TECHNICAL EVALUATION OF SYNCHRONOUS INTERCONNECTION BETWEEN MASHRIQ COUNTRIES

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ABSTRACT

TECHNICAL EVALUATION OF SYNCHRONOUS INTERCONNECTION BETWEEN MASHRIQ COUNTRIES

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The Electrical Interconnection among The Eight Countries Project (EIJLLPST Project) has been initiated by Mashriq countries (Libya, Egypt, Jordan, Palestine, Syria, Lebanon, Iraq) and Turkey. The objectives of the EIJLLPST Project are to investigate necessary investments to reinforce the existing interconnections and to increase transfer capacities between EIJLLPST countries.

This study aims to evaluate the transfer capacities of the existing and planned interconnections between these countries through computer simulations. For this purpose, power system models of each country are obtained and combined. Then, load flow (including contingency analysis), short circuit, transient stability and eigenvalue analysis are conducted on EIJLLPST power system model. Technically acceptable transfer capacities among EIJLLPST countries are determined considering the system security. New interconnection lines and transmission investments needed for transmission system security and increasing transfer capacities among these countries are also discussed and presented.

Keywords: Interconnection, Power system analysis, Transfer capacity calculation.

ÖZ

MAŞRİK ÜLKELERİ ARASINDAKİ SENKRON ENTERKONNEKSİYONUN TEKNİK DEĞERLENDİRMESİ

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Libya, Mısır, Ürdün, Filistin, Suriye, Lübnan, Irak ve Türkiye tarafından bu ülkeler arasındaki elektriksel bağlantıların geliştirilmesi amacıyla Sekiz Ülke Enterkonneksiyonu Projesi (The Electrical Interconnection Among The Eight Countries Project-EIJLLPST Project) başlatılmıştır. Bu proje ile ülkeler arasındaki elektriksel bağlantılarının güçlendirilmesi için gerekli yatırımların değerlendirilmesi ve ülkeler arasındaki elektrik enerjisi transfer kapasitelerinin artırılması amaçlanmıştır.

Bu çalışma, ilgili projenin amacına yönelik olarak, ilgili ülkeler arasındaki mevcut ve planan enerji hatlarının teknik açıdan bilgisayar simülasyonları ile değerlendirilmesini ve transfer kapasitelerinin belirlenmesini hedeflemektedir. İlk olarak, proje katılımcısı ülkelerin kendi şebekeleri için hazırladıkları güç sistemi planlama modelleri kullanılarak tek bir sistem modeli oluşturulmuştur. Bu sistem modeli üzerinde bir şebeke analiz yazılımı kullanılarak yük akışı, kısa devre, transient kararlılık ve özdeğer analizleri yapılmıştır. Bu analizler sonucu, ilgili ülkeler arasındaki planlanan yeni enerji hatları ve iletim yatırımları, transfer kapasiteleri ve sistem güvenilirliği açılarından değerlendirilmiştir.

Anahtar Kelimeler: Enterkonneksiyon, Güç sistemi analizi, Transfer kapasitesi hesaplanması.

To My Family

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LIST OF ABBREVIATIONS

AAC	Already Allocated Capacity
AC	Alternating Current
ATC	Available Transmission Capacity
BCE	Base Case Exchange
DC	Direct Current
EIJLLPST	Egypt, Iraq, Jordan, Lebanon, Libya, Palestine, Syria and Turkey
ENTSO-E	European Network of Transmission System Operators for Electricity
ETSO	European Transmission System Operators
HVDC	High Voltage Direct Current
Hz	Hertz
km	kilometer
kV	kilovolt
MENA	Middle East and North Africa
M.O.U.	Memorandum of Understanding
ms	millisecond
MVA	Mega Volt Ampere
MVAr	Mega Volt Ampere Reactive

MW	Mega Watt
NTC	Net Transfer Capacity
OHL	Overhead Line
PSS/E	Power System Simulator for Engineering
pu	Per Unit
RES	Renewable Energy Sources
SPS	Special Protection System
STATCOM	Static Synchronous Compensators
SVC	Static VAr Compensator
TRM	Transmission Reliability Margin
TSO	Transmission System Operator
TTC	Total Transfer Capacity

CHAPTER 1

INTRODUCTION

Interconnections between power systems take an important role in power system operations and several studies on interconnections are performed to investigate impact of interconnections on power systems. In South America case, driving factors of interconnections are stated as grid connections of international hydro power projects, energy transfer opportunity from a country which has excess energy with low price to a country which has energy deficit or energy with high price and taking advantage of diversity between hydro generation based power systems and thermal generation based power systems [1], [2]. Spain and Portugal operate their power systems as a single electricity market with four 400 kV and three 220 kV interconnection lines, and their plan is to increase the capacity of interconnection with new interconnection lines and internal reinforcements. Having larger electricity market provides some advantages to Spain and Portugal, such as increase in energy exchange, improvement of system reliability, increase in RES generation, benefits of system diversity (generation regime, climate, load curve, etc), decrease in reserves [3]. The study on Korea and Japan interconnections indicates that interconnection between Korea and Japan could improve energy security, economic operation of power systems and reduce environmental impacts [4]. The study on generation adequacy and interconnections states that generation adequacy of interconnected power systems is improved by increasing the interconnection capacity [5].

The Electrical Interconnection among The Eight Countries Project (EIJLLPST Project) has been initiated by Mashriq countries (Libya, Egypt, Jordan, Palestine, Syria, Lebanon, Iraq) and Turkey to take advantage of interconnections between countries. The objectives of the EIJLLPST Project are to investigate necessary investments to reinforce the existing interconnections and to increase transfer capacities between EIJLLPST countries. To increase the energy exchange between countries, to reduce the operational cost of power systems and to increase the system reliability are aimed by increasing transfer capacities. This project was started with signing of the M.O.U. (Memorandum of Understanding) of Interconnection of Electricity of Network on 17 January, 1989 between Egypt, Iraq, Jordan, Syria and Turkey. Project was started as a five-country interconnection project; later Lebanon joined to the project and the project took its final form with joining of Libya and Palestine.

The development of RES generation in MENA region and the transferring the power from RES to Europe is an important topic in the context of European Union sustainability targets [6]. East Mediterranean route is one of the possible connections for the energy transfer between MENA region and Europe. EIJLLPST Project could reinforce transmission infrastructure of East Mediterranean route and could increase the utilization of interconnections by transferring RES generation from MENA region to Europe.

This study aims to evaluate the transfer capacities of the existing and planned interconnections between these countries through computer simulations. For this purpose, power system models of each country are obtained and combined. This study focuses on to analyze the main transmission corridors between countries. Hence, main transmission network is investigated throughout the study. Voltage level of main transmission network for Egypt is 500 kV, for Iraq is 400 kV, for Jordan is 400 kV, for Lebanon is 220 kV, for Libya is 400 kV, for Palestine is 220 kV and 400 kV, for Syria is 400 kV, and for Turkey is 400 kV.

As the size of power systems and interconnections between power systems have increased, the security of power systems became a major concern. The utilization of power systems and interconnections near to their technical limits, and the calculation of transfer capacities more precisely by considering dynamic limitation increased the importance of security analysis on power systems [7], [8], [9]. System limitations for having a secure system operation could be determined by security analysis [7]. In this study, technically acceptable transfer capacities among EIJLLPST countries are determined considering the system security. New interconnection lines and transmission investments needed for transmission system security and increasing transfer capacities among these countries are also discussed and presented. Load flow (including contingency analysis), short circuit, transient stability and eigenvalue analysis are conducted on EIJLLPST power system model. PSS/E software is used for load flow (including contingency analysis), short circuit and transient stability analysis. DIgSILENT PowerFactory software is used for eigenvalue analysis.

This thesis study is composed of 7 chapters. In Chapter 1, advantages of interconnections are stated. The objectives and background of the EIJLLPST Project are expressed. The aim and the content of this study are presented. Chapter 2 describes the power system data required for analyses and gives general information related the network of project countries.

Results of load flow analysis and TTC calculation are presented in Chapter 3. TTC calculation method is also explained in this chapter. Chapter 4 presents short circuit calculation results.

Chapter 5 presents transient stability analysis on EIJLLPST power system data. The cases in transient stability analysis are explained and results of the analyses are given in this chapter. Eigenvalue analysis on EIJLLPST power system data is presented in Chapter 6. Results obtained from eigenvalue analysis are given in Chapter 6.

Chapter 7 presents main conclusions obtained from study. The necessary steps to improve transfer capacity and system security are discussed in this chapter. The work for future studies is also presented in Chapter 7.

CHAPTER 2

SYSTEM MODELLING

EIJLLPST Project aims to investigate necessary investments to reinforce the existing interconnections and to increase transfer capacities between EIJLLPST countries as described in Chapter 1. Project involves eight countries and spans a very large geographic area. Map of project countries is given in Figure 1.

Figure 1 EIJLLPST Project countries

This study aims to evaluate the transfer capacities of the existing and planned interconnections between these countries through computer simulations. In this chapter, power system data required for analyses will be described and general information related the network of project countries will be given.

2.1 DATA GATHERING AND ASSUMPTIONS

The objective of this study is the evaluation of the transfer capacities of the existing and planned interconnections between EIJLLPST countries through computer simulations. Load flow (including contingency analysis), short circuit, transient stability and eigenvalue analysis will be utilized for the evaluation. Load flow and short circuit analysis require static power system data, transient stability and eigenvalue analysis require dynamic power system data. Static data include static models of network elements like transformers, lines, generating units. Dynamic data include generator, exciter, and governor dynamic models of generating units. Power system data of each country is prepared by the representatives of that country involved in the project for the transmission network of the year 2015. Power system models of each country are combined into EIJSLLPST power system data.

The static data of electric network of Egypt, Jordan, Lebanon, Libya and Syria represent high voltage and extra high voltage transmission network in detail. Static data submitted by Iraq represent only extra high voltage network with loads and generation units connected to extra high voltage network. Electric networks of Palestine and Turkey are represented with two bus bars for each country in EIJLLPST power system data. There is no installed transmission line in Palestine. It is planned by Palestine, Egypt and Jordan that the interconnection between Palestine (Gaza) and Egypt will be realized with a 220 kV double circuit OHL and the interconnection between Palestine (West Bank) and Jordan will be realized with a 400 kV double circuit OHL. The feasibility studies of interconnection lines of Palestine are completed and it is expected that interconnection lines will be completed in the near future. Electric network of Palestine is represented with two bus bars (one bus bar for Gaza and one bus bar for West Bank) in EIJLLPST power system data. Turkey is also represented with two bus bars in EIJLLPST power system data. The interconnections of Turkey with Syria and Iraq are planned with asynchronous connection through HVDC back-to-back stations. Two bus bars (one bus bar [Birecik] for Turkey-Syria interconnection and one bus bar [Cizre] for Turkey-Iraq interconnection) are added to represent Turkey interconnections in EIJLLPST power system data.

The dynamic data of electric networks of Egypt, Jordan, Libya and Syria are submitted by the representatives of those countries. Dynamic generator models of electric networks of Egypt, Jordan, Libya and Syria are also adapted for the missing dynamic data of electric networks of Iraq and Lebanon. Generator, exciter, and governor dynamic models of generating units are used in transient stability analysis. However, in eigenvalue analysis, only generator dynamic models of countries are used for the simplification of analysis.

2.2 NETWORK DATA AND STATIC ANALYSIS OF EACH COUNTRY

In this part, electric power system of each country is introduced by giving general information related to the power network (installed capacity, length of transmission lines, maximum demand and demand forecast) obtained from Statistical Bulletin 2013 Issue 23 published by Arab Union of Electricity [10] for Arab Countries and from Turkish Electrical Energy 5-Year Generation Capacity Projection 2013-2017 published by TEİAŞ (Turkish Electricity Transmission Company) [11] for Turkey. Transmission network maps of Arab Countries, which are given in upcoming parts, are produced by Arab Union of Electricity. In addition, static analysis conducted on the power system of each country is presented in this part. As stated in Chapter 1, this study focuses on the analysis of the main transmission corridors between countries. Hence, the main transmission network is investigated in this part.

2.2.1 POWER SYSTEM OF EGYPT

Egyptian power system is owned by Egyptian Electricity Holding Company (EEHC) and transmission activities are performed by Egyptian Electricity Transmission

Company (EETC). Total installed capacity of Egypt is 31,039 MW as of 2013 and details of the installed capacity of Egypt by the year 2013 are given in Table 1.

Table 1 Installed capacity of Egypt in 2013

	Total (MW)	Steam Turbines	Gas Turbines	Combined Cycle	Diesel	Coal Turbines	Hydro	Wind	Solar	Others
EGYPT	31,039	13,806	3,428	10,080	238	-	2,800	547	140	-

Maximum demand of Egypt occurs in summer times. Maximum demand in 2013 was 27,000 MW and forecasted to be 54,260 MW by the year 2024. Maximum demand in years of 2012, 2013 and demand forecast of the years 2014, 2019 and 2024 are given in Table 2.

Table 2 Maximum demand and electricity forecast of Egypt

	2012 (MW)	2013 (MW)	2014 (MW)	2019 (MW)	2024 (MW)
EGYPT	25,705	27,000	30,950	42,680	54,260

Transmission network of Egypt is composed of 500 kV, 220 kV and 132 kV transmission lines. Lengths of transmission lines are given in Table 3. 500 kV transmission lines constitute main transmission corridors of Egyptian transmission network. Transmission network of Egypt has a meshed network topology around Cairo and Nile Delta which are the main load centers of Egypt. Egyptian transmission network has weak radial parts in Eastern and Western Egypt. Radial part of Egyptian transmission network in Eastern Egypt connects Egyptian transmission network and Jordanian transmission network with the submarine cable. Egyptian transmission network and Libyan transmission network are connected over the radial part of Egyptian transmission network in Western Egypt. Hydro generation (Aswan Low Dam and Aswan High Dam) of Egypt is located in Aswan (south of

Egypt) and connected with radial transmission lines to Egyptian transmission network. Radial part of Egyptian transmission network between Cairo and Aswan supplies electrical energy to the cities located along the Nile River.

Table 3 Lengths of transmission lines of Egypt

	500 kV (km)	**400 kV (km)**	**230 kV (km)**	**220 kV (km)**	**150 kV (km)**	**132 kV (km)**
EGYPT	2,863	33	-	17,000	-	2,485

The interconnection line between Egyptian transmission network and Libyan transmission network is a 220 kV double circuit OHL with 163 km length and connects Saloum Substation (Egypt) and Tobruk Substation (Libya). This interconnection will be reinforced by a new 500 kV OHL between Saloum Substation (Egypt) and Tobruk Substation (Libya).

The interconnection line between Egyptian transmission network and Jordanian transmission network is a 400 kV AC, single circuit, submarine cable with 13 km length across the Red Sea between Taba (Egypt) and Aqaba (Jordan). This submarine cable is planned to be converted to DC by adding converter substations in Taba and in Aqaba by the year 2020.

Egypt is interconnected with the Gaza Strip through a 22 kV line supplying power to the Southern part of Gaza Strip. Egypt will be interconnected with the Gaza Strip through a 220 kV double circuit OHL between Al Arish in Egypt and Rafah in Gaza by the year 2015. The map of transmission network of Egypt is given in Figure 2 and Figure 3.

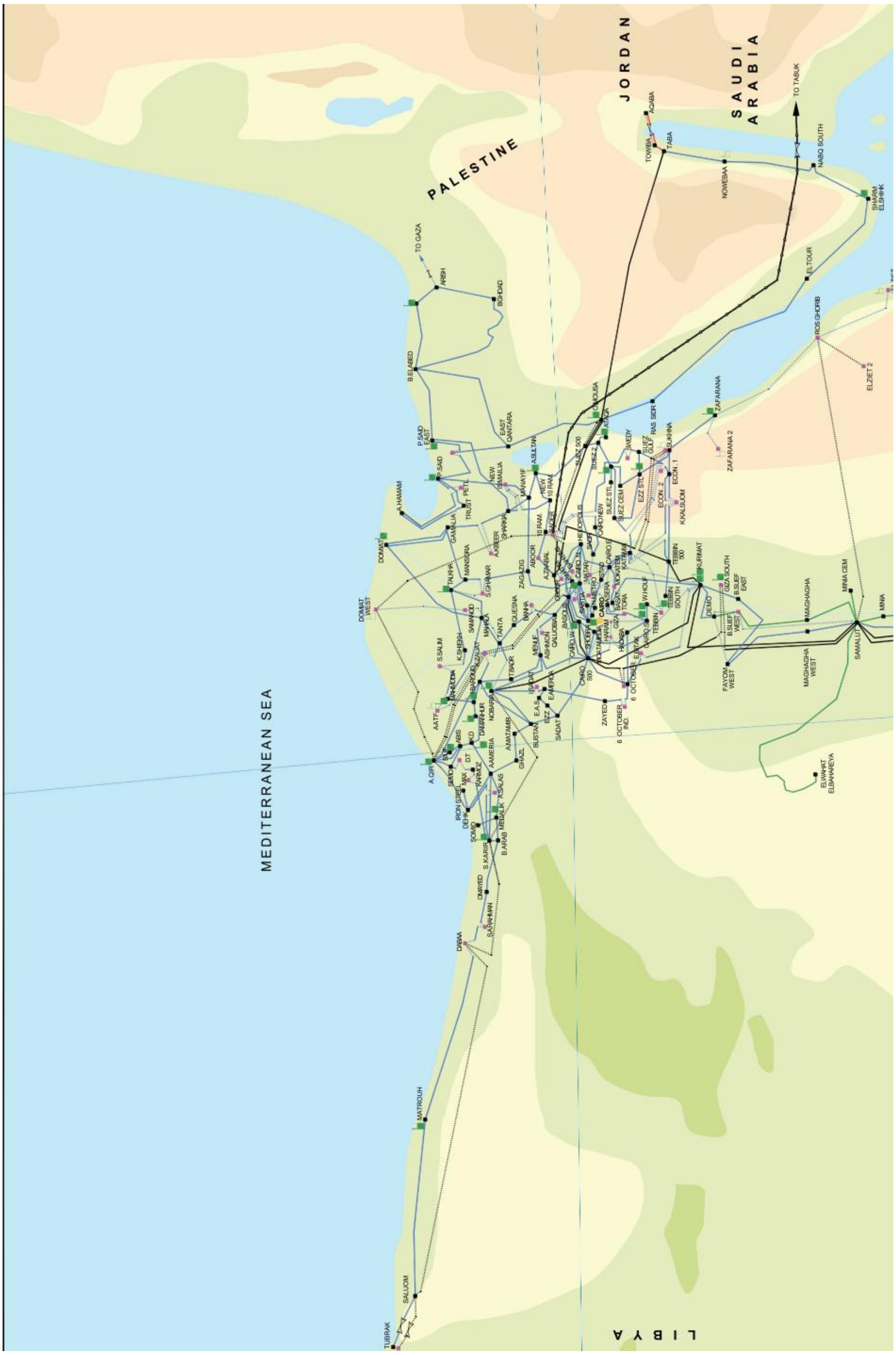

Figure 2 Transmission network map of Egypt (Northern Egypt)

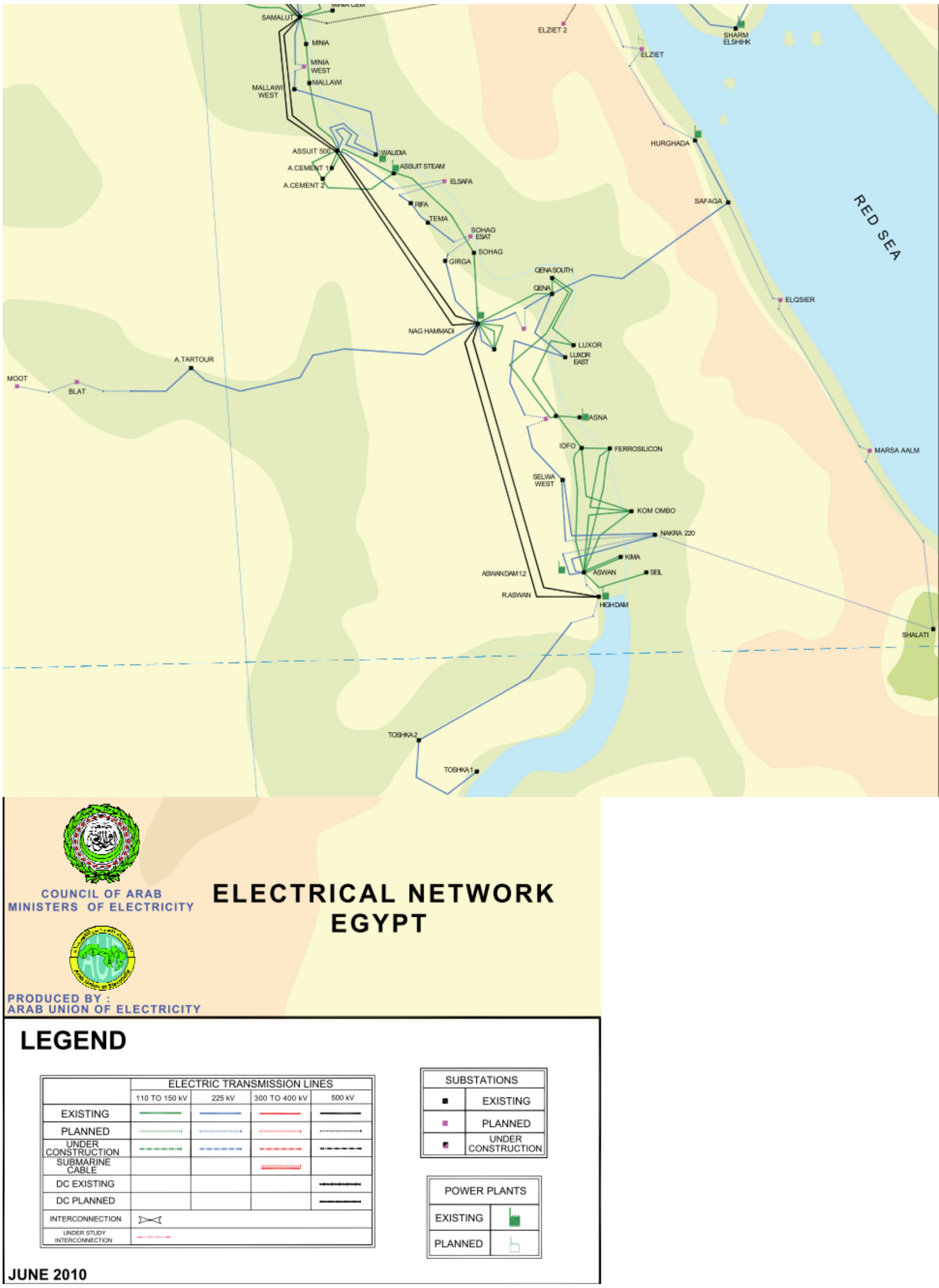

Figure 3 Transmission network map of Egypt (Southern Egypt)

Static analysis is conducted on power system data of Egypt prepared for year 2015. Peak demand of Egypt is assumed to be 33,468 MW in 2015 and total generation is 33,983.3 MW. Load flow and contingency analysis are conducted. Substations with bus voltages greater than 1.05 pu in Egypt network are given in Table 4, and bus voltages less than 0.95 pu in Egypt network are given in Table 5. System losses are calculated as 515.3 MW in the base case.

Table 4 Bus voltages greater than 1.05 pu in Egypt network

Bus #	Bus Name	Base kV	V(pu)	V(kV)
30126	NOB-500	500	1.0722	536.12
30248	GIZA NOR	500	1.0799	539.97
30561	A-KIR	500	1.0897	544.84
30563	K-ZIAT	500	1.0654	532.71
30586	DIROUT	500	1.0864	543.22

Table 5 Bus voltages less than 0.95 pu in Egypt network

Bus #	Bus Name	Base kV	V(pu)	V(kV)
30001	NAG-H	500	0,9128	456,41

Buses with voltages greater than 1.05 pu are usually generator buses; generators are connected to these buses with step up transformers at 500 kV voltage level and 220 kV network is supplied with 500/220 kV autotransformers from these buses.

Lines loaded above 50% of their ratings in Egyptian network are given in Table 6. There is only one line loaded above 50% in 500 kV network.

Table 6 Lines loaded above 50% in Egypt network

Bus #	Bus Name	Base kV	Bus #	Bus Name	Base kV	Circuit #	Loading (MVA)	Rating (MVA)	Loading Percentage
30004	C.500	500	30248	GIZA NOR	500	1	1411.9	1732	81.5

Contingency analysis is also conducted for 500 kV transmission lines of Egyptian transmission network. Four problems are identified from the contingency analysis. One of the problems is observed in the southern part of Egyptian transmission network. Map of south part of Egyptian transmission network is given in Figure 4. Black lines represent 500 kV transmission lines, blue lines represent 220 kV transmission lines and green lines represent 132 kV transmission lines in Figure 4. When one of 500 kV double circuit lines between High Dam and Nag Hammadi is out of service, load flow does not converge. High Dam (Aswan High Dam) is a hydro power plant which has 12 generator units with 2,100 MW total installed capacity and located at the south end of Egyptian transmission network. High Dam is connected to the transmission network with two 500 kV OHLs and two 500/220 kV autotransformers (each autotransformer has 500 MVA capacity). Also Aswan Low Dam is connected to the south end of Egyptian transmission network at 132 kV voltage level. Aswan Low Dam has 11 generator units with 550 MW (7x40 MW+4x67.5 MW) total installed capacity. Generation of High Dam and Aswan Low Dam is evacuated mainly via two 500 kV OHLs (each line has 1,732 MVA capacity) and two 220 kV OHLs (each line has 305 MVA capacity). To transfer generation from High Dam to Nag Hammadi, which is the injection point for both 220 kV and 132 kV networks, the installation of a third 500 kV OHL with 236 km length between High Dam and Nag Hammadi is found to be necessary according to result of the load flow analysis. Addition of a third OHL between High Dam and Nag Hammadi would increase system security and decrease system losses.

The other two problems are observed for 500 kV transmission lines which connect Samalut to upper 500 kV network, Samalut – Giza North (represented as Giza South in Figure 5) and Samalut – Kurimat OHLs. Map of the Egyptian transmission network that shows south of Cairo is given in Figure 5. Samalut is an injection point for 220 kV and 132 kV networks and also connects the south part of the Egyptian transmission network to the north of the network. Giza North is a thermal power plant which has 9 units with 2,250 MW total installed capacity and is connected to the transmission network with two 500 kV OHLs (each line has 1,732 MVA capacity) and two 500/220 kV autotransformers (each autotransformer has 125 MVA capacity). As shown in Table 6, Giza North – Cairo 500 OHL is loaded to 81.3% of its rating. Kuraimat is a thermal power plant which has 2 units with 1,254 MW total installed capacity and Kuraimat plant is connected to the transmission network through three 500 kV OHLs (each line has 1,732 MVA capacity) and one 500/220 kV autotransformer (the autotransformer has 500 MVA capacity). When one of the Samalut – Giza North and Samalut – Kuraimat OHLs is out of service, load flow does not converge. Result of load flow analysis indicates that addition of a third OHL between High Dam and Nag Hammadi would solve this problem. Generation of Giza North is transferred mainly via two 500 kV OHL. To transfer this generation in a secure manner from Giza North, a second 500 kV OHL with 35 km length should be installed between Giza North and Cairo 500. Cairo 500 substation is an important injection point for 220 kV network, it supplies 220 kV network with three 500/220 kV autotransformers (each autotransformer has 500 MVA capacity).

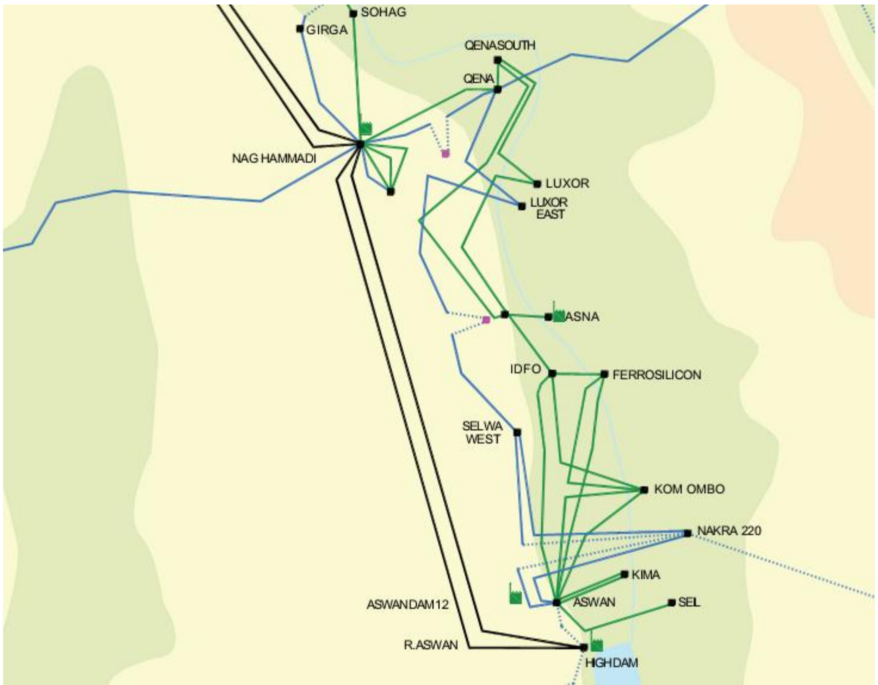

Figure 4 South part of Egyptian transmission network

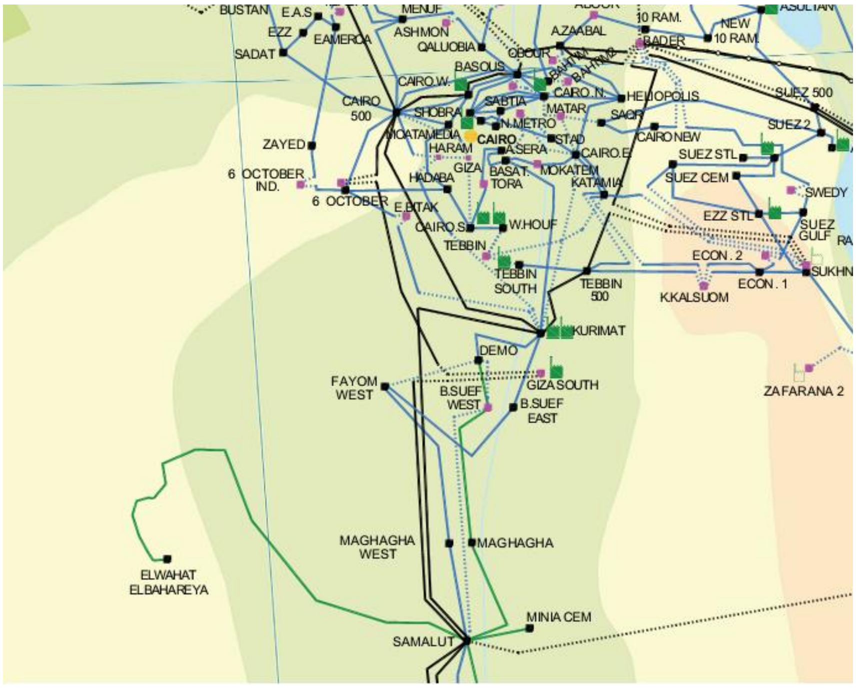

Figure 5 Egyptian transmission network (south of Cairo)

Fourth problem is observed in the eastern part of Egyptian transmission network. Map of the eastern part of Egyptian transmission network is given in Figure 6. When 500 kV O.Mousa –Taba transmission line or 220 kV lines between Taba and Nowebaa are out of service, load flow does not converge. 500 kV O.Mousa –Taba transmission line is important, because this line connects Egypt – Jordan interconnection cable to Egypt network. To provide supply security to the eastern part of Egyptian transmission network, a second 500 kV OHL with 244 km length should be installed between O.Mousa –Taba. Second 500 kV OHL between O.Mousa –Taba is also important to increase the transfer capacity between Egypt and Jordan.

Based on load flow analysis results, it is observed that most 500/220 kV autotransformers are overloaded. To decrease the loading of autotransformers and to increase the system security, number of autotransformers could be increased in existing substations or new 500/220 kV substations could be installed in suitable areas to provide injection points for the 220 kV network.

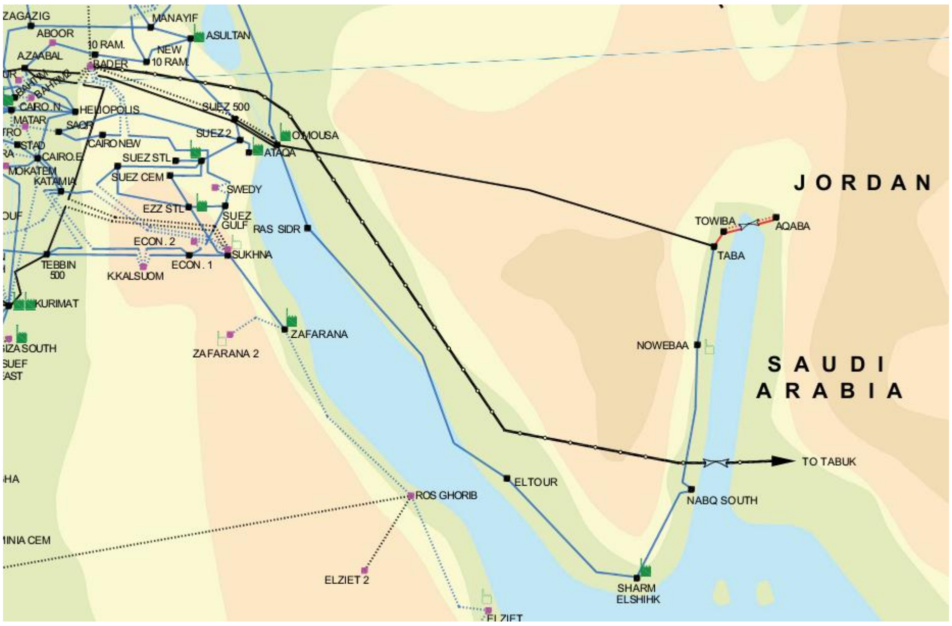

Figure 6 East part of Egyptian transmission network

2.2.2 POWER SYSTEM OF IRAQ

Iraq power system is owned by Ministry of Electricity and transmission activities are performed by Transmission Office of Ministry. Total installed capacity of Iraq is 27,110 MW as of 2013. Details of the installed capacity of Iraq by the year 2013 are given in Table 7.

