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PERSPECTIVES OF LARGE WIND POWER PLANT INSTALLATIONS TO THE NATIONAL TRANSMISSION POWER SYSTEM OF LIBYA

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ABSTRACT

This paper deals with the transmission power system of Libya and its capacity to incorporate renewable power sources, especially large wind power farms. First, the initial load flow case of the eastern part of the Libyan transmission network has been performed. Second, another load flow study has been analyzed to demonstrate the steady-state behaviour (especially voltage and power conditions) of the network when incorporating planned wind power farms for year 2010. Final load flow problem has been strictly defined as an optimization problem to examine maximum possible power generations from prospective wind power farms in selected locations of the eastern network part in 2015 (with estimated loading situations) for maintaining all bus voltages and branch power flows within their permitted limits. Based on these simulations, further research activities in this area will continue.

KEYWORDS

Transmission Power System of Libya, Load Flow Analysis, the NEOS Server, KNITRO, PowerWorld Simulator

1. INTRODUCTION

Unlike the rest of the North African region, where less than 10 percent of population has an access to the electricity, Libya is a fully electrified country with current electricity consumption of 4360 kWh per capita.

In Tripoli in 1984, the General Electric Company of Libya (GECOL) has been established for providing distribution services of electrical energy to the entire population of Libya and securing declared inter-tie flows on the transmission level to all electric power utilities in neighbouring countries with particular focus on reliability, sustainability and economy of the power system operation and control. Moreover, state-owned GECOL is responsible for the entire power sector in the country, from the generation, transmission and distribution of electrical energy, through the oil and gas industry up to the branch of water desalination.

For covering the load-growth rate of 8 percent per year on average, the transmission network with all main electric power plants remains the most important part of the Libyan power sector. The transmission power system of Libya consists of seven geographically dispersed, sparsely interconnected island areas (Tripoli, Benghazi, Western, Eastern, Kufra, Central and Southern regions). In a simplified form, the entire transmission power system (Fig. 1) contains approx. 75 substations on 220 kV (13,677 km) and 132 kV (1,208 km) voltage levels with connections to sub-transmission networks of 66 kV (13,973 km) and distribution systems of 30 kV (8,583 km) and 11 kV. Connections in the transmission network of Libya are realised as overhead lines (14,747 km) and cables (138 km).

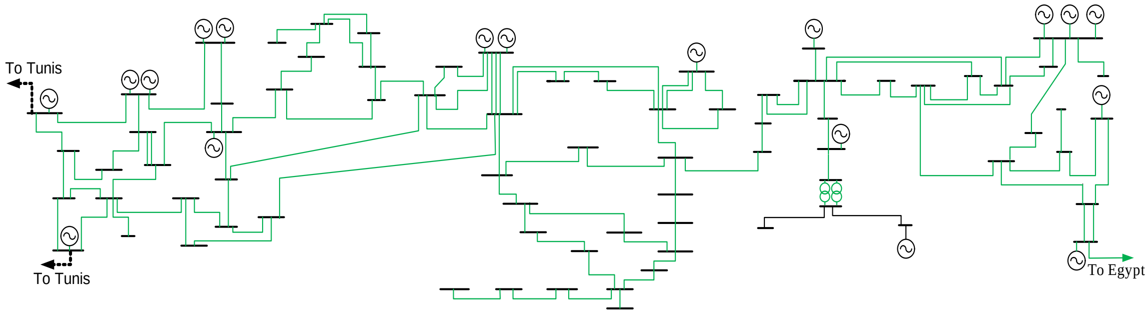

Figure 1 – Transmission power system of Libya

Since being constructed in a broad time interval, huge variety of technological solutions performed by distinct power utilities and companies can be seen in the transmission network. This can be taken mostly as an advantage for the operation of the entire system, because this technological diversity prevent the occurrence of massive faults caused by possible hidden defect in the appliances provided by only one manufacturer.

For covering the power consumption, over 62 generating units are connected to the transmission network of Libya. These are mainly steam/gas-turbine and combined cycle power plants along with several smaller diesel generators located in rural areas of the Sahara Desert.

