BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVIII (LXII), Fasc. 2, 2012
Secţia
ELECTROTEHNICĂ. ENERGETICĂ. ELECTRONICĂ

EFFECTS OF SHUNT FACTS DEVICES (TCR AND TSC) ON DISTANCE RELAYS SETTING ZONES IN 400 KV TRANSMISSION LINE

BY

MOHAMED ZELLAGUI[*] **and ABDELAZIZ CHAGHI**

University of Batna, LSP-IE Research Laboratory, Faculty of Technology,
Department of Electrical Engineering, Batna, Algeria

Received, May 7, 2012
Accepted for publication: June 28, 2012

Abstract. This paper presents a study on the performances of distance relays setting in 400 kV in Eastern Algerian transmission networks at Sonelgaz Group (Algerian Company of Electricity) compensated by shunt Flexible AC Transmission System (FACTS). The facts are used for controlling transmission voltage, power flow, reactive power, and damping of power system oscillations in high power transfer levels. The direct impacts of SVC devices, *i.e.* Thyristor Controlled Reactor (TCR) and the Thyristor Switched Capacitors (TSC) insertion on the total impedance of a transmission line ($\underline{Z}_{AB}$) protected by MHO distance relay, are investigated.

The modified setting zones protections ($\underline{Z}_1$, $\underline{Z}_2$ and $\underline{Z}_3$) have been calculated in order to improve the performances of distance relay protection and prevent circuit breaker nuisance tripping. The simulation results are performed in MATLAB software and show the direct impact of the thyristors firing angle (α) and substance on the total impedance of the protected line.

Key words: tansmission line; MHO distance relay; setting zones; shunt FACTS; SVC devices; substance; TCR; TSC.

---

[*] Corresponding author: *e-mail*: m.zellagui@ymail.com

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 (Sen *et al.*, 2009).

The literature shows an increasing interest in this subject for the last two decades, where FACTS devices are introduced in power systems to increase the transmitting capacity of transmission lines and provide the optimum utilization of the system capability. This is done by pushing the power systems to their limits (Zhang *et al.*, 2006; Noroozian, 2006). It is well documented in the literature that the introduction of FACTS devices in a power system has a great influence on its dynamics. As power system dynamics changes, many sub-systems are affected, including the protective systems. The application of SVC was initially for load compensation of fast changing loads such as steel mills and arc furnaces. Here the objectives are: increase power transfer in long lines, improve stability with fast acting voltage regulation damping low frequency oscillations due to swing modes and damping sub-synchronous frequency oscillations and over-voltages dynamic control (Noroozian, 2006).

Unlike the power system parameters, the controlling parameters of FACTS devices, as well as their installation points, could affect the measured impedance. This variation has a direct effect on the protective zones settings for distance relays protecting this compensated line. 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 be utilized satisfactorily in the presence of FACTS devices.

Many researcher study the impact of series FACTS devices on distance protection, for Static Synchronous Compensator (STATCTOM). Liu *et al.*, (2010), study a novel method of distance protection in transmission mine high voltage; Zhang *et al.*, (2010), study a novel distance relay setting on for transmission line and Sham *et al.*, (2011), have performed simulation studies on the distance relay performance in the presence phase to earth fault. Zellagui *et al.*, (2012), study the impact of inserting STATCOM on MHO distance relay setting in Algerian transmission line. For Static Synchronous Series Compensator (SSSC) Shojaei *et al.*, (2010), Jamali *et al.*, (2011), Zellagui *et al.*, (2012), have performed an analysis of measured impedance ($\underline{Z}_{\text{seen}}$) by distance relay in the fault presence on transmission line of 400 kV, and Khederzadeh *et al.*, (2009), study the global impact of insertion SSSC on the digital relay.

For Compensator based Thyristor Controlled Series Capacitor (TCSC)

Kazemi *et al*., (2011), study this impact on $\underline{Z}_{\text{seen}}$ by distance relay in double circuit lines considering MOV operation and Hosny *et al*., (2009), study artificial neuron network (ANN) based protection system on transmission line. Therefore, it is essential to study the effects of shunt FACTS devices on the protective systems, especially the distance protection, which is the main protective device at HV and EHV levels. Albasri *et al*., (2007), study the performance comparison of distance protection schemes for shunt FACTS compensated transmission lines, and Jamali *et al*., (2008), Kazemi *et al*., (2010), Jamali *et al*., (2010, 2012), study the impact of shunt FACTS based SVC on distance relay tripping characteristic and impedance $\underline{Z}_{\text{seen}}$ in fault presence Khederzadeh *et al*., (2012), have performed a comparative study between SVC devices and STATCOM.

