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FACTS (Flexible AC transmission system) by using TSR (Thyristor Switch Reactance)

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ABSTRACT: The circuit is designed to implement FACTS by TSR (Thyristor Switch Reactance). This method is used either when charging the transmission line or when there is very low load at the receiving end. Due to very low or no load, very low current flows through the transmission line and shunt capacitance in the transmission line becomes dominant. This causes voltage amplification (Ferranti Effect) due to which receiving end voltage may become double than the sending ends voltage (generally in case of very long transmission lines). To compensate this, shunt inductors are automatically connected across the transmission line. In this proposed system the lead time between the zero voltage pulse and zero current pulse duly generated by suitable operational amplifier are fed to two interrupt pins of the microcontroller, where the program takes over to bring the shunt reactors to the circuit to get the voltage duly compensated. Back to back SCRs duly interfaced through optical isolation from the programmed microcontroller are used in series for switching the reactor (in our case a choke is used). The microcontroller used in the circuit is of 8051 family.
Further the circuit can be enhanced by using firing angle control methodology for smooth control of the voltage. Thus, this is better than switching reactors in steps where voltage control (also in steps) is not very precise.

KEYWORDS: Flexible AC Transmission System (FACTS), FACTS Controllers, Power Transmission, Power Flow Control, Power Electronics, Modern Power Systems, Electricity Markets.

I. INTRODUCTION

The electricity supply industry is undergoing a profound transformation worldwide. Market forces, scarcer natural resources, and an ever-increasing demand for electricity are some of the drivers responsible for such unprecedented change. Against this background of rapid evolution, the expansion programs of many utilities are being thwarted by a variety of well-founded, environment, land-use, and regulatory pressures that prevent the licensing and building of new transmission lines and electricity generating plants.
The ability of the transmission system to transmit power becomes impaired by one or more of the following steady state and dynamic limitations: (a) angular stability, (b) voltage magnitude, (c) thermal limits, (d) transient stability, and (e) dynamic stability. These limits define the maximum electrical power to be transmitted without causing damage to transmission lines and electrical devices. In principle, limitations on power transfer can always be relieved by the addition of new transmission lines and generation facilities. Alternatively, flexible alternating current transmission system (FACTS) controllers can enable the same objectives to be met with no major alterations to power system layout. FACTS are alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability. The FACTS concept is based on the substantial incorporation of power electronic devices and methods into the high-voltage side of the network, to make it electronically controllable. FACTS controllers aim at increasing the control of power flows in the high-voltage side of the network during both steady state and transient conditions. The concept of FACTS as a total network control philosophy was introduced in 1988 by Dr. N. Hingorani [1]. Owing to many economical and technical benefits it promised, FACTS received the support of electrical equipment manufacturers, utilities, and research organizations around the world. This interest has led to significant technological developments of FACTS controllers [1]-[6]. Several

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kinds of FACTS controllers have been commissioned in various parts of the world. The most popular are: load tap changers, phase-angle regulators, static VAR compensators, thyristor controlled series compensators, interphase power controllers, static compensators, and unified power flow controllers. In this paper, the state of the art in the development of FACTS controllers is presented. The paper presents the objectives, the types, and the benefits of FACTS controllers. Moreover, various FACTS controllers are described, their control attributes are presented, and their role in power system operation is analyzed.

II. OBJECTIVES OF FACTS CONTROLLERS

The main objectives of FACTS controllers are the following:
1. Regulation of power flows in prescribed transmission routes as per controlled conditions.
2. Secure loading of transmission lines nearer to their thermal limits.
3. Prevention of cascading outages by contributing to emergency control.
4. Damping of oscillations that can threaten security or limit the usable line capacity.

The implementation of the above objectives requires the development of high power compensators and controllers. The technology needed for this is high power electronics with real time operating control. The realization of such an overall system optimization control can be considered as an additional objective of FACTS controllers [7].

III. TYPES OF FACTS CONTROLLERS

Series controllers: The series controller could be variable impedance, such as capacitor, reactor, or a power electronics based variable source of main frequency, sub-synchronous and harmonic frequencies (or a combination) to serve the desired load. In principle, all series controllers inject voltage in series with the line. As long as the voltage is in phase quadrature with the line current, the series controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well. Series controllers include SSSC, IPFC, TCSC, TSSC, TCSR, and TSSR.

