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ANN BASED PROTECTION for SERIES COMPENSATED LINES

A Santosh Kumar[1], V Surendranath Chowdary[2]

M.Tech, Department of Electrical Engineering, Sreenidhi Institute of Science & Technology, Hyderabad, India[1]

Assistant Professor, Department of Electrical Engineering, Sreenidhi Institute of Science & Technology, Hyderabad, India[2]

Abstract: This paper presents Artificial Neural Networks based protection for series compensated lines and the problem faced by the distance protection scheme used for transmission lines protection when they are compensated in series with the FACTS devices like TCSC. The use of TCSC creates certain problems to distance protection schemes as there is a change in the apparent impedance measured by the relay. The change in the apparent impedance measured is corrected by using Artificial Neural Networks (ANN) for the correct operation of the relay, which is extensively tested using MATLAB Simulation for different conditions. The results obtained show that by using the Artificial Neural Networks training methods the operation accuracy of the relay used for distance protection is improved.

Keywords: Artificial Neural Networks, Distance protection, FACTS devices, Thyristor Controlled Series Capacitor,

I. INTRODUCTION

Presently due to the deregulation of power industry and the restriction faced by power industry due to energy, environmental and regulatory issues, the main challenge is to improve the power transfer capability and also to improve the system integrity of the given transmission facility. The above mentioned problem can be addressed by using series compensation. Series compensation when introduced in power systems influences the power flow in a particular network segment which reduces active power losses and also prevents system - sub synchronous oscillations[1]-[3].

FACTS device are normally used in power systems which takes care of the power transfer capability, voltage stability and power oscillation damping. Thyristor Controlled Series Capacitor (TCSC) is one of the series compensation device used but, the use of TCSC creates certain problems for conventional distance protection schemes due to the changes in the apparent impedance measured by the relay. The apparent impedance seen by the relay is influenced by the uncertain variation of series compensation voltage [4]-[5].

Providers of transmission facilities normally prefer distance protection as the primary protection system, As series compensation is introduced in power transmission lines it needs additional attention while choosing the protection scheme as series compensation requires extra care in addition to the well know protection challenges on HV transmission networks . In modern days power system protection systems has become intelligent has it uses micro processor based techniques like Artificial Neural Networks to improve distance protection of transmission line with TCSC compensation which uses back propagation algorithm and is extensively tested using MATLAB Simulation for different conditions[6]-[11].

This paper is organized as follows: In the first section the introduction to Protection of Series Compensated Transmission Lines using Artificial Neural Networks is discussed, in the second section brief introduction of Thyristor Controlled Series Capacitor(TCSC) is presented, in the third section Artificial Neural Networks are discussed, in the fourth section Distance Protection basics and effect of SC Compensation on Protection is presented, in fifth section simulation methods used and results are presented and in sixth section conclusions based on the results obtained are presented.

II. THYRISTOR CONTROLLED SERIES CAPACITOR

For many years series compensation technique is used to adjust the power transfer between two stations by adjusting the net series impedance of the line. Installation of a series capacitor is a conventional and established method of increasing transmission line capacity, by reducing the net series impedance, thus increasing power transmission. As this method is well established method but, due to the limitation of its slow switching time it is replaced by Thyristor controllers, which are fast acting devices due to which rapid and continuous control of line compensation is possible. Thyristor Controlled Series Capacitor (TCSC) is one of the controllers used for series compensation. TCSC is a FACT device which is a combination of thyristor-controlled reactor (TCR) parallel with capacitor. TCR is a variable inductive reactor X_L (α) controlled by firing angle α. The variation of X_L (α) with respect to α can be calculated by [12]:

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$$X_L(\alpha) = X_L\left(\frac{\Pi}{\Pi - 2(\alpha) - \sin(\alpha)}\right) \quad \text{--------- (1)}$$

