Optimization for Electric Power Load Forecast

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Article Info	ABSTRACT
	Load flow studies are one of the most important aspects of power system planning and operation. The main information obtained from this study comprises the magnitudes and phase angles of load bus voltages, reactive powers at generators buses, real and reactive power flow on transmission lines, other variables being known. To solve the problem of load flow, we use the iterative method, of Newton-Raphson. Analysis of the found results using numerical method programmed on the Matlab software and PSS/E Simulator lead us to seek means of controlling the reactive powers and the bus voltages of the Nouakchott power grid in 2030 year. In our case, we projected the demand forecast at 2015 to 2030 years. To solve the growing demand we injected the power plants in the system firstly and secondly when the production and energy demand are difficult to match due to lack of energy infrastructures in 2030.It is proposed to install a FACTS (Flexible Alternative Current Transmission Systems) system at these buses to compensate or provide reactive power in order to maintain a better voltage profile and transmit more power to customers.

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1.   INTRODUCTION

Electric power load forecasting (EPLF) is a vital process in the planning of electricity industry and the operation of electric power systems. The natures of these forecasts are different as well:

a. Short-term forecasts are usually from one hour to one week. They play an important role in the day-to-day operations of a utility such as unit commitment, economic dispatch and load management.

b. Medium-term forecasts are usually from a few weeks to a few months and even up to a few years. They are necessary in planning fuel procurement, scheduling unit maintenance and energy trading and revenue assessment for the utilities.

c. Long-term electricity demand forecasting is a crucial part in the electric power system planning, tariff regulation and energy trading [12].

d. A long-term forecast is required to be valid from 5 to 25 years. This type of forecast is used to deciding on the system generation and transmission expansion plans.

In this context, it proposed an analysis for the current and evolving production system to satisfy the domestic demand of the 33 kV network. This analysis let use to find, and maintain a voltage profile between 0.95 and 1.05 pu, for the electrical network through its modeling by its transfer abilities and by analyzing its simulated results programmed in Matlab and PSS/E Simulator. This modeling is carried out to maintain this voltage profile within the rated limits for the network manager. Another objective is, to propose a methodology for the management and control of power transfer and voltage, in order to make the most

efficient use of the system more suitable. The FACTS system is a mean of to achieve this function. Several types of FACTS currently exist and the choice of the appropriate device depends largely on the goals to be achieved [10], [8], [11].

For the insertion of FACTS systems, it is sought a stable electrical energy network which is capable even during a disturbance to provide the demand power [3]. This is done while keeping the frequency values constant and close to nominal ones , the alternators rotational speed and the voltage magnitude at the various network buses are kept near the rated values as well.

2. STRUCTURE OF THE 33 KV LOOP OF NOUAKCHOTT SYSTEM

The single –line diagram (Figure1.) only represents the 33 KV part of network .The data lines (cables),the generators powers and loads are shown in tables 1 and 2 . The electrical network consist of 9 transmissions lines, 5 generators and 5 loads at bus 2,4,5,6 and 7 of (Figure1.).The active and reactive powers generated are given in MW and MVAr respectively. The voltage of 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 slack bus .Finally, it should also be noted that a bus is numbered (i) and it is connected to n other buses such as those shown in Figure 1.
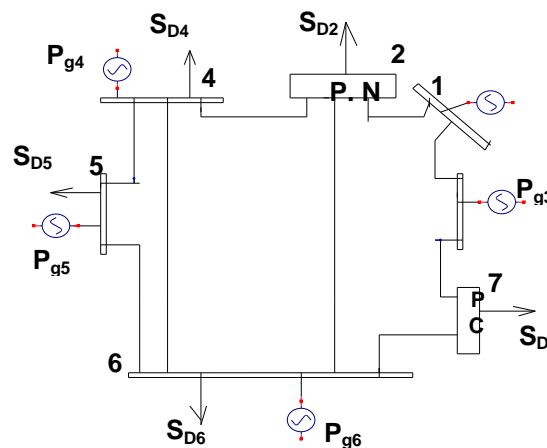

Figure 1. Simplified line diagram; of Nouakchott supply network [12]

It also proposed in Table 1, the active resistances, the line reactances as well as corresponding lengths of each line

