

Impact of Thyristor Controlled Series Capacitor Insertion on Short-Circuit Calculation in Presence Phase to Earth Fault

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Article Info

Article history:

Received Jun 2, 2012
Revised Aug 11, 2012
Accepted Aug 16, 2012

Keyword:

Transmission line
TCSC
Voltage injected
Reactance injected
Earth fault
Symmetrical components

ABSTRACT

This research paper presents a study on phase to earth fault short-circuit calculation with fault resistance on a single transmission line 400 kV in eastern Algerian transmission networks at Algerian Company of Electricity and Gas (Sonelgaz Group) compensated by series Flexible AC Transmission System (FACTS) i.e. Thyristor Controlled Series Capacitor (TCSC) installed in midline. The facts are used for controlling transmission voltage, power flow, reactive power, and damping of power system oscillations at high power transfer levels. The direct impacts of TCSC insertion on the total impedance, active power and reactive power an electrical transmission line and also parameters of short-circuit : symmetrical currents, line currents, symmetrical voltages and line voltages are carried out. More the effects of injected voltage by TCSC for three case studies are presented.

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1. INTRODUCTION

Power systems have to be planned, projected, constructed, commissioned and operated in such a way to enable a safe, reliable and economic supply of the load. The knowledge of the equipment loading at the time of commissioning, the prediction is necessary in the future for the design and determination of the rating of the individual equipment and of the power system as a whole. Faults, i.e., short-circuits in the power system cannot be avoided despite careful planning and design, good maintenance and thorough operation of the system. This implies influences from outside the system, such as faults following lightning strokes into phase-conductors of overhead lines and damages of cables due to earth construction works as well as internal faults due to ageing of insulation materials [1]. Fault currents therefore have an important influence on the design and operation of power systems equipment. More than 83% of the occurred faults on the 220 and 400 kV overhead transmission networks in Group Sonelgaz are single phase to ground type [2].

Distance protection relays have been widely applied as the primary protection in high voltage transmission lines due to their simple operating principle and capability to work independently under most circumstances [3], [4]. The TCSC belongs to the FACTS group of power systems devices. The concept of the TCSC has been around since the mid 1980s, with the first known commercial installation being in 1992 [1] in the United States of America. Essentially a TCSC is a variable reactance device that can be used to provide an adjustable series compensating reactance to an electrical transmission line. Its advantage over other series compensating devices is that its reactance can be instantaneously and precisely controlled. This makes the TCSC well suited to enhance the stability of a power system [3], [5]. 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 trajectory 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. The impact of FACTS devices on distance protection varies depending on the type of FACTS device used, the application for which it is applied and the location of the FACTS device in the power system.

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 transmission lines protection in [6] while the impact on communication-aided distance protection schemes and its mitigation is reported in [7]. Authors in [8] study this impact on numerical relay using computational intelligence based ANN method. In reference [9], the Z_{seen} by distance relay for inter phase faults with TCSC on a double transmission line high voltage is being studied and in [10]. Comparing TCSC placements on double circuit line at mid-point and at ends from measured impedance point of view is mentioned in [11]. The authors report in [12] a comparative study of GCSC and TCSC effects on distance relay setting in single 400 kV Algerian transmission line. However, there is no work reported on mitigation of the impact of midpoint TCSC compensated transmission lines on distance protection.

In this paper study effect of variation voltage injected (V_{TCSC}) by TCSC in inductive and capacitive mode on short-circuit parameters is presented with resistance fault (R_F) varied between 0 to 100 Ω , the impact on resistance and reactance measured by relay in case of earth fault at the end of transmission line and with the presence of TCSC installed on 400 kV midline single transmission line, short-circuit calculation on presence TCSC is important for settings relay in overcurrent protection, distance protection and differential protection, ...etc.

2. VOLTAGE AND REACTANCE INJECTED BY TCSC

The compensator TCSC mounted on figure 1 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 extinction angle (α) varied between 90° and 180° .

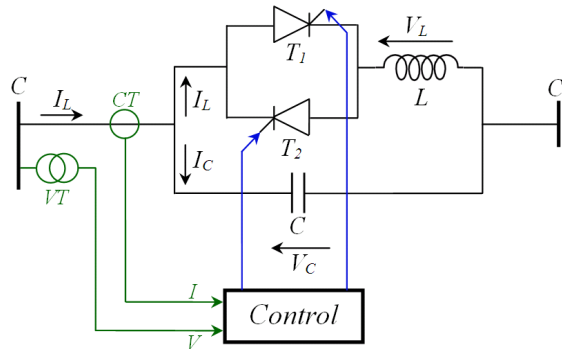


Figure 1. System configuration for TCSC system.

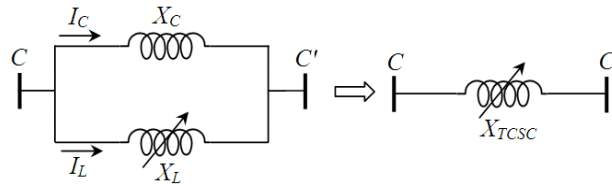


Figure 2. Apparent reactance injected by TCSC.

