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THE IMPACT OF SVC DEVICE ON THE VOLTAGE AND POWER QUALITY IN THE ELECTRICAL TRANSMISSION NETWORK

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The new challenges in the Romanian National Power System (NPS), namely the integration of very high electricity production from renewable sources and the concentration of wind power production in the South -East of the NPS (about 80% of the installed capacity in power plants) determines the change of power flows in short intervals of time. Therefore, a fast voltage level adjustment is required and appropriate to the respective NPS mode of operation. In this paper, the simulation were carried out with Eurostag software, which is specific for energy processes modeling and simulation that are made in NPS and it was demonstrated how a SVC device can improve the voltage level (limiting the voltage with about 4 kV in steady-state operation) in areas where the voltage is constantly exceeded.

Keywords: reactive power, voltage stability, compensation, power quality

1. Introduction

Considering that in the Romanian Power System is installed only one SVC that belongs to a disruptive consumer (which has been fitted to reduce the disturbances introduced by a steel plant production which has an Electric Arc Furnace (EAF) and a Foundry Metallurgical Furnace (FMF)) and the fact that there are ongoing projects for the installation in two important nodes from the system of other FACTS devices to help in controlling the voltage, it is important to analyze the impact that this type of devices can produce in Romanian NPS. The method used in the paper, modeling of this type of devices in the software specific for energy processes used by the Transmission and System Operator is a novelty for national power system and simulations can be extended to more complex networks.

It is known that long-term operation at very high voltages (or that constantly exceed the permissible limits) affects the equipment of the Electrical Transmission or Distribution network. Thus, maintaining a voltage level in the admissible band (which at the level of 400 kV is, according to the European Regulations 360-420 kV at unlimited operation) is essential for the development of the National Power System. This overlaps in the case of Romania with the fact

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that the substations are not all upgraded and the primary and secondary equipment already has an outdated operating life. Thus, optimal solutions must be found to help the system and its operation in terms of voltage stability, power quality and reactive power circulations. And making an optimal distribution of these types of installations is important for the stable operation of the system. Was considered that SVC is one of these solutions and I showed in this paper how the installation of such a device in a node (or more nodes) of the network can also help also the adjacent nodes by limiting the voltage with about 3 kV in steady-state operation, in a sensitive area from National Power System, where voltage level was constantly exceeded.

The percentage of active electricity losses from Electricity Transmission Network resulting from reactive power flows is increasing from year to year. The proposed measures to reduce this percentage are the control of the voltages at the power plants that evacuate in the Electric Transmission Network, the regulation of the voltages in the 400 kV, 220 kV and 110 kV substations by modifying the plots of the transformer units and realizing unblocking in the network of 110 kV to reduce the circulations of reactive power. The installation of SVC devices for compensate the reactive power in some 400 kV stations also helps to reduce the active energy losses resulting from the reactive power flows.

A FACTS device (SVC, STATCOM) can improve power system transmission and distribution performance in a number of ways. The Static Var Compensator (SVC) is a device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids. Installing a SVC in one or more suitable points in the network can increase transfer capability and reduce losses while maintaining a smooth voltage profile under different network conditions. The dynamic stability of the grid can also be improved, and active power oscillations mitigated. The SVC regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive).

Considering the major changes that the National Power System from Romania has over the past few years, the installation of a very large number of renewable power plants in a very short time, and the fact that this power system was not built to integrate this type of power plants, the system had to adapt to the new requirements. Another important issue was the concentration of these power plants from renewable sources in a certain area of the power system (about 80% of the installed capacity in wind power plants are concentrate in south-east zone of power system) where weather conditions were favorable (wind, sun). So it creates an increasing need for flexibility, reliability, fast response and accuracy in the areas of generation, transmission, distribution and consumption of the National Power System [1].

One of the major problems that can be associated with power systems is voltage instability or voltage collapse. Most of the incidents that occurred in some electricity systems, which led to "blackout", were based on voltage instability. Under stressful conditions, the only possibility to avoid voltage collapse is to reduce reactive power consumption or increase reactive power output by introducing reactive power sources. The introduction of FACTS devices means of compensating the reactive power, capable of controling the voltage in network nodes is a very good way to improve the voltage profile and the voltage stability limit of the system due to the very fast response, with fine adjustment of the reactive power of these equipments, when changing the operating status of the system.