2.1. Cable data

Table 1. Cable Data of Figure 1

Cable	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	2	4	0.027	0.037	33	13.98
4	2	6	0.032	0.044	33	16.8
5	3	7	0.141	0.193	33	7.25
6	4	5	0.17	0.232	33	8.72
7	4	6	0.127	0.173	33	4.51
8	5	6	0.101	0.15	33	5.66
9	6	7	0.232	0.31	33	11.87

2.2. Generators and electrical loads data

It is also proposed in Table 2, the initials voltages and their phases. In the analysis of power flow, the generators are modeled as current injectors. In the steady state, a generator is generally controlled so that the active power P (MW) injected to the bus and the voltage across the generator terminals are kept constant.

Table 2. Data System in 2015 year of Figure 1

| N	Voltage		Generators		Loads	
	Voltage (pu)	Angl. (deg)	P (MW)	Q (MVAr)	P (MW)	P (MVAr)
1	1.06	0	180	85.54	0	0
2	1.045	0	0	0	5.306	2.557
3	1	0	15	7.226	0	0
4	1	0	36	17.43	2.245	1.088
5	1	0	30	14.52	0.41	0.208
6	1	0	93.95	45.5	1.908	0.924
7	1	0	0	0	2.548	1.235

Table 3 shows the generation data at 2015 to 2030 years [12].
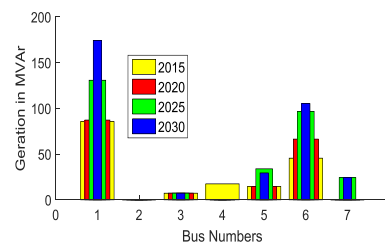Figure 2 shows the injected powers between 2015-2030.
Table 4 shows the 2015-2030 demand forecast data [12].

Table 3. Generation Data at 2015 to 2030 years [12]

Bus	Years					
	2015-2020		2020-2025		2025-2030	
	P_G(MW)	Q_G(MVAr)	P_G(MW)	Q_G(MVAr)	P_G(MW)	Q_G(MVAr)
1	180	87.17	270	130.68	360	174.24
2	-	-	-	-	-	-
3	15	7.26	15	7.26	15	7.26
4	-	-	-	-	-	-
5	30	14.52	70	33.88	60	29.4
6	137	66.346	199.75	96.679	217.25	105.149
7	-	-	50	24.2	50	24.2
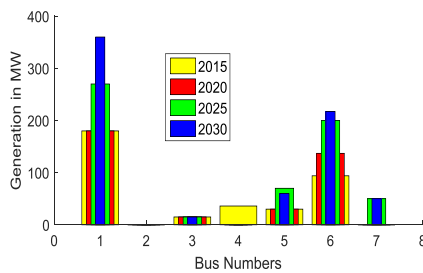
(a)

(b)

Figure 2. Injected powers between 2015-2030, (a) active, (b) reactive

Table 4. 2015-2030 Demand Forecast Data [12]

Bus	Years					
	2015-2020		2020-2025		2025-2030	
	P_D(MW)	Q_D(MVAr)	P_D(MW)	Q_D(MVAr)	P_D(MW)	Q_D(MVAr)
1	-	-	-	-	-	-
2	27.68	15.8	142.55	81.37	734.142	419.05
3	-	-	-	-	-	-
4	11.71	6.36	60.3	32.3	310.05	166.345
5	1.34	1.138	6.9	5.86	35.53	30.179
6	9.4	1.17	48.41	6.02	249.31	36.82
7	13.49	7.18	69.48	7.18	357.86	190.39

Figure 3 shows the demand forecast between 2015 and 2030 years.
Table 5 shows the admittance matrix of buses in per unit (YBUS).
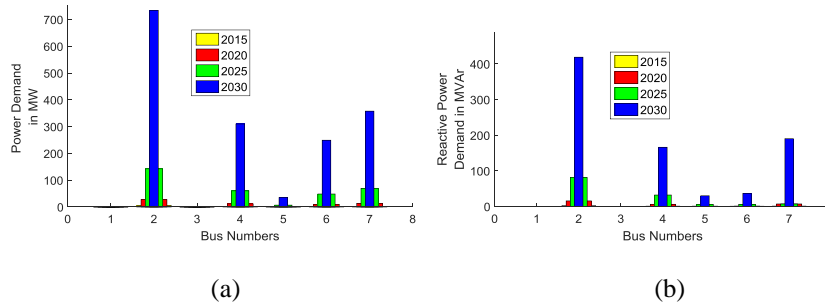Table 6 shows the results of NR without STATCOM [3].