This compensator injects in the transmission line a variable reactance (X_{TCSC}) indicated by figure 2. The characteristics of the TCSC are determined from the series capacitor and reactor circuit parameters shown in figure 2. The steady-state TCSC power frequency reactance $X_{TCSC}(\alpha)$ as a function of thyristors control angle (α) can be calculated from equation (1), based on an analysis of thyristors current [13-14].

$$X_{TCSC}(\alpha) = X_C \cdot [1 - A + B] \quad (1)$$

Where,

$$A = \frac{K^2}{K^2 - 1} \left(\frac{\sigma + \sin(\sigma)}{\pi} \right) \quad (2)$$

$$B = \frac{4K^2}{K^2 - 1} \cos^2 \left(\frac{\sigma}{2} \right) \cdot \frac{K \cdot \tan \left(\frac{K \cdot \sigma}{2} \right) - \tan \left(\frac{\sigma}{2} \right)}{\pi} \quad (3)$$

And,

$$\sigma = 2 \cdot (\pi - \alpha) \quad (4)$$

$$K = \frac{\lambda}{\omega} \quad (5)$$

$$\lambda = \frac{1}{\sqrt{LC}} \quad (6)$$

Vernier mode allows the TCSC to behave either as a continuously controllable capacitive reactance or as a continuously controllable inductive reactance. It is achieved by varying the thyristors firing angle in an appropriate range. However, a smooth transition from the capacitive to inductive mode is not permitted because of the resonant region between the two modes [15].

A variant of this mode is the capacitive vernier mode, in which the thyristors are fired when the capacitor voltage and capacitor current have opposite polarity. This condition causes a TCR current that has a direction opposite to that of the capacitor current, thereby resulting in a loop-current flow in the TCSC controller. Another variant is the inductive vernier mode, in which the TCSC can be operated by having a high level of thyristors conduction.

In this mode, the direction of the circulating current is reversed and the controller presents net inductive impedance. The active and reactive power at load busbar with TCSC is :

$$P_B(\delta) = \frac{V_A \cdot V_B}{Z_{AB} \pm X_{TCSC}(\alpha)} \sin(\delta) \quad (7)$$

$$Q_B(\delta) = \frac{V_B^2}{Z_{AB} \pm X_{TCSC}} - \frac{V_A \cdot V_B}{Z_{AB} \pm X_{TCSC}} \cos(\delta) \quad (8)$$

Indices (-) for capacitive boost mode and (+) for capacitive boost mode on equations (7) and (8). The voltage at load busbar with TCSC is defined by:

$$V_B = V_{B,W} + V_{TCSC}(\alpha) \quad (9)$$

$$V_{B,W} = V_{A,W} - \Delta V \quad (10)$$

Where, $V_{B,W}$ and $V_{A,W}$ it is voltages at load busbar (B) and at source busbar (A) without TCSC respectively, and ΔV is voltage drop on transmission line

3. PHASE TO EARTH FAULT CALCULATION

Figure 3 shows transmission line in case of a single phase (phase A) to ground fault at busbar B with fault resistance in the presence of a TCSC inserted on midline, while figure 4 shows the equivalent circuit.

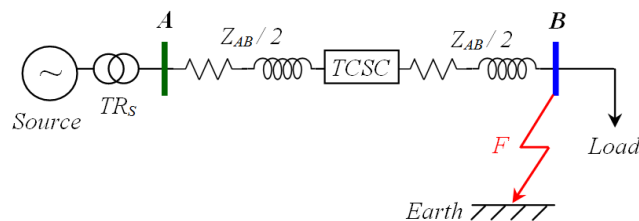


Figure 3. Transmission line with TCSC in midline.

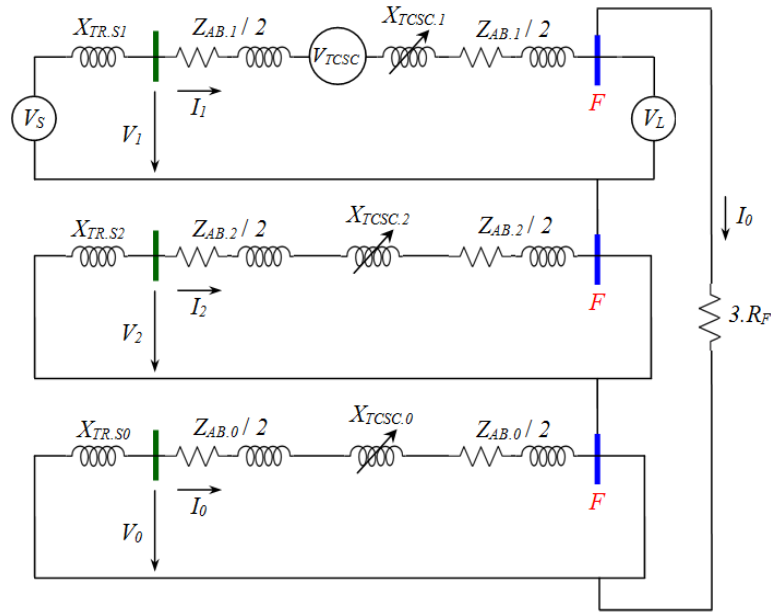


Figure 4. The equivalent circuit with TCSC.

