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Thyristor-based FACTS controllers for electrical transmission systems

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Abstract

In nowadays functionality of power electrical systems is very complicated. The successful result of operation depends on many technical and economical factors. Therefor more effective ways are searched for better functionality of power transmission system. In this paper the main principles of thyristor based FACTS controllers are inspected and analysed. At present moment these controllers determine tendencies of development of power transmission systems.

Key words: electrical transmission system, FACTS, unified power flow controller, reactive power.

1. Introduction

We can think that the beginning of all electrical transmission systems was in 1873, when French engineer H. Fonten revealed the first DC transmission system in Vienna. The first DC transmission system was 1 kilometre long with possibility to transmit 750 W. The first DC transmission system consisted of DC source, electrical transmission line and load. (Fig.1, 2).

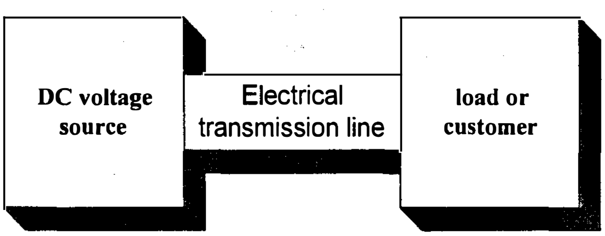


Fig.1. The block diagram of the first DC transmission line.

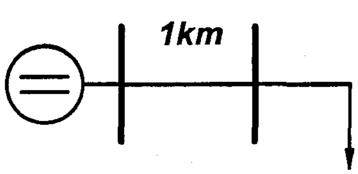


Fig.2. Electrical scheme of the first DC transmission line.

In 1889 the famous scientist and engineer M.Doļivo – Dobrovoļskis (which had studied in Riga technical university) developed 3-phase electrical AC motor. We can believe that it was the beginning of new stage in power transmission systems. In 25 august, 1891 the first 3-phase AC transmission system the world over was built up in Germany. The first AC transmission line supplied city Frankfurt at the river Maine with electrical energy from electrical station Laufena where the water turbine turned 3- phase electrical power generator which power was 230 kVA. (Fig.3, 4).

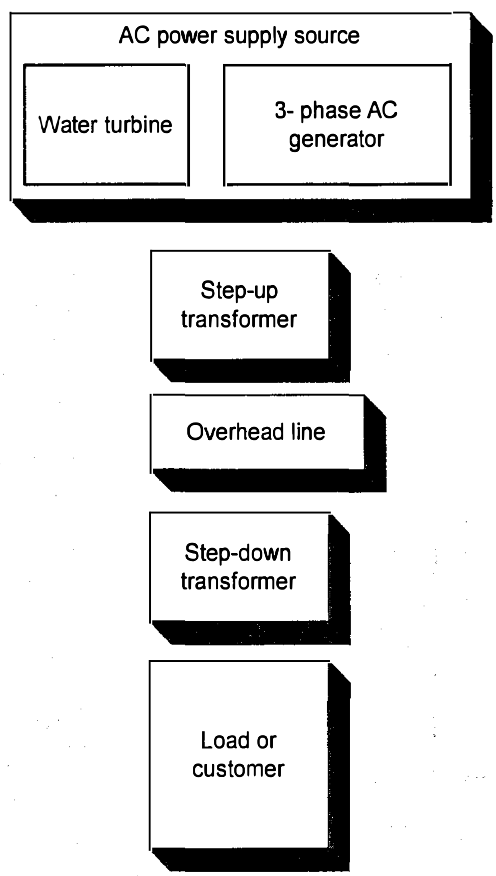


Fig.3. The block diagram of the first DC transmission system.

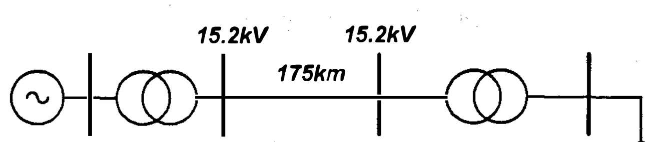


Fig.4. The principal scheme of the first DC transmission system.

