FACTS as Efficient Alternative to Network Reinforcements in the SouthWest Libyan System

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Abstract

This paper investigated the effectiveness of installing Flexible AC Transmission Systems (FACTS) devices in the Libyan transmission network as an alternative to network reinforcement. The Libyan 220 kV transmission system is suffering from voltage stability problems especially in case of long transmission line and heavily loads in the southwestern networks.This work concentrates on the use of the application of reactive power compensation devices (FACTS) on the southwestern region networks .The focus of this work is to study the application of the reactive power compensation devices (FACTS) on Libyan high voltage 220 kV and extra high voltage 400 kV electrical power network, as an effective alternative to network . In This paper a very integrated and comprises software tool designed for power system analysis and operation analysis and study were used. The package, named SPIRA was designed by (ENEL-CISE) of ITALY, and made available at General Electricity Company of Libya (GECOL).

Keywords: Power transmission, Load-flow, Loadability, Reactive power, FACTS, Series Compensation.

1. Introduction

Nowadays, it is becoming increasingly difficult to build new transmission lines, due to restrictions regarding environment and financial issues. Besides that, electrical energy consumption continues to increase, leading to a situation where utilities and independent system operators have to operate existing transmission systems much more efficiently and closer to their stability limits. One important benefit of FACTS (Flexible AC Transmission Systems) technology is that it makes it possible to improve the use of the

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existing power transmission system and to postpone or avoid the construction of new transmission facilities.

The fast-changing energy market has brought the operators of high-voltage transmission systems a combination of fresh opportunities and new challenges. The latter stem mainly from the strong increase in inter-utility power transfers, the effects of deregulation, and economic and eco-logical constraints on the building of new transmission facilities. Today's AC power transmission networks are not designed for easy voltage and power flow control in a deregulated market, and steady-state control problems as well as dynamic stability problems are the result. The development of Flexible AC Transmission Systems, or FACTS, based on high-power electronics, offers a powerful new means of meeting the challenges.

2. FACTS - The concept

The term "FACTS" Flexible AC. Transmission Systems ,covers several power electronics based systems used for AC power transmission.

1. Power electronic based devices
2. Control of active and reactive power flow on transmission lines
3. Improve voltage regulation
4. Improve transient and dynamic stability

FACTS offers ways of attaining an increase of power transmission capacity at optimum conditions, i.e. at maximum availability, minimum transmission losses, and minimum environmental impact. Plus, of course, at minimum investment cost and time expenditure.

FACTS devices are becoming more and more important in today's Electricity Supply Industry (ESI). After years of studies, the first prototype realizations of FACTS devices are now evolving to industrial equipment that can be installed in real power systems to improve both static and dynamic performances. Furthermore, FACTS devices are able to control power flows acting upon the line impedance and the phase angle.

FACTS devices can be helpful in sharing power flows between two or more corridors avoiding possible overloads (balance of active power flow) or unacceptable voltage profile (balance of reactive power flow).[8]

3. Types of FACTS Devices

1- Static Var Compensator (SVC);
2- Static Var Generator (SVG) or Static Compensator (STATCOM);
3- Controlled Series Compensation (CSC) either with thyristor or GTO converter. The variation of the compensation can be achieved by switching on/off the series capacitors (TSSC: Thyristor Switched Series Capacitors) or by varying in a continuous mode the thyristor controlled reactor in parallel to the capacitance (TCSC: Thyristor Controlled Series Capacitor); Synchronous static series compensator (SSSC).
4- Phase Shifting Transformer (PST) which can be Phase Angle Regulator (PAR), when only a phase shift between input and output voltages is applied, or Quadrature Boosting Transformer (QBT), when the phasor of the injected voltage of the QBT series branch is shifted at constant angle with respect to the input voltage vector;
5- Interphase Power Controller (IPC);
6- Unified Power Control (UPFC).

