Improvement of Transfer Capacity by TCSC and WAMS in Central East Europe power

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Abstract: Implementation of new technologies into existing power system can solve the problems associated with increasing power consumption. Increasing demand of electricity in combination with unplanned power flows from north part of interconnected power system to south creating serious problems for TSO. This paper investigates the use of WAMS systems for management of TCSC equipment to increase net transmission capacity in Central East Europe power system. Optimal control and allocation of TCSC is very important for TSO. Optimal allocation, effectiveness, and utilization of phasor measurement units (PMUs) for TCSC device which was designed for power flow control and increasing of net transfer capacity were investigated

Keywords: TCSC, WAMS, transfer capacity, FACTS

1 Introduction

The liberalization of the electricity market we have gained new opportunities and possibilities for electricity market participants. On the other hand, liberalization also causes considerable problems for operators of transmission system operators (TSO). Unsolved problem of our time is the constantly increasing number of unpredictable renewable energy in northern Europe and insufficient power generation in south.

Due to unplanned power flow, the security criterion N-1 is unfulfilled cause of overloading of interconnecting transmission lines.

This facts brings operation of existing transmission systems closer to their physical limits.

One of the opportunities for solving this problems was building of new power transmission lines or effectiveness utilization of existing transmission system capacity by utilization of specialized systems such as flexible alternating current (AC) transmission systems (FACTS). This special devices can perfectly control the power flow across transmission lines and helps operators to maintaining stable operation of power systems. In combination with sophisticated WAMS systems it can solve this problem.

Transmission system operators of each power systems talk about the need of increase of the reliability and safety of the power system. Transmission system operators sometimes have to manage the power system to its safety operational limits. Moreover, in some cases, it may also occur a large area outages (Black out), that have negative consequences for society as a whole. Due to the facts, the monitoring of power systems are made through a SCADA (Supervisory Control and Data Acquisition) systems and EMS (Energy Management Systems), which do not work in real time and thus the results are not applicable for fast transient processes occurring in the system. Moreover, both these control schemes are not time synchronized.

2 WIDE-AREA MONITORING SYSTEM (WAMS)

First GPS - based PMU was invented in 1988. Synchrophasor technology has developed for few years. During this time, many new promising concepts have been proposed and implemented, for instance, the wide-area measurement / monitoring system (WAMS). It brings huge potential for upgrading the operation, control, supervision and protection of power systems.

WAMS (Wide Area Monitoring System) systems is synchronous measurements of phasors and applied mainly in the transmission lines.

In addition to surface monitoring and visualization of the network in real time or subsequent off-line analysis of events, these subsystems are used also for the operational management of the network (for example, using the full capacity of transmission lines), monitoring of system stability and rocking and early warnings. Application of WAMS systems can also be found in distribution networks, for example in the management of distributed energy resources. Synchronous measurement in general reduces the error in subsequent calculations and process control systems, resulting in improvement of dispatching network management.

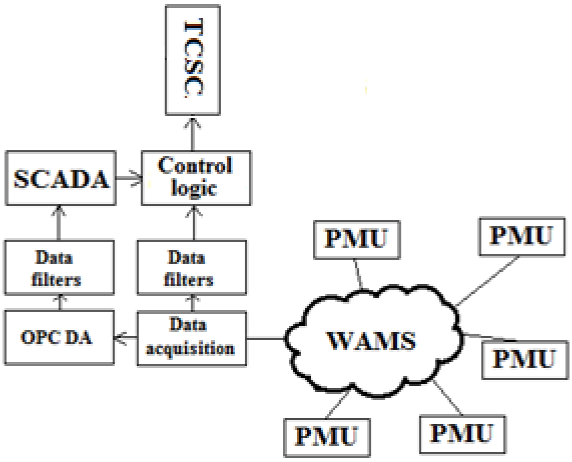

Figure 1 TCSC control scheme with WAMS

Use of PMU for data acquisition for regulation of FACTS devices can bring new possibilities for further development of the network control. Measurement of phasors at different part of the power system, can be used for optimization of power flow, minimize power loses or to maximize transmission capacity between various TSO. Example of utilization of WAMS for control of TCSC is shown on Figure 2.