For more clear understanding we will pay attention to fact that the grid built up in Germany become more complicated and consisted of more new grid elements as hidro-turbine, 3-phase AC generator, step-up transformer, overhead lines, step-down transformer and loads.

2.Power-system in nowadays

100 years had gone since aforementioned period. Very important findings in electrical engineering constituted and prepared preconditions for development of power-electric systems. These findings were done by important and famous European and American physicists in electrical engineering branch. Comparing power-systems in nowadays with power-systems before 100 years ago we can surely affirm that
they had become more:

a) Powerful;
b) Safely and qualitative;
c) Distributed around the whole country making interconnected power-systems;
d) Friendly for environment;
e) Flexible;
f) Complicated.

In nowadays power-systems are developed and improved by using modern achievements in electrical engineering, electronics, and power electronics and in other studies.
The flexibility of power-systems is possible to increase using newest findings in power electronics. Newest findings in power electronics contribute the safely of developing of own system, too. (Fig.5, 6).
We can accept any finding in all studies as big contribution for common development.

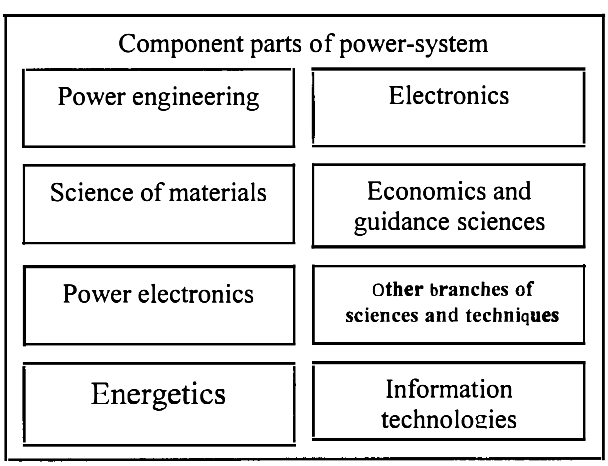


Fig.5. Branches of power-systems from view of point of classification of science.

3. Controlled AC transmission systems.

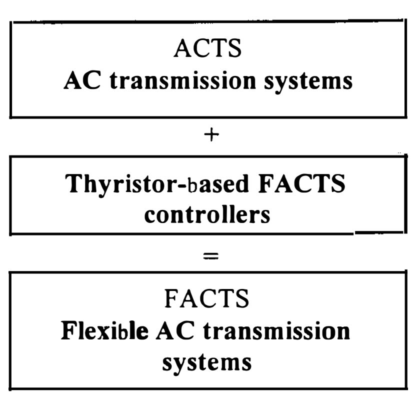
Usually generation, transmission and distribution of electrical energy are unified in power systems. In most cases these kinds of systems are regionally monopolised and supported by state. There are not competitions in monopolised power-system that's the reason why the quality of electrical energy for customer is improved very slowly. Therefore practice of the world are informing as about possibility to divide power system in generation, transmission and distribution. This kind of disintegration gives the system possibility to develop in new level of quality. For example it is possible to establish free market of electrical energy, which gives a customer a possibility to choose producer of electrical energy according his special requirements. The result of disintegration is formation of operator centres what is necessary for controlling of power flow. The new requirements to improve transmission systems are appearing for companies whose object is power transmission. Every imperfection of power system influences directly to incomes of transmission companies. Consequently request is appearing for transmission systems with:

- High voltage and current quality;
- Possibility to control reactive and active power;
- Possibility to control power flow;
- Height power transmission factor;
- Flexible and fast-moving response;
- Suitability to changeable loads;
- Possibilities smoothly regulate changeable loads.