3-1 Series Compensation

Series compensation is frequently found on long transmission lines used to improve voltage regulation. Due to the long transmission lines, voltage begins to decay as the line moves further from the source. Series compensation devices placed strategically on the line increase the voltage profile of the line to levels near 1.0 p.u. Series compensation is a valid solution to increasing power transfer capabilities mainly because it is a more cost effective method compared to other methods currently available.

3-1-1 Impact of series compensation on power systems

Series capacitors have been used successfully for many years to enhance the stability and load capability of HV transmission networks. They work by inserting capacitive voltage to compensate for the inductive voltage drop in the line, i.e. they reduce the effective reactance of the transmission line, Figure 1. shown the reduce the effective reactance of the transmission line .[2]

Figure 1. Reduction The Effective Reactance Of The Transmission Line

From Figure 1. can write these equations:

$$X_{TOT} = X - X_C = X - \eta_C X = X(1-\eta_C) \qquad \eta_C = \text{compensation level}$$

$$P_C = \frac{V_R V_S}{X(1-\eta_C)}\sin\delta \qquad (1)$$

Transfer capability is increased by $\frac{1}{1-\eta_C}$

Typically, η_C is between 0.3 and 0.7.

4. Power System Steady State Analysis

4-1 Steady-State Power System Component Modelling

Many components constitute an electrical power system. However, the main components of a power system, which are of interest in a sinusoidal steady-state analysis, such as load-flow analysis, are:[1]

(a) Power generators.

(b) Transmission lines;

(c) Power transformers;

(d) Series inductors;

(e) Shunt capacitors.

(f) System loads.

5. Study Cases and Results

5.1 An Overall View of the Libyan Power system

The Libyan system has been subdivided electrically into seven zones as shown in Figure 2. The names of the main substations are shown for each division . The list and total number of the substation is summarized in Table 1.

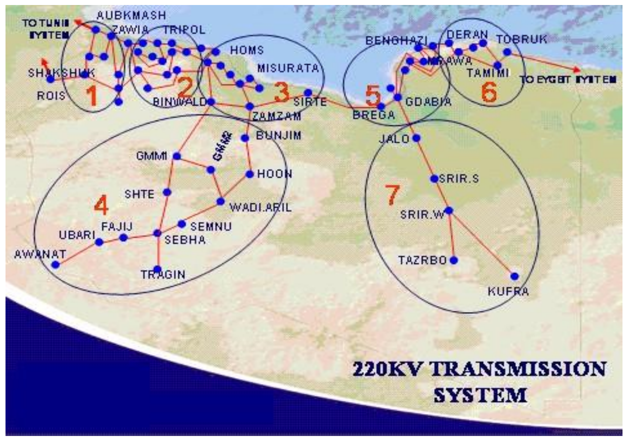

Figure 2. The Seven Area Of Libyan System

Table 1.The list and total number of the substation

Area1 (Western)	Area2 (Tripoli)	Area3 (Central)	Area4 (SEBHA)	Area5 Bengazi	Area6 (Eeastern)	Area7 (Srir & kufra)
Abkmash	Anzar	Benwald	Bunjm	Bengazi	Derna	Jalo
Aglat	Baziz	Grbli	Fajij	Beng-n	Mrawa	Kfra
Azhra	Gryan	Hommp	Gmmr1	Beng-s	Tmimi	Srir-s
Bganm	Hkdra	Homms	Gmmr2	Brega	Tobrk	Srir-w
Rabta	Hera	Homm	Hoon	Butni	Xroad	Tzrbo
Rowis	Ntion	Misrata-w	SEBHA-svc	Gdbia		
Shksk	Saraj	Masrtat-e	SEBHA-w	Gmins		
Zawia-h	Trhuna	Masrata-t	SEBHA-n	Gwrsh		
Zawia -p	Tripe	Sirte	Shate	Maraj		
Zuara	Trips	Wkaam	Semnu	Rlnuf		
	Tripw	Zlitn	Tragn	Zwtna		
		Zmzam	Waril			
			Awanat			

The total loads in the network subdivided for the different zones, at peak load condition for the base case 2010, and the forecasted demand for years 2020, are show in Figure 3 and Figure 4.

