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Stability Analysis of AC Transmission Line Using FACTS

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Abstract- Due to the rapid technological progress, the consumption of electric energy increases continuously. But the transmission systems are not extended to the same extent because building of new lines is difficult for environmental as well as political reasons. Hence, the systems are driven closer to their limits resulting in congestions and critical situations endangering the system security. Power Flow Control devices such as Flexible AC Transmission Systems (FACTS) provide the opportunity to influence power flows and voltages and therefore to enhance system security, e.g. by resolving congestions and improving the voltage profile. Several kinds of FACTS controllers have been commissioned in various parts of the world. This paper presents various types of FACTS devices such as: load tap changers, phase-angle regulators, static VAR compensators, thyristor-controlled series compensators, interphase power controllers, static compensators, and unified power flow controllers. There classification based on steady sate and transient state stability and Power electronic and control technology have been studied.

I. Introduction

Nowadays changing electric power systems generate a growing need for reliability, flexibility, fast response and accuracy in the fields of electric power generation, transmission, distribution and consumption. An efficient, reliable transmission system will persist to have a vital role in satisfying the nation's growing thirst for electricity. The transmission system of the future (Smart Transmission) is the logical extension of today's electric grid. Transmission has a long history of installing new technologies that always improve performance in reply to the varying needs of society. This approach of innovation is required today, more than ever before. A transmission system that is both bigger and smarter than today's system is wanted to meet the nation's goal of a sustainable future for electric energy. The transmission system is the high-voltage part of the electric power infrastructure responsible for the bulk transfer of electricity from power plants to substations located near population centres. Transmission and Distribution (T&D) losses between 6% and 8% are considered normal [1].

As utilities shift forward with smart grid uses, there has never been a better time to think about the use of advanced power electronics as a workable transmission planning choice. With the use of *FACTS Devices* known as flexible AC transmission systems, the future of electric transmission systems can be smart. FACTS can raise transmission to a new level of performance and can provide a variety of benefits for increasing transmission efficiency [2]. There are two generations for realization of power electronics-based FACTS controllers: the first generation employs conventional thyristor-switched capacitors and reactors, quadrature tap-changing transformers, that second generation employs gate turn-off (GTO) thyristor-switched converters as voltage source converters (VSCs). The first generation has resulted in the Static Var Compensator (SVC), the Thyristor-Controlled Series Capacitor (TCSC), and the Thyristor-Controlled Phase Shifter (TCPS). The second generation has produced the Static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Unified Power Flow Controller (UPFC) [1], [3] and the Interline Power Flow Controller (IPFC).the system, large dynamic swings between different parts of the system and bottlenecks [4]. In this paper classification of Facts devices based on stability will be discussed.

II. INHERENT LIMITATIONS OF TRANSMISSION SYSTEMS

The characteristics of a given power system evolve with time, as load grows and generation is added. If the transmission facilities are not upgraded sufficiently the power system becomes vulnerable to steady state and transient stability problems, as stability margins become narrower [5].

The ability of the transmission system to transmit power becomes impaired by one or more of the following steady-state and dynamic limitations [6]:

_ angular stability;
_ voltage magnitude;
_ thermal limits;
_ transient stability;
_ dynamic stability.

These limits define the maximum electrical power to be transmitted without causing damage to transmission lines and electric equipment. In principle, limitations on power transfer can always be relieved by the addition of new transmission and generation facilities. Alternatively, FACTS controllers can enable the same objectives to be met with no major alterations to system layout. The potential benefits brought about by FACTS controllers include reduction of operation and transmission investment cost, increased system security and reliability, increased power transfer capabilities, and an overall enhancement of the quality of the electric energy delivered to customers [7].

