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Transient stability enhancement of statcom integration in power grid

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ABSTRACT

To solve load growth of a hybrid existing electrical system, we at first build generation stations (wind, solar or thermical). And secondly in 2025 year, when the system is so meshed, some buses will be very far from production energy, the transits power will be lower than the transmission capacity, and the voltage drop out margin limit of stability. Therefore it is proposed to install Flexible AC Transmission System (FACTS) devices to enhance the transient power stability and quality in the power system. The power flow analysis of Newton Raphson method is performed on a seven (7) bus system with and without static synchronous compensator (STATCOM). The STATCOM is a shunt connected FACTS devices that are useful for reactive power compensation and mitigation of power quality problems in transmission and distribution systems. These investigations indicate the need of power flow analysis and determine best locations of STATCOM on the proposed system. The results of simulation have been programmed in MATLAB and PSS/E Simulator. In the end the expected disturbances and the power quality enhancement of the network in the horizon 2025 were attenuated by integration of STATCOM that is able to supply or absorb reactive power and to maintain the voltage at 1pu.

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1. INTRODUCTION

The concern for good power grid management is not only to ensure that transits power are lower than the transmission capacity [1-3]. It is also necessary to monitor several technical parameters, including the voltage level(voltage drop). The voltage must remains within an authorized range at any point in the network, in all foreseeable production and consumption situations. The proposed goal for this work is to find solution for load shedding [4-9]. In this case we proposed an analysis for both the current and projected production system. Those we will to meet the domestic demand of a 33 KV network. This analysis allows us to reach and maintain a voltage profile in stability margin ($0,95 < Upu < 1,05$) for the network manager. Before that we modelize the network by its transit capabilities. And analysis its simulation results programmed in MATLAB and PSS/E. Another goal is, to propose a methodology for the management and control of transits power and voltage, in order to make the most efficient use of the system in a more suitable situation. The FACTS system is a means of fulfilling this goal. Several types of FACTS currently exist and the choice of the appropriate device depends largely of the aims to be achieved [10-14]. Thus, to realize predetermined goals, we take the following four steps:

a) First step, a schematic diagram of the 33 KV loop network is given.
b) Second step, the production and load forecasts are given from 2015 to 2025 years.

c) Third step, a numerical model of Newton Raphson (NR) method is resolved and programmed on MATLAB environment and PSS/E simulator for two situations (without FACTS and with FACTS devices) [15, 16]. The results of simulations will be accompanied by discussions.
d) The last step, a conclusion will be given of the work.

For the insertion of FACTS systems, it is sought a stable electrical energy network which is capable even during a disturbances to provide the demand power. FACTS devices as defined by IEEE as “power electronic based controllers and other static equipment which can regulate the power flow and transmission voltage through rapid control action”. In earlier days power system control was only based on generator control(Table 5) and the controlling ability on the transmission lines was little (negleted). Different FACTS controllers can influence these parameters to regulate the power flow in interconnected systems. The STATCOM device is a technique for achieving this goal (Table 4) [17-19]. The STATCOM can facilitate the fast voltage control, the reactive power control and reduce the harmonics in a power system. This is done while keeping frequency, the alternators rotation speed and the voltage magnitudes constant and close to nominal values, at the various network buses. At the end these work propose also to replace conventional system of reactive power compensation (shunt capacitor banc, series capacitor, reactor…) by STATCOM device for an existing system.

2. RESEARCH METHOD

2.1. Structure of 33KV Loops of Nouakchott System

The single –line diagram (Figure 1) only represents the 33 KV part of the network. The lines (cables) data, the generators powers and loads are shown in Table 1 and Table 2. The electrical network consist of 11 transmissions lines, 5 power plants (one wind power [20], one solar plant [21], two thermal plants and 1 Dual fuel plant) and 5 loads at bus 2, 4, 5, 6 and 7 of (Figure 1). The active and reactive powers generated are given in MW and MVAR respectively. The voltage at each bus (i) is given in per unit. The load bus is characterized by its active power P and reactive power Q. Therefore, (P, Q) are specified, while (V) is to be calculated. In this context, it is proposed for the North bus (1), to be a slack bus. Finally, it should also be noted that a bus is numbered (i) and it is connected to (k) other buses such as those shown in Figure 1.

