Distinguished Keynote Paper:
On Quality Energy Management in a Third World Country: The Case Study of War Torn Libya

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ABSTRACT
The ever growing energy demands and the negative environmental impacts associated with global warming have pushed the policy makers toward adopting renewable energy sources. Unfortunately, the management of energy resources in many countries still fall short of optimizing the depleting nature of conventional energy sources and balancing them with untapped and abundant renewable energy sources. This calls for a detailed study on quality management of energy with the objective of minimizing losses and capitalizing on more efficient conversion methods of energy transfer for use in important industry applications. A good case study is in war torn country like Libya. Libya is one of the countries that recently struggles to satisfy its energy demand, although, the country has a high potential for solar energy. One major sector is electricity generation, which uses gas and fuel-fire to operate the turbines in the generation stations. Libya currently produces 33 TWH of energy to meet the demand of the local electricity market. The demand on energy will substantially increase in the near future as a result of economic development in order to build new infrastructure in Libya after the massive destruction that happened during the last four years. This will lead to more consumption of oil and gas, which causes a reduction in the national economical revenues, and more carbon dioxide emission. Therefore, Libya should use its alternative energy supplies to cover some of its load requirements. In this paper, we investigate the current energy situation in Libya while exploring the use of renewable energy to improve the current poor situation through some example scenarios. A quality management program of the energy landscape may be necessary as a way forward for the country to sustain any form of economic development amidst the shortage of energy resources in the country.

Keywords: Grid-Connected, Libya, PV, Renewable Energy, Rooftop, Solar Energy, Wind energy.

1. Introduction

Libya is one of the countries that is blessed with many natural resources. Oil and the natural gas are the main energy suppliers in Libya, which form around 90% of the country's revenue. The country makes one of the best location sites for solar energy and wind energy harvesting. Solar energy is among the fastest growing renewable energy technologies in the world. The large area, the high solar radiation and its geographical location near Europe make Libya an ideal country for solar energy harvesting. The average daily solar radiation ranges from 7kWh/m^2 to 8kWh/m^2. The average wind speed is roughly between 6 m/s and 7.5 m/s at 40m height. However, with the abundance of these precious renewable resources, the contribution in the Libya energy mix is still negligible [1]. It is interesting to know that solar energy in Libya has been used early on in the seventies. However, it is restricted to small remote loads such as communication repeaters, rural electrification, water pumping and Cathodic Protection (CP) for the oil pipelines in the desert.

The energy infrastructure in Libya is based on the conventional centralized fossil fuel-fired power plants, which are mainly fueled by gas and the oil reserves [2]. Additionally, oil and the natural gas exports contribute to most of the Libyan economic revenue. Before the civil war in 2011, the oil production was around 1.6 million barrels per day (mbb/day). If Libya returns to this production level, it will be adequate only for the next 29 years [3]. This triggers the alarm for an urgent and effective plan of investing into generating electricity from alternative energy sources. Recent studies show that PV technology can be comfortably and economically used in many applications in Libya [3-7].

Libya has an ambitious plan to increase the renewable energy share in the energy mix. However, this plan has faced many barriers and difficulties [6]. Due to the lack of the meteorological data and poor planning by relevant quarters and lack of instant resources, some renewable energy projects are delayed and while others are even suspended [6]. The renewable energy authority has focused on the centralized renewable energy projects [6]. In addition, the General Electricity Company of Libya (GECOL) is responsible for the generation, the transmission and the distribution of electric power, and has accordingly assumed a leading role in utilizing the PV technology leaving the private sector with little room for any active involvement.

For each process the organization should define indicators related to produced quality (efficiency, cost, time, resources, etc.) and information related to perceived quality. This latter information should be quantitative (ex.: average level of perceived performance) and qualitative (ex.: which are the main repetitive errors). Qualitative information will help the organization to better identify the causes of negative results or to anticipate these negative results.

The energy demands in Libya are increasing and they could result in having oil and gas exports reduced considerably. Additionally, distribution and transmission costs are avoidable when renewable energy is used and the energy source is sustainable. If the policy makers in Libya are aware of the precious solar energy resource, it can be an alternative for the hydrocarbon and saves the oil and gas.