Natural gas, residual fuel oil (heavy/light oil) and distillate are used as prime fuels. When comparing the volumes of individual prime fuels spent during each year, both heavy and light oils are used only complementarily (mostly due greater amounts of emissions released during the burning process). During each year, almost 40 percent of electric energy is produced by combined-cycle power plants, while 35 and 25 percents supplied by gas and steam power plants, respectively.

Libya is fully self-reliant in terms of electricity production. In 2008, total power generation was 28,666 GWh, while transferred electrical energy from neighbouring countries was only 66 GWh. Overview of all conventional electric power sources on 220/132 kV levels is shown in Tab. 1 below.

Table 1 – Overview of power sources in Libyan transmission network (220 kV, 132 kV), [5]

Steam power plants:

Substation name	Fuel	No. of units	Unit capacity (MW)	Total capacity (MW)
Homs	Heavy oil/Gas	4	120	480
Tripoli West	Heavy oil	5	65	325
		2	120	240
Derna	Heavy oil	2	65	130
Tobruk	Heavy oil	2	65	130

Gas power plants:

Substation name	Fuel	No. of units	Unit capacity (MW)	Total capacity (MW)
Abu Kamash	Light oil	6	15	90
Homs	Light oil/ Gas	4	150	600
Tripoli South	Light oil	5	100	500
Zwitina	Light oil/ Gas	4	50	200
Kufra	Light oil	3	25	75

Combined-cycle power plants:

Substation name	Fuel	No. of units	Unit capacity (MW)	Total capacity (MW)
Zawia	Gas	4	165	660
		2	165	330
Bengazi North	Gas	3	150	450
		1	165	165
	Steam	2	195	390

Private power plants:

Substation name	Fuel	No. of units	Unit capacity (MW)	Total capacity (MW)
Misurata Steel	Heavy oil/ Gas	6	85	510
Nahr	Light oil/ Gas	6	15	90

Similarly as in another countries lying in subtropical or tropical regions, electric power consumption in Libya is significantly higher in summer months than during the winter. This is caused especially by massive use of air-conditioners and ventilators in large consumption centres in the country. In 2008, the maximum/minimum load in Libya was 4,756 and 1,973 MW measured in July and March, respectively. In comparison, the maximum load in 2008 is more than 62 percent higher than in 2001.

Unfortunately, many problems are typical for the operation of the Libyan transmission system in respect to rather adverse operating conditions of the system. First, the majority of electric power installations (especially the overhead power lines) are located close to the sea. Therefore, all insulation parts on the lines and in substations suffer from salt sediments which may eventually cause numerous faults or even local blackouts. Second, similar problems can be found in areas close to the Sahara Desert, where the wind containing large volume of very soft sand may result in scratches on the outdoor insulators or even chokes of important power appliances inside the substations leading again to the fault. Third, relatively large number of illegal power consumptions occurs in the Libyan distribution network. Therefore, proper investigations must be carried out not only for reducing power losses created by these ‘black consumptions’ but also for increasing the reliability of the power system operation. Moreover, load flow studies examining current and future operational/failure state conditions of the system would correspond better to the real network behaviour.

Currently, electric power system of Libya undergoes the period of significant upgrades and developments corresponding to new global trends in the area of power engineering. Reasons for these changes are especially increasing tendency of electric power consumption not only in present large consumption centres in the north but also in developed localities outside the seacoast. To these challenges especially belongs the construction of the superior 400 kV power system, planned interconnections to foreign national grids, infrastructure reinforcements and capacities for incorporation of renewable power sources (especially photovoltaic systems and large wind power farms). The latter problems are further discussed in the following Chapter.

2. EMPLOYMENT OF RENEWABLE POWER SOURCES IN LIBYA

As already presented, natural gas and light/heavy oils are the only conventional energy sources in Libya. However, their reserves are rapidly decreasing. Total discovered resources are estimated to 1300 billion m^3 for natural gas and almost 40 billion bbl for oil. In other words, with current demand of both of these key resources, natural gas reserves would be depleted in approx. 390 years, oil reserves even in 50 years. In that time, counting only on conventional sources for covering the electric power consumption in the country would be highly hazardous. Therefore, many actions are currently under way to consider reasonable extent of other technologies for replacing conventional energy sources.

