IMPLEMENTATION OF SINGLE-PHASE TCSC AT LABORATORY SCALE LEVEL

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Abstract

The main aim of this paper is the implementation and development of the single-phase TCSC at laboratory scale level and related results of tests conducted on TCSC module to verify its performance. The value of inductor and resistor of a ferrite core winding has been decided by performing least square identification method. Laboratory model for the single-phase TCSC system is implemented using arduino uno and it is further tested by loading the pulse generation programme in arduino uno. Pi transmission line has been constructed and implemented for single-phase voltage level. The value of active power is compared for two cases:

I. When TCSC is not connected in series with the pi-transmission line

II. When TCSC is connected in series with the pi-transmission line

Keywords: **FACTS, TCSC, Arduino Uno, Thyristor, Pi-transmission line**

I. INTRODUCTION

The use of flexible alternating current transmission system (FACTS) devices have been increased in last two decade due to its flexibility and ability to reduce the many power system problems like (overloading of transmission line, stability issues, voltage regulation). The FACTS devices are became more popular because it provides high speed operation with considering minimum maintenance by using wide range of power electronics devices. There are many FACTS devices out of which use of TCSC has been increased in last one decade because it provides smooth control over power flow in the transmission line. As incorporation of TCSC in the transmission line provides number of benefits like it emphasizes on enhancement of dynamic and transient stability and its control, it also diminishing the damping of SSR (sub synchronous resonance) and loop flows. [9, 10]

The paper is organized as follows. Section II presents a steps to design and development of TCSC hardware circuit which includes the Test circuit of TCSC and its hardware implementation along with the inductor and capacitor parameter's identification. Section III shows the experimental results of TCSC connection when it is not connected with pi transmission line and when it is connected with pi transmission line.

II. DESIGN AND DEVELOPMENT OF TCSC HARDWARE CIRCUIT

Fig. 1 depicts the test circuit of TCSC. It can be seen from the circuit that 230 V AC supply is applied to the TCSC device which consists of a two antiparallel thyristor in series with one inductor (L) and this two combination is in parallel with one capacitor (C) [9]. The combination of inductor in series with two antiparallel thyristor is called thyristor controlled reactor (TCR). TCR is a variable inductive reactor ($X_L(\alpha)$) tuned at firing angle alpha (α).

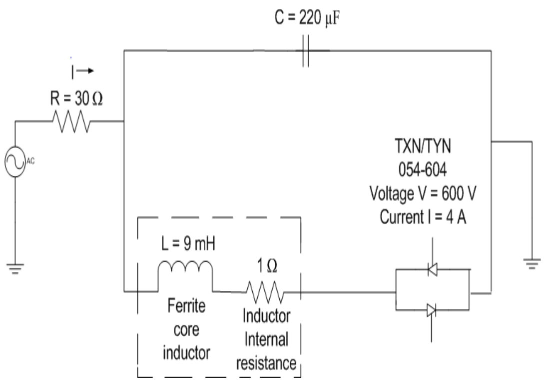

Fig. 1 Test circuit of TCSC

TABLE I

Components	Ratings
Transformer	Step down – 230/3 volt
Opto coupler	EL817-G
Thyristor	TXN/TYN 604, Voltage - 600 V, Current - 4 A, Temperature – 110° C
Inductor	9 mH Ferrite cored inductor
Capacitor	220 µF
Arduino uno	Max current – 50 mA Max voltage – 5 V

Different components and its ratings are tabulated in TABLE I. The ratings are standard and taken from the datasheet given for individual components. Here arduino uno has been used for generating pulse to give anti-parallel thyristors and further to trigger it. TXN/TYN - 604 category thyrsitors have been used and implemented in TCSC module, it can sustain maximum voltage up to 600 volt, maximum current up to 4 A and maximum temperature up to 110° C. 9 mH ferrite cored inductor has been used for proving the inductive effect in TCSC module and capacitor rating is 220 µF. Here 230/3 volt (3 volt is RMS value * 1.41 = 4.23 volt) step-down transformer has been used to give the ac supply to the arduino Uno's input. It is not possible to supply more than 5 volt to the arduino uno and if it is supplied than there may be chances of heat up of arduino uno board and board may get damage. EL817-G Opto coupler has been used to provide the isolation between power circuit and electronic components circuit (TCSC module) [8].

Fig. 2 depicts implemented TCSC hardware circuit on printed circuit board (PCB). On extreme left hand side port is for suppling 230 V AC supply and two more ports are there on right side which are for giving the pulse to the two antiparallel thyristors.