With TCSC inserted in midline, the total impedance of transmission line ($Z_{AB-TCSC}$) is:

$$Z_{AB-TCSC} = R_{AB} + j[X_{AB} \pm X_{TCSC}(\alpha)] \quad (11)$$

The basic equations for this type of fault [16], [17] are:

$$I_b = I_c = 0 \quad (12)$$

$$V_a = V_1 + V_2 + V_0 = R_F \cdot I_a \neq 0 \quad (13)$$

The symmetrical components of currents are:

$$\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} \quad (14)$$

From equation (12) and matrix (14), the symmetrical components of currents become:

$$I_1 + I_2 + I_0 = \frac{I_A}{3} \quad (15)$$

The symmetrical components of voltages are:

$$\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} \quad (16)$$

From equation (13) and matrix (16), the direct components of voltage become:

$$V_1 = -(V_0 + V_2) + R_F \cdot I_A \quad (17)$$

$$\text{And, } V_s + V_{TCSC} - I_1 \left[\frac{Z_{AB.1}}{2} \pm X_{TCSC.1} + \frac{Z_{AB.1}}{2} \right] = A + B + C \quad (18)$$

Where, the coefficients A, B and C are defined as:

$$A = -\frac{1}{3} \left[-\left(\frac{Z_{AB.0}}{2} \pm X_{TCSC.0} + \frac{Z_{AB.0}}{2} \right) I_0 \right] \quad (19)$$

$$B = -\frac{1}{3} \left[-\left(\frac{Z_{AB.2}}{2} \pm X_{TCSC.2} + \frac{Z_{AB.2}}{2} \right) I_2 \right] \quad (20)$$

$$C = R_F \cdot I_A \quad (21)$$

The coefficients Z_{AB-T} and Z_{TCSC-T} are defined for simplicity as:

$$Z_{AB-T} = Z_{AB,1} + Z_{AB,2} + Z_{AB,0} \quad (22)$$

$$X_{TCSC-T} = X_{TCSC,1} + X_{TCSC,2} + X_{TCSC,0} \quad (23)$$

$$V_s \pm V_{TCSC} = \frac{I_A}{3} \left[\frac{Z_{AB-T}}{2} \pm X_{TCSC-T} + \frac{Z_{AB-T}}{2} \right] + R_F \cdot I_A \quad (24)$$

From equations (22), (23) and (24), the current at phase (A) in presence TCSC on midline is given by:

$$I_A = \frac{3 \cdot (V_s \pm V_{TCSC})}{\left(\frac{Z_{AB-T}}{2} \right) \pm X_{TCSC-T} + \left(\frac{Z_{AB-T}}{2} \right) + 3 \cdot R_F} \quad (25)$$

From equation (15), the symmetrical components of currents in presence TCSC on midline are:

$$I_1 = I_2 = I_0 = \frac{V_s \pm V_{TCSC}}{\left(\frac{Z_{AB-T}}{2} \right) \pm X_{TCSC-T} + \left(\frac{Z_{AB-T}}{2} \right) + 3 \cdot R_F} \quad (26)$$

The direct components of voltages in presence TCSC are:

$$V_1 = V_s \pm V_{TCSC} - \left(\frac{Z_{AB,1}}{2} \pm X_{TCSC,1} + \frac{Z_{AB,1}}{2} \right) \cdot I_1 = \frac{(V_s \pm V_{TCSC}) \cdot [Z_{AB}' \pm X_{TCSC}' + 3 \cdot R_F]}{\frac{Z_{AB-T}}{2} \pm X_{TCSC-T} + \frac{Z_{AB-T}}{2} + 3 \cdot R_F} \quad (27)$$

Where, the coefficients Z_{AB}' and X_{TCSC}' are defined as:

$$Z_{AB}' = Z_{AB,2} + Z_{AB,0} - 2 \cdot Z_{AB,1} \quad (28)$$

$$X_{TCSC}' = X_{TCSC,2} + X_{TCSC,0} - 2 \cdot X_{TCSC,1} \quad (29)$$

The inverse components of voltages in presence TCSC are:

$$V_2 = - \left(\frac{Z_{AB,2}}{2} \pm X_{TCSC,2} + \frac{Z_{AB,2}}{2} \right) \cdot I_2 = - \frac{(V_s \pm V_{TCSC}) \cdot [Z_{AB,2} \pm X_{TCSC,2}]}{\left(\frac{Z_{AB-T}}{2} \right) \pm X_{TCSC-T} + \left(\frac{Z_{AB-T}}{2} \right) + 3 \cdot R_F} \quad (30)$$

