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Voltage stability improvement using Relocatable Static Var Compensator in Algerian Southeastern region

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***Abstract*—In recent years, many voltage instability incidents have occurred in the Algerian power system. The main cause of the voltage instability is the reactive power limit of the system. Flexible Alternative Current transmission systems devices can play very important role in preventing voltage instability. The Static Var Compensator as a flexible alternative current transmission system device can significantly provide the continuous voltage control under various operating conditions. In this paper a new three relocatable Static Var Compensator inserted in the Algerian power system is studied. The simulated tests made in southeast region, which was originate of 2003 blackout, showed an improvement of the voltage stability of the power system.**

***Keywords* — Voltage stability, Static Var Compensator, relocatable, Voltage stability margin**

I. Introduction

Today, due to the delay of the transmission lines and generation construction projects, Algerian's power system is operating close to their operational limits and system conditions have become increasingly complex. Under this situation, one of the major problems that may occur often is the voltage instability. Conventional voltage control devices like capacitor and reactor banks were used to improve voltage stability of a power system.

These devices, however, are based on electromechanical mechanisms thus preventing high speed and flexible control. Moreover, frequent capacitor bank switching in the power system has led to several capacitors bank failures and switching device malfunctions in the past few years [1]-[2].

Application of "Flexible AC Transmission System" (FACTS) technologies, such as the Static Var Compensator (SVC) is a very effective solution to prevent voltage instability and voltage collapse due to their fast and flexible control [3]. For avoid another voltage collapse similar to that registered on summer 2008 and in the same time for to improve the stability of the power system during 2013 summer a real model of the Algerian power system corresponding is developed in this paper where the load peak is taken account. Results of steady state and dynamic studies using commercials software, SPIRA and SICRE programs are presented to demonstrate the voltage problems and the effectiveness of the SVCs solutions.

Rest of the paper is organized as follows: Section II presents the characteristics of Algerian power system. Section III concerns the modeling and optimal placement of SVC. The results are discussed in the section IV.

II. The Algerian Power System

The power system in Algeria consists of five interconnecting major areas systems, Alger, Oran, Annaba, Sétif and South (Hassi Messouad and Hassi Berkine). Fig. 1 gives Map of the Algerian Transmission System on February 2011. The transmission system is supplied via 55 generating plants. It consists of high voltage lines of 400 kV, 220 kV,150 kV and 60 kV and covers a total length of 23741 km. Currently, the Algerian transmission system is interconnected in the northern part of the country with Morocco (400 and 220 kV lines) and in the east with Tunisia (220, 150 and 90 kV lines).

On 2012, installed generation capacity was 10276 MW. The load peak during the summer was 9950 MW and the total energy production was of 35 870 GWh.

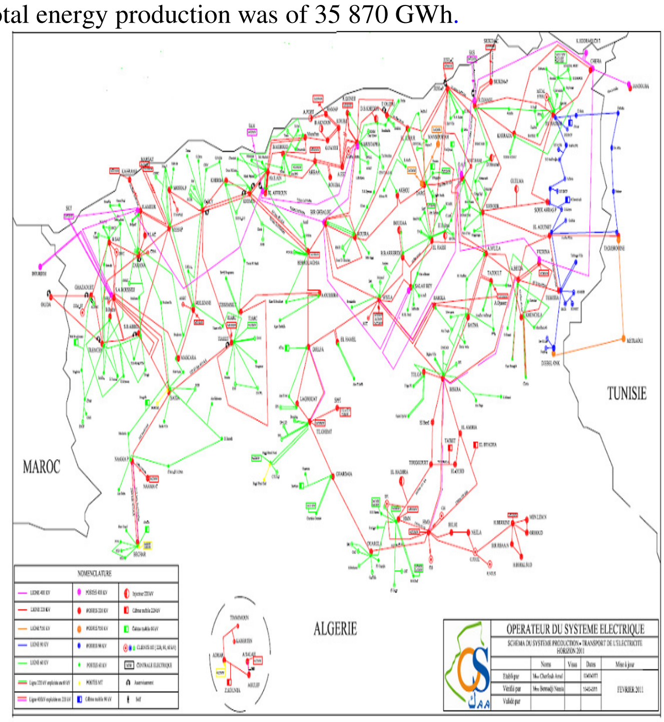

Fig.1. Map of the Algerian Transmission System on February 2011.