Figure 3. Demand forecast between 2015 and 2030 years (a) active power, (b) reactive power

Table 5. Admittance Matrix of Buses in Per Unit (Y$_{BUS}$)

N	1	2	3	4	5	6	7
1	89.2-118i	-32.6+40.1i	-56.6+77.9i	0	0	0	0
2	-32.6-40.1i	165.8-223.8i	0	-14.4+19.8i	0	-118.8+47.1i	0
2	-56.6-77.9i	0	87.3-115.8i	0	0	0	-30.7+37.9i
3	0	-14.4+19.8i	0	39.9-55.4i	-22.5+31.5i	-2.9+4.1i	0
3	0	0	0	-22.5+31.5i	57.3-78.8i	-34.8+47.2i	0
4	0	-118.8+163.8i	0	-02.9+04.1i	-34.8+47.2i	173.5+22.5i	-16.9+22.5i
5	0	0	-30.7+37.9i	0	0	-16.9+22.5i	47.6-60.4i

Table 6. Results of NR without STATCOM [3]

Bus	Type	Vpu	Angle (°)
1	Slack	1.05	0
2	PQ	0.9	-3.88
3	PV	1.01	-0.97
4	PQ	0.87	-4.86
5	PV	0.88	-4.54
6	PV	0.89	-4.26
7	PQ	0.94	-2.8

3. NUMERICAL MODEL OF STATCOM
3.1. Description of STATCOM:
     The static synchronous compensator STATCOM is one of FACTS derivates family, it us the forcing electronic power commutation (GTO, IGBT or IGCT). A STATCOM is a 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 4 [11].

3.2. System of equations to determine bus voltages:
3.2.1. Gauss-Seidel iterative method (GS) [1], [5], [6] and [2]

$$V_i = \frac{1}{Y_{ii}}\left(\frac{(P_i - jQ_i)}{V_i^*} - \sum_{k=1, k \neq i}^{n} Y_{ik} V_k \right) \qquad i = 1,2,........,n \ et \ i \neq s \tag{1}$$

Where the active and reactive power each bus with indice i take the following form:

$$P_i = \sum_{k=1}^{n} |Y_{ik}||V_i||V_k|\cos(\delta_k - \delta_i + \delta_{ik})$$ (2)

$$Q_i = \sum_{k=1}^{n} |Y_{ik}||V_i||V_k|\sin(\delta_k - \delta_i + \delta_{ik})$$

Since the voltage at the buses must be maintained within certain specified statutory limit, the voltage bound constraint limit at bus i is then defined by Equation (3):

$$V_{i(\min)} \leq V_i \leq V_{i(\max)}$$ (3)

Where Vi (min) and Vi (max) are minimum and maximum values of voltage at bus i.
The reactive power supply constraint at bus i is specified by Equation (4):

$$Q_{gi(\min)} \leq Q_{gi} \leq Q_{gi(\max)}$$ (4)

Where Qgi (min) and Qgi (max) are minimum and maximum values of reactive power supply at bus i
If the constraint defined by Equation (4) is not satisfied, Qgi is set to Qgi (max) if Qgi is greater than Qgi (max) ,and it is set to Qgi (min) if Qgi is less Qgi (max) and the constraint that voltage at bus i is fixed must be released [8]. When STATCOM is shunt-connected at bus i in Figure 1 and it is treated as VAr source, the power equations writing as following:

$$P_i = P_{gi} + P_{STCi} - P_{li}$$ (5)

$$Q_i = Q_{gi} - Q_{STCi} - Q_{li}$$ (6)

Where PSTCi STATCOM real power at bus i, QSTCi STATCOM reactive power at bus i.
Equations (5) and (6) represent a case where STATCOM injects VAr into the system at bus i and for VAr absorption, the signs of PSTCi and QSTCi become reversed.
Due to the non-linearity of algebraic Equations (5) and (6) 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 Equations (5) and (6) 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 [1], [7].

