international standard for communication networks and systems in substations [26]. The hierarchical information model is shown in figure 8.

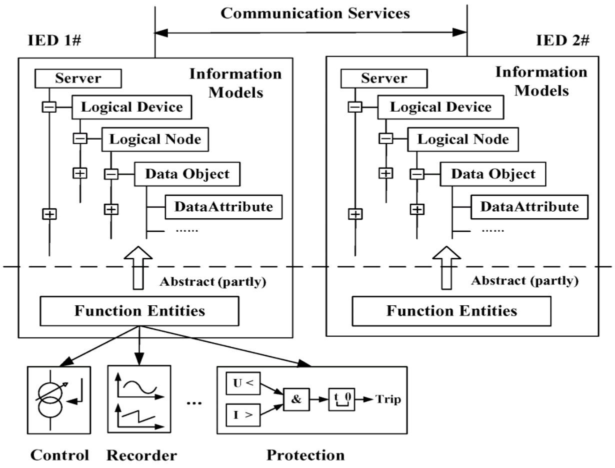


Figure 8. Information model of the IEC 61850.

LN is an important concept in the IEC 61850, which represents the "smallest part of a function that exchanges data". Each LN consists of mandatory, conditional, or optional DOs containing corresponding DAs. LNs can be grouped into a LD, while LDs can be grouped into a server representing the communication visible behaviors of an IED. Furthermore, the standard also offers a series of communication services to access the information model and exchange data (e.g., directory, data access, event report, and log). The interoperability among IEDs from different manufacturers is achieved if they adopt the standard information model and communication services.

C). Network Topologies

The reliability of a network depends much on its topology. In figure 19 and 10, the switches and the multimode optical fibers form a ring, carrying light signals of wavelength of 1,3μm. The switches support the prioritization of GOOSE telegrams. Up to six bay/protection devices may be connected to an Ethernet switch via a twisted-pair cables. Each device has two electrical Ethernet ports providing redundancy. Each port is connected to different Ethernet switches. If one port fails, the other port would take over within a few milliseconds and communication is restored. The entire network is monitored at the station controller by means of Simple Network Management Protocol [26-27].

The controller knows the status of all the components in the network as the devices are constantly monitored. As soon as a network fault is identified, for example a broken fibre, the network is immediately re-configured by means of the rapid spanning tree algorithm. Such a fault, as well as a port failure, raises an alarm at the station controller. The twisted-pair cables in figure 8 could be replaced with optical fibers to form a fully optical network is desired.

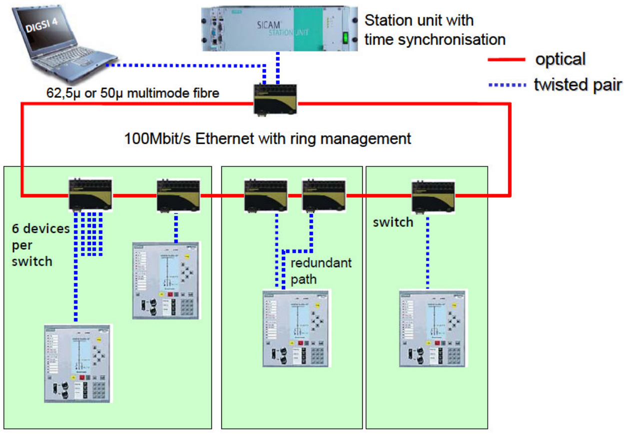


Figure 9. IEC 61850 network in a ring with switches and optical fiber.

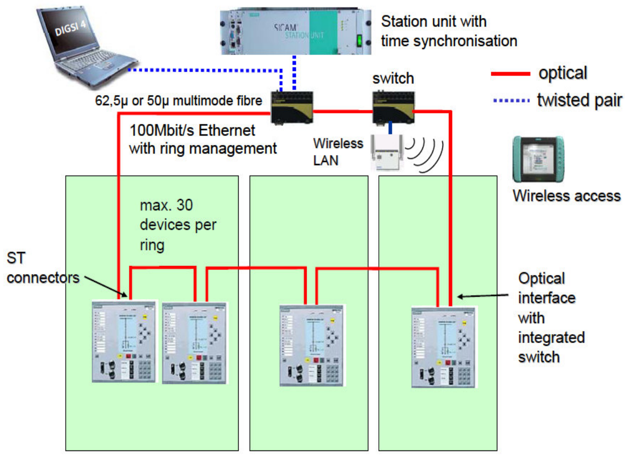


Figure 10. Optical Ethernet rings with integrated switches.