In this paper, the three protection zones setting ($\underline{Z}_1$, $\underline{Z}_2$ and $\underline{Z}_3$), for an MHO distance relay based analytic method on a 400 kV single transmission line installed at eastern Algerian electrical network, is considered. The investigation concerns TCR and TSC shunt FACTS devices, for different values of firing angle (α) for injected reactive power of ±60 MVAr shunt compensation on midline transmission high voltage.

2. MHO Distance Relay in HV Transmission Line

MHO 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 electrical impedance of the transmission line ($\underline{Z}_L$) between busbar A and B as shown in Fig. 1. The distance protection measures the distance to a fault by means of a measured voltage to measured current ratio computation (Zigler, 2008). The philosophy of setting relay at Sonelgaz Group (Manamani, 2010; Zellagui *et al*., 2011) is three forward zones ($\underline{Z}_1$, $\underline{Z}_2$ and $\underline{Z}_3$) for protection the HV line between busbar A and B with total impedance, Z_{AB}.

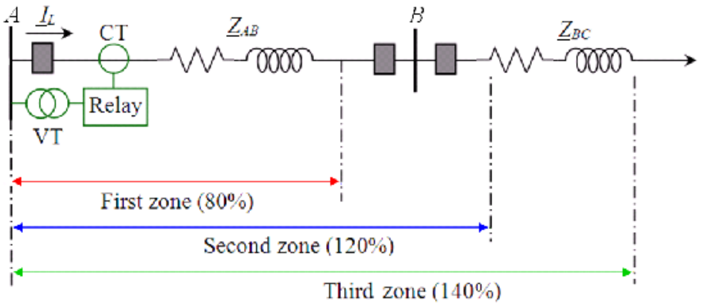


Fig. 1 – Principal setting zones for distance protection.

The setting zones for protected transmission line without shunt FACTS devices are expressed by Manamani, (2010); Zellagui *et al*., (2011)

$$\underline{Z}_1 = R_1 + \mathrm{j}X_1 = 80\%\underline{Z}_{AB} = 0.8(R_{AB} + \mathrm{j}X_{AB}), \tag{1}$$

$$\underline{Z}_2 = R_2 + \mathrm{j}X_2 = R_{AB} + \mathrm{j}X_{AB} + 0.2(R_{BC} + \mathrm{j}X_{BC}), \tag{2}$$

$$\underline{Z}_3 = R_3 + \mathrm{j}X_3 = R_{AB} + \mathrm{j}X_{AB} + 0.4(R_{BC} + \mathrm{j}X_{BC}). \tag{3}$$

The total impedance ($\underline{Z}_{AB}$) of transmission line *AB* measured by distance relay, is given by

$$\underline{Z}_{AB} = K_Z \underline{Z}_L = \frac{K_{VT}}{K_{CT}} \underline{Z}_L, \tag{4}$$

where K_{VT} and K_{CT} are ratio of voltage to current respectively installed at busbar *A*. The characteristic curves $X = f(R)$ (Gérin-Lajoie, 2009; Zellagui *et al.*, 2011, 2012) for MHO distance relay are represented in Fig. 2.

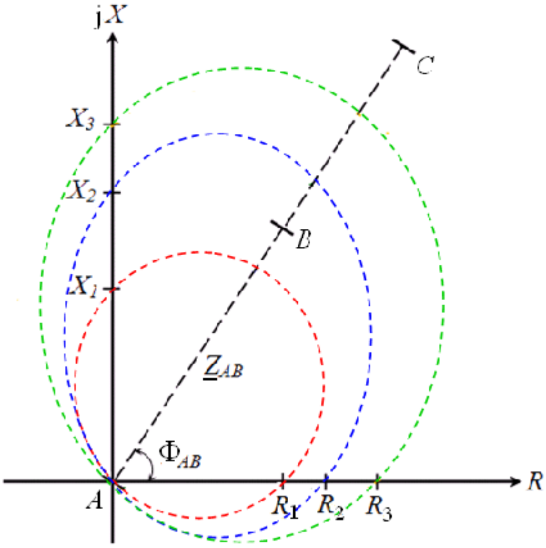


Fig. 2 – Characteristic curves of MHO distance relay.