III. Modelling and Optimal Placement of SVC Devices

A- SVC Model

A Static Var Compensator (SVC) is a power quality device, which employs power electronics to improve voltage profile by injecting or absorbing the reactive power [4]. The SVC consists of a group of shunt-connected capacitors and reactors banks with fast control action by means of thyristor switching circuits [4].

In this paper, the SVC is modelled and integrated into the SPIRA load flow program. The SVC implementation in the SPIRA software is modelled as a variable reactive power connected to a bus in a system [5]. This is presented as a *PV*-node at an auxiliary bus. The PV-node can be treated like any other generator, with no real power output (P= 0) and with specified minimum and maximum reactive limits representing the range of SVC-reactive power outputs.

The reactive power generated by SVC is given by:

$$Q_{SVC}^{Min} \leq Q_{SVC} \leq Q_{SVC}^{Max} \quad \text{………… (1)}$$

If the SVC is operating outside the limits, so the bus becomes PQ-type and the reactive power Q is set [6] and is expressed by Eq. (2):

$$Q = -B * U^{2} \quad \text{…………….. (2)}$$

Where :

B : is equivalent suspectance of the SVC

U : is the calculated voltage magnitude at the SVC node

The load flow can then continue until a solution is reached.

B- Optimal Location of SVC

Like other FACTS devices, SVC is an expensive device; therefore it is important to find the optimal location and its size in a power system, so that voltage profile may be improved effectively. Various mathematical methods and criteria are used to optimal allocation of these devices in the power systems [7]-[11]. In this paper, the Static Voltage Stability Margin (SVSM) is used to decide optimal location for the placement of SVCs. Voltage stability margin is defined as the distance with respect to the loading parameter, between the current operation point and voltage collapse point (Fig. 2).

The SVSM is calculated using continuation power flow (CPF) based software package SPIRA. The continuation methods generally trace the voltage profile of the system up to the point of maximum load of the system [12]-[14].

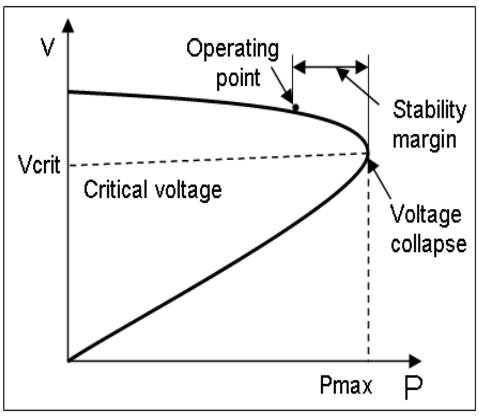

Fig.2 .The V-P curve for node i of a general power system.

IV. Results and Discussions

To improve the stability of the power system during 2013 summer a real model of the Algerian power system is developed in this paper. The load peak of 2013 summer is selected as base condition of operation. The total load peak is expected to increase by about 9 % in 2013, thus it will be of 10845 MW. Active power generation of the Algerian power system will be about 10274 MW in 2013. The model includes other power source and high voltage line transmission projects which are expected to be into service in 2012 and 2013. The power system model consists of 937 nodes, 948 lines, 421 transformers and 164 equivalent generators.

A-Steady State Analysis of the Algerian Transmission System

In this section, the Newton-Raphson method of the SPIRA power flow program is used to obtain the voltage profile of the steady state condition [15]. The results of this analysis were compared with the Algerian power system Voltage Stability Criteria.

The operational limits for nodes voltages are summarised in table. I.

TABLE I. OPERATIONAM LIMITS FOR NODES VOLTAGES.

Magnitude	Steady-state voltage		Dynamic voltage	
	Lower	Upper	Lower	Upper
400 kV level	380	420	360	440
220 kV level	209	231	198	242
60 kV level	57	63	53	66

The 220 kV critical nodes voltages of Algerian power system in a steady state operation are shown in table .II.

