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Traditional Algorithms and New Decisions in Regulation of TCSC

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FACTS, TCSC, Control algorithms for TCSC, Damping of power system oscillations.

1 INTRODUCTION

Introduction of FACTS offers wide possibilities for control of power system operating conditions. Thyristor controlled series compensation (TCSC) based on series – parallel connection of power thyristors is in a moment one of the most used FACTS solutions worldwide. TCSC have been installed and operate on EHV power lines in USA, Brazil, Sweden and many other countries. Realized installations are changing the reactive line impedance of power lines where they are installed and:

- Increase the transmission capacity of transmission networks
- Increase static and dynamic stability of complete power systems
- Minimize losses in power networks
- Eliminate the possibility for subsynchronous resonance, etc.

A special unit, controlling the amount of compensation degree on TCSC appears as the basic element of controlled series compensation. Traditional technical solutions and algorithms for TCSC are analyzed in paper and a new method for control of thyristors during power system transient conditions is suggested as well. The proposed TCSC control algorithm is based on analyzing the transmitted power angular characteristics and provides effective way for system oscillation damping independent on present compensation degree as well as on system oscillation frequency.

2 BASICS

2.1 Traditional solutions for control of the TCSC

TCSC, realized on the basis of series – parallel connected thyristors, is composed of series connected capacitor battery with fixed capacitance and parallel connected reactor with thyristor block (see **Ошибка! Источник ссылки не найден.**). Changing of thyristor firing angle in wide range (from 90 to 180 deg relative to voltage drop on capacitor battery) makes possible to change the reactor current, which on its turn influences the voltage drop on the capacitor and, consequently, on the complete TCSC.

Operation of complete TCSC depends very much on characteristic of its control equipment. As presented in [1] the controller for TCSC could be divided in two basic parts:

1. Control module, providing correct compensation degree of power line by TCSC
2. Module for direct control of thyristors used for TCSC

The first module is responsible for continuous adjustment of appeared series capacitance according to system needs. The second block directly controls the thyristor firing angle and provides control impulses for operation of all thyristors.

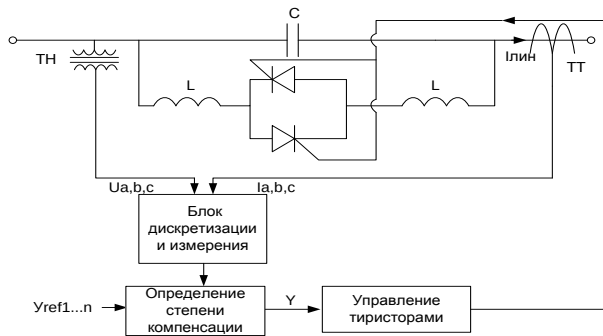


Fig. 1: TCSC control structure

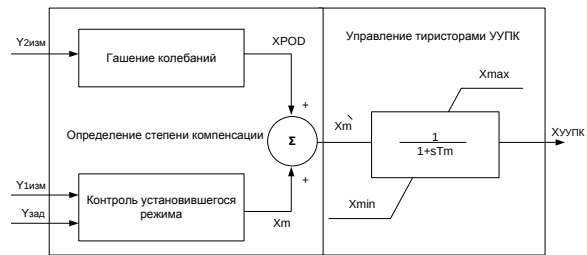


Fig. 2: Traditional algorithm of TCSC

According to the analysis of different documents [1–5] consist the control algorithms for TCSC of two basic modules (see **Ошибка! Источник ссылки не найден.**): in first module are placed two sub-elements, responsible for control of compensation degree during steady state conditions and power system oscillation damping during different transients.

For the steady state algorithm usually two possibilities related to compensation degree of power line are used. Either direct control from the higher level (direct signal from the power system operator or from the local system detecting the deficiencies in power system stability) or the local control based on the locally controlled parameters in proportional – integrated (PI) controller based on the comparison of locally set operating parameters and their actual measured values. The most frequent controlled parameters are the apparent power transmitted over the power line or the estimated value of the angle δ between series compensated line ends, which is based on the measurement of current through the TCSC installation.