3.3. 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 4 [8] and [9].
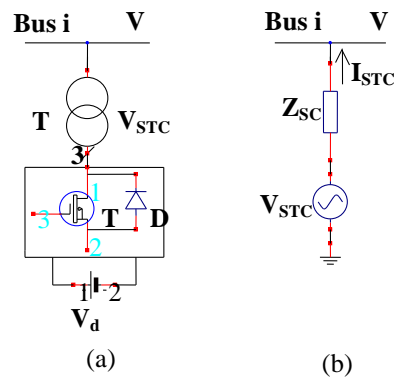

Figure 4. (a) Basic schematic diagram; (b) equivalent circuit [2]

From Figure 4, we obtain Equation (8):

$$V_{STC} = V_i + Z_{SC}I_{STC} \tag{8}$$

Where V_{STC} - Statcom voltage, I_{STC} - Statcom current, Z_{SC} - Transformers impedance.
The voltage injection bound constraint of STATCOM is given by Equation (9) [12].

$$V_{STC(min)} \leq V_{STC} \leq V_{STC(max)} \tag{9}$$

Where V_{STC} (min) and V_{STC} (max) - are the Statcom's minimum and maximum voltages.
Equation (8) is transformed into a power expression for STATCOM and power injected into bus i by Equations (10) and (11) respectively:

$$S_{STC} = V_{STC}I_{STC}^* = V_{STC}V_{STC}^*Y_{SC}^* - V_{STC}Y_{SC}^*V_i \tag{10}$$

$$S_i = V_iI_{STC}^* = V_iV_i^*Y_{SC}^* - V_iY_{SC}^*V_{STC}^* \tag{11}$$

Where S_{STC} – STATCOM injected apparent power, I_{STC}^* - complex conjugate of STATCOM current, V_{STC}^* - complex conjugate of STATCOM voltage, Y_{SC}^* - complex conjugate of short-circuit admittance
The bus i and STATCOM voltages in rectangular coordinates system are expressed as Equations (12) and (13) respectively:

$$V_i = e_i + jf_i \tag{12}$$

$$V_{STC} = e_{STC} + jf_{STC} \tag{13}$$

Where e_i - real component of bus i voltage, f_i - imaginary component of bus i voltage, e_{STC} – real component of STATCOM voltage, f_{STC} - imaginary component of STATCOM voltage.
The STATCOM's voltage magnitude and angle are expressed as Equations (14) and (15) respectively:

$$|V_{STC}| = \left(e_{STC}^2 + f_{STC}^2\right)^{\frac{1}{2}} \tag{14}$$

$$\delta_{STC} = \tan^{-1}\left(\frac{f_{STC}}{e_{STC}}\right) \tag{15}$$

The active and reactive power components for the STATCOM and bus i on the basis of Equations (10) to (15) are respectively expressed by Equations (16) to (19):

$$P_{STC} = G_{SC}\left\{\left(e_{STC}^2 + f_{STC}^2\right) - \left(e_{STC}e_i + f_{STC}f_i\right)\right\} + B_{SC}\left(e_{STC}f_i - e_{STC}f_i\right) \tag{16}$$

$$Q_{STC} = G_{SC}\left(e_{STC}f_i - f_{STC}e_i\right) + B_{SC}\left\{\left(e_{STC}e_i + f_{STC}f_i\right) - \left(e_{STC}^2 + f_{STC}^2\right)\right\} \tag{17}$$

$$P_i = G_{SC}\left\{\left(e_i^2 + f_i^2\right) - \left(e_ie_{STC} + f_if_{STC}\right)\right\} + B_{SC}\left(e_if_{STC} - e_if_{STC}\right) \tag{18}$$

$$Q_i = G_{SC}\left(e_if_{STC} - f_ie_{STC}\right) + B_{SC}\left\{\left(e_ie_{STC} + f_if_{STC}\right) - \left(e_i^2 + f_i^2\right)\right\} \tag{19}$$