The controlled reactor is placed across the series capacitor, so that TCSC can be modelled as a variable parallel LC circuit, made of a fixed capacitive impedance Xc, and a variable inductive impedance $X_L(\alpha)$, as follows,

$$X_{TCSC} = \frac{X_c X_L(\alpha)}{X_L(\alpha) - X_c} \quad \text{------------- (2)}$$

where α is the delay angle measured from the peak of the capacitor voltage (or, equivalently, the zero-crossing of the line current). For α between 0 to 90, $X_L(\alpha)$ is varied from minimum value ($X_L = \omega L$) to its maximum (infinity), hence effective reactance of TCSC starts increasing from its minimum value of ($X_L Xc/(X_L.Xc)$) at α=0, to till occurrence of parallel resonance condition at $Xc = X_L(\alpha)$, theoretically X_{TCSC} is infinite which is known as inductive region. Still increasing of $X_L(\alpha)$ gives capacitive region, here TCSC reactance $X_{Tcsc}(\alpha)$ starts decreasing from infinity point to minimum value of capacitive reactance $X_C = 1/\omega C$. Fig. 2 shows the impedance characteristic curve of TCSC versus the firing angle α. From figure we see that both capacitive and inductive regions are possible by varying firing angle (α).

In practical scheme, the TCSC is usually made with a Metal Oxide Varistor (MOV) and a bypass switch used as protective devices, as per Fig. 1 MOV, which is a nonlinear resistor, protects the TCSC against high capacitor over-voltage by providing a alternate path for the fault current. The V-I characteristic of MOV is calculated by the following exponential equation:

$$I_{MOV} = I_{Ref}\left(\frac{V_{MOV}}{V_{Ref}}\right)^q \quad \text{---------------- (3)}$$

where I_{MOV} and V_{MOV} are MOV current and voltage; I_{Ref} and V_{Ref} are the reference quantities and q is an exponent of the characteristic. A circuit breaker is also present across the TCSC to bypass it if a severe fault or equipment mal-function occurs. There is also provision for a current limiting inductor, Ld, in the circuit breaker branch to restrict the capacitor current during the bypass operation

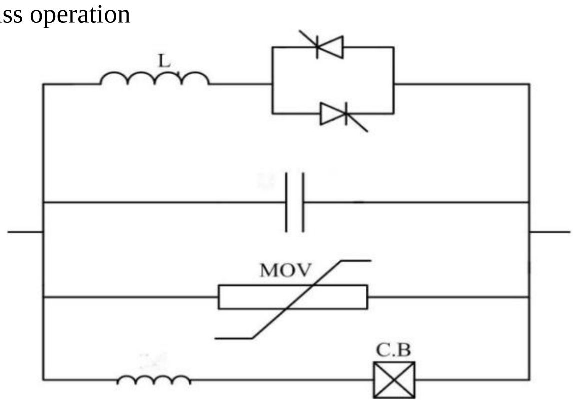

Fig. 1: TCSC circuit configuration

A. Different Modes Of Operation

By changing the firing angle of the thyristors the effective reactance of the TCR is varied. This variable TCR reactance in parallel with a fixed capacitor combination makes the TCSC to operate in four different modes; blocking mode; bypass mode; capacitive boost mode; and inductive boost mode. Since we are interested in the problem faced by the protection scheme in this paper we only take up the capacitive boost mode which is used for increasing the power transfer capability of the particular line segment.

B. Capacitive Boost Mode

In capacitive boost mode of operation a trigger pulse is supplied to the thyristor having forward voltage just before the capacitor voltage crosses the zero line, so a capacitor discharge current pulse will circulate through the parallel inductive branch. The discharge current pulse adds to the line current through the capacitor and causes a capacitor voltage that adds to the voltage caused by the line current. The capacitor peak voltage thus will be increased in proportion to the charge that passes through the thyristor branch. The fundamental voltage also increases almost proportionally to the charge. From the system point of view, this mode inserts capacitors to the line up to nearly three times the fixed capacitor. This is the normal operating mode of TCSC.

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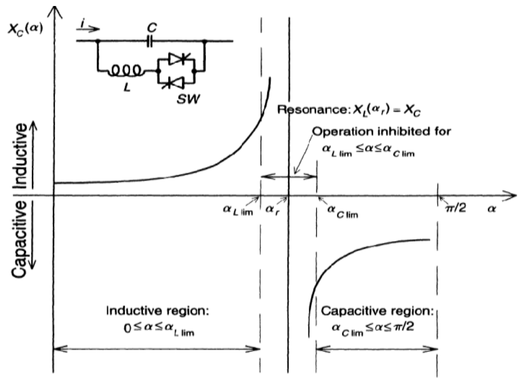

Fig. 2: TCSC reactance versus delay angle α

III. ARITIFICAL NEURAL NETWORKS

An Artificial Neural Network, just named as Neural Network, is a mathematical model inspired by biological neural networks. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. In most cases a neural network is an adaptive system changing its structure during a learning phase. Neural networks are used for modelling complex relationships between inputs and outputs or to find patterns in data. There are

- Modelling
- Forecasting and prediction
- Estimation and Control

To train an ANN using BP to solve a specific problem there are generally four major steps in the training process:

- Step 1- Assemble the suitable training data
- Step 2- Create the network object
- Step 3- Train the network and
- Step 4- Simulate the network response to new inputs.