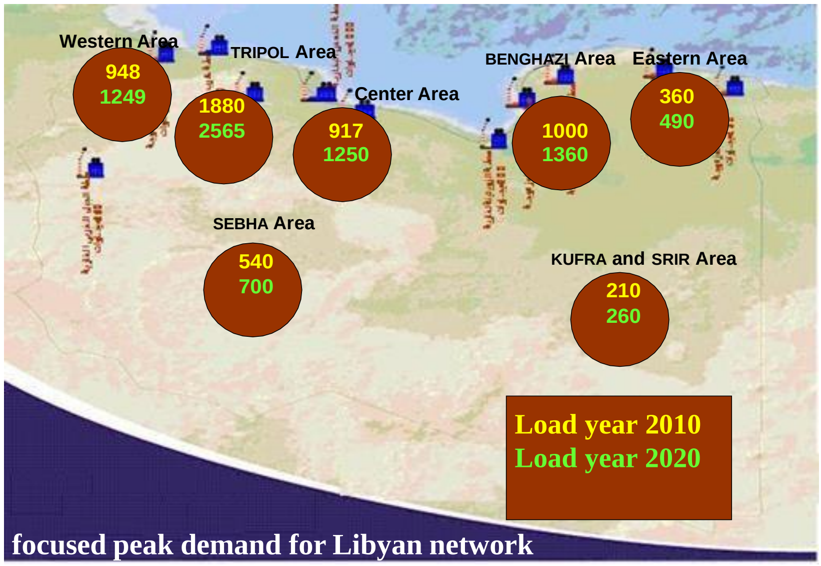

Figure 3. The total loads in the network subdivided for the different zones

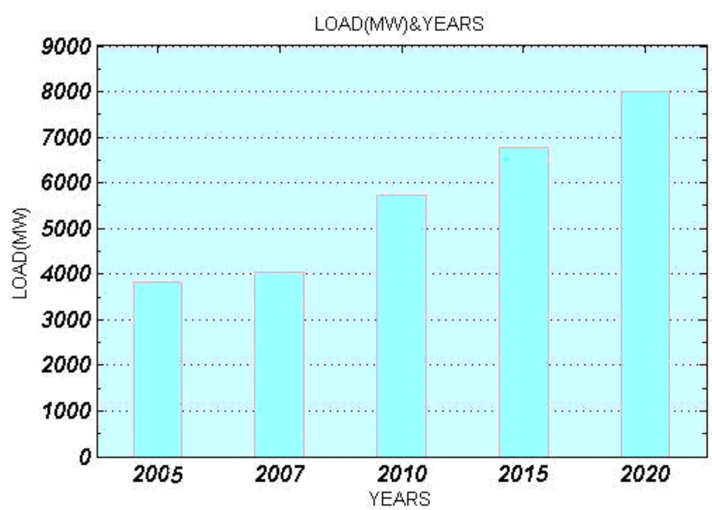

Figure 4. Focused peak demand for Libyan network

6. Study Methodology

The adopted study methodology for the work presented in this paper consists of the following:

1) Assessment of the performance of the 2010 network for peak and minimum loading condition at normal (N) and contingency (N-1) operating states through comprehensive load flow study cases;

6-1 Load flow study for the peak load case

The steady state load flow analysis of the system in year 2010 at peak load condition showed satisfactory system performance. The bus bar voltage and the loading of the transmission equipment were all within the permissible values. All the expected demand during this year can be supplied in an acceptable condition. for the south western region the total load supplied in this case was (758MW).However, the maximum power transfer to the south western region without compensation i.e. without FACTS was (758MW) beyond this it is not possible to cover more demand even through the new 400kV reinforcement. All the line currents with fixed maximum value are within the limits, all the reactive power of the generators are in the limits. Summary of the results are shown in Tables 2,3. [1]