III. STABILITY

The stability of a system refers to the ability of a system to return to its steady state when subjected to a disturbance. As mentioned before, power is generated by synchronous generators that operate in synchronism with the rest of the system. A generator is synchronized with a bus when both of them have same frequency, voltage and phase sequence. We can thus define the power system stability as the ability of the power system to return to steady state without losing synchronism. Usually power system stability is categorized into **Steady State, Transient and Dynamic Stability**

a) Steady State Stability studies are restricted to small and gradual changes in the system operating conditions. In this we basically concentrate on restricting the bus voltages close to their nominal values. We also ensure that phase angles between two buses are not too large and check for the overloading of the power equipment and transmission lines. These checks are usually done using power flow studies.

b) Transient Stability involves the study of the power system following a major disturbance. Following a large disturbance the synchronous alternator the machine power (load) angle changes due to sudden acceleration of the rotor shaft. The objective of the transient stability study is to ascertain whether the load angle returns to a steady value following the clearance of the disturbance

c) The ability of a power system to maintain stability under continuous small disturbances is investigated under the name of Dynamic Stability (also known as small-signal stability). These small disturbances occur due random fluctuations in loads and generation levels. In an interconnected power system, these random variations can lead catastrophic failure as this may force the rotor angle to increase steadily.

IV. FACTS CONTROLLERS

Power flow control has traditionally relied on generator control, voltage regulation by means of tap-changing and phase-shifting transformers, and reactive power plant compensation switching. Phase-shifting transformers have been used for the purpose of regulating active power in alternating current (AC) transmission networks. A number of FACTS controllers have been commissioned. Most of them perform a useful role during both steady-state and transient operation, but some are specifically designed to operate only under transient conditions. FACTS controllers intended for steady-state operation are as follows:

- Thyristor-controlled phase shifter (PS):

This controller is an electronic phase-shifting transformer adjusted by thyristor switches to provide a rapidly varying phase angle. Figure 1 shows the schematic diagram of the Thyristor Controlled Phase Shifter (TCPS). The series transformer injects the voltage in series in the system. The active and reactive power injected by the series transformer is taken from the shunt transformer. For sake simplicity of analysis, the insignificant losses from transformer and converter is neglected. Thus the net complex power (real and reactive power) exchange between the TCPS and the system is zero. The injection of this complex power depends on the injection of a series voltage controlled by a converter.

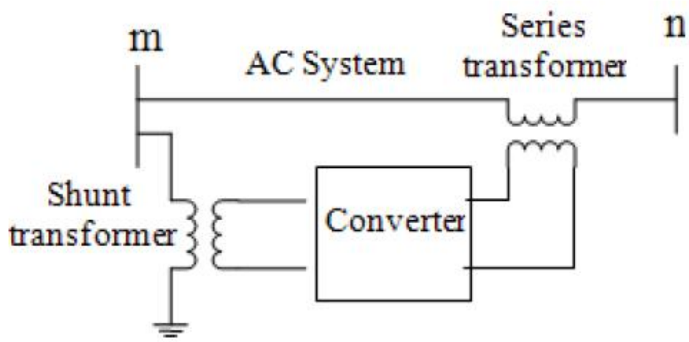

Fig. 1 Schematic Diagram Of The Thyristor Controlled Phase Shifter

- Load tap changer (LTC):

This may be considered to be a FACTS controller if the tap changes are controlled by thyristor switches.

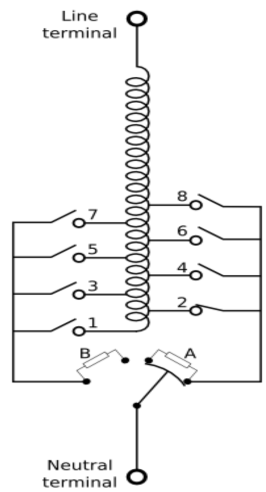

Fig. 2 Load Tap Changer

- Thyristor-controlled reactor (TCR):

This is a shunt-connected, thyristor-controlled reactor, the effective reactance of which is varied in a continuous manner by partial conduction control of the thyristor valve.