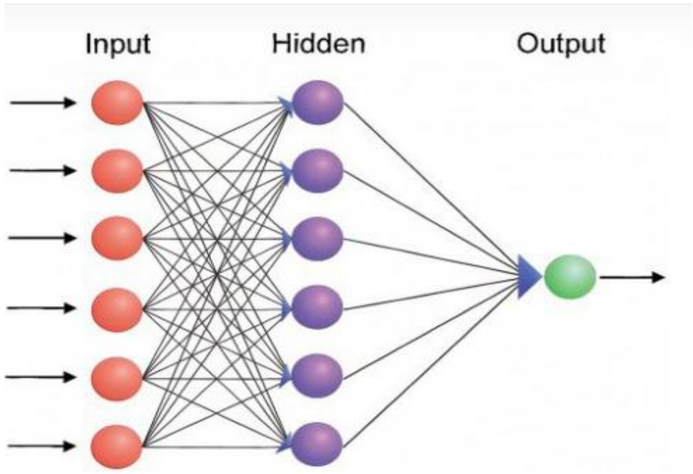

Fig. 3: Architecture of artificial neural network

IV. DISTANCE PROTECTION BASICS AND EFFECTS OF SC ON PROTECTION

A. Distance Relays

Distance relays, as the name says, measures distance. This is true in case of transmission line, as distance relay measures the impedance between the relay point and the fault location. This impedance is proportional to the length of the conductor, and hence to the distance between the relaying point and the fault [13].

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B. Zones Of Protection

Basically distance protection has instant directional Zone 1 protection and one or more time delayed zones. Numerical distance relays consists up to five zones, of which some are used in the reverse direction. The instant Zone I protection setting is up to 85% of the protected line using Numerical distance relays. The Zone 2 protection setting should be at least 120% of the protected line impedance. Zone 3 reach should be set to at least 1.2 times the impedance presented to the relay for a fault at the remote end of the second line section [13]. Typical reach for a 3-zone distance protection are shown in Fig.4.

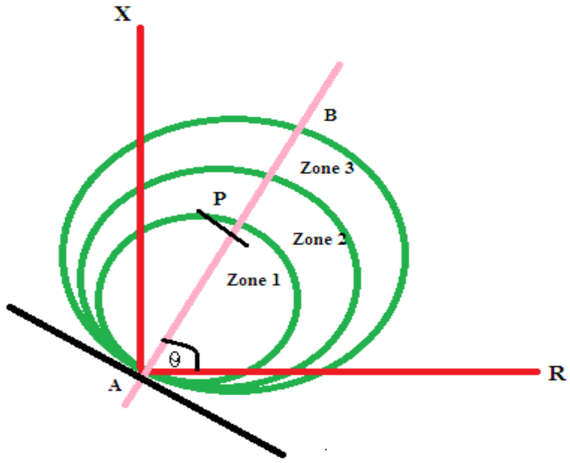

Fig. 4: Typical 3 zones of distance protection relay

where AB Protected line
θ Line angle
AP Impedance setting

C. Effect Of Tcsc On Distance Protection

Series compensation using TCSC plays a crucial role in loaded transmission lines. The usage of TCSC in transmission networks requires additional studies into the expected performance of the new system and also the influence on the operation of existing protection control and monitoring systems. Due to the introduction of series capacitance in the line, the line reactance creates problems for the effective operation of impedance based distance relays. The relays, which make use of impedance measurements in order to determine the presence and location of faults, are "fooled" by installed series capacitance on the line when the presence or absence of the capacitor in the fault circuit is not known priori.

TCSCs and their overvoltage protection devices (typically Metal Oxide Varistors (MOVs) and/or air gaps), in spite of their beneficial effects on the power system performance, introduce additional problems and make the operating conditions unfavourable for the protective relays that use conventional techniques and include phenomena such as voltage and/or current inversion, sub harmonic oscillations, and additional transients caused by the air gaps triggered by thermal protection of the MOVs. The apparent reactance and resistance seen by the relay are affected due to the variation of series compensation voltage during the fault period.

