

IMPACT OF SVC DEVICES ON DISTANCE PROTECTION SETTING ZONES IN 400 kV TRANSMISSION LINE

Mohamed ZELLAGUI¹, Abdelaziz CHAGHI²

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 (Z_{AB}) protected by MHO distance relay are investigated. The modified setting zones protections (Z_1 , Z_2 and 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) on the total impedance of the protected line.

Keywords: Transmission line, Total impedance, MHO distance protection, Setting zones, SVC devices, TCR, TSC, Substance.

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]. 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 [2, 3] [28, 29]. 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

¹ PhD Student, LSP-IE Research Laboratory, Faculty of Technology, Department of Electrical Engineering, University of Batna, Algeria, e-mail: m.zellagui@ymail.com

² Prof., LSP-IE Research Laboratory, Faculty of Technology, Department of Electrical Engineering, University of Batna, Algeria.

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 due to torsional modes and over-voltages dynamic control [3]. Unlike the power system parameters, the controlling parameters of FACTS devices, as well as their installation points could affect the measured impedance [8-13]. This variation has a direct effect on the protective zones settings for distance relays protected this line compensated. 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.

May researcher study the impact of series FACTS devices on distance protection, for Static Synchronous Compensator (STATCOM) in [4] is study on a novel method of distance protection in transmission mine high voltage, and in [5] is study on a novel distance relay setting on for transmission line and in [6] simulation studies on the distance relay performance in the presence phase to earth fault, and in [7] is study the impact of inserting STATCOM on MHO distance relay setting in Algerian transmission line. For Static Synchronous Series Compensator (SSSC) in [8-10] analysis of measured impedance (Z_{seen}) by Distance Relay in the presence fault on transmission line 400 kV, and in [11] is study the global impact of insertion SSSC on the digital relay. For Compensator based Thyristor Controlled Series Capacitor (TCSC) in [12] is study this impact on Z_{seen} by distance relay in double circuit lines considering MOV operation and in [13] is 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. In [14] is study the performance comparison of distance protection schemes for shunt FACTS compensated transmission lines, and in [15-19] is study the impact of shunt FACTS based SVC on distance relay tripping characteristic and impedance Z_{seen} in presence fault, and in [20] is comparative study between SVC devices and STATCOM.

In this paper, the three protection zones setting (Z_1 , Z_2 and Z_3) for a 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 ± 60 MVar shunt compensation on midline transmission high voltage.

2. Principal and setting zones for MHO distance protection

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 series electrical impedance of the transmission line (Z_L) between busbar A and B as shown in figure 1. The distance protection measures distance to a fault by means of a measured voltage to measured current ratio computation [21]. The philosophy of setting relay at Sonelgaz Group [22-23] is three forward zones (Z_1 , Z_2 and Z_3) for protection the line HV between busbar A and B with total impedance Z_{AB} .

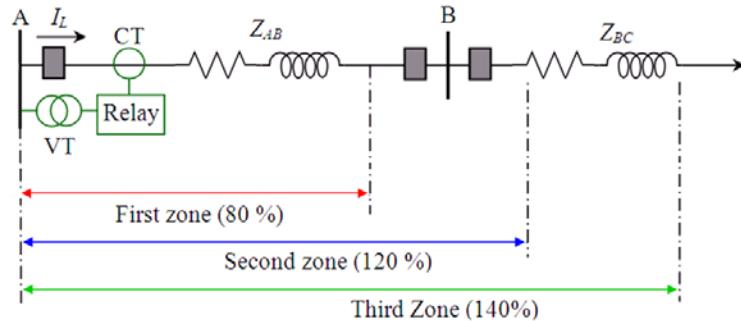


Fig. 1. Setting zones for distance relay.

