VOLTAGE SECURITY IMPROVEMENT IN TRANSMISSION NETWORKS USING SVC DEVICE

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The new challenges for electric power systems are the integration of renewable energy sources along with the continuous increase in load. In such conditions, power system stability issues such as insufficient voltage control and regulation must be resolved in the most cost-effective and efficient way to improve overall system safety and reliability.

This paper presents the voltage security improvement for transmission networks in power systems using an SVC device. In this work, the SVC device is used for power system performance improvement, and the location and capacity of SVC under large share of the renewable energy sources (RES) is determined by using the DIgSILENT software.

Keywords: voltage improvement, renewable energy sources, Static VAr Compensator

1. Introduction

The electrical power transmission systems are subjected to constant development aiming to boost the safety and reliability, whereas maintaining a high-quality power supply. To achieve these aims with the best and most comprehensive results, this is done through the use of FACTS devices (flexible alternating current transmission systems) [1- 2].

FACTS units, such as the Static VAr Compensator ‘‘SVC’’, use the most recent technology in electronic power switching devices to improve the voltage level in the transmission system in order to reach optimum level in the transmission system, while being environmentally friendly and cost-effective solutions for a wide range of power system requirements [3]. Flexible alternating current transmission systems (FACTS) provided utilities the option of delaying the construction of a new transmission line by rising capacity on existing transmission lines [4].

For a reliable power system, the profile of voltage all over the transmission network must be maintained within recommended limits, as voltage instability and line overloading are among the essential problems faced by power

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systems. Some actions may be required in order to guarantee that the system continues to run safely and reliably at an adequate level of functionality. There are many other types of impacts that may be studied at different resolutions, such as local system-wide and system-wide effects (see Fig. 1). In this figure, the red line includes issues that are more regional in nature, such as transmission and power system troubles. When it comes to local distribution system issues, the green dotted lines are important since they indicate where the problem is. Transmission and distribution efficiency are referred to as grid losses in the context of grid losses, whereas hydro/thermal efficiency is referred to as generating losses in the context of generating losses [5]. A typical problem of network integration concerns at the distribution level is that they are more concerned with the local or regional consequences of wind turbine/Photovoltaic deployment than they are with issues affecting the transmission network and system-wide issues, such as grid dependability.

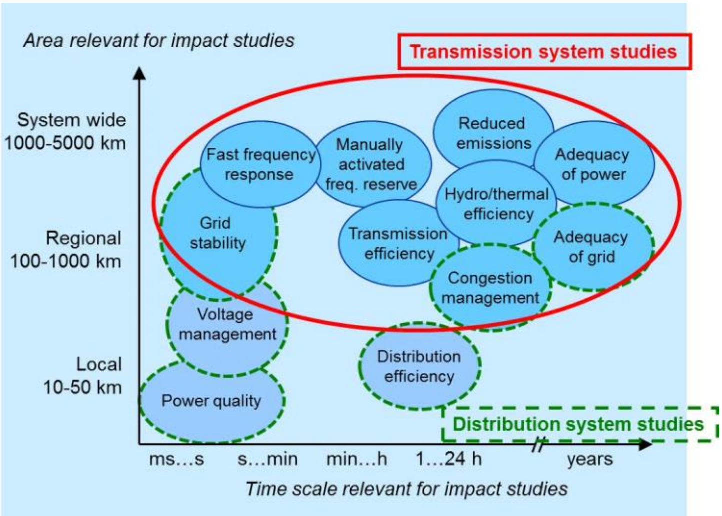

Fig. 1. The impacts of wind and solar energy on power systems/ divided into several time scales and geographic widths, depending on the study's aims, in order to better understand them [5].

2. SVC MODEL

Providing a high-level overview of the Static VAr Compensator model and the manner in which it impacts the system so as to communicate the problem formulation is the purpose of this part.

An example of this would be a variable shunt admittance, which may be positioned in the terminal node of the line or in the midst of a long line [6-8]. Generally speaking, a static VAr generator (SVC) is defined as a shunt-connected static VAr which has the ability to interchange inductive or capacitive current with the electrical power system in order to maintain or regulate specific power variables; in most cases, this control variable is the node voltage of the power system [9-10]. When the SVC is analyzed without losses, the admittance consists just of its imaginary component, which may take any value within a specified range, and the actual component (ordinarily between 0 and the max. SVC capacity calculated, herein the capacitance is 600 MVAr), this is indicated by:

$$y_{SVC} = jb_{SVC} \tag{1}$$

A Static VAr Compensator (SVC) placed in a node (Fig. 2) with a constantly varying setpoint is the subject of this article, which will be discussed further.