One of the barriers that prevents the application of renewable energy in Libya is the poor research in the area of renewable energy. In this paper analytical data for the current and future energy situations are briefly presented. Simple models for prediction of the energy demands and the oil and natural gas prices are used. The challenges and obstacles faced by the renewable energy sector in Libya are discussed. In order to promote the application of renewable energy a number of recommendations are made.

2. Oil and Gas in Libya

Libya depends entirely on fossil fuel for meeting its electricity generation demands as shown in Table 1. The power plants in Libya depends on oil with an increase reliance on natural gas in recent years.

Table I Proven Oil and Natural Gas reserves

Year	The Proven Libyan Oil (Billion Barrels)	The Proven Libyan Natural Gas reserves (Trillion cubic meters)
1990	22.8	1.3
1995	29.5	1.3
2000	36.0	1.3
2005	41.5	1.3
2010	47.1	1.5
2015	48.4	1.5

2.1 The Current Oil Situation

Libya is one of the largest oil producers in North Africa and is currently producing around 1 mbb/d compared to 1.68 mbb/d before the civil war in Feb 2011. The total crude oil proven reserves **are** around 47.1 billion barrels [3]. The crude oil production during the last five years is as shown in Figure 1. The oil production was suspended because of the Feb 2011 events [3]. During 2012/13 the situation in the country improved where the production settles at approximately 1.4 mbb/d. Due to the spread of the militias who took control of some important refineries and oil harbors the oil production is suspended in the mid-2013.

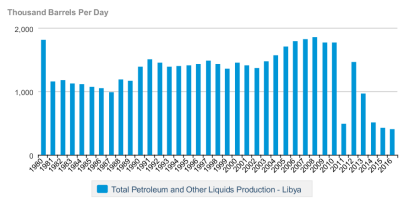

Fig 1 Libya crude oil production from 2010 to 2016 (EIA)

Before the 2011 events the main player in the oil industry was the state-owned company of National Oil Corporation (NOC) that has a target of 2.5 mbb/d by 2015 which was not achievable until the production returns to its pre-2011 levels. This recovery needs a secure environment in order for the companies to

continue the oil exploration in Libya. Most of the oil resource in Libya are in the Sirth Basin, the eastern part of the country as shown in Figure 2 and around 25% in the southern area, called Murzuk Basin.

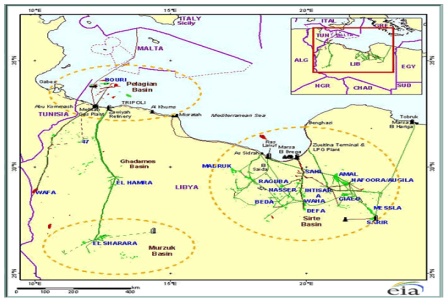

Fig 2 The distribution of the oil resource in Libya

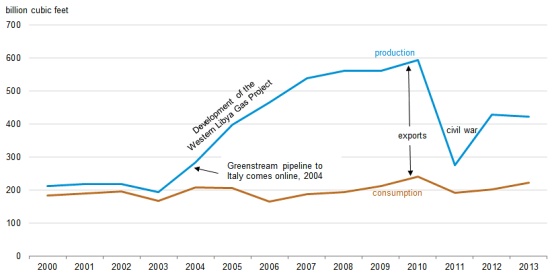

Fig 3 The natural gas production and consumption from 2000 to 2013

2.2 The Current Natural gas Situation

Natural gas is ranked as the second precious resource for energy production. The proven natural gas reserves reported in 2012 is 52.8 trillion cubic feet. Libyan natural gas production and consumption is shown in Figure 3, of which most of it is exported. The large change in the gas production starts when the gas pipeline between Libya and Italy starts production for export to Italy [3]. The increase in the gas consumption is due to the reliance on gas instead of oil for electricity production.

3. Electricity in Libya

The electricity consumption has been increased from 10 *TWh* in 1990 to around 33.98 *TWh* in 2012 in the last 3 decades as shown in Fig 4 and accordingly based on the normal growth could reach 90 *TWh* in 2030.

