

## THE APPROACH FOR OPTIMIZATION OF TRANSMISSION OVER POWER LINKS USING THE THYRISTOR-CONTROLLED SERIES COMPENSATION

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**Abstract:** The energy transportation networks can be improved by multiplying or creating new lines. This is not always the case for various reasons. The series capacities controlled by SCRs (Silicon Controlled Rectifiers) represent a good alternative to optimize the existing or the new electric links, because they allow the increase of the dynamic stability, the damping of the power oscillations, while balancing the loads between the parallel circuits. This paper presents a resolution method to the power distribution by inserting the TCSC transit controller in the network. The insertion of the TCSC devices has given satisfying results that are, an increase of the transmitted active power and reduction of active losses, an improvement of the angular stability and the voltage stability without decreasing the transportation capacity.

**Keywords:** FACTS devices, TCSC, power flow.

### 1. INTRODUCTION

The recent upheavals appeared in the field of the electricity supply has placed the grid system owners toward new opportunities and also new challenges. They mainly come from the great increase of the energy transfer between zones and countries, the effects of the deregulation, the political, economical and ecological considerations with respect to the construction of new lines. Technically, it is possible to find a solution to the lack of the transport capacity by creating new lines and/or new generators. (R.L.Hauth, et al., 1978), (L.Gérin-Lajole, et al., 1990), (P.K.Steimer, et al., 1996).

In practice and for various reasons, this is not always realizable, nor desirable. The creation of new lines and/or the extension of existing stations can appear too expensive and require long time. To obtain new right-of-ways can be difficult even impossible. Lastly, the environmental impact takes more and more importance and must be taken into account seriously in the development procedures of the electricity transport. The series capacities controlled

by thyristors (TCSC), using recent power electronics, can help to be freed from these constraints, in all the cases where it is necessary to transport great quantities of energy on long distances or when interconnections are made between countries or areas. It is a favorable alternative from technical, economical and environmental point of view.

The principal advantages of the TCSC insertion in an electrical supply network are:

- Compensation in the unbalance of the loading currents.
- Improvement of the dynamic stability, the power oscillations damping and the voltage stability.
- Reduction of the hypo-synchronous resonance risks.
- The networks Interconnection.
- Controlled series compensation.

### 2. FACTS DEVICES

The FACTS program was elaborated by Electric Power Research Institute (EPRI) of Palo Alto,

California, with the collaboration of equipment manufacturers and electricity companies. The various types of FACTS devices used today can be divided into three categories:

- Shunt category.
- Series category.
- Combined shunt - series category.

The static device either TCSC or SVC become important equipment because of the advantages resulting from its use in the electrical distribution grid systems and the industrial networks. Concerning its use in the distribution grid systems, it improves the voltage and the network behavior stability, limits the line losses by reducing the reactive power transport and increases the transport capacity. For the industrial networks which are characterized by the strong and fast fluctuations of the reactive power, it reduces the disturbing influences such as the flicker effect and the important voltage drop.

Several noted objectives can be carried out simultaneously which makes it possible to obtain a great safety service of the network and thus an increase in efficiency. The compensator has good dynamic performances (response time of some tenth of a second). It is however, an expensive apparatus as well as in investment or in exploitation, because of the losses that it is the cause and the low frequency harmonics that it generates.

These harmonics can cause serious problems (amplification of the voltage network by the resonance phenomenon). Thus, it is necessary to install passive filters and takes into account the regulation. (Allaoui Tayeb, et al., 2002).

The universal power flow controller (UPFC) remains the more sophisticated FACTS device. This is due essentially to the various control techniques that gives it the character of flexibility, during an unspecified disturbance, while acting with compensation effect of series or parallel type.

