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Concepts And Application Of Flexible Alternating Current Transmission System (FACTS) In Electric Power Network

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***Abstract:** Our effort in this work is directed towards the tactical and theoretical evaluation of the structural and functional characteristics of Flexible Alternating Current Transmission System (FACTS). The device is technically inspected from the view point of its natural composition with a look from the different components that constitute the system equipment. Several impart of these components are widely examined and discussed, looking at the major operations that solidly accept the equipments into the network for reactive power compensation ,bus voltage improvement, electric power oscillation damping, system power factor improvement to mention but a few. The essential parts of TCR segment such as capacitor, thyristor and reactor are as a matter of fact briefly discussed, considering their basic function in the reactive power switching principle of the Fixed capacitor thyristor controlled reactor composite. In this work, FACTS equipment is categorized into series, shunt, combined series-series and combine shunt – series FACT devices and each of these categories in this work is identified solely on the basis of connection and functional participation in electric power network quality improvement.*

***Keyword:** Facts, Concepts, Application, Power Network.*

I. INTRODUCTION

Flexible alternating current transmission system is a new technological concept that aims at control of power flow and improvement of capacity of power system at large. The idea of establishing power network at appreciable cost gives rise to reduction of excessive impact of line reactance to encourage large flow of line current so as to enhance the capability of the existing system; and enable corresponding quantity of electric power to flow along the network under normal and abnormal situations.

Similarly, such state as explained above can arise through the ability of FACTS controllers to regulate the interrelated system electric quantities that influence the performance of power network, thus, enabling some degree of flexibility in system operation to allow the conveyance of electric power nearer to the system thermal rating. Such quantities as mentioned above may include series and shunt impedance, current, voltage, phase angle and electric power oscillation angles at diverse range of system frequencies below the rated frequency.

FACTS equipment is a collection of controllers which can be employed independently or in connection with other system components to govern the interrelated electrical system characteristics. Under a proper choice of the equipment for system operation, certain constaints of a well designed transmission network can be minimized. Such problems as transient instability, frequent voltage fluctuation, power oscillation, poor power factors etc, that lead to overall system instability are not alien in a power system; and these must be eradicated to ensure adequate system performance. One of the major approach for stabilization of system profile can be obtained by introducing FACTS devices into the power network. Examples are seen in installation of shunt controllers for voltage control at and around the point of connection through injection of reactive current or a combination of active and reactive current for a more effective voltage control and damping of voltage oscillations. This keeps the line voltage within the specified and acceptable range of the system voltage profile.

Obviously, shunt FACTS equipment is very active in keeping the voltage profile within the expected limit at the substation buses. It serves the bus nodes independent of the individual lines that are connected to the bus. Unlike the shunt controllers, the series FACTS equipment counterpart permits installation of the controllers on separate lines that interconnect the system nodes; more especially, when the situation calls for power outage at any one line in the network. This is a great advantage it has over shunt controllers. In addition, series-connected controllers are designed to get rid of system perturbation such as dynamic overloads, short circuit currents among many other problems in the system.

From the above explanation, it can be observed that combination of the two kinds of FACTS devices: series and shunt controllers can provide the best of their independent functions in order to achieve effective power and current flow as well as line voltage control for the stability of the entire network.

Structurally, FACTS components are built of thyristor devices as the basic functional units which in composition of other working electronic components grant effective operation of the controllers for power system advancement. It can be based on thyristor devices with no gate turn-off (i.e. with gate turn-on) or built with only gate turn-off capability as obtained with GTO series.

Functionally, the principal controllers with gate turn-off devices are designed on dc to ac conversion bases with the capability of exchanging active and reactive power on the ac network. In a situation where only the exchange of reactive power is being considered, a small storage facility is provided at the dc section of the device.