A thyristor controlled reactor is usually a three-phase assembly, normally connnected in a delta arrangement to provide partial cancellation of Harmonics. Often the main TCR reactor is split into two halves, with the thyristor valve connected between the two halves. This protects the vulnerable thyristor valve from damage due to flashovers, lightning strikes etc.

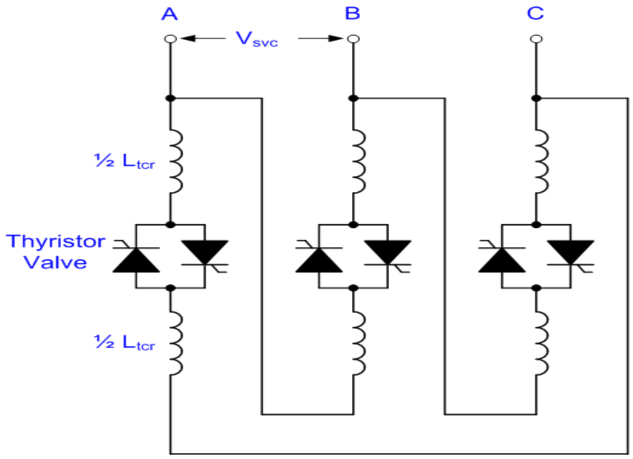

Fig. 3 Circuit Diagram Of Thyristor-Controlled Reactor

- Thyristor-controlled series capacitor (TCSC):

This controller consists of a series capacitor paralleled by a thyristor-controlled reactor in order to provide smooth variable series compensation.

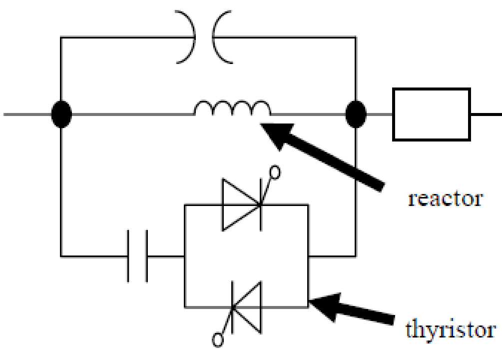

Fig. 4 Simple Diagram of TCSC

- Interphase power controller (IPC):

This is a series-connected controller comprising two parallel branches, one inductive and one capacitive, subjected to separate phase-shifted voltage magnitudes. Active power control is set by independent or coordinated adjustment of the two phase-shifting sources and the two variable reactances. Reactive power control is independent of active power.

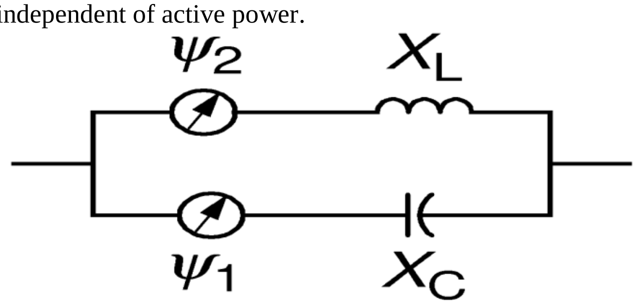

Fig. 4 Generic single-line diagram of the interphase power controller.

Ψ_1, Ψ_2 - Internal phase shifts
X_C - Capacitive reactance
X_L - Inductive reactance

- Static compensator (STATCOM): this is a solid-state synchronous condenser connected in shunt with the AC system. The output current is adjusted to control either the nodal voltage magnitude or the reactive power injected at the bus.
- Solid-state series controller (SSSC): this controller is similar to the STATCOM but it is connected in series with the AC system. The output current is adjusted to control either the nodal voltage magnitude or the reactive power injected at one of the terminals of the series-connected transformer.
- Unified power flow controller (UPFC): this consists of a static synchronous series compensator (SSSC) and a STATCOM, connected in such a way that they share a common DC capacitor. The UPFC, by means of an angularly unconstrained, series voltage injection, is able to control, concurrently or selectively, the transmission line impedance, the nodal voltage magnitude, and the active and reactive power flow through it. It may also provide independently controllable shunt reactive compensation.

