Modelling and Performance Evaluation of the Egyptian National Utility Grid Based on Real Data

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***Abstract*— In this paper, the Egyptian National Power System of Extra-High Voltage 500 kV and High-voltage 220 kV is evaluated through modelling and simulation. The Egyptian national power system went through fast developments in the last ten years. Several power plants have been integrated into grid bringing the total installed capacity to about 38857 MW in 2016. A Model of the complete Egyptian Utility Grid has been implemented based on real data using DigSILENT PowerFactory simulation package. Moreover, the paper presents the analysis of grid performance such as voltage profile, power losses, transmission lines loading based on power flow results. The voltage profile for National Power System in normal conditions clarified that the voltage level in many locations is under the permissible secure limits (0.95 p.u.≤ voltage level ≤ 1.05 p.u.). Therefore, suitable solutions and suggestions for improving the grid performance have been introduced.**

Keywords—Egypt grid; DigSILENT PowerFactory; Power System

I. INTRODUCTION

Energy is the main driving force of modern economic development. With the increase in the world population, more energy is needed to meet the growing human needs for maintaining well-being. Improving the standard of living and prolonging a person's life depends, on average, on energy consumption per person. In Egypt, as throughout the world, energy plays a significant role in economic development. On the other hand, Egypt, as a developing fast-growing country, suffers from rapid annual population growth with a rate of 1.68%. As of October 2017, the population of Egypt was estimated at 96.125 million. According to the Cairo Demographic Center, It is expected that the population of Egypt will reach 110 million by 2031 and 128 million by 2051 [1]. Such rapid population growth along with other environmental problems is overexertion limited energy resources of the country.

The first electric power system in Egypt has introduced about one hundred years ago when a private company was given the concession to generate and distribute electricity for lighting purpose in Cairo city and then in Alexandria. In the early of 1930's, the Egyptian government started land reclamation programs in Delta region in the north of Egypt and for lifting water from Nile River to irrigate the reclaimed land, small steam turbine plants were installed with capacities of 1000-2500 kW. Long transmission lines were designed and constructed to operate at the voltage level of 66 kV. Insulators and outdoor switchgear were not suitable for operation in the prevailing environment in Egypt, so the transmission system had to operate at 33kV instead of 66kV. In 1961, a hydroelectric power plant was constructed at Aswan to utilize the potential energy from the old dam in Aswan. A voltage level of 132kV used for the transmission network to operate a fertilizer factory and for agriculture development in Upper Egypt. At that time, it was realized that it is necessary to interconnect the different isolated systems in order to operate in one unified network. Studies and plans were set to construct a 220kV network and commissioning of the first section of this system began in 1967 with the integration of the first generating units of Aswan High Dam hydroelectric power plant. The construction of the 2100MW hydroelectric power plant of Aswan High Dam was associated with the construction of the 500kV transmission network to transmit the available energy to the load centers in the north. In the mid of 1960's the 500kV voltage level was the highest transmission voltage used and Egypt was one of the pioneers in this voltage level besides USA & USSR.

The aim of the paper is to provide a complete description of the Egyptian power system. Furthermore, the national power system of high voltage and extra high voltage in modeled using DigSILENT PowerFactory simulation package. Also, the grid performance is studied depending on the results of power flow study.

II. GENERAL DESCRIPTION OF THE EGYPTIAN POWER SYSTEM

The power system in Egypt consists of three sub-systems are; generation system, the transmission system consists of transmission lines at different voltages levels and substations, and the distribution system of electricity on medium and low voltages.

The total installed capacity of power plants, connected with the utility grid with a developing rate of 7.52% from 2010/2011 to 2015/2016 is shown in Fig.1. The installed capacity reached 38.857 gigawatts at the end of fiscal year 2015/2016. The maximum load reached 29200 MW in 2015/2016 compared with 28015 MW in 2014/2015 with a developing rate of 4.2% as shown in Fig. 2. The total energy generated from the power plants connected to the utility grid

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increased from about 174.9 billion kWh in 2014/2015 to 186.3 billion kWh in 2015/2016 with a growth rate of 6.5% [2-4].

