Implementing FC–TCR in Kalpakam – Khammam Line for Voltage Regulation

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Abstract: ***Voltage stability is an ability of a system to provide constant voltage for a wide range of load variations. This paper presents an application of fixed capacitor-thyristor controlled reactor (FC-TCR) in regulating the voltage of a real system. The system under study is an interconnected network located in Andhra Pradesh, India. Main aim of the study is to provide a constant voltage to the system under different loading conditions. The simulations are performed in MATLAB/SIMULINK platform.***

Keywords: Power System, Voltage Regulation, FACTS device, Fixed Capacitor, Thyristor Controlled Reactor (TCR)

1. Introduction

Power system is always in a delicate condition whenever load changes there will be a disturbance in voltage profile. Many of the appliances in our system are designed for a particular range of voltage i.e. in a range of + 5% of the system voltage so any violation of permissible voltage level is not acceptable. Voltage regulation is an important aspect of power system and can be defined as the ability of a system to provide constant voltage for a wide range of load variations.

Recent improvements in transmission system with power electronic devices have resulted in new technology called as FACTS devices. FACTS are a family of devices which can be inserted into power grids in series, in shunt, and in some cases, both in shunt and series. Important applications in power transmission and distribution involve devices such as SVC (Static Var Compensators), Thyristor-Controlled Series Capacitors (TCSC), STATCOM, SSSC and UPFC and so on [1 - 4].

This paper uses a compensator which is one among the classification of SVC - FC-TCR, for voltage regulation. It provides system improvements and benefits system by controlling shunt reactive power sources in both capacitive and inductive modes with state-of-the-art power electronic switching devices.

The operation of FC-TCR device and its control methodology are discussed in section II and III respectively. Section IV describes about the Kalpakam and Khammam transmission system and its data. The modeled system is tested for various loading conditions and results are analyzed with waveforms in section V.

2. Operation of FC-TCR

A basic VAR generator arrangement using a fixed (permanently connected) capacitor with a thyristor-controlled reactor (FC-TCR) is shown in Figure 1.

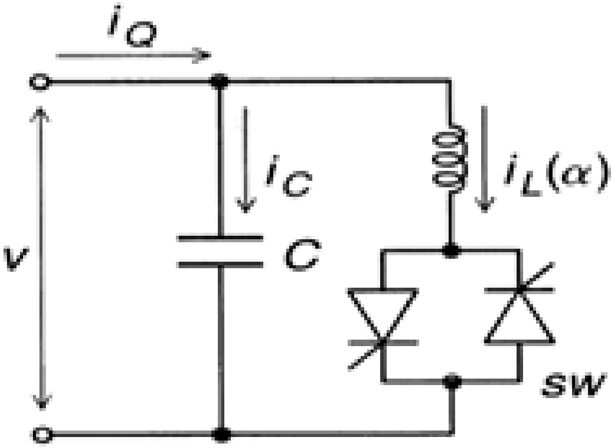

Figure 1: Basic circuit of FC-TCR

FC-TCR is a combination of Fixed Capacitor (FC) and Thyristor Controlled Reactor (TCR). Fixed Capacitor has a constant reactive power (QC) this reactive power is fixed and depends on the capacitor used. The TCR circuit consists of two thyristors connected in anti parallel.

The relationship between firing angle α and current in reactor is given by [2],

$$I_1(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha\right) \quad (1)$$

By varying firing angle α, current in reactor and reactive power (QL) can be varied. The constant capacitive VAR generation (QC) of the fixed capacitor is opposed by the variable VAR absorption (QL) of the thyristor controlled reactor, to yield the total VAR output (Q) required. At the maximum capacitive VAR output, the thyristor-controlled reactor is off .To decrease the capacitive output, the current in the reactor is increased by decreasing firing angle α. At zero VAR output, the capacitive and inductive currents become equal and thus the capacitive and inductive VARs cancel out. With a further decrease of angle α the inductive current becomes larger than the capacitive current, resulting in a net inductive VAR output.

So by using FC-TCR and with calculated values of capacitance and inductance, FC-TCR can inject inductive (lagging) or capacitive (leading) reactive power to the system.

3. Control Logic

The control circuit is the most important part of any FACTS device. The control of the thyristor-controlled reactor in the FC-TCR type VAR generator needs to provide four basic functions as shown in Fig. 2 [2].

The first function of synchronous timing is usually to check whether the pulses given to thyristors are in synchronous to the given reference signal or not.

The second function is the reactive current to firing angle conversion. This can be provided by a real time circuit implementation of the mathematical relationship between the amplitude of the fundamental TCR current ITCR and the delay angle α given by above (1). Several control circuit approaches are possible for this design.

The third function is the computation of the required fundamental reactor current Ifl, from the requested total output current Iq (sum of the fixed capacitor and the TCR currents) defined by the amplitude reference input Iqref to the VAR generator control. This is simply done by subtracting the (scaled) amplitude of the capacitor current IC from Iqref.

