EXPLORE
International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 2, February, 2012

A Comparative Study of GCSC and TCSC Effects on MHO Distance Relay Setting in Algerian Transmission Line

Mohamed ZELLAGUI, Abdelaziz CHAGHI
LSP-IE Research Laboratory, Faculty of Technology, Department of Electrical Engineering,
University of Batna, 05000, Batna - ALGERIA.

ABSTRACT

This paper presents a comparative study of the performance of distance relays for transmission line high voltage (HV) 400 kV in Eastern Algerian transmission networks at Group Sonelgaz compensated by two different series Flexible AC Transmission System (FACTS) i.e. GTO Controlled Series Capacitor (GCSC) and Thyristor Controlled Series Capacitor (TCSC) connected at midpoint of an electrical transmission line. The facts are used for controlling transmission voltage, power flow, reactive power, and damping of power system oscillations in high power transfer levels.

This paper studies the effects of GCSC and TCSC insertion on the total impedance of a transmission line protected by MHO distance relay .The modified setting zone protection in capacitive and inductive boost mode for three forward zones (Z_1, Z_2 and Z_3) and reverse zone (Z_4) have been investigated in order to prevent circuit breaker nuisance tripping to improve the performances of distance relay protection. The simulation results are performed in MATLAB software.

Keywords: *Series Compensation, FACTS Devices, GCSC, TCSC, Transmission line HV, Distance relay, Zones Setting.*

1. INTRODUCTION

In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. As a consequence, some transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor. Flexible AC transmission systems (FACTS) controllers have been mainly used for solving various power system steady state control problems [1]. However, recent studies reveal that FACTS controllers could be employed to enhance power system stability in addition to their main function of power flow control. The literature shows an increasing interest in this subject for the last two decades, where the enhancement of system stability using FACTS controllers has been extensively investigated.

There are two generations for realization of power electronics based FACTS controllers: the first generation employs conventional thyristor-switched capacitors and reactors, and quadrature tap-changing transformers, the second generation employs gate turn-off (GTO) thyristor-switched converters as voltage source converters (VSCs). The first generation has resulted in the Static Var Compensator (SVC), the Thyristor-Controlled Series Capacitor (TCSC), and the Thyristor-Controlled Phase Shifter (TCPS) [2, 3]. The second generation has produced the Static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Unified Power Flow Controller (UPFC), and the Interline Power Flow Controller (IPFC) [4-7].

The two groups of FACTS controllers have distinctly different operating and performance characteristics. The voltage source converter (VSC) type FACTS controller group employs self-commutated DC to AC converters, using GTO thyristors, which can internally generate capacitive and inductive reactive power for transmission line compensation, without the use of capacitor or reactor banks. The converter with energy storage device can also exchange real power with the system, in addition to the independently controllable reactive power. The VSC can be used uniformly to control transmission line voltage, impedance, and angle by providing reactive shunt compensation, series compensation, and phase shifting, or to control directly the real and reactive power flow in the transmission line [7].

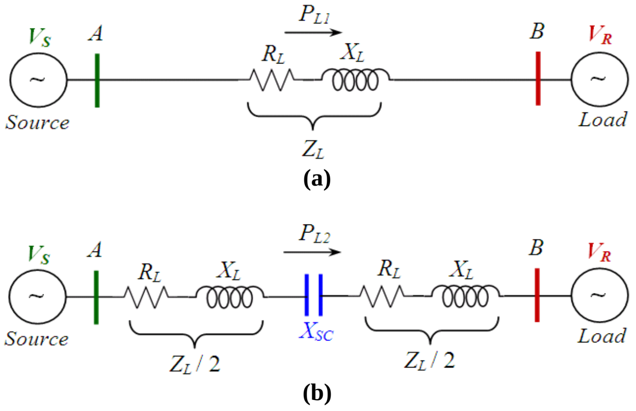
Many researchers have focused on GCSC's different aspect into the power systems. In [8] the GCSC with a simple controller, can damp both SSR and low frequency oscillations. However their concentration is on mitigating the SSR rather those LFOs damping and the controller parameters are designed by trial and error. In [9], in addition to introducing the structure of the GCSC, a comparative work, shows some advantages of the GCSC with respect to the TCSC, such as smaller size of GCSC's capacitor and lower current rating in the GCSC's switches.

They mentioned that although the GCSC has a better performance with respect to the TCSC, especially in power oscillation damping purposes, TCSC is more practical because of its simpler protection scheme and being an already established technology. In [10] introduced principle of operation and some prospective applications of the GCSC proved by simulation that in most situations, GCSC can be more attractive than TCSC. References [11-12], present a new, simple and robust control strategy for the GCSC controlling the active power transmitted by very long lines. The GCSC was proved to be very effective, in controlling the power-flow of the transmission lines that are little longer than half the wavelength of the system frequency comparative to the HVDC systems [13]. Reference [14] study the distance relay measured impedance for faults on a double circuit transmission line in the presence of TCSC in the case of phase to phase and three phases, faults. The effect of TCSC on a double circuit transmission line, on the measured impedance at the relaying point is carried out in [15]. In the presence of TCSC, the measured impedance at the relaying point is affected not only in its compensation degree, but also in its installation point. In reference [16], the influence of TCSC to EHV transmission line protection, especially to the high-frequency directional protection and presents a novel transient protection scheme based on Wavelet Transform (WT) is analyzed. Paper [17] study analytically by using simple models the impact of TSCS on transmission line protection.

