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Comparative Study of Prototype Model Results and Simulation Results of TCSC Facts Controller for Congestion Management

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ABSTRACT

TCSC prototype comprises 400 KV, 300 Km transmission line model operates on lab voltage of 400 V, 8 Amp, 50 Hz. Compensator consists of capacitors in series with transmission line across which thyristor (valve) connected back to back and is connected in series with air gap type linear inductor. Simple hardware consisting of measuring circuits using CTs and PTs, with AVR ATmega 2560 controller, thyristor firing circuit using IC-MOC3021 is implemented and avoided the circuit complications as compared to when firing circuit incorporated with pulse transformers and different transistors. Simple software strategy of either proportional plus integral (PI) or proportional plus integral plus derivative (PID) control is introduced to maintain the voltage level at receiving end within desirable limit for variation of load. In this paper, TCSC simulation results are compared with prototype results to validate the controller design parameter with manual tuning. However, the aim of this dissertation is to enhance the voltage stability and increase the power transfer capability of the long transmission line

Keywords: FACTS, Series Compensator, TCSC, thyristor, MATLAB, physical model, controller, experiment.

I. INTRODUCTION

During the last several years interest in the possibilities to control the (active) power flows in transmission systems has increased significantly. There is a number of reasons for this, originating both from the application side that is, from the power system operation and from the technological side, that is, the advent of new system components such as semiconductor based devices. In many countries the operation of power systems has changed due to higher utilization of the transmission network and a deregulation of the power market. In certain deregulated environments, transmission capacity becomes a commodity. For the use of transmission capacity, fees have to be paid, and the transmission grid operator depends economically on these fees. The new components that are becoming feasible are to a large extent based on advances in power electronics and related technologies.

The scope of application of such devices has been extended considerably in recent years, as these devices provide much better transient responses, compared with their mechanical, electrical and electromechanical counterparts. The use of any such device can increase the level of power that can be transferred over a transmission corridor without endangering the system stability.(TCSC) is a type of series compensator, can provide many benefits for a power system including controlling power flow in the line, damping power oscillations, and mitigating sub synchronous resonance. Shunt compensation is ineffective in controlling the actual transmitted power as given The variable series compensation is highly effective in both controlling power flow in line and improving stability, design, model and implement the TCSC in power system model is simulations are performed using the MATLAB.The use of any such device can increase the level of power that can be transferred over a transmission corridor without endangering the system stability.

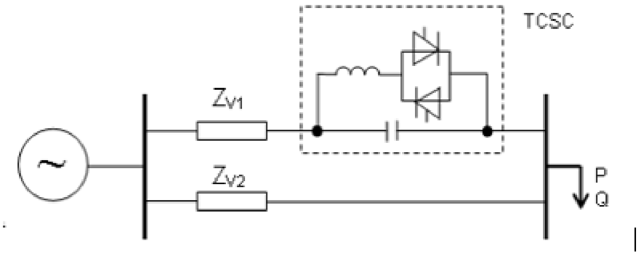

Figure1:Generalized Block diagram of TCSC scheme

The Thyristor Controlled Series Capacitor (TCSC) belongs to the Flexible AC Transmission Systems (FACTS) group of power systems devices. Essentially a TCSC is a variable reactance device that can be used to provide an adjustable series compensating reactance to a transmission line. Its advantage over other series compensating devices is that its reactance can be instantaneously and precisely controlled. This makes the TCSC well suited to enhance the power transfer capability of a power system.

A TCSC is typically made up of the following major components:

- Thyristor valves
- Reactors
- Capacitors (often tuned for harmonic filtering)

II. METHODS AND MATERIAL

Thyristor Controlled Reactor (TCR) in combination with a Fixed Capacitor (FC) is used, to provide a smoothly variable series capacitive reactance. It is a one-port circuit in series with transmission line; it uses natural commutation; its switching frequency is low; it contains insignificant energy storage and has no DC-port. Insertion of a capacitive reactance in series with the line’s inherent inductive reactance lowers the total, effective impedance of the line

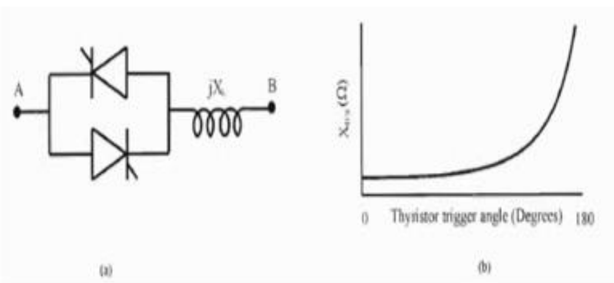

Figure2:(a) TCR; (b) Plot of TCR reactance versus thyristor trigger angle

As a result, both angular and voltage stability gets improved. Furthermore, in contrast to capacitors switched by circuit breakers, TCSC will be more effective because thyristors can offer flexible adjustment, and more advanced control theories can be easily applied.This gives continuously controllable lagging to leading VARs by thyristor control of reactor Current only. This is depicted in Fig2.