New controllers are created to satisfy the requirements. These controllers are used in power systems to increase power quality and flexibility of systems.

The word FACTS in English language means "Flexible AC transmission systems". The word "Flexible" in term FACTS shows possibilities smoothly regulate currents and voltages of power-systems what gives a wide possibilities for direction of development of FACTS controllers. It means that FACTS controllers based on fully controllable thyristors or semiconductor switches (GTO, MCT, IGBT etc.) can provide reactive and active power flow control.

4. The usage of FACTS controllers in power-systems



FACTS controllers includes many solutions, what are based on base of high voltage electronics and what are used for AC transmission. (Table 1, 2).

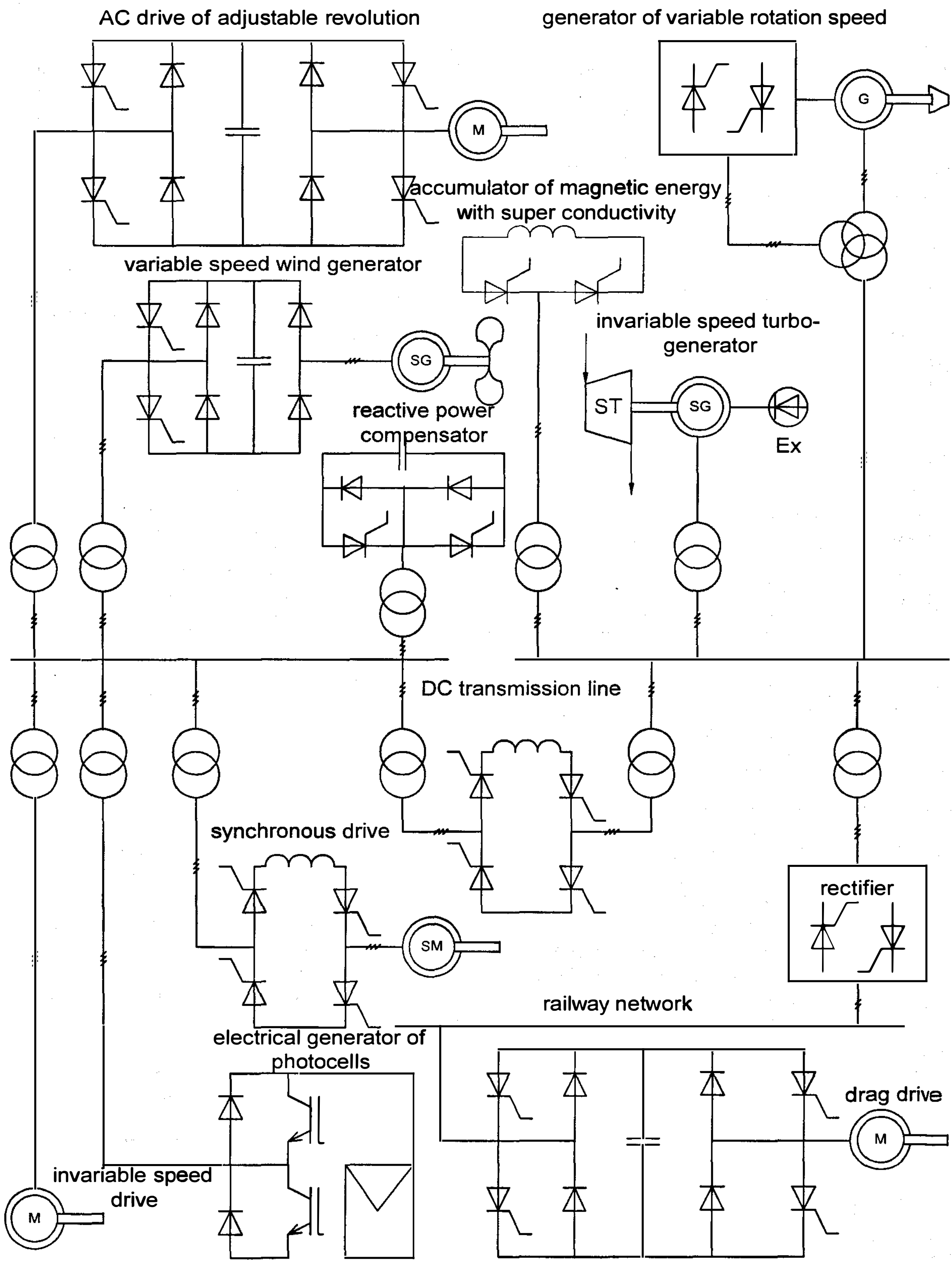


Fig.6. Thyristor usage in power systems

FACTS controllers based on fully controllable semiconductor switches

1	2	3	4	5	6
SVC Static Var Compensators	**TCSC** Tyristor-Controlled series Capacitors	**STATCOM** Synchronos static compensator	**PST** Phase – shifting transformer	**SSSC** Synchronous static series compensator	**UPFC** Universal power flow controller

Table 1. Full titles of FACTS controllers