Libya has high potentialities to take advantage of electrical power generation from renewables, such as solar, wind and biomass. Especially, photovoltaic technology seems to be the most reliable in rural areas of Libya for its convenient use and economical attraction. According to MED-CSP (Trans Mediterranean Interconnection for Concentrating Solar Power), solar energy in Libya has the most promising potential of 140,000 TWh per year, while wind and biomass have only potentials of 15,000 and 2,000 TWh per year, respectively.

Concerning the photovoltaics, in spite of more than optimal climate conditions along with enormous number of possible locations, the share of solar power plants in total generation capacity in Libya was less than 0.1 percent (2006). Therefore, many projects for building photovoltaic facilities are in the construction/planning process for purposes of supplying small remote localities (e.g. villages in Sahara Desert), water pumping and heating, sea water desalination, concentrating solar power generations (CSPs), etc. Currently, approx. 500 new roof PV systems (440 systems already installed with peak power of 405 kWp) are in the construction process. Moreover, 6000 solar water heaters have been recently put into operation covering around 12 percent of total electric power consumption. Also, GECOL is intending to build a pilot solar power plant for sea water reverse osmosis desalination with production of 300 m^3 of potable water per day. Furthermore, one CSP facility (approx. 100 MW) is planned to be installed as well. In the future, this type of renewable power source is intended to be the one for replacing conventional resources when depleted. These units (along with similar installations in Morocco, Algeria, Tunisia and Egypt) will be a part of the European project DESERTEC combining the electric power generation in North Africa and electricity consumption in Europe by means of HVDC submarine cable lines.

With reference to electricity generation from the wind, the Libya has significant potential in many areas where the annual average wind speed is sufficient for building large wind power farms.
Therefore in 2002, GECOL started a special measurement campaign in prospective locations for building new wind parks. Based on regional wind resource assessments with respect to terrain topography and wind climate analyses, three sections of Libyan coast with various levels of annual wind speeds in 50 metres above the ground have been evaluated as the most promising for further studies: at the west (4.7 to 9.1 m/s), at the central (5.4 to 8.9 m/s) and at the east (5.6 to 10.4 m/s). In the eastern part of Libya, where higher annual wind speeds have been measured, GECOL has assessed five coastal sites with 40 metres high measuring towers and anemometers in 10, 20 and 40 metres above the ground. Found site locations are presented in Fig. 2.