The presence of SVC devices has a direct influence on the total impedance of the protected line ($\underline{Z}_{AB}$). Connected at midline point of the line, the SVC is considered as a reactor ($X_{SVC} = 1/B_{SVC}$) and lead to the new setting zones which can be expressed by

$$\underline{Z}_1 = 0.8\left[\left(\frac{\underline{Z}_{AB}}{2} // X_{\mathrm{SVC}}\right) + \frac{\underline{Z}_{AB}}{2}\right], \tag{5}$$

$$\underline{Z}_2 = \left(\frac{\underline{Z}_{AB}}{2} // X_{\text{SVC}} \right) + \frac{\underline{Z}_{AB}}{2} + 0.2\underline{Z}_{BC}, \tag{6}$$

$$\underline{Z}_3 = \left(\frac{\underline{Z}_{AB}}{2} // X_{\text{SVC}} \right) + \frac{\underline{Z}_{AB}}{2} + 0.4\underline{Z}_{BC}. \tag{7}$$

3. Principle and Modelling of Static VAr Compensator (SVC) Devices

The SVC controls voltage where it is connected by adjusting its susceptance in order to supply or absorb the required reactive power (Q_{SVC}) (Benabid *et al.*, 2009). SVC consists of TCR and a set of TSC in parallel, and an associated controlling system. The controlling system operates to regulate the voltage at its connecting point, according to its controlling strategy within its operational limits. In order to investigate the impact of SVC on power systems, appropriate SVC model is very important. It is connected in shunt with the transmission line through a shunt transformer and thus (Nwohu *et al.*, 2009) is represented in Fig. 3; Fig. 4 shows the equivalent circuit which models the SVC.

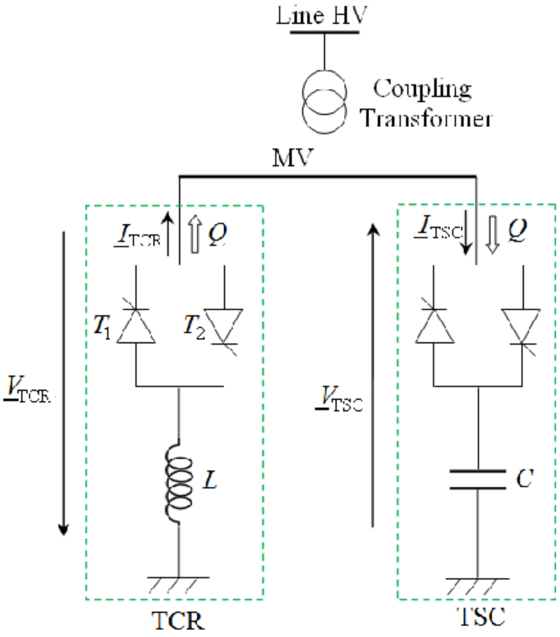
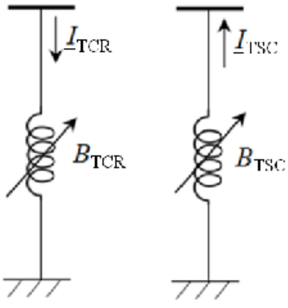


Fig. 3 – Structures of SVC devices.

The overall action of the thyristor controller on the linear reactor of the TCR and capacitor of the TSC is to enable the reactor to act as a controllable susceptance, in the inductive or capacitive mode, which is a function of the firing angle, α (Sen *et al.*, 2009; Zhang *et al.*, 2006; Benabid *et al.*, 2009; Nwohu *et al.*, 2009). The Figs. 4 *a* and 4 *b* represent the substance for TCR and TSC, respectively.



a *b*

Fig. 4 – Injected susceptance of SVC devices.

The current $\underline{I}_{\text{TCR}}$ is directly related to the firing angle of thyristors (α), which was varied between 90° and 180°. The value of the susceptance B_{TCR} will be represented by the eq. (Sen *et al.*, 2009; Zhang *et al.*, 2006; Benabid *et al.*, 2009; Nwohu *et al.*, 2009)

$$B_{\text{TCR}}(\alpha) = B_{L.\max}\left(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha\right), \tag{8}$$

where

$$B_{L.\max} = \frac{1}{\omega L}. \tag{9}$$

For the TSC, the expression B_{TCS} is defined in reference by the eq. (Noroozian, 2006; Zhang *et al.*, 2006; Benabid *et al.*, 2009)

$$B_{\text{TCS}}(\alpha) = B_{C.\max}\left(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha\right), \tag{10}$$

where

$$B_{C.\max} = -C\omega. \tag{11}$$

4. Case Study and Simulation Results

The Fig. 5 represents the power system studied in this paper and this one is the 400 kV, 50 Hz eastern Algerian electrical transmission networks at

Sonelgaz group (Manamani, 2009). The MHO distance relay is located in the busbar *A* at Ramdane Djamel substation (Skikda) to protect transmission line between busbar *A* and busbar *B* at Oued El Athmanai substation (Mila), the busbar *C* at Ain M'lila substation (Oum El Bouaghi).