	Controllers	*Voltage Control*	*Transient Stability*	*Damping Power Oscillations*	*Reactive Power Compensation*	*Power Flow Control*	*SSR Mitigation*
1	SVC	x	x	x	x		
2	TCSC	x	x	x		x	x
3	STATCOM	x	x	x	x		
4	PST		x	x		x	x
5	SSSC	x	x	x	x	x	x
6	UPFC	x	x	x	x	x	x

Table 2. Comparative table of possibilities of FACTS controllers

5. Static var compensator (SVC)

Static **var** compensator (SVC) is based on thyristor controlled reactors-TCR, thyristor switched capacitor (TSC) and fixed capacitors-FC tuned to filters. A TCR consist of a fixed reactor in series with a bi-directional thyristor valve. TCR reactors are as a rule of air core type, glass fibre insulated, epoxy resin impregnated.
A TSC consist of a capacitor bank in series with a bi-directional thyristor valve and a damping reactor which also serves to de-tune the circuit to avoid parallel resonance with the network. The thyristor switch acts to connect or disconnect the capacitor bank for an integral number of half-cycles of the applied voltage.
A complete SVC based on TCR and TSC may be designed in a variety of ways, to satisfy a number of criteria and requirements in its operation in the grid. In addition, slow vars by means of MSC(Mechanically Switched capacitors) can easily be incorporated in the schemes, as well,

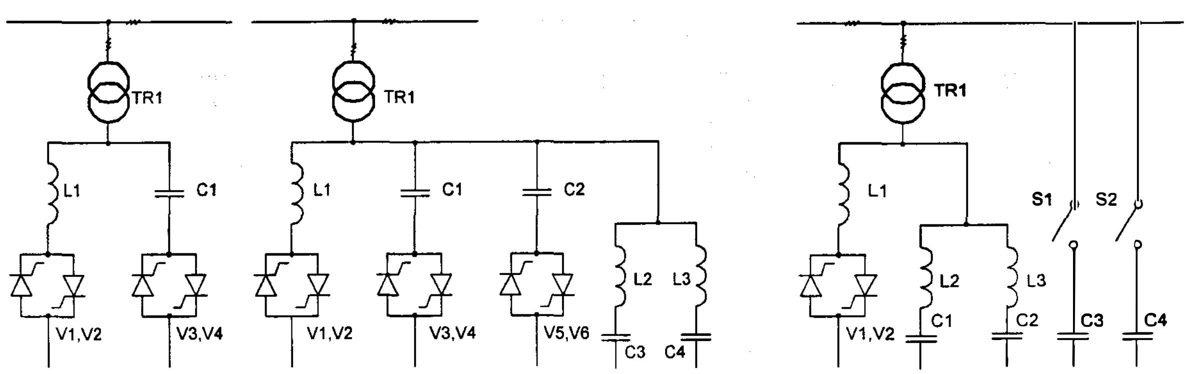


Fig.7. Connection variants of SVC

if required. (Fig.7)