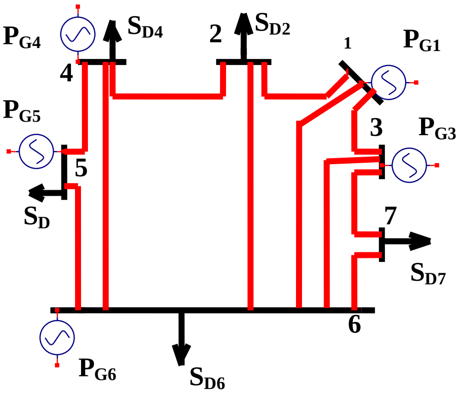


Figure 1. Simplified line diagram; of Nouakchott supply network

2.2. Given Data of System

It is also proposed in Table 1, the active resistances, the reactances and lengths of each line. It is also given in Table 2 and Table 3 the projected generation data and load forecast of studying system at 2015 to 2025 years respectively. Active power is given in MW and reactive power in MVAR.

2.3. Numerical Model of STATCOM

The Static Synchronous Compensator STATCOM is one of FACTS derivates family, it use the forcing electronic power commutation (GTO, IGBT or IGCT). A STATCOM is controlled reactive power source and improve the transient stability of systems. It provides voltage support by generating or absorbing reactive power at the point of common coupling without the need of large external or capacitor banks. The basic voltage source converter scheme is shown in Figure 2. The Table 4 corresponds to the best choice of STATCOM to optimize the system performance. Table 5 shown the illustrates the optimum choice of STATCOM at the cost of point view.

Table 1. Cable Data of Figure 1

N	i	k	R(Ω)	X(Ω)	U(KV)	L(km)
1	1	2	0.122	0.167	33	6.27
2	1	3	0.067	0.092	33	3.47
3	1	6	0.024	0.037	33	20
4	2	4	0.027	0.037	33	13.98
5	2	6	0.032	0.044	33	16.8
6	3	6	0.061	0.08	33	15
7	3	7	0.141	0.193	33	7.25
8	4	5	0.17	0.232	33	8.72
9	4	6	0.127	0.173	33	4.51
10	5	6	0.101	0.15	33	5.66
11	6	7	0.232	0.31	33	11.87

Table 2. Projected Generation Data

N	Year					
	2015		2020		2025	
	MW	MVAR	MW	MVAR	MW	MVAR
1	180	87.17	270	130.68	360	174.24
3	15	7.26	15	7.26	15	7.26
4	36	17.42	36	17.42	36	17.42
5	30	14.52	70	33.88	60	29.4
6	137	66.34	199.75	96.67	217.25	105.149
7	0	0	50	24.2	50	24.2

Table 3. Load Forecast Data

N	Year					
	2015		2020		2025	
	MW	MVAR	MW	MVAR	MW	MVAR
2	27.68	15.8	142.55	81.37	734.142	419.05
4	11.71	6.36	60.3	32.3	310.5	166.34
5	1.34	1.138	6.9	5.86	35.53	30.179
6	9.4	1.17	48.4	6.02	249.31	36.8
7	13.49	7.18	69.48	36.97	357.86	190.39
2	27.68	15.8	142.55	81.37	734.142	419.05
4	11.71	6.36	60.3	32.3	310.5	166.34

Table 4. Comparison of FACTS Systems in Terms of Technical Efficiency

Problem	FACTS Systems					
	Shunt		Series		Hybrid	
	SVC	STATCOM	SSSC	TCSC	IPFC	UPFC
The control of the voltage (static state)	++	++	++	+	+	+
The control of the voltage (dynamic state)	++	++	++	+	+	+
Static stability	++	++	-	-	-	+
Dynamic Stability	++	++	-	-	-	+
Damping of power oscillation	++	++	++	++	+	++
Transitional stability	+	++	-	++	+	++
Power flow (static condition)	+	+	++	++	++	++
Limitation of the fault current	-	-	-	-	+	+

++: Very Good +: Sufficient -: Inappropriate

Table 5. Illustrates the Optimum Choice of STATCOM at the Cost of Point View

Type of Equipment	Response Speed	Voltage Support		Cost	
		Capacity	availibility		
Generator	Fast	excellent	low	Difficult to separate	High
Battery capacitor		Low depends on U^2	High	8-10$	Very low
Compensator static	Fast	Low depends on U^2	High	45-50$	Moderate
STATCOM	Fast	Low depends on U^2	High	50-55$	Moderate
Distributed Génération	Fast	Low depends on U^2	low	Difficult to separate	High

2.4. Equations

When STATCOM is shunt-connected at bus (i) in Figure 1 and it is treated as VAR source, the power equations writing as following:

$$P_i = P_{gi} + P_{STCi} - P_{li} \tag{1}$$

$$Q_i = Q_{gi} - Q_{STCi} - Q_{li} \tag{2}$$

where are P_{STCi} STATCOM real power at bus (i) and Q_{STCi} STATCOM reactive power at bus (i), Pli and Qli are load active and reactive powers at bus (i).