The group of algorithms providing power system oscillation control in case when the supplying part of power system increases its speed (mechanical moment is bigger than electrical one) and consequently, increases the transmitted power. Similar process appears during the decreasing of power system speed (electrical moment on the turbine generator unit is bigger than the mechanical one) but in this particular case the system initiates decrease of transmitted power. This increases the additional moment on the rotor of equivalent generator and is opposite to its acceleration or deceleration, which secures this way fast oscillation damping in a complete system. Damping algorithm realized in one single block uses generally a differentiating link with serial amplification of measured input signal, see Fig. 3.

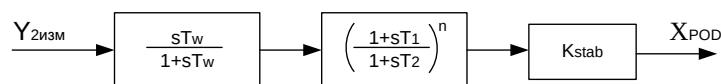


Fig. 3: Traditional oscillation damping algorithm (differentiation of input signal)

Application of real differentiating link makes possible detection of oscillations and to level the influence of the steady state component in input signal. Phase shifting blocks with already inserted phase/frequency characteristics compensate for the phase difference between the input and the output signal respectively. At the output of the algorithm exists a proportional link for amplification of control impact (X_{POD}), which corrects the X_m quantity within the control algorithm for the steady state operation. Parameter n is determined by the input signal in dependence of stability investigation results. Series compensated line current or transmitted power appear as the measured input signal; this is based on the requirement that only the locally available signals should be used for control purposes on the TCSC installation [2, 3]

The second interesting solution within the observed problematic is represented by the algorithm based on the mean and oscillating components of the controlled parameter, which have both earlier determined frequency, see Fig. 4.

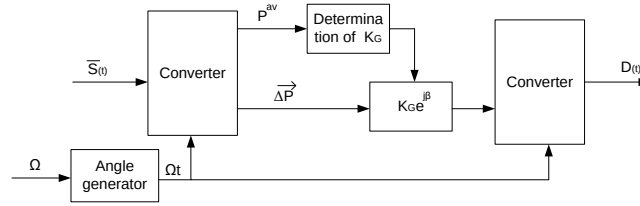


Fig. 4: Traditional oscillation damping algorithm (differentiation of input signal)

Efficiency of the above described algorithms has been proven in practice by different studies [5] and their implementation in many installations worldwide. Their analyze has at the same time indicated the following deficiencies:

- There is a limitation in frequency band of oscillation in input signal for a number of algorithms (see Fig. 4)
- A big number of calculations and necessity to provide many real time digital simulations of power system with TCSC in order to confirm correctness of selected parameters

Suggested traditional algorithms are this way not universal, they do not cover damping of power system oscillations in wide frequency specter and need improvements.

2.2 Improved method for damping of power system oscillations

Based on new possibilities offered by implementation of microprocessor technology in modern devices for emergency and normal power system control a modified structure of control module used for controlling the compensation degree of TCSC has been proposed, see Fig. 5.

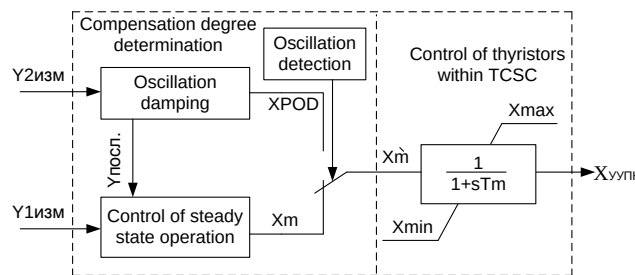


Fig. 5: Suggested structure of TCSC control module

Control during steady state conditions is based on earlier described algorithms for steady state operation, which means that the control block supports the given parameters for steady state operation. After the oscillations have been eliminated and this control block has been reinserted the new steady state operating parameters are corrected according to the set values for TCSC operation. This change is based on the information on new steady state condition (compensation degree, transmitted power or current over the TCSC power line) received from the new oscillation damping block when the automatic system stability control equipment is not present or directly from this equipment, when available.

Oscillation damping and change of control algorithm are based on comparison of controlled quantity (transmitted power) with earlier specified sensitivity limits. Switching action from the control block for steady state operation to the control block for oscillation damping is performed when the observed parameter appears out of the sensitivity limits. The oscillation damping block is again taken out of operation after the observed control quantities (transmitted power or δ angle) remain within the newly determined steady state operating limits for a certain predetermined time. These limits may be considerably narrower than the limits specified for detection of oscillations, which switched on the operation of damping algorithm.