6.Thyristor controlled series capacitor (TCSC)

Though very useful indeed, conventional series capacitors are still limited in their flexibility due to their fixed ratings. By introduction control of the degree of compensation, additional benefits are gained. In early types of controllable series capacitors, mechanical circuit breakers are used to switch segments of the capacitor in and out according to need. This is adequate in most situations for power flow control, but for applications requiring more dynamic response, its usefulness is reduced due to the limitations associated with using circuit breakers as switches.

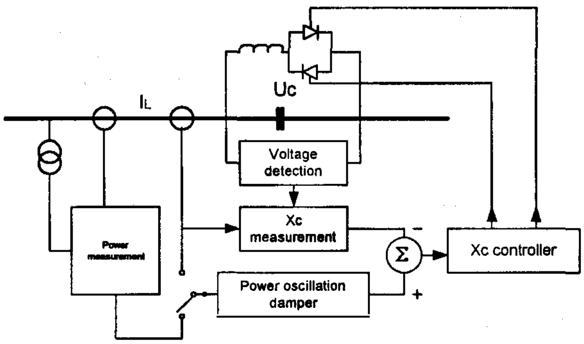


Fig.8. The modern scheme of series compensation

State of the art controllable series compensation is shown in Fig.8. Here, the introduction of thyristor technology has enabled strong development of the concept of series compensation. Added benefits are dynamic power flow control, possibility for power oscillation damping, as well as mitigation of sub-synchronous resonance (SSR).

7. STATCOM

A static compensator consists of a voltage source converter (VSC), a coupling transformer and control system (Fig.9). In Fig.9, Iq is the converter output current and is perpendicular to the converter voltage Vi. The magnitude of the converter voltage and thus the reactive output of the converter (Q) is controllable. If Vi>V_T, the Statcom supplies reactive power to the ac system. If Vi<V_T, the Statcom absorbs reactive power.State of the art for Statcom is by the use of IGBT (Insulated Gate Bipolar Transistors). By use of high frequency Pulse Width Modulation (PWM), it has become possible to use a single converter connected to a standard power transformer via air-core commutating reactors.The semiconductor valves in a Statcom respond almost instantaneously to a switching order. Therefore the limiting factor for the complex plant speed of response is determined by the time needed for voltage measurements and the control system data processing. A high gain controller can be used and a response time shorter than a quarter of cycle is obtained.

8.PST

Phase angle regulating transformers (phase shifters) are used to control the flow of electric power over transmission lines. Varying the phase shift across the series transformer can control both the magnitude and the direction of the power flow. Fig.10. The phase shift is obtained by extracting the line-to-ground voltage of one phase and injecting a portion of it in series with another phase. This is accomplished by using two transformers: the regulating (or magnetising) transformer, which is connected in shunt, and the series transformer. The star-star and star-delta connections used are such that the series voltage being injected is in quadrature with the line-to-ground voltage. A portion of the line voltage is selected by the switching network and inserted in series with the line voltage. The added voltage is in quadrature with the line voltage since, eg, the added voltage on phase