D. Effect Of Tcsc On Zones Of Protection For A Distance Relay

Due to the introduction of TCSC the apparent reactance and resistance seen by the relay are affected due to the variation of series compensation voltage during the fault period. Due to which the Conventional relay gets tripped unnecessarily even though the fault is not present in its zone of protection [3], [5].

Introduction of TCSC results in the changes of zones of protection of normally set distance relay used for transmission line protection. Fig.5 shows the zones of protection of a transmission line when TCSC is introduced, and Fig. 6 shows the combination of Fig. 4 and Fig. 5 to get a clear understanding of presence of TCSC

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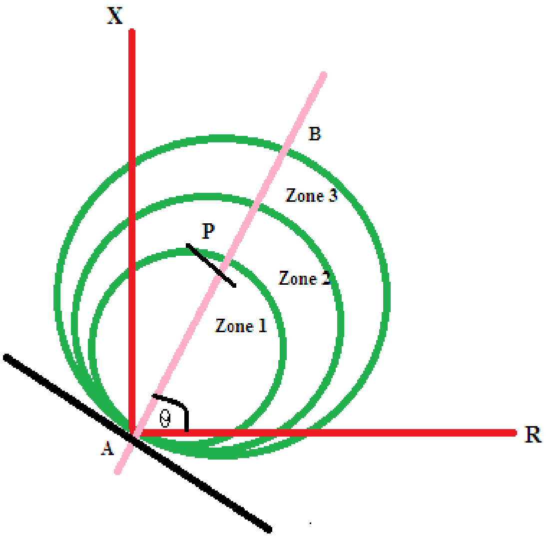

Fig. 5: Zones of protection of a transmission line with TCSC

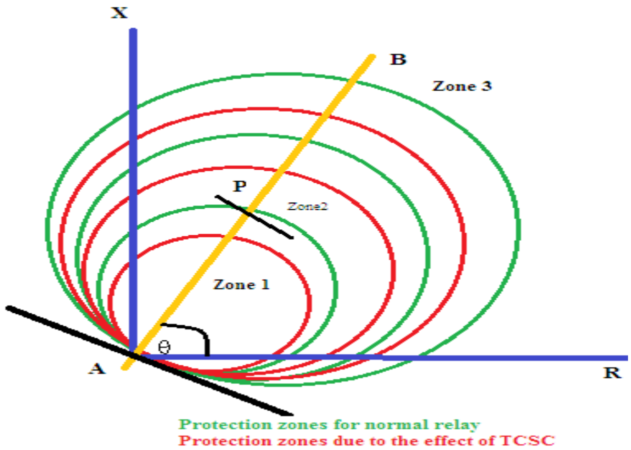

Fig. 6: Combination of Zones of Protection for normal relay and TCSC operation

where AB Protected line
θ Line angle
AP Impedance setting

V. SIMULATION AND RESULTS

The test system used for in this paper is a 500KV, 60 Hz power system which has two sources corresponding to two areas joined by a 400km transmission line. The system parameters used for simulation are given in table (1) in Appendix. In this system the TCSC is placed in the middle of the transmission line as per the single line diagram shown in fig. 7

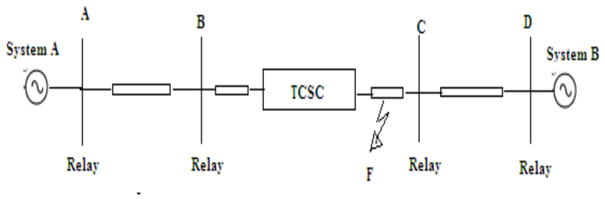

Fig.: 7 Single-line diagram of the test system

The model shown in the single line diagram is modelled for computer simulation in MATLAB/Simulink environment. After the simulation waveforms for different operating conditions are taken Fig. 8 and Fig. 9 shows a three phase voltage and current waveforms without TCSC in the system. Fig.10 and Fig.11 shows the voltages and current waveforms with TCSC present in the system. Fig. 11 also shows that whenever a fault occurs on the system the

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fault current increases abruptly and comes to normal condition after fault is cleared. For different test conditions voltages and current values are collected from them, by the help of fast fourier analysis tool box present in the MATLAB tool box the voltages and currents at the relay are calculated. Based up on the values of voltages and currents at different test conditions and different fault conditions impedance of that particular line section is calculated and the results are presented in table (I).