Table 7 Installed capacity of Iraq in 2013

	Total (MW)	Steam Turbines	Gas Turbines	Combined Cycle	Diesel	Coal Turbines	Hydro	Wind	Solar s	Others
IRAQ	27,110	6,140	15,838	-	2,619	-	2,513	-	-	-

Maximum demand in Iraq occurs during summer. Maximum total demand in 2013 is 14,527 MW and forecasted to be 28,100 MW by the year 2024. Maximum demand in years of 2012, 2013 and demand forecast of the years 2014, 2019, 2024 are given in Table 8.

Table 8 Maximum demand and electricity forecast of Iraq

	2012 (MW)	**2013 (MW)**	**2014 (MW)**	**2019 (MW)**	**2024 (MW)**
IRAQ	10,626	14,527	16,300	23,200	28,100

Transmission network of Iraq is composed of 400 kV and 132 kV transmission lines. Lengths of transmission lines are given in Table 9. 400 kV transmission lines constitute main transmission corridors of Iraqi transmission network. The 400 kV transmission network of Iraq consists of several closed ring along the north to the south of the country.

Table 9 Lengths of transmission lines of Iraq

	500 kV (km)	**400 kV (km)**	**230 kV (km)**	**220 kV (km)**	**150 kV (km)**	**132 kV (km)**
IRAQ	4,465		-	-	14,975	

The interconnection line between Iraqi transmission network and Syrian transmission network is a 400 kV single circuit OHL with 165 km length and connects Tayem (Syria) and Al Qaem (Iraq).

The interconnection line between Iraqi transmission network and Turkish transmission network is a 400 kV single circuit OHL (operated at 154 kV and island mode of operation) with 28 km length which connects Zakho (Iraq) and PS3 (Turkey). A new interconnection line is under construction which is a 400 kV single circuit OHL with 159 km length and connects Mosul (Iraq) and Cizre (Turkey). A HVDC back-to-back station will be constructed for the new interconnection line and interconnection will be realized via this line. The map of transmission network of Iraq is given in Figure 7.

Load flow and contingency analysis are conducted on power system data of Iraq with 17,500 MW peak demand and 17,637.6 MW total generation for year 2015. The voltage magnitudes of 400 kV buses are in the range of 0.95 pu and 1.05 pu. System losses is calculated as 137.6 MW.

Lines loaded above 50% of their ratings in Iraq network are given in Table 10. There are five lines loaded above 50% in 400 kV network. There is no overloaded line in 400 kV Iraqi transmission network.

Table 10 Lines loaded above 50% in Iraqi network

Bus #	Bus Name	Base kV	Bus #	Bus Name	Base kV	Circuit #	Loading (MVA)	Rating (MVA)	Loading Percentage
11403	NYNG	400	11420	MSL4	400	1	564.7	1000	56.5
16401	RSF4	400	18401	ZBDP	400	1	560.4	1000	56.0
16401	RSF4	400	18401	ZBDP	400	2	560.4	1000	56.0
16470	BGC4	400	21401	KRTG	400	1	630.6	1000	63.1
27405	QRN4	400	27421	HRTP	400	1	553.9	1000	55.4

Contingency analysis is conducted for 400 kV transmission lines of Iraqi transmission network. There are no problems according to contingency analysis in terms of voltage magnitudes and line flows.

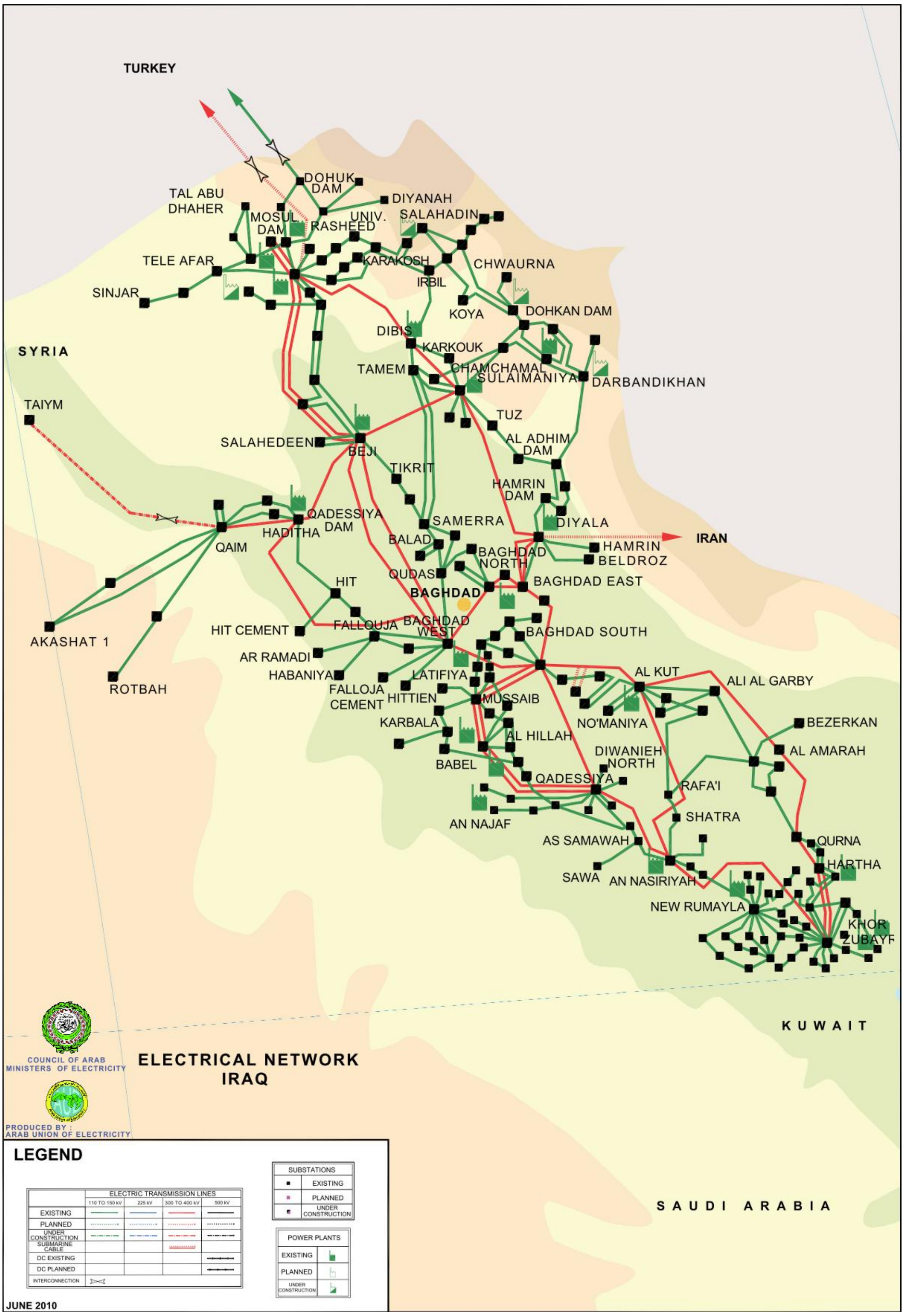

Figure 7 Transmission network map of Iraq

2.2.3 POWER SYSTEM OF JORDAN

Transmission activities are performed by National Electric Power Company (NEPCO) in Jordan. Total installed capacity of Jordan is 3,333 MW. Details of the installed capacity of Jordan by the year 2013 are given in Table 11.

Table 11 Installed capacity of Jordan in 2013

	Total (MW)	**Steam Turbines**	**Gas Turbines**	**Combined Cycle**	**Diesel**	**Coal Turbines**	**Hydro**	**Wind**	**Solar**	**Others**
JORDAN	3,333	876	655.9	1,737	46.8	-	12	1.4	-	3.5

Maximum demand in Jordan occurs during the summer season. Maximum demand in the year 2013 is 2,995 MW and forecasted to be 5,400 MW by the year 2024. Maximum demand in years of 2012, 2013 and demand forecast of the years 2014, 2019, 2024 are given in Table 12.

Table 12 Maximum demand and electricity forecast of Jordan

	2012 (MW)	**2013 (MW)**	**2014 (MW)**	**2019 (MW)**	**2024 (MW)**
JORDAN	2,790	2,995	2,915	3,941	5,400

Transmission network of Jordan is composed of 400 kV and 132 kV transmission lines. Lengths of transmission lines are given in Table 13. 400 kV transmission lines constitute main transmission corridors of Jordan transmission network. Jordanian transmission network at 400 kV voltage level consists of a double circuit ring around Amman city and a double circuit radial part between Amman and Aqaba city. A new 400 kV double circuit transmission corridor between Aqaba and Amman is planned to reinforce the Jordanian transmission network.

Table 13 Lengths of transmission lines of Jordan

	500 kV (km)	**400 kV (km)**	**230 kV (km)**	**220 kV (km)**	**150 kV (km)**	**132 kV (km)**
JORDAN	-	924	17	-	-	3,522

The interconnection line between Egyptian transmission network and Jordanian transmission network is a 400 kV AC, single circuit, submarine cable with 13 km length across the Red Sea between Taba (Egypt) and Aqaba (Jordan). It is planned to transform the existing submarine cable between Taba in Egypt and Aqaba in Jordan to be operated at DC by adding converter substations in Taba and in Aqaba.

The interconnection line between Jordanian transmission network and Syrian transmission network is a 400 kV AC, single circuit OHL with 160 km length and connects Amman North (Jordan) and Der Ali (Syria). A new 400 kV AC, single circuit OHL with 160 km length which connects Amman East (Jordan) and Der Ali (Syria) is planned for the near future. This line has been included in the system model for simulations.

Jordan and West Bank interconnection is planned with a 400 kV double circuit OHL with 40 km length between Amman West Substation (Jordan) and Jerusalem Substation (Palestine) by the year 2015. The map of transmission network of Jordan is given in Figure 8.

In order to investigate the system operating conditions that would occur in 2015, load flow analysis is performed to simulate the base case (i.e., N condition) and contingency cases (i.e., N-1 condition). Peak demand at 2015 is assumed to be 3,335.8 MW. The system losses in the base case is found to be 39.3 MW which corresponds to a total generation of 3,375.1 MW. Results of the load flow analysis indicate that the voltage magnitudes of 400 kV buses are in the range of 0.95 pu and 1.05 pu, and there is no line loaded above 50% of their ratings at 400 kV voltage level. Contingency case results do not indicate any problems in terms of voltage magnitudes and line loadings.

Figure 8 Transmission network map of Jordan

2.2.4 POWER SYSTEM OF LEBANON

Electricité du Liban (EDL) is a public company and carries out transmission, generation and distribution activities in Lebanon. Total installed capacity of Lebanon is 2,258 MW as of 2013. Details of installed capacity of Lebanon by the year 2013 are given in Table 14.

Table 14 Installed capacity of Lebanon in 2013

	Total (MW)	Steam Turbines	Gas Turbines	Combined Cycle	Diesel	Coal Turbines	Hydro	Wind	Solar	Others
LEBANON	2,258	1,028	140	870	-	-	220	-	-	-

Maximum demand of Lebanon occurs in summer times. Maximum demand in 2013 was 2,744 MW and forecasted to be 4,472 MW by the year 2024. Maximum demand in years of 2012, 2013 and demand forecast of the years 2014, 2019, 2024 are given in Table 15.

Table 15 Maximum demand and electricity forecast of Lebanon

	2012 (MW)	2013 (MW)	2014 (MW)	2019 (MW)	2024 (MW)
LEBANON	2,610	2,744	2,880	3,676	4,472

Transmission network of Lebanon is composed of 220 kV and 150 kV transmission lines. Lengths of transmission lines are given in Table 16. 220 kV transmission lines constitute main transmission corridors of Lebanese transmission network. A double circuit 220 kV transmission ring constitutes main backbone of Lebanese transmission network.

Table 16 Lengths of transmission lines of Lebanon

<table>
<tr><th></th><th>500 kV (km)</th><th>400 kV (km)</th><th>230 kV (km)</th><th>220 kV (km)</th><th>150 kV (km)</th><th>132 kV (km)</th></tr>
<tr><td>LEBANON</td><td colspan="2">22</td><td colspan="2">396</td><td colspan="2">190</td></tr>
</table>

The interconnection line between Syria transmission network and Lebanon transmission network is a 400 kV AC, single circuit OHL with 44 km length and connects Demas (Syria) and Kesara (Lebanon). The reinforcement of interconnection with the addition of a new 400 kV AC, single circuit OHL between Demas (Syria) and Kesara (Lebanon) is planned for the near future. The map of transmission network of Lebanon is given in Figure 9.

Static analysis is conducted on power system data of Lebanon prepared for year 2015. Peak demand of Lebanon is assumed to be 1,700 MW in 2015 and total generation is 1,705.2 MW. System losses is calculated as 5.2 MW. Demand of Lebanon is not compliant with the forecast values, because there are not enough generation units in power system data. Load flow and contingency analysis are conducted. There is no 220 kV bus with a voltage greater than 1.05 pu or with a voltage less than 0.95 pu in Lebanon transmission network. There is no line loaded above 50% of their ratings at 220 kV voltage level. Contingency case results do not indicate any problems in terms of voltage magnitudes and line loadings.

Figure 9 Transmission network map of Lebanon

2.2.5 POWER SYSTEM OF LIBYA

General Electricity Company of Libya (GECOL) is responsible of generation, transmission and distribution in Libya. Total installed capacity of Libya is 9,455 MW as of 2013. Details of installed capacity of Libya by the year 2013 are given in Table 17.

Table 17 Installed capacity of Libya in 2013

	Total (MW)	**Steam Turbines**	**Gas Turbines**	**Combined Cycle**	**Diesel**	**Coal Turbines**	**Hydro**	**Wind**	**Solar**	**Others**
LIBYA	9,455	1614	3,846	3,995	-	-	-	-	-	-

Maximum demand in Libya occurs during summer. Maximum total demand in 2013 is 6,520 MW and forecasted to be 11,285 MW by the year 2024. Maximum demand in years of 2012, 2013 and demand forecast of the years 2014, 2019 and 2024 are given in Table 18.

Table 18 Maximum demand and electricity forecast of Libya

	2012 (MW)	**2013 (MW)**	**2014 (MW)**	**2019 (MW)**	**2024 (MW)**
LIBYA	5,981	6,520	6,931	9,222	11,285

Transmission network of Libya is composed of 400 kV and 220 kV transmission lines. Lengths of transmission lines are given in Table 19. 400 kV transmission lines with constitute main transmission corridors of Libyan transmission network. Cities in Libya are located mainly costal area. Tripoli and Benghazi regions are main load centers in Libya, and Tripoli and Benghazi regions have loop designed transmission networks. Transmission networks of Tripoli and Benghazi regions are connected with a double circuit 400 kV and a double circuit 220 kV long transmission lines.

Table 19 Lengths of transmission lines of Libya

	500 kV (km)	**400 kV (km)**	**230 kV (km)**	**220 kV (km)**	**150 kV (km)**	**132 kV (km)**
LIBYA	-	2,290	-	13,706	-	-

The interconnection line between Egyptian transmission network and Libyan transmission network is a 220 kV double circuit OHL with 163 km length and connects Saloum Substation (Egypt) and Tobruk Substation (Libya). This interconnection will be reinforced by a new 500 kV OHL between Saloum Substation (Egypt) and Tobruk Substation (Libya). The map of transmission network of Libya is given in Figure 10 and Figure 11.

Load flow and contingency analysis are conducted on power system data of Libya with 7,700 MW peak demand and 7,770.1 MW total generation for year 2015. The voltage magnitudes of 400 kV buses are in the range of 0.95 pu and 1.05 pu. There is no line loaded above 50% of their ratings at 400 kV voltage level. System losses is calculated as 70.1 MW. Based on the contingency analysis conducted for 400 kV transmission lines of Libyan transmission network, there are no problems according to contingency analysis in terms of voltage magnitudes and line flows.

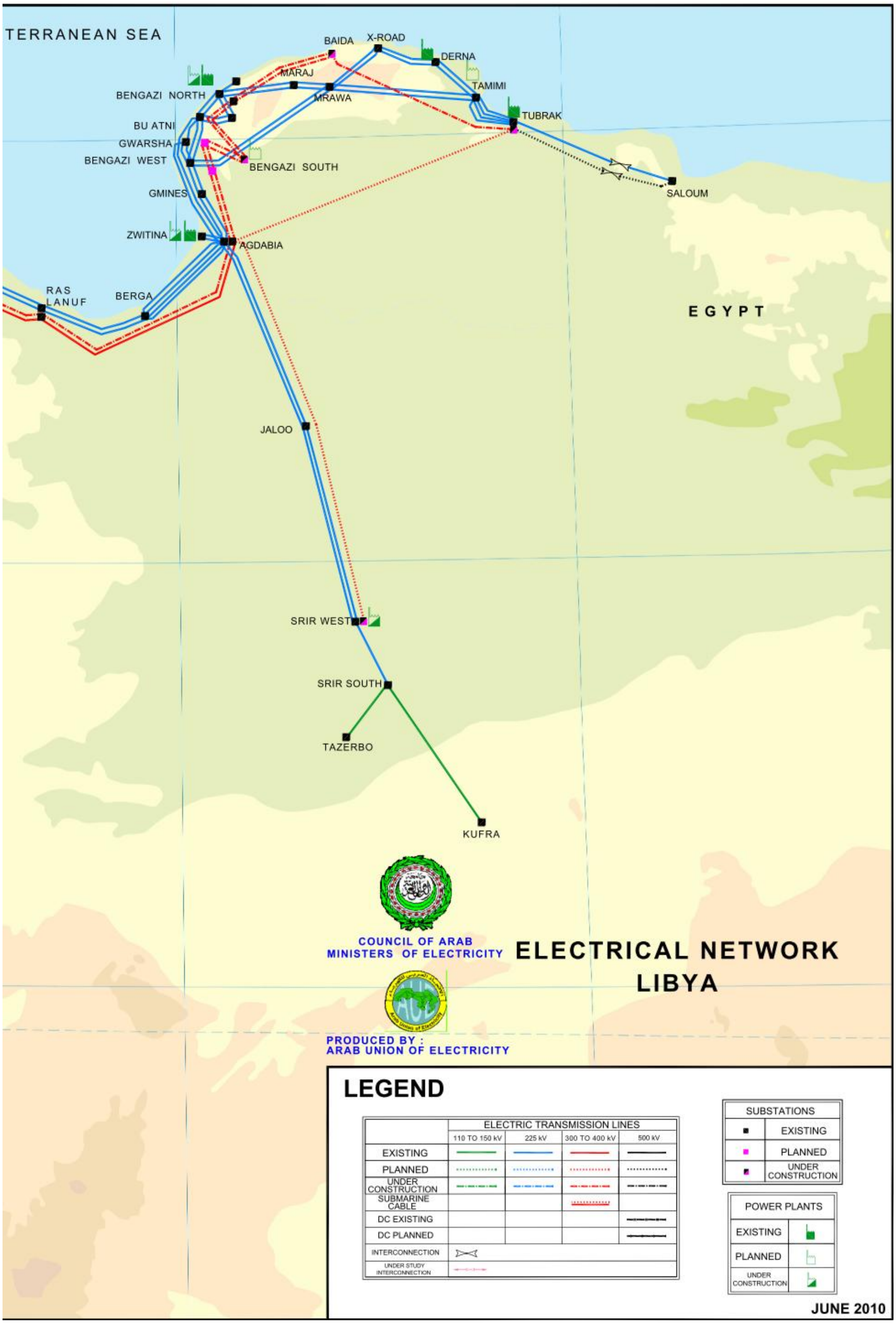

Figure 10 Transmission network map of Libya (Eastern Libya)

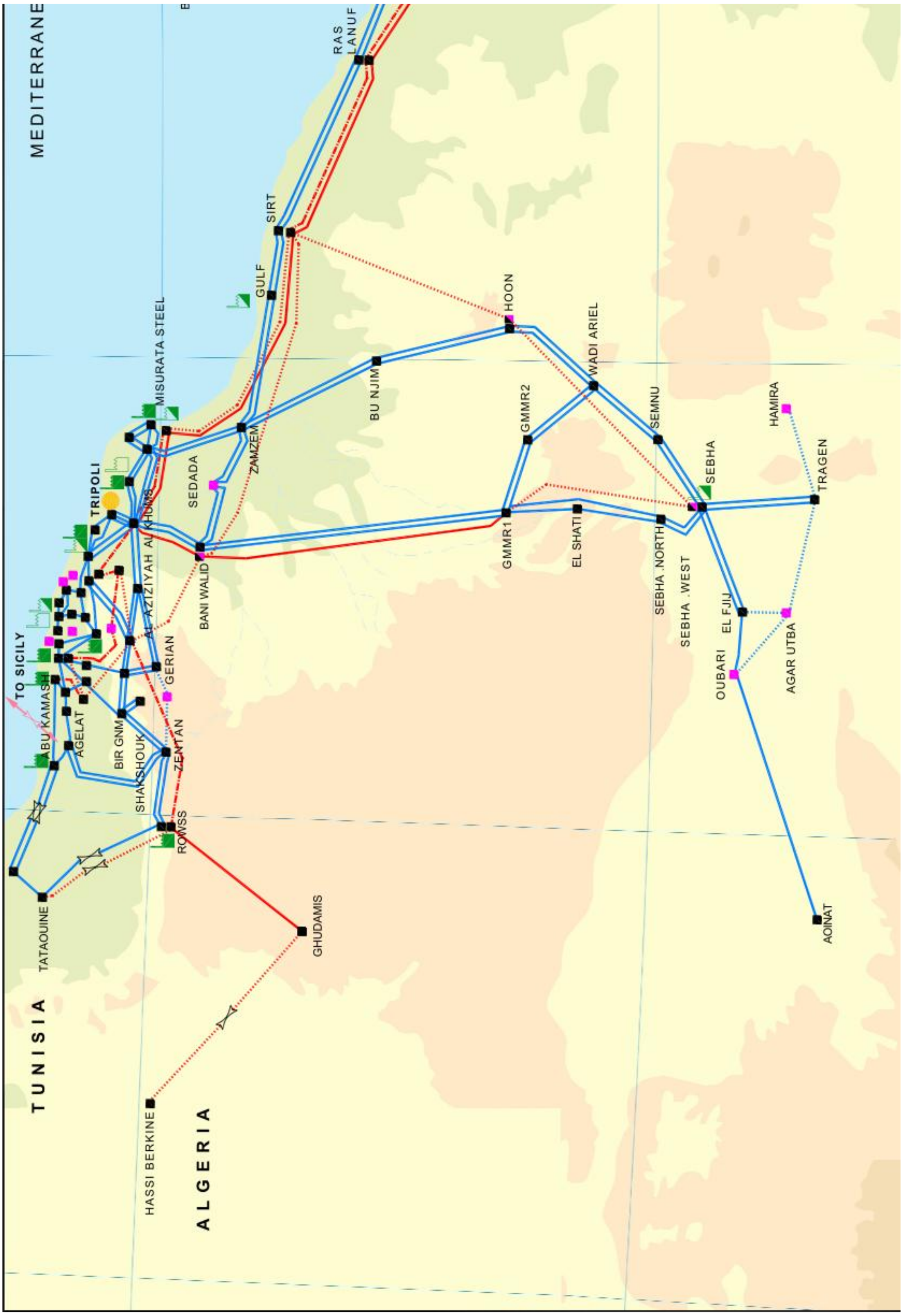

Figure 11 Transmission network map of Libya (Western Libya)

2.2.6 POWER SYSTEM OF PALESTINE

The Palestinian Energy Authority (PEA) is responsible of electricity sector in Palestine and will establish a public transmission company to operate and develop transmission network (Palestine Energy Transmission Company Limited PETL). Total installed capacity of Palestine (Gaza and West Bank) is 126 MW. Details of installed capacity of Palestine by the year 2013 are given in Table 20.

Table 20 Installed capacity of Palestine in 2013

	Total (MW)	Steam Turbines	Gas Turbines	Combined Cycle	Diesel	Coal Turbines	Hydro	Wind	Solar	Others
PALESTINE	126	-	-	125	-	-	-	-	0.6	-

Maximum demand of Palestine occurs in summer times. Maximum demand in 2013 was 1,082 MW and forecasted to be 1,851 MW by the year 2024. Maximum demand in years of 2012, 2013 and demand forecast of the years 2014, 2019 and 2024 are given in Table 21.

Table 21 Maximum demand and electricity forecast of Palestine

	2012 (MW)	2013 (MW)	2014 (MW)	2019 (MW)	2024 (MW)
PALESTINE	1,030	1,082	1,136	1,450	1,851

There is no installed HV transmission line in Palestine. Jordan and West Bank interconnection is planned with a 400 kV double circuit OHL with 40 km length between Amman West Substation (Jordan) and Jerusalem Substation (Palestine) by the year 2015.

Egypt is interconnected with the Gaza Strip through a 22 kV line supplying power to the Southern part of Gaza Strip. Egypt and Gaza interconnection is planned with a

220 kV double circuit OHL between Al Arish in Egypt and Rafah in Gaza by the year 2015. Electric network of Palestine is represented with two bus bars (one bus bar for Gaza and one bus bar for West Bank) in EIJLLPST power system data.

2.2.7 POWER SYSTEM OF SYRIA

Ministry of Electricity is responsible of the electric transmission network in Syria. Total installed capacity of Syria is 9,879 MW. Details of installed capacity of Syria by the year 2013 are given in Table 22.

Table 22 Installed capacity of Syria in 2013

	Total (MW)	Steam Turbines	Gas Turbines	Combined Cycle	Diesel	Coal Turbines	Hydro	Wind	Solar	Others
SYRIA	9,879	3,415	870	4,089	-	-	1,505	-	-	-

Maximum demand of Syria occurs during summer season. Maximum demand in the year 2013 is 7,703 MW and forecasted to be 17,400 MW by the year 2024. Maximum demand in years of 2012, 2013 and demand forecast of the years 2014, 2019 and 2024 are given in Table 23.

Table 23 Maximum demand and electricity forecast of Syria

	2012 (MW)	2013 (MW)	2014 (MW)	2019 (MW)	2024 (MW)
SYRIA	9,595	7,703	9,000	12,450	17,400

Transmission network of Syria is composed of 400 kV and 230 kV transmission lines. Lengths of transmission lines are given in Table 24. 400 kV transmission lines constitute main transmission corridors of Syrian transmission network. Syrian transmission network has two loops and a long radial part in 400 kV voltage level as main transmission corridors. 230 kV transmission network of Syria has meshed network characteristics.

Table 24 Lengths of transmission lines of Syria

	500 kV (km)	**400 kV (km)**	**230 kV (km)**	**220 kV (km)**	**150 kV (km)**	**132 kV (km)**
SYRIA	1,660		6,136		-	

The interconnection line between Syria transmission network and Lebanon transmission network is a 400 kV AC, single circuit OHL with 44 km length and connects Demas (Syria) and Kesara (Lebanon). The reinforcement of interconnection with the addition of a new 400 kV AC, single circuit OHL between Demas (Syria) and Kesara (Lebanon) is planned for the near future.

The interconnection line between Iraq transmission network and Syrian transmission network is a 400 kV single circuit OHL with 165 km length which connects Tayem (Syria) and Al Qaem (Iraq).

The interconnection line between Jordanian transmission network and Syrian transmission network is a 400 kV AC, single circuit OHL with 160 km length which connects Amman North (Jordan) and Der Ali (Syria). A new 400 kV AC, single circuit OHL with 160 km length which connects Amman East (Jordan) and Der Ali (Syria) is planned for the near future.

The interconnection line between Syria transmission network and Turkish transmission network is a 400 kV single circuit OHL (operated as island mode of operation) with 114 km length and connects Aleppo (Syria) and Birecik (Turkey). HVDC back-to-back station located in Birecik with 600 MW capacity will be constructed for this interconnection line. Another 400 kV single circuit OHL is under consideration between Turkey and Syria for the medium term. The connection points of the new line are not determined, but this line has been included in the system model between Aleppo (Syria) and Birecik (Turkey) for simulations. The map of transmission network of Syria is given in Figure 12.

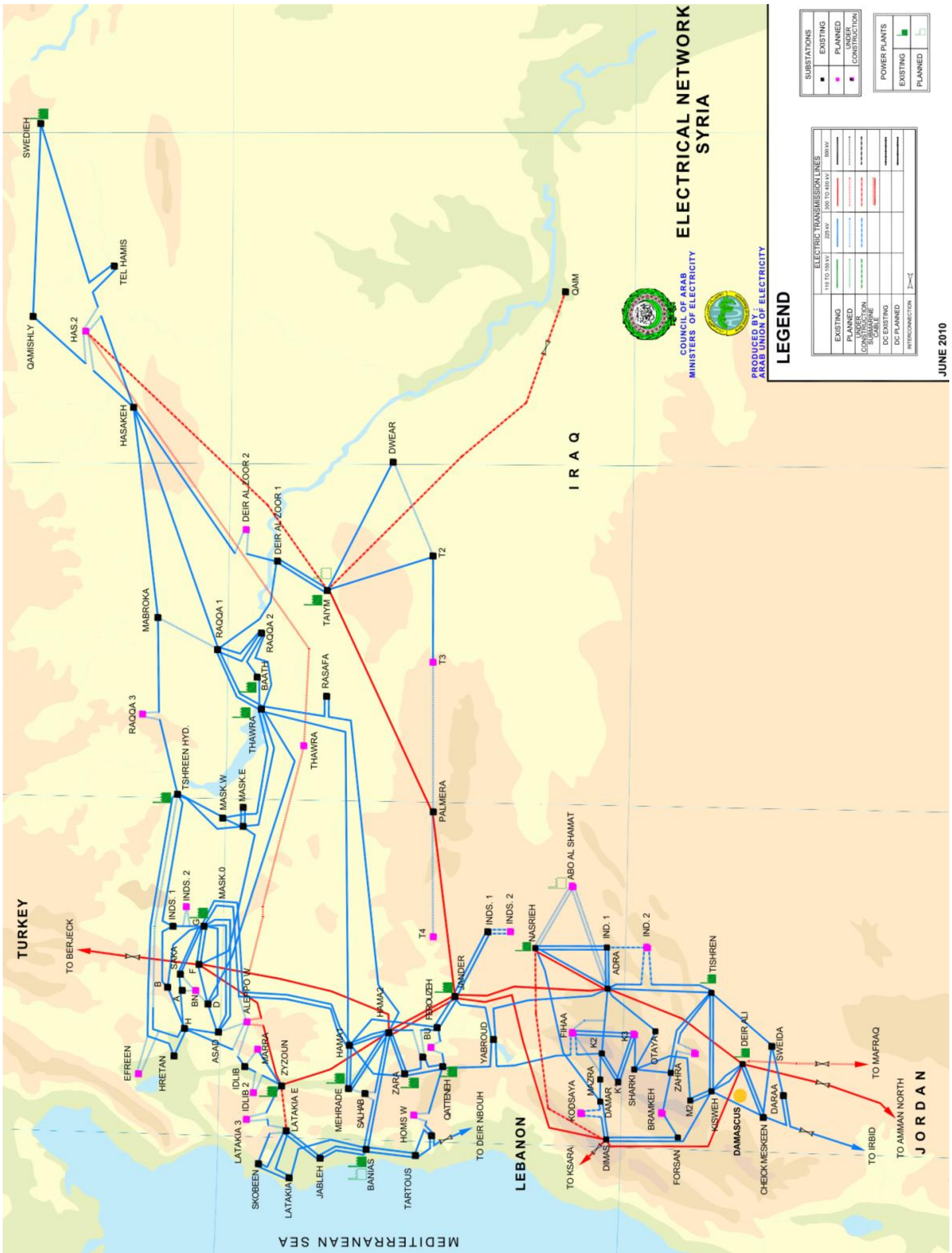

Figure 12 Transmission network map of Syria

In order to investigate the system operating conditions that would occur in 2015, load flow analysis is performed to simulate the base case and contingency case. Peak demand at 2015 is assumed to be 8,663 MW. The system losses in the base case is found to be 113.5 MW which corresponds to a total generation of 8,776.5 MW. Demand of Syria is not compliant with the forecast values, because there are not enough generation units in power system data. Results of the load flow analysis indicate that there is no 400 kV bus with a voltage greater than 1.05 pu in Syrian transmission network. Substations with bus voltages less than 0.95 pu in Syria network is given in Table 25. There is no line loaded above 50% of their ratings at 400 kV voltage level.

Table 25 Bus voltages less than 0.95 pu in Syria network

Bus #	**Bus Name**	**Base kV**	**V(pu)**	**V(kV)**
55297	PALMERA	400	0.9431	377.25
55302	TAYYEM	400	0.8707	348.27
55303	HASAKEH2	400	0.8487	339.47

Results of contingency analysis indicate that radial 400 kV part of Syrian network which is shown in Figure 13 creates problem in system operation. When one of the 400 kV lines, which are in radial 400 kV part of Syria network, is out of service, load flow does not converge. Radial part of the 400 kV network could be taken into ring with the construction of 400 kV OHL between Aleppo – Thawra – Hasakeh 2 substations. Total length of this line is 330 km. Thawra substation is an existing 230 kV substation. With the construction of 400 kV OHL between Aleppo – Hasakeh 2, 400 kV substation and autotransformers could be added to Thawra substation to increase the system security.