The setting zones for protected transmission line without shunt FACTS devices are expressed by [22-23]:

$$Z_1 = R_1 + jX_1 = 80\%Z_{AB} = 0,8.(R_{AB} + jX_{AB}) \quad (1)$$

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

$$Z_3 = R_3 + jX_3 = R_{AB} + jX_{AB} + 0,4.(R_{BC} + jX_{BC}) \quad (3)$$

The total impedance (Z_{AB}) of transmission line AB measured by distance relay is given by:

$$Z_{AB} = K_Z \cdot Z_L = \left(\frac{K_{VT}}{K_{CT}} \right) \cdot Z_L \quad (4)$$

Where K_{VT} and K_{CT} are ratio of voltage to current respectively installed at busbar A . The characteristic curves $X = f(R)$ [7, 10, 23] for MHO distance relay are represented in figure 2.

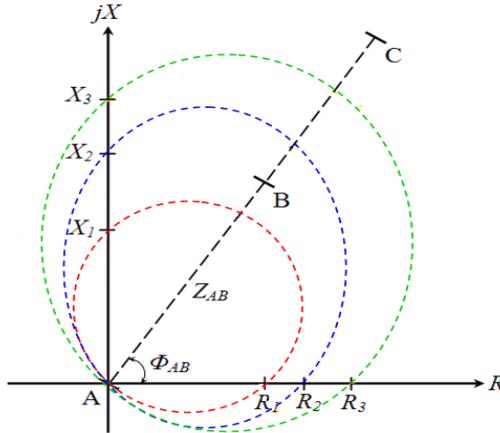


Fig. 2. Characteristic curves of MHO distance relay.

The presence of SVC devices has a direct influence on the total impedance of the protected line (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:

$$Z_1 = 0,8 \cdot \left[\left[\left(Z_{AB} / 2 \right) / X_{SVC} \right] + Z_{AB} / 2 \right] \quad (5)$$

$$Z_2 = \left[\left(Z_{AB} / 2 \right) / X_{SVC} \right] + Z_{AB} / 2 + 0,2 \cdot Z_{BC} \quad (6)$$

$$Z_3 = \left[\left(Z_{AB} / 2 \right) / X_{SVC} \right] + Z_{AB} / 2 + 0,4 \cdot Z_{BC} \quad (7)$$

3. Principal 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}) [25]. 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 [26] is represented in figure 3 and figure 4 shows the equivalent circuit at which SVC is modeled.

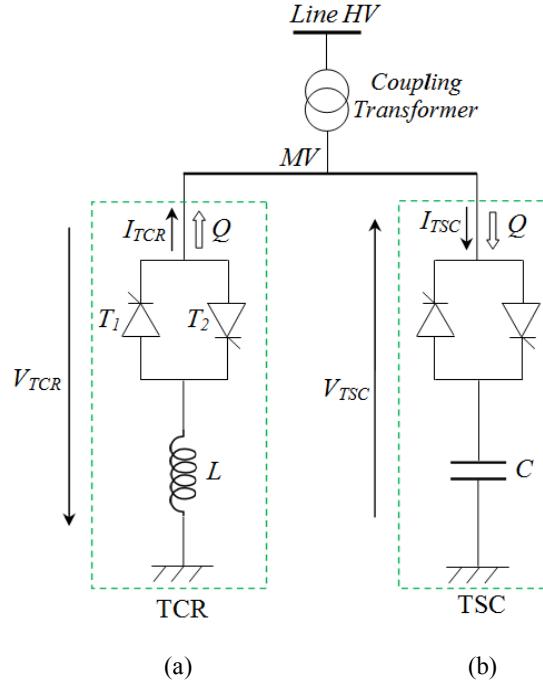


Fig. 3. Structures of SVC devices.

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 [1, 2], [25-26]. The figure 4.a and 4.b represent the substance for TCR and TSC respectively.

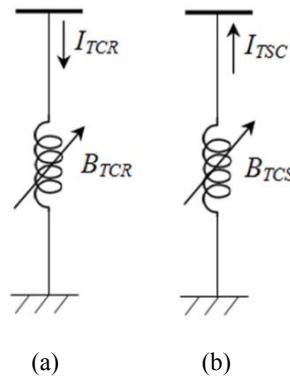


Fig. 4. Injected susceptance of SVC devices.