D). Tele-protection with the IEC 61850 Substation

IEC 61850 is a standard recommended by IEC originally for the design of system automat (SA) systems [15-16], which were recently extended to cover other utility automation functions as well.

Traditionally for the SA systems, the standard divides inter-substation communications into three levels: process level including the I/O devices, intelligent sensors and actuators, bay/unit level including the protection and control IEDs, and the substation level, including the substation computer, operator's desk and the interfaces with outside the substation [28].

All the communications within and between these levels are covered in the standard is shows in figure 11. Moreover, in its recent edition, the standard also covers protection data exchange between the bay and remote protection, as well as control data exchange between the substations [29].

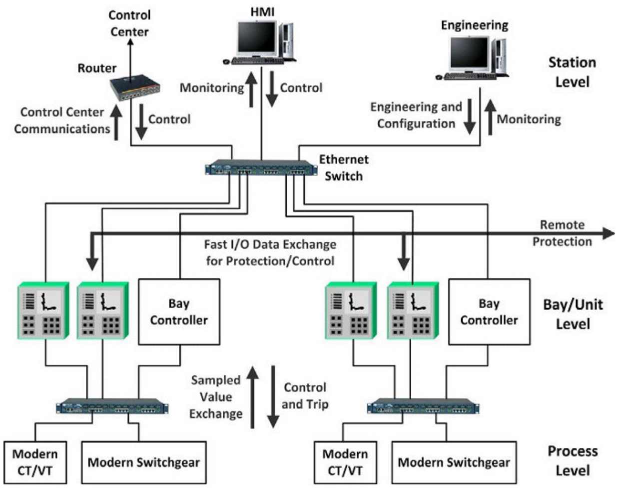


Figure 11. Substation automation topology.

In the IEC 61850 environment, protection and control functions are broken down into smaller units called LN is shows in figure 11.

These virtual units are in fact the objects defined in the object oriented context of the standard, and present one of the most important advantages of the standard over legacy protocols [16-29]. These LNs correspond to various protection, protection related, control, metering, and monitoring functions as well as the physical components such as transformers and breakers. Each LN can have a few or up to 30 data objects, each of which belonging to a Common Data Class (CDC).

Each data object in turn has a few or more than 20 data attributes. The LNs can be on any of the three levels defined for substation automation, and are normally grouped into LD – one or more of which reside in each physical device [25] in figure. IEC 61850 defines an abundance of services that act upon the data objects of the LNs.

V. CASE STUDY AND PROPOSED SHEMAS FOR TELE-PROTECTION

In order to show the performance of the IEC 61850 we chose 400 kV, 50 Hz Algerian electrical transmission line with TCSC installed at station *T* between station *A* and *B*. The TCSCis used control voltage and is located in the middle of transmission line is represented in figure 12.

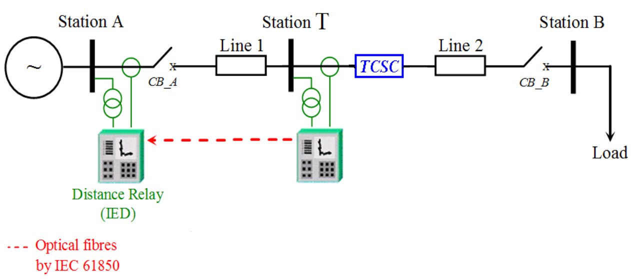


Figure. 12. Tele-protection schemes proposed.

A). Tele-protection Schemas Proposed

Tele-protection is one of the most important systems for power system protection and management. It is the central system of electrical power utilities as being the necessary infrastructure to control the operation of power system from remote power stations to power transmission line, substations, and distribution line by IEC 61850 at reel-time operation. In this case study is shows in figure.

Proposed scheme for tele-protection is based on the detection and monitoring of circulation of electric voltage (V_T) absorbed or injected by the TCSC at station (T). The transmitted the information uses optical fiber based communication protocol IEC 61850 to numerical relay protection install at station A in order to change the settings of the protection zones. The advantage of this scheme is monitoring the two modes of TCSC capacitive and inductive. The figure 13 shows the characteristic curve $X_{TCSC}(\alpha)$ of the compensator used TCSC in case study.