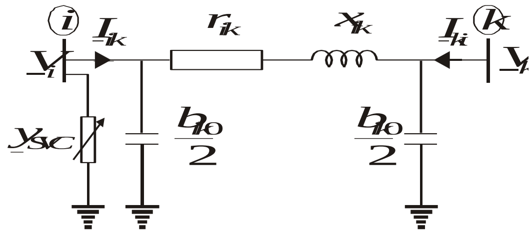

Fig. 2. Equivalent circuit of an SVC connected to a bus terminal

In steady-state, a Static VAr Compensator may be viewed of as a variable susceptance, which is a kind of sensitivity.

A simplified version of this model is seen in Fig. 3, which adds the transformer susceptance (B_T), in addition to the inductive susceptance (B_L), the capacitive susceptance (B_C), among other parameters.

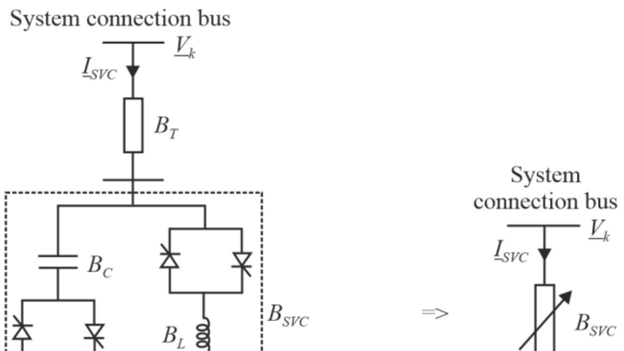

Fig. 3. SVC Modeling: a) structure; b) Simplified model.

The Model steady-state control law of the Static VAr Compensator (SVC), which is used in this application, is shown in Fig. 4, and it can be illustrated by the voltage - current feature described below, which is illustrated in Fig. 4 [11].

$$V_k = V_{ref} + X_{SL} I_{SVC} \tag{2}$$

Where V_k and I_{SVC} signify the regulated node-voltage and current of SVC device, respectively, and V_{ref} means the reference voltage, respectively.

Based on the SVC device rated specifications, typical values for the slope (X_{SL}) are in the range of (0.02 to 0.05) p.u. A suitable value for the slope must be selected in order to prevent hitting the capability limitations even when only minor changes in the bus voltage are present.

The following is the control rule that corresponds to the SVC feature (as seen in Fig. 4):

- In the event that the reference voltage is less than the observed voltage, $V_k > V_{ref}$, the Static VAr Compensator device is then absorbing reactive current at that point.
- In the event that the reference voltage is greater than the observed voltage, $V_k < V_{ref}$, then there is a need for reactive current injection into the node.

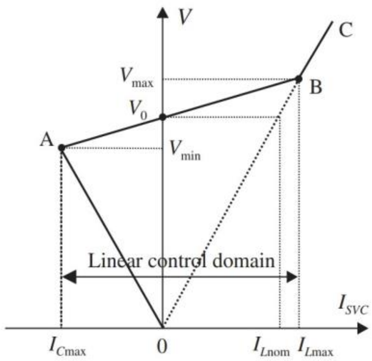

Fig. 4. Steady State V-I characteristic of the SVC

In order to calculate the reactive power generated (MVAr) or absorbed (MVAr) by SVC device, the following formula is used:

$$Q_i = V_i^2 B_{SVC} \tag{3}$$

as well as its sign being dependent on the sign of susceptibility B_{SVC} inductive reactive power is taken into consideration with a positive-mark, whereas Capacitive reactive power is taken into consideration with a negative- mark.

4. Problem Formulation

A - The objective function is to Minimize the voltage deviations:

$$O = \sum_{i=1}^{n} \left(\frac{V_{i,ref} - V_i}{V_{i,ref}} \right)^2 \tag{4}$$

knowing that n means the number of buses, V_i means the actual voltage at bus i and V_{ref} means the reference voltage at bus i.