2. FACTS devices - SVC

Flexible Alternating Current Transmission Systems (FACTS) are new devices emanating from recent innovative technologies that are capable of altering voltage, phase angle and/or impedance at particular points in power systems. Their fast response offers a high potential for power system stability enhancement apart from steadystate flow control. The Static Var Compensator (SVC) is a device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids [5]. The SVC regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive).[2]

Reactive power compensation systems (like SVC) are derivative connected equipment, which include capacitors and/or shunt reactor statically controlled by means of thyristors, respectively voltage source converters, and are particularly advantageous from the following points of view:

- very high response speed;
- continuous regulation of reactive power with the possibility of both absorption and reactive generation;
- insignificant contribution to the short-circuit power;
- easy maintenance;

- resilience to defects (failure of a component of the installation does not lead to unavailability because it has a modular construction).

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).

In transmission applications, the SVC is used to regulate the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use thyristor controlled reactors to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. By connecting the thyristor-controlled reactor, which is continuously variable, along with a capacitor bank step, the net result is continuously variable leading or lagging power[4]. A typically schema of an SVC comprises one or more banks of fixed or switched shunt capacitors or reactors, of which at least one bank is switched by thyristors. Elements which may be used to make an SVC typically include:

- Thyristor controlled reactor (TCR), where the reactor may be air- or iron-cored;
- Thyristor switched capacitor (TSC);
- Harmonic filter(s);
- Mechanically switched capacitors or reactors (switched by a circuit breaker).

SVC can be operated in two different modes: in voltage regulation mode (the voltage is regulated within limits as explained below) or in VAR control mode (the SVC susceptance is kept constant). In the paper we operate SVC in voltage regulation mode, so it implements the following V-I characteristic (Fig. 1).

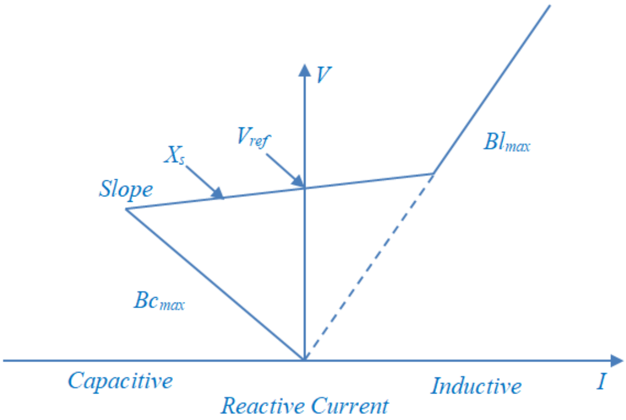

Fig.1. SVC V-I characteristic [4]

As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (Bcmax) and reactor banks (Blmax), the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure. The V-I characteristic is described by the following three equations[6]:

$$V = \begin{cases} V_{ref} + X_s \cdot I & \text{if SVC is in regulation range } (-Bc_{max} < B < Bl_{max}) \quad (1) \\ -\dfrac{I}{Bc_{max}} & \text{if SVC is fully capacitive } (B = Bc_{max}) \quad (2) \\ \dfrac{I}{Bl_{max}} & \text{if SVC is fully inductive } (B = Bl_{max}) \quad (3) \end{cases}$$

where V is the voltage magnitude; Vref is the voltage reference; I is the reactive current (when I > 0 indicates an inductive current); Xs represents the slope or droop reactance; Bcmax is the maximum capacitive susceptance with all TSCs in service, no TSR or TCR and Blmax is the maximum inductive susceptance with all TSRs in service or TCRs at full conduction, no TSC.

Typical values for the slope Xs are in the range of 0.02 to 0.05 p.u. with respect to the SVC base. The slope is needed to avoid hitting limits for small variations of the bus voltage.

3. Case study: SVC installation opportunity in the Romanian NPS

3.1. System analysis

In this paper was analyzed a small part of Romania's National Power System, from a node where the voltage value is constantly exceeded against the limits set by the European Regulation (in this case limits for 400 kV are 360 kV - 420 kV). According to the Electric Transmission Network Technical Code the voltage stability is achieved under the coordination of the TSO (Transmission System Operator) through the participation with the own installations of the producers, of the TSO and of the consumers. The use of the manufacturers' own installations for voltage regulation is limited by the operating program of the respective generators. Thus, for the regulation of the voltage in the analyzed area, the TSO is depending on the operation in compensatory regime of some hydropower groups in certain operating regimes.