In this paper, the setting protection zones for a distance relay on a 400 kV single transmission line is considered for the GCSC and TCSC series FACTS devices, in capacitive and inductive modes for different values of firing angle for series compensation on transmission line using controlled GTO and thyristors.

2. SERIES COMPENSATION IN ELECTRICAL TRANSMISSION LINE

Series compensation (SC) transmission lines utilize based series FACTS to reduce the net series inductive reactance of the line (X_L) in order to enhance the power transfer capability of the line. The power transfer along a transmission line is often explained in terms of the simple power system (source connected in busbar *A* and load connected at busbar *B*) as shown in figure.1.a and figure.1.b with series compensation represented by series reactance X_{SC} connected at midline.



(a)

(b)

Figure 1. Electrical Transmission line (a) Without SC, (b) With SC

The active power, power transferred by the uncompensated (P_{L1}) and compensated (P_{L2}) transmission lines are computed using equations (1) and (2):

$$P_{L1} = \frac{V_S . V_R}{Z_L} \sin(\delta) \tag{1}$$

$$P_{L2} = \frac{V_S . V_R}{Z_L - X_{SC}} \sin(\delta) \tag{2}$$

Where, $Z_L = R_L + jX_L$ is the total uncompensated impedance and δ is the transmission angle between the sending (V_S) and receiving end (V_R) voltages.

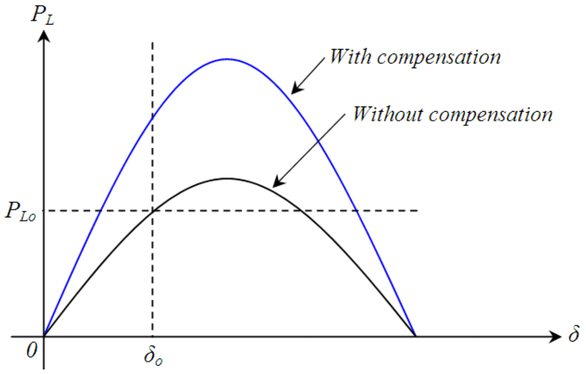


Figure 2. Power-angle curves

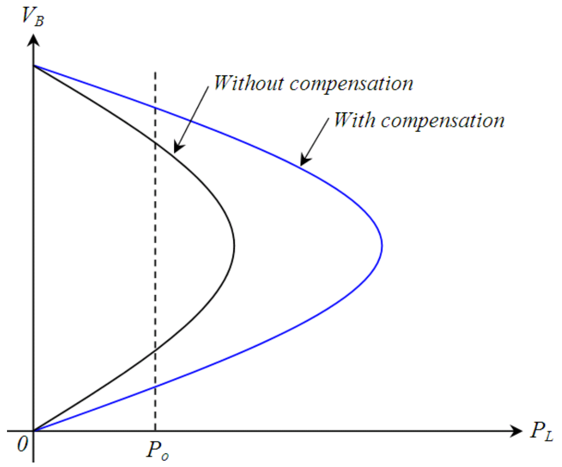


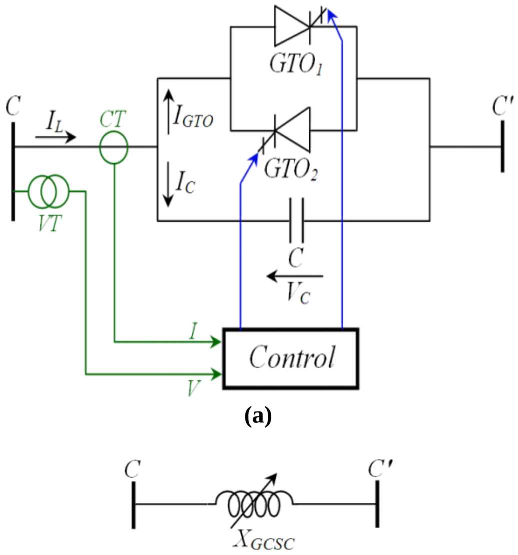
Figure 3. Voltage-power curves

The merits of series compensation can be illustrated by computing power transfer where transmission angle δ is a variable and calculating load bus voltage (V_B) where the load is a variable. To illustrate further the benefits of series compensation, consider a given power transfer, P_o shown in figure 2. The power transfer P_o in the compensated line is further away from steady state maximum power transfer capacity, which indicates increased angular and voltage stability margins for the same power transfer level. The use of series compensation also allows increased power transfer for the same transmission angles δ_o and enhances the voltage profile of the line. Since, series capacitors compensate the inductive reactance of the line, reactive transmission line losses are significantly reduced is showed in figure 3.

3. GTO CONTROLLED SERIES CAPACITORS (GCSC)

The compensator GCSC mounted on figure 4.a is the first that appears in the family series compensators. It consists of a capacitance (*C*) connected in series with the transmission line and controlled by a valve-type GTO thyristors mounted in anti-parallel and controlled by an angle of extinction (γ) is varied between 0° and 180°.

If the GTOs are kept turned-on all the time, the capacitor *C* is bypassed and it does not realize any compensation effect. On the other hand, if the positive-GTO (GTO_1) and the negative-GTO (GTO_2) turn off once per cycle, at a given angle γ counted from the zero-crossings of the line current, the main capacitor *C* charges and discharges with alternate polarity. Hence, a voltage V_C appears in series with the transmission line, which has a controllable fundamental component that is orthogonal (lagging) to the line current.