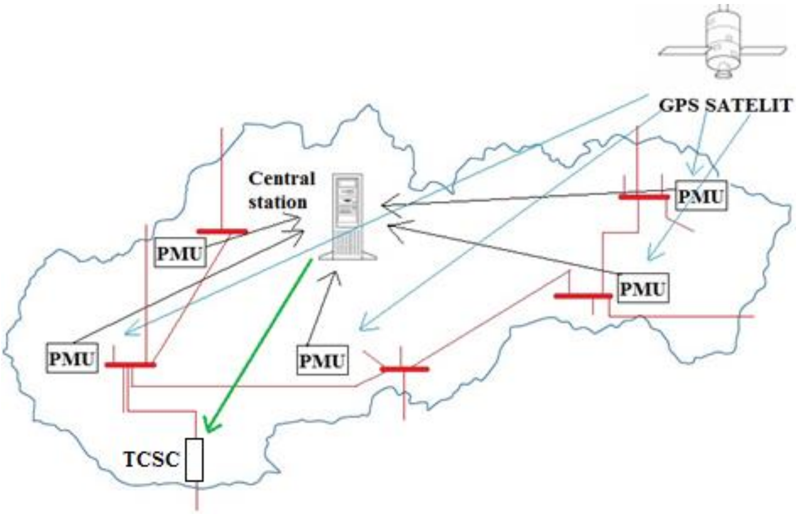

Figure 2

Slovak power system with PMUs and TCSC

3 Thyristor controlled series condenser (TCSC)

TCSC consists of a capacitor which is parallel connected to a thyristor regulated reactor. This configuration allows you to smoothly change the impedance of the transmission lines and smooth control of frequency of the capacitance in a wide range. For proper function of TCSC is control very important.

The control of the reactance of TCSC is very complex and dynamic process. Efficiency and effect of TCSC are very dependent on the accuracy of calculation of the TCSC reactance at the moment. In case of wrong calculation of the reactance, may also occur to the opposite effect than what is provided TCSC.

May also occur to the opposite effect than what is provided TCSC. TCSC consists of 3 parts and these are The Fig.1 shows the main diagram of TCSC. It consists of 3 parts: capacitor battery C, parallel connected reactor L and the thyristors VT1 and VT2 [5].

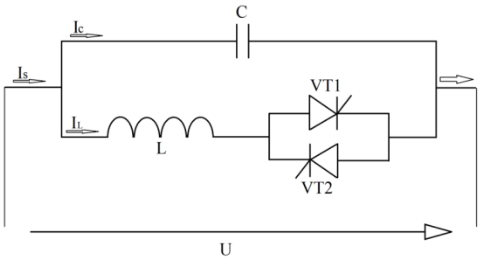

Figure 3 TCSC

$$i_c = C \cdot \frac{dv}{dt} \tag{1}$$

$$i_L = L \cdot \frac{di_L}{dt} \tag{2}$$

$$i_S = i_C + i_L \tag{3}$$

where

I_C and I_L - is the instantaneous capacitor and reactor current
i_S - is the instantaneous current of controlled line
U - is the voltage of TCSC.

TCSC can be controlled by changing the opening angle of the thyristors α, which is modifying the frequency of the capacitor. Relationship below gives the relationship between the opening angle of the thyristor (α) and reactance of whole TCSC - X_{TCSC} (α).

$$X_{TCSC}(\alpha)=X_C-\cdot\frac{X_C^2}{(X_C-X_P)}\cdot\frac{\sigma+\sin\sigma}{\pi}+\frac{4\cdot X_C^2}{(X_C-X_P)}\cdot\frac{\cos^2(\frac{\sigma}{2})}{(k^2-1)}\cdot\frac{\left(k\cdot tg\left(\frac{k\cdot\sigma}{2}\right)-\tan\left(\frac{\sigma}{2}\right)\right)}{\pi}$$

where

X_C - is the capacitor capacitance

X_P - is the inductive reactance of the reactor connected in parallel to the condenser.

σ = 2(π - α) = opening angle of TCSC controller

k = $\sqrt{\frac{X_C}{X_P}}$ = compensation ratio.