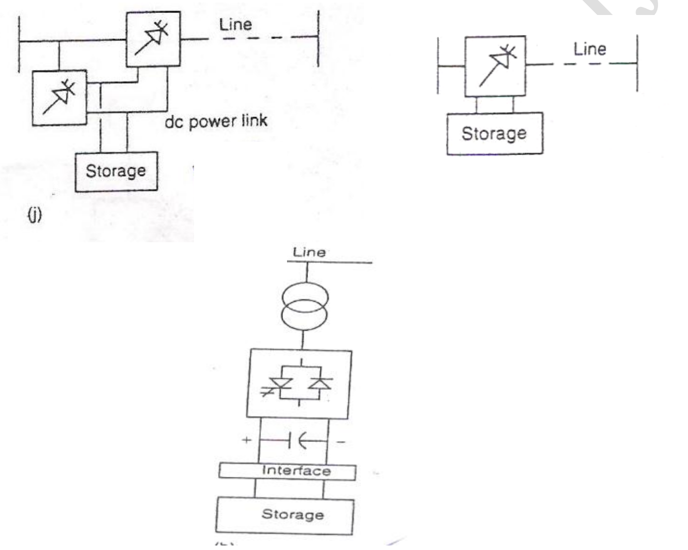

Figure 1: Diagram showing shunt, series and shunt – series FACTS controllers

On the other hand, when ac current and voltage are required to deviate from 90^o with respect to the line current or voltage, the converter dc storage is preferably augmented beyond the minimum network requirement for effective converter operation as the only reactive power source with the aim of covering the system short term storage needs. The storage components include battery, superconducting magnet and other sources of energy. These can be connected in shunt via an electronic interface such as chopper to replenish the dc storage of the converter. There are many advantages when storage facilities are included in power system and these advantages are seen from the control of system dynamics which is obviously required for efficient system operation .This is one of the major benefits with FACTS equipment that have storage devices over a system without storage device. The benefit is seen in dynamic pumping of real power in and out of the system as against transferring of real power within the system as in the case of a system without storage.

At this point, we shall discuss FACTS controllers under various classes in order to give a short explanation for everyone of them. Thus, flexible alternating current transmission system can be categorized into

- ✓ series controllers
- ✓ shunt controllers
- ✓ combined series-series controllers
- ✓ combined series-shunt controllers

SERIES CONTROLLERS

This could be a variable impedance such as capacitor, reactor etc. functionally, every series controller injects series voltage on the line; of course, a variable impedance when multiplied by the current that flows through the line gives expression of injected line series voltage which is subject to variation to suit the system demand as the series impedance is varied.

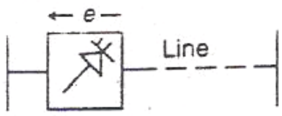

Figure 1.1: Schematic diagram of series FACTS controller

During the system operation, when the voltage is in phase quadrature with the line current, the series controller supplies or consumes variable reactive power only. Every other phase relationship brings about real power generation. Examples of series controllers are as listed below

STATIC SYNCHRONOUS SERIES COMPENSATORS (SSSC)

SSSC is a type of static synchronous generator designed without an external energy source as a system connected series compensator with output voltage which is in quadrature with the line current.

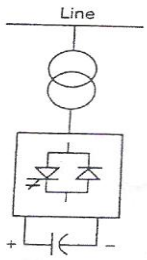

Figure 1.2: Diagram showing Static Synchronous Series controllers Compensators (SSSC)

It can increase or decrease the entire system reactive voltage drop across the line in order to control the transmitted electric power. It may include a transient rated power storage or energy absorbing device to improve the dynamic behavior of the power system. Quite like STATCOM, SSSC can be a voltage-source converter or a current-sourced converter. It injects series voltage to the system which is always small compared to the line voltage.

THYRISTOR CONTROLLED SERIES CAPACITOR (TCSC)

This controller works with the thyristors with no gate turn-off capability. Practically speaking, a variable reactor such as in TCR can be connected across a series capacitor that at 180^{o} firing angle, the reactor becomes non-conductive and the series capacitor maintains its normal capacitive impedance which increases when the firing angle is less than 180^{o}. At

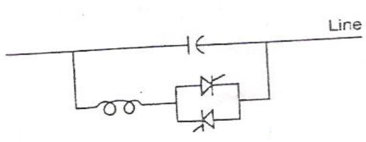

Figure 1.3: Schematic diagram of thyristor Controlled Series Capacitor (TCSC)

90^{o}, TCR becomes fully conductive while the total impedance becomes inductive. At this point, the TCSC can be very instrumental in limiting fault current. It could be a large single unit controller or a combination of many equal or diverse sizes of small capacitors designed to achieve an appreciable system performance.

THYRISTOR CONTROLLED SERIES REACTOR (TCSR)

TCSR is a compensator with a connected series reactor that is shunted by a thyristor controlled reactor in an attempt to establish a smoothly variable series inductive reactance.