(a)

(b)

Figure 4. Transmission line in presence of GCSC system (a) Principle, (b) Apparent reactance

This compensator injected in the transmission line a variable capacitive reactance (X_{GCSC}).From figure 4.b.this capacitive reactance is defined by the following equation [6,7,8,10]:

$$X_{GCSC}(\gamma)=X_C\left[1-\frac{2}{\pi}\gamma-\frac{1}{\pi}\sin(2\pi)\right] \qquad (3)$$

Where, $X_C = {}^{1}\!/_{C.\omega}$

The curve of X_{TCSC} as a function of angle α is divided into two different regions (capacitive and inductive), is summarized in figure 5.

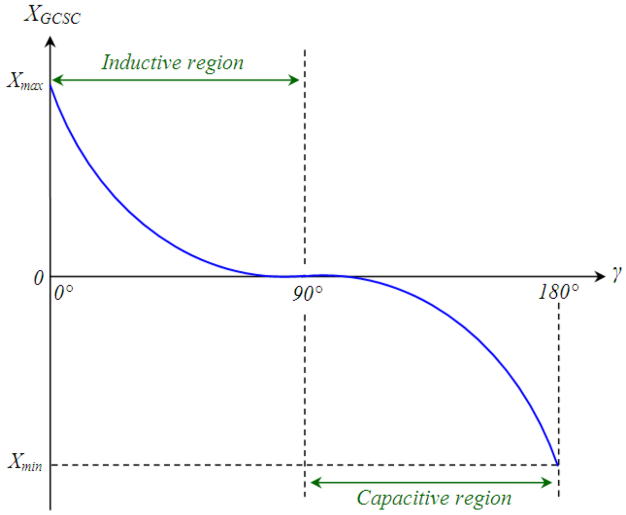
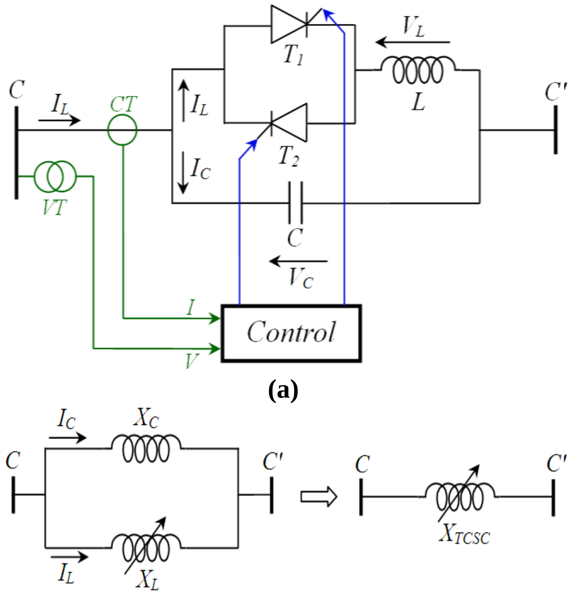


Figure 5. Characteristic curve $X_{GCSC} = f(\gamma)$

4. THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

The compensator TCSC mounted on Figure 6.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 6. 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 6.b.

Its value is function of the reactance of the line X_L where the device is located. It is in the range, $-0{,}8X_L \leq X_{TCSC} \leq 0{,}2X_L$. The apparent reactance X_{TCSC} is defined by the following equation [6, 15, 16]:

$$X_{TCSC}(\alpha) = X_C // X_L(\alpha) = \frac{X_C.X_L(\alpha)}{X_C + X_L(\alpha)} \tag{4}$$

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

$$X_L(\alpha) = X_{L\max}\left[\frac{\pi}{\pi - 2\alpha - \sin(2\alpha)}\right] \tag{5}$$

Where, $X_{L\max} = L.\omega$ and $X_C = \dfrac{1}{C.\omega}$

A part of the equation (5), final the equation (4) becomes:

$$X_{TCSC}(\alpha) = \frac{X_C.X_L\left[\dfrac{\pi}{\pi - 2\alpha - \sin(2\alpha)}\right]}{X_C + X_L\left[\dfrac{\pi}{\pi - 2\alpha - \sin(2\alpha)}\right]} \tag{6}$$

The curve of X_{TCSC} as a function of angle α is divided into three different regions is summarized in the following figure.

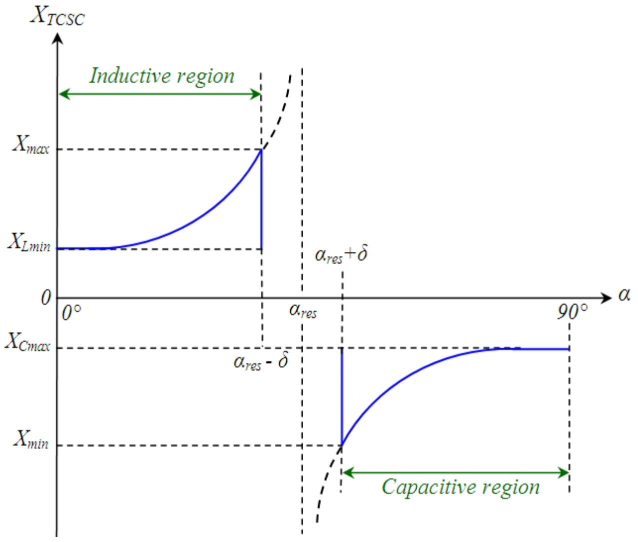


Figure 7. Characteristic curve $X_{TCSC} = f(\alpha)$

5. SETTING DISTANCE RELAYS

Distance protection 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. The philosophy of setting relay at Sonelgaz Group is three zones forward (Z_1, Z_2 and Z_3) and one zone reverse (Z_4) for protection the transmission line HV and EHV between busbar *A* and *B* with total impedance Z_{AB} is showed in figure 8.

