Comparing the Effects of Mid-point and Line End Placements of FACTS device on Distance Relay from Measured Impedance Point of View

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Abstract- The location of FACTS device with respect to the distance relay has a significant effect on the apparent impedance seen by the protective relay. This can be analysed by means of comparing the actual measured impedance at the relaying point and the ideal tripping characteristics of the relay. Two case locations of the Thyristor Controlled Series Capacitor (TCSC) on the Ikeja West to Benin transmission line in the Nigeria power system were considered with respect to the concerned distance relay, i.e. at near end and mid-point. The effects of installation of TCSC at different locations on the transmission line distance relay were investigated under different fault conditions by the simulation model of the TCSC, simulated in the Nigeria power system using MATLAB/ Simulink software. The simulation results were discussed and used to compare the impact of TCSC located at various points on the transmission line with respect to a fault.

Indexed Terms- Relay, Overreach, Faults, Protection, Compensation, Tripping

I. INTRODUCTION

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 [1]. The basic operating principle of distance relay is based on the fact that the line impedance is fairly constant with respect to the line length. However, the implementation of FACTS controllers in power system transmission for enhancing the power system controllability and stability have introduced new power system issues in the field of power system protection that must be considered and analyzed [2]. The apparent impedance seen by a distance relay is influenced greatly [3] by the location and parameters of FACTS device, besides the fault resistance magnitude of the arc in case of a ground fault. If the impedance seen by a relay is lower or higher than the actual line impedance, the distance relay either overreaches or under reaches**.** In the presence of FACT devices, the conventional distance relay characteristics such as Mho and Quadrilateral are greatly subjected to mal-operation in the form of overreaching or under-reaching the fault point. Therefore, the conventional relay characteristics may not work properly in the presence of FACT devices [4], [5]. The effect of compensator TCSC on distance protection of transmission lines has been reported for general research on the influence of TCSC on the transmission lines protection in [6-8], while the impact on communication-aided distance protection schemes and its mitigation is reported in [9]. In [10], the impedance measured by the distance relay for inter phase faults with TCSC on a double transmission line high voltage was studied and in [11], the variation of seen impedance by distance relay for inter phase faults in presence of TCSC on adjacent transmission line by considering MOV operation was investigated. Comparing TCSC placements on double circuit line at mid-point and at ends from measured impedance point of view is mentioned in [12], and impact of TCSC on Z_{seen} by MHO distance relay on 400 kV Algerian transmission line in the presence of phase to earth fault with fault resistance is reported in [13]. In this research work, the effects of installation of TCSC at different locations in the Nigeria 330kV transmission line on distance relay were investigated under different fault conditions.

II. APPARENT REACTANCE INJECTED BY TCSC ON THE TRANSMISSION LINE

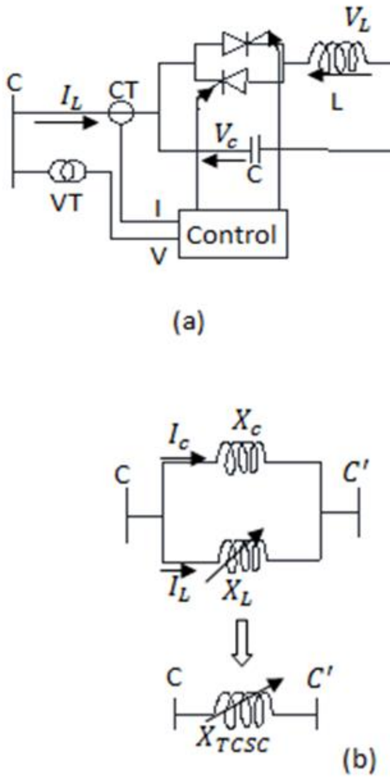

Figure 1 (a) Principal operation of TCSC, (b) Apparent reactance injected by TCSC

