COMPARATIVE ANALYSIS OF A STATCOM WITH ADDITIONAL CAPACITOR AND A SVC FOR IMPLEMENTING IN A POWER SYSTEM

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In this paper an analysis of a STATCOM device with an additional capacitor and a SVC device is made to show their capability to regulate the reactive power flow in an electric node (absorption or injection) and dynamic response after an increase of load. Results of these simulations are illustrated in the chapters below using Eurostag software program.

Keywords: STATCOM, Shunt VAr Compensator, Electric Power System, Eurostag

1. Introduction

Maintaining transmission power systems in a normal and safe operational state represents a great challenge today because of the complex problems that need to be rapidly dealt with. For example the variable operation of renewable power sources, that imply voltage variation, active and reactive power fluctuations in power system, the dynamic character of the load curve, the unpredictable operation of equipments and human errors [1]. Green energy is a reality and wind farms are the most common renewable power sources to be connected to the grid, also if their installed power is significant enough, they represent both an advantage and a disadvantage. Power demand is increasing, putting more and more stress on the grid, therefore existing power networks must be efficiently utilized in order to meet the new demands. One of the solutions for these problems is using FACTS devices for optimize the power transmission capacity and for operate the power system in a safe mode [2], [3].

In this article two Power Electronics devices, a STATCOM and a SVC, were modeled using dynamic simulation software in order to bring out their capabilities to regulate reactive power flows. Also two disturbances were simulated in a modeled network in order to study the response time of the devices. The first scenario consists of an event in the power network, the tripping of a power line that had a high load of both active and reactive power, shifting that

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load on another power line connected to the network, and the second scenario consists of an increase of active and reactive power demand in the node where the compensating device is connected. The analysis of their response time and stabilized output parameter values was made using Eurostag [4] software program.

2. Modelling the devices in Eurostag

2.1 SVC device description

According to IEEE – CIGRE definition the SVC is a Static VAr generator with variable output parameters due to the inductive or capacitive current in order to maintain specific parameters of the Electric Power System, usually the node's voltage at a reference value [3].

Depending on the power system voltage level, the SVC device can operate in two modes: when system voltage is low, the SVC generates reactive power (SVC capacitive), and when system voltage is high, it absorbs reactive power (SVC inductive).

The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three thyristor switches (Thyristor Switched Capacitor or TSC). Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR) [5].

The key component of the SVC is the Voltage Regulator, which based on measurements from the connection node determine the reactive power output for the device. Using thyristors the SVC devices gain an important advantage due to their fast response times. Also the contribution to the short-circuit currents is negligible. The SVC device also eliminated the problems related to mechanical commutation (sudden voltage spikes, and other transient phenomena).

SVC V-I Characteristic

The SVC can be operated in two different modes:

- In voltage regulation mode (the voltage is regulated within limits);
- In VAr control mode (the SVC susceptance is kept constant).

As long as the SVC susceptance B stays within the maximum and minimum values, imposed by the total reactive power of capacitor banks (Bc_{max}) and reactor banks (Bl_{max}), the voltage is regulated at the reference voltage V_{ref}. However, a voltage droop is normally used (commonly between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the fig. 1.

As an important kind of FACTS devices, SVC is widely used in power systems for shunt reactive compensation [5]. However, using TCR and TSC for reactive power generating, the thyristor controlled SVC brings harmonics and possible harmonic resonance into system.

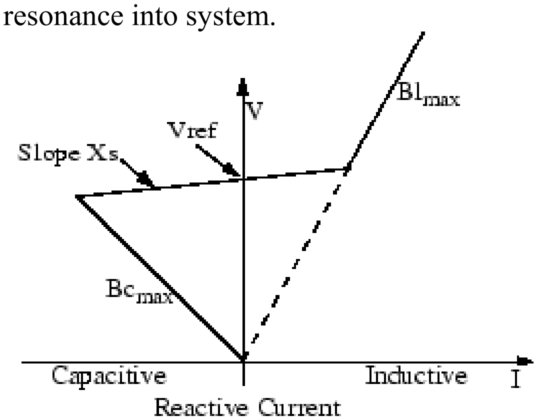


Fig. 1. SVC V-I characteristic [6]

The V-I characteristic is described by the following three equations [6]:

$$V = \begin{cases} V_{ref} + X_s \cdot I \quad \text{if SVC is in regulation range } (-B_{C\max} < B < B_{l\max}) \\ -\dfrac{I}{B_{c\max}} \quad \text{if SVC is fully capacitive } (B = B_{c\max}) \\ \dfrac{I}{B_{l\max}} \quad \text{if SVC is fully inductive } (B = B_{l\max}) \end{cases} \tag{1}$$

where: V is positive sequence voltage [kV];

I – reactive current [A], I > 0 indicates an inductive current;

X_S – slope or droop reactance [%];

B_{cmax} – max capacitive susceptance with all TSCs in service, no TSR or TCR [μS];

B_{lmax} – max inductive susceptance with all TSRs in service or TCRs at full conduction, no TSC [μS].