The tasks of the Egyptian Electricity Transmission Company are to manage, operate and maintain electric transmission networks for high and extra-high voltage, to regulate the movement of loads on networks through the National Center for Energy Control and Regional Control Centers and to implement electrical linking projects and the exchange of electric energy with other countries.

On 30/06/2016, the total transformer capacity on the high and extra high voltage levels reached about 110656 MVA compared to 103975 MVA at 30 / 06/ 2015 with a growth rate of 6.4%. On 30/06/2016, the total length of the circuits (transmission lines and cables) for the electricity transmission network reached about 44.9 thousand km compared to about 44.4 thousand km in 30/06/2015 with a growth rate of 1.13% [3-4].

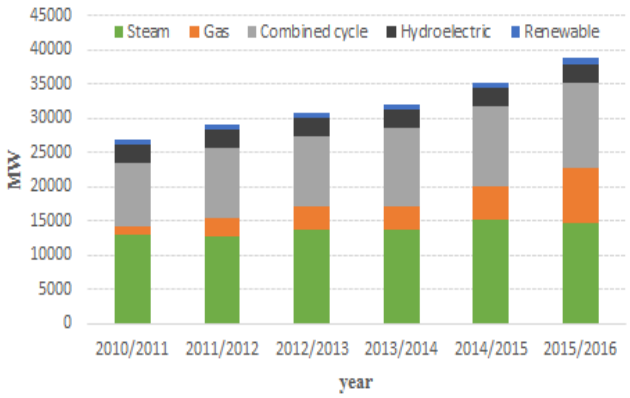

Fig.1. Evolution of nominal capacities according to type of generation.

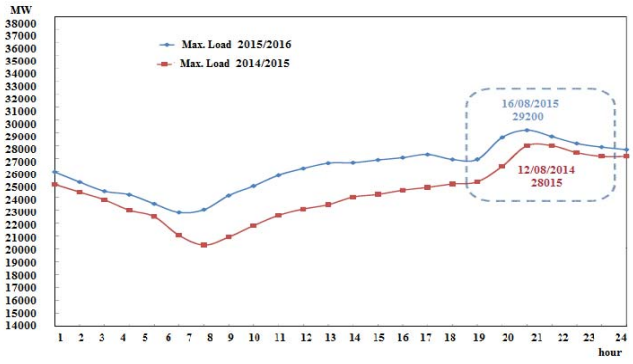

Fig.2. Maximum Load for the fiscal year 2014/2015 and 2015/2016

Because of the localization of the inhabited area within the valley of the Nile River, the high voltage transmission system also limited to the valley and Nile Delta in the north. In the east, 500kV lines have been constructed to reach the borders to interconnect with Jordan. The interconnection with Jordan was in October 1998 with a maximum power transfer of 500MW. In the west, 220kV lines have been constructed along the Mediterranean Sea coast to reach the borders with Libya and the interconnection was in May 1998 with a maximum power transfer in the two directions of 150MW [5]. In order to complete the electrical interconnection system with the neighboring countries, the electrical connection between Egypt and Saudi Arabia is currently underway to exchange electricity within 3000 MW [4]. The partial pilot operation is expected in the last quarter of 2019 and the project will be fully operational by the end of 2020. Fig. 3 shows total energy sold and purchased with neighboring countries in the period from 2006 to 2016.

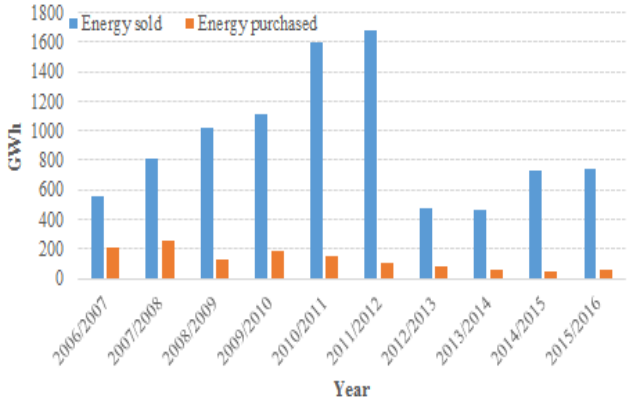

Fig.3. Total energy sold and purchased with neighboring countries.