As shown in (1) and (2) represent a case where STATCOM injects VAR into the system at bus (i) and for VAR absorption, the signs of Q_{STCi} is reversed.

Due to the non-linearity of algebraic (1) and (1) describing the power flow, their solution is usually based on an iterative technique. Hence, the method of solution adopted in this work for power flow (1) and (2) with a shunt-connected STATCOM at bus (i) is Newton-Raphson iterative method and it was adopted because of its faster rate of convergence and accuracy when compared with other methods of solution for non-linear power flow equations such as Gauss-Seidel method.

2.5. Mathematical Model of Power Flow with STATCOM

The Thevenin's equivalent circuit of the fundamental frequency operation of the switched mode voltage source inverter STATCOM and its transformer is shown in Figure 2.

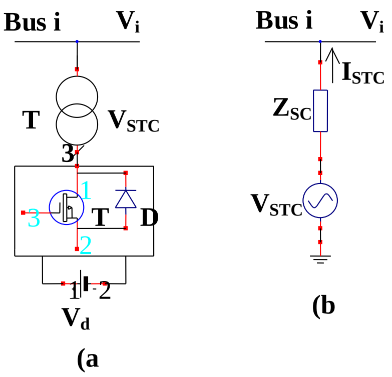


Figure 2. (a) Basic schematic diagram; (b) equivalent circuit

From the Figure 2, we obtain (3):

$$V_{STC} = V_i + Z_{SC} I_{STC} \tag{3}$$

where V_{STC} - is STATCOM voltage, I_{STC} - is STATCOM current, Z_{SC} - is transformer impedance. The voltage injection bound constraint of STATCOM is given by (4)

$$V_{STC(\min)} \le V_{STC} \le V_{STC(\max)} \tag{4}$$

where V_{STC} (min) and V_{STC} (max) are STATCOM's minimum and maximum voltages. As shown in (3) is transformed into a power expression for STATCOM and power injected into bus (i) by (5) and (6) respectively:

$$S_{STC} = V_{STC} I_{STC}^* = V_{STC} V_{STC}^* Y_{SC}^* - V_{STC} Y_{SC}^* V_i \tag{5}$$

$$S_i = V_i I_{STC}^* = V_i V_i^* Y_{SC}^* - V_i Y_{SC}^* V_{STC}^* \tag{6}$$

where S_{STC} – is a STATCOM's injected apparent power, I^*_{STC} - is a STATCOM's complex conjugate current, V^*_{STC} - is a STATCOM's complex conjugate voltage, Y^*_{SC} - is complex conjugate of short-circuit admittance.

The bus (i) and STATCOM voltages in rectangular coordinates system are expressed as (7) and (8) respectively:

$$V_i = e_i + jf_i \tag{7}$$

$$V_{STC} = e_{STC} + jf_{STC} \tag{8}$$

where e_i – is real component of vottage at bus (i) , f_i - is imaginary component of voltage at bus (i) , e_{STC} – is a STATCOM's real component voltage, f_{STC} – is a STATCOM's imaginary component voltage.

The STATCOM's voltage magnitude and angle are expressed as (9) and (10) respectively:

$$|V_{STC}| = \left(e_{STC}^2 + f_{STC}^2\right)^{\frac{1}{2}} \tag{9}$$

$$\delta_{STC} = \tan^{-1}\left(\frac{f_{STC}}{e_{STC}}\right) \tag{10}$$

The active and reactive power components for the STATCOM and bus i on the basis of (7) to (10) are respectively expressed by (11) to (14):

$$P_{STC} = G_{SC}\left\{\left(e_{STC}^2 + f_{STC}^2\right) - \left(e_{STC}e_i + f_{STC}f_i\right)\right\} + B_{SC}\left(e_{STC}f_i - e_{STC}f_i\right) \tag{11}$$

$$Q_{STC} = G_{SC}\left(e_{STC}f_i - f_{STC}e_i\right) + B_{SC}\left\{\left(e_{STC}e_i + f_{STC}f_i\right) - \left(e_{STC}^2 + f_{STC}^2\right)\right\} \tag{12}$$