In the case of the operation of the hydropower groups in compensatory regime the costs are very high, costs that are found in the tariff of system services paid by the final consumer of electricity. Another method used to control the voltage at this moment in Romania's NPS is the disconnection of the overhead lines from the electrical transmission network, which must also be solved. In this context, it is necessary to identify new solutions for voltage control in the analyzed area, and the FACTS type devices are the most efficient in this case.

The analyzed area consists of 3 nodes of 400 kV, respectively 4 OHLs with the nominal voltage 400 kV.

The performed analysis consists of identification of the SVC impact on the voltage regulation and improve the voltage profile and power quality. The simplified schema of the network used in the paper is shown in Fig. 2. In the analyzed scenario we considered the production in the wind power plants as maximum (100% production in wind power plant). Node 1 voltage is constantly exceeded in the normal way of functioning reaching values greater than the limit set by European Regulation - 420 kV (Fig. 3).

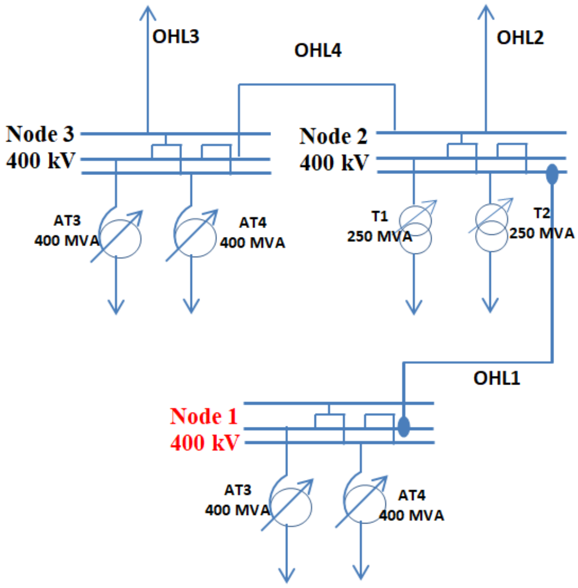

Fig. 2. Simplified schema used in the paper regarding 400 kV analyzed area 3 nodes of 400 kV, respectively 4 OHLs with the nominal voltage 400 kV

Node 1 voltage is constantly exceeded in the normal way of functioning reaching values greater than the limit set by European Regulation - 420 kV (see Fig. 3). The simulations were performed with a database in the complete Romanian National Power System scheme and were made with Eurostag program, which is a program specific to the activities carried out in the energy system.

3.2. Eurostag modeling for the 400 kV area

For the network area used in the paper, was analyzed the voltage level for a period of one year for Node 1 (August 2018-August 2019).

During this year, the voltage in Node 1 was exceeded during the normal operating period, for 219 days with an average voltage of 423 kV (minimum 421 kV, maximum 431 kV). The profile of the voltages that exceed the limit of the European Regulation of 420 kV, for this analysis period is presented in Fig. no. 3. Introducing of reactive power compensation devices (FACTS devices), capable of regulating voltage in network nodes is a great way to improve the voltage profile and system stability limit due to fast response, fine tuning of the reactive power of these equipments, at changing the system's operating state. In this paper was analyzed the impact of a SVC type device on the voltage stability and how can influence voltage level in a 400 kV area.

At this moment, in the Romanian National Power System is an ongoing project for installing two FACTS type devices (SVC/STATCOM) in Node 1 and Node 3, considered very important nodes in system. Node 3 is also a connection node with an interconnection OHL with the neighbours of the country.