The tasks of the electricity distribution companies are to distribute and sell electricity to the subscribers on the medium and low voltage, in addition to the management and operation of medium and low voltage networks, in full compliance with the instructions of the control centers in accordance with the requirements of economic operation as well as management, operation and maintenance of power stations not connected to the unified network. As of 30/6/2016, the total length of medium voltage lines and cables is 185 thousand km compared with 180 thousand km on 30/6/2015 with a growth rate of 2.8%.The total length of low voltage cable lines reached about 275 thousand km compared to 265 thousand km on 30/6/2015 and an increase of 3.8%. The total amount of energy sold by the distribution companies distributed according to the purposes of use is shown in Fig. 4.

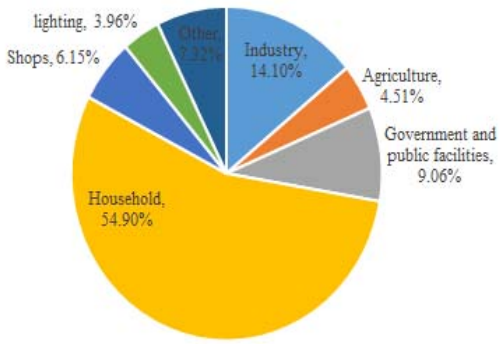

Fig.4. Energy sold by the distribution companies distributed according to the type of consumer.

III. Configuration Of Egyptian National Power System

The Egyptian power system went through fast developments in the last two decades. Transmission lines

extensions were implemented in order to supply the existing load centers and also reach the most of the isolated systems. This paper tries to formulate a model for the Egyptian unified power system which may be appropriate for academic as well as field research purposes. The starting point in this long way toward achieving this goal was the electrical map of the unified power system of Egypt. Fig. 5 illustrates such map which is taken from the official website of the ministry of electricity and energy [6]. Egypt is interconnected through 500 kV and 220 kV national network. 500 kV lines form a long corridor, which extends from Aswan in the south to Alexandria in the Far North. The 220 kV lines shared routes of 500 kV, but more divergent to reach new areas of Egypt.

The power system under study is modeled and analyzed using DigSILENT PowerFactory simulation software. The model included the following elements:

- 500kV and 220kV overhead transmission lines,
- 500/220kV substations,
- 220/66kV substations,
- Conventional and renewable energy sources,
- Interconnection between Egypt and Jordan,
- The interconnection between Egypt and Libya.

The system generated electric power is obtained, nowadays, from 38 main conventional steam power stations, the High-dam hydraulic power station, in addition to the Zaafrana and Gabl El-Zait wind power stations. Values of the lines resistances, inductances, capacitances, in addition to the lines power limits for 500 kV and 220 kV networks are obtained from the Egyptian National Control Centre. Generators data are taken directly from the available generation data of the reports of the National Control center. The transformer parameters are taken according to the rated of the transmission lines. During modeling, the 220kV grid is divided into 6 regions, which mimic the existing reality for electricity transmission companies in Egypt, in addition to the 500kV grid. Single line diagrams for all these regions are given in the following sections. The complete model includes 205 substations, 426 bus-bars, 443 transmission lines, 248 two winding transformers, 218 synchronous machines and 369 loads. According to the Egyptian Grid code for transmission of Electric Energy, the values of allowable voltages under different operating conditions for the different transmission voltage levels are shown in Table I [7].

A. 500kV national grid

The 500kV network covers approximately all territory Egypt from Aswan in the south to Alexandria in the north. A single line diagram of the 500kV grid is shown in Fig. 6. It contains the largest power generation station in Egypt which is HIGH DAM hydroelectric power generation station. Moreover, 12 power plants are integrated into the 500kV grid. The generating capacities of the generating units and the name of buses to which the power plants are connected are shown in Table I. From the results of power flow study, the power interchange from the 500kV grid to the 220kV and 400kV grids are (14000.26+j4137) and (40+j16.55) MVA respectively. The total generating capacities of the power plants, connected to 500kv grid have been shown in Table II.