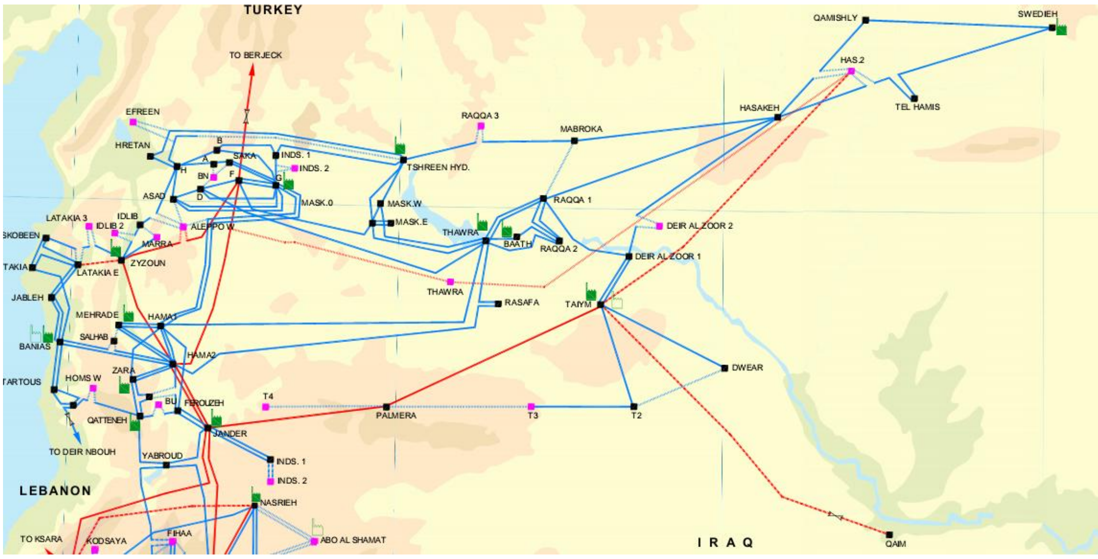

Figure 13 Radial 400 kV Part of Syria Network

2.2.8 POWER SYSTEM OF TURKEY

Türkiye Elektrik İletim A.Ş. (TEİAŞ- Turkish Electricity Transmission Company) is the state owned transmission system operator of Turkey. Total installed capacity of Turkey is 64,007.5 MW by the end of 2013. Details of installed capacity of Turkey by the year 2013 are given in Table 26.

Table 26 Installed capacity of Turkey in 2013

	Total (MW)	Hard Coal +Lignite	Imported Coal	Natural Gas	Geothermal	Fuel Oil+ Diesel+ Other	Biogas-Waste	Hydro	Wind
TURKEY	64,007.5	8,515.2	3,912.6	24,620.7	310.8	1,375.5	224	22,289.1	2,759.6

Maximum demand of Turkey is occurred during summer in the last several years. Maximum demand at 2013 is 38,274 MW and forecasted to be 64,490 MW by the year 2022. Maximum demand in years of 2012, 2013 and demand forecast of the years 2014, 2019 and 2022 are given in Table 27.

Table 27 Maximum demand and electricity forecast of Turkey

	2012 (MW)	2013 (MW)	2014 (MW)	2019 (MW)	2022 (MW)
TURKEY	39,045	38,274	42,300	54,970	64,490

Transmission network of Turkey is composed of 380 kV and 154 kV transmission lines. Lengths of transmission lines are given in Table 28. 380 kV transmission lines constitute the main transmission corridors of Turkish transmission network.

Table 28 Lengths of transmission lines of Turkey

	500 kV (km)	380 kV (km)	230 kV (km)	220 kV (km)	154 kV (km)	132 kV (km)
TURKEY	-	16,344		85	33,481	

The interconnection line between Syrian transmission network and Turkish transmission network is a 400 kV single circuit OHL (operated as island mode of operation) with 114 km length and connects Aleppo (Syria) and Birecik (Turkey). HVDC back-to-back station located in Birecik with 600 MW capacity will be constructed for this interconnection line. Another 400 kV single circuit OHL is under consideration between Turkey and Syria for the medium term. The connection points of the new line are not determined, but this line has been included in the system model between Aleppo (Syria) and Birecik (Turkey) for simulations.

The interconnection line between Iraqi transmission network and Turkish transmission network is a 400 kV single circuit OHL (operated in 154 kV and island mode of operation) with 28 km length which connects Zakho (Iraq) and PS3 (Turkey). A new interconnection line is under construction which is a 400 kV single circuit OHL with 159 km length and connects Mosul (Iraq) and Cizre (Turkey). HVDC back-to-back station will be constructed for new interconnection line and interconnection will be realized via this line. The map of transmission network of Turkey is given in Figure 14.

Turkish Power System is synchronously interconnected with ENTSO-E since 18 September 2010. Interconnection of Turkish Power System with the countries other than ENTSO-E countries is possible within ENTSO-E rules. According to ENTSO-E rules, interconnection of Turkey with Syria and Iraq is only possible with the installation of HVDC back-to-back stations between these countries. HVDC back-to-back stations between Turkey and Syria will be installed at Birecik substation with 600 MW capacity. Location of the HVDC back-to-back station installed between Turkey and Iraq has not been determined yet but pre-feasibility studies show that 500 MW capacity is appropriate for HVDC back-to-back stations between Turkey and Iraq. With the installation of HVDC back-to-back stations, Turkey will be asynchronously interconnected with Syria and Iraq; so internal network of Turkey will not affect the load flow analysis of Syrian and Iraqi systems, Turkish Power System will only supply or demand constant power on interconnection lines. For this reason Turkey will be represented with only two bus bars (Birecik for Syria interconnection and Cizre for Syria interconnection) on EIJLLPST power system data, and will supply or demand power from EIJLLPST power system according to the exchange scenario. Static analysis is not conducted on Turkish Power System in the scope of this study.

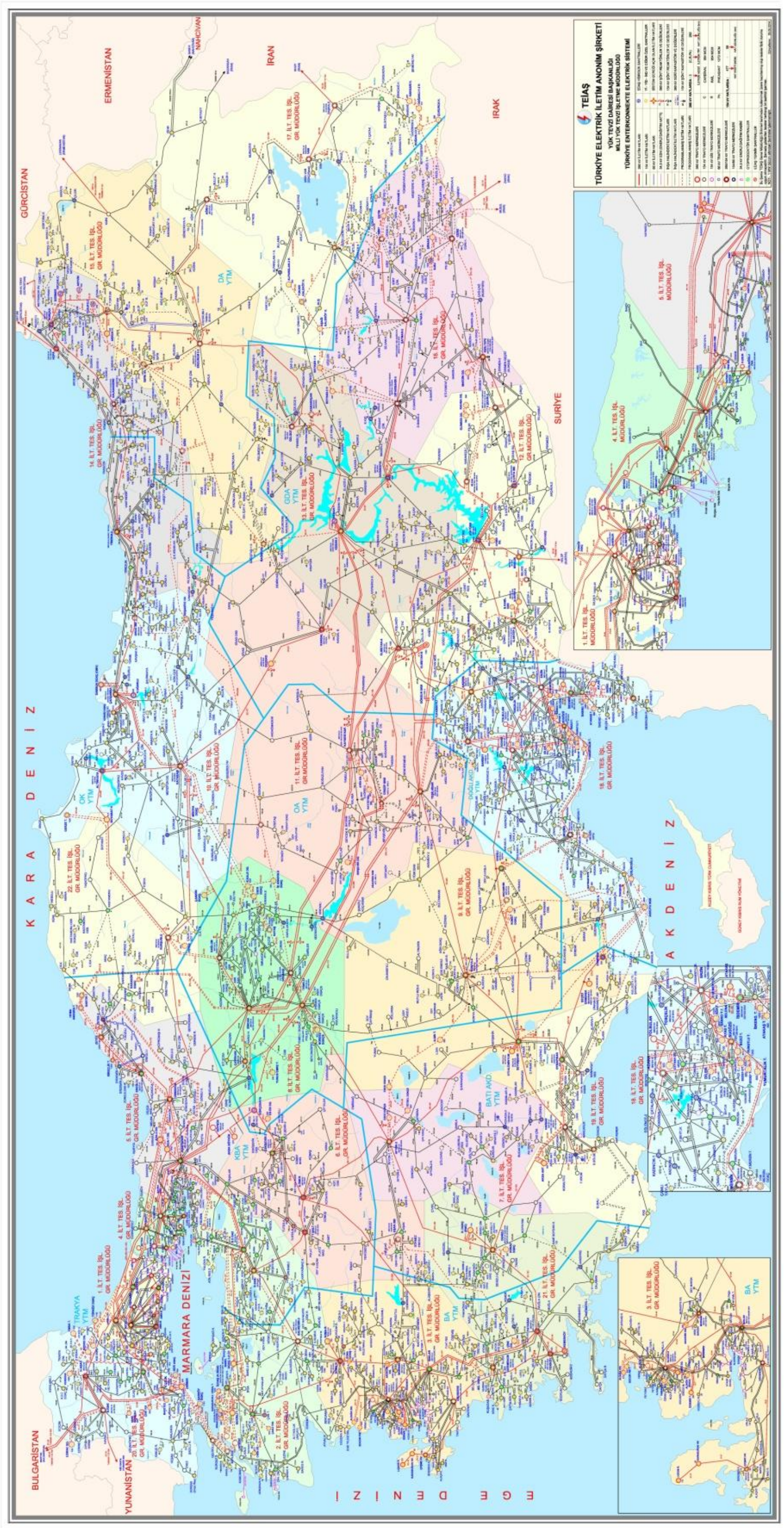

Figure 14 Transmission network map of Turkey

CHAPTER 3

STATIC ANALYSIS ON EIJLLPST POWER SYSTEM DATA

Load flow analyses are conducted on the complete EIJLLPST power system data to investigate the operation of system with respect to static system security. Static power system data of countries are combined to form the EIJLLPST power system data. Static data of electric network of Egypt, Jordan, Lebanon, Libya and Syria represent high voltage and extra high voltage transmission network in detail. Static data submitted by Iraq represents only extra high voltage network with loads and generation units connected to extra high voltage network. Electric networks of Palestine and Turkey are represented with two bus bars for each country in EIJLLPST power system data. EIJLLPST power system data have 2,692 bus bars and 722 generating units with 100,404.7 MW installed power.

Main focus of this study is to analyze the main transmission corridors between countries. Voltage level of main transmission network of Iraq, Jordan, Libya, Syria and Turkey are 400 kV. Voltage level of main transmission network of Egypt is 500 kV and voltage level of main transmission network of Lebanon is 220 kV. Voltage level of main transmission network of Palestine is 220 kV and 400 kV.

Static analyses are conducted on EIJLLPST power system data for summer and winter maximum load conditions of year 2015 with two different network configurations; with existing interconnections and with planned interconnections. First, load flow analyses are conducted on EIJLLPST power system data with existing interconnections to identify bottlenecks and limiting factors. Then, load flow analyses are conducted on EIJLLPST power system data with planned interconnections and required investments for summer and winter maximum load conditions of year 2015 to calculate TTC values between EIJLLPST countries. PSS/E software is utilized for load flow analysis.

3.1 STATIC ANALYSIS ON EIJLLPST POWER SYSTEM DATA WITH EXISTING INTERCONNECTIONS

In this section, load flow analyses are conducted on EIJLLPST power system data with existing interconnections between related countries. Interconnection lines and their capacities which are considered in this section are given as follows;

- Turkey –Syria interconnection line is a 400 kV single circuit OHL with 1,375 MVA thermal capacity. Transfer capacity of this interconnection line is considered as 600 MW during the study, because of the capacity of HVDC back-to-back station that will be located in Birecik.
- Turkey – Iraq interconnection line is a 400 kV single circuit OHL with 1,000 MVA thermal capacity. Transfer capacity of this interconnection line is considered as 500 MW during the study, due to the capacity of HVDC back-to-back station that will be located in Cizre or Mosul.
- Iraq – Syria interconnection line is a 400 kV single circuit OHL with 1,000 MVA thermal capacity.
- Syria – Lebanon interconnection line is a 400 kV single circuit OHL with 1,375 MVA thermal capacity.
- Syria – Jordan interconnection line is a 400 kV single circuit OHL with 1,065 MVA thermal capacity.
- Egypt – Jordan interconnection line is a 400 kV single circuit submarine cable with 550 MVA thermal capacity.
- Egypt – Libya interconnection line is a 220 kV double circuit OHL with 952 MVA thermal capacity in total.
- Jordan – West Bank interconnection line is a 400 kV double circuit OHL with 2,100 MVA thermal capacity in total.

- Egypt – Gaza interconnection line is a 220 kV double circuit OHL with 952 MVA thermal capacity in total.

Representation of interconnection lines between EIJLLPST countries is given in Figure 15. Static analyses are conducted on EIJLLPST power system data for three different scenarios;

- Zero Exchange Scenario
- Summer Exchange Scenario
- Winter Exchange Scenario

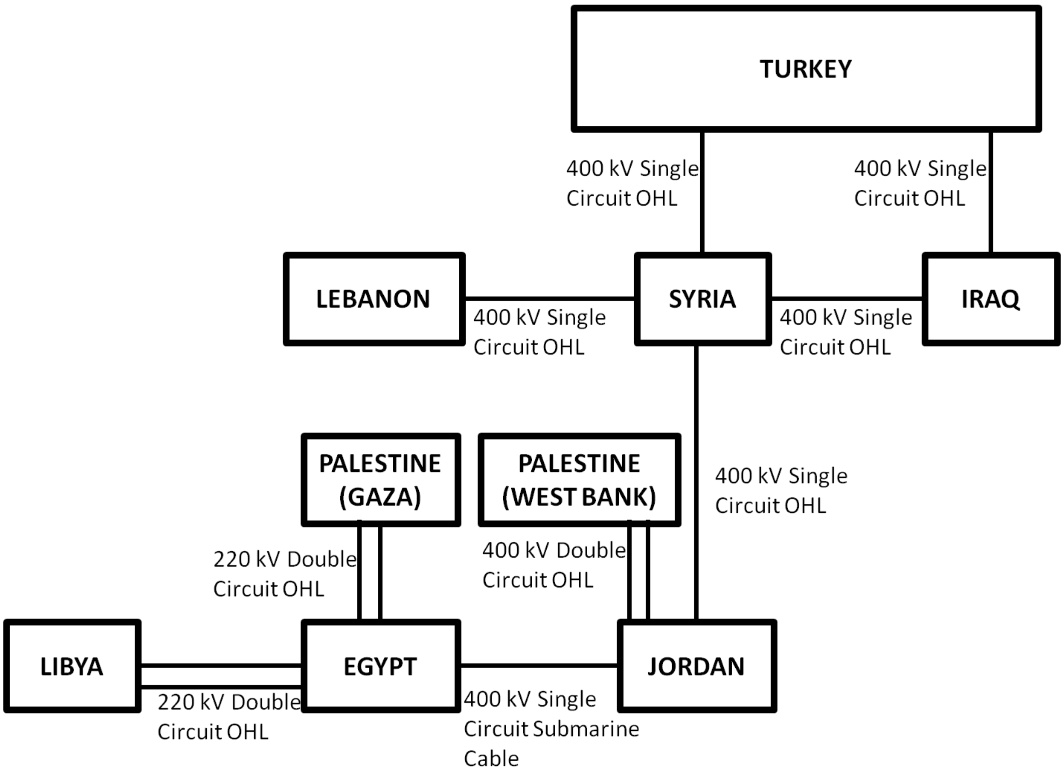

Figure 15 Existing interconnection lines between EIJLLPST countries

Zero Exchange Scenario represents a base scenario with interconnection lines in service without any power exchange between countries. Summer and Winter Exchange Scenarios are prepared based on system conditions and assumptions.

Exchange values and directions of power flow in Summer and Winter Exchange Scenarios are determined by representatives of EIJLLPST Project Countries in the General Planning Committee Meeting of the EIJLLPST Project was held in Trabzon during the period 4-5/10/2012. For Summer Exchange Scenario, direction of power flow is assumed from Turkey to Egypt, taken into account of the energy need of Mashriq Countries during summer time. Maximum demand of the Mashriq Countries in EIJLLPST Project occurs in summer time. For Winter Exchange Scenario, flow direction is assumed from Egypt to Turkey, considering the energy need of Turkey in winter conditions. Maximum demand of Turkey in winter is very near to summer demand. Lebanon and Palestine are assumed as net importers in both Summer and Winter Exchange Scenarios, because of their installed capacities and energy forecasts.

3.1.1 ZERO EXCHANGE SCENARIO

In the Zero Exchange Scenario, load flow analysis is conducted on EIJLLPST power system data with no exchange between countries except Palestine. Load and generation values of each country for Zero Exchange Scenario are given in Table 29.

Table 29 Load and generation values of Zero Exchange Scenario

	Load (MW)	**Generation (MW)**
Egypt	33,468.6	34,136.4
Libya	7,700	7,770
Jordan	3,335.8	3,477.8
Syria	8,663	8,766
Lebanon	1,700	1,704.8
Iraq	17,500	17,637.6
Palestine	250	0
Turkey	0	0
Total	72,617.4	73,492.6

The load of Palestine is 250 MW while the generation is 0 MW. To evaluate the interconnection between Palestine – Jordan and Palestine – Egypt, Palestine network is defined as a load only and load values are chosen according to the expected power exchange between Palestine and Jordan (100 MW), and between Palestine and Egypt (150 MW).

Similar to the previous chapter, load flow and contingency analysis (i.e., N-1 analysis) are conducted. In the Zero Exchange Scenario, some parts of the 220 kV Egyptian network are included in the investigation, because Libya –Egypt and Egypt – Gaza interconnection is realized with 220 kV lines.

Substations with bus voltages greater than 1.05 pu in EIJLLPST network are given in Table 30, and substations with bus voltages less than 0.95 pu in EIJLLPST network are given in Table 31.

Table 30 Bus voltages greater than 1.05 pu in EIJLLPST network in Zero Exchange Scenario Base Case

Bus #	Bus Name	Base kV	V(pu)	V(kV)
30126	NOB-500	500	1.0565	528.27
30561	A-KIR	500	1.0892	544.59
30586	DIROUT	500	1.0860	542.99
30248	GIZA NOR	500	1.0757	537.83
30563	K-ZIAT	500	1.0647	532.37

Table 31 Bus voltages less than 0.95 pu in EIJLLPST network in Zero Exchange Scenario Base Case

Bus #	Bus Name	Base kV	V(pu)	V(kV)
30001	NAG-H	500	0.9120	455.99
55303	HASAKEH2	400	0.9189	367.57
55302	TAYYEM	400	0.9480	379.21

Substations with bus voltages greater than 1.05 pu and substations with bus voltages less than 0.95 pu in EIJLLPST network are similar to results of analyses which are conducted on previous chapter.

Lines loaded above 50% of their ratings in EIJLLPST network are given in Table 32. Lines loaded above 50% of their rating in EIJLLPST network for 500 kV and 400 kV voltage levels are similar to results of analyses which are conducted on previous chapter. Other 220 kV transmission lines listed in Table 32 are in Egyptian transmission network.

Loading of the double circuit line between KRIR.PS (Egypt) and B-ARAB (Egypt) buses are important, because this double circuit line is in the west 220 kV Egyptian network and loading of 220 kV west Egypt network could limit the transfer capacity from Egypt to Libya direction. Map of the west 220 kV Egypt network is given in Figure 16.

Table 32 Lines loaded above 50% in EIJLLPST network in Zero Exchange Scenario

Bus #	**Bus Name**	**Base kV**	**Bus #**	**Bus Name**	**Base kV**	**Circuit #**	**Loading (MVA)**	**Rating (MVA)**	**Loading Percentage**
30004	C.500	500	30248	GIZA NOR	500	1	1419.7	1732	82
16470	BGC4	400	21401	KRTG	400	1	630.4	1000	63
16401	RSF4	400	18401	ZBDP	400	1	560.2	1000	56
16401	RSF4	400	18401	ZBDP	400	2	560.2	1000	56
27405	QRN4	400	27421	HRTP	400	1	553.9	1000	55.4
11403	NYNG	400	11420	MSL4	400	1	552.5	1000	55.2
30377	MASED2	220	30525	BERABD	220	2	154.2	95	162.3
30376	MASED1	220	30525	BERABD	220	1	151.5	95	159.5
30376	MASED1	220	30524	ARISH	220	1	117.3	95	123.4
30377	MASED2	220	30524	ARISH	220	2	86.1	95	90.6
30499	B-ARAB	220	30523	KRIR.PS	220	1	326.0	426	76.5
30499	B-ARAB	220	30523	KRIR.PS	220	2	326.0	426	76.5
30443	P.SAID-E	220	30525	BERABD	220	1	279.8	426	65.7
30443	P.SAID-E	220	30525	BERABD	220	2	279.8	426	65.7
30503	DEKHELA	220	30523	KRIR.PS	220	1	276.2	426	64.8
30503	DEKHELA	220	30523	KRIR.PS	220	2	276.2	426	64.8
30493	AMRIA	220	30523	KRIR.PS	220	1	261.3	426	61.3
30493	AMRIA	220	30523	KRIR.PS	220	2	261.3	426	61.3
30513	BAGDAD	220	30525	BERABD	220	2	91.9	152	60.4
30512	BAGDAD	220	30525	BERABD	220	1	86.5	152	56.9

Loading of single circuit lines listed below are important. Loadings of these 4 lines are expected to limit the transfer capacity from Egypt to Palestine (Gaza) direction. Load flow diagram of Egypt – Palestine (Gaza) Interconnection is given in Figure 17.

- Single circuit line between BERABD (Egypt) - MASED2 (Egypt) buses,
- Single circuit line between BERABD (Egypt) and MASED1 (Egypt) buses,
- Single circuit line between MASED1 (Egypt) and ARISH (Egypt) buses,
- Single circuit line between MASED2 (Egypt) and ARISH (Egypt) buses

Figure 16 Map of west 220 kV Egypt network

It is not possible to transfer 150 MW power from Egypt to Palestine (Gaza) with the line loadings which are represented in Figure 17 between BERABD and ARISH buses. Thermal capacity of overloaded lines shown in Figure 17 is 95 MVA according to EIJLLPST power system data. To be able to transfer 150 MW power from Egypt to Palestine (Gaza), power transfer capacity of single circuit lines between BERABD (Egypt) and MASED2 (Egypt), between BERABD (Egypt) and MASED1 (Egypt), between MASED1 (Egypt) and ARISH (Egypt), between MASED2 (Egypt) and ARISH (Egypt) buses should be increased.

Most of the interconnection lines between countries are single line as seen in Figure 15. When one of these lines trip, system is separated into two parts and each part would be operated independently with no exchange between two parts.

Contingency analysis results are similar to results of analyses which are conducted on previous chapter. It should be noted that when one of 220 kV lines listed in Table 32 is out of service, voltage drop and overloaded lines are detected in the network.

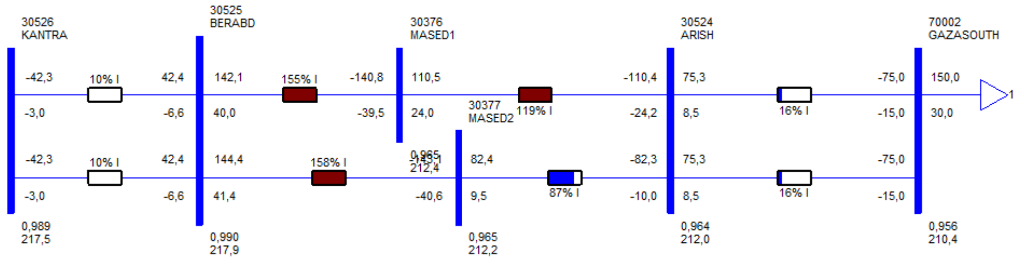

Figure 17 Load flow diagram of Egypt – Palestine (Gaza) 220 kV interconnection

3.1.2 SUMMER EXCHANGE SCENARIO

For Summer Exchange Scenario, power flow direction is assumed from Turkey to Egypt, taken into account the energy need of Arab Countries during summer. Maximum demand of the Arab Countries in EIJLLPST Project occurs in summer time. Summer Exchange Scenario is given in Figure 18. Transfer capacities in Summer Exchange Scenario are determined according to HVDC back-to-back capacities of Turkey-Syria and Turkey-Iraq interconnections, submarine cable thermal capacity for Egypt-Jordan interconnection by representatives of EIJLLPST Project Countries in the General Planning Committee Meeting of the EIJLLPST Project was held in Trabzon during the period 4-5/10/2012. Load and generation values of each country for Summer Exchange Scenario are given in Table 33.

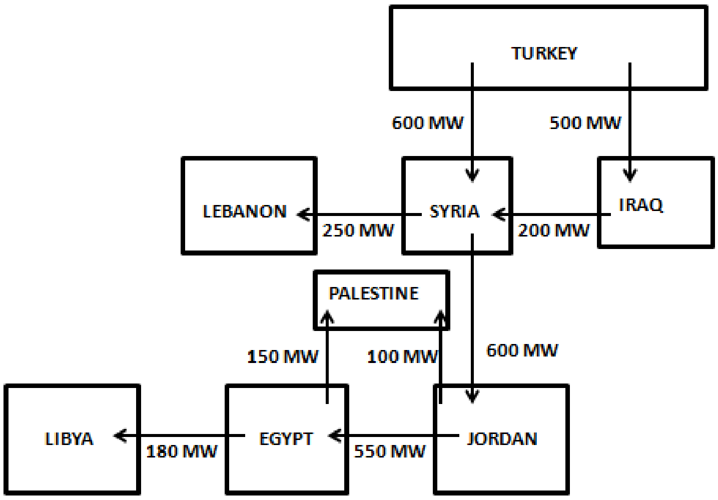

Figure 18 Summer Exchange Scenario

Table 33 Load and generation values of Summer Exchange Scenario

	Load (MW)	**Generation (MW)**
Egypt	33,408.7	33,709.8
Libya	7,700	7,624.9
Jordan	3,335.8	3,428.6
Syria	8,663	8,816.1
Lebanon	1,950	1,704.8
Iraq	17,500	17,337.5
Palestine	250	0
Turkey	0	1,100
Total	72,807.5	73,721.7

In order to investigate the system operating conditions that would occur in Summer Exchange Scenario, load flow analysis is performed on EIJLLPST power system data to simulate the base case and contingency case. Substations with bus voltages greater than 1.05 pu in EIJLLPST network are given in Table 34, and substations with bus voltages less than 0.95 pu in EIJLLPST network are given in Table 35.

Table 34 Bus voltages greater than 1.05 pu in EIJLLPST network in Summer Exchange Scenario

Bus #	Bus Name	Base kV	V(pu)	V(kV)
30126	NOB-500	500	1.0720	536.02
30561	A-KIR	500	1.0885	544.27
30586	DIROUT	500	1.0858	542.91
30248	GIZA NOR	500	1.0806	540.32
30563	K-ZIAT	500	1.0644	532.18
31551	DUMM 1&	500	1.0608	530.40

Table 35 Bus voltages less than 0.95 pu in EIJLLPST network in Summer Exchange Scenario

Bus #	Bus Name	Base kV	V(pu)	V(kV)
30001	NAG-H	500	0.9138	456.89
30664	SIDI ABD RAH	220	0.8690	191.17
61001	KSARA	220	0.9471	208.36
30501	MATROUH	220	0.9108	200.38
55303	HASAKEH2	400	0.9217	368.69

Substations with bus voltages greater than 1.05 pu in EIJLLPST network are similar to results of analyses which are conducted on previous chapter. Substations with bus voltages less than 0.95 pu in EIJLLPST network are similar to results of analyses which are conducted on previous chapter except four busses. TAYYEM bus of Syria is not in the list, because TAYYEM bus of Syria is connected to Iraq system and power flow from Iraq system to Syria system increase voltage of this bus. KSARA bus of Lebanon is in the list, because load of Lebanon is increased in Summer Exchange Scenario by comparing to Zero Exchange Sdenario and voltage drops observed in KSARA bus of Lebanon. SIDI ABD RAH and MATROUH buses of Egypt are in the list, because SIDI ABD RAH and MATROUH buses of Egypt are the buses located in west 220 kV Egypt network and voltage drops observed in these buses with increasing power flow from Egypt to Libya.

Lines loaded above 50% of their ratings in EIJLLPST network are presented in Table 36. The loading of 400 kV Taba (Egypt) – Aqaba (Jordan) submarine cable is 566.4 MVA (550.1 MW, 135.2 MVAr from Aqaba end) and submarine cable limits the transfer between Egypt and Jordan to ~550 MW. Load flow diagram of Egypt – Jordan interconnection is given in Figure 19.

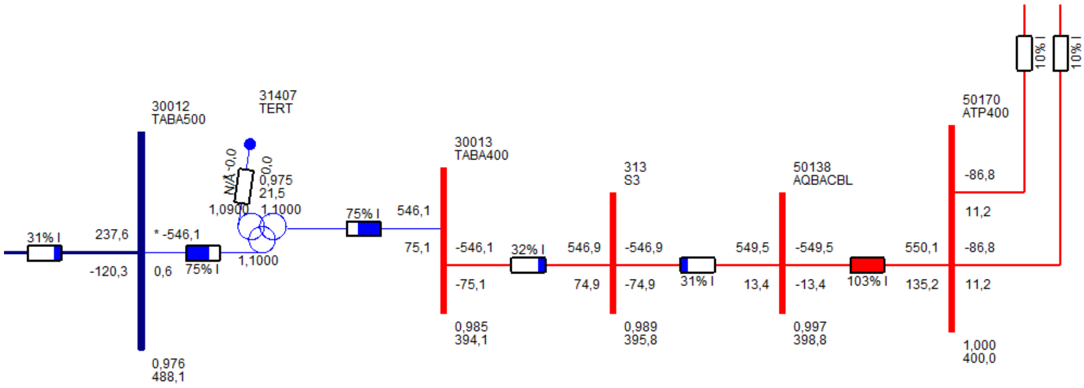

Figure 19 Load flow diagram of Egypt – Jordan interconnection in Summer Exchange Scenario

As mentioned in Zero Exchange Scenario, loading of single circuit lines listed below buses are important, because loading of these 4 lines limits the transfer capacity from Egypt to Palestine (Gaza) direction.

- Single circuit line between BERABD (Egypt) - MASED2 (Egypt) buses,
- Single circuit line between BERABD (Egypt) and MASED1 (Egypt) buses,
- Single circuit line between MASED1 (Egypt) and ARISH (Egypt) buses,
- Single circuit line between MASED2 (Egypt) and ARISH (Egypt) buses

Table 36 Lines loaded above 50% in EIJLLPST network in Summer Exchange Scenario

Bus #	Bus Name	Base kV	Bus #	Bus Name	Base kV	Circuit #	Loading (MVA)	Rating (MVA)	Loading Percentage
30004	C.500	500	30248	GIZA NOR	500	1	1393.7	1732	80.5
50138	AQBACBL	400	50170	ATP400	400	1	564.9	550	102.7
55290	DIR-ALI	400	55305	BORDER	400	1	633.3	1000	63.3
50184	AMM.NOR	400	55305	BORDER	400	1	623.4	1000	62.3
16470	BGC4	400	21401	KRTG	400	1	602.9	1000	60.3
27405	QRN4	400	27421	HRTP	400	1	540	1000	54
16401	RSF4	400	18401	ZBDP	400	1	535.1	1000	53.5
16401	RSF4	400	18401	ZBDP	400	2	535.1	1000	53.5
55300	ALEPPO F	400	55307	TURKYA-B	400	1	604.1	1135	53.2
11420	MSL4	400	27445	TIBORDER	400	1	508.3	1000	50.8
30377	MASED2	220	30525	BERABD	220	2	153.3	95	161,4
30376	MASED1	220	30525	BERABD	220	1	150.7	95	158,6
30376	MASED1	220	30524	ARISH	220	1	116.7	95	122,9
30499	B-ARAB	220	30523	KRIR.PS	220	1	408.9	426	96
30499	B-ARAB	220	30523	KRIR.PS	220	2	408.9	426	96
30500	OMID	220	30664	SIDI ABD RAH	220	1	213.9	229	93.4
30500	OMID	220	30664	SIDI ABD RAH	220	2	213.9	229	93.4
30377	MASED2	220	30524	ARISH	220	2	85.8	95	90.3
30499	B-ARAB	220	30500	OMID	220	1	284.3	425	66.9
30499	B-ARAB	220	30500	OMID	220	2	284.2	425	66.9
30503	DEKHELA	220	30523	KRIR.PS	220	1	265.8	426	62.4
30503	DEKHELA	220	30523	KRIR.PS	220	2	265.8	426	62.4
30513	BAGDAD	220	30525	BERABD	220	2	91.0	152	59.9
30493	AMRIA	220	30523	KRIR.PS	220	1	253.1	426	59.4
30493	AMRIA	220	30523	KRIR.PS	220	2	253.1	426	59.4
30443	P.SAID-E	220	30525	BERABD	220	1	252.3	426	59.2
30443	P.SAID-E	220	30525	BERABD	220	2	252.3	426	59.2
30501	MATROUH	220	30664	SIDI ABD RAH	220	1	134.3	229	58.6
30501	MATROUH	220	30664	SIDI ABD RAH	220	2	134.3	229	58.6
30512	BAGDAD	220	30525	BERABD	220	1	85.8	152	56.5
61010	ARAMON	220	61011	PINS	220	1	134.0	240	55.8

The west Egypt network limits the transfer capacity from Egypt to Libya direction in 220 kV voltage level. The loading of the double circuit line between B-ARAB (Egypt) and KRIR.PS (Egypt) buses is 96%. Load flow diagram of west 220 kV Egypt network is given in Figure 20. Power transfer from Egypt to Libya limited to 150 MW because of loading of these lines in summer exchange case. Also the loading of double circuit lines between OMID (Egypt) and SIDI ABD RAH (Egypt) buses are 93.4%, and also these lines are the limiting factors for power transfer from Egypt to Libya in normal operation.