Libya relies on the oil and the gas reserves to generate its demands. The installed capacity is 8.347 *GW* while the available capacity is 6.357 *GW* [3]. The peak demand in the summer of 2012 was 5.98 *GW*. It is expected that peak load demand would be increased, but its value has not been reported because when the demands exceed the generation GECOL is forced to apply load shedding in order to secure the stability of the power system. The estimated peak demand in 2015 has been at around 8 *GW* as shown in Fig. 5.

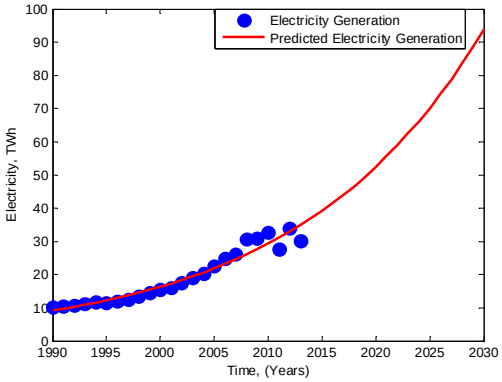

Fig 4. The electricity consumption from 1990 to 2015.

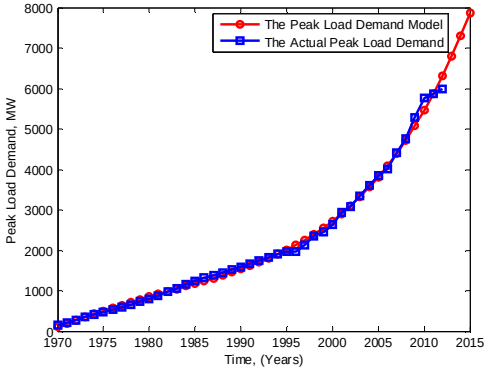

Fig 5. The peak demand from 1970 to 2015.

In order to save oil and reduce CO_2 emissions, GECOL increased its installed gas-fired power plants. Currently, the energy produced from oil is around 37% and from gas is 54% [2]. Libya has thus far 71 fossils-fueled generating units. This summary shows that the contribution of renewable energy in the Libyan energy mix is negligible. Additionally, the electricity is heavily subsidized and consequently Libya has the highest energy per capita in its region with 4,850 *MWh* per capita [2]. The losses too in the Libyan grid are very high because of infrastructure damage due to war-torn conditions and the lack of the maintenance in the last few years

4. The Renewable Energy in Libya

The renewable energy plan for Libya is divided into 4 basic phases as shown in Fig. 6 [7]. Due to the instability in Libya this plan is suspended resulting in unachieved 6 % target in 2015. As an example of the bad planning, the first phase of the plan was to build 60 MW wind-farms in the city of Dernah. The project lasted from 2008 to 2012. The farm consisted of 37 wind turbines, each rated 1.65 MW. Due to some issues about the ownership of the land used for the wind farm the project is delayed .

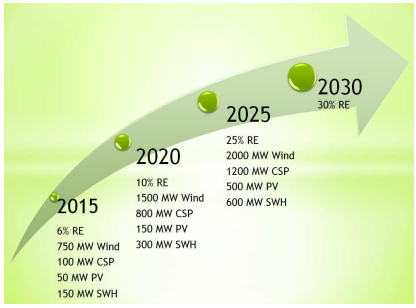

Fig 6. The Libyan renewable energy plan

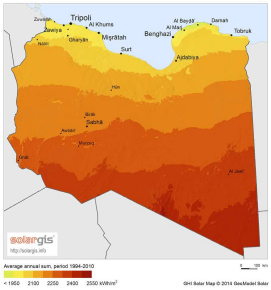

Fig 7. Libya map of Global horizontal irradiation

GECOL considered only centralized large scale renewable energy plants in their original work, which is insufficient. In order to promote renewable technology small and medium scale projects should be considered too. Depending on some studies for the load of around 75 kWh located more than 1.2 Km from 11 KV grids it is economical and most convenient to use PV system [8].