$$P_i = G_{SC}\left\{\left(e_i^2 + f_i^2\right) - \left(e_ie_{STC} + f_if_{STC}\right)\right\} + B_{SC}\left(e_if_{STC} - e_if_{STC}\right) \tag{13}$$

$$Q_i = G_{SC}\left(e_if_{STC} - f_ie_{STC}\right) + B_{SC}\left\{\left(e_ie_{STC} + f_if_{STC}\right) - \left(e_i^2 + f_i^2\right)\right\} \tag{14}$$

where P_{STC} – is STATCOM real power, Q_{STC} - is STATCOM reactive power, G_{SC} - is short-circuit conductance, B_{SC} – is short-circuit susceptance.

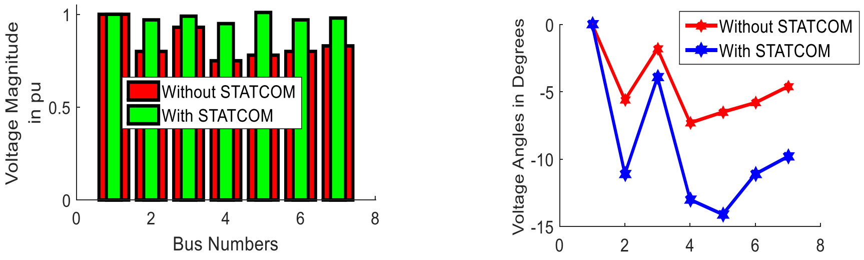
The Newton-Raphson set of linearized equations for power flow (5), (6), (11) and (12) obtained taken into consideration the modeling of shunt-connected STATCOM at bus (i) is given by (15):

$$\begin{bmatrix} \Delta P_i \\ \Delta Q_i \\ \Delta P_{STC} \\ \Delta Q_{STC} \\ \end{bmatrix} = \begin{bmatrix} \frac{\partial P_i}{\partial e_i} & \frac{\partial P_i}{\partial f_i} & \frac{\partial P_i}{\partial e_{STC}} & \frac{\partial P_i}{\partial f_{STC}} \\ \frac{\partial Q_i}{\partial e_i} & \frac{\partial Q_i}{\partial f_i} & \frac{\partial Q_i}{\partial e_{STC}} & \frac{\partial Q_i}{\partial f_{STC}} \\ \frac{\partial P_{STC}}{\partial e_i} & \frac{\partial P_{STC}}{\partial f_i} & \frac{\partial P_{STC}}{\partial e_{STC}} & \frac{\partial P_{STC}}{\partial f_{STC}} \\ \frac{\partial Q_{STC}}{\partial e_i} & \frac{\partial Q_{STC}}{\partial f_i} & \frac{\partial Q_{STC}}{\partial e_{STC}} & \frac{\partial Q_{STC}}{\partial f_{STC}} \end{bmatrix} \begin{bmatrix} \Delta e_i \\ \Delta f_i \\ \Delta e_{STC} \\ \Delta f_{STC} \end{bmatrix} \tag{15}$$

3. RESULTS AND ANALYSIS

The voltage profile before and after STATCOM connected are shown in the Figure 3(a), it demonstrates the voltage magnitude increased for the bus 2 at 0.80 (value out limit [0, 95; 1, 05 pu]) to 0.97 pu, bus 3 at 0.93 to 0.99pu, the bus 4 at 0.75 to 0.95pu, the bus 5 at 0.78 to 1.01pu, the bus 6 at 0.8 to 0.97pu and the bus 7 at 0.83 to 0.98 pu.

The voltage angle before and after STATCOM connected are shown in the Figure 3(b), it demonstrates the voltage angles increased for the bus 2 at -5.6 to -11.1 degree, bus 3 at-1.8 to -3.9 degree, the bus 4 at -7.3 to -13 degree, the bus 5 at -6.5 to -14.1 degree, the bus 6 at -5.8 to -11.1 degree and the bus 7 at -4.6 to -9.8 degree.