The shunt FACTS study type SVC is installed in the midpoint of the line protected by a MHO distance relay as represented in Fig. 5. The parameters of the transmission line and installed SVC device are summarized in the Appendix.

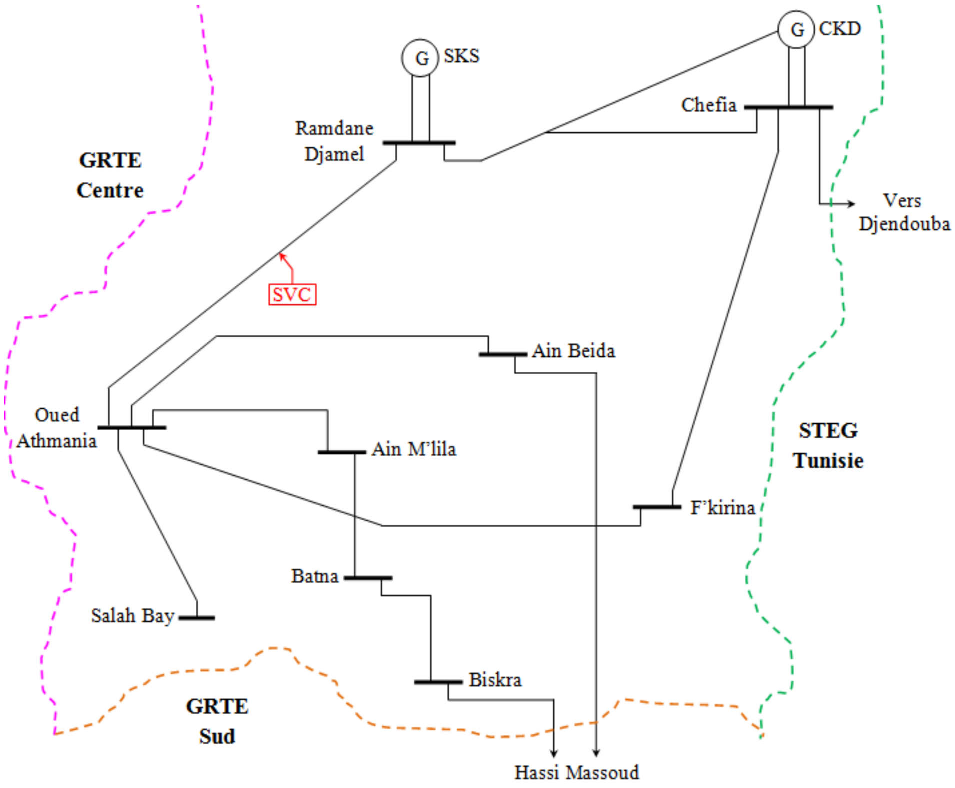


Fig. 5 – Algerian electrical networks study in presence of SVC.

The characteristic curves of the SVC compensator (TCR and TSC) used in this network are indicated by Figs. 6 *a* and 6 *b*, respectively.

Figs. 7 and 8 represent the impact of the variation angle, α, in the presence of TCR and TSC, on the total reactance, X_{AB} , and resistance, R_{AB} , respectively measured by distance relay.

As can be seen the presence of TCR and TSC has a direct influence on the parameters of the protected line, X_{AB} and R_{AB}.