B - Choosing the optimal location for the SVC

The choice of location of the FACTS device depends largely on the influence to be achieved as well as the specific system characteristics. The SVC is often appropriate when reactive power flow or voltage improvement is required [12], because choosing the optimal location of FACTS devices in the power system means increasing the load capacity of the system as well as minimizing system losses [13-15].

C- SVC reference value

The SVC capacitance (SVC size) is expressed as the quantitative value of the reactive power linked to the bus voltage 1 per unit.

The capacitive case refers to that the SVC generates reactive power and injects it into the system through its connected bus and taken into consideration with a positive - mark. the inductive case refers to that the SVC absorbs reactive power from the system and is taken into consideration with a negative- mark.

The size of static var compensator is changing that can take discrete values within the interval:

$$-Q_{L\max} \le Q_{SVC} \le Q_{C\max} \tag{5}$$

5. Case study

In this section, the voltage regulation in transmission networks using SVC device is studied on the test network Nordic32, which consisted of 32 buses, 20 units of generating, 46 transmission lines, and 22 consumers (loads).

In 1995, the Nordic 32 Test System was developed by Cigre Task Force 38.02.08. The purpose of its creation is to illustrate the voltage collapse in the State of Sweden, as it represents an imaginary model, but it has characteristics and features analogous to the transmission network system in Sweden [16-17]. The power system is designed to simulate transmissions of large amounts of electrical power from hydroelectric power plants in the north to the high load region in southern Sweden. So, the system consists of two regions with different production and consumption characteristics:

- North: with mainly hydro generation and few load
- South: with a few thermal power generation units and much load.

The total generation of real power in MW is 11368.46 and the total load of real power in MW is 10940 MW. The nominal voltage of the system is 400, 220 and 130 kV. Fig. 4 shows the single-line diagram of the Nordic 32 power system.

I. Base case results

The one-line diagram of the Nordic32 test network is illustrated in Fig. 5.