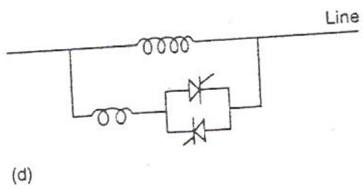

Figure 1.5: Schematic diagram of thyristor Controlled Series Reactor (TCSR)

At 180^{o} thyristor firing angle, the TCSR stops conducting and the uncontrolled reactor works as a fault current limiter. When the angle drops below 180^{o}, the system net inductance decreases until the angle falls down to 90^{o} when the net inductance becomes a parallel combination of the two reactors. TCSR may be a large single unit or a large member of many smaller series units that are connected in a power system.

SHUNT CONTROLLERS

Just as obtained with the series controller's counterpart, these controllers can also be varied while connected in parallel on the system. It could be parallel impedance such as capacitor, reactor, variable source or their combination that are connected in the network to effect system current injection. The connected shunt device in the system inputs a variable current at the point of connection and around the point of installation.

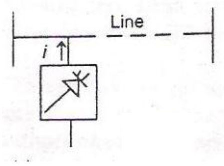

Figure 1.4: Schematic diagram of shunt FACTS controller

As long as the injected current is in phase quadrature with the line voltage, the shunt controllers only supply or consume variable system reactive power. Any other phase relationship relates the system real power generation. Examples of shunt controllers are shown below

STATIC VAR COMPENSATOR

SVC generally includes thyristor controlled reactor, thyristor switched reactor, thyristor switched capacitor or a combination of them such as fixed capacitor thyristor controlled reactor, FC-TCR. See the diagram below.

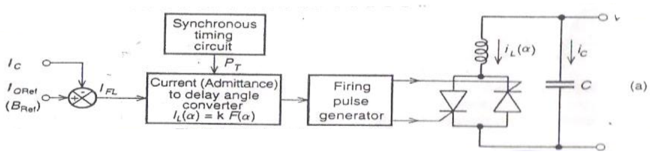

Figure 1.6: A schematic diagram of an FC-TCR and the control circuit

Static Var Compensator is based on thyristors without the gate turn-off capability,and It involves separate devices for leading and lagging vars; thyristor controlled/ switched reactors for absorbing reactive power ;and thyristor switched capacitor for generating the system reactive power. Among SVC members are the following:

- ✓ *Thyristor Controlled Reactor (TCR)*
- ✓ *Thyristor Switched Reactor (TSR)*
- ✓ *Thyristor Switched Capacitor (TSC)*

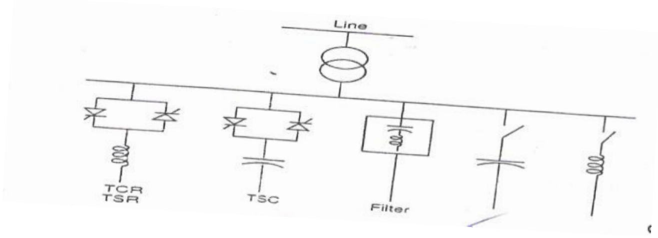

Figure 1.7: Diagram showing TSR,TCR ,Capacitor and reactor connected in shunt

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II. FIXED CAPACITOR, THYRISTOR CONTROLLED REACTOR

From the name, fixed capacitor thyristor controlled reactor, we can see that there are three basic components that come into focus in forming the single compensator device. Functionally, the three system components combined to perform their respective fundamental operation so as to achieve an integrated result that is required from FC – TCR as a shunt controller composite in the work of shunt reactive power compensation in electric power system.

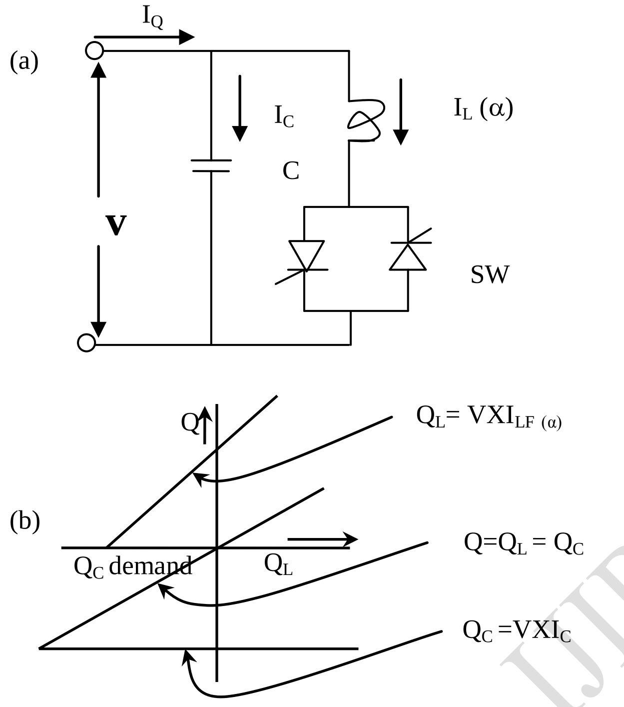

Figure 1.7: Diagrams illustrating the functional circuit and graph of a FC-TCR device