The compensator TCSC mounted on Figure 1(a) consists of variable inductance (L) connected in series with the transmission line controlled by thyristors mounted in anti-parallel and controlled by a firing angle (α) which varies between 90° and 180°, and a fixed value capacitance (C) connected in shunt [14], [15]. This compensator can be modeled as a variable reactance (X_{TCSC}) as shows in Figure 1(b). From Figure 1(b), the apparent reactance of the TCSC injected on transmission line is defined by the following equation [14], [15], [16]:

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

The reactance of the variable inductance $X_{L(\alpha)}$ controlled by thyristors is defined by equation

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

Where $X_{L(max)}$= Lω

$$= L\omega\left[\frac{\pi}{\pi-2\alpha-\sin(2\alpha)}\right] \qquad (3)$$

The capacitance is defined by

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

From Eqn. (2) and (4), Eqn. (1) becomes

$$X_{TCSC(\alpha)} = \frac{L\omega\pi}{\pi-2\alpha-\sin(2\alpha)-LC\omega\pi} \qquad (5)$$

III. TOTAL IMPEDANCE MEASURED BY DISTANCE RELAY PROTECTION

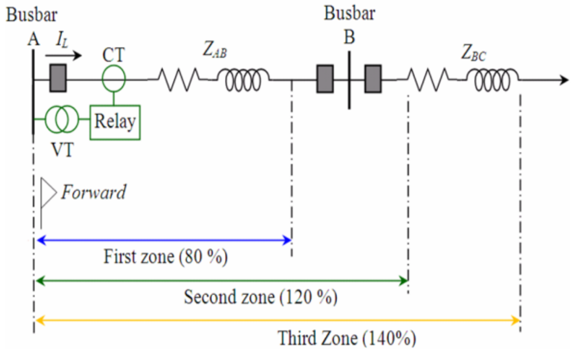

Figure 2: Principal and setting zones for distance protection.

The total impedance of electrical transmission line AB measured by distance relay without fault is [16],[17], [24], and [31]:

$$Z_{seen} = K_Z.Z_{AB} = \left({}^{K_{VT}}/_{K_{CT}}\right).Z_{AB} \qquad (6)$$

Where, $K_{VT} = {}^{V_{prim}}/_{V_{sec}}$

and $K_{CT} = {}^{I_{prim}}/_{I_{sec}}$

The impedance Z_{AB} is real total impedance of protected transmission line AB, and K_{VT} and K_{CT} are a ratio of voltage to current transformers respectively. The presence of TCSC, the X_{TCSC} has a direct influence on the total impedance of the protected line Z_{AB} by distance relay. The voltage would fall towards zero at the point of the fault. In case of earth fault in phase (A), the impedance measured is calculated by the following equation [1], [12], [13], [16]:

$$Z_{seen} = {}^{V_{Relay}}/_{I_{Relay}} = \frac{{}^{V_A}/_{I_A}+K_0.I_0}{K_Z} = R_{seen} + j.X_{seen} \qquad (7)$$

Where $K_0 = \frac{Z_0-Z_1}{3Z_1}$

and $K_Z = \frac{K_{CT}}{K_{VT}}$

The coefficient K_Z is a ratio of impedance transformers and $K_0$is coefficient for earth fault.

Case Study Transmission line in the Nigeria 330kV network

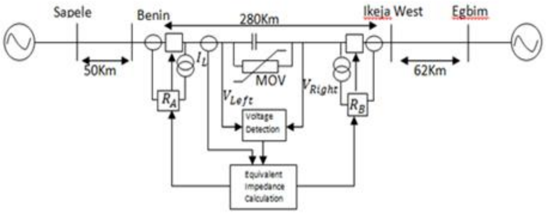

Figure 3: Schematic diagram of the Ikeja West to Benin transmission line

The simulations using Matlab/Simulink to show the Mho characteristics of the two relays R_A and R_B on the case transmission line, a 280km length Ikeja West to Benin transmission line in the Nigeria 330kV network was simulated under different fault conditions.