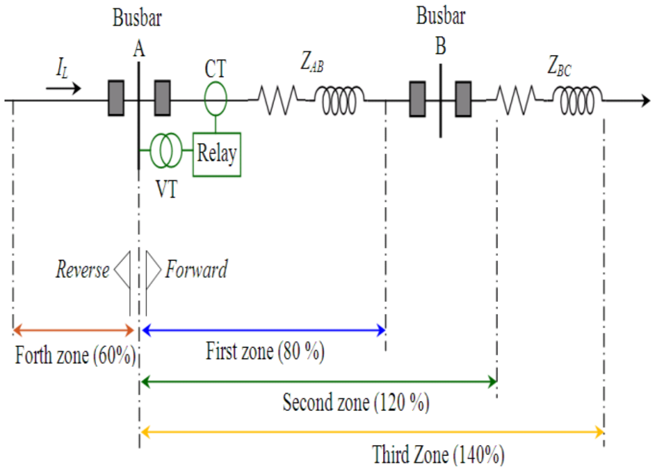


Figure 8. Setting zones for distance relay

The setting zones for protected transmission line without series FACTS is:

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

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

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

$$Z_4 = R_4 + jX_4 = 60\% Z_{AB} = 0{,}6.(R_{AB} + jX_{AB}) \tag{10}$$

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

$$Z_{AB} = K_Z.Z_{L-AB} = {K_{VT}}/{K_{CT}}\, Z_{L-AB} \tag{11}$$

$$Z_{BC} = K_Z.Z_{L-BC} = {K_{VT}}/{K_{CT}}\, Z_{L-BC} \tag{12}$$

Where, $Z_{L\text{-}AB}$ and $Z_{L\text{-}BC}$ is real total impedance of line AB and BC respectively. K_{VT} and K_{CT} is ratio of voltage to current.

The presence of series FACTS systems in a reactor (X_{FACTS}) 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}, it is represented in figure.9

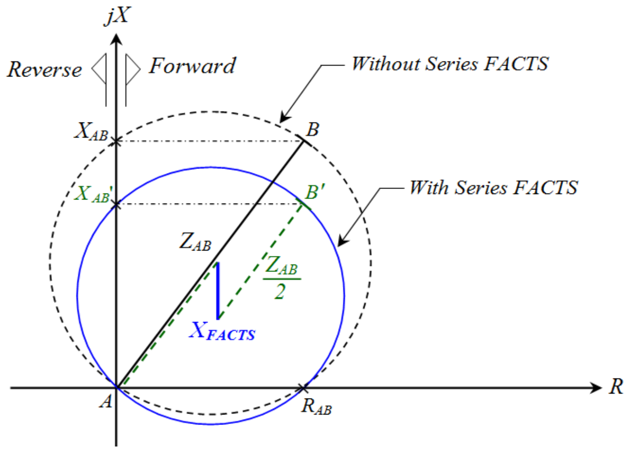


Figure 9. Impact of presence series FACTS on Z_{AB}

From figure 9, the setting zones for protected transmission line with series FACTS (GCSC or TCSC) connected at midline are:

$$Z_1 = 80\% Z_{AB} = 0{,}8.(R_{AB} + jX_{AB} - jX_{FACTS}) \quad (13)$$

$$Z_2 = R_{AB} + jX_{AB} - jX_{FACTS} + 0{,}2.(R_{BC} + jX_{BC}) \quad (14)$$

$$Z_3 = R_{AB} + jX_{AB} - jX_{FACTS} + 0{,}4.(R_{BC} + jX_{BC}) \quad (15)$$

$$Z_4 = 60\% Z_{AB} = 0{,}6.(R_{AB} + jX_{AB}) \quad (16)$$

For the case of on integration of GCSC, the reactance X_{FACTS} is equal X_{GCSC} and on integration of TCSC, the reactance X_{FACTS} is equal X_{TCSC}.

6. CASE STUDY AND SIMULATION RESULTS

The power system studied in this paper is the 400 kV, 50Hz eastern Algerian electrical transmission networks at group SONELGAZ. The MHO distance relay is located in the bus bar at Oued El Athmania substation to protect transmission line between busbar *A* and busbar *B* at Ain El Beida substation, the bus bar *C* at Bir El D'heb substation in Tébessa. The parameters of transmission line are summarized in the appendix.

6.1 Impact of Insertion of GCSC

The figure below represents a 400 kV transmission line in the presence of a series FACTS type GCSC controlled by GTO installed in the mid point of the line protected by a MHO distance relay is show in figure 10, the parameters of transmission line and GCSC installed is summarized in the appendix.

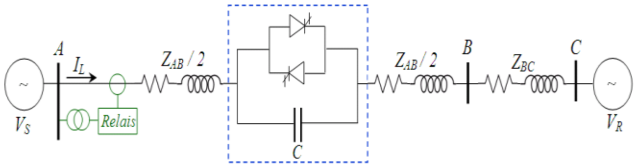


Figure10. Transmission line in presence GCSC

The figure 11 shows the characteristic curve $X_{GCSC}(\gamma)$ of the compensator used GCSC in this case study.