### 2.1. The Series Category

In this category the series compensator commutated by thyristors (TCSC: thyristor controlled series compensator) is a series FACTS, used in the network in the form of variable elements, and adjustable very quickly by thyristors. It is especially used to distribute the power flow between the parallel lines and to improve the transitory stability of alternators, by modifying the total line reactance where it is installed. (Théodore Wildi, et al., 2000), (Noroozian, H, et al., 1993)

#### 2.2.1. Series condensers controlled by thyristors (TCSC)

Figure 2 gives a diagrammatic representation of a series compensator circuit commutated by thyristors: (Faur. Z.T, 1996)

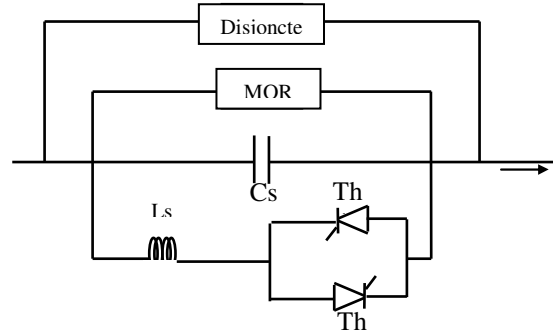


Fig1. Diagrammatic representation of TCSCs single-phase current.

With:

Ls: Series inductance

Cs: Series capacity

The circuit is composed of a series capacity assembled in parallel with an inductance coil whose reactance is gated by thyristors assembled in head to tail (gradator).

The circuit includes also a safety device to shunt the compensator during the only moments where the over voltage exceeds the acceptable level for the condensers. This safety device is a nonlinear zinc oxide (ZnO) resistance, called also varistor or "MOR" (Metal Oxyde Resistor). The circuit is shunted by a circuit breaker.

The group of condensers is connected with a TCR which allow current impulses to circulate in phase with the current line. This increases the condenser voltage beyond the voltage which can be obtained by the current line alone. Each thyristor is gated once per cycle and with a conducting time lower than a half-cycle of the applied fundamental frequency. If the added voltage, created by the flow of the current impulses, is controlled to be proportional to the line current, the electrical supply network sees the TCSC as a reactance which increases beyond the physical reactance of the condensers. Because of the interval conduction of the thyristors, current harmonics will be injected into the condensers. The current harmonics increase with the increase of the over voltage degree.

The TCSC characteristics are:

- The material design is adapted to the maximum voltage to be supported.

- The Mvar flow of the condenser group is proportional to the maximum voltage produced and the corresponding maximum current.
- An advanced control, particularly for the attenuation mode of Sub-Synchronous Resonances (SSR).
- An unrestricting number of operations and sequences.
- A precise configuration of a compensation degree.
- A frequent adjustment of the compensation degree for the attenuation of SSRs and the damping of the current oscillations. (Grunbaum. R, et al., 2001)

### 3. THE CSC APPLICATIONS

The series compensation is the best currently known technique to increase the power transfer capacity of the transmission line. The series condensers operate by inserting a voltage source in series with the transmission line with an opposite polarity to that of the line voltage drop. The apparent effect is the reduction in the apparent transmission line reactance. The various modes of the series condensers control can be suitable solutions for the following objectives:

#### 3.1. A high degree of the series compensation

The series condensers increase the transfer capacity of the transmission lines. The maximum compensation degree in a transmission network is limited by the potential risk of interaction between the closest series condensers and the turbo alternators. This phenomenon is known under the term of sub-synchronous resonance (SSR). If a condenser with a reactance  $X_C$  is connected in series with the transmission line figure 8, the impedance becomes  $(X_L - X_C)$ . Then the power transmitted through this line is given by:

$$(1) P_t = \frac{E_S E_R}{X_L - X_C} \sin \delta$$

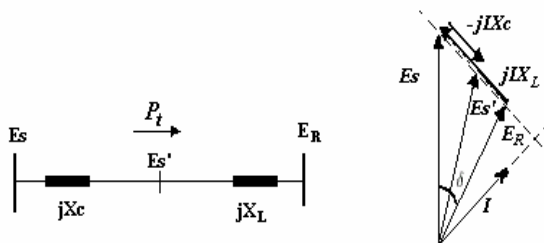


Fig.1. Series Compensation

The maximum power transmitted is increased by  $(X_L/X_C - X_L)$  compared to the no compensated line, if the condenser is provided with an insulating

device, the ratio  $(X_L/X_C - X_L)$  becomes variable, and the transferred power could be controllable.