The current I_{TCR} directly related to the firing angle of thyristors (α), which was varied between 90° and 180° [1, 2, 25]. The value of the substance B_{TCR} will be represented by the equation [2, 25-27]:

$$B_{TCR}(\alpha) = B_{L,\max} \left[1 - \frac{2\alpha}{\pi} - \frac{1}{\pi} \sin(2\alpha) \right] \quad (8)$$

Where,

$$B_{L,\max} = \frac{1}{L \cdot \omega} \quad (9)$$

For the TSC, the expression B_{TCS} is defined in reference [1-3], [25-27] by the equation:

$$B_{TCS}(\alpha) = B_{C,\max} \left[1 - \frac{2\alpha}{\pi} - \frac{1}{\pi} \sin(2\alpha) \right] \quad (10)$$

Where,

$$B_{C,\max} = -C \cdot \omega \quad (11)$$

4. Case Study and Simulation Results

The figure below represents the power system studied in this paper and is the 400 kV, 50 Hz eastern Algerian electrical transmission networks at SONELGAZ group [22]. 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 bus bar 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 figure 5.

The parameters of the transmission line and installed SVC device are summarized in the appendix.

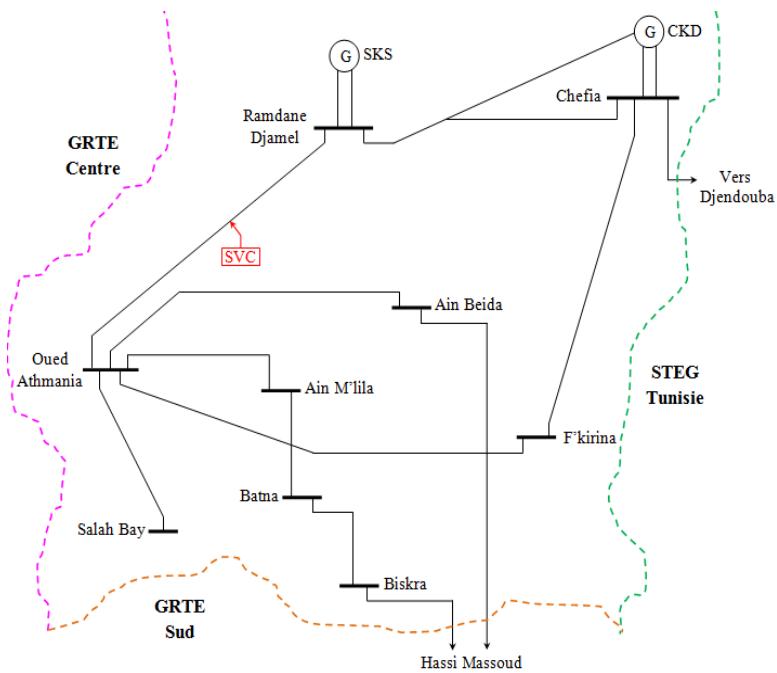
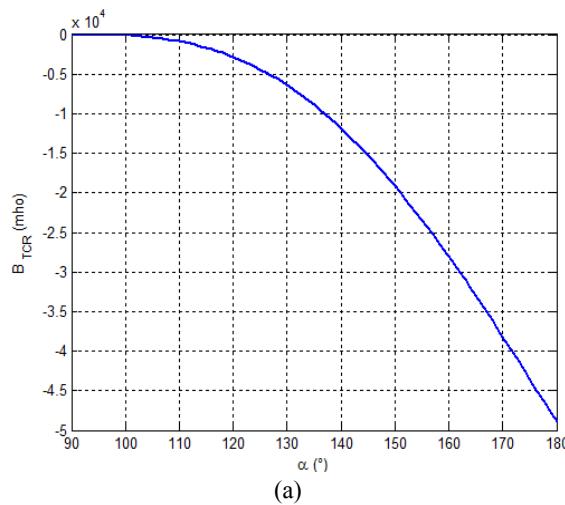


Fig. 5. Algerian electrical networks study in presence SVC.