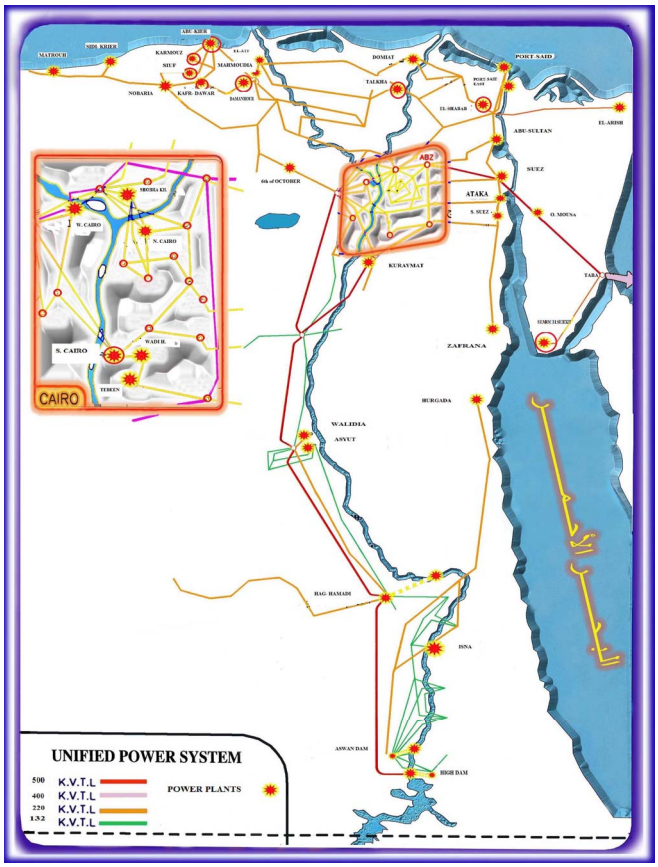

Fig.5. Electricity map of the Egyptian unified power system

TABLE I. THE ALLOWED VOLTAGE VALUES FOR THE EGYPTIAN

Voltage level (kV)	Voltage in case of ordinary operation		Voltage in case of contingency disconnect	
	Higher Voltage	*Least Voltage*	*Higher Voltage*	*Least Voltage*
500	525	475	550	450
400	420	380	420	360
220	231	209	242	198

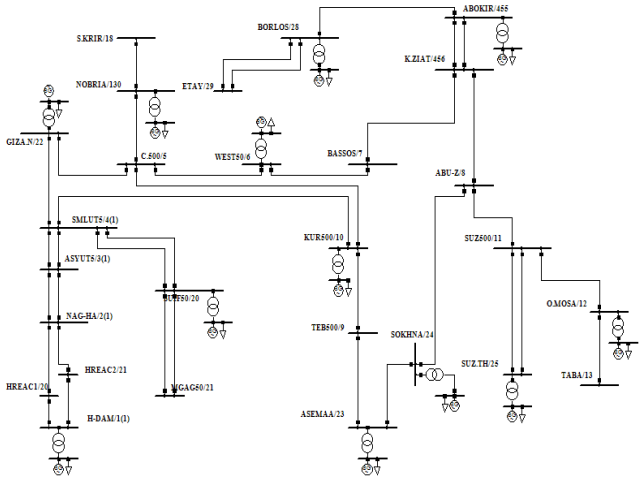

Fig.6. Single line diagram of 500kV network.

TABLE II. GENERATING CAPACITIES OF THE POWER PLANTS, CONNECTED TO 500KV GRID

Power plant	Bus Number	Capacity (MW)
HIGH DAM	1	2100
BENI SUIF	20	2400
KURAIMAT 1	10	1250
ASEMAA	23	800
AIN SOKHNA	24	1300
SUEZ TH.	25	650
CAIRO W.	6	1360
GIZA N.	22	2250
NOBARIA	130	2250
BOROLOS	28	1600
ABU KIER	455	1300

B. South Egypt Region

The existing Upper Egypt power system of high voltage shown in Fig.7. The power system in the south of Egypt is heavily loaded, as it contains the most important industrial loads such Aluminum factory in a city called Nag Hammadi, Ferrosilicon factory, Kima factory, and cement factories. The load distribution of some of the buses is listed in Table III [8]. Two generating power plants are integrated into the 200kV grid in the south as follow. 550MW hydroelectric power plant behind Aswan Dam and 600 MW thermal power plants depending on black oil.