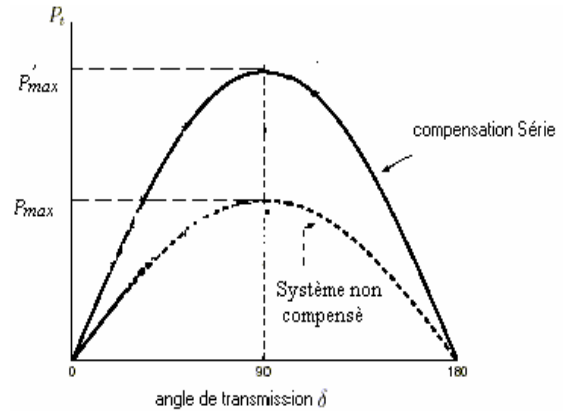


Fig.2. Effect of the compensation on the transmitted power.

#### 3.2. Damping of the power oscillations

Several no damped current oscillations with frequencies going from 0.2 to 2.0 Hz appear for high power levels in the long transmission lines. The CSCs can damp these oscillations and thus allow a transfer of a power high level on long distances. Moreover, the CSCs can offer a significant support for the network when significant defaults happened by making it to find its synchronous operation.

#### 3.3. Interconnections

Two or several electrical supply networks are often inter-connected to allow between them an economic power transfer, to share their stocks when necessary and to increase their profitability and reliability. The CSCs are an effective means of interconnection to benefit a regular economical power exchange when the points of interconnections are electrically weak.

#### 3.4. Power Flow Control

The CSCs allow to the operators a better manage of the power flow through a transmission line. This is useful especially when an irregular power distribution between various transmission circuits leads to an overload and forces the operator to reduce the use capacity of certain lines.

#### 3.5. Control of loading capacity of the transmission lines:

The CSCs are an effective means to improve the transfer capacity of the transmission lines.

The degree of compensation can be controlled to minimize the system losses during its normal operation. Analyze of a TCSC circuit and its principal functionalities. Since the fundamental components of the voltage and the current are

controllable, the TCSC becomes similar to controllable impedance, which is the result of the parallelization of the equivalent reactance of a TCR component and a capacity Let us note:

The TCSC equivalent impedance by:

$$Z_{TCSC} = jX_{TCSC}$$

The TCR equivalent impedance by:

$$(2) Z_{TCR} = jX_{TCR} = j \frac{X_L \pi}{2(\pi - \alpha) + \sin 2\alpha}$$

And the capacity impedance by:

$$Z_C = -jX_C$$

We can write:

$$(3) Z_{TCSC} = Z_C // Z_{TCR} = \frac{-jX_C \cdot jX_{TCR}}{-jX_C + jX_{TCR}}$$

$$Z_{TCSC} = \frac{-jX_C \cdot jX_{TCR}}{-jX_C + jX_{TCR}}$$

$$(4) Z_{TCSC} = j \frac{X_C X_L}{\frac{X_C}{\pi} (2(\pi - \alpha) + \sin 2\alpha) - X_L}$$

And:

$$(5) X_{TCSC}(\alpha) = \frac{X_C X_L}{\frac{X_C}{\pi} (2(\pi - \alpha) + \sin 2\alpha) - X_L}$$

#### 4. TCSCS IMPLEMENTATION IN THE POWER FLOW MANAGEMENT

Let us suppose that a TCSC device is placed between two nodes k and m figure 10. If the losses are neglected, the power P injected into the TCSC starting from the generation node k is equal to that injected by the TCSC in the load node m. The TCSC model represented in figure 10 is described by the system of Eq. 6: (Orfanogiannia. T, 2000)

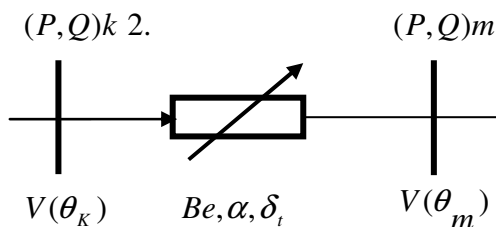


Fig.3. The TCSC Model in a Power Flow.