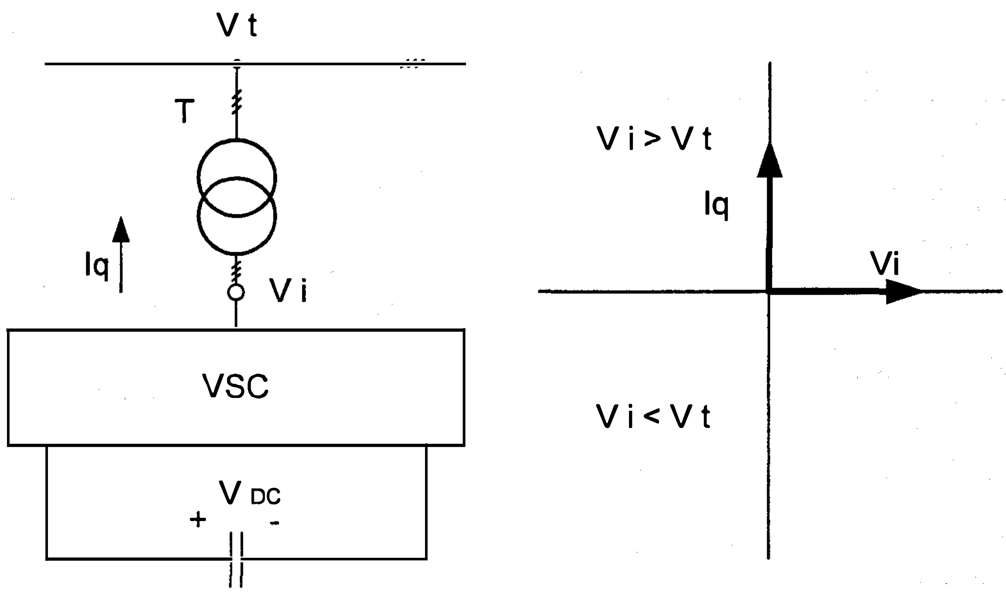


Fig.9. Vectors diagram and scheme of STATCOM

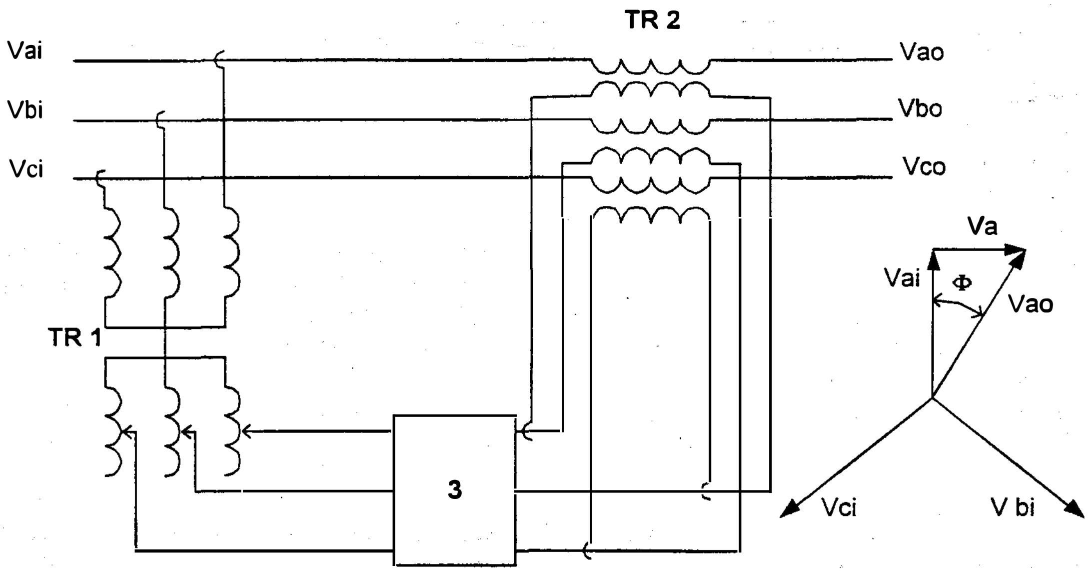


Fig.10. The principal scheme of PST

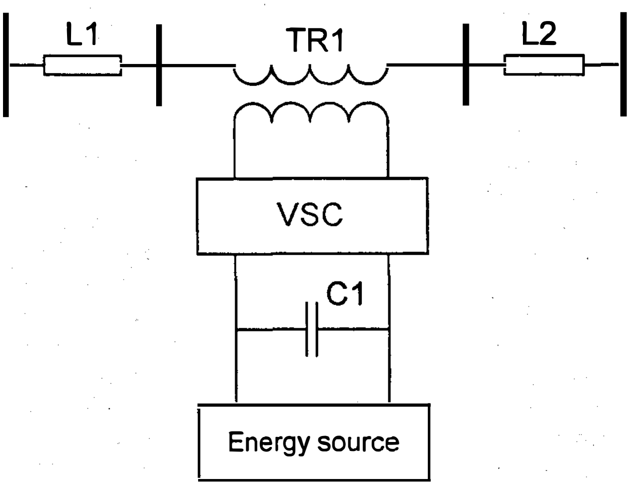


Fig.11. The principal scheme of SSSC

'a' is proportional to Vbc. The angle of a phase shifter is normally adjusted by on-load tap-changing (LTC) devices. The series voltage can be varied by the taps on the regulating winding.

9.SSSC

Static synchronous series compensator can be used in series in power transmission system. Such a device is referred to as a static synchronous series compensator what consist of voltage source converter, DC link and voltage source.
Fig.11 shows a voltage source converter connected in series with a transmission line via a transformer. Such connection provides regulation of power flow in transmission system. If it is necessary to compensate only reactive power of transmission line then voltage source is needed