TABLE III. LOADS AT DIFFERENT STATIONS IN THE POWER SYSTEM

Station	Bus Number	Load (MW and MVAR)
HIGH DAM	490	364.7+J208.8
NAG HAMMADI	501	799.3+j481.7
ASSIUT	504	232.2+j114.4
SAMALUT	612	167.9+j147.7
KURAIMAT	815	173.2+j 97.9

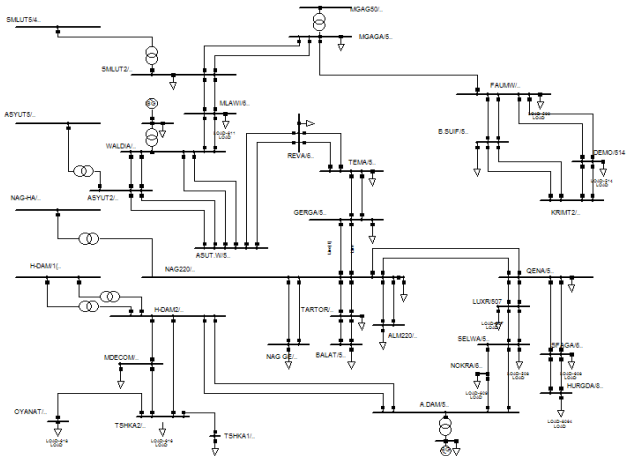

Fig.7. Single line diagram of south of Egypt region (220kV)

C. Cairo region

The power system in this region is very loaded, as it supplies the energy to a very important industrial and residential area distributed in three governorates Cairo, Giza, and Qaliubiya. A very important load in this region is Cairo Subway, which is fed by electricity from four substations named; METRO RAMSIS1 (bus No. 539), METRO RAMSIS 2(bus No. 702), METRO ABASIA (bus No. 591) and SOUTH TEBEEN (bus No. 522). The single line diagram of the 220kV transmission network in Cairo is presented in Fig. 8 and the generating capacities of the power plants, connected to the transmission network in this region are given in Table VI.

TABLE IV. GENERATING CAPACITIES OF THE POWER PLANTS IN CAIRO REGION.

Power plant	Bus Number	Capacity (MW)
SHOBRA KH.	541	1550
KURAIMAT2	515	750
CAIRO N. GEN.	542	1500
TEBEEN GEN.	352	700
T. OCTOBER	5031	600
GEN. OCTOBER	461	450
CAIRO SOUTH GEN.	518	495

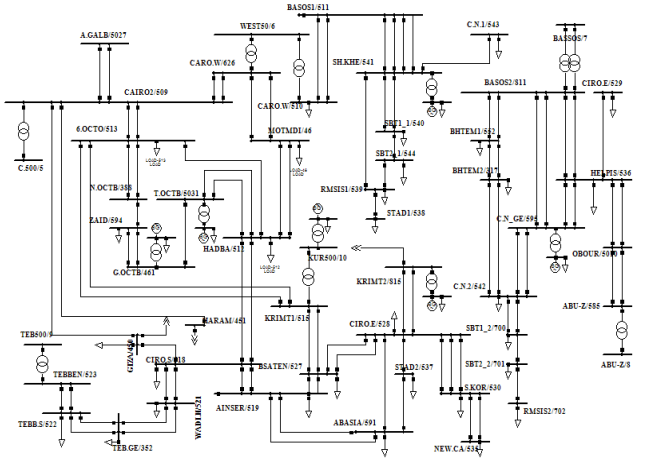

Fig.8. 220 kV transmission network in Cairo region

D. Delta region

This part of the transmission network exists in the north of Egypt mainly in five governorates; Menoufia, Gharbia, Dakahlia, Damietta and Kafr El-Shiekh. Fig. 9 represents the single line diagram of the 220kV grid in this region and generating capacities of a part of the power plants integrated into the grid are given in Table V.