$$P = -V_k V_m B_e \sin(\theta_k - \theta_m)$$

$$Q_k = V_k V_m B_e \cos(\theta_k - \theta_m) - V_k^2 B_e$$

$$Q_m = V_k V_m B_e \cos(\theta_k - \theta_m) - V_m^2 B_e$$

$$(6) B_e = \frac{1}{X_C} - \frac{(2(\pi - \alpha) + \sin 2\alpha)}{\pi X_L}$$

$$\sqrt{P^2 + Q^2} = IV_k$$

$$\theta_k = \theta_m + \delta_t$$

$$\text{Where } B_e = \frac{1}{X_e}$$

#### 5. APPLICATION EXAMPLE IN A POWER ELECTRIC NETWORK OF 57 NODES

The objective of this article is to apply the calculation of the power flow by Newton-Raphson method in an electrical supply network model with 57 IEEE nodes, by inserting a TCSC: power transit controller.

The network represented in figure 11 includes:

- 57 nodes including 48 consumption nodes;
- 03 production nodes (generators) and consumption;
- 03 production nodes (compensators) and consumption;
- 78 lines;
- 18 transformers

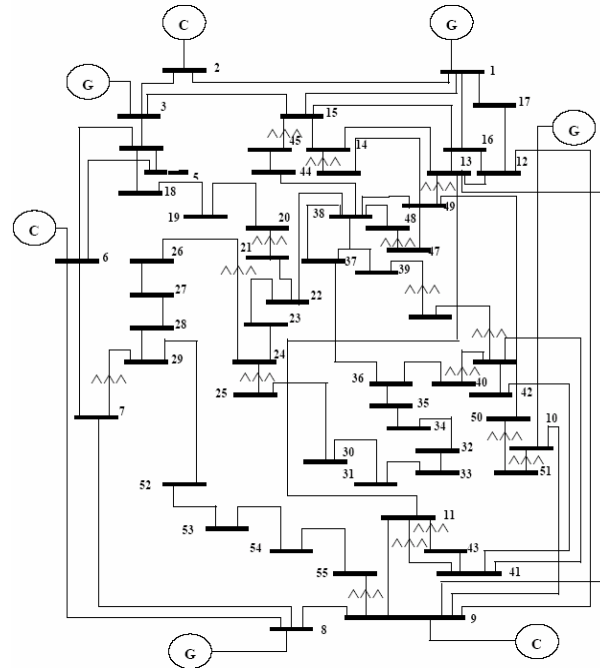


Fig.4. Electrical supply Network with 57 IEEE nodes

### 5.1. Network analyze without FACTS device

The analysis of our network is realized with a program developed under MATLAB 6.5. This program enables us to follow the evolution of each network parameter by the means of the power flow calculation. It includes also the operating and the controlling subroutines of TCSC devices.

The power flow calculation is a necessary stage to be able to compare our results. It is carried out initially for the determination of the system initial conditions before the default. Indeed, it allows finding the voltage at different nodes and thereafter the transmitted and injected powers. The results of the power flow calculation are obtained with a program using the Newton-Raphson method. This program converges in 4 iterations with an accuracy of  $10^{-4}$ .

Table1 Active and reactive losses of the network

Losses	$P_L$ [MW]	$Q_L$ [MVAR]
Results	28.059	35.395

#### 5.1.1 Interpretation

In the first calculation, we have determined the values of the transmitted powers, the injected powers, the voltage, the angles and the losses, using the traditional calculation of the power flow with the Newton-Raphson method. This program converges in 4 iterations with an accuracy of  $10^{-4}$ . We noticed that the transmitted powers, which are connected directly with the most powerful generator, have more significant values.

### 5.2. Basic parameters to insert the TCSC

There are several control strategies. In our case, we have chosen the control by the angle transmission of modulation.