TABLE II.THE VIOLATED VOLTAGE OF THE ALLGERIAN POWER SYSTEM.

Node-name	Voltage (kV)	region
El Berd	207	South-East
El Oued	202.5	South-East
Biskra	219.6	South-East
Amiria	204.3	South-East
Touggourt	205.5	South-East
Taibet	205.8	South-East

It is observed from results presented in table. II, that South-East region of Algeria is weakest in terms of voltage stability. The voltage profile in the several 220 kV nodes of the South-East region has a voltages magnitude outside the desired limits. The voltage magnitude of El Berd , El Oued, Amiria, Touggourt and Taibet nodes is below the lower limit.

As shown in table. III, the reactive power of the generators in South-East region in a steady state operation approaches the maximum limits. Thus, the generators do not support the reactive power requirement. The shortage of reactive power generation in this region can lead to voltage instability of the transmission system or to voltage collapse.

TABLE III.THE REACTIVE POWER GENERATION OF THE SOUTHERN REGION IN STEADY STATE OPERATION.

Power plant	Generato r	Real power (MW)	Q Generate (MVAR)	Q min (MVAR)	Q max (MVAR)
HMO	G4	125	62.7	-60	63
HMO	G3	125	62.7	-60	63
HMO	G1	125	62.7	-60	63
HMO	G2	125	62.7	-60	63
HMN	G6	110	50	-60	57
HMN	G5	24	8	-12	10
HMN	G4	24	8	-12	10
HMN	G1	24	8	-12	10
HMN	G2	24	8	-12	10
HMN	G3	24	8	-12	10
HMN	G7	110	50	-60	57
H.BERK	G1	123	70	-54	80
H.BERK	G2	123	70	-54	80
H.BERK	G3	123	70	-54	80
HMS	G1	16	5	-9	9
HMS	G2	16	5	-9	9
HMS	G3	20	5	-9	9
HMS	G4	20	5	-9	9

C- Steady State Analysis of the Algerian Transmission System with SVC.

In this section, we focus our study on the voltage stability in the South-East region. A one-line diagram of the South-East region system containing the 3 main voltage levels 400,220 and 60 kV is shown in Fig. 3.

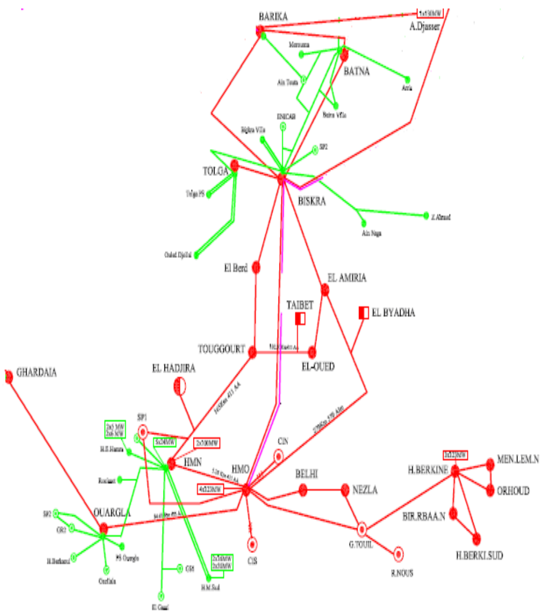

Fig.3. One-line diagram of the South-East region system

In this paper, SVC devices are used to solve the voltage stability problems in this region. Generally, there are two options for the design of SVC devices [16]:

- A conventional or fixed large Static VAR Compensators
- A relocatable Static VAR Compensators

In comparison with conventional large SVCs, a relocatable SVC provides additional performance benefits:

-The ease and quickness of relocation in response to network design changes. By making a svc relocatable, dynamic voltage support can be obtained where it is needed in the power grid in order to meet current demands for network stability. Then, when the picture changes to follow the demands of a changing power market, the static var compensators can be relocated to enable the system to adapt to the situation [17].

-Moreover they can be a temporary alternative to improve the network until the reinforcement measures can be carried out [18].

-The relocatable design of SVC enables full relocation of each installation from one place in the grid to another within just a few weeks [17].