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



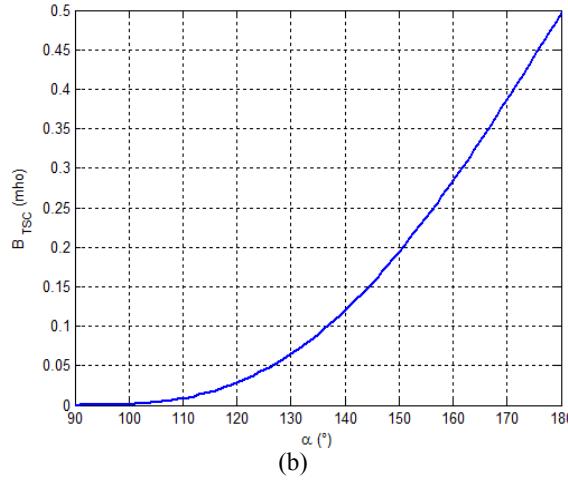


Fig. 6. Characteristic curves of the installed SVC;
a). $B_{TCR} = f(\alpha)$, b). $B_{TSC} = f(\alpha)$.

Figure 7 and 8 represented 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.

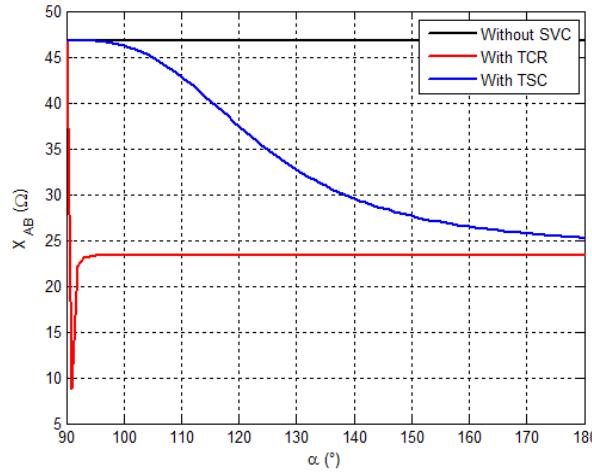


Fig. 7. Impact of α on X_{AB} measured by distance relay.

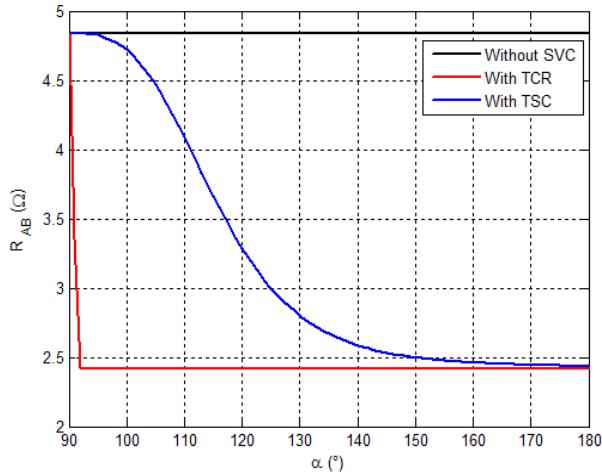


Fig. 8. Impact of α on R_{AB} measured by distance relay.

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} . The total impedance measured by the distance relay without SVC devices is equal $4,8407 + j 46,8048$ (Ω), the settings zones are summed in table 1.

Table 1
Setting Distance Relay without SVC Devices.

Setting zones	$X(\Omega)$	$R(\Omega)$
Z_1	1,8722	0,1936
Z_2	2,6172	0,2707
Z_3	2,8943	0,2993

4.1. Setting Relay on Presence TCR

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

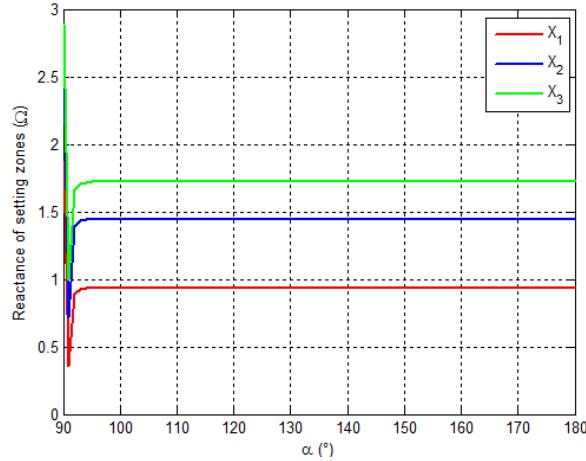


Fig. 9. Impact of the firing angle α on the setting zones in the presence of TCR.