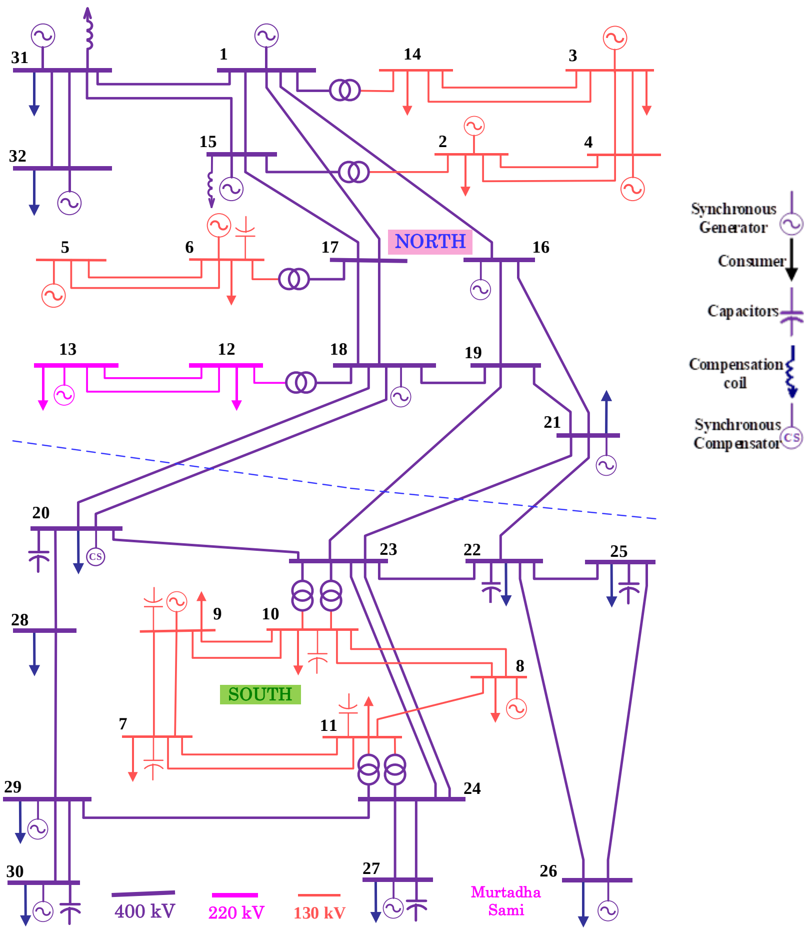

Fig. 5. Single line diagram of NORDIC 32-Bus power system

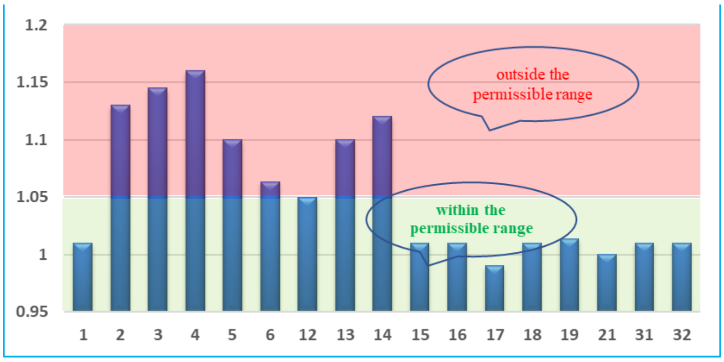

Fig. 6. Voltage profile in North region in the base case.

Fig. 6 shows that the voltages in the North region are normal (i.e., within the recommended range) for some buses, and the other buses having a significant increase (out of the permissible limit). Fig. 7 shows that the voltages in the South Region are all within the permissible limit.

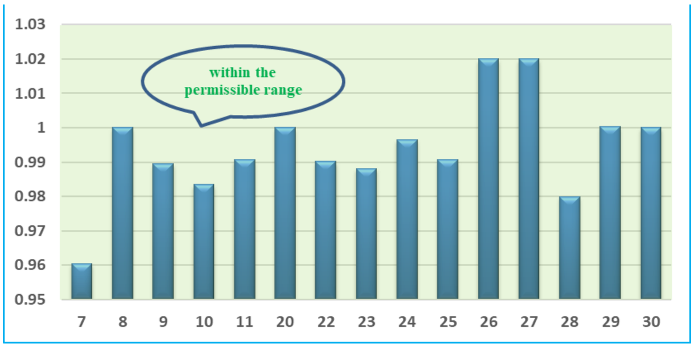

Fig. 7. Voltage Profile in South region in the base case

II. Results of incorporating RES into the Nordic 32 power system:

In order to reach a voltage limit case, the voltage setpoints of several buses (2, 3, 4, 5, 6 and 13) are reduced from 1.05 p.u. to 1.02 p.u. At the same time, 15% of the total generation in the system is replaced by RES (see Tabel 1).

Table 1

The location and capacity of RES

	The Location	The Capacity [MW]	RES Type	The Region
1	Bus 7	600	WT	South region
2	Bus 11	505.3	PV	
3	Bus 17	300	WT	North region
4	Bus 19	300	PV	
Total		1705.3	RES	

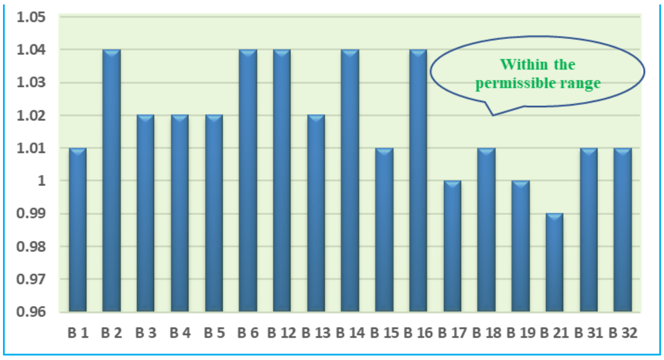

Fig. 8. Voltage profile in North Region after adding RES.