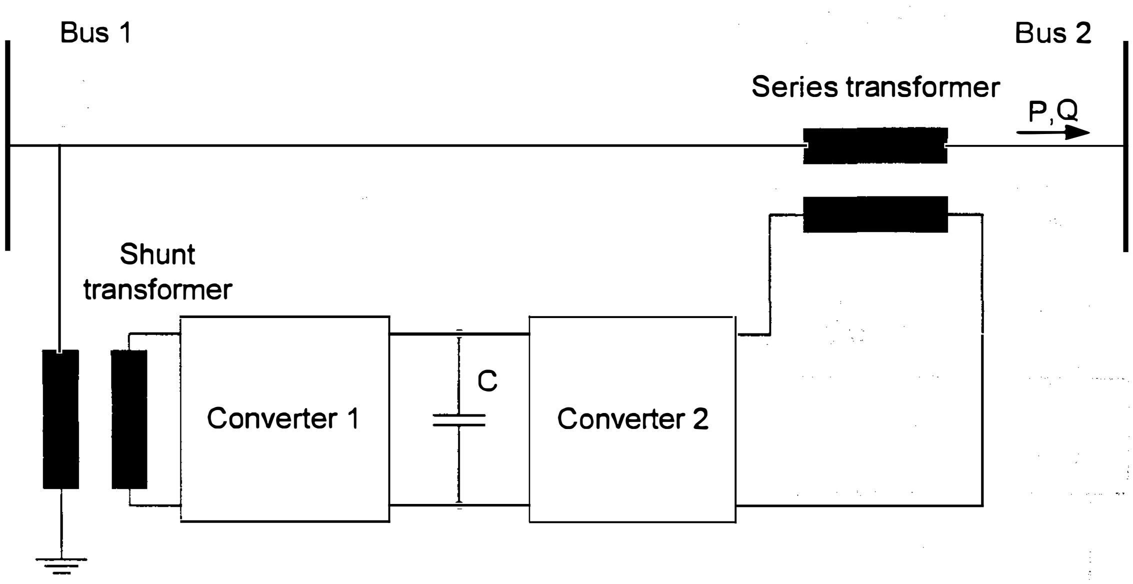


Fig.12. The principal scheme of UPFC

quite small and it is possible to regulate the value and offset angle of voltage what is delivered in line. With reactive power compensation, only the magnitude of the voltage is controllable since the vector of the inserted voltage is perpendicular to the line current. In this case the series injected voltage can either lead or lag the line current by 90 degrees. This means that the SSSC can be smoothly controlled at any value leading or lagging within the operating range of the VSC. The basic difference is that the voltage injected by an SSSC is not related to the line current and can be independently controlled. This important characteristic means that the SSSC can be used with great effect for both low and high loading.