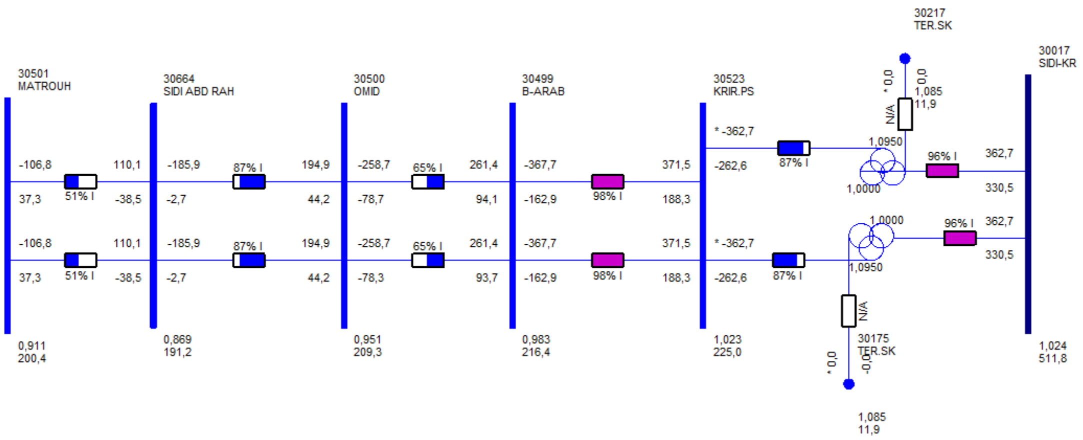

Figure 20 Load flow diagram of west 220 kV Egypt network

Results of contingency analysis are similar with the Zero Exchange Scenario. Most of the interconnection lines between countries are single line. When one of interconnection lines trips, system separates into two parts and power exchange could not be realized. It is not possible to transfer 550 MW power from Jordan to Egypt, when the line from O-MOUSA (Egypt) to TABA500 (Egypt) is open. There is no 500 kV alternative line between O-MOUSA (Egypt) and TABA500 (Egypt), and 220 kV network in east area of Egypt could not transfer power between O-MOUSA (Egypt) and TABA500 (Egypt). It is not possible to transfer power from Egypt to Libya when contingency cases occur in west 220 kV Egypt network.

3.1.3 WINTER EXCHANGE SCENARIO

For Winter Exchange Scenario, flow direction is assumed from Egypt to Turkey, considering the energy need of Turkey in winter conditions. Maximum demand of Turkey in winter times is very near to summer demand. Winter Exchange Scenario is given in Figure 21. Transfer capacities in Winter Exchange Scenario are determined according to HVDC back-to-back capacities for Turkey-Syria and Turkey-Iraq interconnections, submarine cable thermal capacity for Egypt-Jordan interconnection by representatives of EIJLLPST Project Countries in the General Planning Committee Meeting of the EIJLLPST Project was held in Trabzon during the period 4-5/10/2012. Load and generation values of each country for Winter Exchange Scenario are given in Table 37.

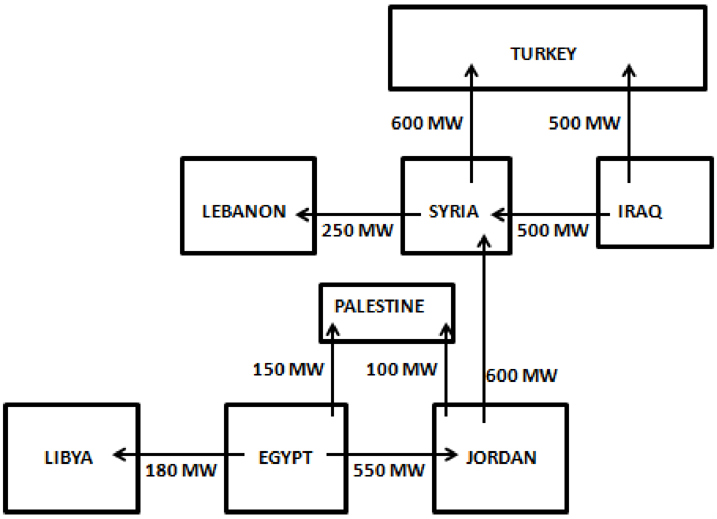

Figure 21 Winter Exchange Scenario

Static analysis is conducted on EIJLLPST power system data of Egypt prepared for Winter Exchange Scenario. Load flow and contingency analysis are conducted. Substations with bus voltages greater than 1.05 pu in EIJLLPST network are given in

Table 38, and substations with bus voltages less than 0.95 pu in EIJLLPST network are given in Table 39.

Table 37 Load and generation values of Winter Exchange Scenario

	Load (MW)	**Generation (MW)**
Egypt	32,849.2	34,259.8
Libya	7,700	7,624.5
Jordan	3,286.1	3,496
Syria	8,663	8,540.8
Lebanon	1,950	1,706.9
Iraq	17,500	18,731.7
Palestine	250	0
Turkey	1,100	0
Total	73,298.3	74,359.7

Table 38 Bus voltages greater than 1.05 pu in EIJLLPST network in Winter Exchange Scenario

Bus #	**Bus Name**	**Base kV**	**V(pu)**	**V(kV)**
30561	A-KIR	500	1.0908	545.40
30586	DIROUT	500	1.0873	543.64
30248	GIZA NOR	500	1.0850	542.49
30126	NOB-500	500	1.0750	537.48
30563	K-ZIAT	500	1.0677	533.86
31551	DUMM 1&	500	1.0635	531.75

Substations with bus voltages greater than 1.05 pu in EIJLLPST network are similar with the Summer Exchange Scenario analysis results. Substations with bus voltages less than 0.95 pu in EIJLLPST network are similar with the Summer Exchange Scenario analysis results except QIM4 and TABA500 buses. In Winter Exchange Scenario, transfer value from Iraq to Syria increases from 200 MW to 500 MW and this results in voltage drop in QIM4 buses of Iraq. TABA500 bus of Egypt is the radial part of Egypt 500 kV network and this bus is connection point of Egypt –

Jordan interconnection cable. When flow direction changed from Jordan – Egypt to Egypt – Jordan, voltage drop observed at TABA500 bus. Also there are some buses with voltages less than 0.95 pu in 220 kV Lebanon and Egypt network.

Table 39 Bus voltages less than 0.95 pu in EIJLLPST network in Winter Exchange Scenario

Bus #	**Bus Name**	**Base kV**	**V(pu)**	**V(kV)**
31552	DUMM 2&	500	0.9432	471.62
30012	TABA500	500	0.9411	470.54
30001	NAG-H	500	0.9208	460.41
19411	QIM4	400	0.9482	379.26
55302	TAYYEM	400	0.9267	370.67
55303	HASAKEH2	400	0.9018	360.73
70002	GAZASOUTH	220	0.9471	208.35
61009	BASALIM	220	0.9450	207.90
61010	ARAMON	220	0.9431	207.49
61008	MIKALLS	220	0.9425	207.35
61011	PINS	220	0.9406	206.94
61006	COMERCIA	220	0.9405	206.92
61007	RASBEIRU	220	0.9405	206.91
61013	SOUR	220	0.9361	205.94
61001	KSARA	220	0.9311	204.85
30501	MATROUH	220	0.9227	203.00
30664	SIDI ABD RAH	220	0.8844	194.57

Lines loaded above 50% of their ratings in EIJLLPST network are given in Table 40. Loading of 400 kV Taba (Egypt) – Aqaba (Jordan) submarine cable is 600.5 MVA (546.6 MW, -138.4 MVAr from Taba end) and submarine cable limits the transfer between Egypt and Jordan to ~550 MW. Load flow diagram of Egypt – Jordan interconnection is given in Figure 22. Loading of the line between O-MOUSA (Egypt) and TABA500 (Egypt) is 71.8%. There is no 500 kV alternative line between O-MOUSA (Egypt) and TABA500 (Egypt), and 220 kV network in east area of Egypt could not transfer ~750 MW power.

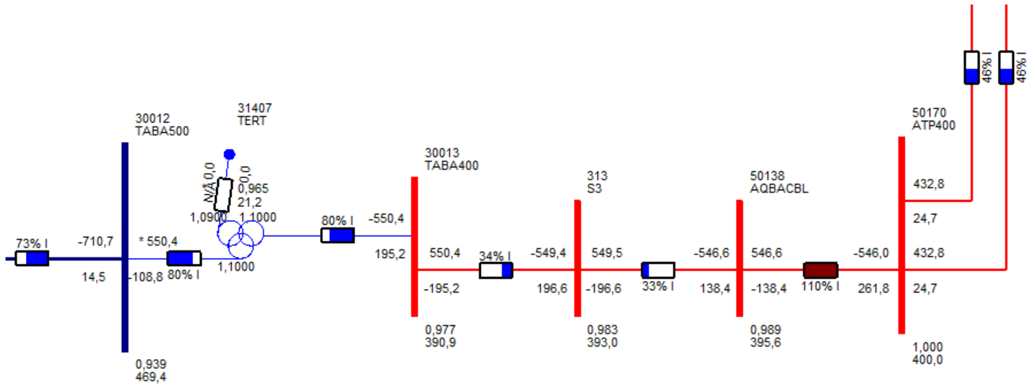

Figure 22 Load flow diagram of Egypt – Jordan interconnection in Winter Exchange Scenario

In Winter Exchange Scenario, power transfer value from Iraq to Syria increases from 200 MW to 500 MW and this result in loading of some transmission lines in Iraq network, but these loadings do not create limitations in normal operation.

Similar to the Zero Exchange Scenario, loadings of single circuit lines listed below are important, because loading of these lines limit the transfer capacity from Egypt to Palestine (Gaza) direction.

- Single circuit line between BERABD (Egypt) - MASED2 (Egypt) buses,
- Single circuit line between BERABD (Egypt) and MASED1 (Egypt) buses,
- Single circuit line between MASED1 (Egypt) and ARISH (Egypt) buses,
- Single circuit line between MASED2 (Egypt) and ARISH (Egypt) buses

Similar to the Summer Exchange Scenario, the West Egypt network limits the transfer capacity from Egypt to Libya direction in 220 kV level. The loading of double circuit lines between B-ARAB (Egypt) and KRIR.PS (Egypt) buses are 93.7%

Table 40 Lines loaded above 50% in EIJLLPST network in Winter Exchange Scenario

Bus #	Bus Name	Base kV	Bus #	Bus Name	Base kV	Circuit #	Loading (MVA)	Rating (MVA)	Loading Percentage
30004	C.500	500	30248	GIZA NOR	500	1	1440.4	1732	83.2
30011	O-MOUSA	500	31552	DUMM 2&	500	1	746.4	1040	71.8
30012	TABA500	500	31552	DUMM 2&	500	1	746.4	1040	71.8
50138	AQBACBL	400	50170	ATP400	400	1	600.5	550	110.1
11403	NYNG	400	11420	MSL4	400	1	771.3	1000	77.1
16470	BGC4	400	21401	KRTG	400	1	752.9	1000	75.3
16401	RSF4	400	18401	ZBDP	400	1	639.9	1000	64.0
16401	RSF4	400	18401	ZBDP	400	2	639.9	1000	64.0
19411	QIM4	400	19430	ANBG	400	2	598.4	1000	59.8
27405	QRN4	400	27421	HRTP	400	1	598.1	1000	59.8
55290	DIR-ALI	400	55305	BORDER	400	1	596.9	1000	59.7
50184	AMM.NOR	400	55305	BORDER	400	1	592.8	1000	59.3
22401	HYDG	400	24401	SMWG	400	1	555.3	1000	55.5
55300	ALEPPO F	400	55307	TURKYA-B	400	1	627.4	1135	55.3
19411	QIM4	400	55302	TAYYEM	400	1	549.5	1000	54.9
11420	MSL4	400	27445	TIBORDER	400	1	538.7	1000	53.9
23401	DWNG	400	25402	NSRG	400	1	537.0	1000	53.7
23402	KDS4	400	24401	SMWG	400	1	516.5	1000	51.7
23401	DWNG	400	23402	KDS4	400	1	512.8	1000	51.3
23401	DWNG	400	23402	KDS4	400	2	512.7	1000	51.3
16443	AMN4	400	18401	ZBDP	400	1	505.6	1000	50.6
16436	BGN4	400	16442	QDSG	400	1	504.1	1000	50.4
16436	BGN4	400	16442	QDSG	400	2	504.1	1000	50.4
30377	MASED2	220	30525	BERABD	220	2	153.7	95	161.8
30376	MASED1	220	30525	BERABD	220	1	151.0	95	159.0
30376	MASED1	220	30524	ARISH	220	1	117.1	95	123.3
30499	B-ARAB	220	30523	KRIR.PS	220	1	399.0	426	93.7
30499	B-ARAB	220	30523	KRIR.PS	220	2	399.0	426	93.7
30377	MASED2	220	30524	ARISH	220	2	86.2	95	90.7
30500	OMID	220	30664	SIDI ABD RAH	220	1	207.3	229	90.5
30500	OMID	220	30664	SIDI ABD RAH	220	2	207.3	229	90.5
30443	P.SAID-E	220	30525	BERABD	220	1	309.5	426	72.7
30443	P.SAID-E	220	30525	BERABD	220	2	309.5	426	72.7
30499	B-ARAB	220	30500	OMID	220	1	275.8	425	64.9

Table 40 (continued)

Bus #	Bus Name	Base kV	Bus #	Bus Name	Base kV	Circuit #	Loading (MVA)	Rating (MVA)	Loading Percentage
30499	B-ARAB	220	30500	OMID	220	2	275.6	425	64.9
30503	DEKHELA	220	30523	KRIR.PS	220	1	264.6	426	62.1
30503	DEKHELA	220	30523	KRIR.PS	220	2	264.6	426	62.1
30513	BAGDAD	220	30525	BERABD	220	2	91.0	152	59.9
30493	AMRIA	220	30523	KRIR.PS	220	1	251.7	426	59.1
30493	AMRIA	220	30523	KRIR.PS	220	2	251.7	426	59.1
61010	ARAMON	220	61011	PINS	220	1	138.7	240	57.8
30501	MATROUH	220	30664	SIDI ABD RAH	220	1	130.3	229	56.9
30501	MATROUH	220	30664	SIDI ABD RAH	220	2	130.3	229	56.9
30512	BAGDAD	220	30525	BERABD	220	1	85.7	152	56.4

Results of contingency analysis are similar with the Zero Exchange Scenario. Most of the interconnection lines between countries are single line. When one of interconnection lines trips, system is separated into two parts and power exchange could not be realized.

Increased loading in transmission lines of Iraq network creates some problems in contingency cases. When the line from bus QIM4 to bus ANBG is open, low voltage (0.818 pu) at QIM4 bus and overloading (102%) of the line from bus QIM4 to bus HDTH are observed. When the line from bus QIM4 to bus HDTH is open, low voltage (0,913 pu) at QIM4 bus and overloading (95%) of the line from bus QIM4 to bus ANBG are observed. When line from bus ANBG to bus HDTH is open, voltage drop (0,927 pu) in QIM4 bus is observed. When line from bus NYNG to bus MSL4 is open, load flow is not converged. It is not possible to transfer 500 MW power from Iraq to Syria, when contingencies occur in following lines from Iraq network: line from bus QIM4 to bus ANBG, line from bus QIM4 to bus HDTH and line from bus ANBG to bus HDTH It is not possible to transfer 500 MW power from Iraq to Turkey, when contingency occurs in line from bus NYNG to bus MSL4.

It is not possible to transfer 550 MW power Egypt to Jordan, when line from O-MOUSA (Egypt) to TABA500 (Egypt) is open. There is no 500 kV alternative line between O-MOUSA (Egypt) and TABA500 (Egypt), and 220 kV network in east area of Egypt could not transfer power between O-MOUSA (Egypt) and TABA500 (Egypt).

It is not possible to transfer power from Egypt to Libya when contingency cases occur in west 220 kV Egypt network.

In winter exchange case, also 180 MW power transfer from Libya to Egypt in 220 kV level is analyzed. Effects of the power transfer from Libya to Egypt is observed on west 220 kV Egypt network. Because direction of power flow is changed, loading of 220 kV lines in west Egypt network is lowered and voltage drops are not observed in west Egypt network. By considering the loading of the lines, 180 MW power transfer from Libya to Egypt is possible. Transferring power from Libya to Egypt via 220 kV transmission lines decreases the loading of 220 kV west Egypt network. Loading of the double circuit line from SALOUM (Egypt) to MATROUH (Egypt) would be limiting factor for power transfer from Libya to Egypt in contingency cases. When one of the double circuit lines from SALOUM (Egypt) to MATROUH (Egypt) is out of service, loading of the other circuit increases to 77%.

3.2 PLANNED INTERCONNECTIONS AND REQUIRED TRANSMISSION INVESTMENTS

There are some preliminary plans for new interconnection projects to increase the transfer capacities between countries and for internal network reinforcement projects. Also some investment needs are detected after analyses.

The transfer capacity between Egypt and Libya will be increased with installing a new 500 kV single circuit OHL between Saloum Substation (Egypt) and Tobruk Substation (Libya). This project is planned with the internal reinforcement project in Egyptian network. 500 kV single circuit OHL of 400 km length between Saloum Substation (Egypt) and S.Karir Substation (Egypt) is also planned, because 500 kV network of Egypt ends at S.Karir Substation. Installation of a 500/220 kV autotransformer is planned to reinforce the 220 kV Egyptian network.

The transfer capacity between Egypt and Jordan will be increased with operating the existing AC submarine cable at DC voltage by installing converter stations each side of the cable. Capacity of the cable is designed as 1.200 MW in DC operation. The other solution to increase the transfer capacity between Egypt and Jordan is to install a new AC submarine cable in parallel with the existing cable. AC submarine cable solution will be considered in upcoming analyses. Analyses show that the transfer capacity between Egypt and Jordan is limited by the capacity of 500 kV OHL between Taba (Egypt) and O.Mousa (Egypt). This line connects the submarine cable to Egypt network and has no other alternative. To increase the system security and the transfer capacity between Egypt and Jordan, a 500 kV transmission line with 244 km length between Taba (Egypt) and O.Mousa (Egypt) is needed. Also a new 400 kV corridor (double circuit OHL with 350 km length) between Aqaba and Amman in Jordan is planned to reinforce Jordanian transmission network for improving security of interconnection between Egypt and Jordan.

Egypt-Palestine (Gaza) interconnection will be realized in 220 kV voltage level. Analysis shows that 220 kV Egypt network needs reinforcement to realize secure interconnection between Egypt and Palestine (Gaza). To be able to transfer 150 MW power from Egypt to Palestine (Gaza), power transfer capacity of single circuit lines between BERABD (Egypt) and MASED2 (Egypt), between BERABD (Egypt) and MASED1 (Egypt), between MASED1 (Egypt) and ARISH (Egypt), between MASED2 (Egypt) and ARISH (Egypt) buses should be increased.

Analyses show that two internal reinforcements are needed in Egyptian network. A 500 kV single circuit OHL with 236 km length should be installed between High Dam and Nag Hammadi to transfer generation from High Dam to Nag Hammadi, which is the injection point for both 220 kV and 132 kV networks. 500 kV single circuit OHL with 35 km length should be installed between Giza North and Cairo 500, to transfer generation in a secure manner from Giza North.

The transfer capacity between Jordan and Syria will be increased with installing 400 kV single circuit OHL with 160 km length which connects Amman East (Jordan) and Der Ali (Syria).

The security of interconnection between Syria and Lebanon will be increased with installing 400 kV single circuit OHL between Demas (Syria) and Kesara (Lebanon).

The transfer capacity between Syria and Turkey will be increased with installing a new400 kV single circuit OHL with HVDC back-to-back station.

Analyses show that the radial part of Syria network creates problems in contingency cases. Radial part of the 400 kV network could be taken into ring with the construction of a 400 kV single circuit OHL between Aleppo – Thawra – Hasakeh 2 substations. Total length of this line is 330 km. Thawra substation is an existing 230 kV substation. With the construction of 400 kV OHL between Aleppo – Hasakeh 2, 400 kV substation and autotransformers could be added to Thawra substation to increase system security.

Mentioned investments will be included in EIJLLPST power system data, and transfer capacities will be calculated as described in Definitions of Transfer Capacities in Liberalised Electricity Markets published by ETSO (European Transmission System Operators) and Procedures for Cross-border Transmission Capacity Assessments documents published by ETSO. Representation of interconnection lines of EIJLLPST power system with new investments is given in Figure 23.

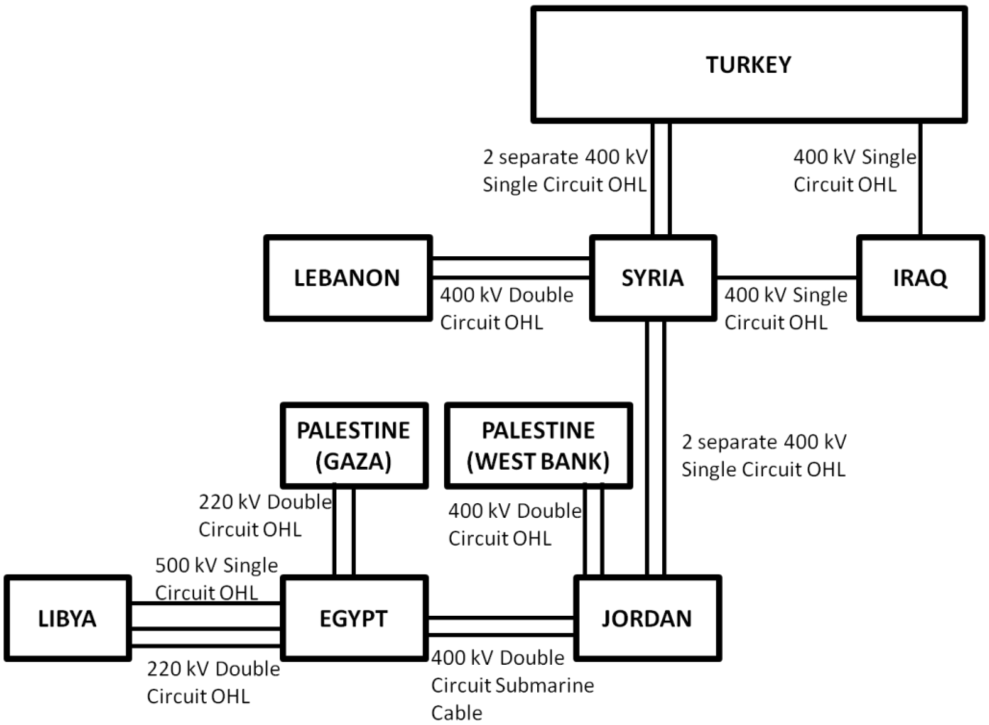

Figure 23 Existing and planned interconnection lines between EIJLLPST countries for the near future

3.3 TRANSER CAPACITY CALCULATION

Transfer capacity between countries would be evaluated for two directions; one is from Turkey to Libya direction for summer case, and the other is from Libya to Turkey for winter case. Before transfer capacity calculation, effects of new investments are investigated in power system data of countries. Load flow and contingency analyses are conducted on power system data of Egypt, Iraq, Jordan, Lebanon, Libya and Syria separately and with the interconnection lines are in service but no power exchange between countries. Results of the analyses show that there is no problem to affect operation of power systems.

Transfer capacities will be calculated as described in Definitions of Transfer Capacities in Liberalised Electricity Markets published by ETSO (European Transmission System Operators) [12] and Procedures for Cross-border Transmission

Capacity Assessments documents published by ETSO [13]. It is important to mention transfer capacity definitions:

Total Transfer Capacity, TTC, refers to the maximum power exchange between two network areas in compliance with operational security rules for a defined system operating condition [12].

Transmission Reliability Margin, TRM, refers to a security margin to overcome uncertainties on TTC values due to deviation of physical flows in real time operation, power exchanges between TSOs in emergency cases and inaccuracies in system modeling. TRM is related with the real time operation and each TSO determines TRM to guarantee the operation security of the network [12].

Net Transfer Capacity, NTC, is defined as maximum power exchange between two network areas in compliance with operational security rules in both areas and by considering technical uncertainties in future operating conditions [12]:

$$NTC = TTC - TRM \quad (1)$$

Already Allocated Capacity, AAC, is the total amount of allocated transmission rights [12].

Available Transmission Capacity, ATC, is defined as the part of NTC that is not allocated [12]:

$$ATC = NTC - AAC \quad (2)$$

Graphical presentation of transfer capacity definitions is given in Figure 24.

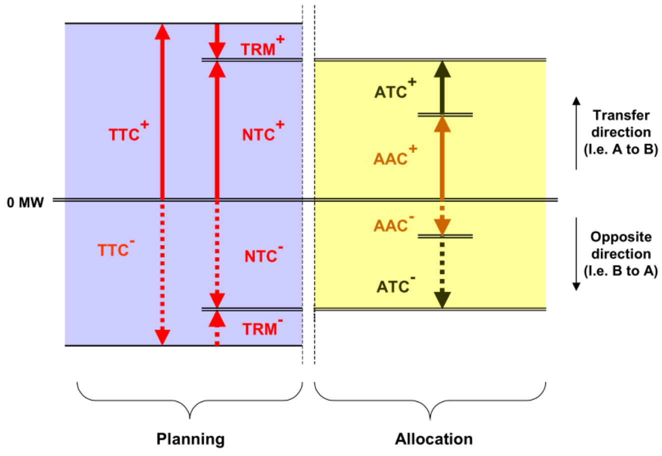

Figure 24 ETSO transfer capacity definitions [12]

Calculation of TTC begins with a base case. This base case includes power exchange programs between network areas, if there is power exchange between areas. Figure 25 gives an example to power exchange in the base case between areas A and B with a magnitude BCE (Base Case Exchange) [12]. Graphical presentation of transfer capacities in planning and for allocation phases is given in Figure 25.

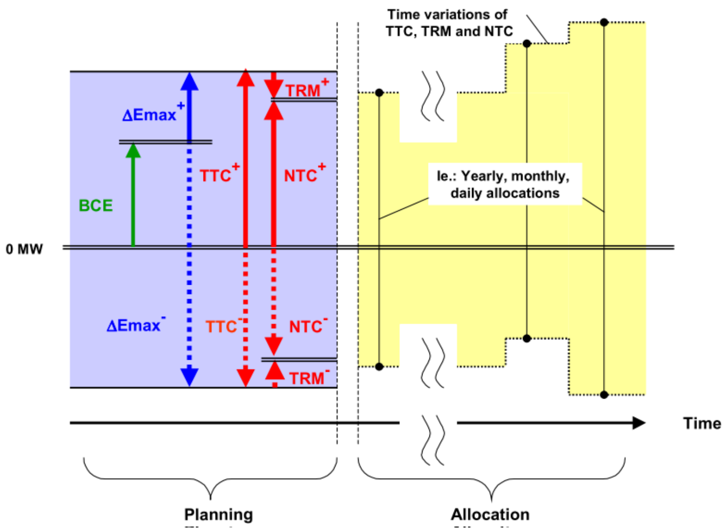

Figure 25 Transfer capacities in planning and for allocation phases [12]

To calculate TTC from Area A to Area B, generation is increased in Area A and is decreased in Area B gradually in base case by keeping the loads of whole networks unchanged. The generation increase in Area A and the generation decrease in Area B result in raise of the power flow from Area A to Area B. In Figure 25, generation shifts is represented as ΔE^+ and ΔE^- for the increase and decrease, respectively. The generation increase or decrease is continued up to limitation detected in area A or B in security wise ($\Delta Emax^+$ / $\Delta Emax^-$). Limitation detected in the networks could be thermal, voltage or stability limitations. BCE + $\Delta Emax^+$ is the maximum power exchange from Area A to Area B in compliance with security rules, i.e., TTC from A to B. Reverse of the process results in TTC from Area B to Area A. Generation is increased in Area B and is decreased in Area A up to maximum power exchange from Area B to Area A. $\Delta Emax^-$ - BCE is the maximum power exchange from Area B to Area A in compliance with security rules, i.e., TTC from B to A. After the calculation of TTC, NTC is obtained for both directions by subtracting TRM from the TTC values. TTC, TRM and NTC values are dependent on direction. In general, TTC, TRM and NTC values are different in both directions. [12], [13]. Graphical presentation of TTC calculation process is given in Figure 26.

To perform generation increase/decrease, following methods could be used:

- Proportional increase/decrease: Generation difference is distributed between generators with a ratio proportional to their base case schedule.
- Increase/decrease according to previously observed behavior of generators: Generation difference is distributed with a ratio according to the usual response pattern of generation to different system loads.
- Increase/decrease according to a well-known merit order: Generation difference is realized according to merit order [13].

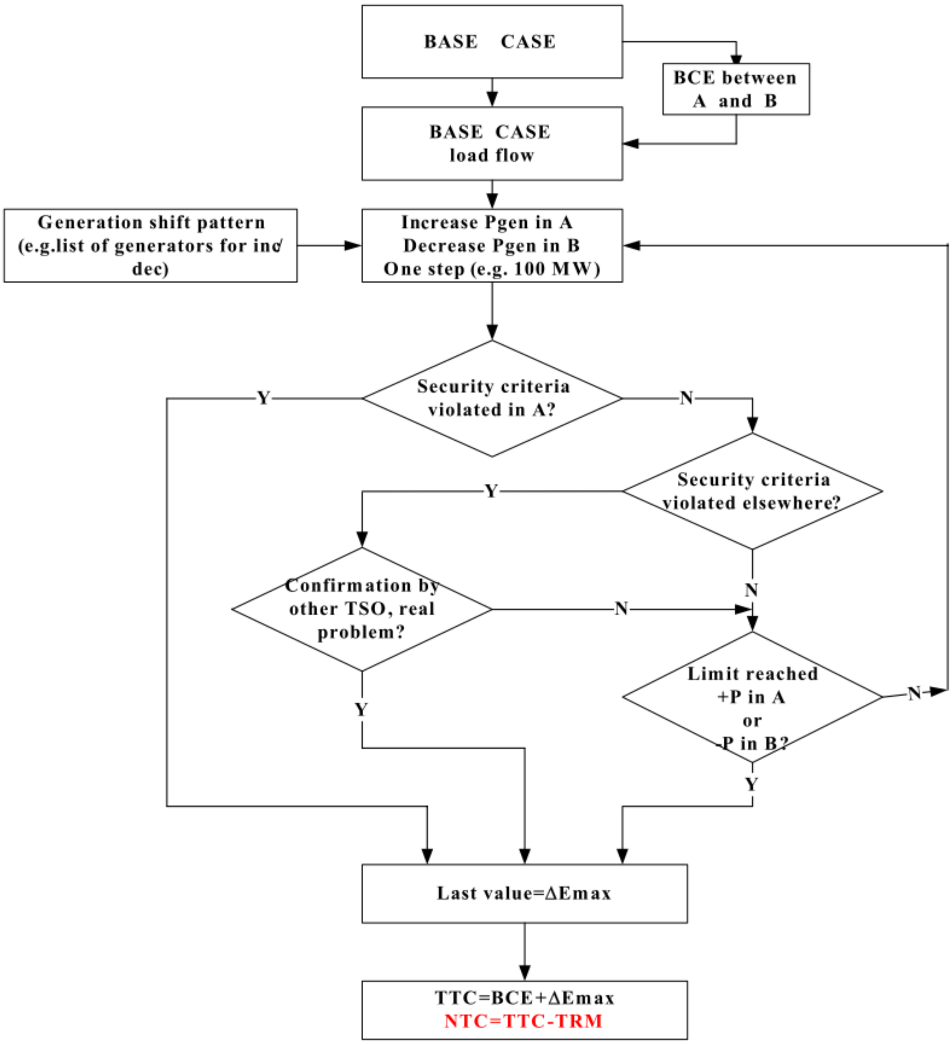

Figure 26 Process of TTC calculation [13]

In TTC calculation, Palestine and Lebanon are assumed as importer countries by considering existing transmission networks of these countries. The interconnection line between Syria and Lebanon is a 400 kV double circuit OHL with 1,375 MVA capacity for each circuit. However, power imported to Lebanon from Syria is limited to 250 MW, because of the capacity of 400/220 kV autotransformer located in Kesara (Lebanon). There is one autotransformer with 250 MVA capacity in Kesara substation. Transfer capacity could be increased and security of transfer could be obtained for N-1 conditions with the addition of another autotransformer. Interconnection line between Egypt and Gaza (Palestine) is a 220 kV double circuit OHL with 952 MVA thermal capacity in total and transfer is limited to 150 MW. Interconnection line between Jordan and West Bank (Palestine) is a 400 kV double circuit OHL with 2,100 MVA thermal capacity in total and transfer is limited to 100 MW. The exchange values for Palestine are limited according to exchange values which are determined by representatives of EIJLLPST Project Countries in the General Planning Committee Meeting of the EIJLLPST Project, held in Trabzon during the period 4-5/10/2012. Besides mentioned three interconnections, TTC between Turkey-Syria, Turkey-Iraq, Iraq-Syria, Syria-Jordan, Jordan-Egypt and Egypt-Libya are calculated in both directions between countries. Flow directions are from north to south for Summer Exchange Scenario and from south to north for Winter Exchange Scenario. Schematic presentation of flow directions for Summer and Winter Exchange Scenarios are illustrated in Figure 27 and Figure 28, respectively.

