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Enhanced Utilization of the Transmission Line by using FC–TCR based SVC System

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Abstract: For the steady operation of the electrical power system control over reactive power flow is of great importance, as its correct handling not only maintain the system voltages constant but can also increase the stability margin for the existing transmission system. An application of the Fixed Capacitor–Thyristor Controlled Reactor (FC–TCR) type Static VAR Compensator (SVC) for increased power handling capacity and improved voltage regulation is presented in this paper. The system under consideration is an interconnected 220KV transmission network in Sindh, Pakistan. Key objective of the study is to enhance the utilization capacity of the installed transmission system by allowing the increased active and reactive power flows over the same line and to improve the system voltages under various loading conditions. Simulation work is carried out in MATLAB/SIMULINK environment.

Keywords: Reactive power; Voltage regulation; Transmission system, SVC, FC–TCR.

1. INTRODUCTION

The advantages offered by the electrical energy like easily controllable, greater flexibility to transport at the far distances and free from pollution not only make this form of energy superior to other forms but also give a high pace to its demand. This increased demand can be meet either by erecting new power generating stations and transmission lines or by increasing the utilization capacity of the installed system. The major economic concerns with the former option leave the latter option suitable, but various technical limits in transmission system also make its implementation difficult. Various technical hindrances which limit the utilization of the existing transmission system at full extent are;

- Surge Impedance Loading (SIL) limits
- Voltage stability limits
- Thermal limits

At present electrical power system deal these issues with various electro–mechanical devices which are alleged with the drawbacks of slow response, more losses, higher cost, larger size and need of large space to place these devices. Few of these devices are;

- Shunt reactors
- Shunt capacitors
- Series capacitors
- Synchronous condensers
- Automatic Generation Control System
- Auto–transformer
- Phase shift transformer

2. FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEM (FACTS)

New emerging technologies open the door to deal with the aforesaid issues within economic and technical limits. One of these technologies includes FACTS. According to IEEE definition, FACTS is defined as "Alternating current transmission system incorporating the power electronic converter based and other static controllers to enhance controllability and increase the power transfer capability (Hingorani and Gyugyi, 1999)."

From the last 2–3 decades this power electronic converters based technology attains the great attention in the electrical market. Implementation of the FACTS devices not only enrich the power system utilities through increased power handling capacity with the same installed equipment but also provide the benefit of reduced per unit cost to the customers of that utility. Two key benefits offered by the FACTS technology include the improved power handling capacity of the present installed system and direct the power flows to the designated routes of the transmission lines.

FACTS controllers are classified as;

- Series FACTS controllers
- Shunt FACTS controllers
- Series – Shunt FACTS controllers
- Series – Series FACTS controllers

These devices are either act as variable impedance or as voltage and current source converters (Hingorani and Gyugyi, 1999). In both cases, their basic function is to control the transmission parameters; voltage (*V*), reactance (*X*) and rotor angle (*δ*) which in turn controls the active and reactive power flows of line. These quantities are related as;

$$P = \frac{V_s V_r}{X} Sin\delta \tag{1}$$

$$Q_r = V_r \frac{V_s Cos\delta - V_r}{X_s} \tag{2}$$

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Eqs.(1) and (2) clearly show that system voltages have direct impact active and reactive flows; hence require proper handling for different loading conditions.

3. FIXED CAPACITOR – THYRISTOR CONTROLLED REACTOR (FC–TCR): CONSTRUCTION AND OPERATION

Among all the FACTS devices Static VAR Compensator (SVC) is the most implemented FACTS device because of its better performance at lowest cost. It is a shunt connected device which offers variable impedance at the point of connection. Static var compensator systems are categorized in a variety of devices, which are (Hussain, 1994);

- Thyristor controlled reactor (TCR)
- Thyristor switched capacitor (TSC)
- Fixed capacitor–Thyristor controlled reactor (FC–TCR)
- Thyristor switched capacitor–Thyristor controlled reactor (TSC–TCR)

Basic single phase arrangement of FC–TCR is shown in **(Fig. 1)**. It comprises of a fixed capacitor or a capacitor bank which provides constant leading reactive power in the system. On the other hand a reactor is provided in parallel with the capacitor, which is connected in series with anti–parallel connected thyristors. By varying the thyristors firing angle (α) impedance and hence reactive power absorption of the reactor can be varied from zero to the maximum value. The current flow through TCR is the function of firing angle (α) and can be calculated by using the relation;

$$I_L(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}Sin2\alpha\right) \qquad (3)$$