X_{TCSC} (α) is a unique feature by which we can continuously change the TCSC reactance. TCSC can operate in capacitive or inductive mode, but the transition from one mode to another we must avoid resonance. TCSC is modelled as a variable capacitor, which is limited only by the regulatory scope of the angle α.

The Control range of TCSC is:

$$X_{TCSC}(\min) \le X_{TCSC}(\alpha) \le X_{TCSC}(\max), \tag{5}$$

where

X_{TCSC} (min) = X_{TCSC} (180°) – thyristor in permeable state

X_{TCSC} (max) = X_{TCSC} (α_{min}), – thyristor in trailing state [5].

4 TRANSFER CAPACITY CALCULATION

TTC represents the maximum feasible power exchange, which can be transmitted between two interconnected power systems reliably and without observance of the system stability criterion. To determine Total transfer capacity ex ante, modelling and simulation of the effects of power exchanges between the two interconnected power systems are necessary. This is usually carried out by simulating of load flows within the two systems and between them. Starting from expected configurations of networks, cross-border exchanges, consumption scenarios and power generations, the generated power is pushed between both systems in order to cause additional cross-border flows. This is done by increasing the generation in system X and decreasing the generation in system Y by the same steps. The consumer loads in both systems remain unchanged. The shifts of generation are stopped when security problems occur in system X, in system Y or on the interconnection tie lines [3], [4], [7], [9].

The resulting Total transfer capacity value in this case is to be interpreted as the expected maximum volume of power flow that can be transferred through the interconnection between the two systems, which does not lead to power system constraints in either system, if future network conditions and especially generation scenario were perfectly known in advance.

NTC is given by the following equation:

$$NTC = TTC - TRM \tag{6}$$

TRM covers the forecast uncertainties of tie-line power flows due to imperfect information from market players and unexpected real time events. Information from market players is imperfect at the time the transfer capacities have to be communicated. This comes in addition to the uncertainty on some power system parameters, as well as the uncertainty of tie-line flows due to unexpected real time events, which are always possible. In this paper value of TRM is assumed to be 200 MW.

Figure 4 TCSC placements in Slovak power system

Calculation of maximal transfer capacity between Slovakia - Hungary and Slovakia - Czech Republic was provided by simulation program. In the simulation program there was constructed Central East Europe power system, with all branches and generators. Transfer capacity calculation was realised by maintaining of safety criterion N-1 in whole power system. For maintaining maximum power flow in cross section between Slovakia and Hungary was decreased power generation in south part of the whole power system and in the north part was increased.

There were 4 variants of cross-border transaction between Slovakia - Czech Republic and 3 variants between Slovakia - Hungary. All variant were defined below.

4.1 Variant SK-HU I.

Values of transfer capacity for SK – HU cross-border connection for default grid without TCSC installed on power system are shown in table 1. For maintaining N-1 criterion was line V 448 (VE Gabčíkovo - Györ) when line V449 (Levice - Göd) was switched off.

Table 1. Transfer capacity for variant SK-HU I.

Branch	Line loads [MW]	TTC [MW]	NTC [MW]	Limit element (N-1)
448 (Gabčíkovo-Györ)	1077,2	1928,4	1728,4	448 (449)
449 (Levice-Göd)	851,2			

4.2 Variant SK-HU II.

Values of transfer capacity for SK – HU cross-border connection for default grid with TCSC installed to series with line V 449 (Levice - Göd) are shown in table 2. For maintaining N-1 criterion was line V 490 (EMO - Levice) when line V491 (EMO - Levice) was switched off.

Table 2. Transfer capacity for variant SK-HU II.

Branch	Line loads [MW]	TTC [MW]	NTC [MW	Limit element (N-1)
448 (Gabčíkovo-Györ)	1085,8	2382,8	2182,8	490 (491)
449 (Levice-Göd)	1296,9			

4.3 Variant SK-HU III.

Values of transfer capacity for SK – HU cross-border connection for default grid with TCSC installed to series with line V 448 (VE Gabčíkovo - Györ) are shown in table 3. For maintaining N-1 criterion was line V 440 (Lemešany - Mukačevo) when line V449 (Levice - Göd) was switched off.