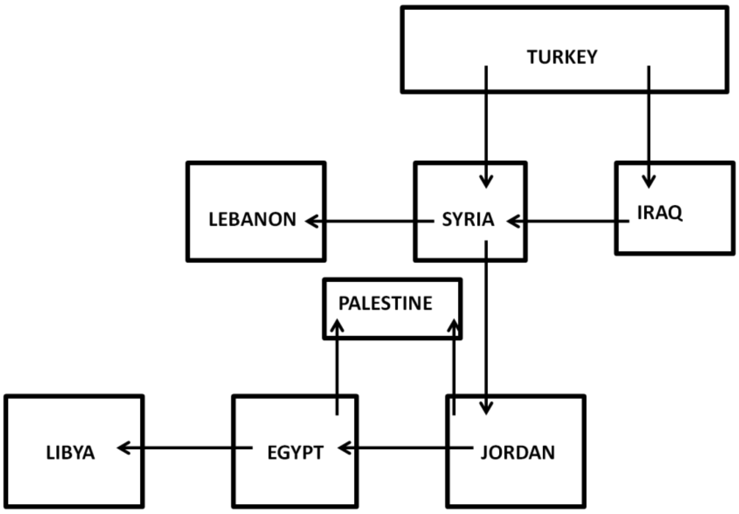

Figure 27 Power flow directions in Summer Exchange Scenario

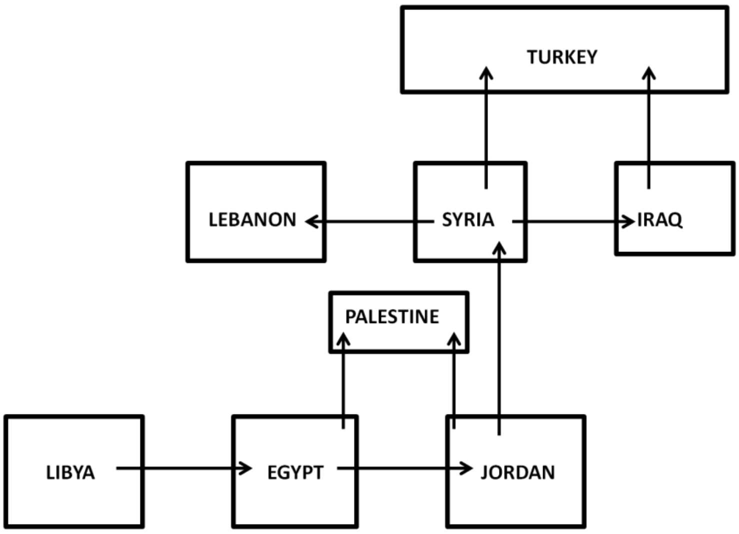

Figure 28 Power flow directions in Winter Exchange Scenario

TTC between countries is calculated simultaneously for the complete EIJLLPST power system; power exchange between two countries could create limitation in another country or in TTC values between different countries [13].

Power generation is increased in exporting countries and is decreased in importing countries by using proportional increase/decrease method to raise exchange values between countries with 100 MW steps. When loading limit for a network element is reached in N condition for a specific exchange value between two countries, that exchange value is stated as TTC between two countries for N condition. When loading limit for a network element is reached in N-1 conditions for a specific exchange value between two countries, that exchange value is stated as TTC between two countries for N-1 condition.

Interconnection lines and their capacities which are considered in TTC calculation is given in Figure 23 and summarized as follows;

- Turkey –Syria interconnection line is 400 kV two single circuits OHL with 1,375 MVA thermal capacity for each line. Transfer capacity of these interconnection lines is limited to 1,200 MW in total, because of HVDC back-to-back station capacity (2x600 MW) that will be located in Birecik.

- Turkey – Iraq interconnection line is a 400 kV single circuit OHL with 1,000 MVA thermal capacity. Transfer capacity of this interconnection line is limited to 500 MW, because of HVDC back-to-back station capacity that will be located in Cizre or Mosul.
- Iraq – Syria interconnection line is a 400 kV single circuit OHL with 1,000 MVA thermal capacity.
- Syria – Jordan interconnection line is 400 kV two single circuit OHLs with 1,065 MVA thermal capacity for each line.
- Egypt – Jordan interconnection line is 400 kV two single circuit submarine cables with 550 MVA thermal capacity for each cable.
- Egypt – Libya interconnection line is a 220 kV double circuit OHL with 952 MVA thermal capacity in total and a 500 kV single circuit OHL with 1,782 MVA thermal capacity.

3.3.1 TTC IN SUMMER EXCHANGE CASE

In summer exchange case, peak load of Egypt is 31,970 MW, peak load of Iraq is 17,500 MW, peak load of Jordan is 2,982.4 MW, peak load of Lebanon is 1,950 MW, peak load of Libya is 7,700 MW, peak load of Syria is 8,000 MW and peak load of Palestine is 250 MW. TTC for summer exchange case with these load values is calculated as follows;

Turkey-Syria

TTC from Turkey to Syria is found to be 1,200 MW in Base Case (i.e., N condition; all lines are in operation), which is HVDC back-to-back station capacity located in Birecik. When one of the two interconnection lines between Turkey and Syria is out of service, other line is loaded to its limit with 1,200 MW exchange.

Contingency cases (i.e., N-1 conditions; one line is out of service) in Syria network does not limit the power transfer from Turkey to Syria. TTC from Turkey to Syria is 1,200 MW in contingency cases.

Turkey-Iraq

TTC from Turkey to Iraq is 500 MW in base case, which is HVDC back-to-back station capacity located in Cizre or Mosul. Turkey and Iraq is interconnected via one interconnection line, hence it is not possible to transfer power when this line is out of service.

Contingency cases in Iraq network do not limit the power transfer from Turkey to Iraq. TTC from Turkey to Iraq is also found to be 500 MW in contingency cases.

Iraq-Syria

TTC from Iraq to Syria is 900 MW in Base Case; interconnection line between Iraq and Syria is loaded at its limit when the exchange value is 900 MW from Iraq to Syria. Iraq and Syria is interconnected via one interconnection line, it is not possible transfer power when this line is out of service.

Contingency cases in Iraq network limit the power transfer from Iraq to Syria. TTC from Iraq to Syria is 500 MW when 400 kV OHL between QIM4 and ANBG is out of service and TTC from Iraq to Syria is 600 MW when 400 kV OHL between QIM4 and HDTH is out of service. Line loadings in Iraq network limit the power transfer for these two cases. Other contingencies occur in Iraq network does not limit the power transfer between two countries.

Contingency cases in Syria network limit the power transfer from Iraq to Syria. TTC from Iraq to Syria is 700 MW when 400 kV OHL between TAYYEM and HASAKEH or 400 kV OHL between TAYYEM and PALMERA is out of service. Voltage drop observed in TAYYEM bus limit the power transfer for these two cases. Other contingencies occur in Syria network does not limit the power transfer between two countries.

Syria-Jordan

TTC from Syria to Jordan is 1,700 MW in Base Case; 400 kV DIR-ALI-AMM.NOR interconnection line between Syria and Jordan is loaded at its limit when exchange value is 1,700 MW from Syria to Jordan. When one of the two interconnection lines between Syria and Jordan is out of service, other line is loaded to its limit with 1,000 MW exchange. TTC from Syria to Jordan is 1,000 MW when contingency occurs in interconnection lines between Syria and Jordan.

Results reveal that the power transfer from Syria to Jordan is not limited for contingency cases in Syria network. TTC from Syria to Jordan is 1,700 MW for contingency cases in Syria network.

Contingency cases in Jordan network limit the power transfer from Syria to Jordan. TTC from Syria to Jordan is 1,000 MW when 400 kV OHL between AMM.EAS and AMM.SHT is out of service. There two OHL between AMM.EAS and AMM.SHT and one is out of service, other line is loaded to its limit with 1,000 MW exchange. Other contingencies occur in Jordan network does not limit the power transfer between two countries.

Jordan-Egypt

TTC from Jordan to Egypt is 1,000 MW in Base Case; submarine cables between Jordan and Egypt are loaded at their limits when exchange value is 1,000 MW from Jordan to Egypt. When one of the two submarine cables between Jordan and Egypt is out of service, other cable is loaded to its limit with 500 MW exchange. TTC from Jordan to Egypt is 500 MW when contingency occur in submarine cables between Jordan and Egypt.

Studies indicate that contingency cases in Jordan network do not limit the power transfer from Jordan to Egypt. TTC from Jordan to Egypt is 1,000 MW in contingency cases.

Contingency cases in Egypt network create limitation for the power transfer from Jordan to Egypt. TTC from Jordan to Egypt is 600 MW when 500 kV OHL between SUEZ-500 and BADR is out of service. There is only one 500 kV line between SUEZ-500 and BADR and when this line out of service, 500/220 kV autotransformer with 500 MVA capacity in SUEZ-500 substation is loaded at its limit. Addition of second OHL between SUEZ-500 and BADR or increasing installed power of autotransformer in SUEZ-500 substation by adding a new autotransformer overcome loading problem and increase TTC to 1,000 MW from Jordan to Egypt in contingency cases. Other contingencies occur in Egypt network does not limit the power transfer between two countries.

Egypt-Libya

Applying the procedure explained in the previous section, TTC from Egypt to Libya is determined as 1,000 MW in Base Case. Two 500/400 kV autotransformer with 400 MVA capacity located in TOBRUK Substation (Libya) are loaded at their limits when exchange value is 1,000 MW from Egypt to Libya. Egypt and Libya is interconnected via two 220 kV OHLs and one 500 kV OHL between SALOUM Substation (Egypt) and TOBRUK Substation (Libya). When 500 kV OHL between Egypt and Libya is out of service, 500/220 kV autotransformer with 500 MVA capacity located in SALOUM Substation is loaded at its limit with 500 MW exchange. TTC from Egypt to Libya is 500 MW when a contingency occurs in 500 kV OHL between Egypt and Libya. When one of the 220 kV OHL between Egypt and Libya is out of service, two 500/400 kV autotransformers with 400 MVA capacity located in TOBRUK Substation are loaded at their limits with 900 MW exchange. Hence, TTC from Egypt to Libya is found to be 900 MW when a contingency occurs in 220 kV OHL between Egypt and Libya.

Results of studies reveal that contingency cases in Egypt network limit power transfer from Egypt to Libya. TTC from Egypt to Libya is 100 MW when 500 kV OHL between SALOUM and SIDI-KR is out of service. Line loadings in 220 kV Egypt network limit the power transfer for this case. TTC from Egypt to Libya is 500

MW when one of the 220 kV OHL between KRIR.PS and B-ARAB is out of service. When one of the 220 kV OHL between KRIR.PS and B-ARAB is out of service, other line is loaded to its limit with 500 MW exchange. TTC from Egypt to Libya is 900 MW when 500/220 kV autotransformer with 500 MVA capacity located in SALOUM is out of service. When 500/220 kV autotransformer with 500 MVA capacity located in SALOUM is out of service, two 500/400 kV autotransformer with 400 MVA capacity located in TOBRUK Substation is loaded its limit with 900 MW exchange. TTC from Egypt to Libya is 900 MW when one of the 220 kV OHL between OMID and SIDI ABD RAH is out of service. When one of the 220 kV OHL between OMID and SIDI ABD RAH is out of service, other line is loaded to its limit with 900 MW exchange. TTC from Egypt to Libya is 1,000 MW when one of the 220 kV OHL between OMID and B-ARAB is out of service. When one of the 220 kV OHL between OMID and B-ARAB is out of service, other line is loaded to its limit with 1,000 MW exchange. Other contingencies occur in Egypt network does not limit the power transfer between two countries.

Studies indicate that any of the contingency cases occur in Libya network does not limit the power transfer from Egypt to Libya. TTC from Egypt to Libya is 1,000 MW in contingency cases in Libya network. Only one contingency case, contingency of two 500/400 kV autotransformer with 400 MVA capacity located in TOBRUK Substation, limit the power transfer from Egypt to Libya. TTC from Egypt to Libya is 700 MW when one of the 500/400 kV autotransformer with 400 MVA capacity located in TOBRUK is out of service. When 500/400 kV autotransformer with 400 MVA capacity located in TOBRUK is out of service, other 500/400 kV autotransformer with 400 MVA capacity located in TOBRUK Substation is loaded at its limit with 700 MW exchange.

TTC values for summer exchange case for N and N-1 conditions are given in Figure 29 and Figure 30, respectively.

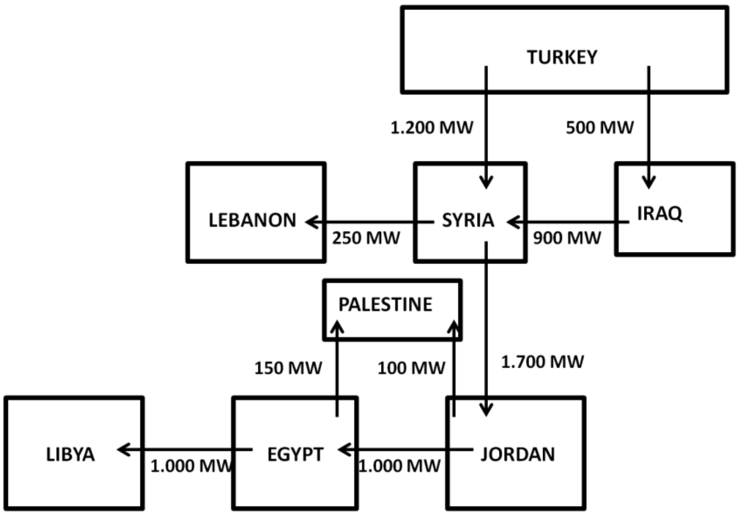

Figure 29 TTC values in N condition for Summer Exchange Scenario

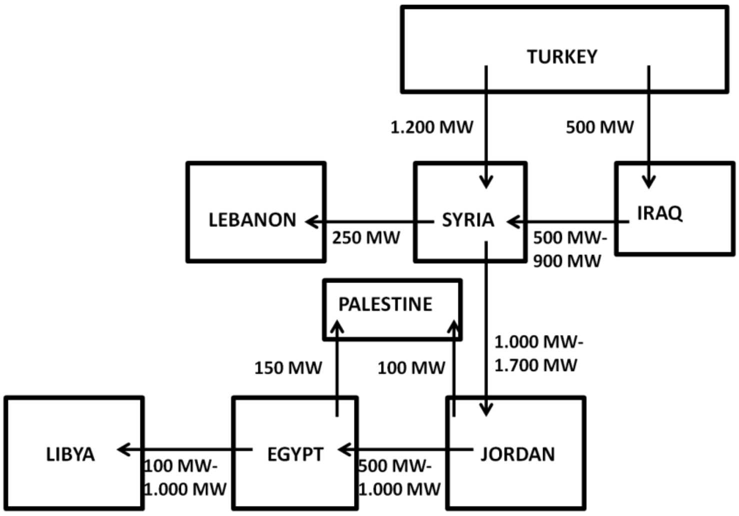

Figure 30 TTC values in N-1 condition for Summer Exchange Scenario

3.3.2 TTC IN WINTER EXCHANGE CASE

In winter exchange case load of Egypt is 31,970 MW, load of Iraq is 17,500 MW, load of Jordan is 2,982.4 MW, load of Lebanon is 1,950 MW, load of Libya is 7,700 MW, load of Syria is 8,000 MW and load of Palestine is 250 MW. TTC for winter exchange case with these load values is calculated as follows;

Libya-Egypt

TTC from Libya to Egypt is 1,000 MW in N condition; two 500/400 kV autotransformers with 400 MVA capacity located in TOBRUK Substation (Libya) are loaded at their limit when exchange value is 1,000 MW from Libya to Egypt. Egypt and Libya is interconnected via two 220 kV OHL and one 500 kV OHL between SALOUM Substation (Egypt) and TOBRUK Substation (Libya). When 500 kV OHL between Egypt and Libya is out of service, 500/220 kV autotransformer with 500 MVA capacity located in SALOUM Substation is loaded at its limit with 700 MW exchange. TTC from Libya to Egypt is 700 MW when contingency occur in 500 kV OHL between Egypt and Libya. When one of the 220 kV OHL between Egypt and Libya is out of service, two 500/400 kV autotransformers with 400 MVA capacity located in TOBRUK Substation are loaded at their limit with 1,000 MW exchange. TTC from Libya to Egypt is 1,000 MW when contingency occur in 220 kV OHL between Egypt and Libya.

Results reveal that contingency cases in Libya network do not limit the power transfer from Libya to Egypt. TTC from Libya to Egypt is 1,000 MW in contingency cases. Only one case, contingency in two 500/400 kV autotransformers with 400 MVA capacity located in TOBRUK Substation, limits the power transfer from Libya to Egypt. TTC from Libya to Egypt is 700 MW when one of the 500/400 kV autotransformers with 400 MVA capacity located in TOBRUK is out of service. When 500/400 kV autotransformer with 400 MVA capacity located in TOBRUK is out of service, other 500/400 kV autotransformer with 400 MVA capacity located in TOBRUK Substation is loaded at its limit with 700 MW exchange.

Contingency cases in Egypt network limit the power transfer from Libya to Egypt. TTC from Libya to Egypt is 400 MW when 500 kV OHL between SALOUM and SIDI-KR is out of service. Line loadings in 220 kV Egypt network limit the power transfer for this case. TTC from Libya to Egypt is 400 MW when 500 kV OHL between SIDI-KR and NOB-500 or 500 kV OHL between NOB-500 and C.500 is out of service. There is only one 500 kV OHL from C.500 (Cairo) to Libya and when this line out of service, two 500/220 kV autotransformer with 500 MVA capacity located in SIDI-KR are loaded at their limits. TTC from Libya to Egypt is 800 MW when one of the 220 kV OHL between SALOUM and MATROUH is out of service. When one of the 220 kV OHL between SALOUM and MATROUH is out of service, other line is loaded at its limit with 800 MW exchange. Other contingencies occur in Egypt network does not limit the power transfer between two countries.

Egypt-Jordan

TTC from Egypt to Jordan is 1,000 MW in base case; submarine cables between Jordan and Egypt are loaded at their limits when exchange value is 1,000 MW from Egypt to Jordan. When one of the two submarine cables between Jordan and Egypt is out of service, other cable is loaded at its limit with 500 MW exchange. TTC from Egypt to Jordan is 500 MW when contingency occur in submarine cables between Jordan and Egypt.

Contingency cases in Jordan network do not limit the power transfer from Egypt to Jordan. TTC from Egypt to Jordan is 1,000 MW in contingency cases.

Studies indicate that contingency cases in Egypt network limit power transfer from Egypt to Jordan. TTC from Egypt to Jordan is 600 MW when 500 kV OHL between SUEZ-500 and BADR is out of service. There is only one 500 kV line between SUEZ-500 and BADR and when this line out of service, 500/220 kV autotransformer with 500 MVA capacity in SUEZ-500 substation is loaded at its limit. Addition of second OHL between SUEZ-500 and BADR or increasing installed power of autotransformer in SUEZ-500 substation by adding a new autotransformer overcome loading problem and increase TTC to 1,000 MW from Jordan to Egypt in contingency cases. TTC from Egypt to Jordan is 900 MW when one of the 500 kV OHL between O-MOUSA and TABA500 is out of service. When one of the 500 kV OHL between O-MOUSA and TABA500 is out of service, other line is loaded at its limit with 900 MW exchange. Other contingencies occur in Egypt network does not limit the power transfer between two countries.

Jordan-Syria

TTC from Jordan to Syria is 900 MW in base case; voltage values observed in Syria network limit the power transfer from Jordan to Syria to 900 MW. TTC from Jordan to Syria is 900 MW when contingency occur in interconnection lines between Syria and Jordan. When one of the two interconnection lines between Jordan and Syria is out of service, other line is loaded to its limit with 900 MW exchange.

Contingency cases in Jordan network do not limit the power transfer from Jordan to Syria. TTC from Jordan to Syria is 900 MW in contingency cases.

Results reveal that contingency cases in Syria network limit the power transfer from Jordan to Syria. TTC from Jordan to Syria is 700 MW in contingency cases in Syria network; voltage values observed in Syria network limit the power transfer from Jordan to Syria to 700 MW.

Syria-Iraq

TTC from Syria to Iraq is 800 MW in base case; interconnection line between Iraq and Syria is loaded at its limit when exchange value is 800 MW from Syria to Iraq.

Results of studies indicate that contingency cases in Syria network limit the power transfer from Syria to Iraq. TTC from Syria to Iraq is 400 MW when 400 kV OHL between PALMERA and TAYYEM or 400 kV OHL between JANDAR and PALMERA is out of service. Voltage drop observed in TAYYEM bus limit the power transfer for these two cases. TTC from Syria to Iraq is 500 MW when 400 kV OHL between THAWRA and HASAKEH is out of service. Voltage drop observed in TAYYEM bus limit the power transfer for this case. TTC from Syria to Iraq is 600 MW when 400 kV OHL between TAYYEM and HASAKEH is out of service. Voltage drop observed in TAYYEM bus limit the power transfer for this case. TTC from Syria to Iraq is 700 MW for other contingency cases in Syria network; voltage values observed in Syria network limit the power transfer from Syria to Iraq to 700 MW.

Contingency cases in Iraq network limit the power transfer from Syria to Iraq. TTC from Syria to Iraq is 600 MW when 400 kV OHL between QIM4 and ANBG is out of service and TTC from Iraq to Syria is 700 MW when 400 kV OHL between QIM4 and HDTH is out of service. Voltage drop observed in TAYYEM bus limit the power transfer for these two cases. Other contingencies occur in Iraq network does not limit the power transfer between two countries.

Iraq-Turkey

TTC from Iraq to Turkey is 500 MW in base case, which is HVDC back-to-back station capacity located in Cizre or Mosul.

Studies indicate that contingency cases in Iraq network limit the power transfer from Iraq to Turkey. TTC from Iraq to Turkey is 100 MW when 400 kV OHL between NYNG and MSL4 is out of service. Voltage drop observed in MSL4 bus limit the power transfer for this case. TTC from Iraq to Turkey is 400 MW when 400 kV OHL between MSE4 and DBSG is out of service. When 400 kV OHL between MSE4 and DBSG line is out of service, 400 kV OHL between NYNG and MSL4 line is loaded at its limit. TTC from Iraq to Turkey is 500 MW when 400 kV OHL between DBSG and KRK4 or 400 kV OHL between SHMP and BAJP is out of service. When 400 kV OHL between DBSG and KRK4 or 400 kV OHL between SHMP and BAJP is out of service, 400 kV OHL between NYNG and MSL4 line is loaded at its limit. Other contingencies cases in Iraq network do not limit the power transfer between two countries.

Syria-Turkey

TTC from Syria to Turkey is 900 MW in base case; voltage drop observed in Birecik bus limit the power transfer from Syria to Turkey. When one of the two interconnection lines between Turkey and Syria is out of service, TTC from Syria to Turkey is 700 MW; voltage drop observed in Birecik bus limit the power transfer from Syria to Turkey in this contingency case.

Contingency cases in Syria network limit the power transfer from Syria to Turkey. TTC from Syria to Turkey is 700 MW in contingency cases in Syria network; voltage values observed in Syria network limit the power transfer from Syria to Turkey to 700 MW.

TTC values for winter exchange case for N and N-1 conditions are given in Figure 31 and Figure 32, respectively.

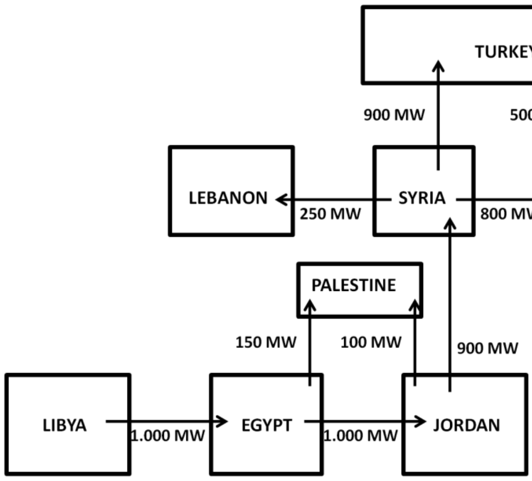

Figure 31 TTC values in N condition for Winter Exchange Scenario

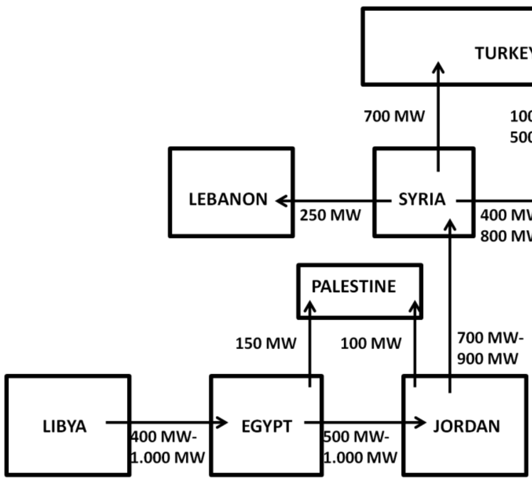

Figure 32 TTC values in N-1 conditions for Winter Exchange Scenario

3.3.3 RESULTS OF TTC CALCULATION

To validate the TTC values obtained from analyses explained in sections 3.3.1 and 3.3.2, some additional analyses are conducted.

Load flow analysis is conducted for the validation of TTC values in N condition for Summer Exchange Scenario with 31,970 MW load for Egypt, 17,500 MW load for Iraq, 2,982.4 MW load for Jordan, 1,950 MW load for Lebanon, 7,700 MW load for Libya, 8,000 MW load for Syria, 250 MW load for Palestine and 1,200 MW export from Turkey to Syria, 500 MW export from Turkey to Iraq, 900 MW export from Iraq to Syria, 250 MW export from Syria to Lebanon, 1,700 MW export from Syria to Jordan, 100 MW export from Jordan to Palestine, 1,000 MW export from Jordan to Egypt, 150 MW export from Egypt to Palestine and 1,000 MW export from Egypt to Libya. Lines are not loaded beyond their limits and voltage of busses is in the range of 0.9 pu and 1.1 pu in N condition for Summer Exchange Scenario.

Load flow analysis is conducted for validation of TTC values in N-1 conditions for Summer Exchange Scenario with 31,970 MW load for Egypt, 17,500 MW load for Iraq, 2,982.4 MW load for Jordan, 1,950 MW load for Lebanon, 7,700 MW load for Libya, 8,000 MW load for Syria, 250 MW load for Palestine and 1,200 MW export from Turkey to Syria, 500 MW export from Turkey to Iraq, 500 MW export from Iraq to Syria, 250 MW export from Syria to Lebanon, 1,000 MW export from Syria to Jordan, 100 MW export from Jordan to Palestine, 500 MW export from Jordan to Egypt, 150 MW export from Egypt to Palestine and 100 MW export from Egypt to Libya. Lines are not loaded beyond their limits and voltage of busses is in the range of 0.9 pu and 1.1 pu in N-1 conditions for Summer Exchange Scenario.

TTC values in N condition and N-1 conditions for Summer Exchange Scenario are given in Table 41.

Table 41 TTC values in Base Case and contingency case for Summer Exchange Scenario

	Base Case (MW)	Contingency Case (MW)
Turkey to Syria	1,200	1,200
Turkey to Iraq	500	500
Iraq to Syria	900	500
Syria to Lebanon	250	250
Syria to Jordan	1,700	1,000
Jordan to Palestine	100	100
Jordan to Egypt	1,000	500
Egypt to Palestine	150	150
Egypt to Libya	1,000	100

Load flow analysis is conducted for validation of TTC values in N condition for Winter Exchange Scenario with 31,970 MW load for Egypt, 17,500 MW load for Iraq, 2,982.4 MW load for Jordan, 1,950 MW load for Lebanon, 7,700 MW load for Libya, 8,000 MW load for Syria, 250 MW load for Palestine and 900 MW export from Syria to Turkey, 500 MW export from Iraq to Turkey, 800 MW export from Syria to Iraq, 250 MW export from Syria to Lebanon, 900 MW export from Jordan to Syria, 100 MW export from Jordan to Palestine, 1,000 MW export from Egypt to Jordan, 150 MW export from Egypt to Palestine and 1,000 MW export from Libya to Egypt. Lines are not loaded beyond their limits and voltage of busses is in the range of 0.9 pu and 1.1 pu in N condition for Winter Exchange Scenario.

Load flow analysis is conducted for validation of TTC values in N-1 conditions for Winter Exchange Scenario with 31,970 MW load for Egypt, 17,500 MW load for Iraq, 2,982.4 MW load for Jordan, 1,950 MW load for Lebanon, 7,700 MW load for Libya, 8,000 MW load for Syria, 250 MW load for Palestine and 700 MW export from Syria to Turkey, 100 MW export from Iraq to Turkey, 400 MW export from Syria to Iraq, 250 MW export from Syria to Lebanon, 700 MW export from Jordan to Syria, 100 MW export from Jordan to Palestine, 500 MW export from Egypt to Jordan, 150 MW export from Egypt to Palestine and 400 MW export from Libya to

Egypt. Lines are not loaded beyond their limits and voltage of busses is in the range of 0.9 pu and 1.1 pu in N-1 conditions for Winter Exchange Scenario.

TTC values in N condition and N-1 conditions for Winter Exchange Scenario are given in Table 42.

Table 42 TTC values in Base Case and contingency case for Winter Exchange Scenario

	Base Case (MW)	Contingency Case (MW)
Syria to Turkey	900	700
Iraq to Turkey	500	100
Syria to Iraq	800	400
Syria to Lebanon	250	250
Jordan to Syria	900	700
Jordan to Palestine	100	100
Egypt to Jordan	1,000	500
Egypt to Palestine	150	150
Libya to Egypt	1,000	400

TTC calculation process which is explained in section 3.3 states that calculated TTC values would not create security violation in transmission network. Limiting factors and cases for transfer capacities are indicated in sections 3.3.1 and 3.3.2, and TTC values which could be realized in secure manner are stated in section 3.3.3 for Summer and Winter Exchange Scenario N-1 conditions. TTC values for Summer and Winter Exchange Scenario N-1 conditions should be taken as main figures for exchange programs between countries. To reach TTC values for Summer and Winter Exchange Scenario N conditions requires additional activities. TTC values which are stated for Summer and Winter Exchange Scenario N-1 conditions could be increased by realizing transmission investments which would overcome to limiting factors and cases. TTC values which are stated for Summer and Winter Exchange Scenario N-1 conditions could also be increased by using special protection systems (SPS) which operate when limiting factors and cases occur in networks. SPS could bring the network to a secure operation state by taking measures to reduce loading of network elements when limiting factors and cases occur in networks. When there is no incident in networks, TTC values for Summer and Winter Exchange Scenario N conditions could be realized with presence of SPS. When incidents occur in networks, SPS would operate, and transfer values between countries would be reduced to a secure level.

CHAPTER 4

SHORT CIRCUIT ANALYSIS ON EIJLLPST POWER SYSTEM DATA

Interconnection of power systems increase installed capacity of power systems and this result in increase of the short circuit current values. To observe the impact of interconnections on short circuit current values, maximum short circuit values of the EIJLLPST power system and short circuit values of substations to which interconnection lines are connected are calculated. Static power system data used in load flow analysis are also used in short circuit calculation. PSS/E software is utilized for short circuit calculations.

First, short circuit calculation is conducted when interconnection lines are out of service and bus bars with maximum short circuit values are obtained for 2015 maximum load condition (summer). Then short circuit calculation is conducted for summer and winter exchange scenarios (year 2015) with interconnection lines in service and bus bars with maximum short circuit values are obtained for summer and winter exchange scenario. Results of the short circuit calculation for maximum short circuit values are given in Table 43.

When interconnection lines are in service, increase in short circuit values are observed in general. However values of increase are not significant. In some cases short circuit values decrease because of generation change according to import-export values and directions.

Table 43 Maximum short circuit MVA values observed on EIJLLPST power system

	Without interconnection lines	Summer Exchange Case	Winter Exchange Case
	Libya	Libya	Libya
Voltage Level	400 kV	400 kV	400 kV
Bus bar no	40036	40036	40036
Three Phase (MVA)	20,021.47	19,989.20	20,029.96
Three Phase (A)	28,898.5	28,851.9	28,910.8
	Egypt	Egypt	Egypt
Voltage Level	500 kV	500 kV	500 kV
Bus bar no	30004	30004	30004
Three Phase (MVA)	33,985.15	34,012.10	33,881.36
Three Phase (A)	39,242.7	39,273.8	39,122.8
	Jordan	Jordan	Jordan
Voltage Level	400 kV	400 kV	400 kV
Bus bar no	50208	50208	50208
Three Phase (MVA)	9,099.81	13,199.91	13,216.84
Three Phase (A)	13,134.4	19,052.4	19,076.9
	Syria	Syria	Syria
Voltage Level	400 kV	400 kV	400 kV
Bus bar no	55291	55291	55290
Three Phase (MVA)	13,766.94	14,613.23	14,663.40
Three Phase (A)	19,870.9	21,092.4	21,164.8
	Iraq	Iraq	Iraq
Voltage Level	400 kV	400 kV	400 kV
Bus bar no	27402	27402	27402
Three Phase (MVA)	28,899.34	28,899.31	28,899.35
Three Phase (A)	41,712.6	41,712.6	41,712.6
	Lebanon	Lebanon	Lebanon
Voltage Level	220 kV	220 kV	220 kV
Bus bar no	61003	61003	61003
Three Phase (MVA)	6,864.91	7,386.42	7,379.76
Three Phase (A)	18,015.7	19,384.3	19,366.8

Short circuit calculation is conducted when interconnection lines are out of service and short circuit MVA values are obtained for substations to which interconnection lines are connected. Then short circuit calculation is repeated for summer and winter exchange scenarios as well with interconnection lines in service. Results of the short circuit calculation for substations to which interconnection lines are connected are given in Table 44.