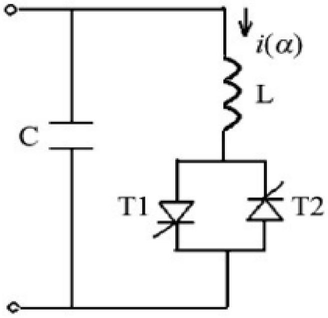

Fig 1: Basic arrangement of FC–TCR

Reactors rating must be greater than the capacitor rating by the times equal to the capacitive leading vars that have to be absorbed from the system under no load condition (Acha, 2002). At zero firing angle maximum current will flow through the reactor and maximum reactive vars can be absorbed from the system. By increasing the firing angle conduction through reactor will decrease and inductive reactive vars of the SVC will decrease. At some firing angle α, both inductive and capacitive vars will be equal and FC–TCR will float on the transmission line (Acha, 2002). **(Fig. 2)** shows VI characteristics of FC-TCR scheme.

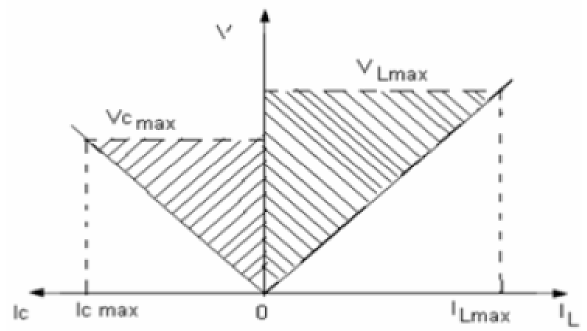

Fig 2: VI characteristics of FC–TCR

By further increasing the firing angle capacitive leading vars will be greater than the inductive lagging vars and can be supplied to the system. Hence, by varying the firing angle (α) of the TCR, in the range of 0° to 90°, overall susceptance of the FC–TCR can be varied.

System Modeling:

In this research work 220kV, 144.4km three phase transmission line from Shikarpur to Guddu is considered for analyzing impacts of FC-TCR. Technical data of the selected transmission line has been collected from (Rehman, 2015) and is given in **(Table-1)**;

Table1: Technical data of Shikarpur to Guddu line

Distance	144.4 km
System voltage	220 kV
Power transfer	330 MVA
Line Resistance	0.06 Ω/km
Line Inductance	0.0012 H/km

Four different conditions, on the transmission line, are modeled in MATLAB simulink environment. First, subject transmission line is modeled with and without any compensator under heavy inductive loading and later on no–loading condition is simulated in MATLAB/Simulink environment.

4. RESULTS AND DISCUSSIONS

Case A: Without compensation (inductive load)

(Fig-3) shows the MATLAB model of subject transmission line without any compensation for inductive load (as around the world 80% of the load is inductive in nature). To observe the effect of inductive load, two loads of 165MVA, operating at 0.8 power factor lagging, are simulated. Operating time of load 1 is set from 0–1 second, whereas load 2 will be put into system after delay of 0.1second, i.e. its operating time is from 0.1 – 1 second. Receiving end voltage, active and reactive power flows are included in **(Table-2)**.

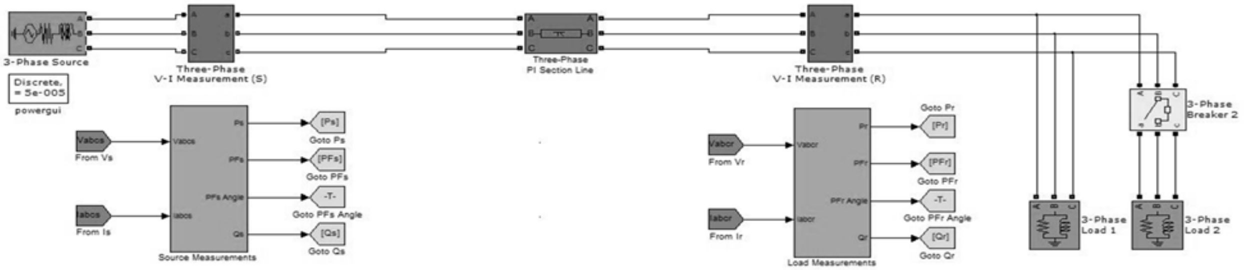

Fig 3: Uncompensated transmission system (for inductive load)