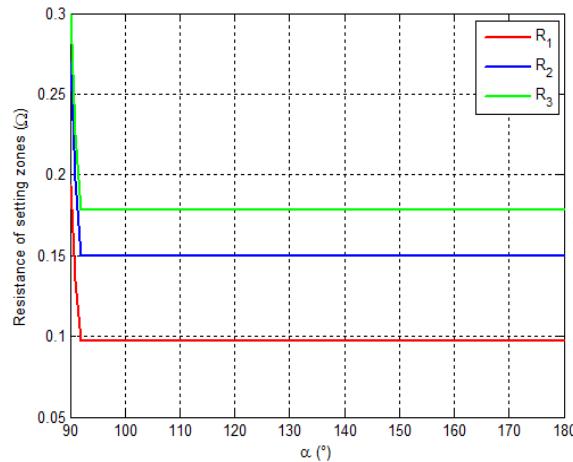
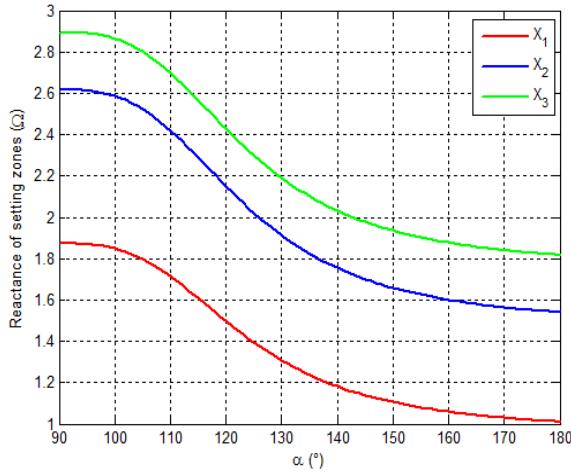
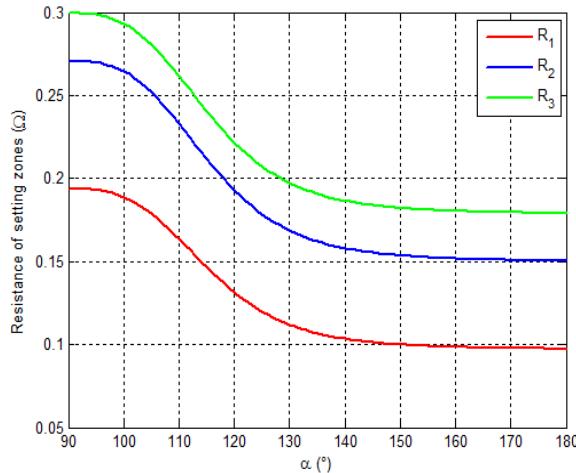


Fig. 10. Impact of the firing angle α on the setting zones in the presence of TCR.

From figures 9 and 10, the setting of the three zones of protection is dependent on the angle α of the TCR.

4.2. Setting Relay on Presence TSC

Figure 11 and 12 represented 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 figures 11 and 12 the setting of the three protection zones is dependent on the angle α of the TSC.

6. Conclusions

The results presented in this paper show the direct effects of SVC devices i.e. TCR and TSC insertion, on the total impedance of a transmission line protected Z_{AB} and Z_{seen} by MHO distance relay based analytical method. The impact is investigated for different values of the thyristors firing angle. As

demonstrated these angles injected variable substance (B_{TCR} or B_{TCS}) in the protected line which results in direct 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 SVC compensator on single electrical transmission line 400 kV.