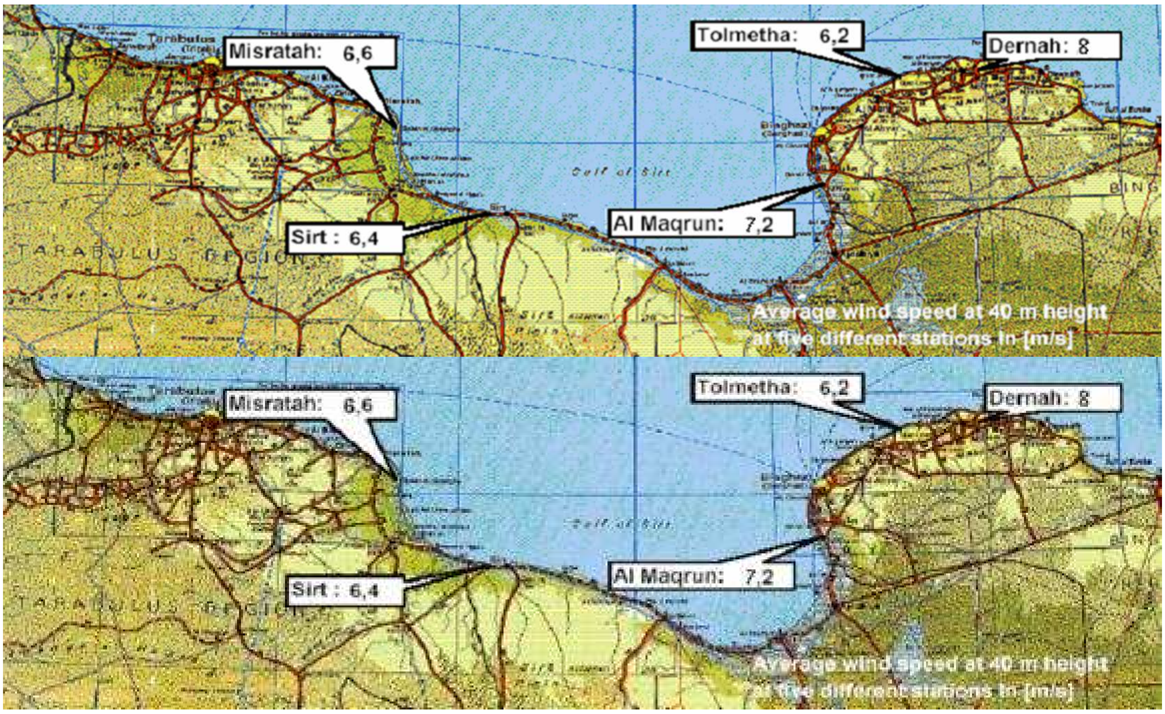

Figure 2 – Possible wind site locations on the Libyan coast [3]

These locations with their average wind speeds are Misratah (6.6 m/s), Sirt (6.4 m/s), Al-Maqrun (7.2 m/s), Tolmetha (6.2 m/s) and Derna (8 m/s). In remaining areas of Libya, GECOL evaluated other locations for possible wind farms (e.g. Al-Bayda, Aziziyah, Asaaba, Murzuq, Ghat, Ubari and Sabha). Various wind farm sizes (5 MW, 15 MW and 25 MW) and wind turbine types (< 1 MW, < 1.5 MW and > 1.5 MW) have been considered. Based on excellent measured conditions in Derna location, also due to logistical and operational reasons (especially transport of material to the seaport of Derna), pilot project of 25 MW was declared with estimated construction start in 2008. However, this concept has been thoroughly reviewed resulting in a more elaborated plan for the following decade concerning the wind power plants in Libya.

According to the new concept, a wind farm of 60 MW (1st stage) has been put into construction process in Fattaih area, Derna in May 2010. Another 60 MW (2nd stage) are scheduled to be finished until the end of 2012. In total, this power plant should consist of 37 turbines of 1.65 MW each with total installation costs of 103 million euros. Second wind farm project in Benghazi region (also to be realized in 2 stages) is in Al-Maqrun location with planned total of 240 MW, first half (80 Siemens turbines, 1.5 MW/each) being constructed since 2011. Other projects are the installations of 50 MW wind farms (25 turbines, 2 MW/each) in Misratah and Tarhona. Moreover, feasibility studies for building 120 MW wind farms are currently under way in the west (Asaaba), in the south (Gallo, Almasarra, Tazerbo) and in the south-west (Aliofra, Sabha, Ghat and Ashwairef) regions. These projects will be started during the next three-year term.

All these projects are strongly supported by Libya's government, GECOL and by government organization Renewable Energy Authority of Libya (REAOL) which is carrying out all planning and building operations relating to renewable power sources. By these huge projects, REAOL tries to reach the strategy target of 10 percent of electric power generation from renewables until 2020 with estimated capacity of 800 MW (CSPs), 150 MW (PVs), 300 MW (solar water heaters) and 1500 MW (wind).

3. LOAD FLOW ANALYSIS OF THE TRANSMISSION POWER SYSTEM OF LIBYA

In this research work, the Authors proposed the procedure for verifying the steady-state stability of the Libyan transmission power system using the conventional load flow analysis when it is operated with connected wind power farms.

Load flow analysis of the Libyan transmission network is relatively challenging due to several reasons. First, the transmission network is only sparsely linked interconnecting individual consumption points at long distances (quite often over 200 kilometres). Second, the entire system is rather over-dimensioned, i.e. markedly lower loadings than transfer capacities of transmission lines/transformers can be found in the network leading to the Ferranti’s phenomenon in some parts of the system. Therefore, large number of reactive power compensators (shunt inductors) is used almost at every substation to compensate capacitive currents in long lightly loaded circuits. Because of an insufficient capability for transmitting reactive power for long distances, however, bus voltage conditions can be strongly affected by these ‘artificial loads’. Then, it is almost impossible to model the network without exact loading values in each bus of the system. Third, approx. 61 percent of total electric power is generated on the 220 kV level when compared to 30 percent of power produced on the 400 kV level. Along with working interconnection to Egypt via a 220 kV circuit, it is more difficult to choose appropriate slack bus in the entire network for intended load flow calculations.