2.2 STATCOM device description

A STATCOM is also called an Advanced Static Var generator (ASVG). Its operation mode is basically the same as SVC device with wider operation ranges and faster responses. As stated before, the control element of SVC is a thyristor, a semi-controllable element that can only be turned off when valve current crosses zero. STATCOM device is made of fully controllable elements [7].

The basic connection of a STATCOM is shown in fig. 2. Its control element is the fully controlled valve (GTO). The ideal GTO switch characteristic is that the valve is turned on under positive valve voltage with positive control current on its gate valve is turned off with negative control current on its gate. Valve resistor is zero when it conducts, and is infinity when it is turned off. A GTO can manage the switch-off by gate control in comparison with the thyristor where switch-off is only possible at current zero-crossing. STATCOM in fig. 2 is a voltage type self commutation full-bridge inverter according to power electronic theory.

The capacitor DC voltage acts as an ideal DC voltage source to support the inverter. The regular diode connected in the opposite direction and parallel with the GTO is a path for continuous current, providing route for the feedback energy from the AC side. The inverter normal operation is to transfer the DC voltage into AC voltage having controllable magnitude and phase angle at the same frequency as the AC system.

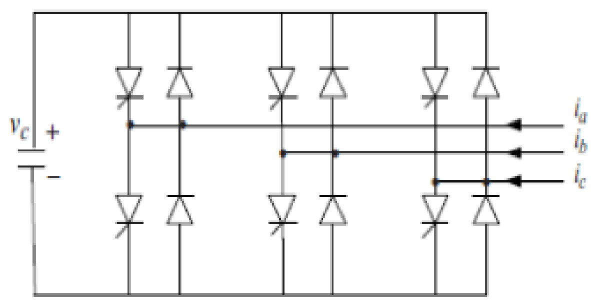


Fig. 2. STATCOM VSC circuit [6]

Every GTO of the converter has a turn-on/off period of 180 degrees. Assuming V the line voltage of the network connection node R is equivalent phase resistance, L is equivalent phase reactance, δ is converter fire angle, and system voltage is [6]:

$$\begin{cases} u_a(t) = \sqrt{2}U\ \sin(\omega t) \\ u_b(t) = \sqrt{2}U\ \sin(\omega t - \frac{2\pi}{3}) \\ u_c(t) = \sqrt{2}U\ \sin(\omega t + \frac{2\pi}{3}) \end{cases} \tag{2}$$

According to mathematical model of STATCOM, the dynamic model of 6-pulse STATCOM from fig. 3 can be described as following [6]:

$$\begin{cases} \dfrac{di_a}{dt} = \dfrac{1}{L}\left[KV_{dc}\sin(\omega t+\delta) - u_a(t) - Ri_a\right] \\ \dfrac{di_b}{dt} = \dfrac{1}{L}\left[KV_{dc}\sin(\omega t+\delta-\dfrac{2\pi}{3}) - u_b(t) - Ri_b\right] \\ \dfrac{di_c}{dt} = \dfrac{1}{L}\left[KV_{dc}\sin(\omega t+\delta+\dfrac{2\pi}{3}) - u_c(t) - Ri_c\right] \\ C\dfrac{dV_{dc}}{dt} = -K\left[i_a\sin(\omega t+\delta) + i_b\sin(\omega t+\delta-\dfrac{2\pi}{3}) + i_c\sin(\omega t+\delta+\dfrac{2\pi}{3})\right] \end{cases} \quad (3)$$

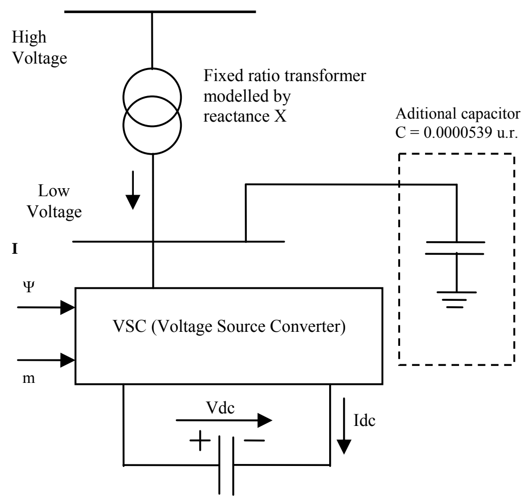


Fig. 3. Studied STATCOM structure

STATCOM V-I Characteristic

The operation characteristics of STATCOM are shown in fig. 4, and approach rectangular.