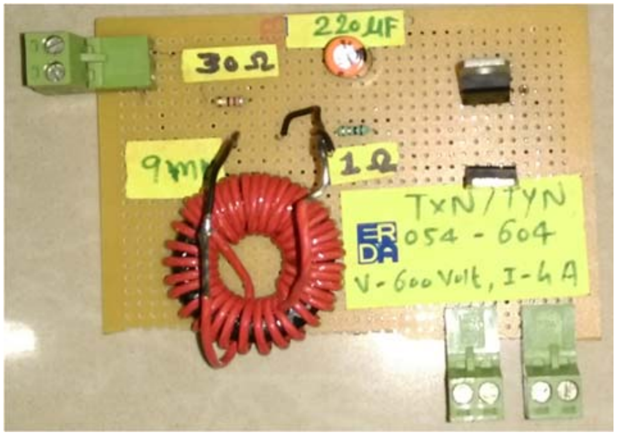

Fig. 2 TCSC hardware circuit

III. Experimental results

Fig. 3 and TABLE I depicts the experimental results of pi- transmission line when thyristor controlled series capacitor (TCSC) is not implemented in series with the pi-transmission line. The different parameters like sending end side active power, sending end side voltage, sending end side current, power factor at sending at side and same way receiving end side active power, receiving end side voltage, receiving end side current and power factor at receiving end side are measured by power factor meter in laboratory.

Pi-Transmission has been implemented to check the effect of constructed TCSC module on it. Wire gauge has been as 4 AWG according to the current handling capacity of the pi-transmission line. Choke coil and bulb in series with it is taken as load which is connected at the end of the pi-transmission line. In pi-transmission line four 220 µF capacitor is connected in shunt pattern and ferrite cored inductor is deployed in series with the transmission line to provide the inductive effect in transmission line [6].

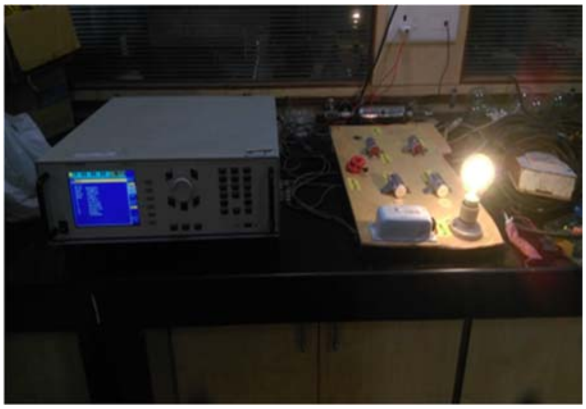

Fig. 3 Measurements of pi transmission line parameters

Results of the measured parameters are tabulated in below

TABLE II when TCSC is not implemented in series with the pi-transmission line. ABCD parameters are also calculated from the measured parameters values and the value of A, B, C, D are 1.03, 385.55, 2.07 * 10^{-3} mho, 0.7704 respectively.

TABLE II

Measured Parameters	**Values of different measured parameters when TCSC is not connected with pi transmission line**
Voltage at sending end side (V_S)	235.19 V
Current at sending end side (I_S)	0.47 A
Voltage at receiving end side (V_R)	227.05 V
Current at receiving end side (I_R)	0.61 A
Power factor at sending end side ($Cos\phi_S$)	0.642
Power factor at receiving end side ($Cos\phi_R$)	0.51
Active power at sending end side (P_{IN})	70.96 W
Active power at receiving end side (P_{OUT})	70.63 W
Voltage regulation (V_{R1})	3.58 %

It can be seen from the TABLE II that the value of sending end and receiving end voltage and current is 235.19 V, 0.47 A and 227.05 V, 0.61 A respectively and voltage regulation is 3.58 %.

Fig. 4 depicts the synchronization of supply with arduino pulses. In order to do to do synchronization of AC supply with arduino pulses 230/3 volt transformer has been used. The secondary of transformer is being given to the input pin of arduino and further the pulse generation programme has been loaded in the arduino uno. From the output pin of arduino one can see and observe the results.