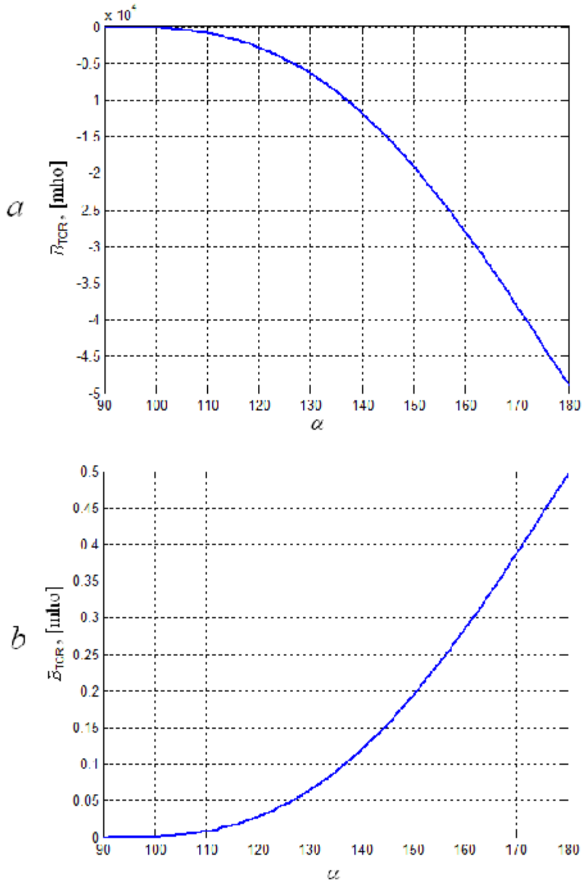


Fig. 6 – Characteristic curves of the installed SVC; $a - B_{\mathrm{TCR}} = f(\alpha)$, $b - B_{\mathrm{TSC}} = f(\alpha)$.

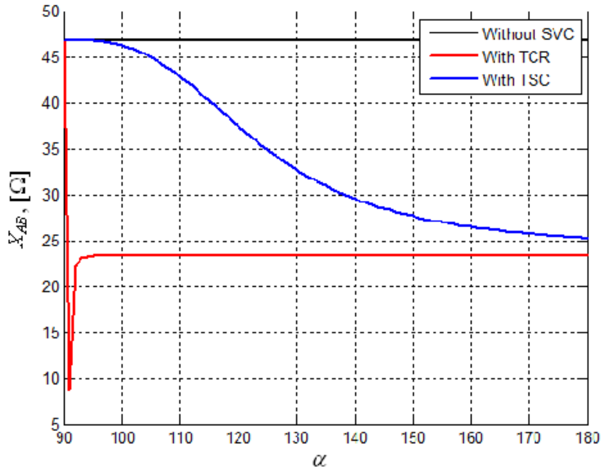


Fig. 7 – Impact of angle α on reactance X_{AB} measured by distance relay.

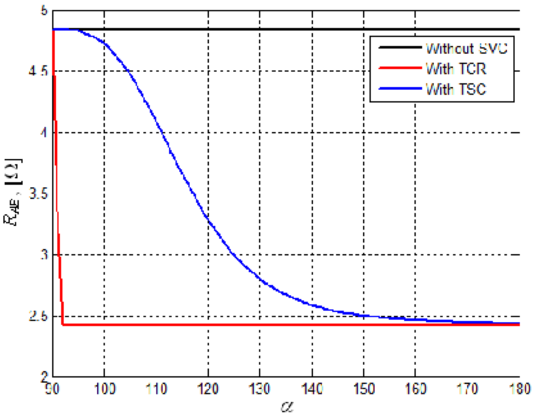


Fig. 8 – Impact of angle α on resistance R_{AB} measured by distance relay.

The total impedance measured by the distance relay without SVC devices is equal to 4.8407 + j46.8048 Ω; the settings zones are summered in Table 1.

Table 1

Setting Distance Relay without SVC Devices

Setting zones	$\underline{Z}_1$	$\underline{Z}_3$	$\underline{Z}_2$
X, [Ω]	1.8722	2.6172	2.8943
R, [Ω]	0.1936	0.2707	0.2993

4.1. Setting Relay in Presence of TCR

Figs. 9 and 10 represent the impact of the firing angle variation on the settings zones reactance and resistance, respectively, for the protected transmission line.

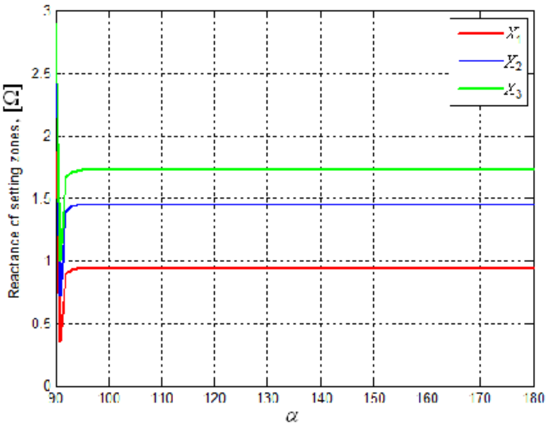


Fig. 9 – Impact of the firing angle, α, on the setting zones in the presence of TCR.