Appendix

1). Transmission Line: $U_n = 400$ kV, $f_n = 50$ Hz, $Z_L = 0, 03293 + j 0, 3184 \Omega/\text{km}$, $l_{AB} = 147$ km, and $l_{BC} = 87$ 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, $X_{TR} = j0,0371 \Omega$.

3). Current Transformer: $I_{pri} = 1000$ A, $I_{sec} = 5$ A, $K_{CT} = 200$.

4). Voltage Transformer: $V_{pri} = 400000/\sqrt{3}$ V, $V_{sec} = 100/\sqrt{3}$ V, $K_{VT} = 4000$.

R E F E R E N C E S

- [1]. *K.K. Sen, M.L. Sen*, Introduction to FACTS Controllers: Theory, Modeling and Applications, John Wiley & Sons, Inc., and IEEE, New Jersey, USA, 2009.
- [2]. *X.P. Zhang, C. Rehtanz, B. Pal*, Flexible AC Transmission Systems: Modelling and Control, Springer Publishers, Heidelberg, Germany, February 2006.
- [3]. *M. Noroozian*, Modelling of SVC in Power System Studies, Published by ABB Power Systems, Reactive Power Compensation Division, Västerås, Sweden, April 2006.
- [4]. *Q. Liu, Z. Wang, Y. Zhang*, Study on a Novel Method of Distance Protection in Transmission Line with STATCOM, Power and energy Engineering conference (APPEEC'10) Asia-Pacific, Chengdu, China, 28-31 March, 2010.
- [5]. *W.H. Zhang, S.J. Lee, M.S. Choi, S. Oda*, Considerations on Distance Relay Setting for Transmission Line with STATCOM, IEEE Power and Energy Society General Meeting, Minneapolis, USA, 25-29 July 2010.
- [6]. *M.V. Sham, K. Panduranga Vittal*, Simulation Studies on the Distance Relay Performance in the Presence of STATCOM, Journal of Electrical Engineering (JEE), **vol. 11**, no. 3, March 2011, pp.11-18.
- [7]. *M. Zellagui, A. Chaghi*, Impact of Inserting STATCOM on MHO Distance Relay Setting in Algerian Transmission Line, IEEE 6th International Conference on Sciences of Electronics, Technologies of Information and Telecommunications (SETIT'12), Sousse, Tunisia, 21-24 March 2012.
- [8]. *A. Shojaei, S.M. Madani*, Analysis of Measured Impedance by Distance Relay in Presence of SSSC, 5th IET International Conference on Power Electronics, Machines and Drives (PEMD'10), Brighton, UK, 19-21 April 2010.
- [9]. *S. Jamali, H. Shateri*, Locus of Apparent Impedance of Distance Protection in the Presence of SSSC, European Transactions on Electrical Power (ETEP), **vol. 21**, no. 1, January 2011, pp. 398-412.