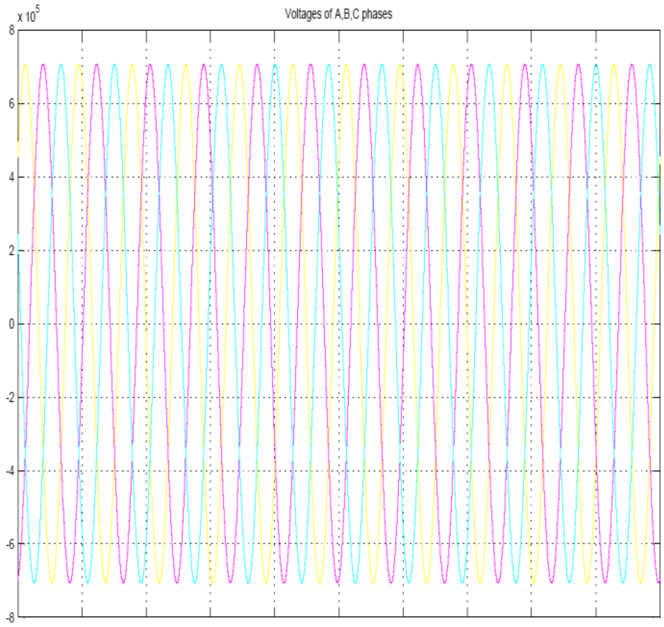

Fig. 8: Voltage waveforms without TCSC

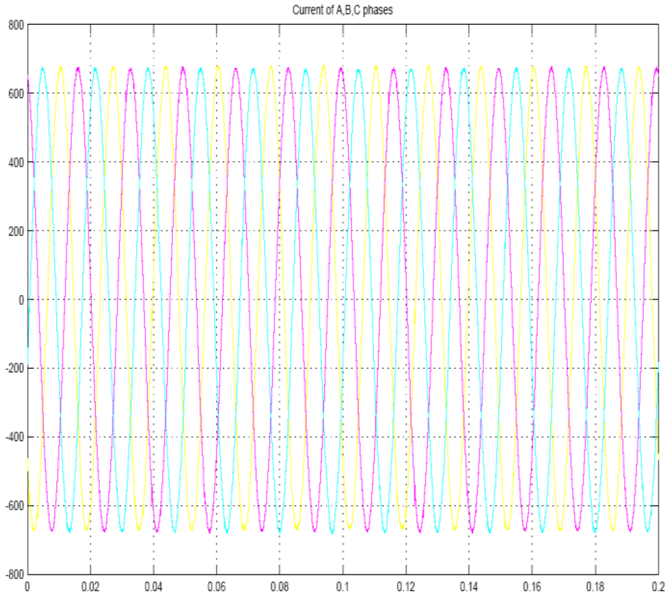

Fig. 9: Current waveforms without TCSC

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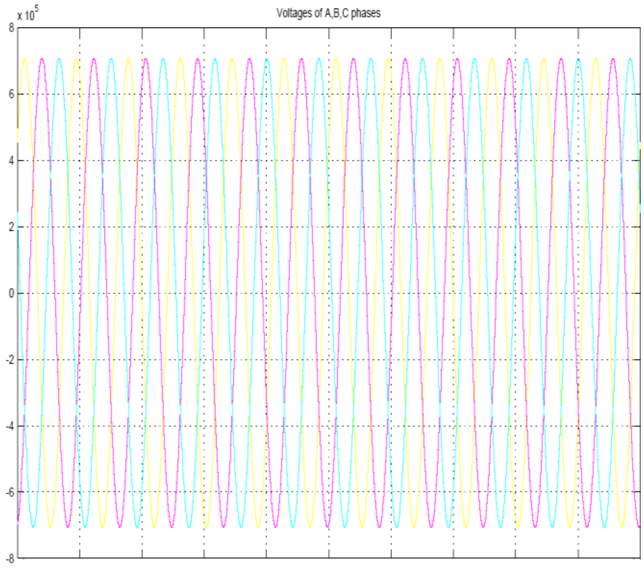