III.DESIGN OF TCSC CONTROLLER

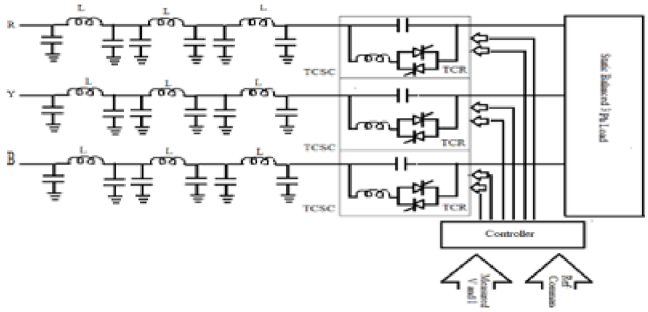

Figure 3:Schematic of Three Phase Transmission Line and TCSC

The Three phase TCSC (TCR) prototype consist of,
Three phase long transmission line
Three phase compensation reactor and capacitor
Three phase static load

- Sensing of receiving end bus voltage and compare it with the set point voltage and give appropriate signal to TCR to reduce the error of voltage.
- Regulation of the power factor, system shall be designed to continuously monitor the present power factor and compare it with the set power factor (unity power factor) and give appropriate signal to TCR to reduce the error.
- Display magnitude of measured signals and firing angle in percentage

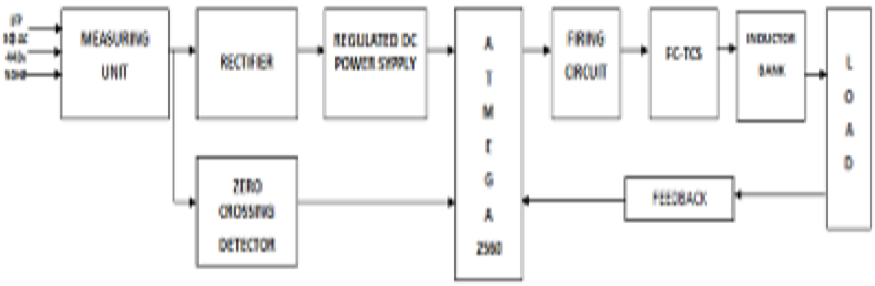

Figure 4: Block diagram of the System

A. The current sensing

The current sensing is done with the help of current transformer (CT) (15A/0.1A). The output of the CT is converted into appropriate voltage (maximum 5 volts) with the help of resistor, and it is given as input to ZCD.A current transformer is a type of "instrument transformer" that is designed to provide a current in its secondary which is accurately proportional to the current flowing in its primary. Current transformers are designed to produce either an alternating current or alternating voltage proportional to the current being measured. Current transformers produce either an alternating current or alternating voltage that is proportional to the measured current.

B. The Voltage sensing

For voltage sensing, potential transformer (PT) (440/15V) is used and its output is given to second channel of ZCD. The standards define a voltage transformer as a device in which "the secondary voltage is substantially proportional to the primary voltage and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections. This, in essence, means that the voltage transformer has to be as close as possible to the "ideal" transformer. In an "ideal" transformer, the secondary voltage vector is exactly opposite and equal to the primary voltage vector, when multiplied by the turn’s ratio.

In a "practical" transformer, errors are introduced because some current is drawn for the magnetization of the core and because of drops in the primary and secondary windings due to leakage reactance and winding resistance. One can thus talk of a voltage error, which is the amount by which the voltage is less than the applied primary voltage, and the phase error, which is the phase angle by which the reversed secondary voltage vector is displaced from the primary voltage.

A simple circuit with an opto-isolator. When switch S1 is open, LED D1 is off, so Q1 is off and no current flows through R2, so Vout = Vcc. When switch S1 is closed, LED D1 lights. Phototransistor Q1 is now triggered, so current flows through R2 Vout is then pulled down to low state. This circuit, thus, acts as a NOT gate.