In this project, the authors decided to examine the possibilities of connecting new wind power farms into the Eastern part of the Libyan transmission power system. In total, this network segment contains two 400 kV, twenty-two 220 kV and three 132 kV buses. From the 400 kV network, only Sirt and Benghazi North substations with fully operational gas power plant in the latter one have been included. With power factor of 0.9, maximum MW loads for year 2010 have been used [5] for loads along with estimated power self-consumption (10 and 6 percent) in each of considered three steam and six gas power plants, respectively. Network topology with branch and shunt compensation data have been also provided by [5]. The 220 kV Benghazi North Power substation has been chosen as the slack bus for all simulations. Each PV bus in the network has been modelled with limited reactive power generations. Moreover, power injection from the 400 kV network to Sirt substation along with the inter-tie flows from Sirt to Zamzam and from Tobruk to Salum in Egypt have been included. Unfortunately, power flows in these circuits for a certain time interval were unknown. Therefore, their active and reactive power values must be reasonably optimized for preserving full active power generation in the slack bus and voltage profiles within their permissible limits (±5% in 400 kV, ±10% otherwise). To preserve the maximum supply system independency on surrounding networks, the objective function minimizing the total area interchange has been used.

For the optimization process, one particular non-commercial software package for optimization purposes – the NEOS Server [7] – has been used. The NEOS (Network Enabled Optimization System) Server contains a broad variety of solvers, divided into several groups according to the type of optimization task and capable to deal with a large number of problems including binary variables and nonlinearities. For each examined problem, the user needs to choose appropriate solver and formulate the problem in the input data file using a specific text format (e.g. GAMS, AMPL, MPS or others). Then, this input data file must be submitted to the NEOS Server, mostly through the e-mail or web interface. Next, the problem is sent from NEOS Server to a remote solver station, where the entire optimization process will be performed by the solver. Finally, when optimizing the objective function value, the solution is sent back to the NEOS Server and either it can be seen on the NEOS webpage or it is delivered to the user’s e-mail address, if required. For more information about the definition of the load flow problem as an optimization task - see [9].

For the verification of results obtained from the NEOS Server, professional programming tool PowerWorld 13 GSO version [8] has been employed. This software package enables broad variety of electric network simulations, such as the load flow analysis, optimal power flow (OPF), sensitivity calculations, AGC modelling, and others. Particularly, this software is useful for its easy operation and its ability for providing transparent visualisation of all outputs for each investigated problem.

In the first study, the load flow analysis of the intended part of the Libyan transmission power system has been performed without any wind power plant considered. The PowerWorld results can be seen in Fig. 3 below. All bus voltages are inside their permitted limits along with majority of branch loadings below 30 percent. The maximum branch loading of 67.4 percent was located on the overhead line between substations Bu Atni and Benghazi South.