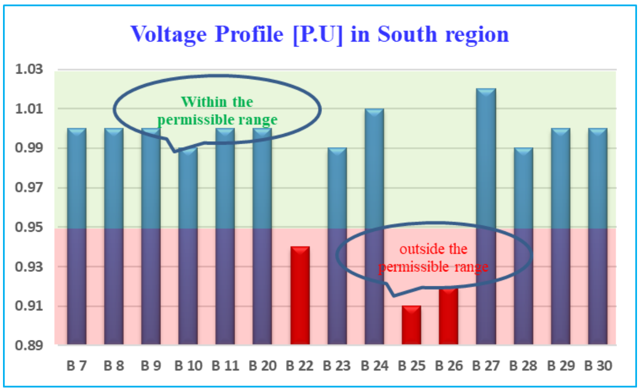

Fig. 9. Voltage Profile in South region after adding RES

Under the new operating conditions, the voltages in the North region are all within the permissible limit, as shown in Fig. 8, whereas in the South region all voltages are within the permissible limit except for buses 22, 25 and 26, which will need to be regulated (Fig. 9).

III. Choosing the optimal location for the SVC and SVC size:

In this case, a complete analysis of the system is performed in order to determine the stability of the system as well as to identify the weak areas and buses in the system. The purpose of this case is to find the appropriate location for the SVC device.

Five regions were analyzed. In the northwest region (**Area 1**) and in the northeast region (**Area 2**), and in the southwestern region (**Area 3**) and in the center of the south region (Area 4) as a region with high loads and low generation, as well as in the southeastern region (Area 5-A and Area 5-B).

The system remains stable, and the bus voltages are within the permissible limit, except in the southeastern Area (**Area 5**), which is considered the weakest Area in the system. The southeastern Area, which is represented by buses 22, 25 and 26, is an area that does not contain generation and is connected to the system by only two transmission lines. Therefore, the appropriate location for installing the SVC device is the southeastern Area (Area 5) represented by Buses (22, 25 and 26).

From the Table 2 above, the 25 Bus is the best location to install the SVC device, as the system voltages will be close to 1 and the size of the device is the smallest compared to the performance required.

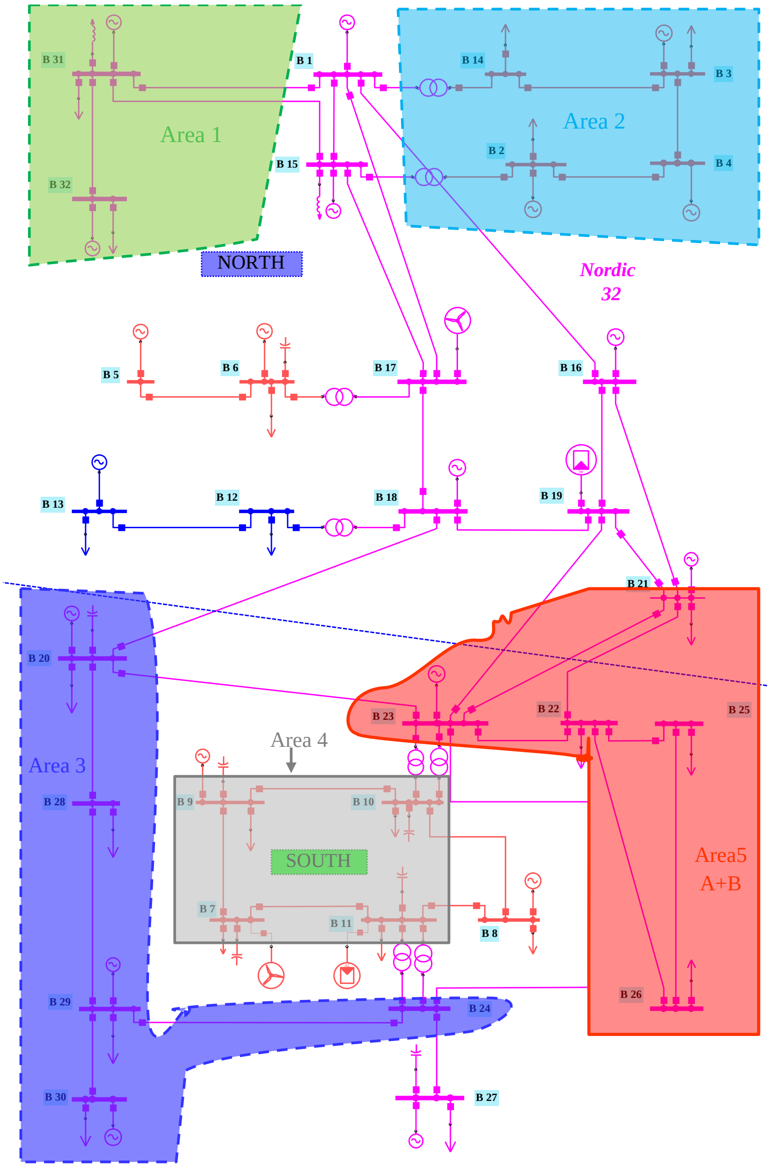

Fig. 10. Single line diagram of Nordic 32 power system divided into several areas.