Where P_{STC} - STATCOM real power, Q_{STC} - STATCOM reactive power, G_{SC} - short-circuit conductance, B_{SC} – short-circuit susceptance
      The Newton-Raphson set of linearized equations for power flow Equations (10), (11), (16) and (17) obtained taken into consideration the modeling of shunt-connected STATCOM at bus i is given by Equation (20) [6], [2].

$$
\begin{bmatrix} \Delta P_i \\ \Delta Q_i \\ \Delta P_{STC} \\ \Delta Q_{STC} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_i}{\partial e_i} & \frac{\partial P_i}{\partial f_i} & \frac{\partial P_i}{\partial e_{STC}} & \frac{\partial P_i}{\partial f_{STC}} \\ \frac{\partial Q_i}{\partial e_i} & \frac{\partial Q_i}{\partial f_i} & \frac{\partial Q_i}{\partial e_{STC}} & \frac{\partial Q_i}{\partial f_{STC}} \\ \frac{\partial P_{STC}}{\partial e_i} & \frac{\partial P_{STC}}{\partial f_i} & \frac{\partial P_{STC}}{\partial e_{STC}} & \frac{\partial P_{STC}}{\partial f_{STC}} \\ \frac{\partial Q_{STC}}{\partial e_i} & \frac{\partial Q_{STC}}{\partial f_i} & \frac{\partial Q_{STC}}{\partial e_{STC}} & \frac{\partial Q_{STC}}{\partial f_{STC}} \end{bmatrix} \begin{bmatrix} \Delta e_i \\ \Delta f_i \\ \Delta e_{STC} \\ \Delta f_{STC} \end{bmatrix} \tag{20}
$$

Where the partial derivatives of the Jacobian matrix are defined on the basis of expression (21).

$$
\begin{cases}
\frac{\partial P_i}{\partial e_i} = G_{SC}(2e_i - e_{STC}) + B_{SC}f_{STC} \\[4pt]
\frac{\partial P_i}{\partial f_i} = G_{SC}(2f_i - f_{STC}) - B_{SC}e_{STC} \\[4pt]
\frac{\partial P_i}{\partial e_{STC}} = -G_{SC}e_i - B_{SC}f_i \\[4pt]
\frac{\partial P_i}{\partial f_{STC}} = -G_{SC}f_i + B_{SC}e_i \\[4pt]
\frac{\partial Q_i}{\partial e_i} = G_{SC}f_{STC} + B_{SC}(e_{STC} - 2e_i) \\[4pt]
\frac{\partial Q_i}{\partial f_i} = G_{SC}e_{STC} + B_{SC}(f_{STC} - 2f_i) \\[4pt]
\frac{\partial Q_i}{\partial e_{STC}} = -G_{SC}f_i + B_{SC}e_i \\[4pt]
\frac{\partial Q_i}{\partial f_i} = G_{SC}e_i + B_{SC}f_{STC} \\[4pt]
\frac{\partial P_{STC}}{\partial e_i} = -G_{SC}e_{STC} - B_{SC}f_{STC} \\[4pt]
\frac{\partial P_{STC}}{\partial f_{STC}} = -G_{SC}f_{STC} + B_{STC}e_{STC} \\[4pt]
\frac{\partial Q_{STC}}{\partial e_i} = -G_{SC}f_{STC} + B_{SC}e_{STC} \\[4pt]
\frac{\partial Q_{STC}}{\partial f_i} = G_{SC}e_{STC} + B_{SC}f_{STC} \\[4pt]
\frac{\partial Q_{STC}}{\partial e_{STC}} = G_{SC}f_i + B_{SC}(e_i - 2e_{STC}) \\[4pt]
\frac{\partial Q_{STC}}{\partial f_{STC}} = -G_{SC}e_i + B_{SC}(f_i - 2f_{STC})
\end{cases}
\tag{21}
$$

3.4. Results of simulation and discussion

In the Table 7 below is given the possible STATCOM location in buses and shown their impact on the system

Table 7. Results of STATCOM Connected to the Bus 2

Bus	Type	V pu	Angle (°)
1	1	1.05	0
2	2	1	-7.07
3	3	1.03	-1.81
4	3	0.97	-7.8
5	2	0.97	-7.53
6	2	0.98	-7.29
7	3	1.01	-5.23

The voltage profile before and after STATCOM connected are shown in the Figure 5, it demonstrates the voltage magnitude increased for the bus 2 at 0.90 (value out limit [0, 95; 1, 05 pu]) to 1 pu, bus 4 at 0.87 to 0.97pu, the bus 5 at 0.88 to 0.97pu, the bus 6 at 0.89 to 0.98pu, the bus 7 at 0.94 to 1.01pu and the bus 3 improved at 1.01 to 1.03pu.