IV. RESULTS

A. Case Study of a Line to Ground Fault without FACTS compensation

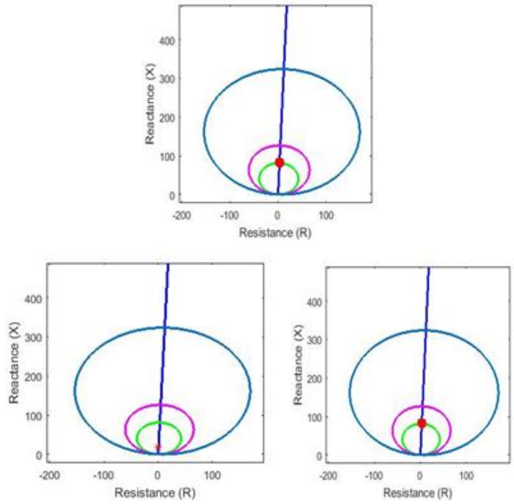

Figure 4: Mho characteristics of Relay A and Relay B for line to ground fault at 50Km without TCSC

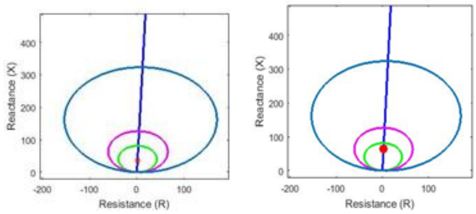

Figure 5: Mho characteristics of Relay A and Relay B for line to ground fault at 100Km without TCSC

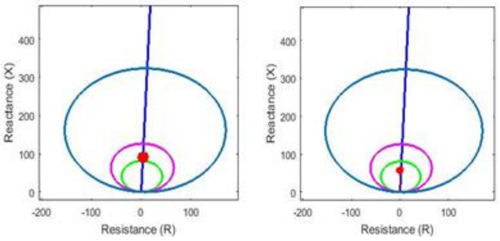

Figure 6: Mho characteristics of Relay A and Relay B for line to ground fault at 250Km without TCSC

B. System Simulation in the Presence of Mid-Point Located TCSC

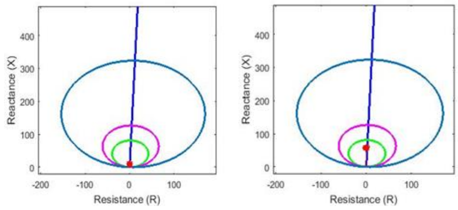

Figure 7: Mho characteristics of Relay A and Relay B for line to ground fault at 50Km mid-point located TCSC

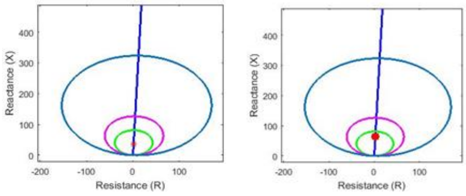

Figure 8: Mho characteristics of Relay A and Relay B for line to ground fault at 100Km mid-point located TCSC

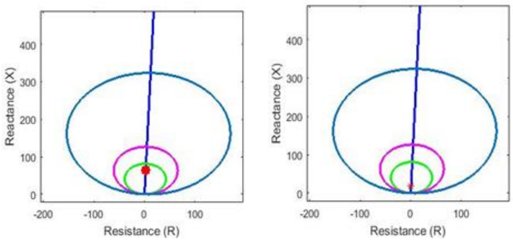

Figure 9: Mho characteristics of Relay A and Relay B for line to ground fault at 250Km mid-point located TCSC

C. System Simulation in the Presence of End-Point Located TCSC

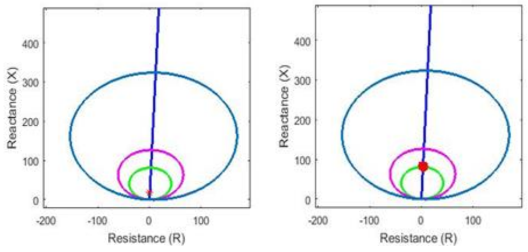

Figure 10: Mho characteristics of Relay A and Relay B for line to ground fault at 50Km end-point located TCSC