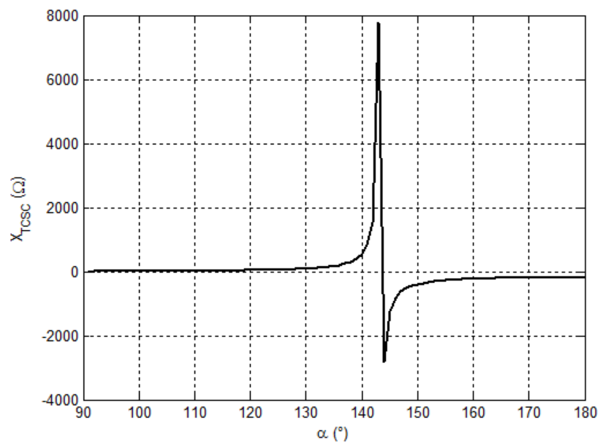


Figure 13. Characteristic curve $X_{TCSC} = f(\alpha)$.

The figures 14 and 15 is shows the impact of insertion TCSC (capacitive and inductive modes) on variation of P_B and Q_B at busbar *B* (load), where angle of line (δ) various between 0° to 180°.

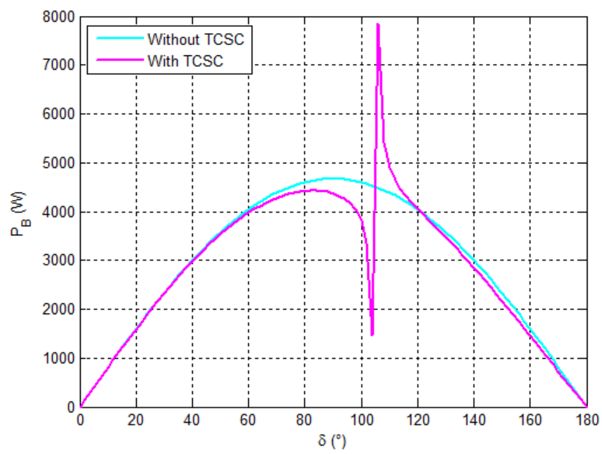


Figure 14. Impact of TCSC on active power P_B (δ).

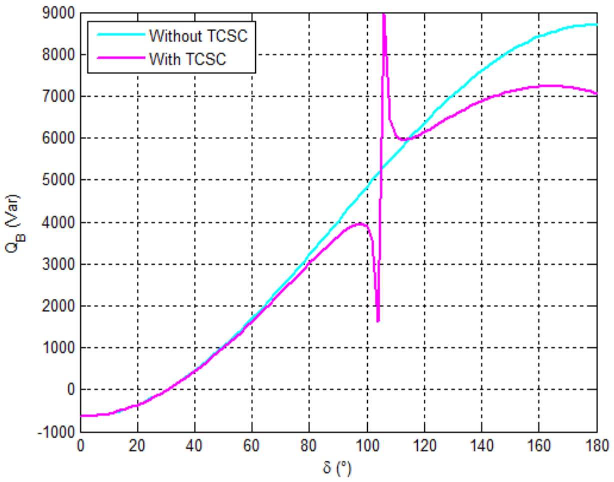


Figure 15. Impact of TCSC on reactive power Q_B (δ).

B). Peer-to-peer Communication Modes

The model is based on cyclic and high-priority transmission of status information. Information like a trip command is transmitted spontaneously and then cyclically at increasing intervals. Although other standard protocols exist that cover communications beyond substations, it is generally believed that the capabilities of IEC 61850 can be potentially used to improve these applications [26-29].

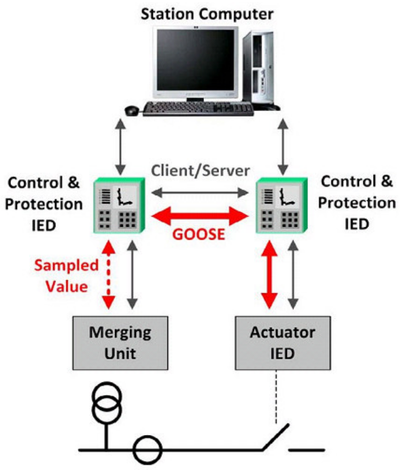


Figure 16. Client/server and peer-to-peer communication modes in IEC 61850.

In this context, IEC 61850 can be used as the communication protocol for feeder automation applications or communication with the control centers in figure 16.