Table 2

Choosing the best location for SVC

SVC location	SVC size [MVAr]	Voltage results in p.u			
		V B22	V 25	V 26	V23
Bus 22	729	1.00	0.97	0.98	1
Bus 25	513.9	0.98	1.00	0.99	1
Bus 26	386.3	0.97	0.96	1.00	0.99

IV. The results after adding SVC to the system to improve system voltages

In this case, an SVC device is installed in the Nordic 32 power system for the purpose of improving the bus voltages.

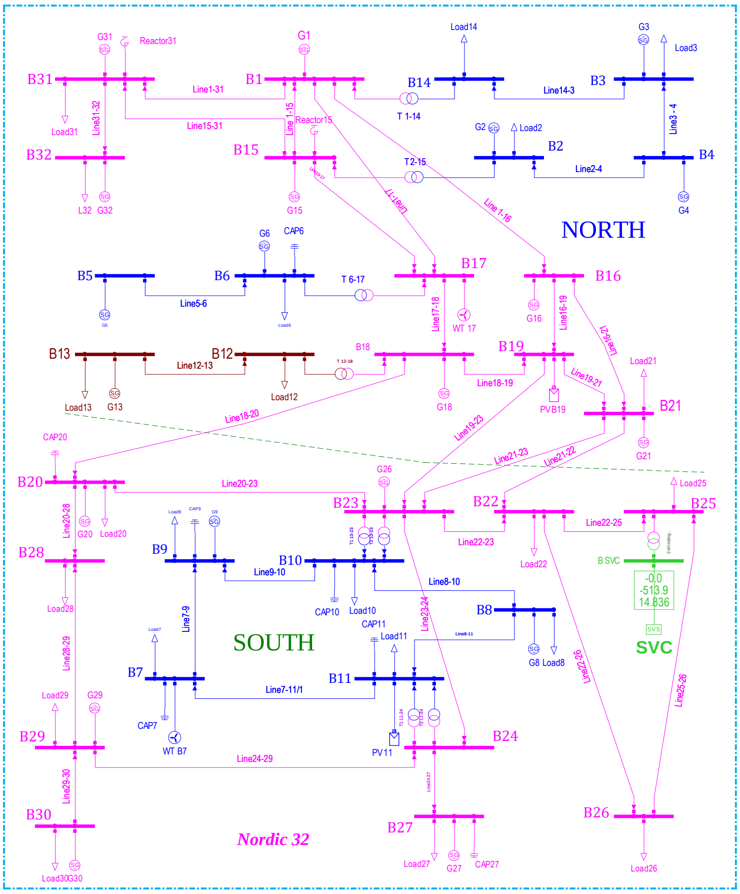

Fig. 11. Single line diagram of Nordic 32 power system with SVC.

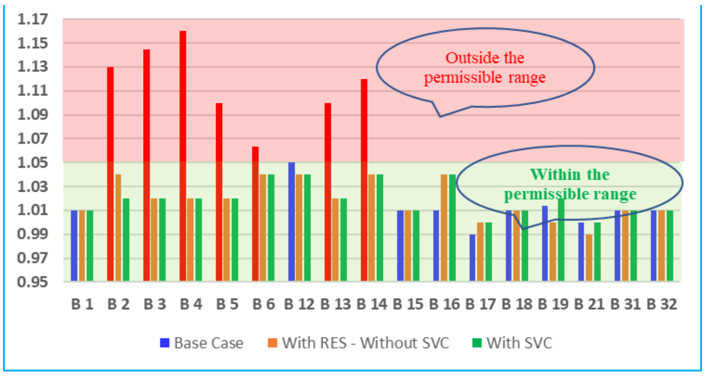

Fig. 12. Voltage profile in North region with SVC.