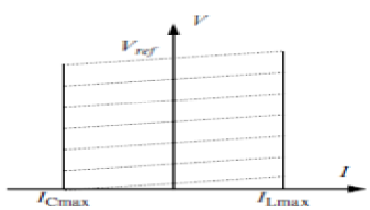


Fig. 4. STATCOM V-I Characteristic

The constraints of maximum voltage and current are determined by the STATCOM capacity. Voltage setting is determined by the control scheme [8]. Comparing with SVC inverse triangular operational characteristics, STATCOM has wider operation ranges.

In order to connect the device to the network a step up fixed ratio transformer is used. An additional capacitor was used in order to increase the reactive power output in the node and decrease the STATCOM cost. The capacitor is efficient when there are high loads in the network. Its control is always ON or always OFF, but a control logic can be implemented in the STATCOM model macroblock.

3. Case study

The analysis was made on a 400 kV power system (fig. 5), with an eleven node network using Eurostag software. The used parameters in the simulations are presented in table 1, table 2 and table 3.

Table 1

Loads

Name	P MW	Q MVAr
NHVC1	300	100
NHVC2	50	40
NHVA1	600	100
NHVA3	10	10
NHVD1	600	150
NHVB1	100	50
NHVCBQ	600	150

Table 2

Transformer parameters

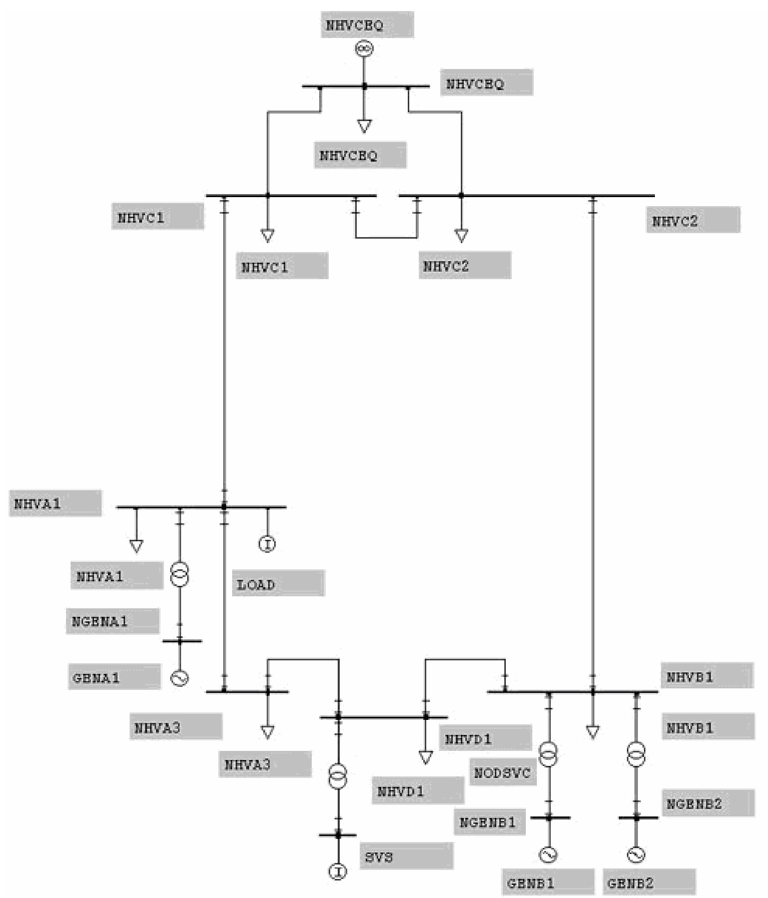
Node	Un1/Un2 kV	Sn MVA	$R_T + jX_T$ %
NHVA1-NGENA1	24/418	1300	0.24 + j10
NHVB1-GENB1	24/418	444	0.24 + j10
NHVB1-GENB2	24/418	111	0.24 + j10
NHVD1-SVS	24/418	200	0.24 + j10