- [10]. *M. Zellagui, A. Chaghi*, Impacts of Static Synchronous Series Compensator (SSSC) on Measured Impedance in Distance Protection, 2nd International Conference on Information Processing and Electrical Engineering (ICIPEE'12), Tébessa, Algeria, 14-16 April 2012.
- [11]. *M. Khederzadeh, A. Ghorbani, A. Salemnia*, Impact of SSSC on the Digital Distance Relaying, IEEE Power & Energy Society General Meeting (PES'09), Calgary, Canada, 26-30 July 2009.
- [12]. *A. Kazemi, S. Jamali, H. Shateri*, Impact_of_TCSC_on_Measured_Impedance_by_Distance_Relay_for_Inter_Phase_Faults_in_Double-Circuit_Lines_Considering_MOV_Operation, 46th International Universities' Power Engineering Conference, Soest, Germany, 5-8 Sept. 2011.
- [13]. *A. Hosny, M. Safiuddin*, ANN-Based Protection System for Controllable Series-Compensated Transmission Lines", IEEE/PES Power Systems Conference and Exposition (PSCE'09), Seattle, USA, 15-18 March 2009.
- [14]. *F. A. Albasri, T.S. Sidhu, R. K. Varma*, Performance Comparison of Distance Protection Schemes for Shunt-FACTS Compensated Transmission Lines, IEEE Transactions on Power Delivery, **vol. 22**, no. 4, October 2007, pp. 2116-2125.
- [15]. *A. Kazemi, S. Jamali, H. Shateri*, Measured Impedance by Distance Relay for Inter Phase Faults in Presence of SVC, International Conference on Power System Technology (ICPST'10), Hong Kong, China, 24-28 October 2010.
- [16]. *S. Jamali, A. Kazemi, H. Shateri*, Comparing Effects of SVC and STATCOM on Distance Relay Tripping Characteristic, IEEE International Symposium on Industrial Electronics (ISIE'08), Cambridge, UK, 30 June - 2 July, 2008.
- [17]. *A. Kazemi, S. Jamali, H. Shateri*, Measured Impedance by Distance Relay for Inter Phase Faults in Presence of SVC, International Conference on Power System Technology (POWERCON' 10), Hangzhou, China, 24-28 October 2010.
- [18]. *S. Jamali, A. Kazemi, H. Shateri*, Measured Impedance by Distance Relay in Presence of SVC, International Review of Electrical Engineering, **vol. 5**, no. 2, April 2010, pp.619-627.
- [19]. *S. Jamali, A. Kazemi, H. Shateri*, Measured Impedance by Distance Relay for Inter Phase Faults in the Presence of SVC on Double-circuit Lines, 11th IET Conference on Developments in Power System Protection, Birmingham, UK, 23 - 26 April 2012.
- [20]. *M. Khederzadeh, A. Ghorbani*, STATCOM / SVC Impact on the Performance of Transmission Line Distance Protection, Transactions on Electrical and Electronic Engineering (TEEJ), **vol. 6**, no. 6, November 2011, pp. 525-533.
- [21]. *G. Zigler*, Numerical Distance Protection: Principles and Applications, Third Edition, Publicis Corporate Publishing, Germany, February 2008.
- [22]. *N. Manamani*, Principles and Settings of Distance Relay on Algerian Transmission Line 220 and 400 kV, Training at GRTE Sétif, Sonelgaz Group, Algeria, June 2010.
- [23]. *M. Zellagui, A. Chaghi*, MHO Distance Relay of Transmission Line High Voltage using Series Compensation in Algerian Networks, Journal of ACTA Electrotehnica, **vol. 52**, no. 3, September 2011, pp.126-133.
- [24]. *L. Gérin-Lajoie*, A MHO Distance Relay Device in EMTP Works, Electric Power Systems Research (EPSR), **vol. 79**, no. 3, March 2009, pp. 484-491.
- [25]. *R. Benabid, M. Boudour, M.A. Abido*, Optimal Location and Setting of SVC and TCSC Devices using Non-dominated Sorting Particle Swarm Optimization, Electric Power Systems Research (EPSR), **vol. 79**, no. 12, December 2009, pp. 1668-1677.
- [26]. *M.N. Nwohu*, Voltage Stability Improvement using Static Var Compensator in Power Systems, Leonardo Journal of Sciences (LJS), **vol. 14**, no.1, June 2009, pp. 167-172.
- [27]. *P. Sankarbabu, J.B.V. Subrahmanyam*, A Novel Online Fuzzy Control Method of Static VAR Compensation for an Effective Reactive Power Control of Transmission Lines, Journal of ACTA Electrotehnica, **vol. 51**, no. 1, March 2010, pp.45-50.

- [28] *C.F. Ionescu, C. Bulac, I. Triștiu, A. Mandiș*, Application of Mixed-Integer Hybrid Differential Evolution of Optimal Reactive Power Dispatch, Scientific Bulletin, University POLITEHNICA of Bucharest, Series C: Electrical Engineering and Computer Science, **vol. 75**. Iss. 1, 2012, pp. 155-162.
- [29] *C. Lazaroiu, C. Bulac, M. Popescu, N. Golovanov*, Control and Protection of a Multiterminal Low Voltage DC System Based on VSC, Scientific Bulletin, University POLITEHNICA of Bucharest, Series C: Electrical Engineering and Computer Science, **vol. 74**. Iss. 1, 2012, pp. 173-180.