The voltage angle before and after STATCOM connected are shown in the Figure 6, it demonstrates the voltage angle increased for the bus 2 at -3.88 to -7.07 degree, bus 3 at-0.97 to-1.81 degree, the bus 4 at -4.86 to -7.8 degree, the bus 5 at -4.54 to -7.53 degree, the bus 6 at -4.26 to -7.29 degree and the bus 7 at -4.03 to -5.23 degree
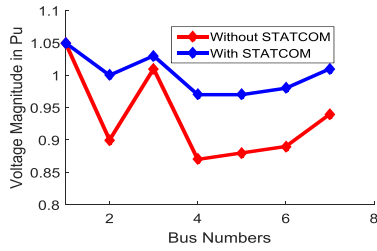
Table 8 shows the total active power loss.
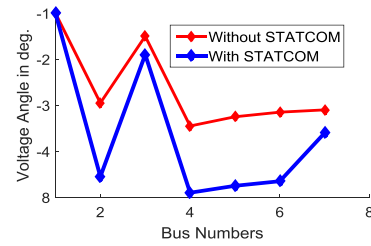
Figure 5. Curve of Voltage magnitude in pu

Figure 6. Curve of Voltage Angle in degree

Table 8. Total Active Power Loss

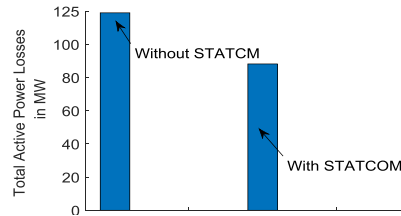|	Total active power loss
Without STATCOM	119
With STATCOM	88.2

Figure 7. Curve of active power loss without with STATCOM

From the above Figure 7, there was a reduction in total active power loss from 119 MW to 88.2 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 loss on the power system.

Table 9 shows the total reactive power loss.

Table 9. Total reactive power loss

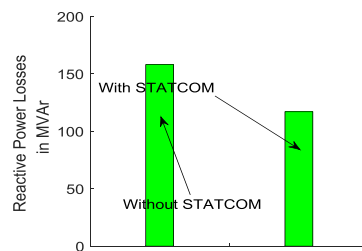|	Total reactive power loss
Without STATCOM	158
With STATCOM	117.2

Figure 8. Curve of reactive power loss without and with STATCOM

From the above Figure 8, there was a reduction in total reactive power loss from 158 MVAr to 117.2 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 loss on the power system [4].

4. CONCLUSION

The simulation of the STATCOM on the Matlab and PSS/E Simulator using the NR method enabled us to see the voltage profile and the lines power mismatches. It should be noted that the STATCOM is in suitable to our predetermined goals, since it responds to all the problems related to the variation of loads and frequencies.

The power losses compared to the NR method without STATCOM are greater than with the STATCOM. The voltage of weakest buses is improved after insertion of the smart device (STATCOM) to 1 pu and greater in stability limit [12].

In the end the expected disturbances of the network in the horizon 2030 were attenuated by installation of a FACTS system that is able to supply or absorb reactive power and to maintain the voltage to 1pu.The completion of one research project opens the way to work in many other related areas. The following areas are identified for future work:

The load flow study can be done on larger interconnected power system like IEEE 14, IEE 30, and IEE 118 bus and even larger.

UPFC, IPFC and other FACTS controller can also be incorporated along the STATCOM and their effect on the system can be studied [11], [10] and [5].

Optimal location of STATCOM can be found out using Genetic Algorithm and fuzzy logic.

Economic Assessment of FACTS devices against other methods can be studied.

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