Table 3

Generator parameters

Name	Sn MVA	Pn MW	Un kV
GENA1	1150	1100	24
GENB1	444	400	24
GENB2	111	100	24

Both devices were implemented in the same node by turn. This was possible because in Eurostag the parameters for basic power flow and dynamic simulation are taken from two different files, allowing the loading of the two configurations one with the SVC and the other with the STATCOM on the same topology easily. The same event sequence was run. The connection node (NHVD1) of the devices has a Q=150 MVAr reactive power consumption (table 1), and it's connected to the rest of the network by two 400 kV lines. The simulations show that at t = 50 s one of the lines is tripped (NHVD1 - NHVB1), and at t = 200 s a load increase. The results are shown in the graphics below. The network can be divided into two large areas. The northern area, where the slack bus is implemented has an excess of power production and the southern area which has an increased power demand. Power transmission between the two areas is done through two OHL with power transmission limit set at 1000 MVA. The SVC has a total reactive power of 100 MVAr (60 MVAr capacitive, 40 MVAr inductive), and the STATCOM has a 100 MVAr reactive power also, with an additional capacitor. The focus was made on the voltage on the connection node (NHVD1), and the reactive power, after each of the event that took place.



Fig, 5. Studied network

4. Simulation results

4.1 Event sequence with the SVC implemented

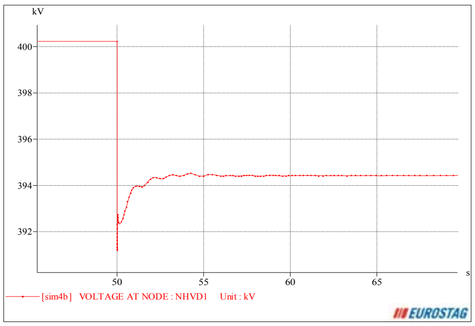


Fig. 6. Voltage variation at the connection node after tripping of the line NHVD1 - NHVB1

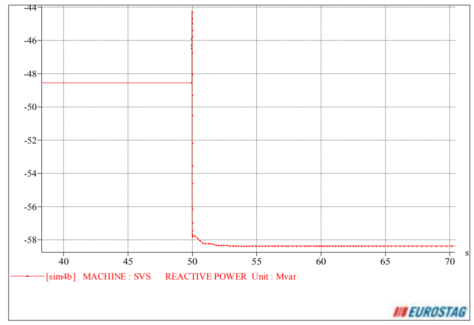


Fig. 7. Reactive power output of SVC after line NHVD1 - NHVB1 tripping

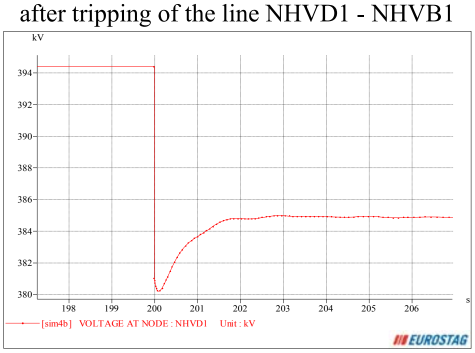


Fig. 8. Voltage variation at the connection node after the load increase

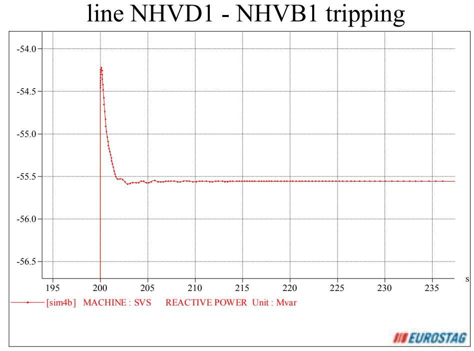


Fig. 9. Reactive power output of SVC after the load increase

4.2 Event sequence with the STATCOM implemented

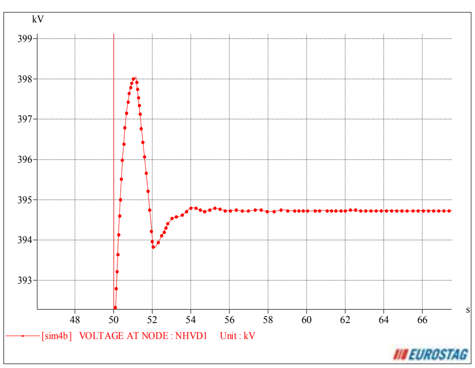


Fig. 10. Voltage variation at the connection node after the line NHVD1 - NHVB1 tripping