The algorithm for control of TCSC in transient conditions is based on the analysis of transmitted power angular characteristic during each discrete oscillation cycle. Let us explain its operation on the basis of simplified power system as presented in Fig. 6, comprising power plant G with local consumption and connected to the remaining power system with two overhead transmission lines. For

the simplification of example we suppose that power plant G does not operate with short or long term turbine regulation. In case of any perturbation and its elimination in power plant as well as on connecting power lines a transient situation will appear, which will be characterized by power oscillation, transmitted over connecting lines between power plant and remaining power system. Electrical angle δ between two EMFs will oscillate as well. Relation between the power, transmitted over power line PL1 and angle δ between voltage phasors at the line PL1 ends is presented by equation (1) [6].

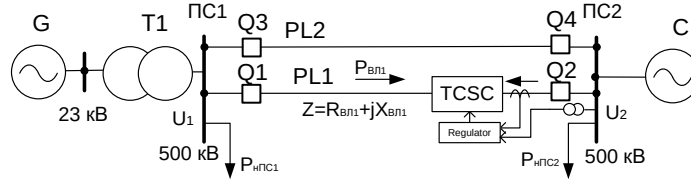


Fig. 6: Power system equivalent diagram

Reduction of acceleration area after the activation of oscillation damping block will happen by means of controlling the TCSC on the basis of fixation of δ angle in (1) between voltage phasors at the PL1 line ends in comparison with previously determined steady state condition $\delta_{\text{ст1 уcx}}$ and calculation of required compensation degree required to get current angle $\delta_{\text{ст1}}(t)$ between line end voltages to the pre-disturbance value under the condition that the measured transmitted power would not change. In this special case will be determined the required compensation degree presented by solution of quadratic equation (2), which follows the reorganization of (1) according to line PL1 reactance X , if one includes also substitutes $P_{B/1(t)}$ and $\delta_{\text{ст1 уcx}}$. The increase of compensation degree in suggested control algorithm is stepwise and related to the increase of current angle $\delta_{\text{ст1}}(t)$. This regulation principle will end immediately after the first breaking process is finished.

The oscillation damping algorithm in TTCS will consequently monitor parameter $P_{B/1 \text{ уcm нocy}}$ (power of the steady state operation) during the breaking of rotor in equivalent power plant on the basis of previous oscillation and fixation in power control (1) corresponding to the newly determined steady state situation (see Fig. 8). This is achieved by replacing quantities P_3 and δ_3 in (3) - (5) with $P_{B/1 \text{ уcm нocy}}$ and $\delta_{\text{ст1}}(t)$. Initial solution of equation (2) at the beginning of control gives also the required compensation degree necessary to bring the current transmitted power at current angle $\delta_{\text{ст1}}(t)$ to the value $P_{B/1 \text{ уcm нocy}}$.

$$\frac{U_1 U_2 X_{B/1} \sin \delta_3}{X_{B/1}^2 + R_{B/1}^2} + \frac{U_1 U_2 R_{B/1} \cos \delta_3}{X_{B/1}^2 + R_{B/1}^2} - \frac{U_2^2 R_{B/1}}{X_{B/1}^2 + R_{B/1}^2} = P_3 \quad (1)$$

$$A_2 x^2 + A_1 x + A_0 = 0, \quad (2)$$

$$A_2 = P_3 \quad (3)$$

$$A_1 = -U_1 U_2 \sin \delta_3 \quad (4)$$

$$A_0 = -U_1 U_2 R_{B/1} \cos \delta_3 + U_2^2 R_{B/1} + P_3 R_{B/1}^2 \quad (5)$$

Calculated characteristic quantity differs at the begging of control from its current value on TCSC. After that it is possible to observe better approaching of compensation degree towards the required one. The adjustment of compensation degree will take place as long as it will need to reaches the required value. For this reason increases also the moment at the output of equivalent generator G, which is providing power to the remaining power system, see Fig. 6. After that and until the algorithm starts again a new required compensation degree on TCSC is determined. It is clear that suggested solution does not depend neither on frequency of oscillation as well as on particular control level of TCSC related to its independence on set compensation angle, see Fig. 4,