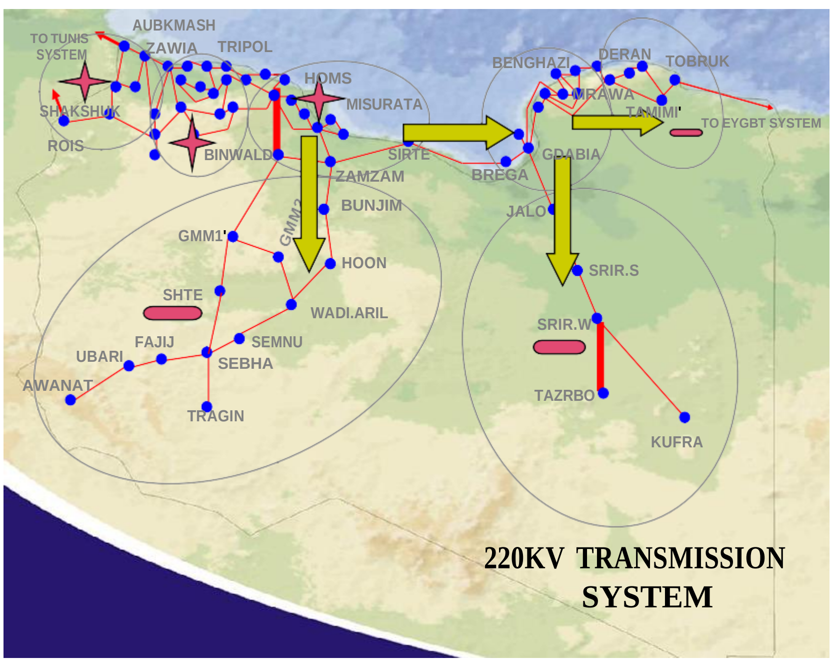

Figure 5. Load flow for case 2010

2) A comprehensive load flow study cases to assess the effectiveness of the application of FACTS devices namely SC (Series Compensation) at various locations in southwestern region (SEBHA region).

3) Analysis of the results of study cases in 1 and 2 to high light the promising alternatives for future studies.

4) Choosing the best alternative that provides better utilization of the existing transmission assets.[1]

6-2 Criteria and Main Assumptions:

In order to carry out the above-mentioned study cases, there was a need to state the following assumptions:

- Minimum load is 50% of the peak load.
- Steel complex and GMMR loads are constant.
- Reactive power is at 0.89power factor.

To keep up with the standards in operating the power systems, the following criteria had to be observed and fulfilled:

- Voltage level should not exceed in normal operation (N), and (-10%,+5%) in emergency operation (N-1).
- Transmission lines should not be loaded more than 100% from the thermal limit of the line.
- Power generation units should be kept within their capabilities both for active and reactive power.

6-3 Study Cases

As has been stated in work focus of this paper is to study the :

- The base case study 2010peak and minimum loading condition at normal(N) and contingency(N-1) operating states.
- Determining the maximum power transfer to SEBHA region (area four)with and without FACTS i.e. compensation device such as:

  •Adjusting set point in terminal voltage for Generators.

  •Using static compensators.

- Operation of new 400 KV line with peak and minimum loading condition at normal (N) and contingency (N-1) operating states.
- FACTS device namely series compensation.

6-3-1 Study Case Year 2010

The total installed generation will be expected to reach (8500MW) and the system total load will be expected to reach 6040MW.The load of the south western region will be expected to reach (758MW).

However, it is clear that the demand of this region can be supplied in an acceptable condition during the year 2010.Without any reinforcement including using FACTS technique. There for the main objective of this case is to verify the effectiveness of SC on the network loadaibility**.** [1]

Table 2. Summary of results for the case of Peak load in 2010**.**

list	MW	Mvar.
TOTAL POWER GENERATION	6094	549
TOTAL LOADES	6040	3019
TOTAL REACTOR LINE	—	3330
LOSSES TARNSFORMRE	0.00	557
LOSSES IN LINES AND 400KV	17	-2681
LOSSES IN LINES AND CABLES 220KV	37	-3618
TOTAL LOSSES	54	-5742

Table 3. Dispatched generation for peak load

POWER PLANT	bwp	BNP	DRN	HMP	glf	kef	MST &msp	
PEAK MW	630	630	100	720	480	15	960	
POWER PLANT	ROW	SRW	TBK	TRS	TRW	ZWP	ZWT	Total
PEAK MW	340	160	100	320	569	990	80	6094

6-3-1-2 Load flow study for the Minimum load case

The generation dispatch for the minimum case is shown in Table 4.The summery of the results is shown in Tables 5.