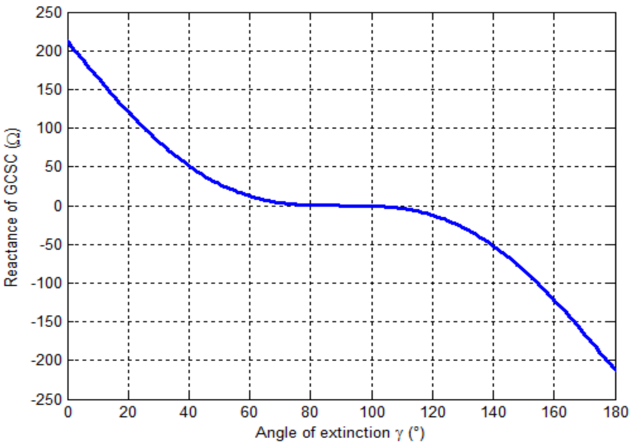


Figure 11. Characteristic curve $X_{GCSC} = f(\gamma)$ installed

The impact of the angle variation γ on reactance X_{GCSC} and the total impedance for transmission line protected (X_{AB} and R_{AB}) is summarized in table 1.

Table 1: The X_{GCSC}, X_{AB} and R_{AB} on function γ

(a). Inductive mode

γ (°)	0	20	40	80
X_{GCSC} (Ω)	212,20	121,63	51,371	0,475
X_{AB} (Ω)	435,09	344,51	274,25	223,36
R_{AB} (Ω)	23,051	23,051	23,051	23,051

(b). Capacitive mode

γ (°)	100	120	140	180
X_{GCSC} (Ω)	-0,476	-12,237	-51,371	-212,20
X_{AB} (Ω)	222,40	210,64	171,51	10,673
R_{AB} (Ω)	23,051	23,051	23,051	23,051

The impact of variation the angle γ and X_{GCSC} on the value of reactance setting zones are represented in following figure.

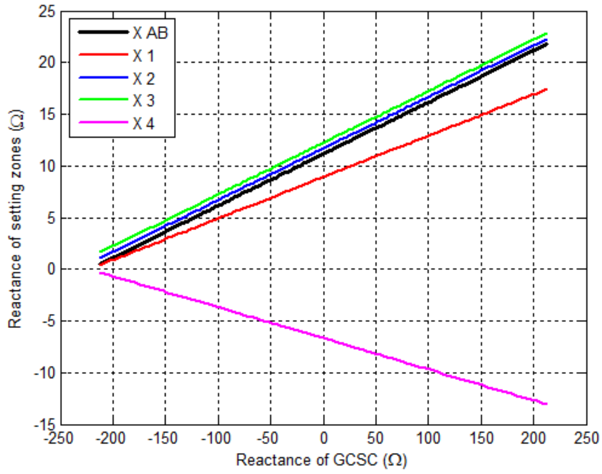


Figure 12. $X = f(X_{GCSC})$

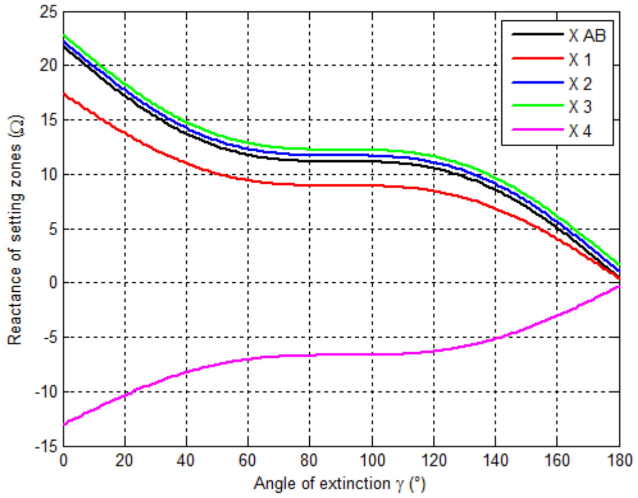


Figure 13: $X = f(\gamma)$

The impact of variation the angle γ and X_{GCSC} on the value of resistance setting zones are represented in following figure.