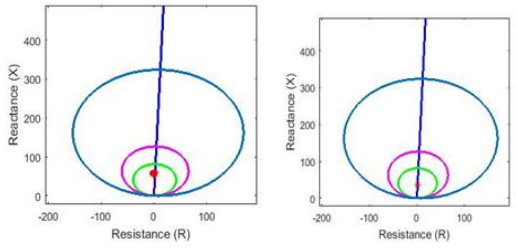

Figure 11: Mho characteristics of Relay A and Relay B for line to ground fault at 100Km end-point located TCSC

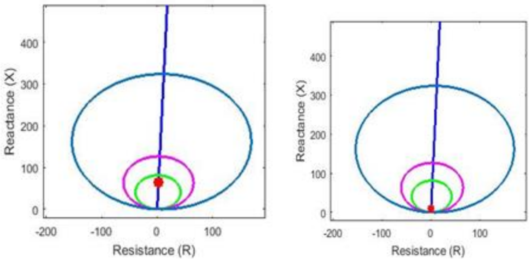

Fig. 12: Mho characteristics of Relay A and Relay B for line to ground fault at 250Km end-point located TCSC

V. DISCUSSIONS

The simulation results for the transmission line without TCSC showed that a 50km fault tripped in zone1 for relay A and zone 2 for relay B, while a 100km fault tripped in zone 1 for relay A and zone 2 for relay B. Also for a 250km fault, relay A tripped in zone 2 and relay B tripped in zone 1. For the simulation of the case transmission line with TCSC incorporated at the mid-point of the line, a single line to ground fault at 50km tripped relay A in zone 1 and relay B also in zone 1 indicating an inaccurate zone coordination. For a 100km fault, both relays tripped correctly in zone 1 while a 250km fault resulted to relays inaccurately tripping in zone 1 for relay A and also zone 1 for relay 2. For end-point located TCSC, a single line to ground fault at 50km will trip relay A at zone 1 and relay B at zone 2 indicating correct zone coordination. Fault at 100 km tripped both relay A and B at zone 1 while a 250km fault tripped relay A in zone 1 and relay B at zone 1 showing wrong zone coordination of the relays.

CONCLUSION

Simulation results showed that TCSC incorporation affected the zone coordination of the relay both for end point located TCSC and mid-point TCSC. The end point located TCSC had accurate zone tripping decision for faults near to the TCSC and the severity of under reaching was increased as the fault was farther away from the TCSC. For midpoint located TCSC, accurate tripping was shown for faults before the TCSC while mal-operation of relay resulted when fault occurred after TCSC. This is because the presence of TCSC in a fault loop protected by distance relay greatly affects the trip boundaries of the distance relay by setting it to an under reaching state. Thus, optimal method for TCSC placement is required and can be determined by using conventional techniques, evolutionary and metaheuristic optimisation methods.

REFERENCES

[1] A.A. Girgis, A.A. Sallam, A.K. El-Din, An adaptive protection scheme for advanced series compensated (ASC) transmission lines, IEEE Trans. Power Deliv. 13 (1) (1998) 414–420.

[2] ZIGLER, G. Numerical Distance Protection: Principles and Applications. 3. ed. Munich: Publicis MCD, 2008. ISBN 978-3895781421.

[3] IEEE Standard 1534. IEEE Recommended Practice for Specifying Thyristor Controlled Series Capacitor. New York: IEEE Power and Energy Society, 2009.

[4] P. K. dash, A. K. Pradhan, G. Panda, and A. C. Liew "Digital Protection Of Power Transmission Lines In The Presence Of Series Connected FACTS Devices," IEEE PES summer meeting, pp. 1967-1972, 2000.