- 1- The basic value is:  $S_b = 100$  MVA.
- 2- The parameters of the power transit controller: TCSC are:

- The frequency  $f = 50$  Hz.
- The inductive reactance:  $X_L = 0.3$  p.u.
- The capacitive reactance:  $X_C = 0.1$  p.u
- Gating angle  $\alpha$  (alpha).

Let us note that the choice of alpha values and their operating limits was based on research which was already done on the best angle of transits control.

The choice of alpha is as follows:

Capacitive effect :

$$\alpha = 148^\circ, \quad \alpha_{\min} = 142^\circ, \quad \alpha_{\max} = 180^\circ$$

Inductive effect:

$$\alpha = 125^\circ, \quad \alpha_{\min} = 90^\circ, \quad \alpha_{\max} = 129^\circ$$

#### 5.2.1 Capacitive effect results

The computation results of the power flow with insertion of the TCSC, power transit controller, are obtained with the same program used previously; using the Newton-Raphson method, for this test we have chosen two different values of  $\alpha$  (alpha), so that each value belongs to an operating zone out of the resonance zone.

Table2 Transmitted powers with insertion of the TCSC transits controller (capacitive)

$\alpha_1 = 148^\circ, \alpha_{1\min} = 142^\circ, \alpha_{1\max} = 180^\circ$				
$\Delta P = 0.0$ it = 4			pr% = 60.7758 %	
	Before insertion of the TCSC		After insertion of the TCSC	
k-m	P km (p.u)	Q km (p.u)	P km (p.u)	Q km (p.u)
52-53	06.396	04.124	06.40	+ 004.12
53-52	- 06.349	- 03.524	03.86	- 011.43

Table 3 Table of comparison of the voltage and angle without and with insertion of the TCSC transit controller (capacitive)

$\alpha_1 = 148^\circ, \alpha_{1\min} = 142^\circ, \alpha_{1\max} = 180^\circ$				
$\Delta P = 0.0001$ it = 4			pr% = 60.7758 %	
	Before insertion of the TCSC		After insertion of the TCSC	
k	Tension (p.u)	Angle (degré)	Tension (p.u)	Angle (degré)
52	0.975	-12.321	1.1112	-12.3213
53	0.931	-16.099	1.1112	-16.0991

Table 4 Active and reactive losses of the network with injection of TCSC (capacitive)

Losses	$P_L$ [MW]	$Q_L$ [MVAR]
Results	19.13	26.34

#### 5.2.1.1 Interpretation

According to these results, we notice that depending on the disposition of the TCSC, the compensated systems may cause more or less losses compared to

the case of no compensation. These losses are reduced with an optimal emplacement of the TCSC, which is, according to our results, related to the branches 53-52 and 24-26.

Indeed, for a compensation level of 70%, the losses of the network transmission power obtained after insertion of the transit controller are reduced by 60.8 % for line 53-52 and 67.96 % for line 24-26.

The position of the TCSC in other branches of the network generates more active losses. For this reason, it is preferable to place the TCSC through the branch 53-52 since the losses are minimized with a good percentage and less iterations.

After having chosen the optimal TCSC emplacement, the power flow in an electrical supply networks is distributed along the transport network according to the lines characteristics.

Also, according to the obtained results, we notice that the TCSC influences the voltage at nodes 53 and 52. The latter which were 0.931 p.u without TCSC, was improved to become 1.1112 p.u. with a compensation of 60.8% for node 53 and 0.975 p.u without TCSC, was improved to become 1.1112 p.u with the same compensation (60.8%) for node 52.

We also notice that the transmitted powers either active or reactive were increased smoothly but always remaining on the same order of magnitude. The goal of this application is to control the way of the power flow, by increasing its transfer in a network branch (53-52).