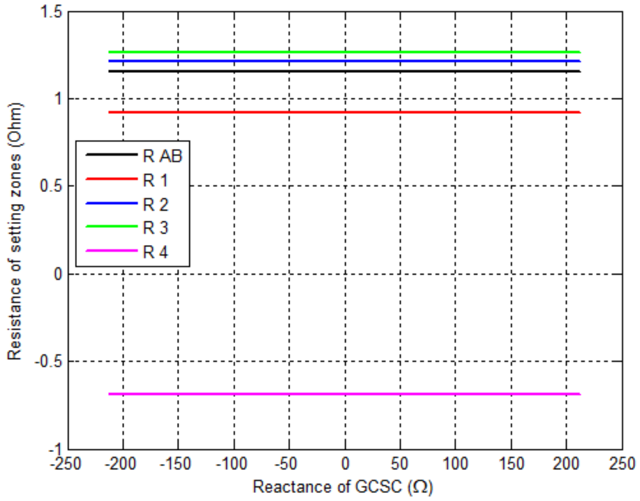


Figure 14. $R = f(X_{GCSC})$

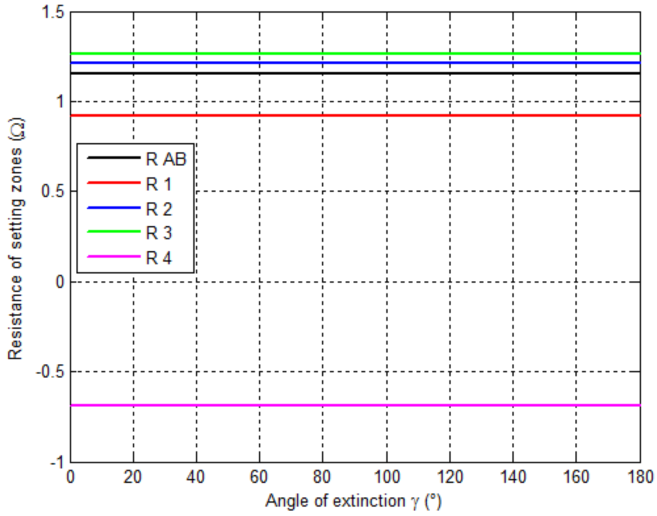


Figure 15: $R = f(\gamma)$

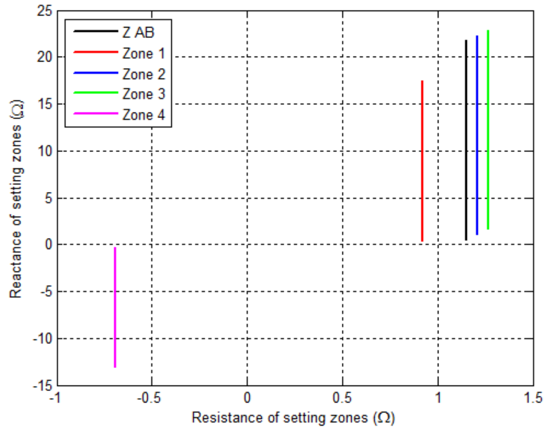


Figure 16: $X = f(R)$

From figure 10, which represents the curve characteristics X_{GCSC} (γ) for GCSC installed, the value of the reactance X_{GCSC} varies with the angle γ. In this case there is a reduction of X_{GCSC} between X_{max} which is equal to 212, 20 Ω and X_{min} equal to -212, 20 Ω.

As can be seen from figures 12, 13 and 16, the total line reactance X_{AB} and the forward reactance zone (X_1, X_2 and X_3) are increased and decrease for X_4 with the same form of X_{GCSC} and γ variation. From figures 14, 15 and 16, the total resistance of the line R_{AB} and the different zones resistance (R_1, R_2, R_3 and R_4) are constant regardless changes in X_{GCSC} and γ.

6.2 Impact of Insertion of TCSC

The figure above represents a transmission line of 400 kV in the presence of a series FACTS type TCSC controlled by thyristors installed in the middle of the line protected by a MHO distance relay is show in figure 17, the parameters of transmission line and TCSC installed is summarized in appendix.

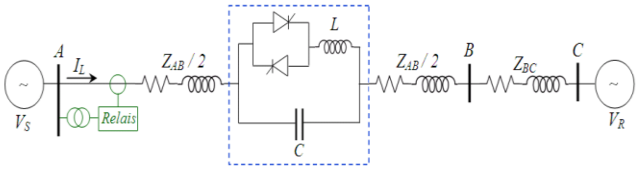


Figure 17. Transmission line in presence

The figure 17 shows the characteristic curve X_{TCSC} (α) of the compensator used TCSC in this case study.

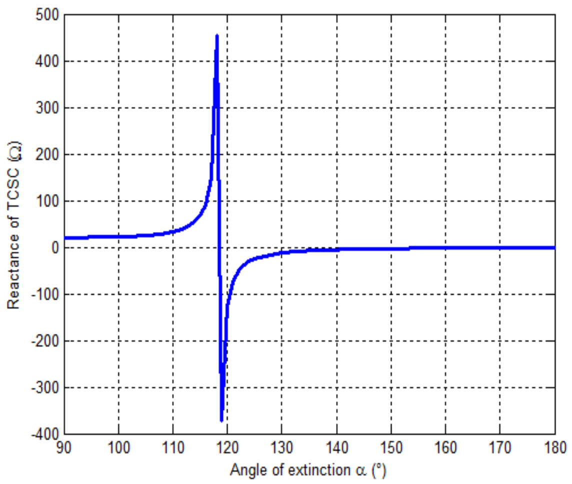


Figure 18. Characteristic curve $X_{TCSC} = f(\alpha)$ installed

The impact of variation the angle α on reactance X_{TCSC} and the total impedance for transmission line protected (X_{AB} and R_{AB}) is summered in table 2.

Table 2. The X_{TCSC}, X_{AB} and R_{AB} on function α

(a). Inductive mode

α (°)	90	95	100	115
X_{GCSC} (Ω)	20,944	21,063	21,938	66,620
X_{AB} (Ω)	243,82	243,94	244,82	289,50
R_{AB} (Ω)	23,051	23,051	23,051	23,051

(b). capacitive mode

α (°)	120	125	130	180
X_{GCSC} (Ω)	-126,91	-25,741	-12,725	-1,090
X_{AB} (Ω)	95,968	197,14	210,15	221,79
R_{AB} (Ω)	23,051	23,051	23,051	23,051

The impact of variation the angle α and X_{TCSC} of the value of reactance setting zones are represented in following figure.