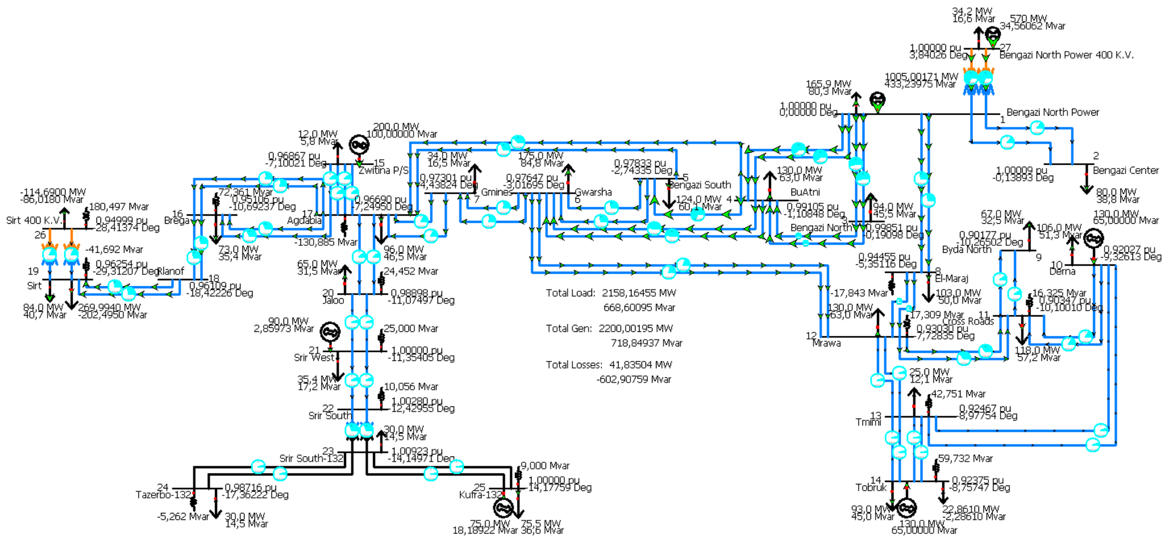

Figure 3 – Load flow solution of the first study (PowerWorld)

In the second study, planned wind power plant of 60 MW (application factor of 40 percent) has been connected to Derna, i.e. the active power in bus 10 has been increased from 1.3 pu to 1.54 pu. Cable lines connecting the wind farm to the transmission network have been neglected. The PowerWorld solution verifying the results from the NEOS Server is shown in Fig. 4 below.

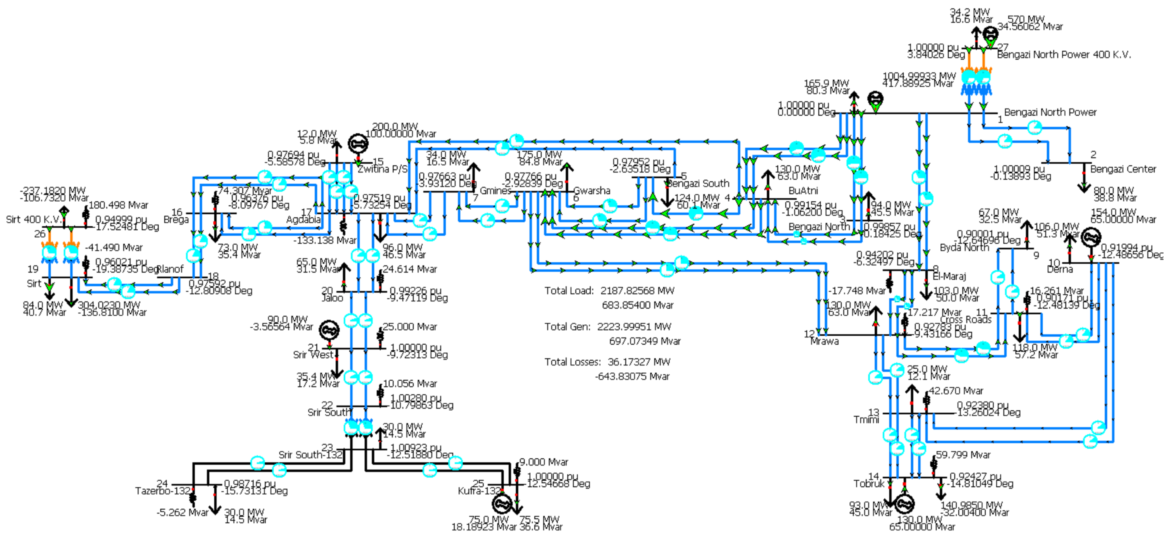

Figure 4 – Load flow solution of the second study (PowerWorld)

In the third study, the Authors estimated the loading conditions in Eastern part of the Libyan transmission network for year 2015 (with constant annual load increase of 8 percent) for maximizing the power generation from prospective wind power farms in Derna, Sirt, Gmines (Al-Maqrun) and Tazerbo. Possible new conventional power plants, buses and bus connections through new transmission lines and transformers constructed have been neglected. As the objective function, the sum of active power generations from all these four wind power farms had to be maximized. Active power dependent var limits in new PV buses (Sirt, Gmines and Tazerbo) have been used. The PowerWorld solution with maximum generation from all four wind power farms is shown in Fig. 5. In remaining two simulations, the maximum branch loading of 67.0 percent was located on each of both parallelly connected transformers between Benghazi North Power and Benghazi North Power 400K.V.