Fig. 10: Voltage waveforms with TCSC in capacitive mode of operation

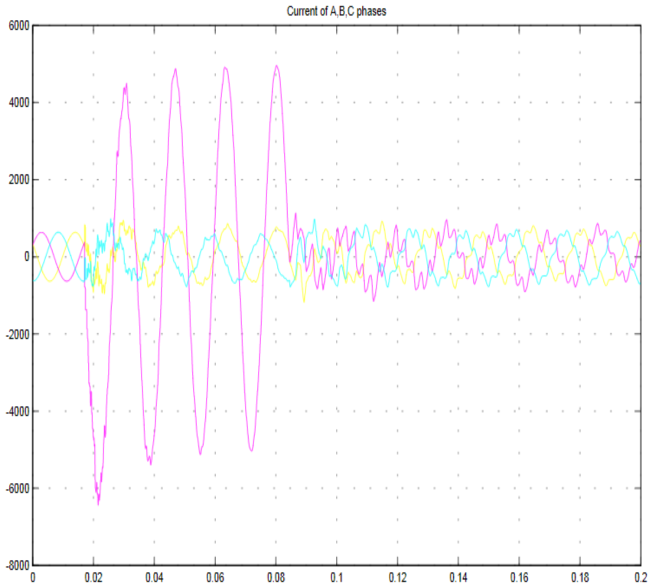

Fig. 11: Current waveforms with TCSC in capacitive mode of operation

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Table: I. Impedance values with TCSC in the middle of the line

Type of Fault	Fault Point in % of line	Impendence without TCSC in Ω for different line sections			Impendence with TCSC in Ω for different line sections α = 70°		
		AB	BC	CD	AB	BC	CD
L-L-L Fault	90%	--	112.0274	--	--	61.7669	--
L-L Fault	90%	--	135.2136	--	--	71.7293	--
L-G Fault	90%	--	383.3196	--	--	267.2748	--
L-L-L Fault	85%	54.6938	105.3275	52.1208	52.1317	59.6032	43.1282
L-L Fault	85%	59.8134	126.9644	135.2136	60.3985	69.1844	51.4553
L-G Fault	85%	118.0037	367.1406	407.9256	123.3292	253.9629	336.2055
L-L-L Fault	80%	49.0294	112.0274	51.3222	49.0249	55.8658	40.7595
L-L Fault	80%	56.2036	135.2136	63.9664	56.7585	64.3762	48.8305
L-G Fault	80%	110.6660	383.0049	402.1007	114.7544	230.8609	323.4493
L-L-L Fault	70%	42.8534	105.3259	44.1768	42.8902	53.0622	35.1386
L-L Fault	70%	49.0294	126.9644	55.0764	49.4169	61.9795	41.8215
L-G Fault	70%	96.1361	366.8508	391.3907	99.2852	207.4894	312.2703
L-L-L Fault	60%	36.7180	100.2228	37.4306	36.7180	51.8518	29.6686
L-L Fault	60%	41.8844	120.4284	46.5251	42.2025	60.8375	35.4104
L-G Fault	60%	81.8226	351.0993	379.7783	84.1352	184.615	301.2829
L-L-L Fault	50%	30.5871	92.8484	31.0369	30.5871	52.6750	24.4962
L-L Fault	50%	34.8016	111.2413	38.3350	35.0210	61.9640	29.2040
L-G Fault	50%	67.7183	335.1488	368.2882	69.3043	162.6950	290.0552

Table: II Protection behaviour of the relay in the particular line section

Type of Fault	Fault Point in % of line	Trip/No Trip of the relay based on impendence calculated		
		AB	BC	CD
L-L-L Fault	90%	--	Trip	--
L-L Fault	90%	--	Trip	--
L-G Fault	90%	--	Trip	--
L-L-L Fault	85%	No Trip	Trip	Trip
L-L Fault	85%	No Trip	Trip	Trip
L-G Fault	85%	No Trip	Trip	Trip
L-L-L Fault	80%	Trip	Trip	Trip
L-L Fault	80%	Trip	Trip	Trip
L-G Fault	80%	Trip	Trip	Trip
L-L-L Fault	70%	Trip	Trip	Trip
L-L Fault	70%	Trip	Trip	Trip
L-G Fault	70%	Trip	Trip	Trip
L-L-L Fault	60%	Trip	Trip	Trip
L-L Fault	60%	Trip	Trip	Trip
L-G Fault	60%	Trip	Trip	Trip
L-L-L Fault	50%	Trip	Trip	Trip
L-L Fault	50%	Trip	Trip	Trip
L-G Fault	50%	Trip	Trip	Trip

Based on the results of table (I) the relay present for protection of that particular zone sends a wrong trip signal which is shown in table (II). As we already discussed in introduction that due to the introduction of TCSC there is a problem for protection circuit which has to be corrected, this change in impedance is corrected with the help of Artificial Neural Network.