The zero components of voltages in presence TCSC are:

$$V_0 = - \left(\frac{Z_{AB,0}}{2} \pm X_{TCSC,0} + \frac{Z_{AB,0}}{2} \right) \cdot I_0 - R_F \cdot I_0 = - \frac{(V_s \pm V_{TCSC}) \cdot [Z_{AB,0} \pm X_{TCSC,0} + R_F]}{\left(\frac{Z_{AB-T}}{2} \right) \pm X_{TCSC-T} + \left(\frac{Z_{AB-T}}{2} \right) + 3 \cdot R_F} \quad (31)$$

The coefficients Z_{AB}' and X_{TCSC}' are defined as:

$$Z_2' = Z_{AB,2} \pm X_{TCSC,2} \quad (32)$$

$$Z_0' = Z_{AB,0} \pm X_{TCSC,0} \quad (33)$$

$$S_a = 3 \cdot a^2 - 1 \quad (34)$$

$$S_b = 3 \cdot a - 1 \quad (35)$$

From equations (27), (30) and (31), the three phase voltages on transmission line in presence of TCSC are:

$$V_A = \frac{3 \cdot R_F \cdot (V_s \pm V_{TCSC})}{\left(\frac{Z_{AB-T}}{2} \right) \pm X_{TCSC-T} + \left(\frac{Z_{AB-T}}{2} \right) + 3 \cdot R_F} \quad (36)$$

$$V_B = \frac{(V_s \pm V_{TCSC}) \cdot [(a^2 - a) Z_2' + (a^2 - 1) Z_0' + S_a R_F]}{\left(\frac{Z_{AB-T}}{2} \right) \pm X_{TCSC-T} + \left(\frac{Z_{AB-T}}{2} \right) + 3 \cdot R_F} \quad (37)$$

$$V_C = \frac{(V_s \pm V_{TCSC}) \cdot [(a - a^2) Z_2' + (a - 1) Z_0' + S_b R_F]}{\left(\frac{Z_{AB-T}}{2} \right) \pm X_{TCSC-T} + \left(\frac{Z_{AB-T}}{2} \right) + 3 \cdot R_F} \quad (38)$$

4. CASE STUDY AND SIMULATION RESULTS

The power system studied in this paper is the 400 kV eastern Algerian electrical transmission networks at Algerian Company of Electrical and Gas (Sonelgaz) which is shown in figure 5 [18].

The relay is located in the busbar at Ramdane Djamel substation to protect transmission line between busbar A and busbar B respectively at Ramdane Djamel and Oued El Athmania substation in Mila. The busbar C is located at Salah Bay substation in Sétif.

The TCSC is installed in midline and different case study for maximum injected voltage V_{TCSC} i.e. 20, 30 and 40 kV respectively in case of phase (A) to earth fault at busbar B with different values of R_F are carried out.

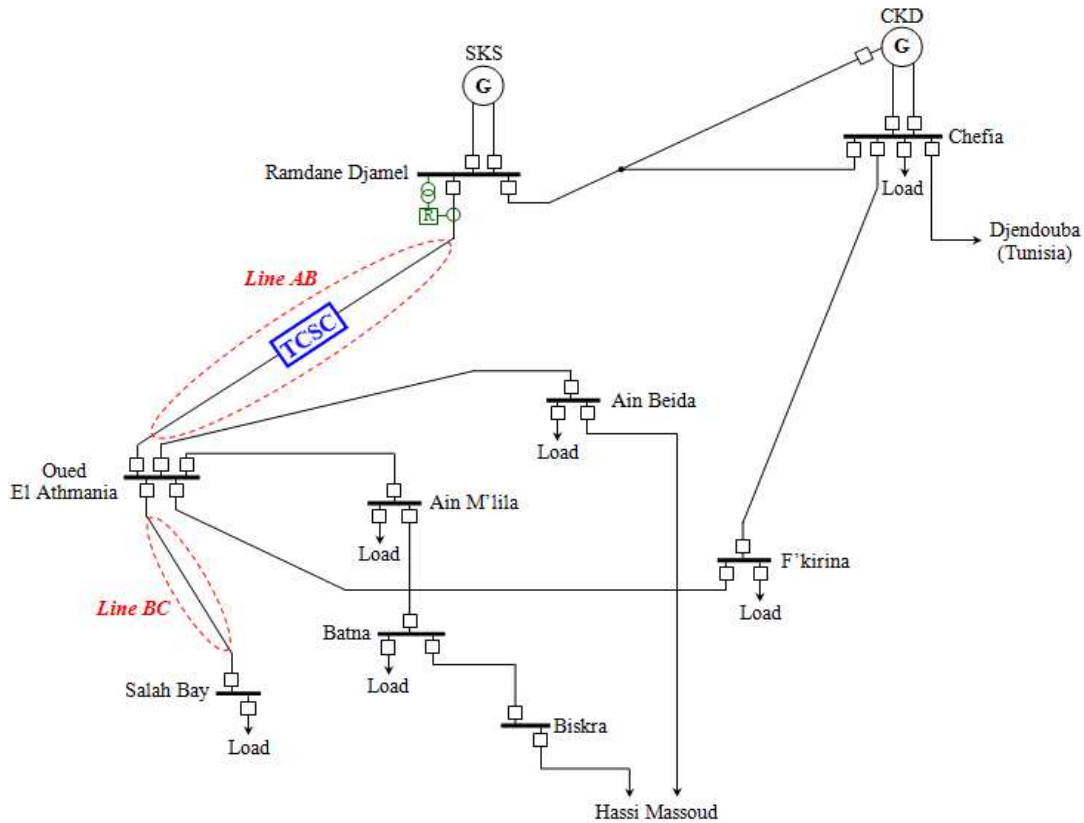
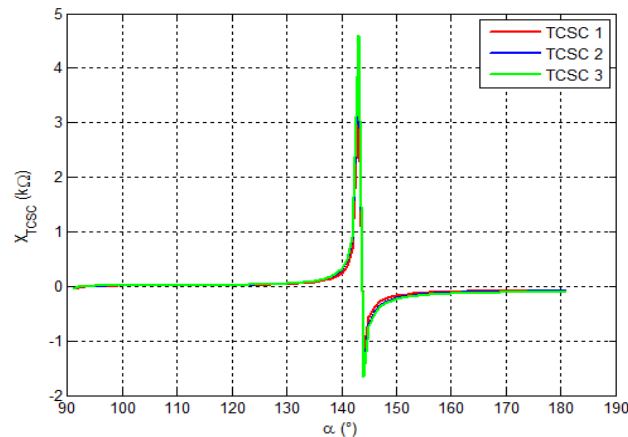