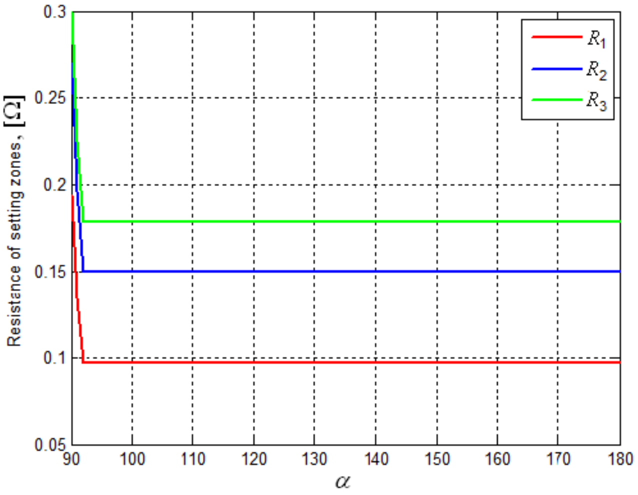


Fig. 10 – Impact of the firing angle, α, on the setting zones in the presence of TCR.

From Figs. 9 and 10 it results that the setting of the three zones of protection depends on the angle, α, of the TCR.

4.2. Setting Relay in Presence of TSC

Figs. 11 and 12 represent the impact of the firing angle variation on the settings zones reactance and resistance, respectively, in the presence of the TSC compensator.

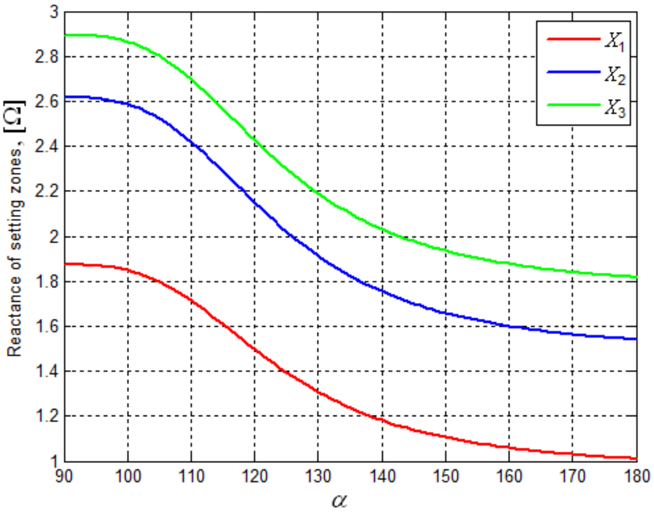


Fig. 11 – Impact of the firing angle α on the setting zones in the presence of TSC.

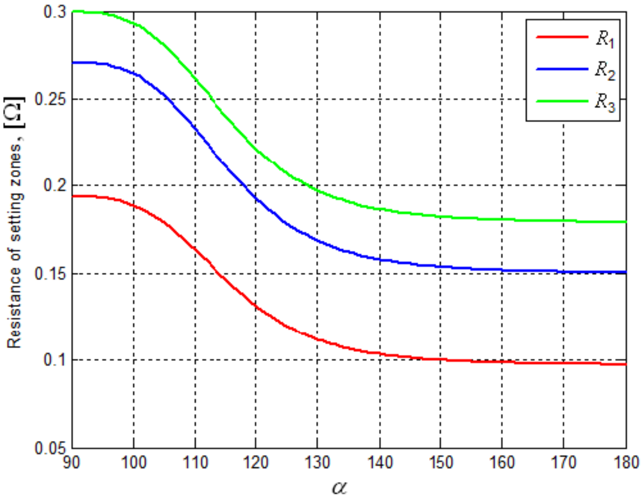


Fig. 12 – Impact of the firing angle, α, on the setting zones in the presence of TSC.

As can be seen from Figs. 11 and 12 the setting of the three protection zones depends on the angle α of the TSC.