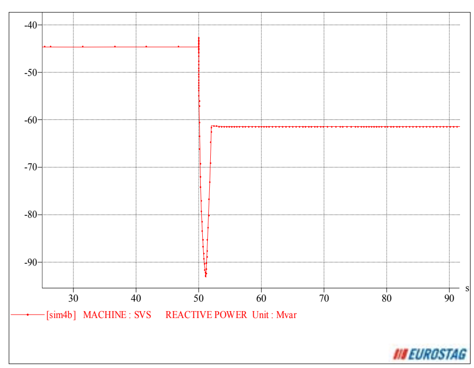


Fig. 11. Reactive power output of STATCOM after the line NHVD1 - NHVB1 tripping

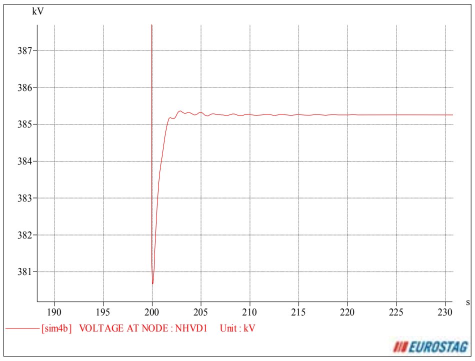


Fig. 12. Voltage variation at the connection node after load increase

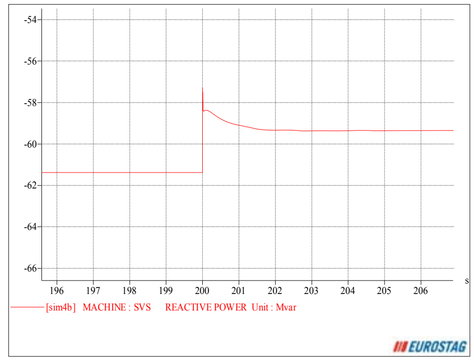


Fig. 13. Reactive power output of STATCOM after the load increase

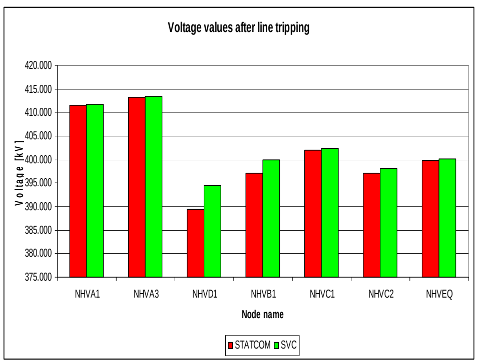


Fig. 14. Voltage variation of the nodes after line tripping

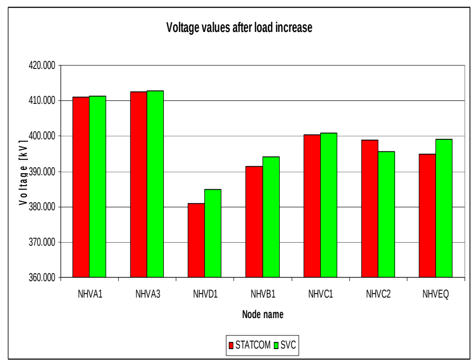


Fig.15. Voltage variation of the nodes after the load increase

By analyzing the two scenarios, it can be concluded that both the SVC and the STATCOM reacted towards bringing the voltage, close to the nominal 400 kV value in the used network. In the first scenario, the post fault voltage was around 394.5 kV for both devices, with about 61 MVAr of reactive power injected, it can be noticed that the STATCOM injects more reactive power, but not by much. In the second scenario, the voltage stabilizes at 385 kV with an output of 55.5 MVAr from the SVC and of 59 MVAr from the STATCOM. The reactive power oscillations dampen faster in the STATCOM scenario confirming that the device has a faster dynamic response time.

6. Conclusions

The paper shows a comparative study between the behaviors of two FACTS devices, STATCOM and SVC, used for voltage issues in the network after different events cases. Because the STATCOM device is more expensive than an SVC device, in order to have the same reactive capability, a capacitor has been added in the software model. The SVC is a widely used device with a mature technology, but the STATCOM has a faster response time, a smaller size, and a better voltage control regulator. Based on V – I characteristics the STATCOM's both capacitive and inductive current can be provided at full range independent of the system voltage, in contrast with the SVC which can supply only diminishing output current with decreasing system voltage, as delimited by its maximum capacitive admittance. As can be observed in the results the STATCOM has an increased transient rating in both capacitive and inductive operating regions, while the conventional SVC has no means to transiently increase the VAR Generation.

Due to their capabilities both devices are recommended for reactive power compensation in a transmission power system. Depending on network requirements the authors have concluded that SVC is the most popular choice, but where the response time is critical the STATCOM is more efficient. Therefore, STATCOM can be successful used for bringing and maintaining voltage at different values in substations where wind farms are connected.

Acknowledgment

The work has been funded by the Sectorial Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labor, Family and Social Protection through the Financial Agreement POSDRU/107/1.5/S/76903.

R E F E R E N C E S

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