Table 4. Dispatched generation for Minimum load

List	MW	Mvar
Total Power Generation	3386	-371
Total Loads	3365	1724
Total Reactor Line	—	4455
Losses Transform	0.00	183
Losses In Lines And 400kv	7	-2800
Losses In Lines And Cables220kv	14	-3886
Total Losses	21	-6503

Table 5. Dispatched generation for Minimum load

POWER PLANT	bwp	BNP	DRN	HMP	glf	kef &SRW	MST &msp
Minimum MW	330	360	50	440	240	92	540
POWERPLANT	ROW	TBK	TRS	TRW	ZWP	ZWT	Total
Minimum MW	200	50	160	320	540	64	3386

6-3-1-3 Contingency (N-1) Operating States

For the objective of checking the system in an emergency state, several (N-1) cases have been studied. The same tower collapse criteria were applied to the following lines:

- ZMZ-BNJ 220kV double circuit lines.
- BWD-GM1 220 kV doubles circuit lines.
- HMS-GM1 400 KV single circuit line.
- GLF-HON 400 KV single circuit line.

In this case, the maximum power that can be transferred to the region with an acceptable condition during (N-1) state was found to be in the range of 680-729MW. The system performance was satisfactory and the operation criterion was justified. Table 6 shows the results obtained in the different cases.[1]

Table 6. Results of this case

LINES	N	N-1		
ZMZ-BNJ	113.36	217.3	146.46	136.44
BWD-GM1220	154.66	190.82	239.5	0
BWDGM1400	255.09	319.27	0	326.42
GLF-HON400	255.59	0	320	287.64
Max load to area4	757.69	703.42	680.8	729.24
Loss (MW)	21.01	23.97	25.16	21.26

6-3-2 Application of series compensation

In this case, the main objective of studying the simulation of FACTS namely, SC on the transmission lines connecting southwestern area (SEBHA region) to the north is to verify the effectiveness of such smart equipment on the system after putting into operation the planed reinforcement on the transmission system and the new generation addition. We are impact the FACTS devise (series compensation) on these lines:

- Line (BNJ- HON) this line link between (BUNJEM-HOON with long 200KM).
- Line (BWD-GM1) this line link between (BENWLED-GMM1 whit long 325 KM).
- Line (BNJ-WRL) this line link between (BUNJEM-HOON-WADE ALREAL with long 400KM).
- Both lines (HON-BNJ, and BWD-GM1).[1]

6-3-2-1 Series compensation on line (BNJ- HON):