5. Conclusion

The results presented in this paper show the direct effects of SVC devices, *i.e.* TCR and TSC insertion, on the total impedances $\underline{Z}_{AB}$ and $\underline{Z}_{\text{seen}}$ of a transmission line protected by MHO distance relay using an analytical method. The impact is investigated for different values of the thyristors firing angle. As demonstrated these angles injected variable susceptances (B_{TCR} or B_{TCS}) in the protected line which results in a direct impact on the total impedance of the protected line. In fact this effect varies the settings zones by increasing the performance of the total system protection and avoiding unwanted tripping of circuit breaker in the presence of SVC compensator on single electrical transmission line of 400 kV.

Appendix

1. Transmission Line:
U_n = 400 kV, $\underline{Z}_L$ = 0.03293 + j0.3184 Ω/km, l_{AB} = 147 km and = 87 km.
2. SVC Devices:
2.1. TCR: Q_{TCR} = +60 MVAr, L = 6.40 mH, U_n = 11 kV.
2.2. TSC: Q_{TSC} = –60 MVAr, C = 1.60 mF, U_n = 11 kV.
2.3. Coupling transformer: U_n = 11/400 kV, Y/Δ, S_n = 60 MVA, X_{TR} = j0.0371 Ω.
3. Current transformer: I_{pr} = 1,000 A, I_{sec} = 5 A, K_{CT} = 200.
4. Voltage transformer: $V_{\text{pr}} = 400{,}000/\sqrt{3}$ V, $V_{\text{sec}} = 100/\sqrt{3}$ V, K_{VT} = 4,000.

REFERENCES

Albasri F.A., Sidhu T.S., Varma R.K., *Performance Comparison of Distance Protection Schemes for Shunt-FACTS Compensated Transmission Lines*. IEEE Trans. on Power Deliv., **22**, *4*, 2116-2125 (2007).

Benabid R., Boudour M., Abido M.A., *Optimal Location and Setting of SVC and TCSC Devices Using Non-Dominated Sorting Particle Swarm Optimization*. Electric Power Syst. Res. (EPSR), **79**, *12*, 1668-1677 (2009).

Gérin-Lajoie L., *A MHO Distance Relay Device in EMTP Works*. Electric Power Syst. Res. (EPSR), **79**, *3*, 484-491 (2009).

Hosny A., Safiuddin M., *ANN-Based Protection System for Controllable Series-Compensated Transmission Lines*. IEEE/PES Power Syst. Conf. a. Expos. (PSCE'09), Seattle, USA, March 15-18, 2009.

Jamali S., Kazemi A., Shateri H., *Comparing Effects of SVC and STATCOM on Distance Relay Tripping Characteristic*. IEEE Internat. Symp. on Ind. Electron. (ISIE'08), Cambridge, UK, June 30 - July 2, 2008, 1568-1573.

Jamali S., Kazemi A., Shateri H., *Measured Impedance by Distance Relay in Presence of SVC*. Internat. Rev. of Electr. Engng. (IREE), **5**, *2*, 619-627 (2010).

Jamali S., Kazemi A., Shateri H., *Measured Impedance by Distance Relay for Inter Phase Faults in the Presence of SVC on Double-Circuit Lines*. 11th Conf. on Devel. in Power Syst. Prot. (DPSP'12), Birmingham, April 23-26, 2012.

Jamali S., Shateri H., *Locus of Apparent Impedance of Distance Protection in the Presence of SSSC*. Europ. Trans. on Electr. Power (ETEP), **21**, *1*, 398-412 (2011).

Kazemi A., Jamali S., Shateri H., *Impact of TCSC on Measured Impedance by Distance Relay for Inter Phase Faults in Double-Circuit Lines Considering MOV Operation*. 46th Internat. Univ. Power Engng. Conf. (UPEC'11), Soest, Germany, September 5-8, 2011.

Kazemi A., Jamali S., Shateri H., *Measured Impedance by Distance Relay for Inter Phase Faults in Presence of SVC*. Internat. Conf. on Power Syst. Technol. (POWERCON' 10), Hangzhou, China, October 24-28, 2010.

Khederzadeh M., Ghorbani A., Salemnia A., *Impact of SSSC on the Digital Distance Relaying*. IEEE Power & Energy Soc. Gen. Meeting (PES'09), Calgary, Canada, July 26-30, 2009.

Khederzadeh M., Ghorbani A., *STATCOM / SVC Impact on the Performance of Transmission Line Distance Protection*. Trans. on Electr. a. Electron. Engng. (TEEJ), **6**, *6*, 2011, 525-533.

Liu Q., Wang Z., Zhang Y., *Study on a Novel Method of Distance Protection in Transmission Line with STATCOM*. Power a. Energy Engng. Conf. (APPEEC'10) Asia-Pacific, Chengdu, China, March 28-31, 2010.