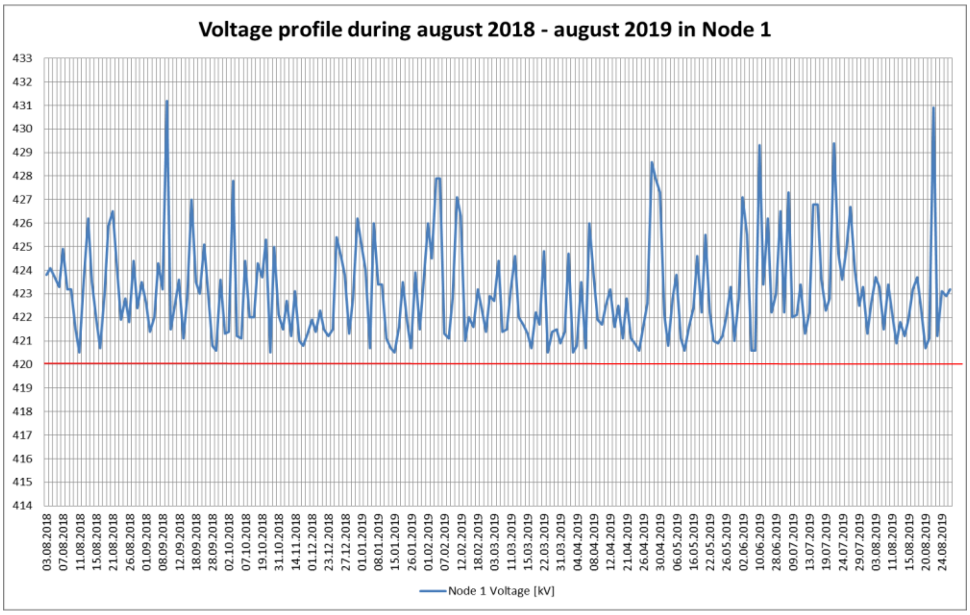

Fig. 3. Node 1 voltage profile during one year period

To highlight the need to install a SVC type device, we analyzed the voltage level in all three Nodes before installing SVC. Very important information is that during the program, no load regime could be used and therefore the voltage level is lower than the values presented above. Two possible solutions are considered: installing a SVC in Node 1 and improving the voltage in this node, or installing also in Node 1 and Node 3 (as provided by the ongoing project) and bringing the voltage to the desired level in all three nodes. The active power and reactive power transited along the buses are also centralized in Table 1.

Table 1

Voltage levels in 400 kV analyzed area without SVC

Name	Ur [kV]	U[kV] without SVC	Branch	Line flow	
			Bus name	Real power [MW]	Reactive power [MVAr]
Node 1	400 kV	408,03	OHL 1	113,6	-56
Node 2		408,56	OHL 1	-112,4	-23,4
			OHL 4	356,9	-96,5
Node 3		412,71	OHL 4	-352,6	58,7

*(*measurements are made from Node 1 to the other Nodes so the sign differs depending on the power flow from a node to another and where the reading is done)*

In order to see what is the influence of a SVC in this area, was simulated the functionality of a SVC device with the rated reactive power of 140 MVAr with Qmin= -100 MVAr and Qmax= +40 MVAr and 405 kV desired voltage, installed in the 400 kV Node 1. The results of this installation shows that SVC improves the voltage level only in this node, in the other two nodes being insignificant changes (see Table 2).

Table 2

Voltage levels with SVC installed in Node 1

Name	Ur [kV]	U [kV]	Branch	Line flow	
			Bus name	Real power [MW]	Reactive power [MVAr]
Node 1	400 kV	405,61	OHL 1	113,6	-68
Node 2		407,72	OHL 1	-111,8	-10,6
			OHL 4	356,9	-100,7
Node 3		412,33	OHL 4	-351,9	63,3

Installing a SVC device also in Node 3 with the rated reactive power of 200 MVAr with Qmin= -100 MVAr and Qmax= +100 MVAr and 407 kV desired voltage we can see the improvement of voltage level in all three nodes.