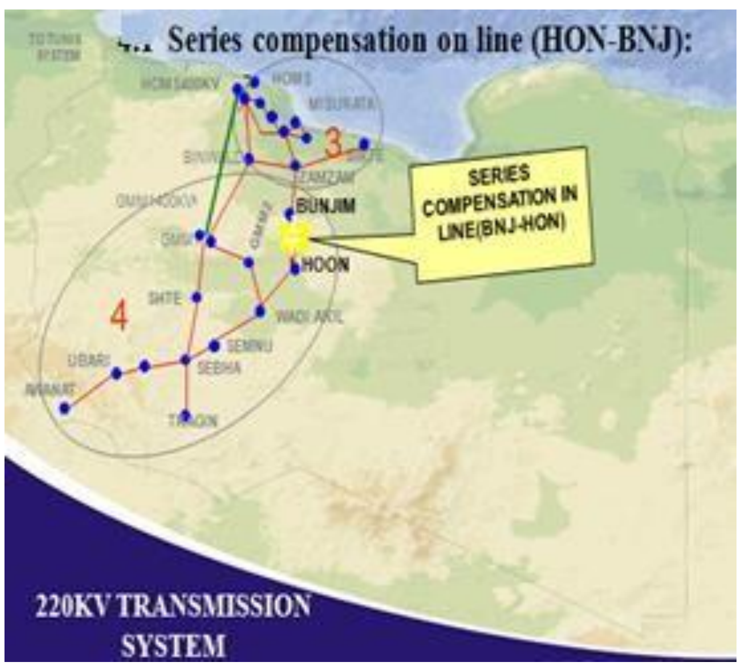

Figure 6. Series compensation on line (BNJ- HON)

Table 7. The result of sc in line (BNJ- HON)

Line (MW)/%SC	Without SC	30%	50%	60%
line(ZMZ-BNJ)220KV	113	136	158	159
line(BWD-GM1)220KV	155	164	161	162
Line (BWD-GM1)400KV	255	268	265	266
line(GLF-HON)400KV	256	267	255	256
Max load in area4	758	812	815	819
losses(MW)	21	23	24	24
Voltage	0.95-1.05			

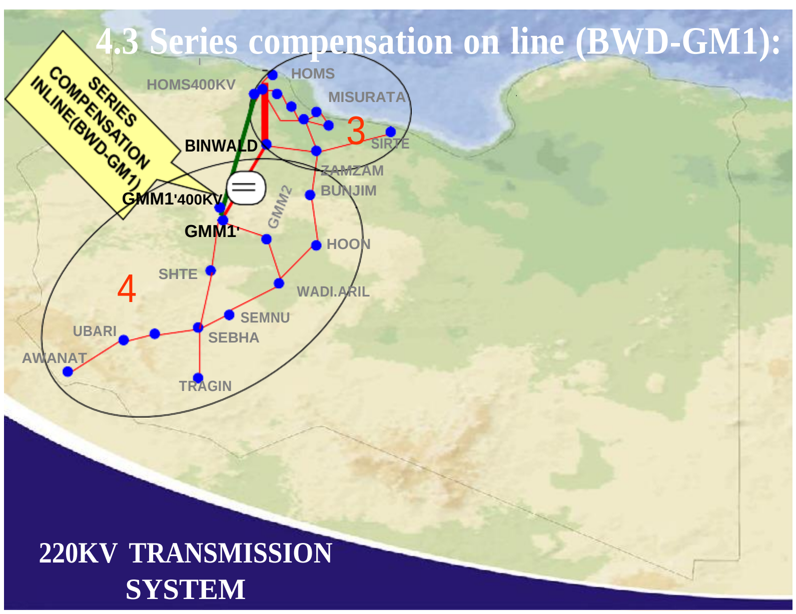

Figure 7. Series compensation on line(BWD-GM1):

Table 8. The result of sc in line (BWD-GM1)

Line (MW)/%SC	WITHOUT	30%	50%	60%
line(ZMZ-BNJ)220KV	113.36	113.6	107.43	103.63
line(BWD-GM1)220KV	154.66	207.2	249.7	279.09
Line (BWD-GM1)400KV	255.09	250.1	229.9	216.84
line(GLF-HON)400KV	255.59	266.1	256.93	251.24
Max load in area4	757.69	813	818	823
losses(MW)	21.01	24	25.96	27.8
Voltage	1.04-0.95			

6-3-2-3 Series compensation on line (BNJ-WRL):