5. Solar Power in Libya

Libya enjoys a unique location with average daily radiation ranging from 7 kWh/m^2 in the northern region to 8 kWh/m^2 in the far southern regions with more than 3500 hours of sunshine annually. Its Global Horizontal Irradiance (GHI) (as shown in Fig 7) is distributed over an area of 1,759,540 km^2 while over 88% of Libya is a desert. Each square kilometer yearly in Libya receives solar energy equivalent to 1.5 million barrels of oil [3]. Libya has a small population of around 7 million. The installed solar capacity at the end of 2015 had been 5 *MWp*. Compared to Germany, the world leader in installed solar systems over an area of 357,168 km^2, Libya has approximately double the radiation. At the end of 2015, the installed PV capacity in Germany was 40 *GWp* that generated 38.5 *TWh* [9]. This amount of energy is slightly higher the energy consumed in Libya in 2012. Bearing these facts in mind, Libya needs around half the installed PV capacity in Germany (around 20 *GWp*) to satisfy its electricity needs.

Although solar technology has been developed from many decades, it has not been used in Libya for electricity production [5]. It was used in Libya for the first time to power Cathodic Protection for the oil pipelines in 1976 [8]. In the 1980s it was used to power the communication repeaters [8]. Eventually, it replaced diesel generators in most of the small remote loads. These systems are still running after 26 years and only the batteries were replaced with 8 years average lifetime [8,10-11] which show that PV technology had been a success from the technical and economic point of view. The applications of the PV systems are still limited to small scale systems. In this study, we investigate the feasibility of larger PV installation in Libya. Due to the increased energy demands, GECOL was forced to apply load shedding and the major cities remain without electricity for days. As most of the loads are domestic there is a strong correlation between the load demands and the weather. The peak load in summer is as a result of the excessive use of air conditioners while in winter is correlated with the excessive use of energy used for heating [4] [11].

6. The Wind Energy in Libya

Wind energy is the second best alternative renewable energy source. The wind speed in some coastal cities is shown in Fig 8. The average wind speed at three different heights in different cities of Libya is as shown in Figure 9.

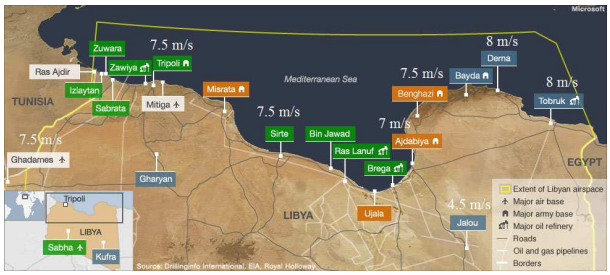

Fig 8. The wind speed in coastal cities in Libya

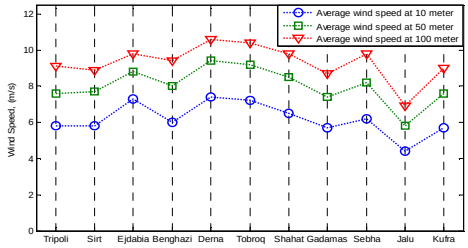

Fig 9. The monthly average wind speed in different cities in Libya

7. Discussion

The electricity in Libya is subsidized because the country adopted a communist economical system since 1969. By that time the consequences of this policy are clear in the irrational use of electricity by most of the Libyans. Additionally, the peculiarity of the weather and the inefficient design of the homes made the air-conditioning unavoidable. It can be concluded that the increase energy demands is not a result of the country's development but rather a consequence of the inefficient use of energy. Libya should initiate a subsidizing plan and legislations for renewable energy to create the awareness among the people of the long and short term impacts of the wasteful use of electricity. This can be done through the social media and TV channels, legislations and laws for using low power electrical appliances, Added taxes on the wasteful consumption of the electricity, initialize the renewable energy market from small-scale and medium scale projects with fix on simple, fast and easy installations, attract local and foreign investors into the Libyan electricity market, build pioneering projects for wind and solar energy. These systems will be pilot projects where real data on energy production could be available after a time. Additionally these projects will create awareness among local people, encourage education and training programs to qualify more people in the field of renewable energy technology.