Table 44 Short circuit MVA values of substations to which interconnection lines are connected

	Without interconnection lines			Summer Exchange Case			Winter Exchange Case		
	Libya (Libya-Egypt)			Libya (Libya-Egypt)			Libya (Libya-Egypt)		
Voltage Level	500 kV	400 kV	220 kV	500 kV	400 kV	220 kV	500 kV	400 kV	220 kV
Bus bar no	40000	40254	40264	40000	40254	40264	40000	40254	40264
Three Phase (MVA)	2,894.69	5,015.23	4,384.88	4,330.95	5,829.42	5,085.51	4,169.03	5,983.11	5,139.95
Three Phase (A)	3,342.5	7,238.9	11,507.3	5,000.9	8,414.0	13,346.0	4,814.0	8,635.9	13,488.9
	Egypt (Libya-Egypt)			Egypt (Libya-Egypt)			Egypt (Libya-Egypt)		
Voltage Level	500 kV	220 kV		500 kV	220 kV		500 kV	220 kV	
Bus bar no	31642	30511		31642	30511		31642	30511	
Three Phase (MVA)	2,072.68	1,608.20		3,923.83	2,951.17		3,971.59	2,948.33	
Three Phase (A)	2,393.3	4,220.4		4,530.8	7,744.8		4,586.0	7,737.4	
	Egypt (Egypt-Jordan)			Egypt (Egypt-Jordan)			Egypt (Egypt-Jordan)		
Voltage Level	500 kV	400 kV		500 kV	400 kV		500 kV	400 kV	
Bus bar no	30012	30013		30012	30013		30012	30013	
Three Phase (MVA)	4,728.66	3,002.08		7,443.04	7,045.51		7,120.74	6,968.98	
Three Phase (A)	5,460.2	4,333.1		8,594.5	10,169.3		8,222.3	10,058.9	
	Jordan (Egypt-Jordan)			Jordan (Egypt-Jordan)			Jordan (Egypt-Jordan)		
Voltage Level	400 kV			400 kV			400 kV		
Bus bar no	50170			50170			50170		
Three Phase (MVA)	6,144.62			8,969.36			8,979.85		
Three Phase (A)	8,869.0			12,946.2			12,961.3		
	Jordan (Syria-Jordan)			Jordan (Syria-Jordan)			Jordan (Syria-Jordan)		
Voltage Level	400 kV	400 kV		400 kV	400 kV		400 kV	400 kV	
Bus bar no	50184	50208		50184	50208		50184	50208	
Three Phase (MVA)	8,941.21	9,099.82		13,000.20	13,199.91		13,017.39	13,216.84	
Three Phase (A)	12,905.5	13,134.5		18,764.2	19,052.4		18,789.0	19,076.9	
	Syria (Syria-Jordan)			Syria (Syria-Jordan)			Syria (Syria-Jordan)		
Voltage Level	400 kV			400 kV			400 kV		
Bus bar no	55290			55290			55290		
Three Phase (MVA)	10,579.83			14,592.46			14,663.40		
Three Phase (A)	15,270.7			21,062.4			21,164.8		

Table 44 (continued)

	Without interconnection lines			Summer Exchange Case			Winter Exchange Case		
	Syria (Syria-Iraq)			Syria (Syria-Iraq)			Syria (Syria-Iraq)		
Voltage Level	400 kV			400 kV			400 kV		
Bus bar no	55302			55302			55302		
Three Phase (MVA)	3,230.70			4,932.32			4,797.28		
Three Phase (A)	4,663.1			7,119.2			6,924.3		
	Syria (Syria-Lebanon)			Syria (Syria-Lebanon)			Syria (Syria-Lebanon)		
Voltage Level	400 kV			400 kV			400 kV		
Bus bar no	55289			55289			55289		
Three Phase (MVA)	10,624.38			12,876.38			12,887.55		
Three Phase (A)	15,335.0			18,585.5			18,601.6		
	Syria (Syria-Turkey)			Syria (Syria-Turkey)			Syria (Syria-Turkey)		
Voltage Level	400 kV			400 kV			400 kV		
Bus bar no	55300			55300			55300		
Three Phase (MVA)	8,288.54			8,362.28			8,389.95		
Three Phase (A)	11,963.5			12,069.9			12,109.8		
	Iraq (Syria-Iraq)			Iraq (Syria-Iraq)			Iraq (Syria-Iraq)		
Voltage Level	400 kV			400 kV			400 kV		
Bus bar no	19411			19411			19411		
Three Phase (MVA)	5,446.41			6,738.06			6,758.68		
Three Phase (A)	7,861.2			9,725.6			9,755.3		
	Iraq (Iraq-Turkey)			Iraq (Iraq-Turkey)			Iraq (Iraq-Turkey)		
Voltage Level	400 kV			400 kV			400 kV		
Bus bar no	11420			11420			11420		
Three Phase (MVA)	10,769.48			10,705.68			10,777.87		
Three Phase (A)	15,544.4			15,452.3			15,556.5		
	Lebanon (Syria-Lebanon)			Lebanon (Syria-Lebanon)			Lebanon (Syria-Lebanon)		
Voltage Level	400 kV	220 kV		400 kV	220 kV		400 kV	220 kV	
Bus bar no	61000	61001		61000	61001		61000	61001	
Three Phase (MVA)	1,245.62	3,616.85		8,742.29	5,121.85		8,743.31	5,119.40	
Three Phase (A)	1,797.9	9,491.8		12,618.4	13,441.4		12,619.9	13,434.9	

Results of short circuit current calculation indicate that short circuit current values of substations to which interconnection lines are connected increase when interconnection lines are in service. The increase in short circuit current values is within limits and there is no need to take any further action in terms of short circuit current values.

CHAPTER 5

TRANSIENT STABILITY ANALYSIS ON EIJLLPST POWER SYSTEM DATA

Transient stability analyses investigate the stability of power systems when a large disturbance occurs in the power system. Transient stability analyses focus on a few seconds after disturbance because loss of synchronism due to transient instability could be detected in that time interval [14]. Conducting transient stability analyses is required in interconnection studies, since dynamic behavior of power systems may be modified by interconnecting power systems [9]. In this chapter, transient stability of EIJLLPST power system is evaluated by applying three phase line faults on interconnection lines.

Dynamic data of EIJLLPST countries are needed for transient stability analyses in addition to the static data of EIJLLPST power system. Dynamic data include generator, exciter, and governor dynamic models of generating units of countries. Dynamic data of Egypt, Jordan, Libya and Syria are submitted by the representatives of those countries. Data required for dynamic analyses for Iraq and Lebanon were not available, hence they were assumed considering the data from actual plants of similar type and ratings. PSS/E software is used for transient stability analysis. Transient stability analysis is conducted on EIJLLPST power system data for the contingency case of both 2015 Summer Exchange Scenario and 2015 Winter Exchange Scenario. Transfer capacities and power flow directions for Summer

Exchange Scenario contingency case and Winter Exchange Scenario contingency case are given in Figure 30 and Figure 32, respectively.

In transient stability analyses, a three phase line fault is applied to interconnection lines between countries following 1 second of normal operation. Fault duration is assumed to be 120 ms. Fault is cleared after 120 ms and faulted line is taken out of service. After faulted line is out of service, simulation is continued up to 10 seconds. Rotor angles and active power flows through interconnection lines are observed.

To evaluate the stability of EIJLLPST power system, rotor angles of generation units from different countries are viewed. Rotor angle of the largest generation unit in each country is selected for graphical representations. Selected generation units are listed below:

- "GLF SG2 (bus bar no: 40380)" with 350 MW installed power for Libya,
- "KURM2 (bus bar no: 30741)" with 627 MW installed power for Egypt,
- "AME_1_S1 (bus bar no: 50335)" with 145 MW installed power for Jordan,
- "DIRALIG1 (bus bar no: 55077)" with 250 MW installed power for Syria,
- "ZBDP (bus bar no: 18401)" with 457,5 MW installed power for Iraq,
- "DEIA-GT1 (bus bar no: 61042)" with 172,8 MW installed power for Lebanon

Fault duration is increased to 300 ms in steps to observe the stability of EIJLLPST power system. Graphical results of transient analyses with 120 ms fault duration are given in following sections.

5.1 TRANSIENT STABILITY ANALYSES OF THE SUMMER EXCHANGE SCENARIO

Results of transient stability analyses which is conducted on EIJLLPST power system data for Summer Exchange Scenario contingency case are presented in this section. Analyses are conducted for faults listed below:

- A three phase line fault on Libya-Egypt 500 kV interconnection line
- A three phase line fault on Libya-Egypt 220 kV interconnection line (circuit 1)

- A three phase line fault on Egypt-Jordan 400 kV submarine cable (circuit 1)
- A three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 1)
- A three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 2)
- A three phase line fault on Syria-Lebanon 400 kV interconnection line (circuit 1)
- A three phase line fault on Syria-Iraq 400 kV interconnection line

5.1.1 LIBYA-EGYPT 500 kV INTERCONNECTION LINE

A three phase line fault is applied on Libya-Egypt 500 kV interconnection line with 120 ms fault duration to evaluate transient stability of EIJLLPST power system. The fault is applied to end point of the line in Egypt side. Rotor angles are given in Figure 33 and active power flow through Libya-Egypt interconnection lines are given in Figure 34 for three phase line fault on Libya-Egypt 500 kV interconnection line. EIJLLPST power system is stable when the three phase line fault is applied on Libya-Egypt 5000 kV interconnection line.

In order to investigate the impact of the clearing time of circuit breakers on stability transient stability analysis is repeated with 200 ms and 300 ms fault duration when a three phase line fault is applied on Libya-Egypt 500 kV interconnection line. Results of the transient stability analyses with 200 ms and 300 ms fault duration indicate that EIJLLPST power system is stable when three phase line fault is applied on Libya-Egypt 500 kV interconnection line for the clearing times investigated.

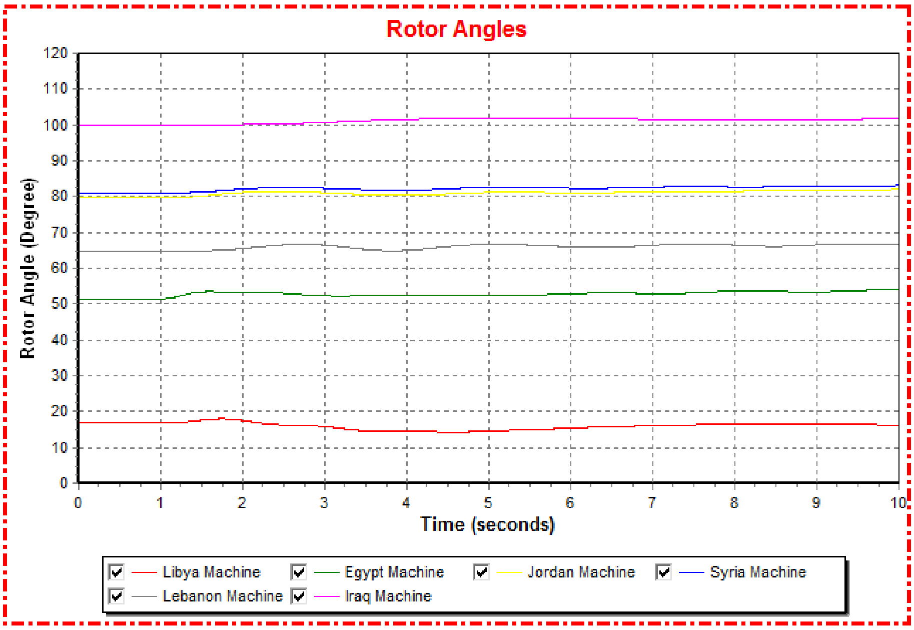

Figure 33 Rotor angles for a three phase line fault on Libya-Egypt 500 kV interconnection line

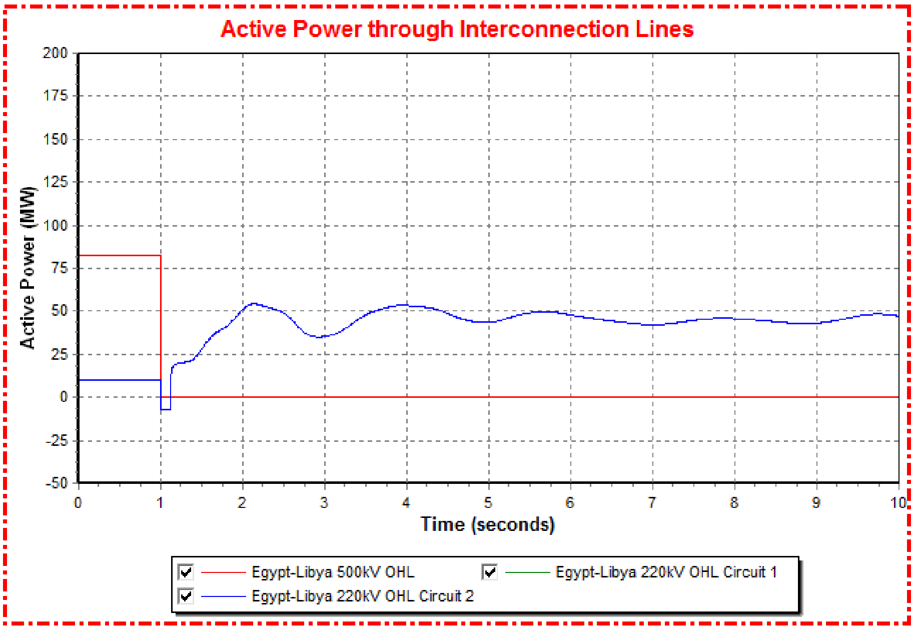

Figure 34 Active power through Libya-Egypt interconnection lines

5.1.2 LIBYA-EGYPT 220 kV INTERCONNECTION LINE (CIRCUIT 1)

There is a 220 kV double circuit OHL between Egypt and Libya. A three phase line fault is applied on Libya-Egypt 220 kV interconnection line (circuit 1) with 120 ms fault duration to evaluate transient stability of EIJLLPST power system. The fault is applied to end point of the line in Egypt side. Rotor angles are given in Figure 35 and active power flow through on Libya-Egypt interconnection lines are given in Figure 36 for three phase line faults on Libya-Egypt 220 kV interconnection line (circuit 1).

Results show that EIJLLPST power system is stable when a three phase line fault is applied on Libya-Egypt 220 kV interconnection line (circuit 1). Transient stability analysis is repeated with 200 ms and 300 ms fault durations to observe the stability of EIJLLPST power system with high fault duration when three phase line fault is applied on Libya-Egypt 220 kV interconnection line (circuit 1). Results of the transient stability analyses with 200 ms and 300 ms fault duration indicate that EIJLLPST power system is stable when three phase line fault is applied on Libya-Egypt 220 kV interconnection line (circuit 1).

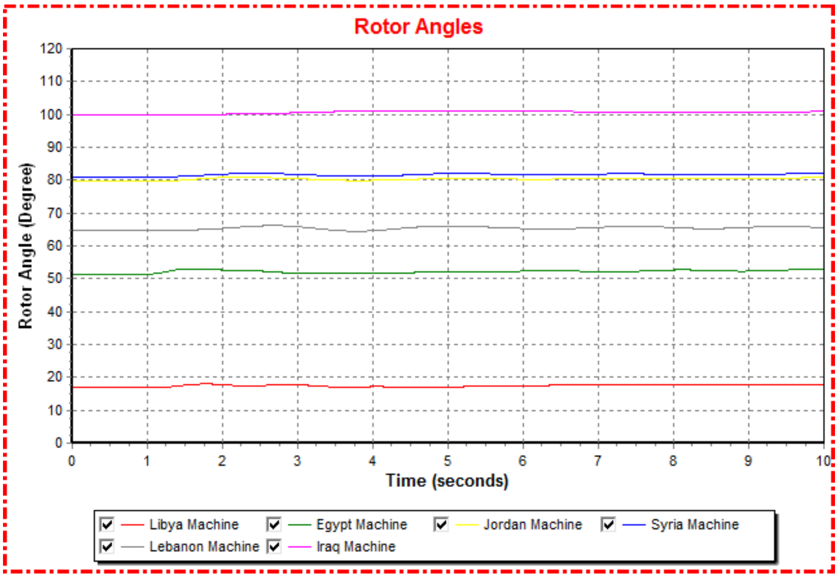

Figure 35 Rotor angles for a three phase line fault on Libya-Egypt 220 kV interconnection line (circuit 1)

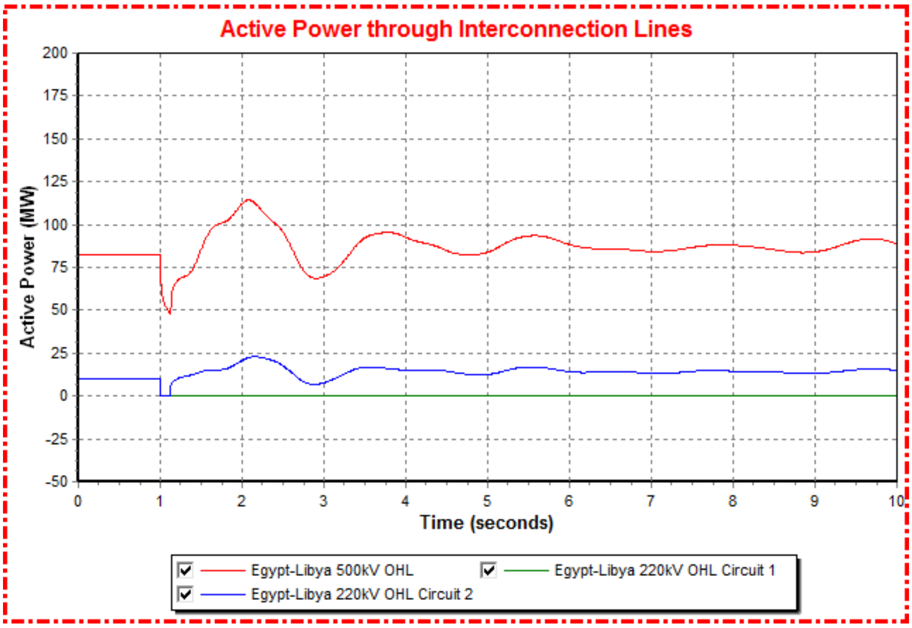

Figure 36 Active power through Libya-Egypt interconnection lines

5.1.3 EGYPT-JORDAN 400 kV SUBMARINE CABLE (CIRCUIT 1)

Transient stability analysis is conducted on EIJLLPST power system data by applying a three phase line fault to Egypt-Jordan 400 kV submarine cable (circuit 1) with 120 ms fault duration. The fault is applied to the end point of the cable at Egypt side.

Rotor angles obtained from computer simulations are given in Figure 37 and active power flow through Egypt-Jordan interconnection lines are given in Figure 38. Results of the transient analysis indicate that EIJLLPST power system is stable when a three phase line fault is applied on Egypt-Jordan 400 kV submarine cable (circuit 1) with 120 ms fault duration. Transient stability analyses are also repeated with 200 ms and 300 ms fault durations for a three phase line fault on Egypt-Jordan 400 kV submarine cable (circuit 1). EIJLLPST power system is also stable when the three phase line fault applied on Egypt-Jordan 400 kV submarine cable (circuit 1) with higher fault durations.

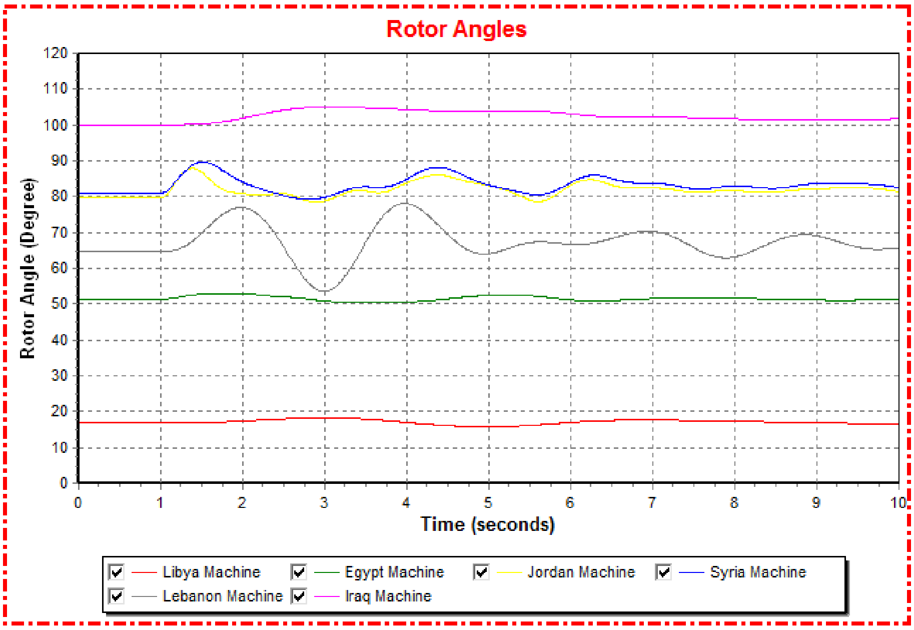

Figure 37 Rotor angles for a three phase line fault on Egypt-Jordan 400 kV submarine cable (circuit 1)

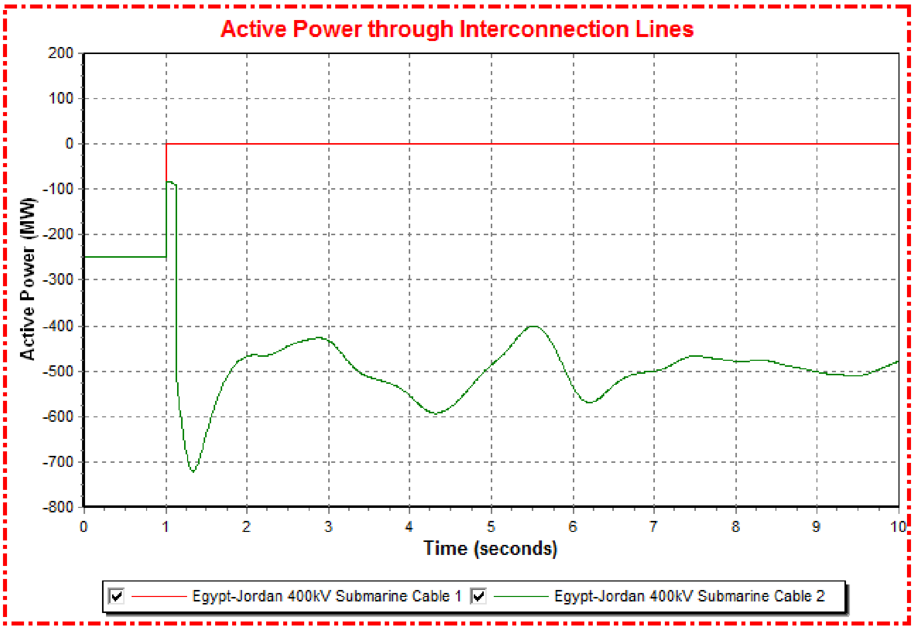

Figure 38 Active power through Egypt-Jordan interconnection lines

5.1.4 JORDAN-SYRIA 400 kV INTERCONNECTION LINE (CIRCUIT 1)

There are two 400 kV single circuit OHLs between Jordan and Syria. A three phase line fault is applied on Jordan-Syria 400 kV interconnection line (circuit 1) with 120 ms fault duration to evaluate the transient stability of EIJLLPST power system. The fault is applied to the end point of the line at Jordan side. Rotor angles are given in Figure 39 and active power flows through Jordan-Syria interconnection lines are given in Figure 40 for a three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 1). EIJLLPST power system is found to be stable when the three phase line fault applied on Jordan-Syria 400 kV interconnection line (circuit 1) with 120 ms fault duration.

Results of the transient stability analysis with 200 ms and 300 ms fault duration for a three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 1) indicate that EIJLLPST power system is stable for this disturbance with 200 ms fault duration. However, EIJLLPST power system is observed to be unstable for a three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 1) with 300 ms fault duration.

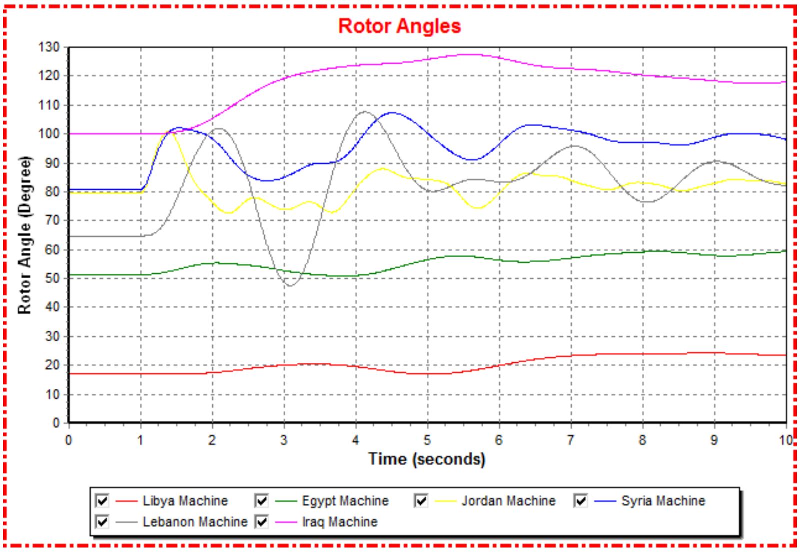

Figure 39 Rotor angles for a three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 1)

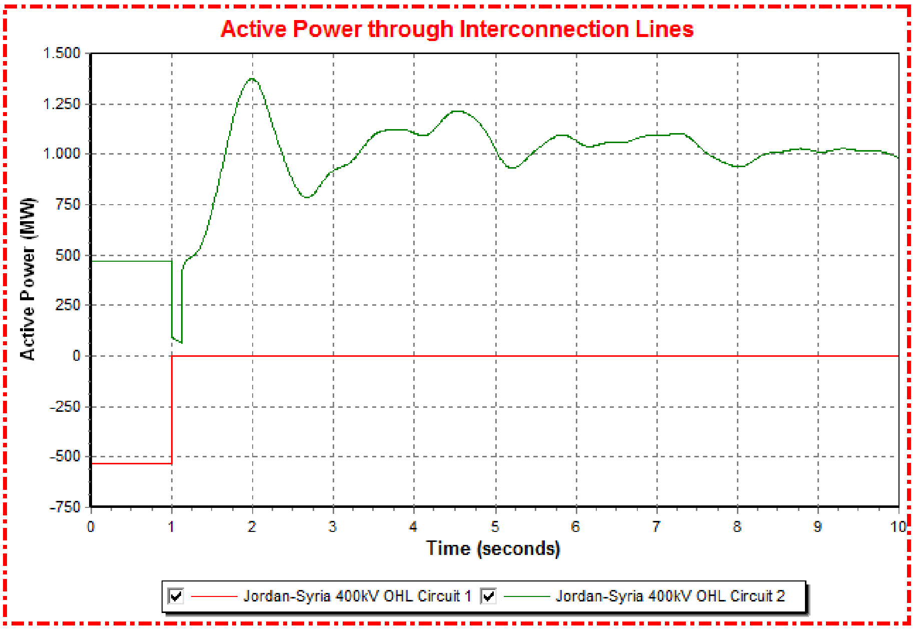

Figure 40 Active power through Jordan-Syria interconnection lines

5.1.5 JORDAN-SYRIA 400 KV INTERCONNECTION LINE (CIRCUIT 2)

A three phase line fault is applied on Jordan-Syria 400 kV interconnection line (circuit 2) with 120 ms fault duration to evaluate the transient stability of EIJLLPST power system. The fault is applied to the end point of the line at Jordan side. Rotor angles are given in Figure 41 and active power flow through Jordan-Syria interconnection lines are given in Figure 42 for three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 2).

EIJLLPST power system is observed to be stable when the three phase line fault applied on Jordan-Syria 400 kV interconnection line (circuit 2) with 120 ms fault duration. Transient stability analyses with 200 ms and 300 ms fault duration indicate that EIJLLPST power system is stable when the three phase line fault applied on Jordan-Syria 400 kV interconnection line (circuit 2).

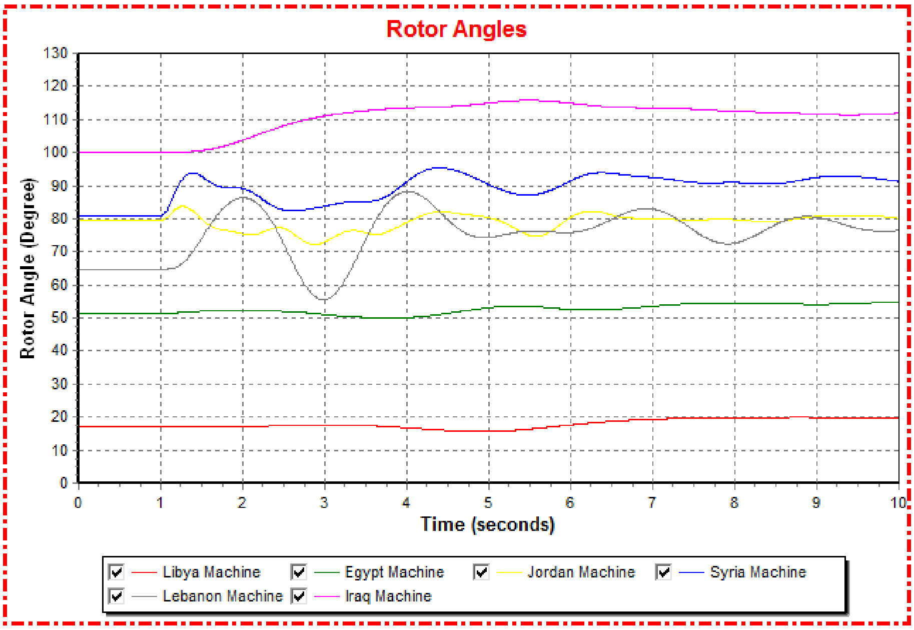

Figure 41 Rotor angles for a three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 2)

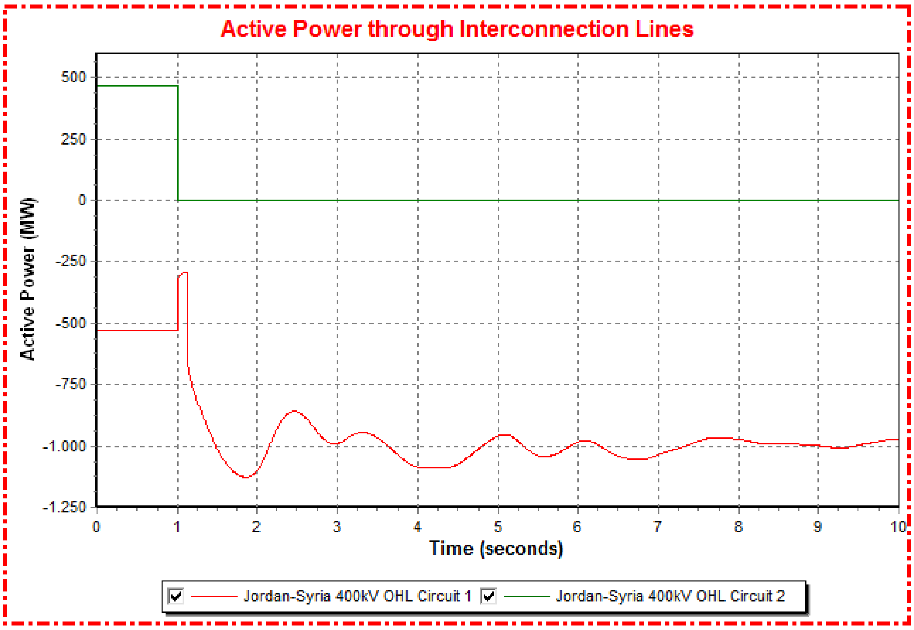

Figure 42 Active power through Jordan-Syria interconnection lines

5.1.6 SYRIA-LEBANON 400 KV INTERCONNECTION LINE (CIRCUIT 1)

Transient stability analysis is conducted on EIJLLPST power system data by applying a three phase line fault to Syria-Lebanon 400 kV interconnection line (circuit 1) with 120 ms fault duration. The fault is applied to the end point of the line at Syria side. Variation of rotor angles and active power flow through Syria-Lebanon interconnection lines for this fault are obtained from computer simulations and are shown in Figure 43 and Figure 44. EIJLLPST power system is stable when the three phase line fault applied on Syria-Lebanon 400 kV interconnection line (circuit 1) with 120 ms fault duration.

Transient stability analyses are repeated with 200 ms and 300 ms fault duration for a three phase line fault on Syria-Lebanon 400 kV interconnection line (circuit 1). EIJLLPST power system is found to be stable when the three phase line fault applied on Syria-Lebanon 400 kV interconnection line (circuit 1) with 200 ms fault duration. Results show that EIJLLPST power system is not stable for a three phase line fault on Syria-Lebanon 400 kV interconnection line (circuit 1) with 300 ms fault duration.