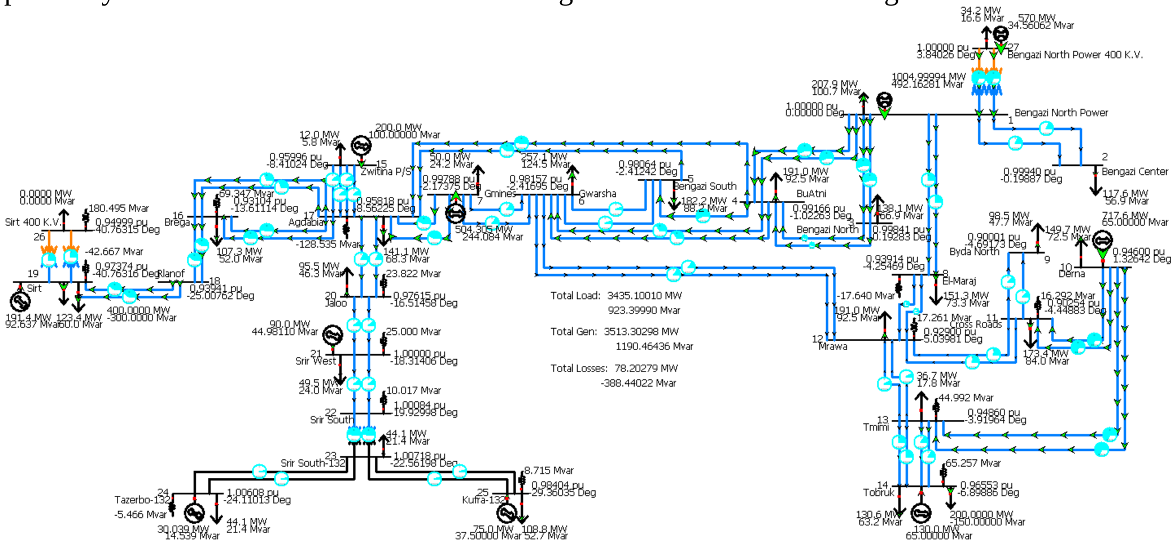

Figure 5 – Load flow solution of the third study (PowerWorld)

In Tab. 2, final comparison of planned wind farm generation capacities in individual four locations to relevant theoretical capacity limits computed using the NEOS Server is clearly stated. For all wind power plants except Derna, application factor of 30 percent has been employed.

Table 2 – Comparison of planned generations and corresponding theoretical capacity limits for individual wind farms

wind power farm	planned [MW]	theoretical [MW]
Derna	120	1794
Al-Maqrun	240	1681
Sirt	N/A	638
Tazerbo	120	100

As can be seen in Tab. 2, theoretical capacities for each proposed wind farm location are more than enormous. However, the theoretical limit for Tazerbo location is less than the planned generation. Understandably, more practical limits should be evaluated using the transient power system analysis since it will more simulate the dynamics of the wind power generation and related network responds to these impacts. Nevertheless, the steady-state analysis clearly specifies the ceiling of the electricity generation because the limits obtained from the transient analysis will be always lower.

4. CONCLUSIONS

In this paper, the introduction to the transmission power system of Libya has been presented focusing primarily on installation possibilities of renewable power sources (especially solar and wind). The impacts of current and planned wind farms on the behaviour of the Eastern part of the Libyan power system has been analyzed using the NEOS server (optimization problems) and PowerWorld (load flow solutions). Theoretical capacity limits have been evaluated for four planned wind farm locations.

Although these limits do not respect the dynamic response of the network to the wind farms, these theoretical limits provide at least the ceiling for the real limits which must be undoubtedly lower.

In future work, further steady-state analysis is proposed to be accomplished for the entire transmission network of Libya (also with the western part). When testing the entire system, however, convergence difficulties occurred due to significantly higher load values and strictly limited voltage margins in some of the network buses. This problem closely relates to the fact that some sets of input data concerning the network were unavailable, so they had to be estimated or guessed which eventually brought certain level of inaccuracy into the simulations.

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