Figure 5. Algerian electrical transmission network with TCSC.

Figures 6.a and 6.b show the X_{GCSC} characteristics curves on two modes and V_{TCSC} as function of the firing angle α of the TCSC compensator used in different cases study.



(a)

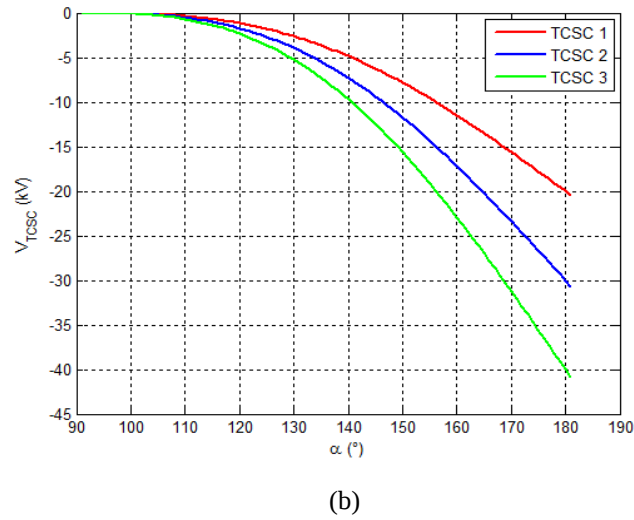


Figure 6. Characteristic curve for TCSC; a). $X_{TCSC}(\alpha)$, b). $V_{TCSC}(\alpha)$.

4.1. Impact of TCSC on Transmission Line

The figures 7.a and 7.b show the impact of TCSC insertion in capacitive and inductive modes on the power variation at load busbar (B) with angle line (δ) varied between 0° to 180° .

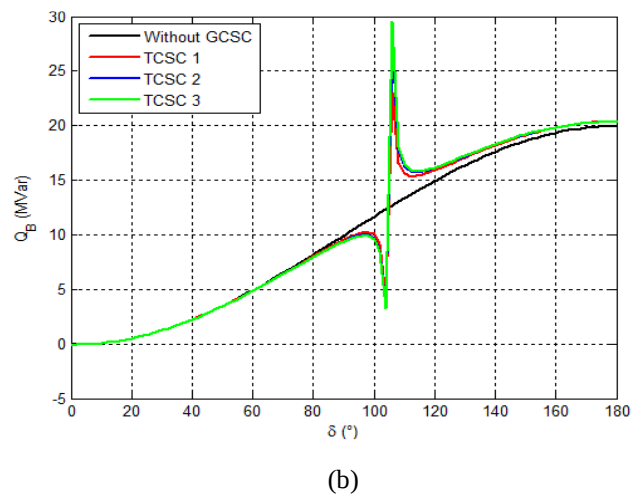
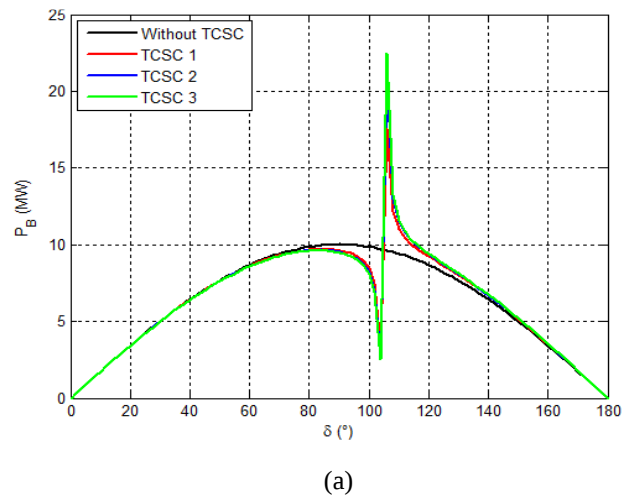


Figure 7. Impact of TCSC on transmission line; a). $P_B(\delta)$, b). $Q_B(\delta)$.