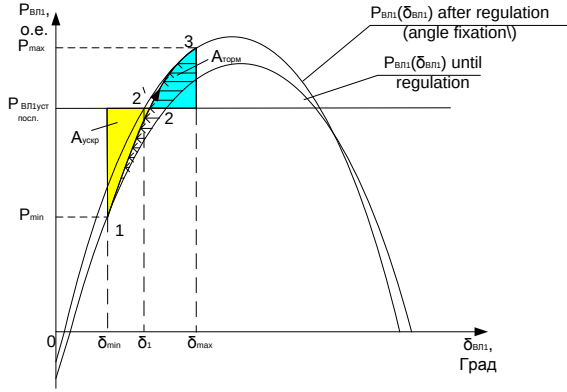


Fig. 7: Angular characteristic change for PL1 at algorithmically fixed angle

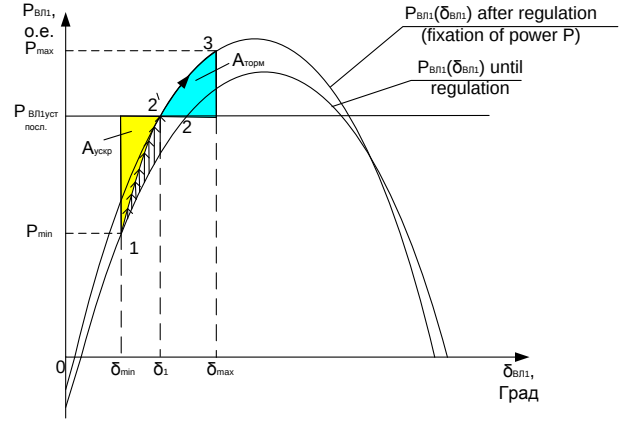


Fig. 8: Angular characteristic change for PL1 at algorithmically fixed power

First question which appeared at realization of this TCSC control algorithm was related to informational availability of locally required parameters. Control parameters (2) U_1 , U_2 and $\delta_{a1(t)}$ are in both cases derived with certain accuracy by the method of modelling the remote terminal point, which is successfully used in different out of step blocking and tripping products worldwide ([7] and [8]). To determine the magnitude of power for new steady state situation is suggested to use the $P_{B/1\text{уст. посл.}}$ parameter, retrieved on the basis of calculating two areas B1 and B2 (equations (6) and (7)) on the angular characteristic of transmitted power and under the conservative assumption that during the calculation for one half cycle there is no power losses. In such case it is possible to use equality (8) (Fig. 9). Inserting in equality (8) expression (7) and considering also (6) it is possible to derive result, as expressed by (9) and presenting the evaluated power for new steady state operation after each oscillation half cycle.

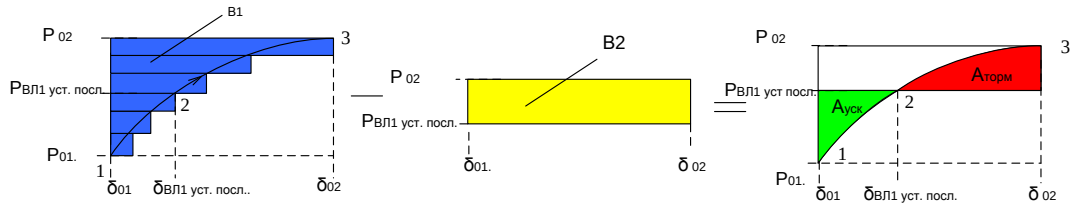


Fig. 9: Graphical presentation of calculation method for $P_{B/1\text{уст. посл.}}$

$$B1 = \int_{\delta_{01}}^{\delta_{02}} (P_{02} - P_{(t)}) d\delta = \sum_{t=t_{01}}^{t_{02}} (P_{(t)} - P_{(t-1)}) (\delta_{(e)} - \delta_{01}) \quad (6)$$

$$B2 = (P_{02} - P_{B/1\text{уст. посл.}}) (\delta_{02} - \delta_{01}) \quad (7)$$

$$B1 - B2 = A_{\text{уст}} - A_{\text{торм}} = 0 \quad (8)$$

$$P_{B/1\text{уст. посл.}} = P_{02} - \frac{B1}{\delta_{02} - \delta_{01}} \text{ where} \quad (9)$$

(δ_{02}, P_{02}) - the integration end point (the limit point of oscillation – point 3 on Fig. 9)

(δ_{01}, P_{01}) - the initial point of integration (the limit point of integration – point 1 on Fig. 9)

The suggested method provides oscillation damping within wide frequency range and with for each particular disturbance case precisely determined control action at the early beginning of acceleration (deceleration). This increases transient and static stability of power system and facilitates at the same time required operating times for relay protection, installed on power lines with TCSC.