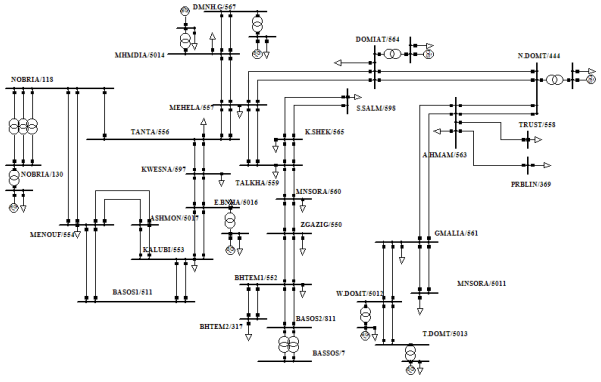

Fig.9. 220 kV transmission network in Delta region.

TABLE V. GENERATING CAPACITIES OF THE POWER PLANTS IN DELTA REGION

Power plant	Bus Number	Capacity (MW)
MAHMOUDIA	5014	268
EAST BANHA	5016	750
NEW DOMIAT	444	600
WEST DOMIAT	5012	500
T. DOMIAT	5013	500

E. West Delta region

This part of the national grid exits in the north-west of Egypt. There are many industrial zones in this area. In addition, there are high voltage loads such as steel factories such as EZZ steel, ELMASREEN steel, and BSHAY steel. The single line diagram describing the 220kV transmission network is shown in Fig. 10.

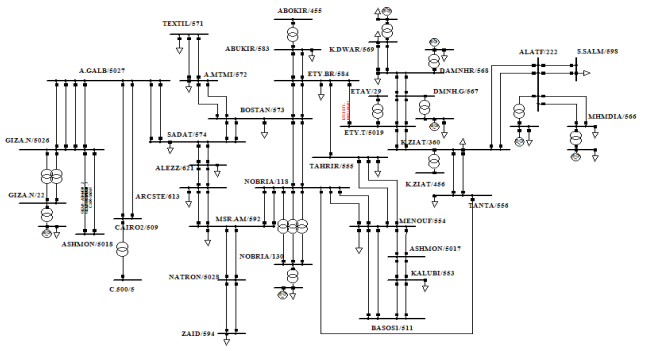

Fig.10. 220 kV transmission network in west Delta region.

F. Alexandria region

In this part of the national grid appears the 165 km 220kV line, connecting substation SALOUM in Egypt with substation TUBROUK in Libya. In addition, DEKHIELA steel factory and soft iron factory are the main loads is this part. A single line diagram of the transmission network in Alexandria region is given in Fig. 11.

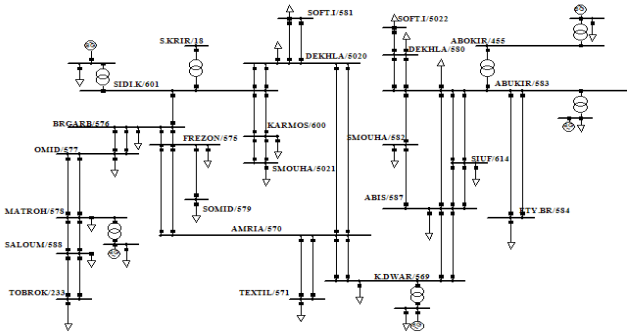

Fig.11. 220 kV transmission network in Alexandria region

G. Canal region

In this part of the network, the transmission lines exist along the Red Sea and Suez Canal. 220 kV transmission lines approximately cover all the territory of the north and south Sinai. In this part of the national grid, two wind farms are interconnected. 547 MW in Zaafarana, Which it is located about 120 kilometers south of the city of Suez and 200MW in Gabl El-Zait on the Red Sea Coast. Fig.12 shows the single line diagram of 220 kV transmission network in Canal region.