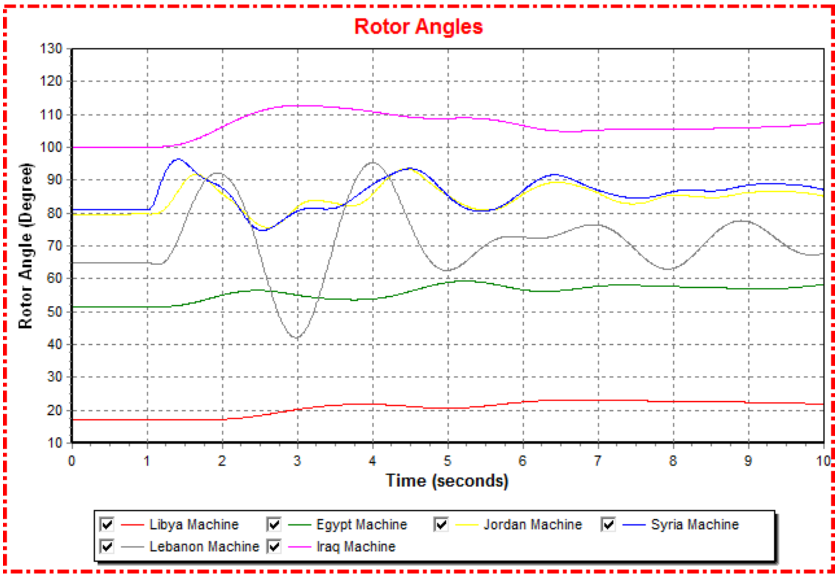

Figure 43 Rotor angles for a three phase line fault on Syria-Lebanon 400 kV interconnection line (circuit 1)

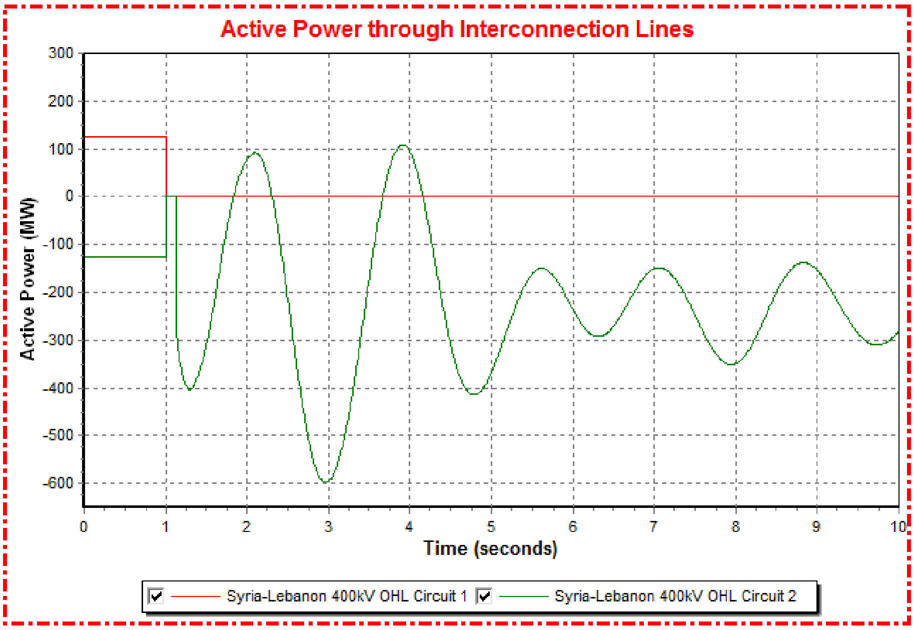

Figure 44 Active power through Syria-Lebanon interconnection lines

5.1.7 SYRIA-IRAQ 400 kV INTERCONNECTION LINE

There is only one 400 kV single circuit OHLs between Syria and Iraq. A three phase line fault is applied on Syria-Iraq 400 kV interconnection line with 120 ms fault duration to evaluate transient stability of EIJLLPST power system. The fault is applied to end point of the line in Iraq side.

Rotor angles are given in Figure 45 and active power flow through Syria-Iraq interconnection line are given in Figure 46 for three phase line fault Syria-Iraq 400 kV interconnection line. Iraq network is connected to the rest of the EIJLLPST power system through only Syria-Iraq 400 kV interconnection line. When the Syria-Iraq 400 kV interconnection line is taken out of service, Iraq network is separated from the EIJLLPST power system.

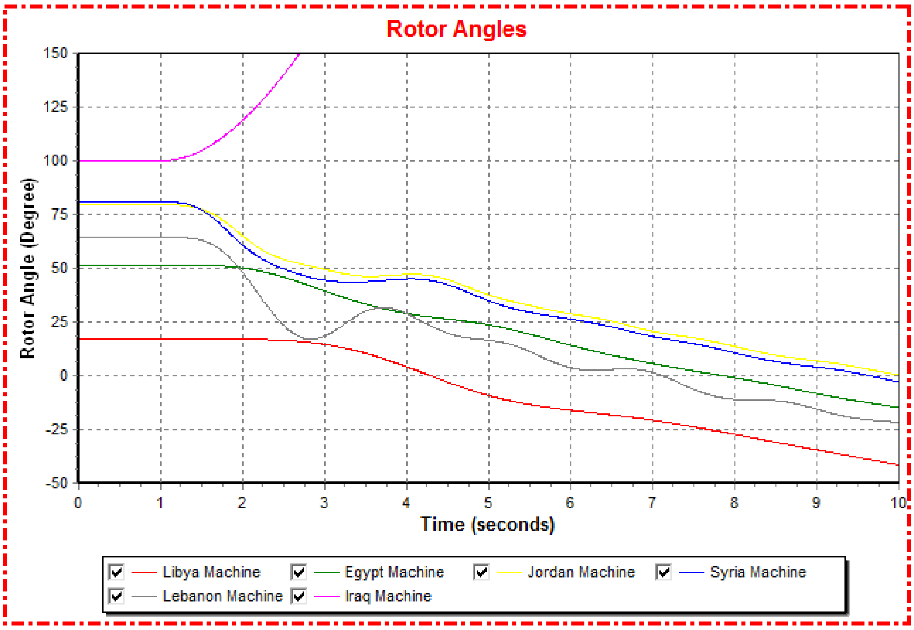

Figure 45 Rotor angles for a three phase line fault on Syria-Iraq 400 kV interconnection line

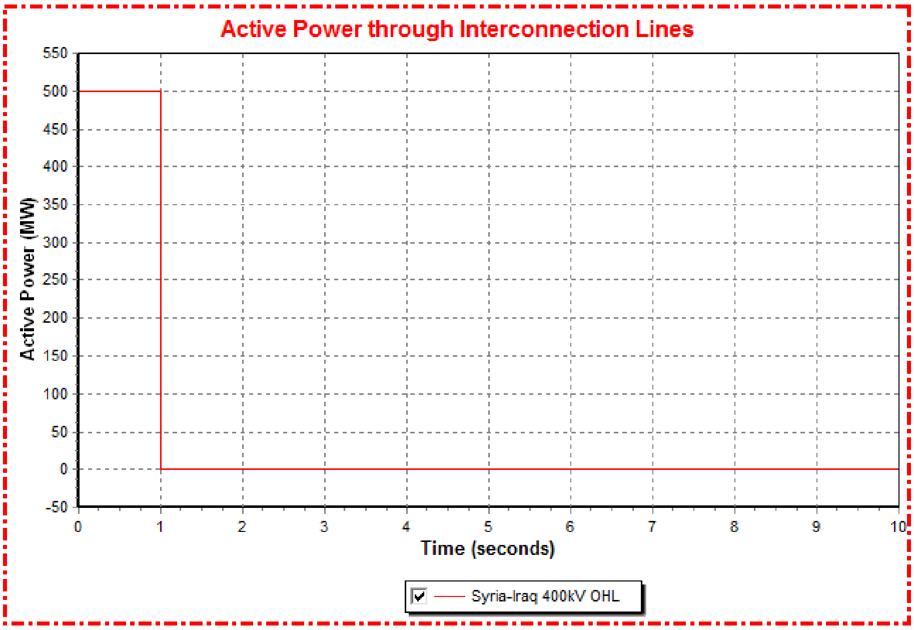

Figure 46 Active power through Syria-Iraq interconnection line

5.2 TRANSIENT STABILITY ANALYSES OF THE WINTER EXCHANGE SCENARIO

Results of transient stability analyses which is conducted on EIJLLPST power system data for Winter Exchange Scenario contingency case are presented in this section. Analyses are conducted for faults listed below:

- A three phase line fault on Libya-Egypt 500 kV interconnection line
- A three phase line fault on Libya-Egypt 220 kV interconnection line (circuit 1)
- A three phase line fault on Egypt-Jordan 400 kV submarine cable (circuit 1)
- A three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 1)
- A three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 2)
- A three phase line fault on Syria-Lebanon 400 kV interconnection line (circuit 1)
- A three phase line fault on Syria-Iraq 400 kV interconnection line

5.2.1 LIBYA-EGYPT 500 kV INTERCONNECTION LINE

A three phase line fault is applied on Libya-Egypt 500 kV interconnection line with 120 ms fault duration to evaluate transient stability of EIJLLPST power system. The fault is applied to end point of the line in Egypt side. Rotor angles are given in Figure 47 and active power flow through Libya-Egypt interconnection lines are given in Figure 48 for three phase line fault on Libya-Egypt 500 kV interconnection line. EIJLLPST power system is stable when the three phase line fault is applied on Libya-Egypt 500 kV interconnection line.

Transient stability analysis is repeated for 200 ms and 300 ms fault durations to observe the stability of EIJLLPST power system with high fault durations when a three phase line fault is applied on Libya-Egypt 500 kV interconnection line. Results of the transient stability analyses with 200 ms and 300 ms fault durations indicate that EIJLLPST power system is stable for the specified disturbance and fault clearing times.

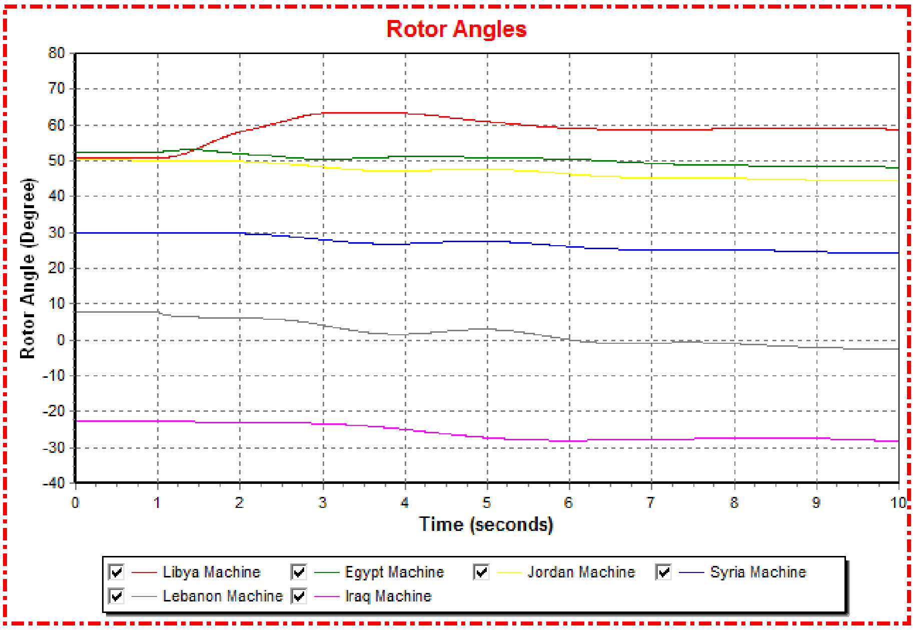

Figure 47 Rotor angles for three phase line fault on Libya-Egypt 500 kV interconnection line

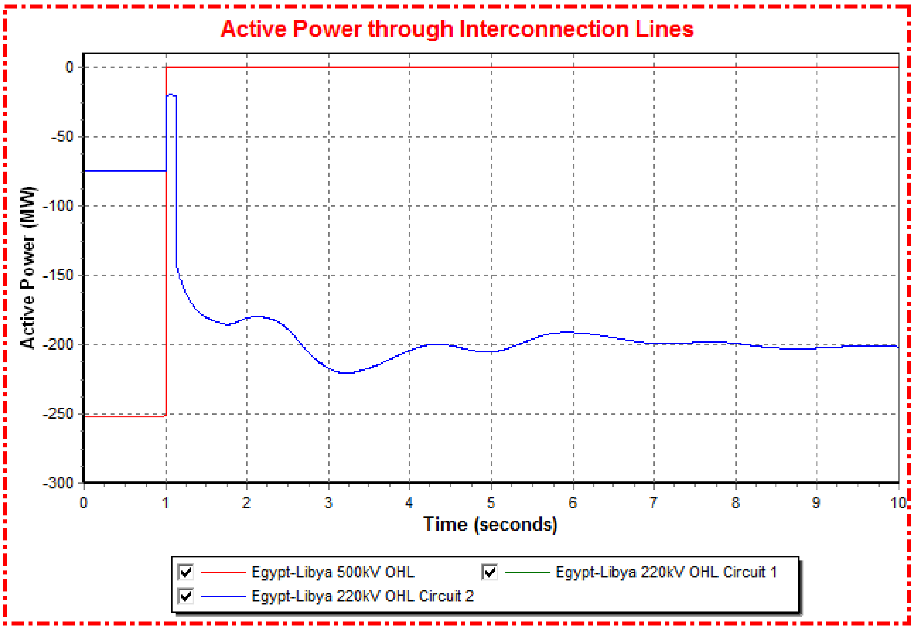

Figure 48 Active power through Libya-Egypt interconnection lines

5.2.2 LIBYA-EGYPT 220 kV INTERCONNECTION LINE (CIRCUIT 1)

There is a 220 kV double circuit OHL between Egypt and Libya. A three phase line fault is applied on Libya-Egypt 220 kV interconnection line (circuit 1) with 120 ms fault duration to evaluate transient stability of EIJLLPST power system. The fault is applied to end point of the line in Egypt side. Rotor angles are given in Figure 49 and active power flow through Libya-Egypt interconnection lines are given in Figure 50 for three phase line faults on Libya-Egypt 220 kV interconnection line (circuit 1).

In order to investigate the impact of the clearing time of circuit breakers on stability transient stability analysis is repeated with 200 ms and 300 ms fault duration when a three phase line fault is applied on Libya-Egypt 220 kV interconnection line (circuit 1). Results of the transient stability analyses with 200 ms and 300 ms fault duration indicate that EIJLLPST power system is stable if a three phase line fault is occurs on Libya-Egypt 220 kV interconnection line (circuit 1).

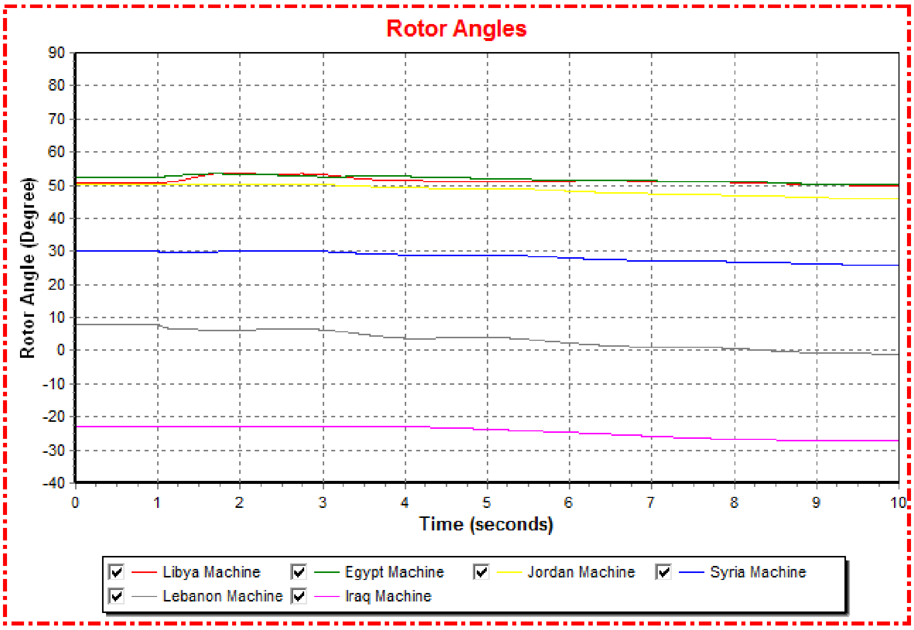

Figure 49 Rotor angles for three phase line fault on Libya-Egypt 220 kV interconnection line (circuit 1)

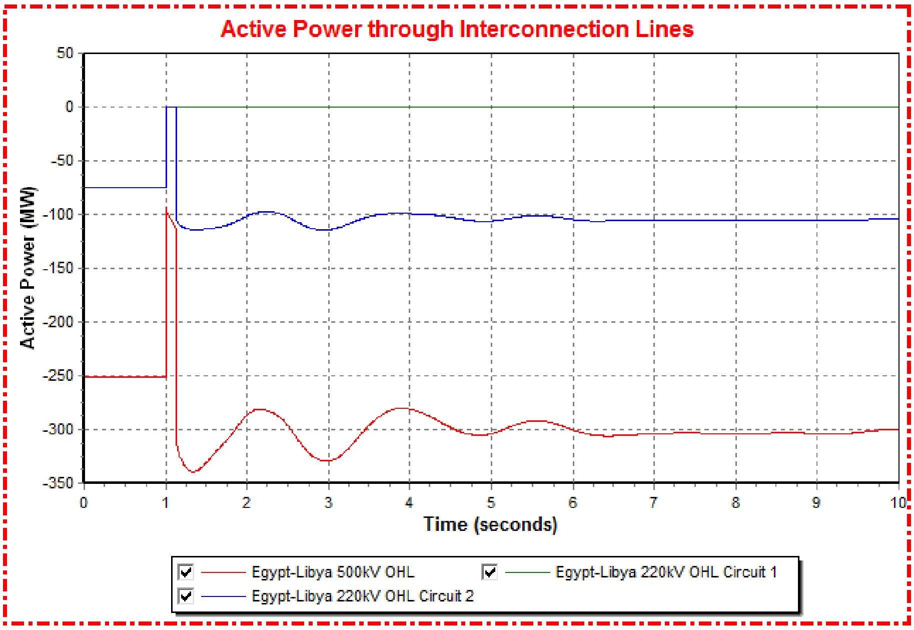

Figure 50 Active power through Libya-Egypt interconnection lines

5.2.3 EGYPT-JORDAN 400 kV SUBMARINE CABLE (CIRCUIT 1)

Transient stability analysis is conducted on EIJLLPST power system data by applying a three phase line fault to Egypt-Jordan 400 kV submarine cable (circuit 1) with 120 ms fault duration. The fault is applied to end point of the cable in Egypt side. Rotor angles are given in Figure 51 and active power flow through Egypt-Jordan interconnection lines are given in Figure 52 for a three phase line fault on Egypt-Jordan 400 kV submarine cable (circuit 1).

Results of the transient stability analysis indicate that EIJLLPST power system is stable when a three phase line fault applied on Egypt-Jordan 400 kV submarine cable (circuit 1) with 120 ms fault duration. Transient stability analyses are conducted with 200 ms and 300 ms fault durations for three phase line fault on Egypt-Jordan 400 kV submarine cable (circuit 1). EIJLLPST power system is also stable when the three phase line fault applied on Egypt-Jordan 400 kV submarine cable (circuit 1) with higher fault duration.

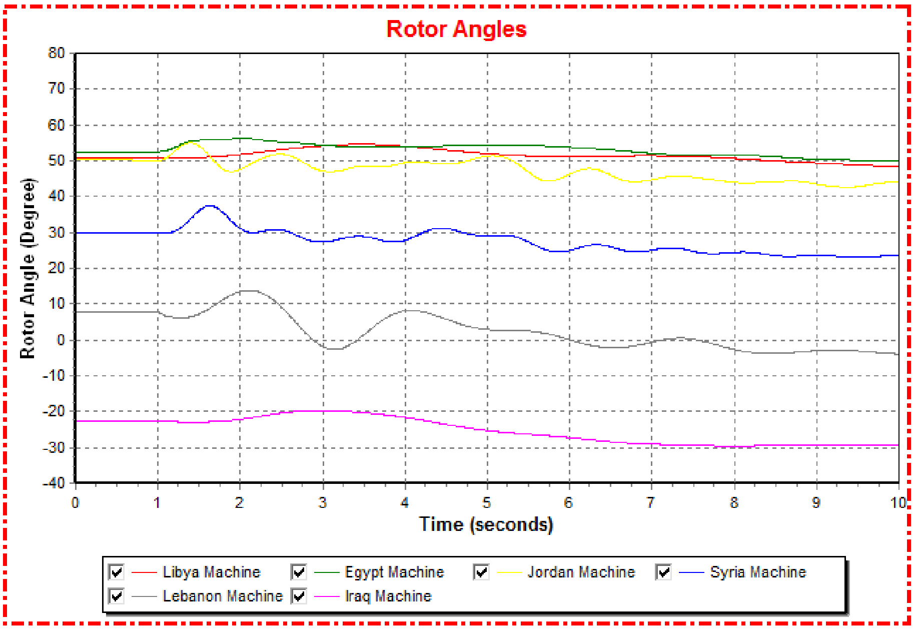

Figure 51 Rotor angles for three phase line fault on Egypt-Jordan 400 kV submarine cable (circuit 1)

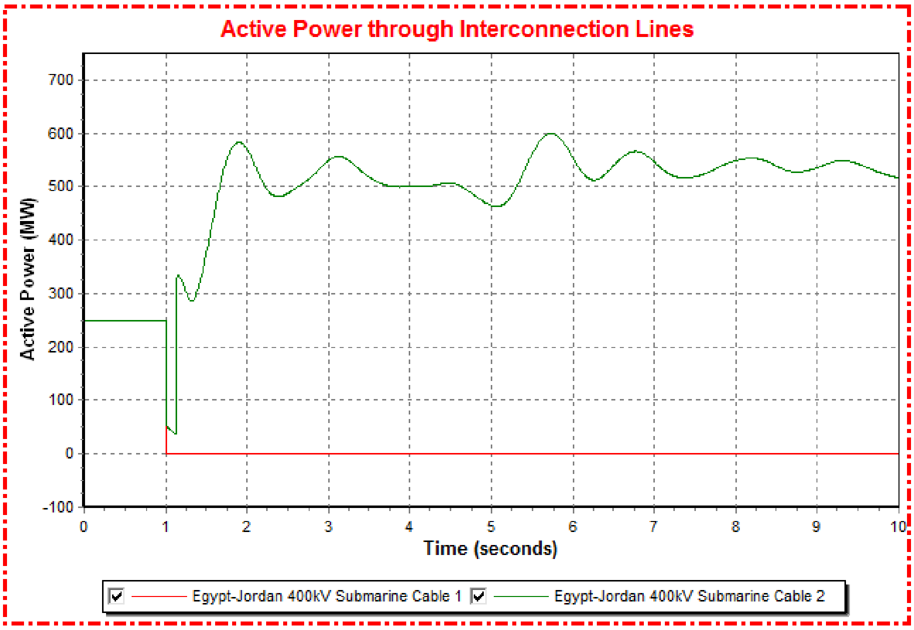

Figure 52 Active power through Egypt-Jordan interconnection lines

5.2.4 JORDAN-SYRIA 400 KV INTERCONNECTION LINE (CIRCUIT 1)

There are two 400 kV single circuit OHLs between Jordan and Syria. A three phase line fault is applied on Jordan-Syria 400 kV interconnection line (circuit 1) with 120 ms fault duration to evaluate transient stability of EIJLLPST power system. The fault is applied to end point of the line in Jordan side. Rotor angles are given in Figure 53 and active power flow through Jordan-Syria interconnection lines are given in Figure 54 for three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 1). EIJLLPST power system is stable when a three phase line fault applied on Jordan-Syria 400 kV interconnection line (circuit 1) with 120 ms fault duration.

Result of the transient stability analysis with 200 ms fault duration for a three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 1) states that EIJLLPST power system is not stable for this disturbance.

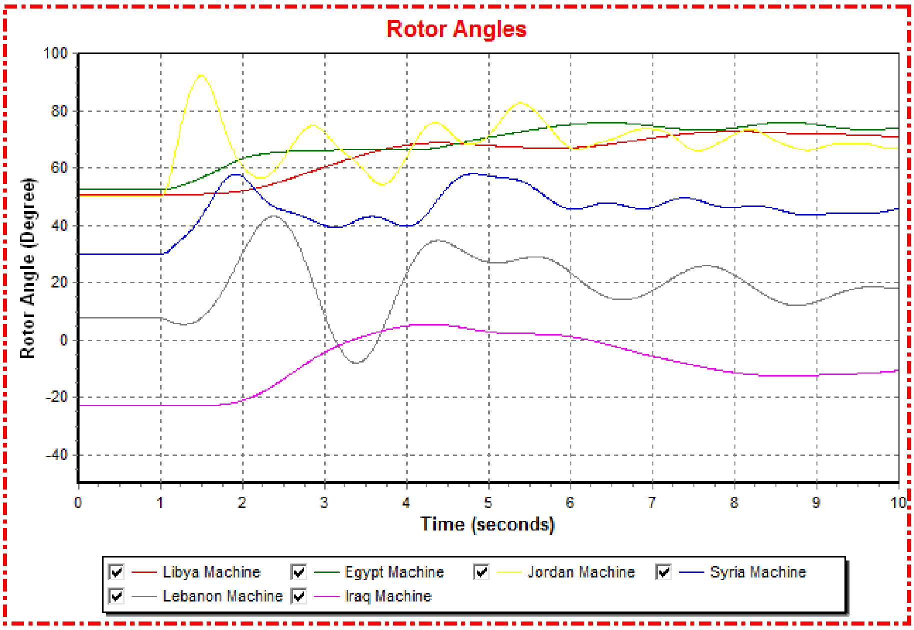

Figure 53 Rotor angles for three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 1)

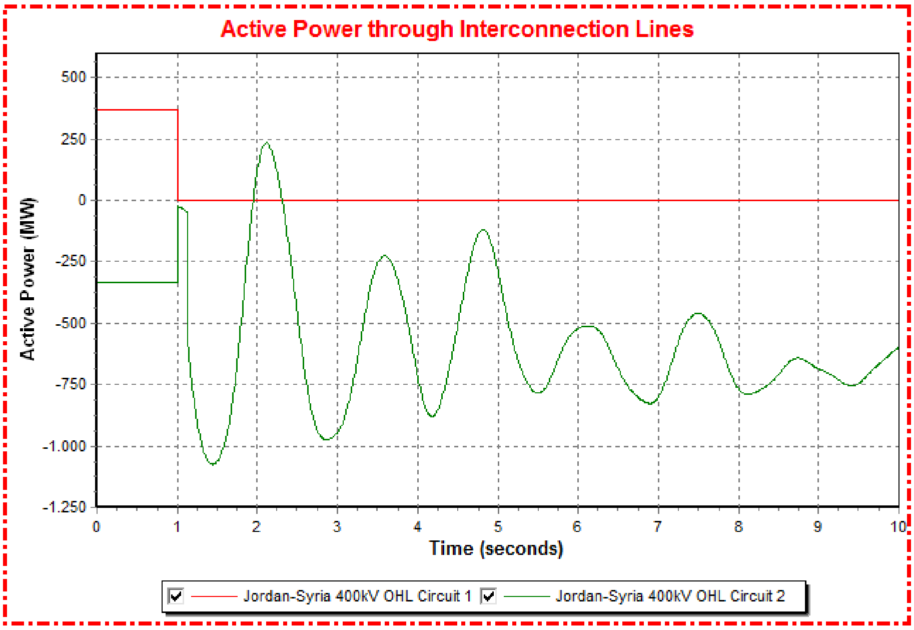

Figure 54 Active power through Jordan-Syria interconnection lines

5.2.5 JORDAN-SYRIA 400 KV INTERCONNECTION LINE (CIRCUIT 2)

A three phase line fault is applied on Jordan-Syria 400 kV interconnection line (circuit 2) with 120 ms fault duration to evaluate transient stability of EIJLLPST power system. The fault is applied to end point of the line in Jordan side. Rotor angles are given in Figure 55 and active power flow through Jordan-Syria interconnection lines are given in Figure 56 for a three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 2).

EIJLLPST power system is stable when a three phase line fault applied on Jordan-Syria 400 kV interconnection line (circuit 2) with 120 ms fault duration. Results of the transient stability analysis with 200 ms and 300 ms fault durations for a three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 2) state that EIJLLPST power system is stable for this disturbance with 200 ms fault duration. However, EIJLLPST power system is not stable for a three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 2) with 300 ms fault duration.

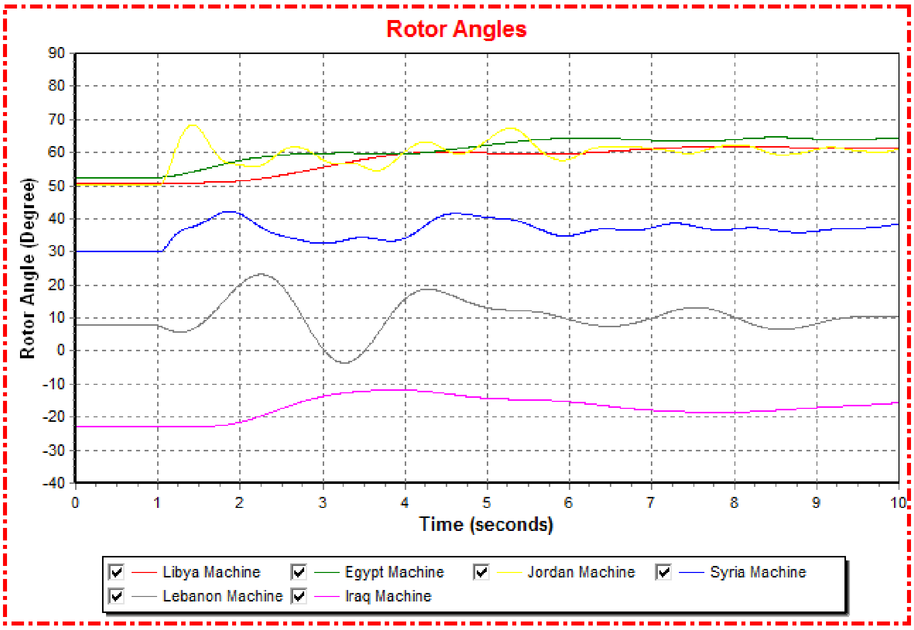

Figure 55 Rotor angles for three phase line fault on Jordan-Syria 400 kV interconnection line (circuit 2)

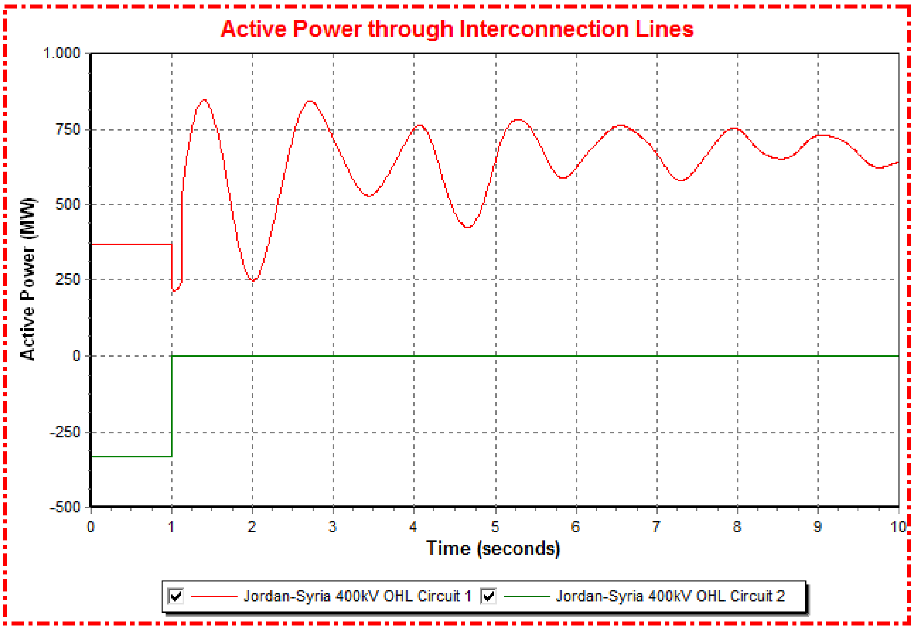

Figure 56 Active power through Jordan-Syria interconnection lines

5.2.6 SYRIA-LEBANON 400 KV INTERCONNECTION LINE (CIRCUIT 1)

Transient stability analysis is conducted on EIJLLPST power system data by applying a three phase line fault to Syria-Lebanon 400 kV interconnection line (circuit 1) with 120 ms fault duration. The fault is applied to end point of the line in Syria side. Rotor angles are given in Figure 57 and active power flow through Syria-Lebanon interconnection lines are given in Figure 58 for three phase line fault on Syria-Lebanon 400 kV interconnection line (circuit 1). EIJLLPST power system is stable when a three phase line fault applied on Syria-Lebanon 400 kV interconnection line (circuit 1) with 120 ms fault duration.

Transient stability analyses are conducted with 200 ms fault duration for a three phase line fault on Syria-Lebanon 400 kV interconnection line (circuit 1). EIJLLPST power system is not stable when a three phase line fault applied on Syria-Lebanon 400 kV interconnection line (circuit 1) with 200 ms fault duration.