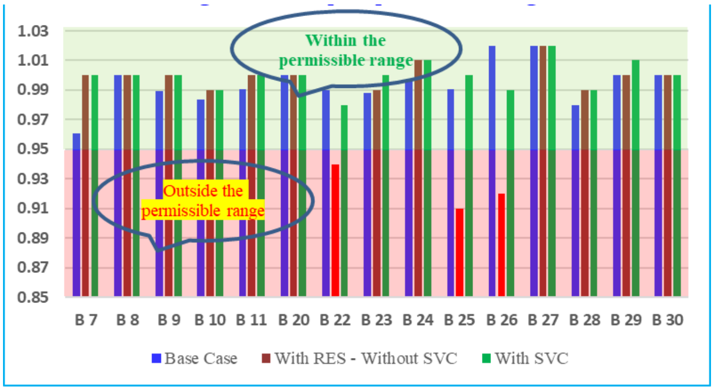

Fig. 13. Voltage profile in South region with SVC

From Figs. 12 and 13, it can be seen that after adding SVC to the system, all system voltages (in the North and South regions) are very good and within the permissible limit (0.95-1.05) p.u., and all system voltages ranges from 0.99 p.u. and 1.04 p.u.

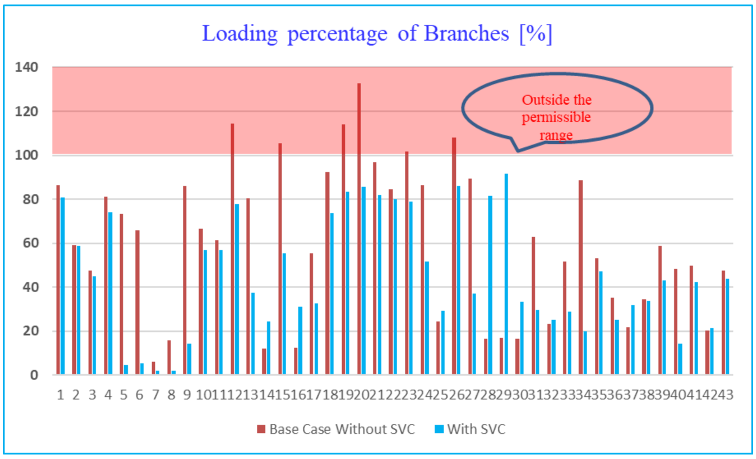

Fig. 14. Loading percentage of branches.

Fig. 14 shows that after adding SVC and RES to the system, the loading percentage of lines and transformers decreased in all branches

V. Simple Contingencies

In this case, two scenarios are defined:

A- The First Scenario: The system operation in the presence of SVC is analyzed, after the line 21 outage (between Bus 18 and Bus 20). The systems voltages are the illustrated in figures.

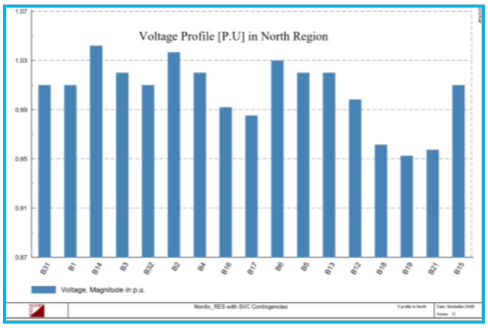

Fig. 15. Voltage profile in North Region when line 21 is lost C3

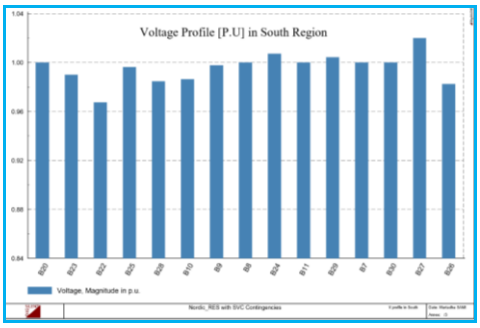

Fig. 16. Voltage profile in South Region when line 21 is lost C3

In the absence of the SVC, in the event of a line 21 lost (between Bus 18 and Bus 20), the system will collapse. But in the case of the presence of SVC, the system remains stable and is not affected as shown in the Fig. 15 and Fig. 16.