Manamani N., *Principles and Settings of Distance Relay on Algerian Transmission Line 220 and 400 kV*. Training at GRTE Sétif, Sonelgaz, Algeria, December 2010.

Noroozian M., *Modelling of SVC in Power System Studies*. Published by ABB Power Systems, Reactive Power Compensation Division, Vasteras, Sweden, April 2006.

Nwohu M.N., *Voltage Stability Improvement using Static Var Compensator in Power Systems*. Leonardo J. of Sci. (LJS), **14**, *1*, 167-172 (2009).

Sankarbabu P., Subrahmanyam J.B.V., *A Novel Online Fuzzy Control Method of Static VAR Compensation for an Effective Reactive Power Control of Transmission Lines*. J. of Acta Electrot., **51**, *1*, 45-50 (2010).

Sen K.K., Sen M.L., *Introduction to FACTS Controllers: Theory, Modeling and Applications*. John Wiley & Sons, Inc., and IEEE, New Jersey, USA, 2009.

Sham M.V., Vittal P.K., *Simulation Studies on the Distance Relay Performance in the Presence of STATCOM*. J. of Electr. Engng. (JEE), **11**, *3*, 11-18 (2011).

Shojaei A., Madani S.M., *Analysis of Measured Impedance by Distance Relay in Presence of SSSC*. 5th IET Internat. Conf. on Power Electron., Machines a. Drives (PEMD'10), Brighton, UK, April 19-21, 2010.

Zellagui M., Chaghi A., *Impacts of Static Synchronous Series Compensator (SSSC) on Measured Impedance in Distance Protection*. 2nd Internat. Conf. on Inform. Proc. a. Electr. Engng. (ICIPEE'12), Tébessa, Algeria, April 14-16, 2012.

Zellagui M., Chaghi A., *MHO Distance Relay of Transmission Line High Voltage Using Series Compensation in Algerian Networks*. J. of Acta Electrot., **52**, *3*, 126-133, 2011.

Zellagui M., Chaghi A., *Impact of Inserting STATCOM on MHO Distance Relay Setting in Algerian Transmission Line*. IEEE 6th Internat. Conf. on Sci. of Electron., Technol. of Inform. a. Telecom. (SETIT' 12), Sousse, Tunisia, March 21-24, 2012.

Zhang W.H., Lee S.J., Choi M.S., Oda S., *Considerations on Distance Relay Setting for Transmission Line with STATCOM*. IEEE Power a. Energy Soc. General Meeting, Minneapolis, USA, July 25-29, 2010.

Zhang X.P., Rehtanz C., Pal B., *Flexible AC Transmission Systems: Modelling and Control*. Springer Publ., Heidelberg, Germany, 2006.

Zigler G., *Numerical Distance Protection: Principles and Applications*, Third Ed., Publ. Corp. Publ., Germany, 2008.

INFLUENŢA DISPOZITIVELOR SHUNT DE TIP FACTS (TCR ŞI TSC) ASUPRA REGLĂRII RELEELOR DE DISTANŢĂ PE LINIILE DE TRANSPORT DE 400 kV

(Rezumat)

Se prezintă un studiu asupra eficienţei reglării releelor de protecţiilor de distanţă prin utilizarea dispozitivelor FACTS, în reţeaua de transport de 400 kV din estul Algeriei aparţinând Grupului Sonelgaz (Compania algeriană de energie electrică). Aceste dispozitive sunt utilizate pentru reglarea tensiunii şi a circulaţiei de putere, pentru compensarea puterii reactive, respectiv pentru amortizarea oscilaţiilor din sistem, la sarcină maximă. De asemenea, este analizată influenţa dispozitivelor SVC cum ar fi bobină controlată cu tiristoare (TCR) şi condensatoarele comutate cu tiristoare (TSC) asupra impedanţei totale a unei liniei de transport ($\underline{Z}_{AB}$), protejate cu relee de distanţă de tip MHO.

S-au determinat zonele de protecţie ($\underline{Z}_1$, $\underline{Z}_2$ şi $\underline{Z}_3$) pentru îmbunătăţirea performanţelor protecţiilor de distanţă şi prevenirea acţionării accidentale ale întrerupătoarelor. Rezultatele simulărilor au fost realizate în MATLAB şi arată influenţa directă a unghiului de amorsare (α) şi a tipului tiristoarelor asupra impedanţei totale a liniei protejate.