4.2. Impact of Injected Voltage on Short-Circuit Calculation

Figures 8 show the variation of the symmetrical currents I_1 , I_2 and I_0 respectively and figures 9 represent the variation of the line currents I_A , I_B and I_C respectively as a function of injected V_{TCSC} by different TCSC study.

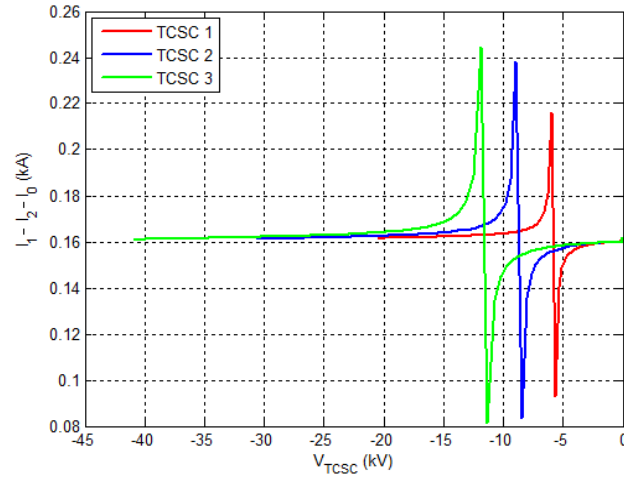
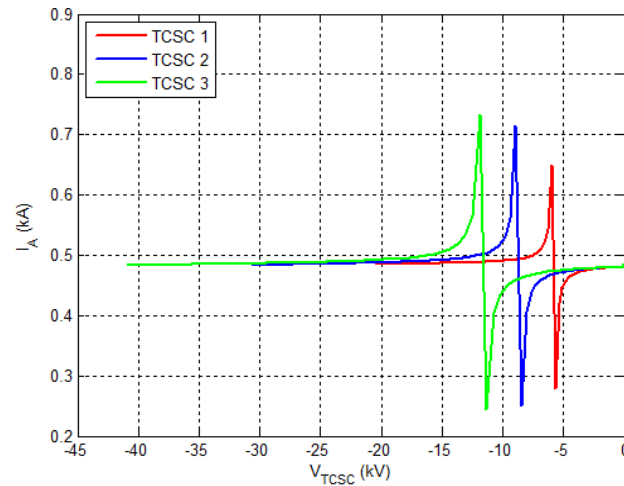
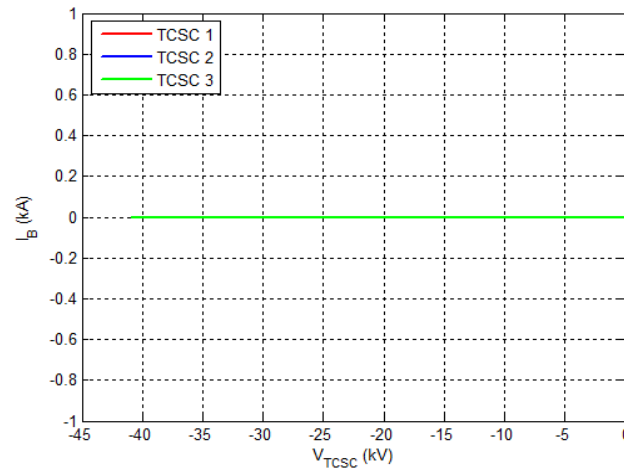


Figure 8. Impact on the symmetrical currents.



(a)



(b)