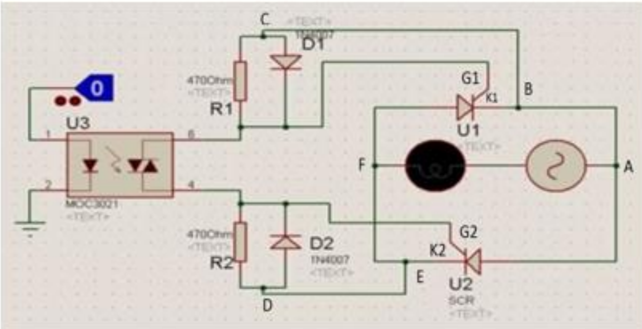

Figure 5: Firing Circuit

Let us consider a cycle of the given AC source, when point “A” is at higher potential than “F”. So the current starts from point “A” and then reaches a junction at B. It will not go to “K1” since it is a cathode and will go to point “C” instead. Now the current would choose a low resistance path through a forward biased diode “D1” and would enter the “Pin 6” of the opto-coupler IC.Now the current would pass through the inbuilt Triac only if the LED inside the IC is forward biased by the micro-controller. Let us assume that the “Pin1” of the IC receives a positive potential from the micro-controller, which forward biases the LED so the Triac starts conducting and current reaches “Pin 4” of the IC from where it goes to Gate “G1” instead of passing through high resistive path of Resistor “R2” or Diode “D2”. Current flows from the gate “G2” to cathode “K2” of SCR “U2” and then completes the circuit through the load and back to the supply.

Once the current flows from the Gate-Cathode junction of the SCR it starts conducting. From the next cycle the current takes the path: A – U2 – F – Load – Supply. It keeps on tracing this path till the internal LED of the IC is forward biased. Once the LED is switched off, the current ceases to flow through the IC and the SCR regains its Blocking state. The same flow of events occurs for the other SCR too. So just by forward biasing an LED in the IC by the micro-controller, the SCRs are triggered. This happens to be a more responsive circuit than the conventional one involving UJT and pulse transformer.

IV. SYSTEM COMPENSATION

To find line compensation a load test is conducted. The power consumption is calculated to find the exact compensation required, ABCD constants are found, circle diagram of line is drawn.

Load specifications: Resistive load: 3-Phase incandescent lamp bank. Bulb rated as 40, 60, 100, 230 V

TABLE I OBSERVATIONS BEFORE COMPENSATION

Vs	Is	Vr	Ir	3ph load app.
220	0.5	230	0	0
220	-	225	-	120
215	0.8	220	0.6	420
212	1.5	222	1.0	720
208	2.1	210	2.0	1320
200	3.8	192	3.2	1920
185	4.8	180	5.0	2820

Characteristics of Receiving End Voltage Vs. Load Current is drawn which shows that at no load and light load condition the receiving end voltage is greater than sending end voltage up to the 1 amp But as load increases beyond 1 amp receiving end voltage decreases From this graph we can say that, the transmission line generate capacitive reactive power (Var) up to the 1 amp load, with this farrenty effect the receiving end voltage get increased up to the 1 amp load. To maintain voltage at receiving end voltage equal to sending end voltage we have to provide reactive power at each loading condition. The amount of reactive power at each loading condition is easily found with the help of receiving end circle diagram. For drawing circle diagram first we need to calculate ABCD parameter of transmission line.

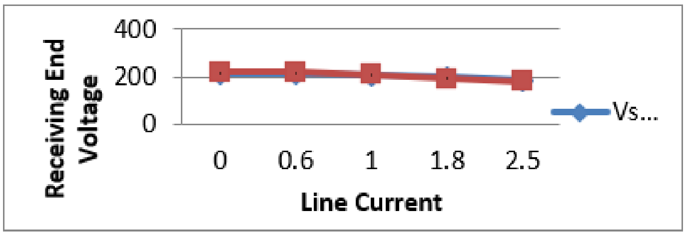

Figure 6: Receiving End Voltage VS Load Current

TABLE III (PIE) MODEL TRANSMISSION LINE PARAMETERS

Particulars	Unit
Input Supply Voltage	3 Phase,400 v, (L-L), 50 Hz,AC.
Current Capacity	8 Amps.
Line Voltage assumed	400 Kv, (L-L)
Surge Impulse Loading (SIL)	400 Mw.
Line Length (Long Line)	300 Km.
Inductance per Phase	24mH, 8Amp, 50 Hz.
Resistance per Phase	0.5Ω, 50 watt, 50Hz.
Capacitor per phase	2.44µf, 630V

After Calculations values of A, B, C, D parameter for 300Km long transmission line are Values for /phase/km are

TABLE IIIII

Parameter	Value
R	1.5Ω
X	j(22.61)Ω
Z	$22.65\angle 86.20\ \Omega$
Y	$4.59\times10^{-3}\angle 90$ ℧
A	$1\angle 0.2081$
B	$22.65\angle 86.20\ \Omega$
C	$4.47\times10^{-3}\angle 90.10$
D	$1\angle 0.2081$

At each loading condition required reactive power is calculated simply multiplying power scale in circle diagram as illustrated in following table.