B- The Second Scenario: In this scenario, the system operation in the presence of SVC is analyzed, after the Generator (535.5 MW) from bus 21 is lost.

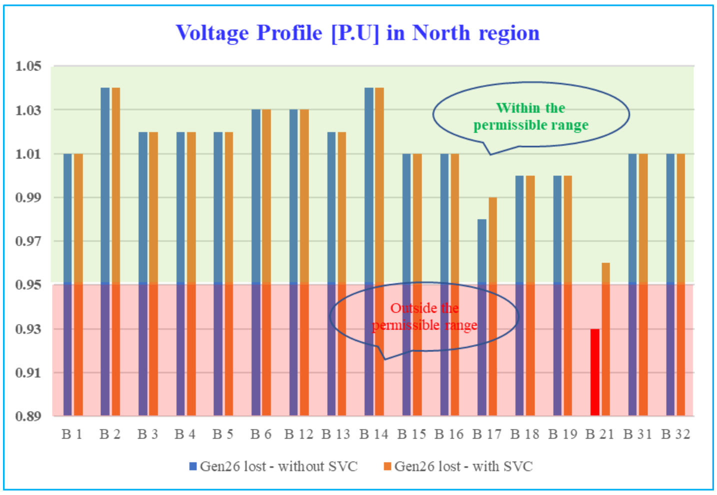

Fig. 17. Voltage profile in North Region when Gen21 Lost.

In the absence of the SVC, in the event of Generator of Bus 21 is lost, the system will be unstable, the voltages at some buses are less than the permissible limit, as shown in Fig. 17 and Fig. 18.

But in the case of the presence of SVC, the system remains stable and is not affected. The criteria that for analysis of the system are:

1. The System stability and reliability;
2. The Voltages are within the permissible limit;

3. All the branches (Transmission lines and transformers) do not exceed the permissible limit (loading percentage);
4. All the Generators do not exceed the permissible limit (Min. and Max MVAr).

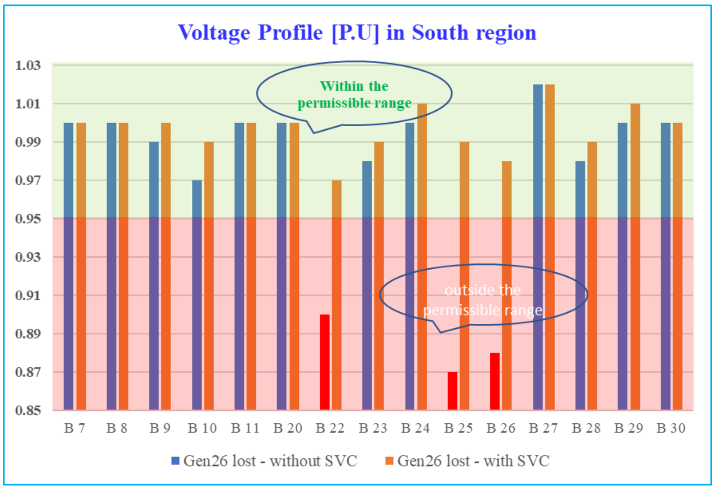

Fig. 18. Voltage profile in South Region when Gen21 Lost

Therefore, after adding SVC to the system, all the above criteria are satisfied in the system, which means that the system is stable and reliable, and all system equipment (The Generators, the transmission lines and the power transformers) did not exceed the permissible limits. This confirms the high performance of the SVC using a designed control system that allows it to operate in both emergency and post-emergency modes of the power system.

6. Conclusions

The concept and development of utilizing SVC for optimization have been discussed in this paper. SVC contributes to an increase in power quality, as well as the stability of active power usage. This effect might be useful in situations where a changeable load voltage has to be adjusted for in some way. It would result in an improvement in power stability, as well as a reduction in the likelihood of catastrophic events produced by such sources.

Through the research presented in this article, the excellent performance of the SVC is validated when it is controlled by a control system that is intended to enable it to function in both emergency and post-emergency power system modes.

The simulations conducted by DIgSILENT have shown that the addition of the Static Var Compensator device to the electrical power system improves the operating performance of the power system in terms of voltage regulation, as well as an increase in reactive power reserves via the use of generator relief.

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