2.3 Some tests performed

The suggested algorithm has been tested on example and the results obtained have been compared with the results obtained on the same example by traditional algorithms. The test have been

performed in simulation environment PSCAD for the network model, including power plant with local load and connected to remaining power system by two overhead transmission lines (see Fig. 6). The suggested method makes possible faster oscillation damping in major number of cases and in wider range of perturbation impacts.

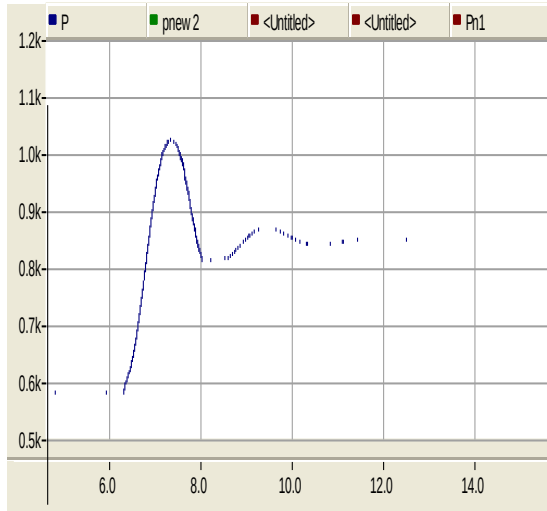


Fig. 10: Traditional algorithm ($\delta=0.65\text{rad}$)

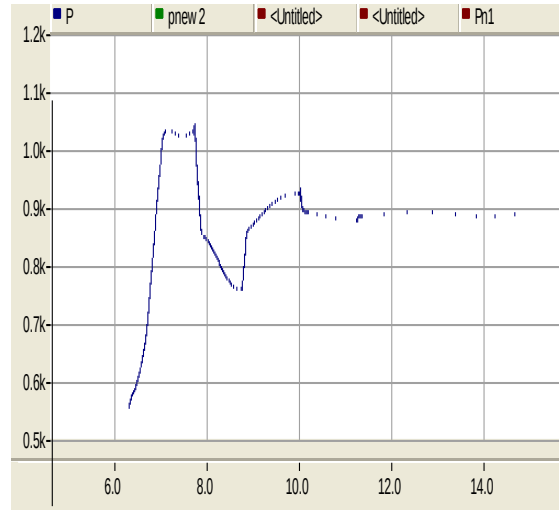


Fig. 11: Improved algorithm ($\delta=0.65\text{rad}$)

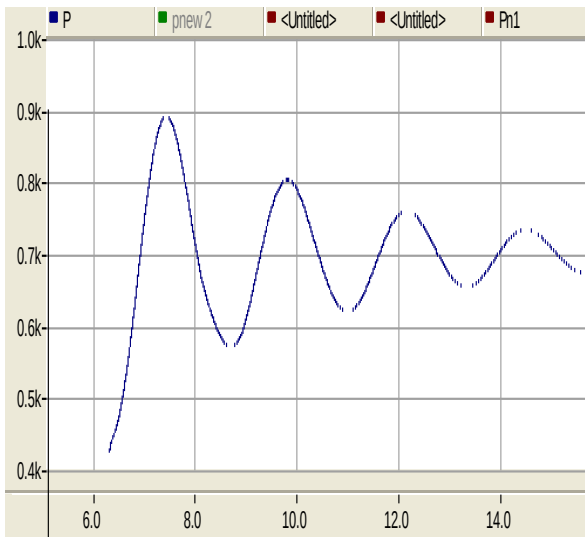


Fig. 12: Traditional algorithm ($\delta=0.45\text{rad}$)