These devices can be an interesting alternative to the conventional large Static VAR Compensators.

In this section, we examine the effect of three relocatable svc devices in enhancing power system stability.

The location of SVC devices in the network needs to be optimized to eliminate or minimize the node voltage violations under steady state condition. The Static Voltage Stability Margin (SVSM) is used to decide optimal location for the placement of SVCs. Table IV shows results of calculation of the Static Voltage Stability Margin (SVSM) for the various 220 kV nodes.

TABLE IV.VOLTAGE STABILITY MARGIN FOR VARIOUS 220 KV NODES OF THE SOUTH-EAST REGION

Node-name	Voltage stability margin (MVA)
El Berd	7.2
El Oued	5.9
Biskra	15.4
Amiria	6.1
Touggourt	6.5
Taibet	6.7
Bayadha	8.1
Hadjira	9.0
Ouargla	9.7
H.Messouad N	10.2
H.Messouad O	10.3
Tolga	16.5
Barika	25.1

We can see that Amiria, El Oued and Tougourt nodes are the lower Voltage stability margin. Therefore, these nodes are selected for the placement of the SVCs devices.

From the results of OPF, the required reactive injection from SVC devices is 240 MVAR. So, a final rate of 80 MVAR for each SVC is required. The used SVCs parameters are given in Fig. 4.

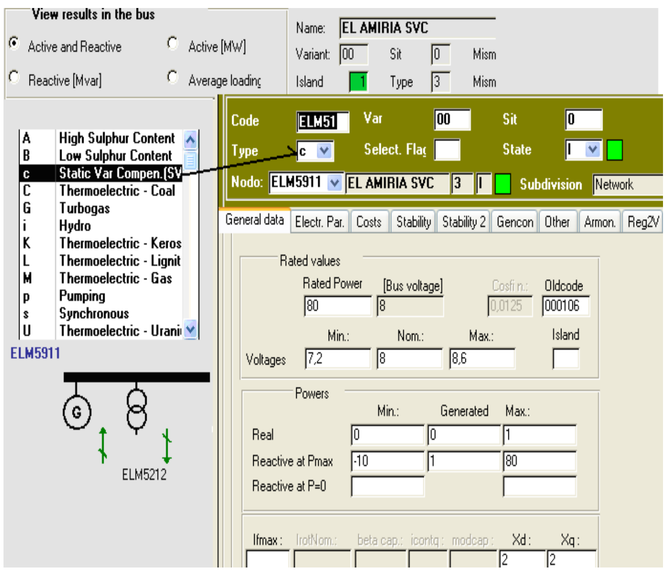

Fig.4. The SVC parameters

The voltage profiles of six 220 kV nodes in the steady state condition with and without SVCs are shown in table V.

TABLE V.THE VOLLTAGE MAGNITUDE OF SIX NODES OF THE SOUTH-EAST REGION WITH AND WITHOUT SVC.

Node-name	Voltage (kV)	
	without SVC	With SVC
El Berd	207	220.2
El Oued	202.5	221.2
Biskra	219.6	223.7
Amiria	204.3	220.9
Touggourt	205.5	222.5
Taibet	205.8	221.3

Table VI shows the results of calculation of the static voltage stability margin for the various nodes before and after the SVCs installation.

TABLE VI.VOLTAGE STABILITY MARGIN FOR VARIOUS 220 KV NODES OF THE SOUTH-EAST REGION WITH AND WITHOUT SVC

Node-name	Voltage stability margin(MVA)	
	without SVCs	with SVCs
El Berd	7.2	156.2
El Oued	**5.9**	**153.4**
Biskra	15.4	289.8
Amiria	**6.1**	**156.6**
Touggourt	**6.5**	**157.1**
Taibet	6.7	153.1
Bayadha	8.1	150.5
Hadjira	9.0	171.6

We can well see that after SVC placing, all of the nodes voltage violations are eliminated. The voltage magnitude of nodes El Berd, El Oued, Biskra, Amiria, Touggourt and Taibet is within the limits. Thus, the installation of SVC highly improves the voltage stability in the studied region.