Table 3. Transfer capacity for variant SK-HU III.

Branch	Line loads [MW]	TTC [MW]	NTC [MW]	Limit element (N-1)
448 (Gabčíkovo-Györ)	1317,8	2514	2314b	440 (449)
449 (Levice-Göd)	1194,2			

4.4 Variant SK-CZ I.

Values of transfer capacity for SK – CZ cross-border connection for default grid without TCSC installed to power system are shown in table 4. For maintaining N-1 criterion was line V 270 (P. Bystrica - Lískovec) when line V404 (Varín - Nošovice) was switched off.

Table 4. Transfer capacity for variant SK-CZ I.

Branch	Line loads [MW]	TTC [MW]	NTC [MW]	Limit element (N-1)
404 (Nošovice – Varín)	-889	2545,7	2345,7	270 (404)
424 (Sokolnice – Križovany)	-532,2			
497 (Sokolnice – Stupava)	-910,1			
280 (Sokolnice – Senica)	-101,2			
270 (Liskovec – P. Bystrica)	-113,4			

4.5 Variant SK-CZ II.

Values of transfer capacity for SK – CZ cross-border connection for default grid with TCSC installed to series with line V 404 (Varín - Nošovice) are shown in table 5. For maintaining N-1 criterion was line V 280 (Senica - Sokolnice) when line V497 (Stupava - Sokolnice) was switched off.

Table 5. Transfer capacity for variant SK-CZ II.

Branch	Line loads [MW]	TTC [MW]	NTC [MW]	Limit element (N-1)
404 (Nošovice – Varín)	-1340,2	2677,5	2477,5	280 (497)
424 (Sokolnice – Križovany)	-336,9			
497 (Sokolnice – Stupava)	-661,3			
280 (Sokolnice – Senica)	-242			
270 (Liskovec – P. Bystrica)	-97,1			

4.6 Variant SK-CZ III.

Values of TTC for SK – CZ cross-border connection for default grid with TCSC installed to series with line V 424 (Križovany - Sokolnice) are shown in table 6. For maintaining N-1 criterion was line V 270 (P. Bystrica - Lískovec) when line V404 (Varín - Nošovice) was switched off.

Table 6. Transfer capacity for variant SK-CZ III.

Branch	Line loads [MW]	TTC [MW]	NTC [MW]	Limit element (N-1)
404 (Nošovice – Varín)	-586,8	2738,5	2538,5	270 (404)
424 (Sokolnice – Križovany)	-1336,3			
497 (Sokolnice – Stupava)	-492,1			
280 (Sokolnice – Senica)	-172,2			
270 (Liskovec – P. Bystrica)	-151,1			

4.7 Variant SK-CZ IV.

Values of TTC for SK – CZ cross-border connection for default grid with TCSC installed to series with line 497 are shown in table 7. For maintaining N-1 criterion was line V 270 when line V404 was switched off.

Table 7. Transfer capacity for variant SK-CZ IV.

Branch	**Line loads [MW]**	**TTC [MW]**	**NTC [MW**	**Limit element (N-1)**
404 (Nošovice – Varín)	-682	2741	2541	270 (404)
424 (Sokolnice – Križovany)	-352,2			
497 (Sokolnice – Stupava)	-1335,1			
280 (Sokolnice – Senica)	-217,4			
270 (Liskovec – P. Bystrica)	-155,2			

5. ECONOMIC ASPECTS

On the final price of TCSC have the greatest impact rated power [MVA]. These characteristic of the TCSC, especially for large transmitted power is significant for economical solution. The investment for TCSC with the same parameters according to experience, reaching about 400% of the PST transformer price, there can therefore be considered with a value of € 19,000 to 1 MVA of installed capacity of PST. For presupposition maximal current limitation 2000A corresponds ca. 1400 MW. Install of TCSC requires the construction of specialized fields in substations. Field for TCSC must be equipped compared to standard outlets (eg. For line or transformer) - a measure, protected and especially on a full field equipment by-pass (In contrast with conventional fields are fields with TCSC featured by 2 or 3 circuit breaker and with an appropriate number of isolators). Price of one average field in substation of 400 kV is approximately 3.0 million €. Price of field with TCSC is approximately 7.5 million €.