### 5.2.2 Inductive effect results

In this simulation the TCSC transit controller is inserted with inductive effect on the branch 41-43. This program converges in 4 iterations with an accuracy of  $10^{-4}$  and a compensating percentage  $pr \% = 11.5165 \%$ . The obtained results are as follows

Table 5 Powers transmitted with insertion of the controller of transits TCSC (Inductive)

$\alpha_2=125^0$		$\alpha_{2 \min} = 90^0$		$\alpha_{2 \max} = 129^0$	
$\Delta P=0.0001$		it = 4		pr% = 11.5165.%	
k-m	Before insertion of the TCSC		After insertion of the TCSC		
	$P_{km}$ (p.u)	$Q_{km}$ (p.u)	$P_{km}$ (p.u)	$Q_{km}$ (p.u)	
41-43	-11.527	0.516	-13.275	0.5275	
43-41	11.527	0.065	11.53	0.0651	

Table 6 of comparison of the voltage and angles without and with insertion of the TCSC controller transits (Inductive)

$\alpha_2=125^0$		$\alpha_{2 \min} = 90^0$		$\alpha_{2 \max} = 129^0$	
$\Delta P=0.0001$		it = 4		pr% = 11.5165 %	
k	Before insertion of the TCSC		After insertion of the TCSC		
	Tension (p.u)	Angle (degree)	Tension (p.u)	Angle (degree)	
41	0.972	-16.341	1.0556	16.3405	
43	0.971	-13.456	1.0556	-13.4560	

Table 7 The network active and reactive losses with insertion of the TCSC between nodes 43-41 (inductive)

Losses	$P_L$ [MW]	$Q_L$ [MVAR]
Results	26.431	27.660

### 5.2.2.1 Interpretation

In the inductive zone, we have reduced the transmission power losses and the total losses with an adequate place of the TCSC, which are according to our results, related to the branches 3-15, 27-28, 32-34, 38-44, 41-43.

Indeed, for a compensation level of 60%, the network transmission power losses obtained after insertion of the transit controller are reduced by 0.5 % for line 3-15, 0.67% for line 27-28, 7.6 % for line 32-34, 0.45 % for line 38-44 and 3.45 % for line 41-43. While, the TCSC disposition in the other network branches, generates more active losses. For this reason, the best place of the TCSC is through the branch 41-43.

## 6. CONCLUSION

This paper has presented a Newton-Raphson load flow algorithm to solve power flow problems in power system with thyristor controlled series capacitor (TCSC). This algorithm is capable of solving power networks very reliably. The IEEE 57 bus system has been used to demonstrate the proposed method over a wide range of power flow variations in the transmission system. It has also been observed that the proposed algorithm is also suitable for large systems with better range of power control. With help of the proposed algorithm, it is possible to place TCSC in specific transmission lines to improve the system performance.

Table 8 of comparison of the active power

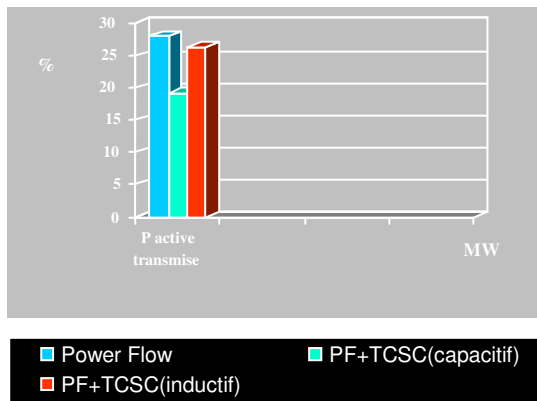
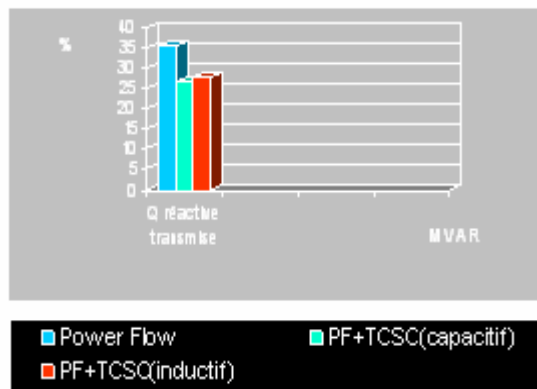


Table 9 of comparison of the reactive power losses



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