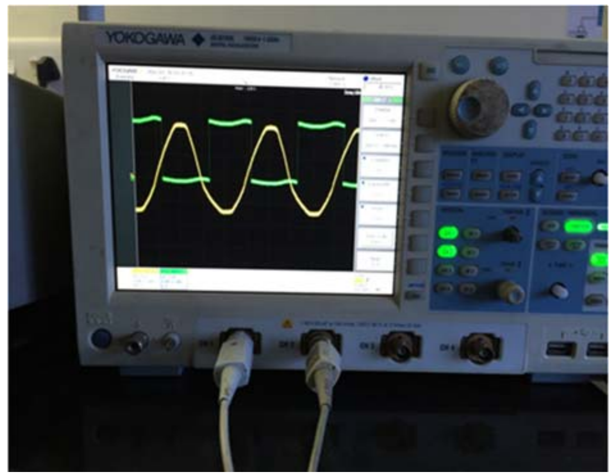

Fig. 4 Synchronization of supply with arduino pulses

Fig. 5 and TABLE III depicts the experimental results of pi-transmission line when TCSC is implemented in series with the pi-transmission line. Again the different parameters like sending end active power, sending end side voltage, sending end side current, power factor at sending at side and same way receiving end side active power, receiving end side voltage, receiving end side current and power factor at receiving end side are measured by power factor meter in laboratory.

Results of the measured parameters are tabulated below in TABLE III when TCSC is implemented in series with the pi-transmission line. ABCD parameters are also calculated from the measured parameters values and the value of A, B, C, D are 1.01, 546.90, 1.63 * 10^{-3} mho, 0.88 respectively.

It can be seen from the TABLE III that the value of sending end and receiving end voltage and current is 235.17 V, 0.38 A and 232.68 V, 0.43 A respectively and voltage regulation is 1.07 %. Here it can be observed that after connecting TCSC module in series with the pi-transmission line the receiving end voltage is increased from 227.05 V to 232.68 V and at the same time voltage regulation is also improved from 3.58 % to 1.07 %.

TABLE III

Measured Parameters	Values of different measured parameters when TCSC is connected with pi transmission line
Voltage at sending end side (V_S)	235.17 V
Current at sending end side (I_S)	0.38 A
Voltage at receiving end side (V_R)	232.68 V
Current at receiving end side (I_R)	0.43 A
Power factor at sending end side ($Cos\o_S$)	0.71
Power factor at receiving end side ($Cos\o_R$)	0.58
Active power at sending end side (P_{IN})	63.44 W
Active power at receiving end side (P_{OUT})	58.03 W
Voltage regulation (V_{R1})	1.07 %

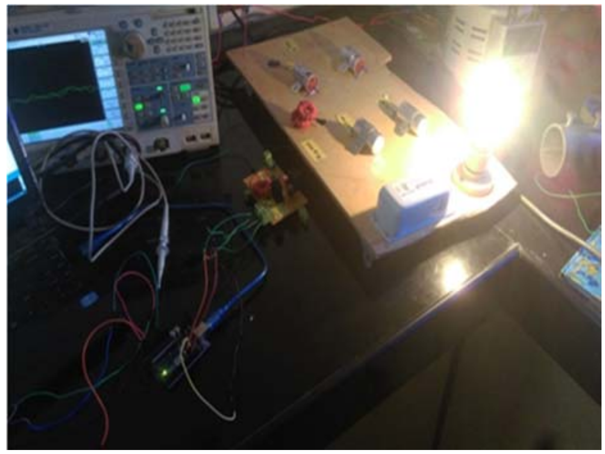

Fig. 5 TCSC connection with pi transmission line

Fig. 6 depicts the complete experimental setup of Thyristor controlled series capacitor (TCSC) along with the operating condition of pi-transmission line and final observations have been made by doing measurements of pi-transmission line parameters and also from the measured parameters conclusion has been made.

Fig. 6 Complete setup of TCSC hardware

IV. CONCLUSIONS

This paper is specifically concerned about the implementation of TCSC at laboratory scale level with all related analysis. This paper also demonstrates the actual behavior of the TCSC module when it is connected in series with the pi-transmission line and when it is not connected in series with the pi-transmission line. The step by step procedure is given to implement and to develop a lab scale prototype of single-phase TCSC. It is also possible to implement a three-phase TCSC device for series compensation by using voltage sourced converters.

Case I - Results when TCSC is not connected with the Pi transmission line: Parameters for the pi transmission has been calculated when TCSC is not implemented with pi transmission line and it has been noted that sending end side active power is 70.96 Watt and receiving end side active power is 70.63 Watt.

Case II - Results when TCSC is connected with the Pi transmission line: Parameters for the pi transmission has been calculated when TCSC is implemented with pi transmission line and it has been noted that sending end side active power is 63.44 Watt and receiving end side active power is 58.03 Watt. So here it can be seen that there is significant reduction in active power consumption because of the increase in the receiving end voltage and reactive power compensation due to TCSC connection with pi transmission line.

It is also noted that there is improvement in voltage regulation from 3.58 % to 1.07 % when TCSC module is implemented in series with the pi transmission line.

V. REFERENCES

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