The fourth function is the thyristor firing pulse generation. This is accomplished by the firing pulse generator (or gate drive) circuit which produces the necessary gate current pulse for the thyristors to turn on in response to the output signal provided by the reactive current to firing angle converter.

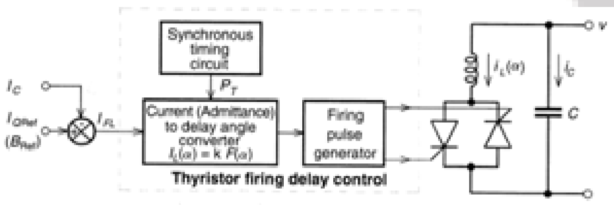

Figure 2: Line diagram of the control logic (adopted from [2])

4. Test System

The system used for the study is a 400 kV, 364 km single line system National Thermal power corporation (NTPC) Kalpakam - Khammam transmission line. The NTPC - Kalpakam generates 1000 MW of power which is transmitted to different parts of Andhra Pradesh.

The net 1000 MW power is transmitted to three load centers viz., Khammam, Rajahmundry and dairy farm of 400 MW, 400 MW and 200 MW respectively. The system is designed in MATLAB/SIMULINK for connecting (1) a resistive load of 400 MW between 0 - 0.2 sec and (2) a resistive and capacitive load of 400 MW at 0.8 power factor leading i.e., 300 MVAR between 0.2 - 0.4 sec. There is a sudden increase in voltage at the receiving end due to inclusion of resistive capacitive load at 0.2 sec which violates the voltage limits.

This paper mainly focuses on the power transmission line between Kalpakam to Khammam and modeled the system using MATLAB software. Data required for developing the SIMULINK model are collected from APTRANSCO and given in table 1.

Table 1: Kalpakam and Khammam line technical data

Technical Data (Kalpakam and Khammam Line)	
Distance	364 km
System Voltage	400 kV
Line Resistance [R1 R0]	[0.0308 0.2118] Ω/km
Line Inductance[L1 L0]	[0.9337e-3 4.1264e-3] H/km
Line Capacitance [C1 C0]	[6.032e-9 3.67e-9] F/km
Power transfer	400 MW

Table 2: TCSC device technical data

Technical Data (TCSC device)	
Compensation degree	30 % (FSC) 20%-20% (TCSC)
FC	9.9373e-5 F
TCSC	1.4906e-4 F 0.01179 H

5. Results and Discussions

As stated above the simulation has been done in MATLAB/SIMULINK software and base model is as shown in Fig. 3. In simulink model, 3 phase programmable voltage source is used as power plant at Kalpakam. The transmission line parameters are collected from APTRANSCO (Kalpakam) and loads are connected at the end Khammam. For the study two cases are considered; a) Resistive load of 400 MW from 0.0 - 0.2 sec and b) Capacitive load of 400 MW at 0.8 pf leading i.e. 300 MVAR from 0.2 - 0.4 sec.

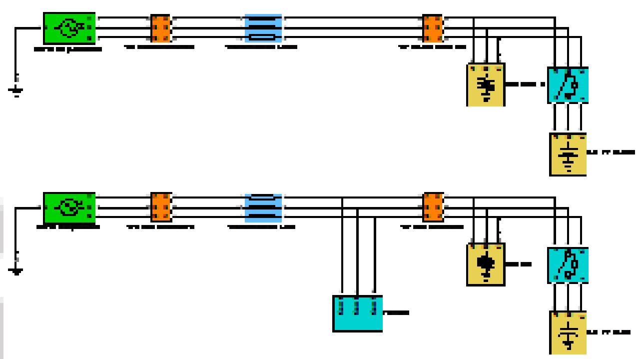

Figure 3: Base model of Kalpakam – Khammam test system

Two studies are conducted on the designed Kalpakam and Khammam system (a) without any compensation and (b) with FC-TCR compensation device for maintaining the receiving end voltage within permissible limits (+ 5%).

(a) Without any compensation

Kalpakam and Khammam transmission system is tested without any compensation device and the results and waveforms are observed. Fig. 4 & 5 shows the sending end and receiving end voltages of the system and Table 1 shows the RMS value of the both the voltages. During capacitive loading condition i.e., from 0.2 sec to 0.4 sec.

the receiving end voltage (Vr) exceeds the permissible limit 242 kV. The Vr = 273.8 kV which will damage the substation equipments and consumers loads at distribution side. Hence implementing compensation device to control the system voltage is essential.

(b) With FC-TCR

By implementing FC-TCR in Kalpakam and Khammam transmission line, the system the simulated and results and waveforms are analyzed. Fig. 5 shows the comparison of receiving end voltages of without compensation and with FC-TCR.