C). Setting distance protection

C.1). Without TCSC

The total impedance measured (Z_{AB}) by the distance relay without TCSC devices is equal 11,844 + *j* 10800 (Ω), the settings zones for distance relay are summered in table 1.

Table 1. Setting zones without TCSC

Setting zones	$X_{setting}$ (Ω)	$R_{setting}$ (Ω)
Z_1	518,4000	0,5685
Z_2	716,4000	0,7857
Z_3	784,8000	0,8607

C.1). With TCSC on midline

The impacts of variation the firing angle (α) of the value of reactance setting zones (X_1, X_2 and X_3) are represented in following figure.

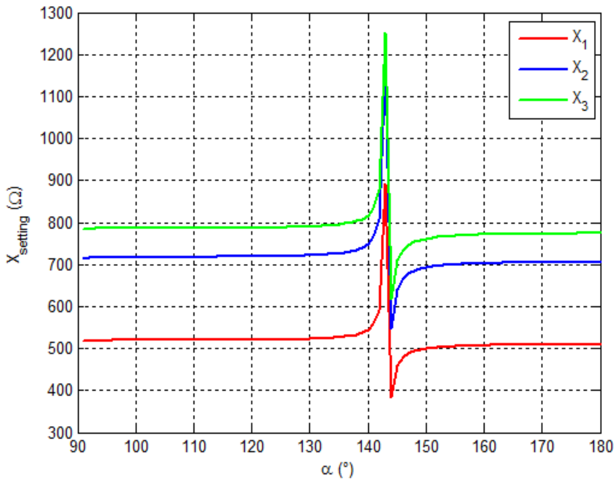


Figure 17. $X_{setting} = f(\alpha)$ for three zones.

The impacts of variation the firing angle (α) of the value of resistance setting zones (R_1, R_2 and R_3) are represented in following figure.

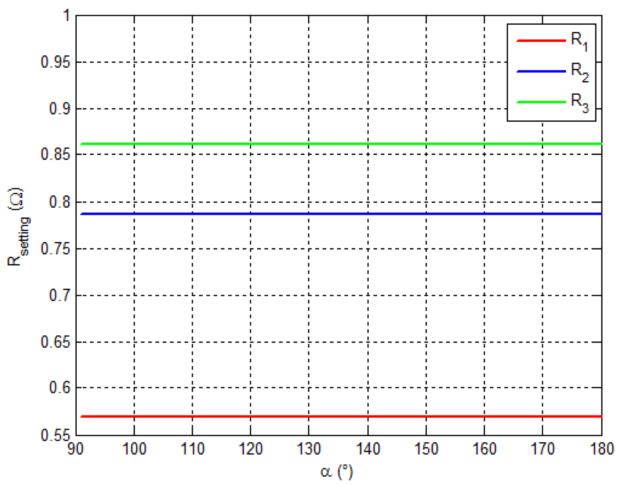


Figure 18. $R_{setting} = f(\alpha)$ for three zones.

VI. CONCLUSIONS

The results are presented in relation to a typical 400 kV electrical transmission system employing TCSC series FACTS devices. The effects of the extinction angle for controlled thyristors on TCSC are investigated. These devices are connected at the midpoint of a power transmission line protected by numerical distance relay.

This paper presents the effects of TCSC on the measured impedance at the relaying point based numerical distance protection an proposed schemes of tele-protection based IEC 61850 to change the settings of distance protection based on numerical technology for monitoring the TCSC have been proposed for modified setting zones.

The IEC 61850 enables control, protection and monitoring devices to communicate with each other without protocol convertors in substations.

VIII. APPENDIX

Element	*Parameters*
Power source	U_n = 400 kV, f_n = 50 Hz. S = 200 MVA.
Power transformer	U_n= 11 kV / 400 kV, Coupling: Y/Δ, S_{Tr} = 200 MVA, X_{Tr} = 0,0143 Ω, R_{Tr} = 0,22 Ω.
Transmission line	U_n = 400 kV, Z_L = 0,0319 + j 0,3184 Ω/km, l_{AB} = 360 km, l_{BC} = 190 km, ΔV = 55 kV.
TCSC	Q = + 30 / - 5 MVar, V_{max} = 30 kV.
Current transformer	I_{pri} = 1200 A, I_{sec} = 5 A, K_{TC} = 240.
Voltage transformer	V_{pri} = 400000/√3V, V_{sec} = 100/√3V, K_{VT} = 4000.

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