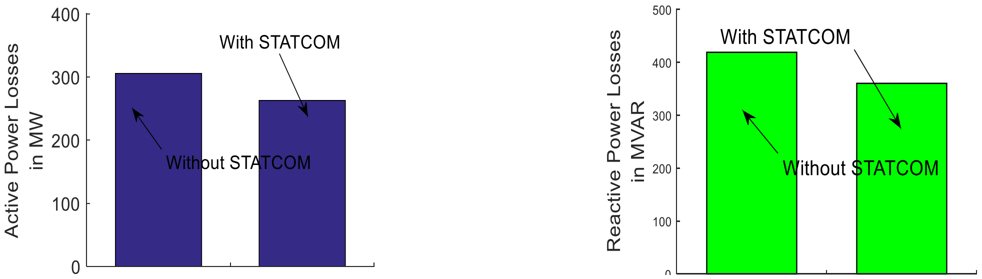


(a) (b)

Figure 3. (a) Voltage a function of bus numbers; (b) voltage angle function of bus numbers

From the Figure 4(a), there was a reduction in total active power losses from 305.7 MW to 262.9 MW, thereby improving the active power transmission lines. These results show that the STATCOM has the capability to improve the voltage at buses and reduce active power losses on the power system.

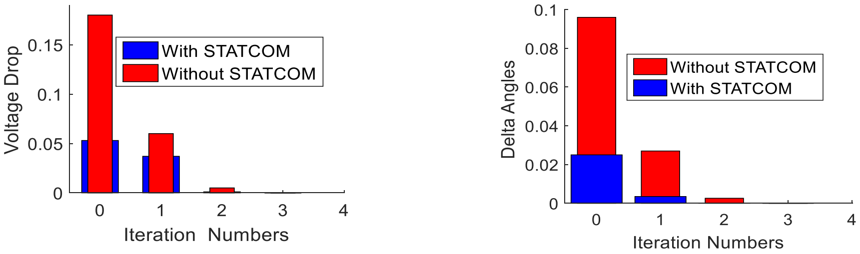
From the Figure 4(b), there was a reduction in total reactive power loss from 419 MVAR to 360.3 MVAR, thereby improving the active power transmission lines. These results show that the STATCOM has the capability to improve the voltage at buses and reduce reactive power losses on the power system.



(a) (b)

Figure 4. (a) is active power losses; (b) is reactive power losses

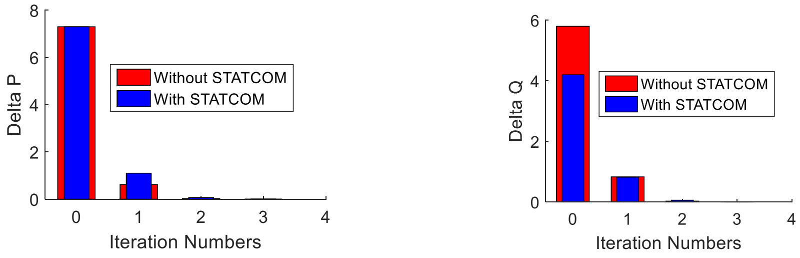
Figure 5 demonstrates the comparison of the voltage errors variation (a) and the delta angle (b) with and without STATCOM connected to the system as a function of ieteration numbers.



(a) (b)

Figure 5. Comparison of the voltage errors variation (a) and the delta angle (b) with and without STATCOM

Figure 6 demonstrates the comparison of the active power variations (a) and the reactive power (b) with and without STATCOM connected to the system as a function of ieteration numbers. It is expected that mismatches (delta Pi and delta Qi) have converged after the third iteration.



(a) (b)

Figure 6. Comparison of the active power variations (a) and the reactive power (b) with and without STATCOM

4. CONCLUSION

The simulation of load flow program on the Matlab and PSS/E Simulator using the NR method has been done. The main information obtained is the out limit of stability all buses voltage of system except the slack bus (Figure 3). After insertion of STATCOM the voltage for all buses has been improved to the stability limit (Figure 3). The power losses compared to the NR method without STATCOM are greater than with the STATCOM (Figure 4).

The novelty is that the studied network presents four different sources in Figure 1. This network undergoes very common load shedding. The cause of these load shedding can be due to the load growth at the nodes. But it can be caused by the presence of clouds or when there is no wind to turn the blades, or non-rainy periods in the Sahel countries. In order to remedy this situation of load shedding, STATCOM has been proposed as a solution [22-26].

The STATCOM will replace also the conventional system compensation of reactive power (as shunt capacitor or series capacitor…). The expected disturbances and the poor power quality problems of the studied power system, at 2025 year , were solved by integration of STATCOM that is able generate or absorb reactive power and maintain the voltage at 1pu.

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