The training cases used for the training of the ANN are generated using MATLAB/Simulink test system shown in fig. 7 for various kinds of faults (LLL-Fault, LL-Fault and LG-Fault) fault location (90%, 85%, 80%, 70%, 60% and 50% length of line) and with different firing angles of TCSC (60°, 63°, 65°, 68° and 70°), with all the above different training cases different training vectors were collected at a sampling rate of 16 samples/cycle. The inputs given for the training of ANN are voltage, current of the relay location and firing angle at which TCSC is operating. The output expected from the ANN system is trip or a no trip signal to the circuit breaker in the form of [0 0 0 1 1 1 1]. ANN uses back- propagation algorithm for its training purpose and the number of neurons in the hidden layer is decided based on the trial and error method. In the present problem based on the trial and error method we come to the conclusion that

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with 10 neurons in the hidden layer gives better results. The results for expected output and the output obtained after training are compared as shown in table (III). The results for expected output and the output obtained after training are compared with the help of bar graph for better understanding as shown in Fig. 12.

Table: III Comparison of Output of Conventional Relay Output with ANN output

Expected Output of ANN Network	Conventional Relay Output	Output of ANN Based Relay
0	1	0.0566915
0	1	0.0467832
0	1	0.0477842
1	1	0.99997
1	1	0.95266
1	1	0.99999
1	1	0.99996

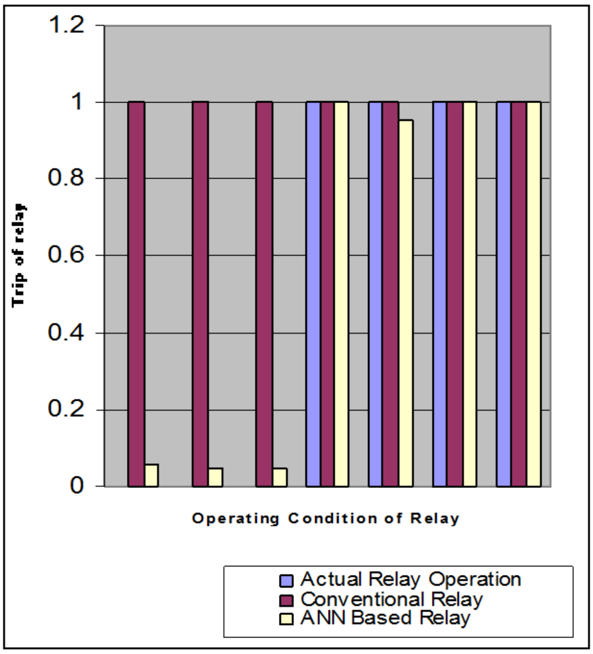

Fig. 12: Bar Graph showing Comparison of Output of Conventional Relay Output with ANN output

VI. CONCLUSION

The introduction of TCSC has advantages like improvement in stability; enhanced active power transfer capability but it creates certain problems to conventional distance protection scheme when used by transmission lines as there is a change in the apparent impedance measured by the relay. The results obtained from simulation for different types of faults and different operating points (with firing angles $\alpha = 60°$ to $70°$) of TCSC. They indicate that presences of TCSC when operating in capacitive mode have changed the impedance measured by the relays used by the protection system, which caused mal operations (like over reach) of protective relay. This mal operation is avoided by ANN trained by Back Propagation Algorithm. ANN based relay gives promising results (for tripping condition (0, 1)) compared to conventional relay with the presences of TCSC. The fault distance can also be obtained with the above network by selecting proper training pairs which will be presented in future work.

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BIOGRAPHY

A Santosh Kumar received his B.Tech degree from Sri Indu College of Engineering and Technology in the year 2007, and he is pursuing his Masters in Electrical Power Engineering from Sreenidhi Institute of Science and Technology Hyderabad.

V Surendranath Chowdary received his B.Tech degree from JNTUH in year 2006 and M.Tech in Power Systems in 2008 from JNTUH. He is currently an Assistant Professor of EEE Department in Sreenidhi Institute of Science and Technology. His areas of interests include Power System Protection, Power Harmonics, Power Quality and Artificial Intelligences.