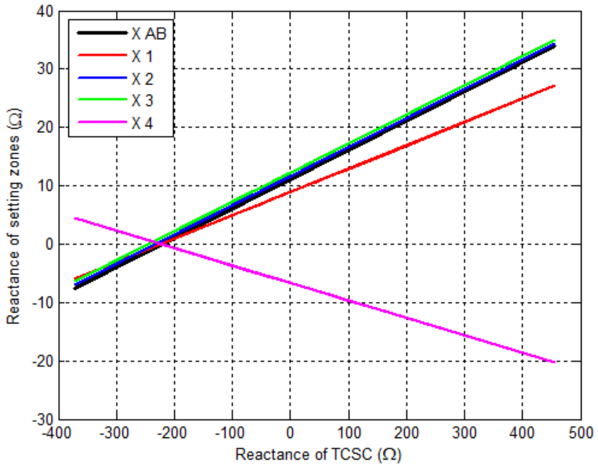


Figure 19. $X = f(X_{TCSC})$

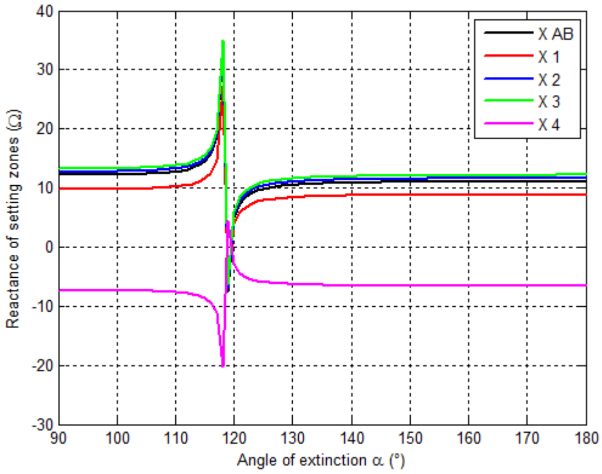


Figure 20. $X = f(\alpha)$

The impact of variation the angle α and X_{TCSC} of the value of resistance setting zones are represented in following figure.

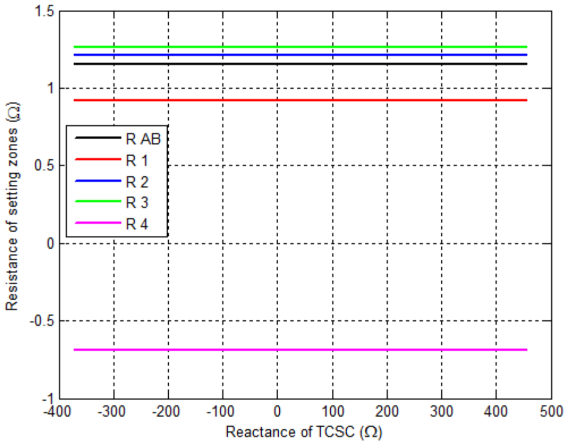


Figure 21. $R = f(X_{TCSC})$.

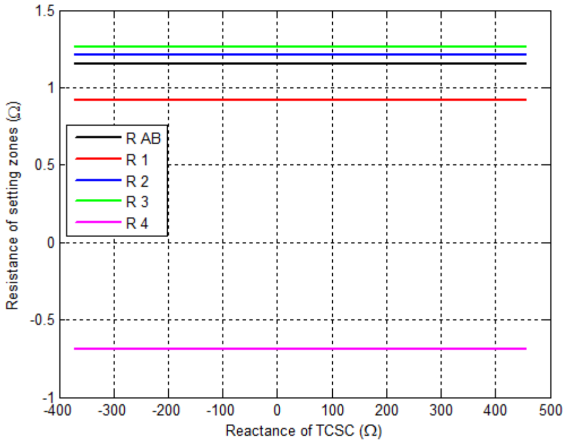


Figure 22. $R = f(\alpha)$

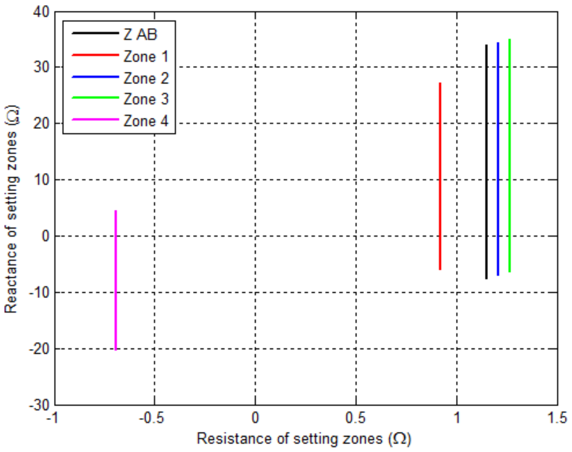


Figure 23. $X = f(R)$

From figure 18, which represents the curve characteristics X_{TCSC} (α) for TCSC installed, the value of the reactance X_{TCSC} varies depending on the angle α. For inductive and capacitive mode the value of reactance is increased between X_{max} which is equal to 454,2 Ω and X_{min} which is equal to -372,9 Ω.

From figures 19, 20 and 23, the total line reactance X_{AB} and different zone reactance (X_1, X_2, X_3 and X_4) have the same form of variation X_{TCSC} and α for two operation modes. From figures 21, 22 and 23, the total resistance of the line R_{AB} and the different zones resistance (R_1, R_2, R_3 and R_4) are constant regardless changes in X_{TCSC} and α for the two operation modes.