C. Dynamic Analysis of the Algerian Transmission System with Relocatable SVC Devices

This section explains performances dynamic analysis of the South-East region. Dynamic analysis have been done using SICRE software tool. This program was developed by CESI power system to cover a dynamic simulation in a wide range of time. The program could be used for dynamic and static simulations of electrical power systems, including short term and long term stability studies [20].

To simulate and verify the dynamic responses of SVCs for the 2013 summer load peak conditions, a dynamic simulation is run for different scenarios. The analysis considered the base case scenario and the two "worst case" contingencies corresponding to the outage of:

- BISKRA- AIN BEIDA 400 kV line
- BISKRA- AIN BEIDA 400 kV line and one generator in HMO power plant.

Fig. 6 and Fig.7 illustrate the voltage profile of the six weakest nodes with and without relocatable SVCS at the base case.

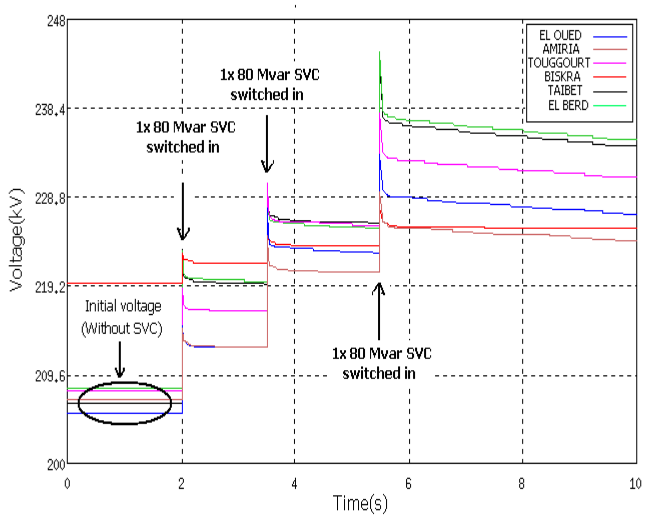

Fig. 5.Voltage simulation results of the six weakest nodes with and without relocatable SVCS (SVCs are connected one by one).

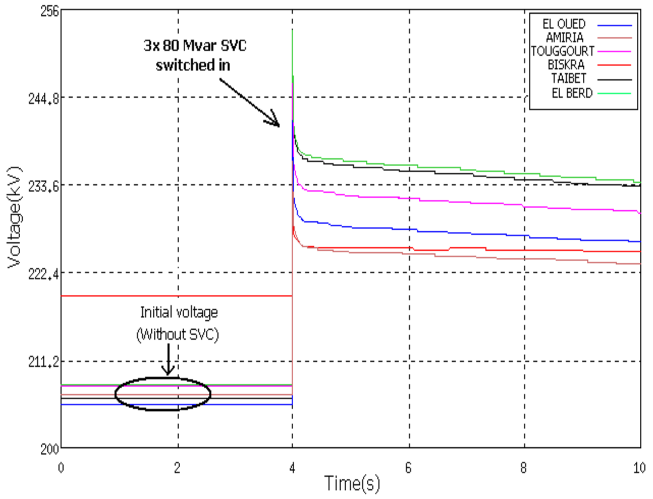

Fig.6. Voltage simulation results of the six weakest nodes with and without relocatable SVCS (SVCs are connected in same time).

As shown in Fig.6 and Fig.7, before placing SVC, the voltage profile does not meet the performance criteria since the voltages at 220 kV nodes El Berd, El Oued, Amiria, Touggourt and Taibet are less than the required operating voltage limits of 209 to 231 kV . After SVCs connection, 220 kV nodes voltage recover to an acceptable level according to the Algerian power system reliability criteria.

The result of dynamic simulation for an outage of 400 kV Biskra- Ain Beida line is shown in Fig. 8.