Case B: With FC–TCR compensation (Inductive load)

Model of the subject transmission line with proposed FC–TCR compensation is shown in **(Fig-4)**. Comparative waveforms of active power, reactive power and receiving end voltages, before and after implementing FC–TCR, are shown in **(Fig-5)**. (**Table-2)** shows the values of said electrical quantities before and after implementing FC–TCR. It is being clearly observed that there is significant improvement in the system voltages and power flows after inserting FC – TCR into the existing system. For voltages allowable limit of change is ±5%, but without compensation there is substantial decrease in voltage when load 1 or the combination of both load1 and load2 are in operation.

Table2: Receiving end voltages and power flows (under inductive loading condition) before and after implementing FC–TCR

Electrical Quantities	Without FC–TCR	With FC–TCR
Vr (kV)	**168.3kV**	**213.9kV**
Pr (MW)	**154.4MW**	**249.2MW**
Qr (MVAR)	**115.8MVAR**	**186.4MVAR**

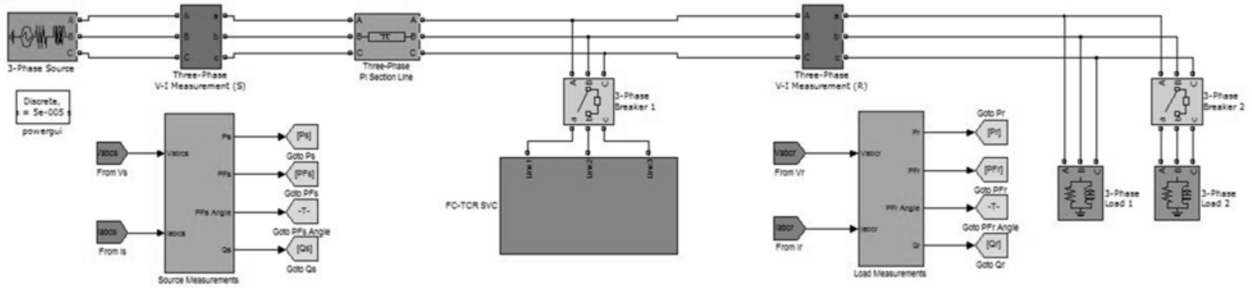

Fig 4: Transmission system with FC – TCR compensation (for inductive load)

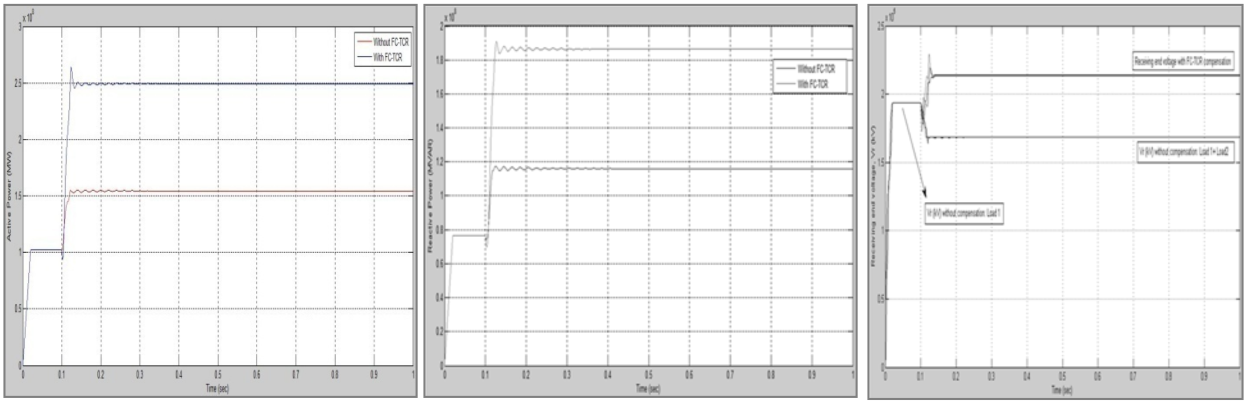

Fig 5: Receiving end active power, reactive power and voltage with and without FC – TCR compensation