Shunt controllers. As is the case of series controllers, the shunt controllers may be variable impedance, variable source, or a combination of these. In principle, all shunt controllers inject current into the system at the point of connection. Even variable shunt impedance connected to the 400 Applied Electromagnetic Engineering line voltages causes a variable current flow and hence represents injection of current into the line. As long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes reactive power. Any other phase relationship will involve handling of real power as well. Shunt controllers include STATCOM, TCR, TSR, TSC, and TCBR.

Combined series-series controllers: This is a combination of separate series controllers, which are controlled in a coordinated manner, in a multiline transmission system. Or it could be a unified controller in which series controllers provide independent series reactive compensation for each line but also transfer real power among the lines via the proper link. The real power transfer capability of the unified series-series controller, referred to as IPFC, makes it possible to balance both real and reactive power flow in the lines and thereby maximize the utilization of the transmission system. The term “unified” here means that the dc terminals of all controller converters are all connected together for real power transfer.

Combined series-shunt controllers: This is a combination of separate shunt and series controllers, which are controlled in a coordinated manner, or a UPFC with series and shunt elements. In principle, combined shunt and series controllers inject current into the system with the shunt part of the controller and voltage in series in the line with the series part of the controller. However, when the shunt and series controllers are unified, there can be a real power exchange between the series and shunt controllers via the proper link. Combined series-shunt controllers include UPFC, TCPST, and TCPAR.

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IV. FACTS CONTROLLERS

STATCOM: STATCOM is a static synchronous generator operated as a shunt-connected static VAR compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage. The use of STATCOM as a FACTS controller is proposed in [8], [9] SVC. SVC is a shunt-connected static VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage). SVC is an important FACTS controller already widely in operation. Ratings range from 60 to 600 MVAR [10]. SVC can be considered as a "first generation" FACTS controller and uses thyristor controllers. It is a shunt reactive compensation controller [11]-[13] consisting of a combination of fixed capacitor or thyristor-switched capacitor in conjunction with thyristor-controlled reactor.

TCR: TCR is a shunt-connected thyristor-controlled inductor whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristor valve. TCR has been used as one of the economical alternatives of FACTS controllers [14].

TSC: TSC is a shunt-connected thyristor-switched capacitor whose effective reactance is varied in a stepwise manner by full- or zero-conduction operation of the thyristor valve [4], [15].

TSR: TSR is a shunt-connected thyristor-switched inductor whose effective reactance is varied in a stepwise manner by full- or zero-conduction operation of the thyristor valve [4], [15].

TCBR: TCBR is a shunt-connected thyristor-switched resistor, which is controlled to aid stabilization of a power system or to minimize power acceleration of a generating unit during a disturbance [4], [16].

SSSC: SSSC is a static synchronous generator operated without an external electric energy source as a series compensator whose output voltage is in quadrature with, and controllable independently of, the line current for the purpose of increasing or decreasing the overall reactive voltage drop across the line and thereby controlling the transmitted electric power [17]. The SSSC may include transiently rated energy storage or energy absorbing devices to enhance the dynamic behavior of the power system by additional temporary real power compensation, to increase or decrease momentarily, the overall real (resistive) voltage drop across the line.

TCSC: TCSC is a capacitive reactance compensator, which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance.

TSSC: TSSC is a capacitive reactance compensator, which consists of a series capacitor bank shunted by a thyristor-switched reactor to provide a stepwise control of series capacitive reactance.

TCSR: TCSR is an inductive reactance compensator, which consists of a series reactor shunted by a thyristor-controlled reactor to provide a smoothly variable series inductive reactance.

TSSR: TSSR is an inductive reactance compensator, which consists of a series reactor shunted by a thyristor-controlled reactor to provide a stepwise control of series inductive reactance.

TCPST: TCPST is a phase-shifting transformer adjusted by thyristor switches to provide a rapidly variable phase angle [20]. This controller is also referred to as TCPAR.