[5] S.G. Srivani, Chandrasekhar Reddy, Atla, KP.Vittal "Comparative Evaluation of Adaptive and Conventional Distance Relay for Parallel Transmission Line With Mutual

Coupling," International Journal of mathematical, Physical and Engineering Sciences, Vol.(3), No.2, pp.118-124,2009.

[6] M. Khederzadeh and T. S. Sidhu, “Impact of TCSC on the Protection of Transmission Lines”, IEEE Transactions on Power Delivery, vol. 21, no. 1, (2006) January, pp. 80-87.

[7] Q. Liu, Z. Wang and Y. Xu, “Study on the Influence of TCSC on Fault Component Distance Protection”, IEEE Transmission and Distribution Conference & Exhibition: Asia and Pacific, China, (2005), August 23-25.

[8] P. A. Kulkami, R. M. Holmukhe, K. D. Deshpande and P. S. Chaudhari, “Impact of TCSC on Protection of Transmission Line”, International Conference on Energy Optimization and Control (ICEOC), Maharashtra, India, (2010), December 28-30, pp. 117-124.

[9] T. S. Sidhu and M. Khederzadeh, “TCSC Impact on Communication Aided Distance Protection Schemes and Mitigation”, IET Conference on Generation, Transmission and Distribution, vol. 152, no. 5, (2005) September, pp. 714-728.

[10] S. Jamali, A. Kazemi and 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), Sydney, Australia, (2008) December 14-17.

[11] S. Jamali, A. Kazemi and H. Shateri, “Measured Impedance by Distance Relay for Inter Phase Faults in Presence of TCSC on Next Line”, IEEE Region 10 Conference (TENCON),

[12] Kazemi, A., S. Jamali and H. Shateri. Comparing TCSC Placements on Double Circuit Line Mid-point and Ends from Measured Impedance Point of View. In: IEEE International Conference on Industrial Technology. ICIT'2008. Chengdu: IEEE, 2008, pp. 1{6. ISBN 978-1-4244-1705-6. DOI: 10.1109/ICIT.2008.4608453.

[13] Zellagui, M. and A. Chaghi. Impact of TCSC on Measured Impedance by MHO Distance Relay on 400 kV Algerian Transmission Line in Presence of Phase to Earth Fault. Journal of Electrical Systems. 2012, vol. 8, no. 3, pp. 273-291.ISSN 1112-5209.India, (2008) November 19-21.

[14] Mathur, R. M. and R. K. Varma. Thyristor-Based FACTS Controllers for Electrical Transmission Systems. New York: John Wiley & Sons,2002. ISBN 978-0-471-20643-9.

[15] Sen, K. K. and M. L. Sen. Introduction to FACTS Controllers: Theory, Modeling and Applications. New Jersey: John Wiley & Sons, 2009. ISBN 978-0470478752.

[16] Zellagui, M. A. and Chaghi. Distance Protection Settings Based Artificial Neural Network in Presence of TCSR on Electrical Transmission Line. International Journal of Intelligent Systems and Applications. 2012, vol. 4, no. 12, pp. 75-85. ISSN 2074-9058.

[17] Salemni, A., M. Khederzadeh and A. Horbani. Impact of Static Synchronous Compensator (STATCOM) on Performance of Distance Relay. In: IEEE PowerTech. Bucharest: IEEE, 2009, pp. 1{8. ISBN 978-1-4244-2234-0.DOI:10.1109/PTC.2009.5282187.

[18] Zellagui, M. and A. Chaghi. Impact of GCSC on Measured Impedance by Distance Relay in the Presence of Single Phase to Earth Fault. In: 32th International Conference on Power Systems Engineering. Dubai: WASET, 2012, pp. 142{149. ISSN 2010-376X.

[19] Gerin-lajoie, L. A MHO Distance Relay Device in EMTP Works. Electric Power Systems Research. 2009, vol. 79, no. 3, pp. 484-490.ISSN 0378-7796.