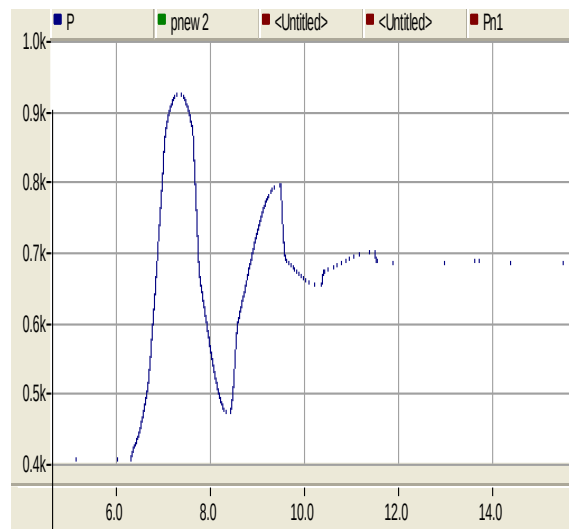


Fig. 13: Improved algorithm ($\delta=0.45\text{rad}$)

Two different cases are presented by corresponding time diagrams, both showing the oscillations caused by sudden disconnection of LP2 parallel power line under different system loading conditions.

Fig. 10 and

Fig. 12 present the oscillations obtained by implementation of traditional TCSC control algorithm, realized on the basis of power line PL1 current differentiation. Fig. 11 and

Fig. 13 present the operation of TCSC controller based on the above explained operating principle. It is clearly visible from both diagrams that due to the absence of influence of oscillation frequency on the operation of new algorithm its effective work does not depend on the current power system operating situation at which the disturbance has been initiated.

A number of additional investigations connected to the operation of new algorithm for more complicated non homogenous systems are planned for the future. The influence of different inaccuracies and a number of other parameters influencing the operation of suggested oscillation

damping method will be studied as well together with development of practically available algorithm for control of TCSC and all necessary documentation.

3 CONCLUSION

- 1) A new method for control of thyristor controlled series compensation in transient conditions has been suggested and investigated. Its operation is based on continuous analyze of transmitted power angular characteristic, which makes possible effective oscillation damping independent on current compensation degree and their oscillation frequency. This is achieved by continuous calculation of required compensation degree and its approximation towards the required value by hyperbolic regulation process. The investigation results have shown that the time of transient oscillation can be reduced for 1.5 to 2 times. In addition to this it is possible to cover for wider range of oscillation frequencies and at the same time secure correct operation of the algorithm.
- 2) Suggested and developed is also a method to obtain the parameters necessary for evaluation of parameters required for post oscillation steady state operation, based on the conservative assumptions of measured accelerating and decelerating energy scuring stability of power system and obtained during each oscillation half cycle

REFERENCES

- [1] R. Mohan Mathur, Rajiv K. Varma. Thyristor-Based FACTS Controllers for Electrical Transmission System. Wiley-IEEE Press, 2002.
- [2] A. Del Rosso, C. A Canizares and V.M. Dona. A study of TCSC controller design for power system stability improvement. IEEE Trans. Power Sys., vol-18, pp. 1487-1496, 2003.
- [3] A. Del Rosso, C. A Cañizares, V. Quintana, and V. Doña. Stability Improvements Using TCSC in Radial Power Systems. Proc. North American Power Symposium (NAPS), Waterloo, October 2000.
- [4] N. Martins, H.J.C.P. Pinto and J.J. Paserba. TCSC Controls for Line Power Scheduling and System Oscillation Damping - Results for a Small Example System. Proceedings of 13th Power System Computation Conference (PSCC), Trondheim. Norway, June 1999.
- [5] L. Ängquist, C. Gama. Damping Algortihm based on Phasor Estimation. Paper 0-7803-6674-3, 2000 IEEE (IEEE PES WM 2001 paper 63-04).
- [6] Веников В.А. Переходные электромеханические процессы в электрических системах. М.: изд. «Высшая школа», 1970 г.
- [7] Наровлянский В.Г. Современные методы и средства предотвращения асинхронного режима электроэнергетической системы. М.: Энергоатомиздат, 2004 г.
- [8] D. Reimert. Protective Relaying for Power Generation Systems. Boca Raton, CRC Press, 2006.