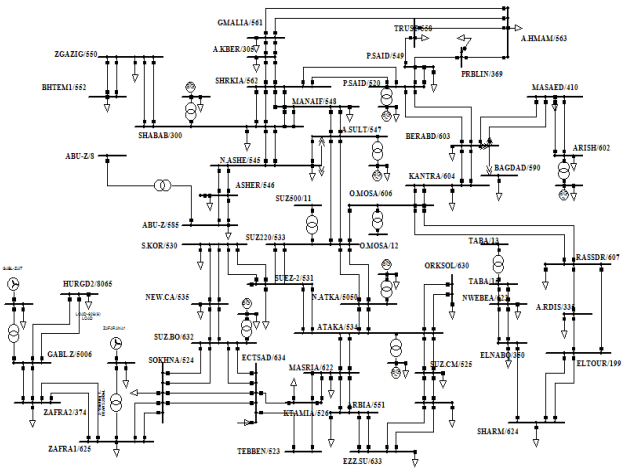

Fig.12. 220 kV transmission network in Canal region

IV. RESULTS OF POWER FLOW STUDY

As a first step for the Egyptian power system stability studies, the system described in the previous sections is considered. Next, the system load flow computations are carried out for the system by using the Newton-Raphson method depending on DigSILENT PowerFactory simulation package. Comparing the results of power flow study with the Egyptian standards for transmission shown in Table I, the voltage level in many locations is out of the permissible secure limits. Table VI shows the locations of the buses that suffer from under voltage and over voltage problems in the Egyptian national power system.

TABLE VI. LOCATION OF THE BUSES THE EXCEED THE EGYPTIAN STANDARDS OF VOLTAGE

Bus No.	Substation	Region	Actual Voltage (kV)	Angle (deg.)	P.U. Voltage
305	ABU KBER	Canal Region	207.28	-12.07	0.942
545	N.ASHER		208.48	-12.27	0.948
546	ASHER		204.41	-13.56	0.929
535	NEW CAIRO		206.10	-11.90	0.937
530	SAKR KOR.		206.52	-11.55	0.939
580	DEKHELA	Alexandria Region	204.00	-13.28	0.927
581	SOFT IRON		203.92	-13.33	0.927
588	SALOUM		232.29	-13.44	1.056
519	AINSERA	Cairo Region	208.33	-10.87	0.947
527	BASATEEN		208.19	-10.90	0.946
528	CAIRO EAST		207.56	-11.11	0.943
591	M.ABASIA		207.89	-11.08	0.945
537	STAD_2		207.63	-11.17	0.944
502	GERGA	South Egypt Region	200.55	2.89	0.912
8064	HURGADA		203.12	-7.96	0.924
507	LXRSHARQ		201.48	6.49	0.916
609	NOKRA		206.64	18.70	0.939
610	REVA		207.47	2.73	0.943
608	SAFAGA		202.34	-5.70	0.920
508	SELWA		204.93	14.96	0.931
506	SOUTH QENA		203.54	5.05	0.925
503	TEMA		200.3	0.76	0.910

Depending on the data of the transmission lines and bus loading, taken from the National Center for Energy Control in Egypt for the fiscal year 2013/2014 and taking into account a growth rate of 6.4% as given in the annual report of the Egyptian Electricity Holding Company in 2015/2016, the value of bus loading is corrected. From the results of power flow study, it is found that there are some overloaded transmission lines. The overloaded lines are shown in Table VII. It is recommended that new transmission lines will be constructed to fulfill the increase in demand for electrical energy.

TABLE VII. OVERLOADED TRANSMISSION LINES IN NATIONAL POWER SYSTEM OF EGYPT

From Bus		To Bus		Region	Loading (%)
ABUKIR	583	ABIS	587	Alexandria Region	106.95
ABUKIR	583	SMOUHA	582		109.89
ABUKIR	583	DEKHELA	580		122.19
CAIRO S.	518	AINSERA	519	Cairo Region	122.91
CAIRO N.	542	BAHTEM2	317		115.18
TEBBEN	523	KATAMIA	526		113.14

V. CONCLUSIONS

In this paper, a complete description of the status of the national power system of Egypt. Depending on a real data received from the Egyptian National Center for Energy Control and the annual reports of the Egyptian Electricity Holding Company, a complete model of the high voltage and extra-high voltage networks is created. From the results of load flow study, it is obvious that there are many bus-bars with an operating voltage below the national standards. In addition, there are a number of loaded transmission lines, so that during the future developments of the national grid it must be taken into account. This study is a prelude to studying the stability of electric power system in Egypt with increasing the penetration level of the renewable energy sources

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