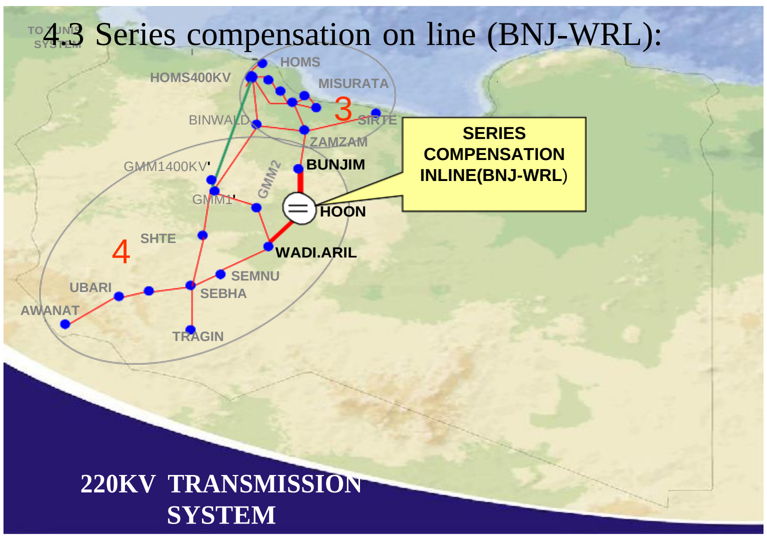

Figure 8. Series compensation on line (BNJ-WRL):

Table 9. The result of s.c in line (BNJ-WRL)

Line (MW)/%SC	WITHOUT	30%	50%	60%
line(ZMZ-BNJ)220KV	113.	146.3	171.1	188
line(BWD-GM1)220KV	154.66	160.6	154.5	150.3
Line (BWD-GM1)400KV	255.09	264.3	256.3	250.8
line(GLF-HON)400KV	255.59	276.5	276.4	276.4
Max load in area4	757.69	823	832	838
losses(MW)	21.01	24.7	26.3	27.5
Voltage	1.04-0.95			

6-3-2-4 Series compensation on both lines (BNJ-HON &BWD-GM1)

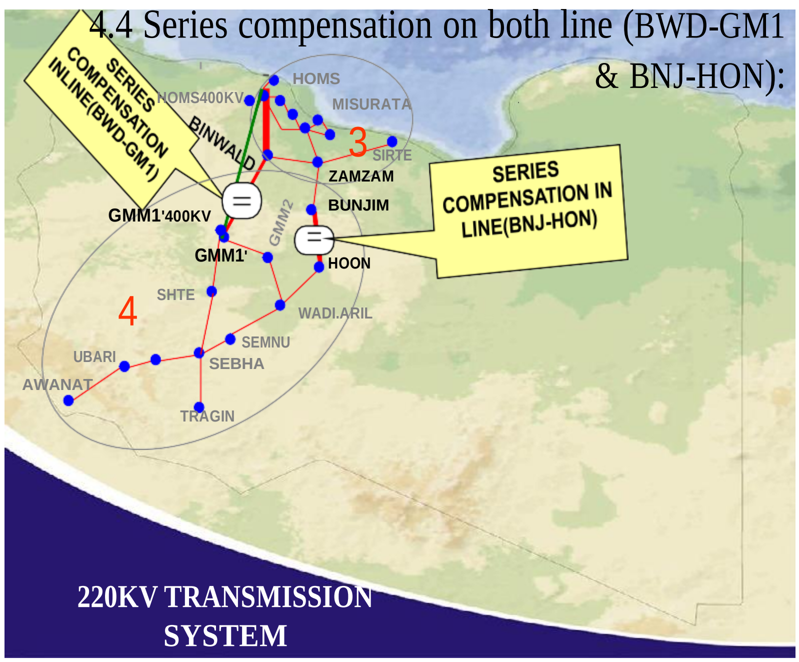

Figure 9. Series compensation on both lines (BNJ-HON &BWD-GM1)

Table 10. The result of sc in both lines (BNJ-HON &BWD-GM1)

Line (MW)/%SC	Without SC	30%	50%	60%
line(ZMZ-BNJ)220KV	113.36	128.8	137.3	141.73
line(BWD-GM1)220KV	154.66	205.7	247.2	274.1
Line (BWD-GM1)400KV	255.09	248.5	227.8	213.62
line(GLF-HON)400KV	255.59	258.2	246.1	238.7
Max load in area4	757.69	817	832.1	840
losses(MW)	21.01	24.37	26.56	28.15
Voltage	1.04-0.95			