TABLE IVV REQUIRED VAR FROM CIRCLE DIAGRAM

Per Phase load App.	Required VAr
R	410
L	580
R-L	550

V. SELECTION OF CAPACITOR AND INDUCTOR FOR SINGLE PHASE TCSC CIRCUIT

Reactive power is calculated by circle diagram as shown in above Table. The maximum reactive power was generated in pure inductive load and minimum reactive power was generated in resistive load. Reactive power in single phase (Qmax) = 580 VAR

Calculations to find required capacitor value in single phase line for TCSC circuit

$Q = 2\pi\times f\times C\times V^2\times10^{-6}$

$580 = 2\pi\times50\times C\times10^{-6}$

$C = (\frac{580}{2\pi\times50})\times10^{-6}$

C = 34.91 μFD

Three phase reactive power = 3×(single phase reactive power)= 3× (580)= 1740VAR

Current calculation for required capacitor

$(Q_{3\text{-phase}}) = \sqrt{3}\times V_L\times I_L\times \sin(85.73)$

$1740 = \sqrt{3}\times 400\times I_L\times \sin(85.73)$

$I_L = 2.51$ Amp

VI. SPECIFICATIONS OF CAPACITOR

TABLE V SPECIFICATIONS OF CAPACITOR

Full load current	Rated frequency	Capacitor	Rated KVAR	No of phase
3.6667 Amp	50 Hz	40 μFD	2.0 KVAR	3

Selection of Inductor: The inductor is used in TCR (Thyristor controlled reactor) for varying the total impedance of the line. This inductor is totally controlled by back to back thyristor as shown in schematic diagram. Basically, it varies the capacitive reactive power.

VII. SPECIFICATIONS OF INDUCTOR

TABLE VI SPECIFICATIONS OF INDUCTOR

Rated KVAR	Rated voltage	Rated frequency	No of phase	Type	Connection
2.41 KVAR	400 volts	50 Hz	3	Gapped core	Star

VIII. LOAD COMPENSATION

Star connected R-L star load test is conducted with transmission line in star

Load specifications

Resistive load: 3-Phase incandescent lamp bank. Bulb rated as 40, 60, 100, 230 V

Inductive Load: L/phase/element = 0.91H, I= 0.8Amps, Z= 285 Ω,

TABLE VII OBSERVATIONS BEFORE COMPENSATION

Ir(A)			Power Transferred Pr (W)		
1.6	1.6	1.61	540	725	662
2.14	2.15	2.15	948	1005	972.7
2.5	2.5	2.5	952	1255	1125

TABLE VIII CONSUMED POWER OF STAR CONNECTED R-L LOAD

Vs(V)			Is (A)			Vr boost (V)		
222	224	229	1.78	1.70	1.80	232	265	242
224	225	229	2.28	2.26	2.20	256	270	259
224	226	230	2.96	2.89	2.60	250	290	260

TABLE IX CONSUMED POWER OF STAR CONNECTED R-L LOAD

Vs(V)			Is(A)			Vr(V)		
222	224	229	1.78	1.70	1.80	240	238	239
224	225	229	2.28	2.26	2.20	245	290	237
224	226	230	2.96	2.89	2.60	230	290	240

TABLE X COMPENSATION RESULT OF STAR CONNECTED R-L LOAD

Ir (A)			Power Transferred(W)			α
1.67	1.75	1.74	694	721	720	55
2.3	2.15	2.4	976	1079	985	38
2.56	2.57	2.74	1019	1290	1138	23

Thyristor-Controlled Series Capacitor is one of the fastacting power electronic controllers which can provide current and power flow control in the transmission line by varying its firing angle. Thus, TCSC can be used as a series capacitor to reduce the overall transmission line reactance. Depending on the enhancement of power transfer desired at the time, without affecting other system-performance criteria, series compensation can be varied by TCSC. Thus TCSC is one of the important FACTS controller, which increases the overall power transfer capacity in the transmission line. The difference between the implemented TCSC model in Matlab-Simulink and Prototype is less than 4 %, moreover, increasing the order of load gives more accurate results, and the disturbance introduced by load resistance can be overcome within 1sec. The control circuit has been designed on the assumption that the three phase load at the receiving end is balanced. However, by taking voltage feedback from each phase, independent control of reactive power in each phase is achieved. The results shows that there is improvement in the both synchronous and voltage stability margins, when TCSC is connected in the test system. Series capacitive compensation is thus used to reduce the series reactive impedance to minimize receiving end voltage variation and the possibility of voltage collapse and it can improve power flow capability of the line. It is also observed that the compensation by using this technique i.e. TCSC is more effective than other compensating techniques such as mechanical switching capacitors and synchronous condensers.

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