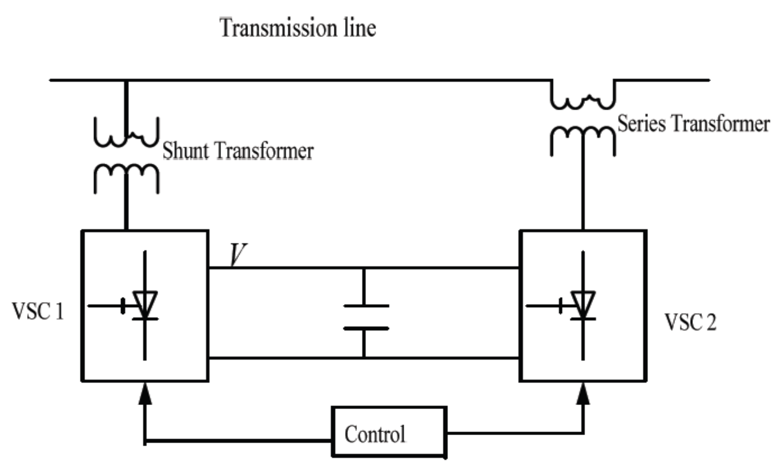

Fig. 5 The Schematic diagram of UPFC

Power electronic and control technology have been applied to electric power systems for several decades. HVDC links and static VAR compensators are mature pieces of technology:

- Static VAR compensator (SVC):

This is a shunt-connected static source or sink of reactive power.

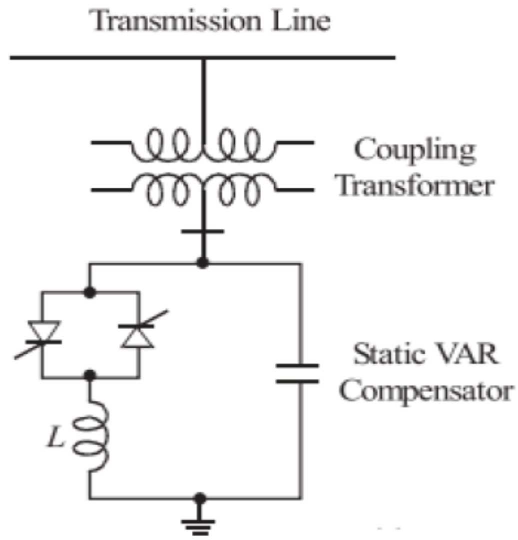

Fig. 6 SVC connected to a transmission line.

- High-voltage direct-current (HVDC) link:

This is a controller comprising a rectifier station and an inverter station, joined either back-to-back or through a DC cable. The converters can use either conventional thyristors or the new generation of semiconductor devices such as gate turn-off thyristors (GTOs) or insulated gate bipolar transistors (IGBTs).

V. RESULT AND CONCLUSION

In order to assist power system engineers to assess the impact of FACTS equipment on transmission system performance, it has become necessary to write new power system software or to upgrade existing software. This has called for the development of a new generation of mathematical models for transmission systems and FACTS controllers, which had to be blended together, coded, and extensively verified. This has been an area of intense research activity, which has given rise to a copious volume of publications. Many aspects of FACTS modelling and simulation have reached maturity, and we believe that the time is ripe for such an important and large volume of information to be put together in a coherent and systematic fashion.

With the history of more than three decades and widespread research and development, FACTS controllers are now considered a proven and mature technology. The operational flexibility and controllability that FACTS has to offer will be one of the most important tools for the system operator in the changing utility environment. In view of the various power system limits, FACTS provides the most reliable and efficient solution. The high initial cost has been the barrier to its deployment, which highlight the need to device proper tools and methods for quantifying the benefits that can be derived from use of FACTS.

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