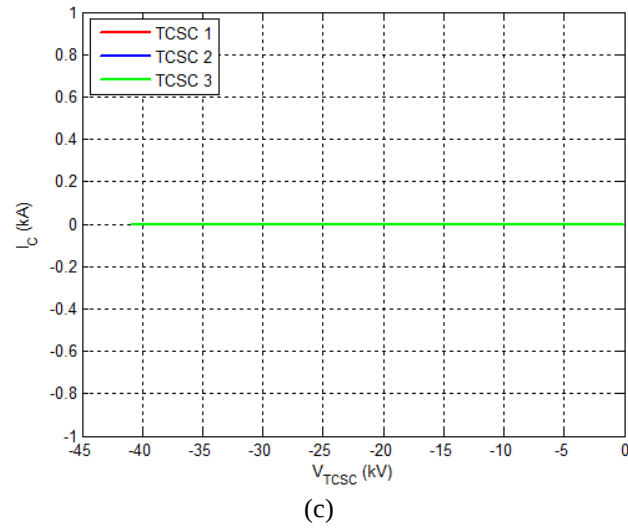
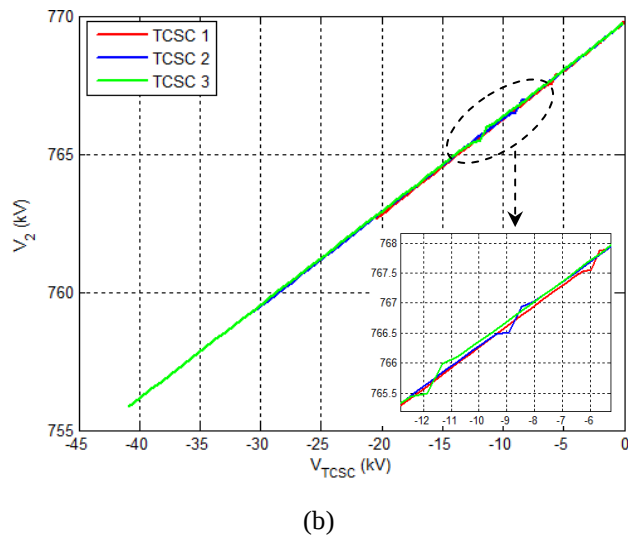
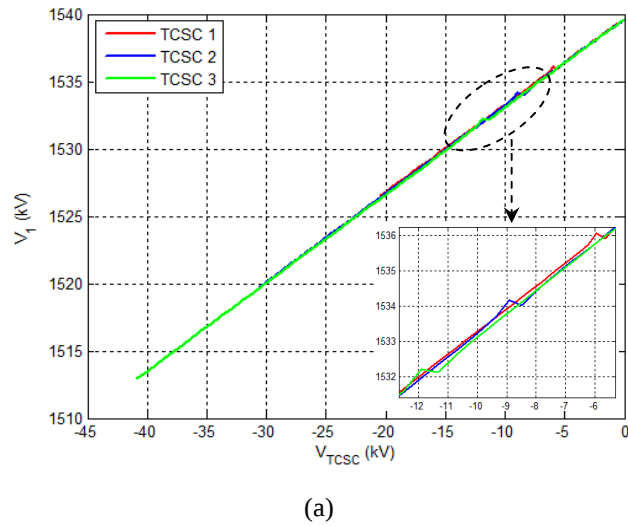


Figure. 9 Impact on line currents.

Figures 10 show the variation of voltages V_1 , V_2 and V_0 respectively and figures 11 show the variation of line voltages V_A , V_B and V_C respectively as a function of injected V_{TCSC} by different TCSC study.



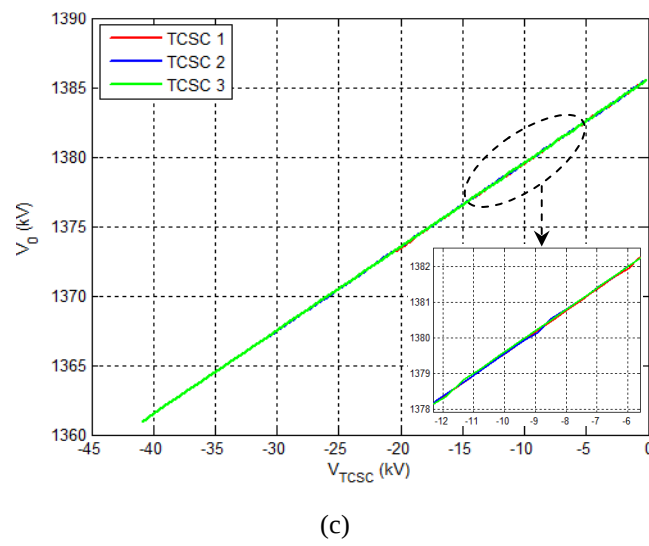
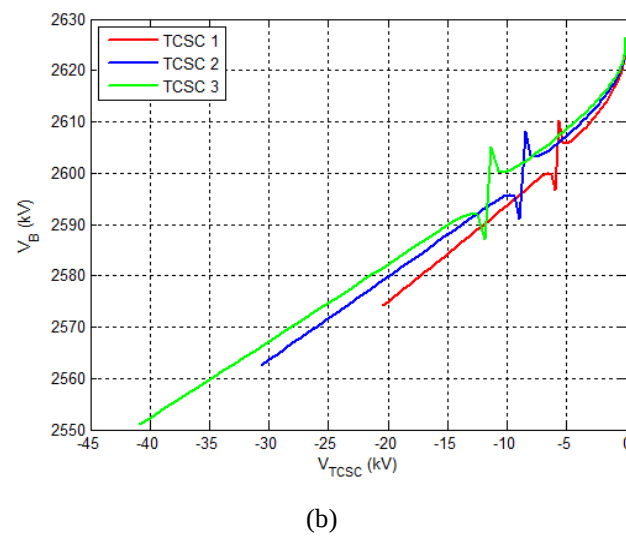
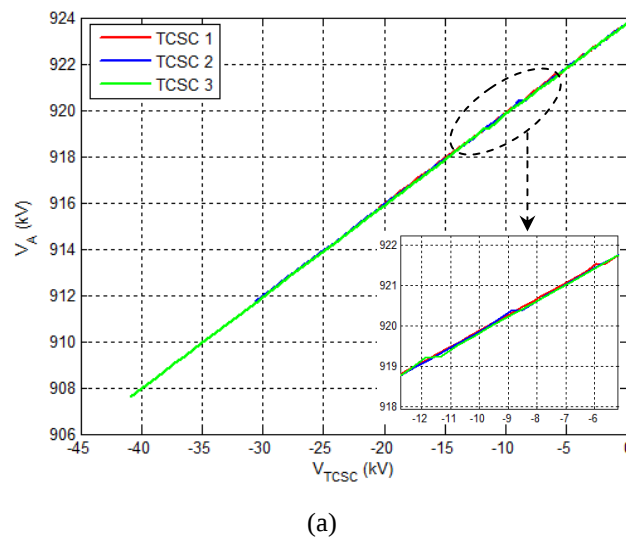