UPFC: UPFC is a combination of STATCOM and a SSSC which are coupled via a common dc link to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently or selectively, the transmission line voltage, impedance, and angle or, alternatively, the real and reactive

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power flow in the line. The UPFC may also provide independently controllable shunt reactive compensation. The UPFC proposed by Gyugyi [2] is the most versatile FACTS controller for the regulation of voltage and power flow in a transmission line.

GUPFC: GUPFC can effectively control the power system parameters such as bus voltage, and real and reactive power flows in the lines [21]-[24]. A simple scheme of GUPFC consists of three converters, one connected in shunt and two connected in series with two transmission lines terminating at a common bus in a substation [7]. It can control five quantities, i.e., a bus voltage and independent active and reactive power flows in the two lines. The real power is exchanged among shunt and series converters via a common dc link.

IPC: IPC is a series-connected controller of active and reactive power consisting, in each phase, of inductive and capacitive branches subjected to separately phase-shifted voltages. The active and reactive power can be set independently by adjusting the phase shifts and/or the branch impedances, using mechanical or electronic switches. In the particular case where the inductive and capacitive impedance form a conjugate pair, each terminal of the IPC is a passive current source dependent on the voltage at the other terminal. The original concept of IPC was first described in [25] and the practical design aspects of a 200 MW prototype for the interconnection of the 120 kV networks were described in [26]. However, the original concept proposed in [25] has undergone modifications that are described in [27]-[31].

TCVL: TCVL is a thyristor-switched metal-oxide varistor used to limit the voltage across its terminals during transient conditions [4].

TCVR: TCVR is a thyristor-controlled transformer that can provide variable in-phase voltage with continuous control [4], [32].

IPFC: IPFC is a combination of two or more SSSCs that are coupled via a common dc link to facilitate bi-directional flow of real power between the ac terminals of the SSSCs and are controlled to provide independent reactive compensation for the adjustment of real power flow in each line and maintain the desired distribution of reactive power flow among the lines [4], [33]. The IPFC structure may also include a STATCOM, coupled to the IPFC common dc link, to provide shunt reactive compensation and supply or absorb the overall real power deficit of the combined SSSCs.

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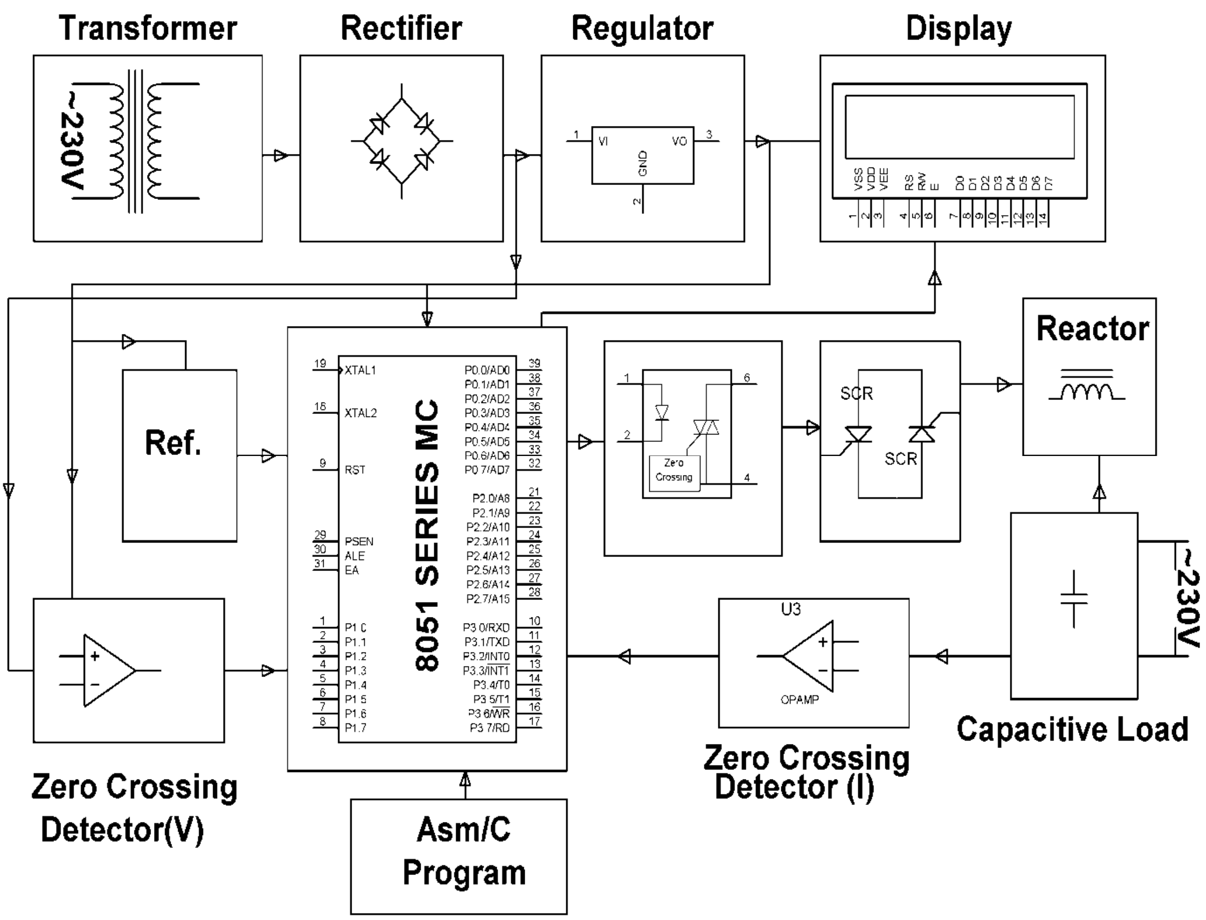
V. BLOCK DIAGRAM