10. Unified power flow controller-UPFC

The unified power flow controller gives as possibility control power flow, improve system stability and increase power transmission through existent lines till thermal limit
The unified power flow controller consist of two switching converters operated from a common DC link. (Fig.12)

The basic function of converter 1 is to supply or absorb the real power demanded by converter 2 at the common DC link. It can also generate or absorb controllable reactive power and provide independent shunt reactive compensation for line. Converter 2 supplies or absorbs the required reactive power locally and exchanges the active power as result of the series injection voltage. A UPFC can regulate the active and reactive power simultaneously.

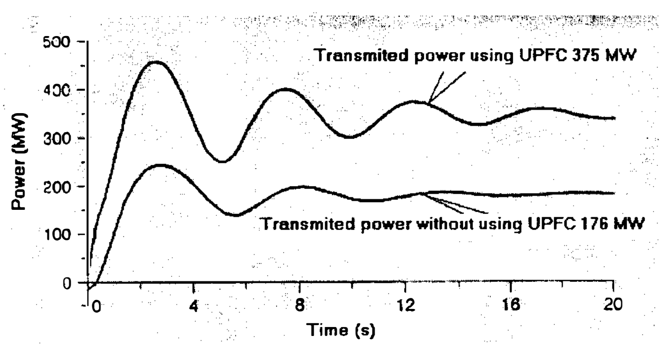


Fig.13. Transmission results with UPFC

Fig.13 shows the results of simulation of UPFC. There we can see that using UPFC controller in transmission systems will increase power transmission through existent lines 2.02 times. The results of experiments what were obtained in Nanyang Technology University on specially constructed model are showed in fig.14 a-b.

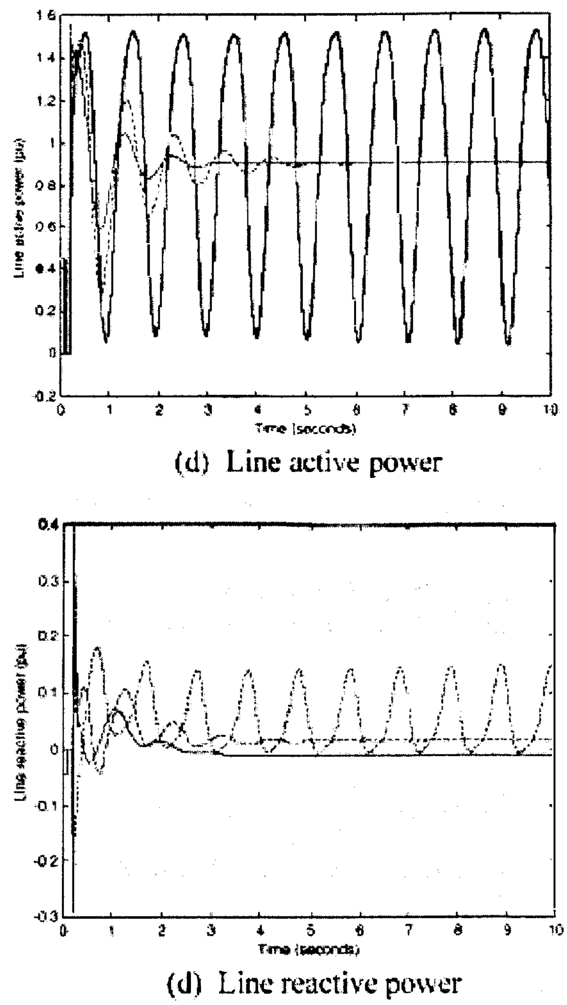


Fig.14. Results of experiments of UPFC model.

Conclusions

It is necessary to analyse power system condition and make very important decisions which kind of solution or controller is more suitable in different situations for increasing of systems quality.

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