7. CONCLUSIONS

The results are presented in relation to a typical 400 kV transmission system employing GCSC and TCSC series FACTS devices. The effects of the extinction angle γ for controlled GTO installed on GCSC as well as extinction angle α for controlled thyristors on TCSC are investigated.

These devices are connected at the midpoint of a transmission line protected by distance relay. However as demonstrated these angles injected variable reactance (X_{GCSC} or X_{TCSC}) in the protected line which result in directly impact on the total impedance of the protected line. In fact this effect varies the settings zones by increasing performance of the total system protection and avoiding unwanted tripping of circuit breaker in the presence of series FACTS compensatory.

REFERENCES

[1] N. G. Hingoran, L. Gyugyi, "Understanding FACTS Concepts and Technology of Flexible AC transmission Systems", Published by John Wiley & Sons Ltd, West Sussex, United Kingdom, 2000.

[2] IEEE Power Engineering Society, "FACTS Overview", Published by IEEE Special Publication 95TP108, New Jersey, USA, 1995.

[3] IEEE Power Engineering Society, "FACTS Applications", Published by IEEE Special Publication 96TP116-0, New Jersey, USA, 1996.

[4] I.A. Erinmez, A. M. Foss, "Static Synchronous Compensator (STATCOM)". Working Group 14.19, CIGRE Study Committee 14, Document No. 144, New Jersey, USA, August 1999.

[5] CIGRE Task Force 14-27, "Unified Power Flow Controller", Published by CIGRE Technical Brochure, USA, 1998.

[6] R.M. Mathur, R.S. Basati, "Thyristor-Based FACTS Controllers for Electrical Transmission Systems", Published by IEEE Press Series in Power Engineering, New Jersey, USA, 2002.

[7] K.K. Sen, M.L. Sen, "Introduction to FACTS Controllers: Theory, Modeling and Applications", Published by John Wiley & Sons, Inc., and IEEE Press, New Jersey, USA, 2009.

[8] F.D. De Jesus, L.F.W. De Souza, E. Wantanabe, J.E.R. Alves, "SSR and Power Oscillation Damping using Gate-Controlled Series Capacitors (GCSC)", IEEE Transaction on Power Delivery, Vol. 22, N°3, pp. 1806-1812, Mars 2007.

[9] L.F.W. De Souza, E.H. Wantanabe, J.E.R. Alves, "Thyristor and Gate-Controlled Series Capacitors: A Comparison of Component Ratings", IEEE Transaction on Power Delivery, Vol. 23, N°2, May 2008, pp. 899-906.

[10] S. Banerjee, J.K. Chatterjee, S.C. Triphathy, "Application of Magnetic Energy Storage Unit as Continuous VAR Compensator", IEEE Transaction on Energy Conversion, Vol.5, N°1, pp. 39-45, January 1990.

[11] E.H. Wantanabe, L.F.W. De Souza, F.D. De Jesus, J.E.R. Alves, "GCSC-Gate Controlled Series Capacitor: A New FACTS Devices for Series Compensation of Transmission Lines", International

Conference IEEE/PES and Distribution, Latin America, pp. 981-986, 2004.

[12] S. Ray, G.K. Venayagamoorthy, E.H. Watanabe, "A Computational Approach to Optimal Damping Controller Design for a GCSC", IEEE Transaction on Power Delivery, Vol. 23, N°3, pp. 1673-1681, July 2008

[13] M. Ardes, C. Portela, E.L.V. Emmerik, R.F. Da Silva Dias, "Static Series Compensators Applied to Very Long Distance Transmission Lines", Electrical Engineering, Vol. 86, N° 2, pp. 69-76, February 2004

[14] S. Jamali, A. Kazemi, H. Shateri, "Measured Impedance by Distance Relay for Inter Phase Faults with TCSC on a Double Circuit Line", 18th Australasian Universities Power Engineering Conference (AUPEC' 08), Sydney, Australia, 14-17 December 2008.

[15] A. Kazemi, S. Jamali, H. Shateri, "Comparing TCSC Placements on Double Circuit Line Mid-Point and Ends from Measured Impedance Point of View", IEEE International Conference on Industrial Technology (ICIT'2008), Chengdu, China, 21-24 April 2008.

[16] Q. Liu, Z. Wang, "Research on the Influence of TCSC to EHV Transmission Line Protection", International Conference on Deregulation and Restructuring and Power Technologies (DRPT'2008), Nanjing, China, 6-9 April 2008.

[17] P.S. Chaudhari, P.P. Kulkarni, R.M. Holmukhe, P.A. Kulkarni, "TCSC for Protection of Transmission Line", 3rd International Conference on Emerging Trends in Engineering and Technology (ICETET'10), Goa, India, 19-21November 2010.

APPENDIX

Power System Element	Parameters
Source	U_n= 400 kV f_n = 50 Hz
Transmission line HV	U = 400 kV Z_L = 0,03293+ j 0,3184 Ω/km *Length AB* = 300 km *Length BC* = 170 km
GCSC	C = 15 *mF* Semi-conductor : *GTO*
TCSC	L = 0,0033 *H* C = 15 *F* Semi-conductor : *Thyristor*
Current transformer	I_{pri} = 1000 A I_{sec} = 5 A K_{CT} = 200
Voltage transformer	V_{pri} = 400000/√3 V V_{sec} = 100/√3 VK_{VT} = 4000