VI. BENEFITS OF FACTS CONTROLLERS

FACTS controllers enable the transmission owners to obtain, on a case-by-case basis, one or more of the following benefits:

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1. Cost: Due to high capital cost of transmission plant, cost considerations frequently overweigh all other considerations. Compared to alternative methods of solving transmission loading problems, FACTS technology is often the most economical alternative [34].

2. Convenience: All FACTS controllers can be retrofitted to existing ac transmission plant with varying degrees of ease. Compared to high voltage direct current or six-phase transmission schemes, solutions can be provided without wide scale system disruption and within a reasonable timescale.

3. Environmental impact: In order to provide new transmission routes to supply an ever increasing worldwide demand for electrical power, it is necessary to acquire the right to convey electrical energy over a given route. It is common for environmental opposition to frustrate attempts to establish new transmission routes. FACTS technology, however,

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allows greater throughput over existing routes, thus meeting consumer demand without the construction of new transmission lines.

However, the environmental impact of the FACTS device itself may be considerable. In particular, series compensation units can be visually obtrusive with large items of transmission equipment placed on top of high-voltage insulated platforms.

4. Control of power flow to follow a contract, meet the utilities own needs, ensure optimum power flow, minimize the emergency conditions, or a combination thereof.
5. Contribute to optimal system operation by reducing power losses and improving voltage profile.
6. Increase the loading capability of the lines to their thermal capabilities, including short term
and seasonal.
7. Increase the system security by raising the transient stability limit, limiting short-circuit currents and overloads, managing cascading blackouts and damping electromechanical oscillations of power systems and machines.
8. Provide secure tie line connections to neighboring utilities and regions thereby decreasing overall generation reserve requirements on both sides.
9. Provide greater flexibility in sitting new generation.
10. Reduce reactive power flows, thus allowing the lines to carry more active power.
11. Reduce loop flows.
12. Increase utilization of least cost generation.
13. Overcome the problem of voltage fluctuations and in particular, voltage fluctuations Low voltage following an outage Supply reactive power; prevent overload STATCOM, SVC Thermal limits:

Transmission circuit overload Reduce overload TCSC, SSSC, UPFC, IPC

Tripping of parallel circuits Limit circuit loading TCSC, SSSC, UPFC, IPC

Loop flows:

Parallel line load sharing Adjust series reactance IPC, SSSC, UPFC, TCSC

Post-fault power flow sharing Rearrange network or use thermal limit actions IPC, TCSC, SSSC, UPFC

Power flow direction reversal Adjust phase angle IPC, SSSC, UPFC

There is a natural overlap among the above-mentioned benefits, and in practice, any one or two of these benefits would be a principal justification for the choice of a FACTS controller.

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