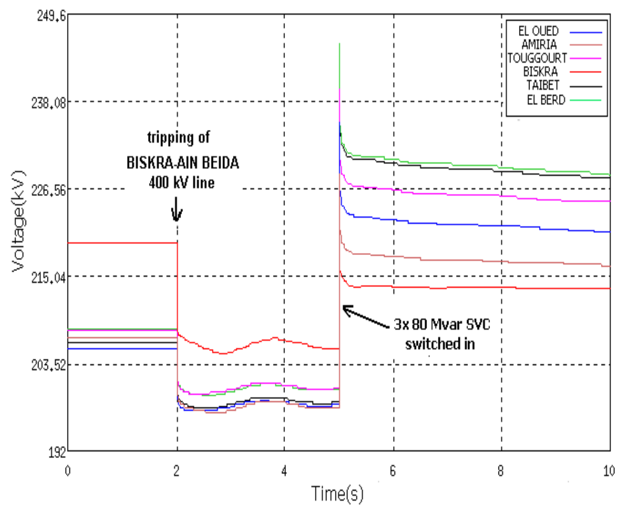

Fig. 7. Voltage dynamic simulation results of the six weakest nodes with SVCs connection when BISKRA- AIN BEIDA 400 kV line is tripped.

After system disturbance, the voltage was decreased to low level (<198kV) at nodes El Berd , El Oued, Biskra , Amiria , Touggourt and Taibet. After placing the SVCs, the voltage magnitudes of all nodes of the south region are significantly improved. This is achieved by means of 240 MVAR reactive power injections from SVCs to power system.

The result of dynamic simulation for a second scenario is shown in Fig. 9 that compares the simulation run with and without the SVCs in the system.

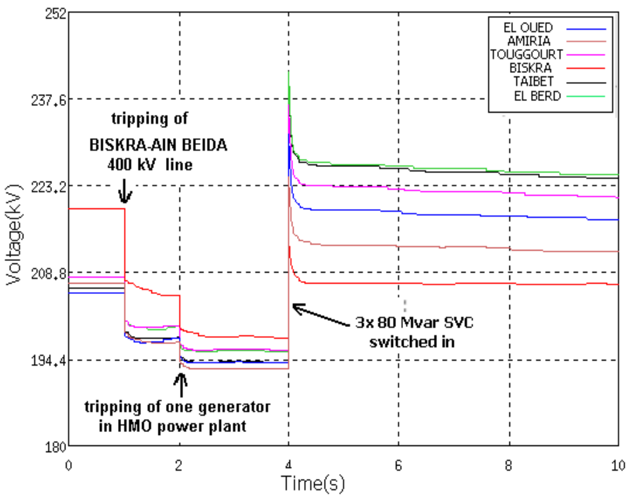

Fig.8. Voltage dynamic simulation results of the six weakest nodes with the SVCs when BISKRA- AIN BEIDA 400 kV line and one generator HMO power plant are tripped.

Before placing SVC, the voltage magnitude of five nodes falls below 198 kV. After placing SVC, the voltage magnitude of all nodes is within the limits. For this case, The SVC provides the necessary reactive power to rapidly support and regulate the study region voltages as a function of disturbances. So, the SVC is capable of keeping the voltage profile in the South-East area within the specified range.

It was deduced from the result that a three SVC devices are connected to provide reactive power compensation not only during steady state conditions (to keep the node voltage at rated condition), but also to achieve high dynamic performance during different fault scenarios. Thus, the placement of SVC at the optimal location provides the regulation of voltage support in conformity with the performance criteria for 2013 load peak as well under steady state as dynamic conditions.

V. CONCLUSIONS

The study and analysis conducted in this paper, are summarized as follows:

- Based on steady state analysis and dynamic analysis, low voltage problems in the South-East area of the Algeria power system were identified.

- The installation of relocatable Static VAR Compensator **(SVC)** devices provide an interesting alternative to the conventional reinforcement measures like building new power plant or transmission line.

- It is has be recommended to power system companies to utilize the existing transmission network by employing FACTS devices.

- The relocatable Static Var Compensator devices offered a cost-effective solution to system problems since it could easily be transported and could be relocated according to needs. Moreover it can be a temporary alternative to improve the network stability before the final reinforcement measures.

- The results of this study help AOSE (Algeria's Operator of System Electric) and other utilities to control the system in a more secure and reliable manner by the use of FACTS devices.

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