Figure 10. Impact of symmetrical voltages.



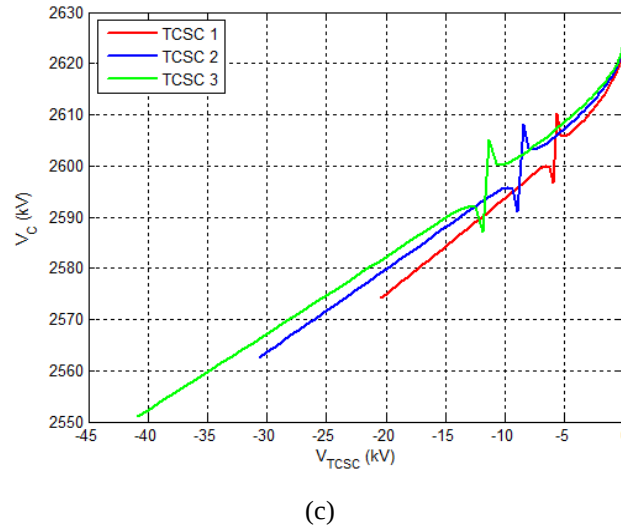


Figure 11. Impact of transmission line voltages.

5. CONCLUSION

In this paper, the effect of TCSC on the parameters of protective transmission line during single phase to ground fault with fault resistance on electrical transmission line 400 kV is being considered.

The impedance of transmission line is influenced by the injected voltage V_{TCSC} of the TCSC, since deviation of the measured impedance is not constant. Because of the varying parameters of the injected reactance by TCSC on inductive and capacitive vernier mode adaptive methods should be utilized. In order to increase the total system protection performance in the presence of series FACTS devices compensator on transmission line care must be taken.

For specified systems, settings of different protections (distance, and overcurrent, ... etc.) can be achieved based on the proposed setting principles. Moreover following state of TCSC (capacitive or inductive modes) in order to avoid circuit breaker unwanted tripping changing the settings relay of overcurrent and distance protection is necessary.

Appendix

A. Transmission line :

$U_n = 400$ kV, $f_n = 50$ Hz, $l_{AB} = 360$ km, $Z_{AB,1} = 0,1213 + j 0, 4227 \Omega/\text{km}$, $Z_{AB,0} = 0,2426 + j 1,2681 \Omega/\text{km}$.

B. TCSC study :

Case 1: $Q_{TCSC} = + 30 / - 5$ MVar, $V_{TCSC-Max} = 20$ kV, $L = 42,44$ mH, $C = 39,788 \mu\text{F}$,

Case 2 : $Q_{TCSC} = + 60 / -10$ MVar, $V_{TCSC-Max} = 30$ kV, $L = 47,75$ mH, $C = 35,367 \mu\text{F}$,

Case 3 : $Q_{TCSC} = + 90 / -15$ MVar, $V_{TCSC-Max} = 40$ kV, $L = 56,58$ mH, $C = 29,841 \mu\text{F}$.

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BIOGRAPHIES OF AUTHORS



Mr. Mohamed ZELLAGUI was born in Constantine, Algeria, 1984. He received the engineer and magister degree in electrical engineering from department of electrical engineering at University of Constantine, Algeria in 2007 and 2010 respectively, PhD student in electrical engineering and member LSP-IE research laboratory from department of electrical engineering at University of Batna, Algeria. He is membership at International Association of Engineers (IAENG), and the Institution of Engineering and Technology (IET). His areas of interest include electrical networks, transmission line, renewable energy sources, power system protection, distance relay, power quality and FACTS devices.



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