One of the issues is the lack of information on solar radiation, wind speed and weather data. Building small pilot projects with data logging can be viable in this time. Research and development within such a huge country with high potential for renewable energy is badly needed. There is only one research center located at the western part of the country. Libya should build a number of research centers in different parts of the country.

Libya needs an urgent national plan to improve its energy sector. The current energy system is inefficient and unsustainable. The electricity is heavily subsidized which has resulted in the irrational use of electricity. GECOL should initiate policies producing thus more space for renewable energy choosing sites ensuring proper integration with GECOL supply network. Power electronic converters (DC-DC or DC-AC) are used as an interface between renewable energy sources and grid in the form of distributed generations (DGs). as shown in Fig. 11.

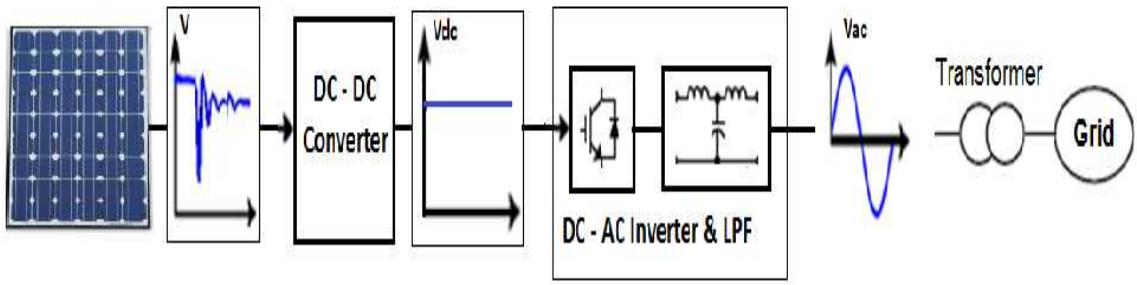

Fig 11. Renewable-to-GECOL Integration

The big issue faced in the integrated system (DGs) is the harmonics which are generated from the interface converters (see Fig. 12). Such integration will be associated with harmonics mitigation. This will necessitate more efforts in working on related areas of research.

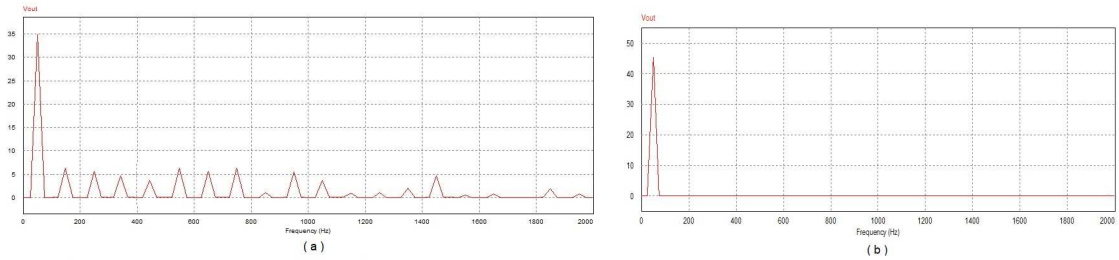

Fig. 12: (a) The harmonic issues (b) Ideal sinusoidal signal.

Using renewable energy with GECOL network will allow customers and the private sector to participate in developing the renewable energy sector. Additionally, the new technologies such as smart meters should be adopted to reduce the irrational use of electricity.

8. Conclusion

This paper provided an overview of assessing photovoltaic potential in Libya, with the aim of supporting the selection of optimal sites as regions of interest in the North and South of the country**.** The electricity energy demand is expected to grow very rapidly in the next few years. The perfect weather in Libya with plenty of land holds a promise of being one of the leading countries in renewable energy production. The share of renewable energy technology in Libya is still very low despite the fact that its geographic location is optimum for exploiting this technology. There is a great potential for utilizing home grid connected photovoltaic systems, large scale grid connected electricity generation using wind farms, and concentrated photovoltaic system. Solar energy resources in particular can be of great source of energy for Libya after oil and natural gas. Renewable energy resources offer good opportunities for technology transfer and international cooperation. Energy efficiency can be implemented in both energy consumption and production sides. Libya should think of immediate plans to increase its share from renewable energy.

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Authors' Backgrounds

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