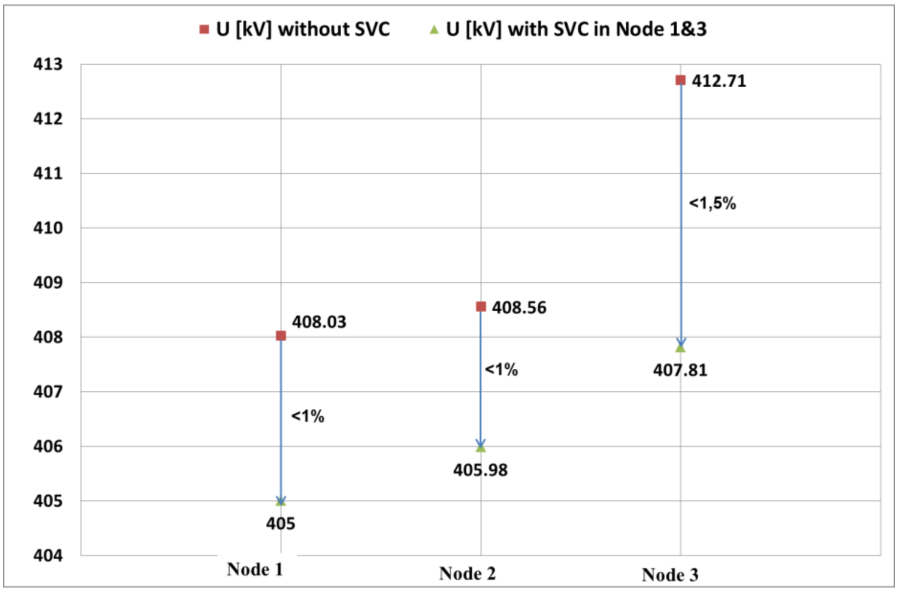

Fig. 4. Voltage values before and after SVC installation in Node 1 and Node 3 (the range of the voltage level in permanent regime is 0.9 p.u.-1.05 p.u. at 400 kV level)

The network area analyzed is a very important one, but also a a sensitive area from National Power System. Thus, bringing the voltage to a level as close as possible to the nominal value (and minimizing the active power losses due to the reactive power circulations) is an important goal in the further development of NPS. In the Electricity Transmission Network Development Plan, are provided measures to improve the power quality in the area, mainly of the voltage level by constructing new lines and installing auxiliary equipment for compensating the reactive power and control the voltage level.

Voltage - reactive power control is a particular importance for the safe operation of the National Power System (NPS). Voltage stability is the ability of a system to maintain the voltage level within acceptable limits in all nodes of the system, both under normal operating conditions and as a result of disturbances. Voltage stability problems are not new in the activities of operational planning, NPS operation programming and operational command, but have gained new importance due to the new challenges to which is facing NPS, namely:

- development of consumption centers outside the production areas, NPS comprising from the point of view of the production-consumption balance both strongly deficient areas and strongly surplus areas. Also, the sources of production in NPS are unevenly distributed between the north and south half of the country, about 80% of the electricity production being in the south-east;
- integration of very large production of electricity from renewable sources (4554 MW installed capacity on 01.01.2020 in wind, photovoltaic and biomass power plants) and concentration of production from wind and photovoltaic power plants in the south-east area of NPS (approximately 80% of the installed power of 4416 MW in the wind and photovoltaic power plants on 01.01.2020), determines the change of the power flows in short intervals.

4. Conclusions

Furthermore, the Static VAr Compensator (SVC) is one of the FACT devices that have their own benefits to improve or enhance in the power system. The main advantage of SVC over simple mechanically switched compensation schemes is their near instantaneous response to change in the system voltage. For this reason they are often operating at close to their zero-point in order to maximize the reactive power correction [8].

In this paper it was demonstrated how a SVC device can improve the voltage level in areas where the voltage is constantly exceeded. Considering that for the analyzed area the voltage is reduced by approximately 4 kV in the adjacent nodes, and in the node where it is installed the voltage is maintained at setpoint, I consider that the installation of such auxiliary devices is essential for the development of the National Power System. Given the situation regarding the voltage control and voltage profile in NPS and that it is necessary to install such equipments in some important network nodes, the disadvantages of SVC equipment is the high price (40$/kVAr) compared to capacitor banks that were installed in NPS to improve voltage control (8$/kVAr) and also the surface it occupies in the substation could be a disadvantage. In any case, a complete cost-benefit analysis has to be carried out to justify the economic viability of SVC installation.

Using this method, various scenarios can be made in several areas of the National Power System and the improvements brought by this type of devices can be observed both in voltage stability but also in limiting active power losses due to reactive power flows. In the analyzed 400 kV area in this paper there are no auxiliary compensation devices, and for voltage control certain hydropower groups are used in compensator mode, which has many disadvantages for NPS safety and. It is, therefore, important to install such devices and with an adequate calculation you can find the most favorable nodes where they can be installed, but also the necessary capacity of these devices. The method can be extended to verify the improvement of the voltage level also in the dynamic mode of operation, but also with more network areas in the NPS.

Taking into account the rapid development of certain Romanian NPS in respect of power plants from renewable sources, and the fact that such plants will be installed in the future, the energy strategy must go in this direction and implement solutions to be most effective regarding voltage control, voltage stability and also considering the installation of this type of equipments in more key points of the system.

The results can be compared with the current situation in the National Power System and is the beginning of the analysis of the impact that the installation of this type of devices has in the substations in Romania.

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