Conclusions

Simulation results shows, that the best place for installing TCSC on cross-border connection between Slovakia and Hungary was on line V 448 (VE Gabčíkovo - Györ). Value of TTC with TCSC installed to series with line V 448 (VE

Gabčíkovo - Györ) is 2512 MW. It was about 151 MW bigger than TTC with TCSC installed on line 449 (Levice - Göd).

The best place for implementation of TCSCb on cross-border connection between Slovakia and Czech Republic was on line V 497 (Stupava - Sokolnice). Value of TTC with TCSC installed on line V 497 was 2741, 9 MW. TTC with TCSC installed on line 424 (Krožovany - Sokolnice) was 2738, 5 MW, that was smaller about 3 MW, and Total transfer capacity with TCSC on line 404 (Varín - Nošovice) was 2677, 5 MW. That was smaller about 60 MW against TTC with TCSC on line 497.b

References

[1] I. Dobson, S. Green, R. Rajaraman, Ch. L. DeMarco, F. L. Alvarado, R. Zimmerman.: Electric Power Transfer Capability: Concepts, Applications, Sensitivity, Uncertainty, Power Systems Engineering Research Center November 2001 online [12.05.2015] <http://www.pserc.cornell.edu/tcc/tutorial/TCC_Tutorial.pdf>

[2] Calculation methods online [12.05.2015] <http://www.elia.be/en/products-and-services/cross-border-mechanisms/transmission-capacity-at-borders/calculation-methods>

[3] Ministry of Economy of Slovak Republic: Návrh Energetickej politiky Slovenskej republiky, May 2014 Online: cit.[19. feb. 2015] <http://www.rokovania.sk/File.aspx/ViewDocumentHtml/ Mater-Dokum-165253?prefixFile=m_>

[4] FAQ CEPS, a.s. online [19. Feb. 2015] <http://www.ceps.cz/ENG/Media/Pages/FAQ.aspx>

[5] Definitions of Transfer capacities in liberalised Electricity Markets online [19. Feb. 2015] <https://www.entsoe.eu/fileadmin/user_upload/_library/ntc/entsoe_transferCapacityDefinitions.pdf>

[6] C. Grande-Moran: Phase-shifting Transformer Modeling in PSS®E online [12.05.2015] <http://ewh.ieee.org/soc/pes/newyork/NewSite/PDFs/Protection%20Related/Phase_Shifting_Transformer_Modeling.pdf>

[7] ENTSO-E, Network Code on Capacity Allocation and Congestion Management, September 2012.

[8] ENTSO-E, Network Code on Forward Capacity Allocation, October 2013.

[9] K. Noháč, L. Noháčová: Detekce nestandardních stavů v sítích s obnovitelnými zdroji energie“. Proceedings of 7th International scientific symposium Elektroenergetika 2013, September 18–20, 2013, Stará Lesná, Slovakia

[10] M. Mešter, M. Hvizdoš : The fundamentals of wide area monitoring in power system. In: Energetika un elektrotehnika, 2005, vol. 15 no. 4, p. 110-115, ISSN 1407-7345

[11] R. Jakubčák, Ľ. Beňa, M. Kmec: Possibilities of Using Facts Devices In Power System. In: Acta Electrotechnica et Informatica. Roč. 13, č. 3 (2013), s. 8-11. - ISSN 1335-8243

[12] Program rozvoja SEPS, a.s., na roky 2011 – 2020. [online]. [cit. 08.08.2011]. Available on internet: http://www.sepsas.sk/seps/Dokumenty/PR2020.pdf

[13] FAQ CEPS, a.s. online [19. Feb. 2015] http://www.ceps.cz/ENG/Media/Pages/FAQ.aspx

[14] Z. Čonka, M. Kolcun: Impact of TCSC on the Transient Stability In: Acta Electrotechnica et Informatica. Roč. 13, č. 2 (2013), s. 50-54. - ISSN 1335-8243 Available on internet :www.versita.com/aei. (2013)