Table 1 shows the RMS values of receiving end voltages of both tests. During capacitive loading condition i.e., from 0.2 sec to 0.4 sec., the receiving end voltage is controlled within the permissible limit 242 kV.

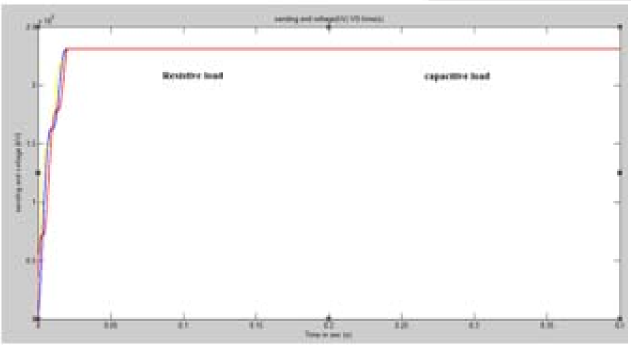

Figure 4: Sending end voltage vs. time

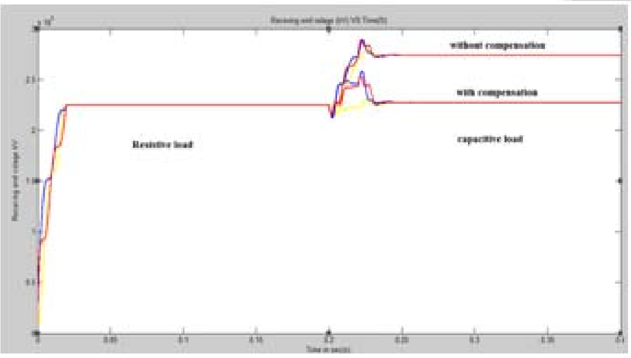

Figure 5: Receiving end voltage vs. Time

Table 2: System voltage without and with FC-TCR compensation

Type of load	*Sending end voltage*	*Receiving end voltage*	
		Without Compensation	*With FC - TCR*
Resistive load (0 - 0.2 sec)	0.9 kV (R.M.S)	5 kV (R.M.S)	5 kV (R.M.S)
Capacitive load (0.2 - 0.4 sec)	0.9 kV (R.M.S)	3.8 kV (R.M.S)	7.1 kV (R.M.S)

FC-TCR uses the thyristors to tune the reactive current thereby controlling the system voltage. Because of tuning, injecting reactive current may have harmonics and its magnitude vary as firing angle of the thyristor is varied. Hence FC-TCR may inject harmonics in to the system. The study also observed the total harmonic distortion (THD) of voltage and line current. Fig. 6 shows the THD of Kalpakam-Khammam transmission system with FC-TCR. The observed THD after 0.2 sec is observed only 0.19 % which is within the IEEE specification limit.

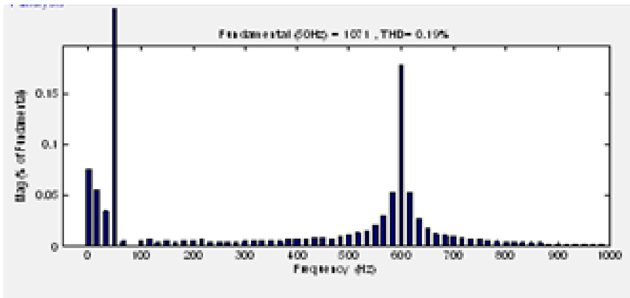

Figure 6: Total harmonic distortion during compensation

6. Conclusion

This paper models the 400 kV 364 km Kalpakam-Khammam transmission system with Kalpakam as Source end and Khammam as Load end in MATLAB/SIMULINK. Developed model is studied for without and with FC-TCR compensation for maintaining the receiving end voltage (Vr) at + 5% of sending end voltage. Both resistive and capacitive loads are connected and respective sending end and receiving end voltages are observed. Without any compensation, the receiving end voltage during capacitive loading is increased abruptly and violated the limits. By installing FC-TCR in shunt, receiving end voltage comes down to within the limits. Also it is observed using FC-TCR, the total harmonic distortion (THD) is well below the limits.

7. Future Opportunities

It can be used in the Integration of Renewable Energy sources with the Grid with optimized Economics and Efficiency.

8. Acknowledgment

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References

[1] N. G. Hingorani and L. Gyugyi, "Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems", IEEE Press,
[2] R. M. Mathur and R.K. Varma, "Thyristor based FACTS controllers for Electrical transmission systems", John Wiley & Sons Inc
[3] Montano, J.C.; Castilla, M.; Lopez, A. "Power-quality improvement in reactive power control using FC-TCR circuits", IECON 02, Vol. 2, pg. 880 – 885
[4] T. Vijayakumar, A. Nirmalkumar and N.S. Sakthivelmurugan, "Implementation of FC-TCR Using Low Cost 89c 2051 Controller", Research Journal of Applied Sciences, Engineering and Technology, 2009 pg. 40-43

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