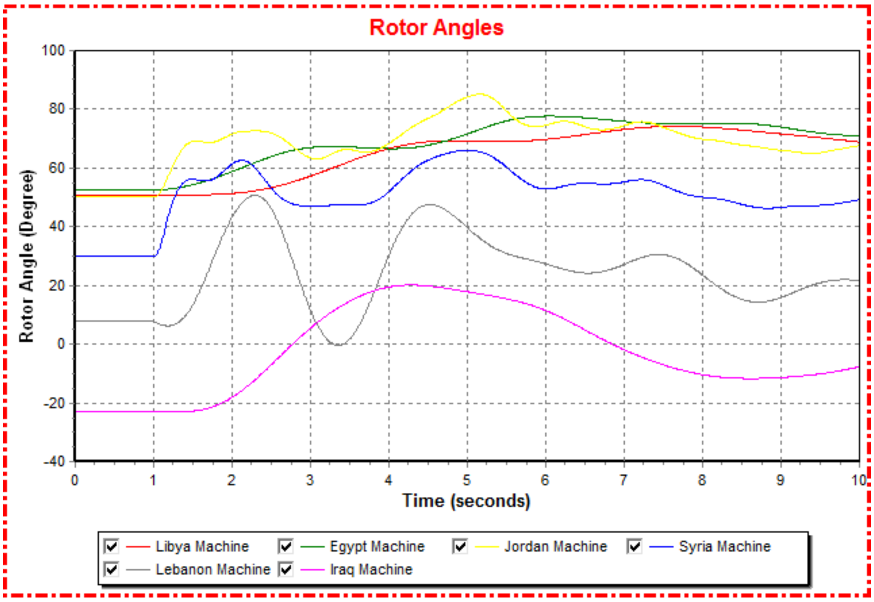

Figure 57 Rotor angles for three phase line fault on Syria-Lebanon 400 kV interconnection line (circuit 1)

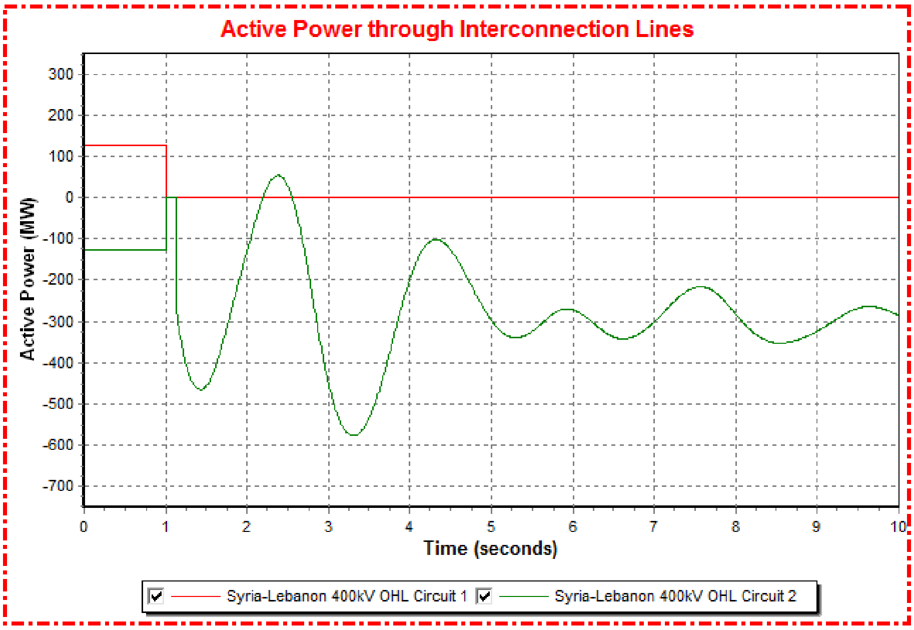

Figure 58 Active power through Syria-Lebanon interconnection lines

5.2.7 SYRIA-IRAQ 400 kV INTERCONNECTION LINE

There is only one 400 kV single circuit OHLs between Syria and Iraq. A three phase line fault is applied on Syria-Iraq 400 kV interconnection line with 120 ms fault duration to evaluate transient stability of EIJLLPST power system. The fault is applied to end point of the line in Iraq side.

Rotor angles are given in Figure 59 and active power flow through Syria-Iraq interconnection line are given in Figure 60 for three phase line fault Syria-Iraq 400 kV interconnection line. Iraq network is connected to rest of the EIJLLPST power system with only Syria-Iraq 400 kV interconnection line. When the Syria-Iraq 400 kV interconnection line is taken out of service, Iraq network is separated from the EIJLLPST power system.

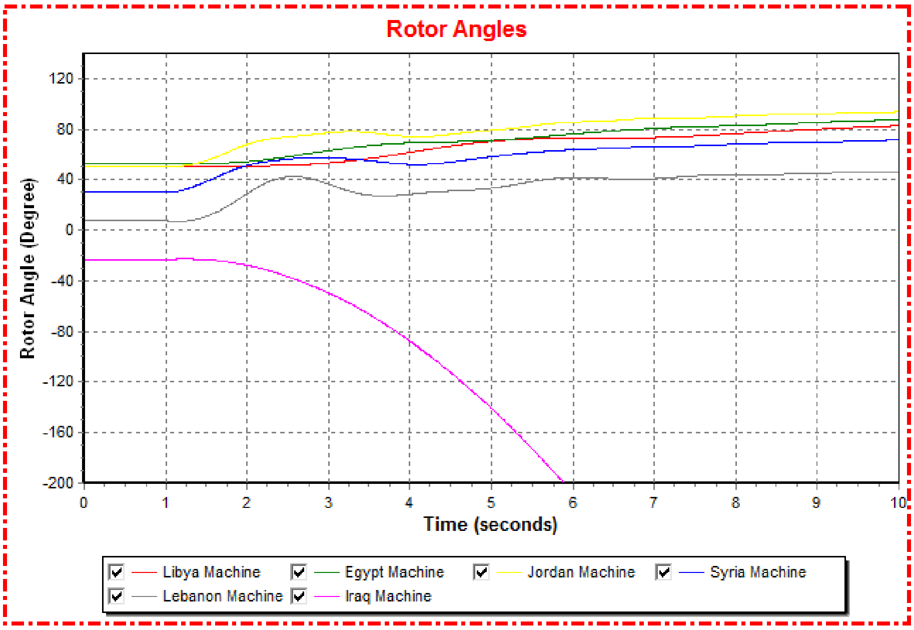

Figure 59 Rotor angles for three phase line fault on Syria-Iraq 400 kV interconnection line

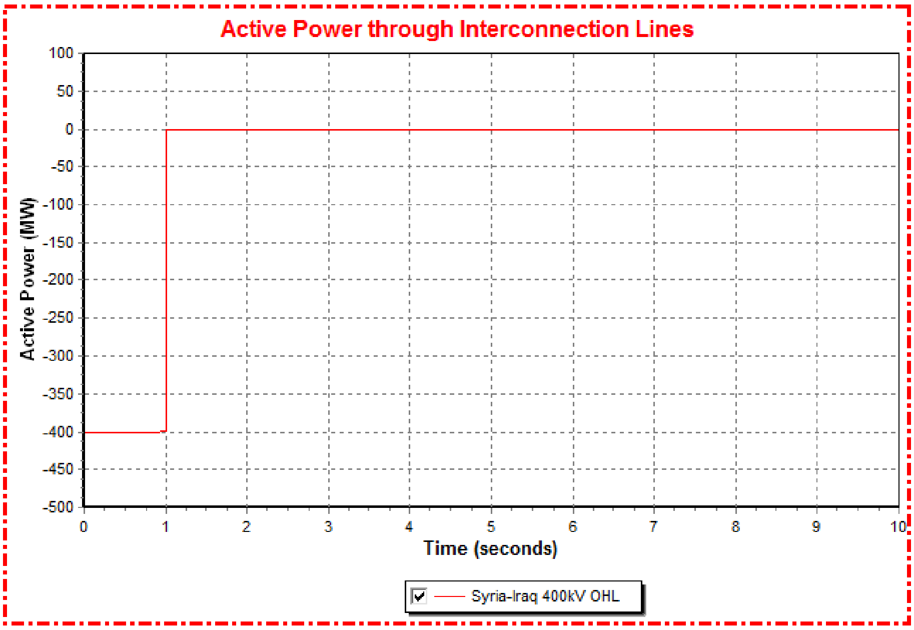

Figure 60 Active power through Syria-Iraq interconnection line

5.3 RESULTS OF TRANSIENT STABILITY ANALYSES

Transient stability analyses results are summarized in Table 45 and Table 46, for Summer Exchange Scenario contingency case and Winter Exchange Scenario contingency case, respectively. Results of the analyses indicate that EIJLLPST power system is stable when a three phase line fault is applied to interconnection lines with 120 ms fault duration except a fault on Syria-Iraq 400 kV interconnection line. Syria and Iraq is connected with only one interconnection line and fault on this line results in separation between Iraq and Syria network. A new interconnection line between Iraq and Syria could improve transient stability characteristic for faults on Syria-Iraq interconnection lines. Transient stability analyses results also state that EIJLLPST power system is stable with longer fault duration except some cases which are stated in Table 45 and Table 46.

Table 45 Results of transient stability analysis for Summer Exchange Scenario

	Fault Duration		
Faulted Line	120 ms	200 ms	300 ms
Libya-Egypt 500 kV interconnection line	stable	stable	stable
Libya-Egypt 220 kV interconnection line (circuit 1)	stable	stable	stable
Egypt-Jordan 400 kV submarine cable (circuit 1)	stable	stable	stable
Jordan-Syria 400 kV interconnection line (circuit 1)	stable	stable	unstable
Jordan-Syria 400 kV interconnection line (circuit 2)	stable	stable	stable
Syria-Lebanon 400 kV interconnection line (circuit 1)	stable	stable	unstable
Syria-Iraq 400 kV interconnection line	unstable	-	-

Table 46 Results of transient stability analysis for Winter Exchange Scenario

	Fault Duration		
Faulted Line	120 ms	200 ms	300 ms
Libya-Egypt 500 kV interconnection line	stable	stable	stable
Libya-Egypt 220 kV interconnection line (circuit 1)	stable	stable	stable
Egypt-Jordan 400 kV submarine cable (circuit 1)	stable	stable	stable
Jordan-Syria 400 kV interconnection line (circuit 1)	stable	unstable	-
Jordan-Syria 400 kV interconnection line (circuit 2)	stable	stable	unstable
Syria-Lebanon 400 kV interconnection line (circuit 1)	stable	unstable	-
Syria-Iraq 400 kV interconnection line	unstable	-	-

Transient stability analyses are conducted for Summer Exchange Scenario contingency case and Winter Exchange Scenario contingency case. Transfer capacities which are stated in section 3.3.3 for Summer Exchange Scenario contingency case and Winter Exchange Scenario contingency case could be realized in a secure manner when a transmission line in EIJLLPST power system is out of service. Results of transient stability analyses state that these transfer capacities could be realized in a secure manner in terms of transient stability.

CHAPTER 6

EIGENVALUE ANALYSIS ON EIJLLPST POWER SYSTEM DATA

Inter-area oscillations have been observed in power systems which are interconnected with weak tie lines. Inter-area modes are associated with the oscillations of generator groups in one part of power systems against the other generator groups. Frequencies of inter-area modes are generally in the range of 0.1 to 0.8 Hz [15]. Inter-area oscillations could create stability problems regarding small-signal stability of power systems. Small-signal stability refers to stability of the power system when small disturbances occur in the power system like small changes in loads and generation [14]. Eigenvalue analysis is used in this study to determine the nature of inter-area modes.

Data used for eigenvalue analysis is the same data used for transient stability analysis. Dynamic and static data of EIJLLPST power system are used for transient stability analysis. Dynamic data used in transient stability analysis include generator, exciter, and governor dynamic models of generating units of countries. However, in eigenvalue analysis, only generator dynamic models of countries are used for the simplification of analysis. DIgSILENT PowerFactory software is utilized for eigenvalue analysis. Eigenvalue analyses are conducted for six different cases based on EIJLLPST power system data for 2015 Summer Exchange Scenario contingency case and 2015 Winter Exchange Scenario contingency case. Transfer capacities and power flow directions for Summer Exchange Scenario contingency case and Winter

Exchange Scenario contingency case are given in Table 41 and Table 42, respectively. Eigenvalue analyses are conducted for six different cases as follows:

- Case 1 – 2015 Summer Exchange Scenario
- Case 2 – 2015 Summer Exchange Scenario with increased tie line impedance
- Case 3 – 2015 Summer Exchange Scenario with exciter models
- Case 4 – 2015 Winter Exchange Scenario
- Case 5 – 2015 Winter Exchange Scenario with increased tie line impedance
- Case 6 – 2015 Winter Exchange Scenario with exciter models

The magnitude of transfers through interconnections in Summer and Winter Exchange Scenarios are assigned based on the limit values found in static analysis. Case 1 and 4 are analyzed to examine inter-area modes of EIJLLPST power system for Summer and Winter Exchange Scenarios. Studies on inter-area oscillations indicate that an increase in the tie line impedance results in decrease of the frequency and damping ratio of the inter-area mode [15], [16]. To investigate the impact of tie line impedance on the inter-area mode, some of the interconnection lines are taken out of service in Case 2 and 5. Libya-Egypt 500 kV interconnection line, Egypt-Jordan 400 kV submarine cable (circuit 2), Jordan-Syria 400 kV interconnection line (circuit 2), Syria-Lebanon 400 kV interconnection line (circuit 2) are taken out of service in Case 2 and 5 to increase tie line impedance between countries and to weaken the interconnections between countries. To observe the effect of exciters on the inter-area mode, Case 3 and 6 are analyzed. In Case 3 and 6, exciter models of all generators are not included in analyses; only 30 exciter models are added for the simplicity of computations. Exciter models for 10 generating units in Egypt network, 10 generating units in Libya network, 5 generating units in Jordan network and 5 generating units in Syria are selected by taken into account of generator installed power and their location. Generators from different locations in a country are selected among country's highest installed power generators.

Results of eigenvalue analysis for Case 1 are given in Table 47 and Figure 61. Analysis indicates that there are 3,891 modes in total. There are seven oscillation modes with frequencies 0.1-0.8 Hz for Case 1. Oscillation modes of Case 1 have positive damping ratio and they are stable. Mode shapes of these oscillation modes are examined with the analysis software. The inter-area oscillation is not observed for these oscillation modes.

Table 47 Oscillation modes with frequencies 0.1-0.8 Hz for Case 1

Mode No	**Damped Frequency (Hz)**	**Damping (1/s)**	**Damping ratio**
Mode 02872	0.136	0.103	0.120
Mode 02795	0.250	0.051	0.032
Mode 02683	0.377	0.133	0.056
Mode 02681	0.556	0.165	0.047
Mode 02679	0.589	0.188	0.050
Mode 02677	0.660	0.247	0.059
Mode 02651	0.667	0.147	0.035

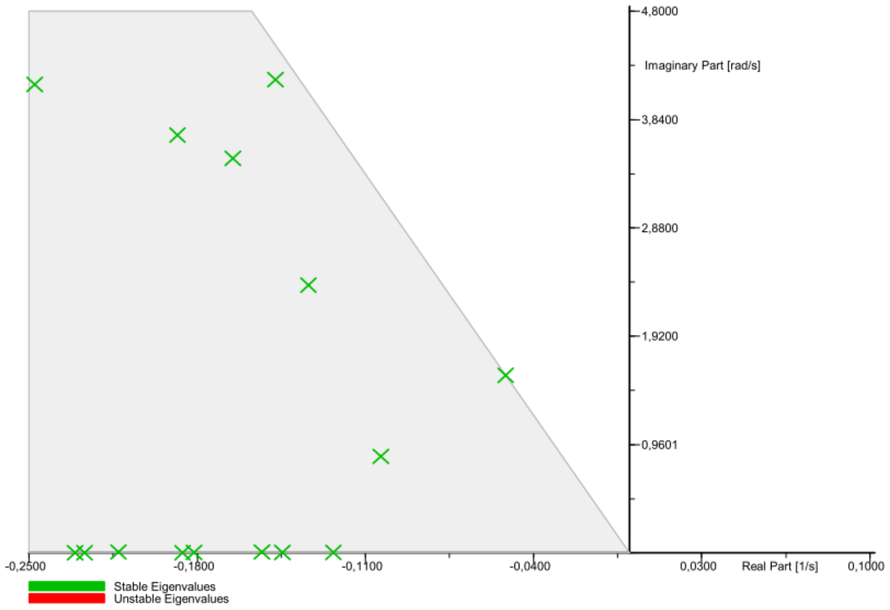

Figure 61 Eigenvalues of Case 1

Oscillation modes with frequencies 0.1-0.8 Hz for Case 2 are presented in Table 48 and eigenvalues of Case 2 are given in Figure 62. Eight oscillation modes are listed in Table 48. It is observed that frequencies of the first seven oscillation modes are smaller than those in Case 1, as expected with the weakened interconnection between countries. Damping ratios for five oscillation modes of Case 2 decrease compared to Case 1, while damping ratios for two oscillation modes of Case 2 increase.

Table 48 Oscillation modes with frequencies 0.1-0.8 Hz for Case 2

Mode No	**Damped Frequency (Hz)**	**Damping (1/s)**	**Damping ratio**
Mode 02889	0.124	0.091	0.115
Mode 02812	0.221	0.062	0.044
Mode 02774	0.356	0.140	0.062
Mode 02653	0.530	0.149	0.044
Mode 02651	0.575	0.178	0.049
Mode 02638	0.659	0.244	0.058
Mode 02636	0.665	0.144	0.034
Mode 02623	0.746	0.246	0.052

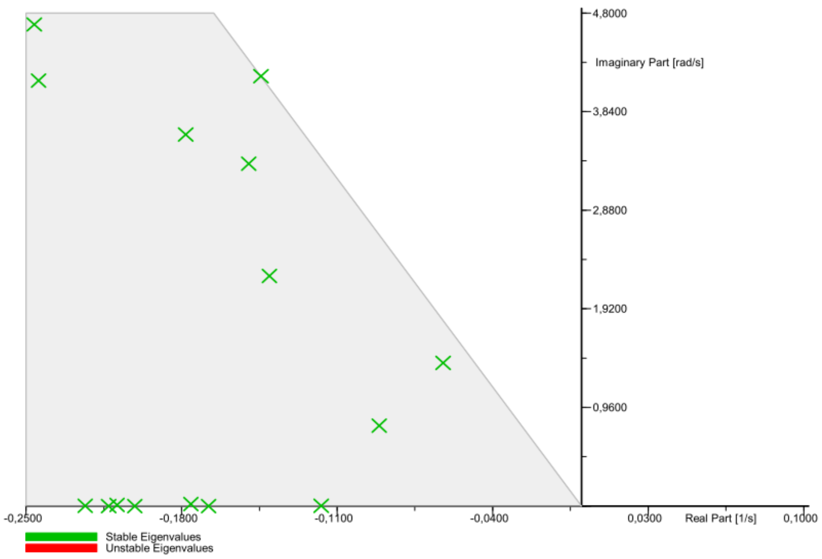

Figure 62 Eigenvalues of Case 2

Results of eigenvalue analysis for Case 3 are given in Table 49 and Figure 63. There are seven oscillation modes with frequencies 0.1-0.8 Hz for Case 3. Damping ratios of first and second oscillation modes in Case 3 are improved by the addition of exciter models to eigenvalue analysis compared to Case 1. Frequency of the first oscillation mode in Case 3 decreases compared to Case 1. Inter-area oscillation is not observed in mode shape of oscillation modes in Case 2 and 3.

Table 49 Oscillation modes with frequencies 0.1-0.8 Hz for Case 3

Mode No	Damped Frequency (Hz)	Damping (1/s)	Damping ratio
Mode 02960	0.127	0.158	0.193
Mode 02873	0.250	0.092	0.058
Mode 02836	0.376	0.128	0.054
Mode 02735	0.558	0.177	0.050
Mode 02733	0.588	0.183	0.049
Mode 02731	0.660	0.247	0.059
Mode 02723	0.667	0.144	0.034

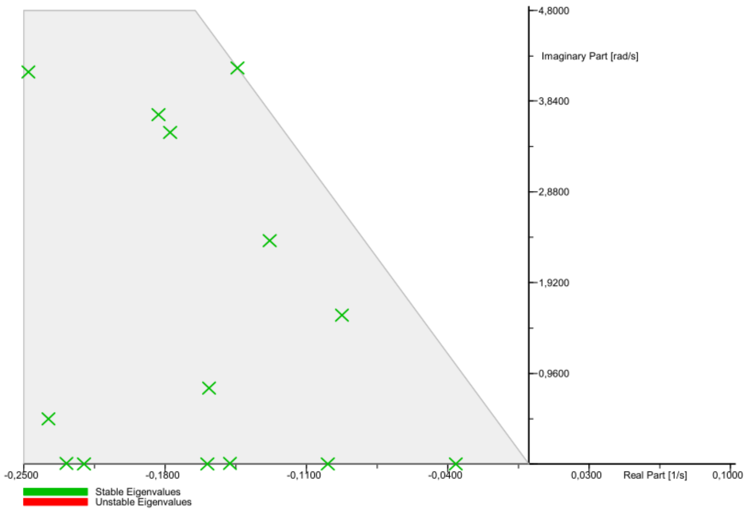

Figure 63 Eigenvalues of Case 3

Oscillation modes with frequencies 0.1-0.8 Hz for Case 4 are given in Table 50 and eigenvalues of Case 4 are given in Figure 64. There are nine oscillation modes with frequencies 0.1-0.8 Hz for Case 4. Oscillation modes of Case 4 have positive damping ratio and they are stable. Mode shapes of these oscillation modes are examined with the analysis software. The inter-area oscillation is not observed for these oscillation modes.

Table 50 Oscillation modes with frequencies 0.1-0.8 Hz for Case 4

Mode No	Damped Frequency (Hz)	Damping (1/s)	Damping ratio
Mode 02868	0.144	0.067	0.074
Mode 02835	0.247	0.077	0.049
Mode 02758	0.375	0.125	0.053
Mode 02684	0.575	0.183	0.050
Mode 02682	0.589	0.216	0.058
Mode 02659	0.666	0.265	0.063
Mode 02651	0.668	0.154	0.036
Mode 02634	0.758	2.824	0.509
Mode 02644	0.760	2.753	0.499

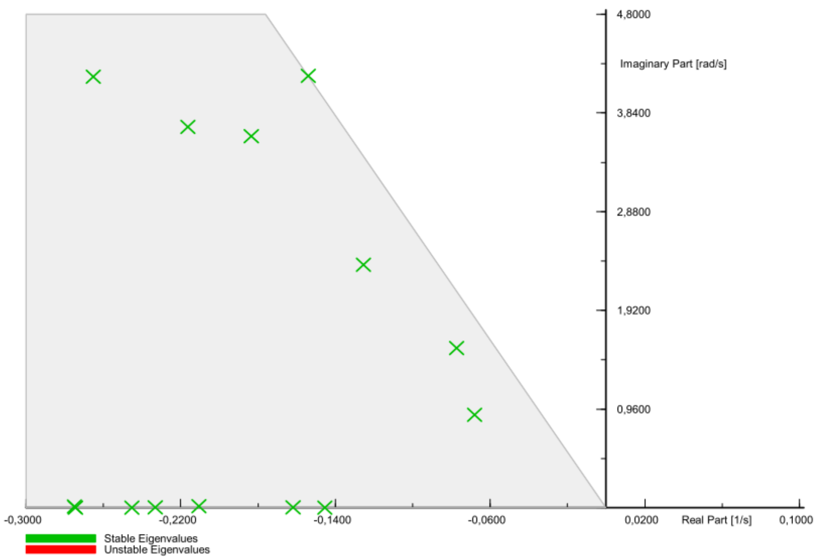

Figure 64 Eigenvalues of Case 4

Results of eigenvalue analysis for Case 5 are given in Table 51 and Figure 65. Eight oscillation modes are listed in Table 51. Decrease of frequency of oscillation modes are observed compared to Case 4, due to weakened interconnection between countries. Damping ratio for seven of oscillation modes of Case 5 decrease compared to Case 4, while damping ratio for one of oscillation modes of Case 5 increases.

Table 51 Oscillation modes with frequencies 0.1-0.8 Hz for Case 5

Mode No	**Damped Frequency (Hz)**	**Damping (1/s)**	**Damping ratio**
Mode 02863	0.131	0.049	0.060
Mode 02833	0.197	0.121	0.097
Mode 02770	0.360	0.111	0.049
Mode 02658	0.526	0.142	0.042
Mode 02656	0.572	0.193	0.053
Mode 02653	0.661	0.256	0.061
Mode 02651	0.663	0.146	0.035
Mode 02649	0.734	0.284	0.061

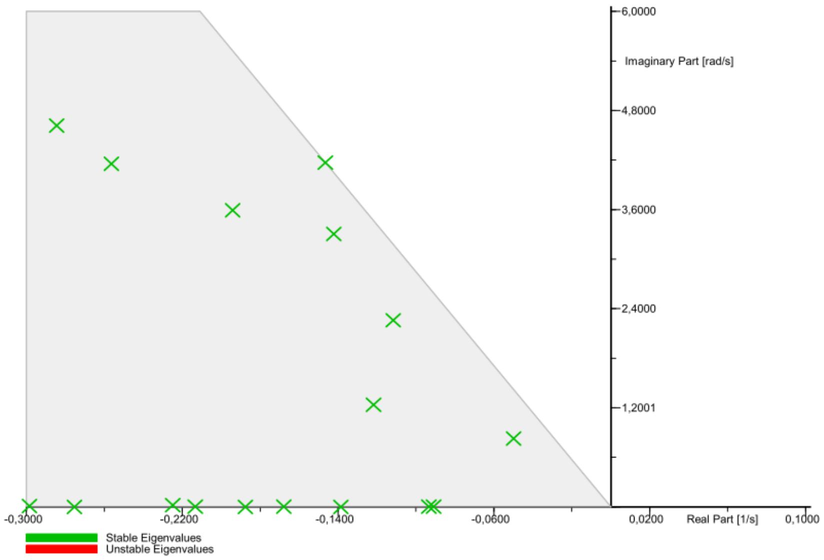

Figure 65 Eigenvalues of Case 5

Oscillation modes with frequencies 0.1-0.8 Hz for Case 6 are given in Table 52 and eigenvalues of Case 6 are given in Figure 66. There are eight oscillation modes with frequencies 0.1-0.8 Hz for Case 6. Damping ratio of second oscillation modes in Case 6 are improved by addition of exciter models to eigenvalue analysis compared to Case 4. Frequency of second oscillation mode in Case 6 decreases compared to Case 4. Inter-area oscillation is not observed in mode shape of oscillation modes in Case 5 and 6.

Table 52 Oscillation modes with frequencies 0.1-0.8 Hz for Case 6

Mode No	**Damped Frequency (Hz)**	**Damping (1/s)**	**Damping ratio**
Mode 02920	0.142	0.069	0.077
Mode 02883	0.232	0.097	0.066
Mode 02819	0.375	0.123	0.052
Mode 02734	0.555	0.164	0.047
Mode 02732	0.586	0.199	0.054
Mode 02721	0.662	0.259	0.062
Mode 02712	0.664	0.144	0.034
Mode 02681	0.794	0.290	0.058

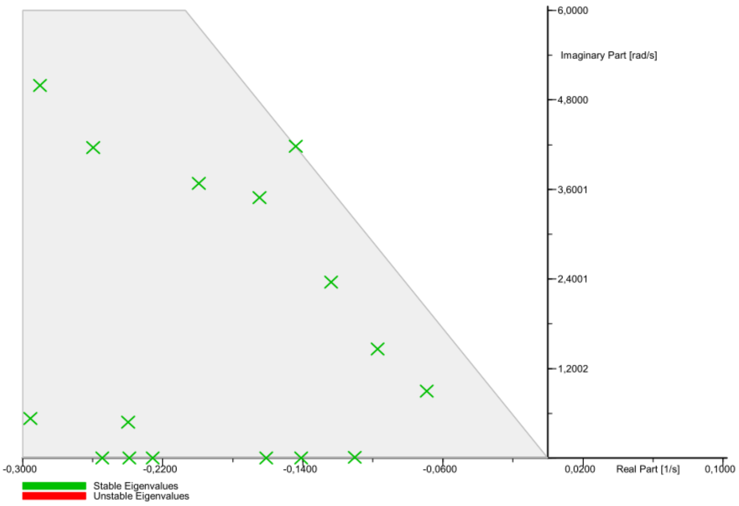

Figure 66 Eigenvalues of Case 6

Results of these studies give us an idea about the critical modes and their frequencies in EIJLLPST power system. There are oscillation modes with frequencies 0.1-0.8 Hz for EIJLLPST power system. Damping ratios of all oscillation modes are positive. This result indicates that oscillation modes are damped. Mode shapes of these oscillation modes are also examined with the analysis software. Inter-area oscillation is not observed for oscillation modes. In addition, impact of planned interconnections is observed. Strengthening interconnections between countries has positive contributions against oscillation modes. Analyses with exciter models indicate that exciters could improve stability characteristics of EIJLLPST power system. It should be noted that it is planned to increase the transfer capacity between Egypt and Jordan with operating existing AC submarine cable with DC voltage by installing converter stations at each side of the cable. Studies on interconnection with DC links indicate that there is no risk of inter-area mode instability due to interconnection with DC links [15]. It could be expected that operating existing AC submarine cable with DC voltage between Egypt and Jordan could improve stability characteristics of EIJLLPST power system. To improve the system stability, power system stabilizers could be added to power system. Studies indicate that power system stabilizers are effective measures for improving stability of power systems [17]. Studies on system stability also indicate that STATCOM and SVCs could also be used as additional damping measures [18].

CHAPTER 7

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORKS

In this study, the transfer capacities of the existing and planned interconnections between EIJLLPST countries are evaluated. TTC values of interconnections are determined according to definitions and procedures defined in documents [12] and [13]. Load flow analyses are conducted on EIJLLPST power system data of the year 2015 for Summer and Winter Exchange Scenarios. TTC values for Summer Exchange Scenario and Winter Exchange Scenario are given in Table 53 and Table 54, respectively. Results of TTC calculation indicate that the planned interconnections will increase the TTC values between countries.

Table 53 TTC values in base case and contingency case for Summer Exchange Scenario

	Base Case (MW)	Contingency Case (MW)
Turkey to Syria	1,200	1,200
Turkey to Iraq	500	500
Iraq to Syria	900	500
Syria to Lebanon	250	250
Syria to Jordan	1,700	1,000
Jordan to Palestine	100	100
Jordan to Egypt	1,000	500
Egypt to Palestine	150	150
Egypt to Libya	1,000	100

Table 54 TTC values in base case and contingency case for Winter Exchange Scenario

	Base Case (MW)	Contingency Case (MW)
Syria to Turkey	900	700
Iraq to Turkey	500	100
Syria to Iraq	800	400
Syria to Lebanon	250	250
Jordan to Syria	900	700
Jordan to Palestine	100	100
Egypt to Jordan	1,000	500
Egypt to Palestine	150	150
Libya to Egypt	1,000	400

TTC definitions and procedures defined in documents [12] and [13] state that calculated TTC values would not create security violation in transmission network. This study reveals that TTC values which could be realized in a secure manner are TTC values which are stated for contingency cases in Table 53 and Table 54. TTC values for Summer and Winter Exchange Scenario contingency cases should be taken as main figures for exchange programs between countries.

To increase the transfer values to TTC values which are stated for Summer and Winter Exchange Scenario base cases requires additional tasks. TTC values which are stated for Summer and Winter Exchange Scenario contingency cases could be increased by realizing new transmission investments which would overcome the limiting factors. This study states the contingency cases which limit the transfer values between EIJLLPST countries, and these contingency cases are the starting point for investment plans of EIJLLPST countries to improve power system security and to increase transfer values between countries. TTC values which are determined for Summer and Winter Exchange Scenario contingency cases could also be increased by using special protection systems (SPS) which operate when limiting factors and cases occur in the network.

Results of short circuit analysis reveal that increase in short circuit value after interconnections are not significant. There is no need to take any measures for the increase in short circuit current values.

Transient stability analysis on EIJLLPST power system data indicates that EIJLLPST power system is stable for three phase line faults on interconnection lines with 120 ms fault duration except Syria-Iraq interconnection line. There is only one interconnection line between Syria and Iraq, and addition of a second interconnection could improve the transient stability of the system. Three phase line fault is one of the severe disturbances in power systems and is selected for the assessment of transient stability of EIJLLPST power system in this study. Location of faults is selected as interconnection lines, because interconnection lines are the most limiting network elements in interconnected networks. Fault duration is increased to 200 ms and 300 ms, and it is observed that EIJLLPST power system is not stable for some cases. The switching time of circuit breakers is important in clearing faults from network for the stability of network and switching time of circuit breakers should be minimal to improve the stability of power system.

Results of eigenvalue analysis reveal that EIJLLPST power system is stable in terms of small signal stability. There are oscillation modes with frequencies 0.1-0.8 Hz for EIJLLPST power system, but damping ratios of all oscillation modes are positive. This result indicates that oscillation modes are damped. Mode shapes of these oscillation modes are also examined with the analysis software and inter-area oscillations are not observed. In addition, impact of planned interconnections on oscillation modes is also observed. Strengthening interconnections between countries has positive contributions against oscillation modes.

This study indicates that power exchange values between EIJLLPST countries will increase with planned interconnection and power exchange could be realized in a secure and stable system operation.

This study could be extended by analyzing DC interconnection between Egypt and Jordan. There is a 400 kV AC, single circuit, submarine cable between Egyptian transmission network and Jordanian transmission network, and it is planned to convert the submarine cable between Egypt and Jordan to be operated on DC by adding a converter substation in Taba (Egypt) and a converter substation in Aqaba (Jordan). In addition, new interconnection projects and internal grid reinforcements could be evaluated to further increase in transfer values between countries.

The economic studies could be performed to evaluate economical benefits resulting from interconnections on power system operation. Results of economic studies could trigger new interconnection projects between countries.

Due to political unrest and turmoil in the region, extending to the most of the Mashriq Countries, EIJLLPST project has been frozen since 2013, and it is expected that there is no chance of implementing the electricity trade in the very near future.

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