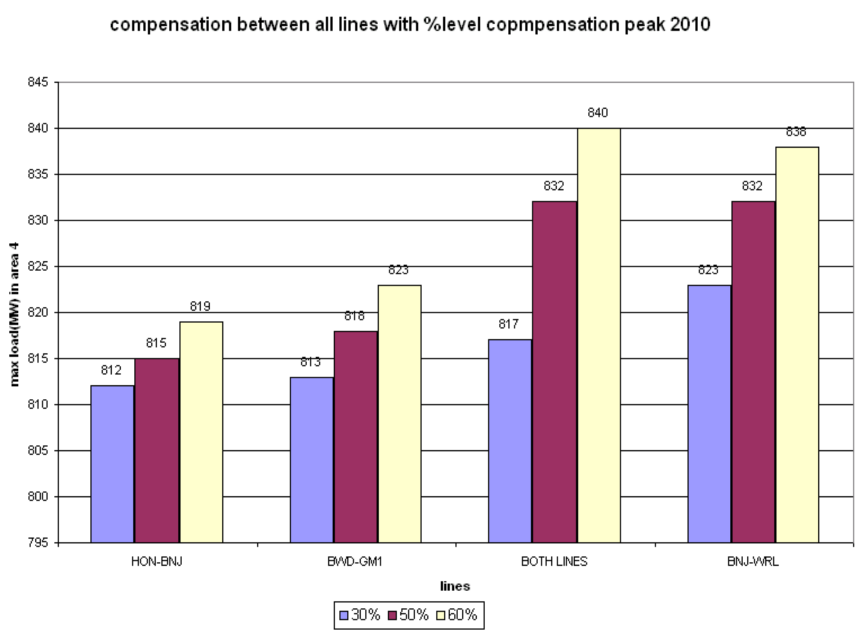

Figure 10. Summary Result on the case year 2010

7. Conclusions

As mentioned above, the objective of this case study is to verify the import and effectiveness of FACTS application on the 220kV lines supplying the southwestern area from the north after the operation of new-planed reinforcement in particular the 400kV network towards the southwestern region. From the study results, the following remarks can be stated:

- Although, the expected demand of the southwestern region can be covered in an acceptable operation condition even without reinforcement, but with compensation i.e. applying FACTS on the 220kV lines supplying the region from the north, the network loadaibility margin can be slightly increased. In addition, the application of FACTS (SC) proved its effectiveness and importance even after the operation of the 400kV network towards the southern, where the voltage profile and the power transfer improved.
- Furthermore, the system proves it is capability to face emergency conditions like N-1 conditions, and the system performance was satisfactory both from the voltage level point of view and from securing the supply from the other point of view.

8. References

[1] Lyela E. M. Galala, FACTS as an Efficient Alternative to Network Reinforcement in the South West Libyan System, M.Sc. Thesis of Higher Institute of Engineering,Dec 2007.
[2] MOHAMED A.ABUAZOOM, “CAPSA Comprehensive Advanced Power Systems Analysis Suite”phD thesis university of strathclyed VolumeI, November 1990.
[3] Rolf Grünbaum, Mojtaba Noroozian and Bj̧ rn Thorvaldsson, “FACTS Solutions and CaseStudy ” ABB Power Systems, 2003.
[4] ABB Power Technologies AB FACTS “500 kV Series Capacitors in the Pacific Intertie ”.
[5] Rolf Grünbaum, Johan Ulleryd ABB Power Technologies AB “Grid flexibility” ABB Power Systems, April 2005.
[6] Tore Petersson, “ Reactive Power Compensation ” ABB Power Systems, Dec.1993.
[7] ITET ETH Z¨urich G¨oran Andersson, “Modelling and Analysis of Electric Power Systems” March 2003.
[8] Elena Vdovina “Optimal Allocation of FACTS Devices in a Power System ; Comparison of Genetic Algorithms and Simulated Annealing” Diploma these (2001).
[9] Vijay Vittal “Use of Series Compensation in Transmission Lines” April 29, 2004