As already stated, the fixed capacitor, thyristor – controlled reactor can be functionally considered to comprise of variable reactor and a fixed capacitor that can operate in a system. The device operation in electric power system can yield an overall Var demand versus Var output characteristics as shown See diagram (b) above. The constant reactive power, Qc (capacitive) generated by the fixed capacitor is operationally opposed to the variable reactive power, Q_L (inductive) that is absorbed by the thyristor controlled reactor in order to supply the net reactive power output (Q) that is required in electric power system. When the capacitive reactive power from the fixed capacitor is at maximum, the thyristor controlled reactor is switched off at the angle at which the thyristor is fired which is 90^0. In order to reduce the capacitive reactive power output from the fixed capacitor, the current flowing through the reactor must be increased by reducing the firing angle, α. As the reactive power output is zero, the capacitive and inductive current becomes equal, leading to cancellation of both inductive and capacitive reactive power. If the firing angle is decreased more, let's say that the rating of the reactor is more than the rating of the fixed capacitor, and in effect, it will cause a net reactive power output. When the firing angle is reduced to zero, the TCR branch conducts current over the full 180^o interval to cause maximum inductive reactive power output that is equal to the difference between the var that is produced by the fixed capacitor and the ones absorbed by the reactor when it is conducting in full.

THYRISTOR CONTROLLED REACTOR (TCR)

TCR is a member of static Var compensators whose conduction time and current with a parallel connected inductor is controlled by a thyristor which functions as a switch in application of a firing pulse. In summary, thyristor controlled reactor is a shunt-connected, thyristor-controlled inductor whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristor valve.

THYRISTOR SWITCHED REACTOR (TSR)

This is a subset of SVC which is made up of many connected reactors. It can be switched in and out using thyristor as a switching component with no firing angle controls to attain the required step changes in reactive power consumed from the system.

THYRISTOR SWITCHED CAPACITOR (TSC)

TSC is a subset unit of SVC device with a bidirectionally connected thyristors that function as switches in company of a shunt capacitor. The thyristor switches are employed to switch in and out the shunt capacitor units, without firing angle control so as to accomplish step change in the reactive power it supplies to power network.

COMBINED SHUNT- SERIES CONTROLLER

Among the combined shunt-series controllers is a unified power flow controllers which is a combination of static synchronous compensator and static series compensator coupled through a dc link to necessitate two way flow of real power between the series output terminals of the composed SSSC and shunt output terminal of the combined STATCOM. The control is aimed at accomplishment of concurrent real and reactive series line compensation without external electric energy source. Adopting angular unconstrained series voltage injection, UPFC can concurrently or selectively control the transmission line voltage, line impedance, phase angle or alternatively the real and reactive power flow on the line.

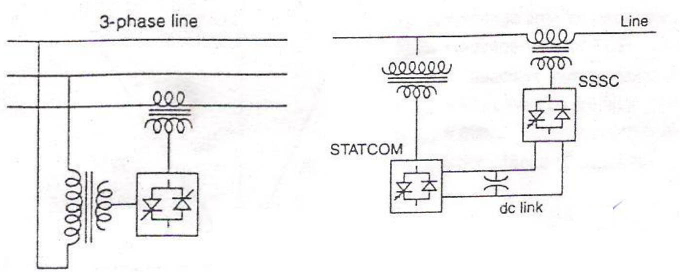

Figure 1.8: Diagrams showing Combined Shunt- Series Controller

The UPFC combines STATCOM and SSSC. The active power for the series component, SSSC is obtained from the line through the shunt unit STATCOM. The later is used for voltage control of its reactive power. The entire composite of the two combined devices, STATCOM and SSSC is used for controlling active and reactive power through the line as well as line voltage control.

A storage facility such as superconducting magnet that is connected to the dc link through an electronic interface can provide a means of further enhancement on effectiveness of the UPFC.

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