Case C: Without compensation (No–load)

(Fig-6) shows the MATLAB model of subject transmission line without any compensation for no–load condition. No load condition may arise practically in case of any fault, such that, entire load may disconnect from the system. Especially in long transmission lines this will give rise to the Ferranti effect i.e. receiving end voltage will increase from the sending end voltage due to capacitive effect of the transmission lines. This condition will be dealt by decreasing the firing angle of thyristors in FC–TCR, allows inductive current to increase, so that overall SVC will act as an inductor and absorb the systems leading vars. Receiving end voltage is measured under no – load condition and is included in **(Table-3)**.

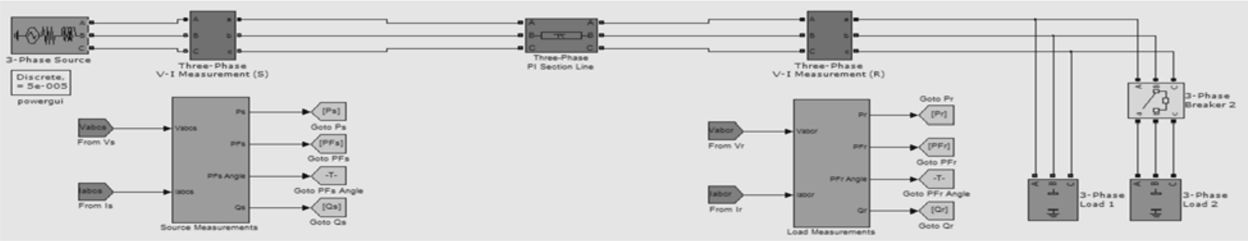

Fig 6: Uncompensated transmission system (for no – load)

Case D: With FC–TCR compensation (No–load)

Model of the subject transmission line under no–load with proposed FC–TCR compensation is shown in **(Fig-7)**. Comparative waveforms for receiving end voltages, before and after implementing FC–TCR, are shown in **(Fig-8)**. Though receiving end voltage without compensation is already within permissible limits of +5%, as case study transmission line is medium length transmission line whose capacitive effect is normally neglected under no –load condition. But again with the help of FC–TCR we can keep the voltage very close to 1p.u. Compensated receiving end voltage is also included in **(Table-3)**.

Table3: Receiving end voltage (under no – load condition) before and after implementing FC–TCR

Electrical Quantities	Without FC–TCR	With FC–TCR
Vr (kV)	224.2kV	219.9kV

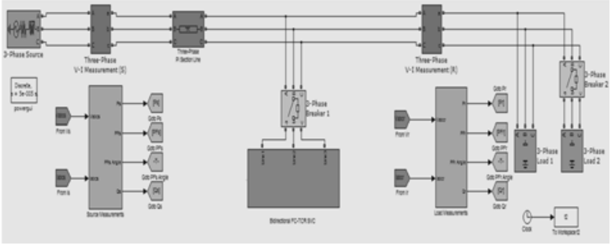

Fig 7: Transmission system with FC – TCR compensation (for no – load)

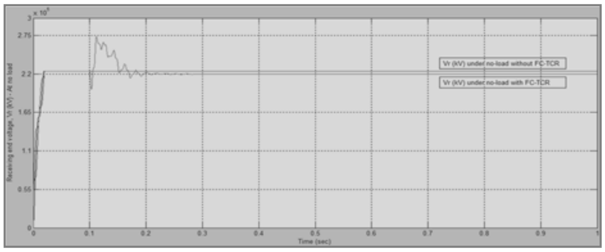

Fig 8: Receiving end voltage (at no–load) with and without FC–TCR

5. CONCLUSION

It is well observed from the simulation results that before and after implementing the FC–TCR there is an ample difference in the performance of the system. By implementing the FC–TCR in the system, active and reactive power flows through the subject transmission line are increased by immense margins. Hence installed transmission line can be utilized to their full extent, i.e. close to the thermal limit, with addition of FC–TCR in the existing system. Also, improved voltage regulation of the subject transmission line is achieved, under both loading and no-loading conditions, with FC–TCR.

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