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Potentials towards a Smart Grid in Egypt

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Abstract - *This paper reviews the concept and definitions of the smart grid, shedding light on the research performed on the smart grid applications in Egypt. The challenges and potential of the Egyptian electrical power sector towards promoting the smart grid were further reviewed. A detailed description of the various preliminary steps and initiatives taken by the government and the regulatory body in Egypt to promote a smarter grid in the country is presented. Despite being simplified, this review study highlights the key barriers/challenges and potential/opportunities for developing a smart grid in Egypt. It is concluded that although the challenges that Egypt faces are difficult ones, Egypt is capable of overcoming those challenges and moving forward towards promoting, developing, and establishing its smarter grid.*

Key Words: Developed country electricity, Egypt, Electric power sector, Electricity sustainability, Smart grid

1. INTRODUCTION

It was reported in the IEA Global Energy Review 2019 [1] that the global energy consumption in 2018/2019 increased significantly at almost twice the rate of growth since 2010. Moreover, the demand for all types of fuel also increased, and also the CO_2 emissions increased tremendously at a rate of 1.7% counting to about 33.1 Giga tons. Furthermore, according to the Global Energy Review 2019 the increase in the energy demand by sector and region were foreseen and projected to continue rising as shown in Figure 1 and Figure 2 respectively. Unfortunately, this expected rise was not met for the year 2020 as a result of the COVID-19 pandemic. This pandemic which is a global health crisis, has implications which are beyond the impact on health. It is dramatically affecting the worldwide economies, the global energy usage, and the CO_2/GHG emissions.

According to the IEA Global Energy Review 2020 [4], there was a declination of 3.8% in the 2020 (first quarter). All energy resources and fuels were and will be negatively affected. Fortunately, renewable energy resources were the only resource not negatively impacted; on the contrary, it posed a growth in demand during the pandemic and this is due to the larger installed capacity and its dispatch priority.

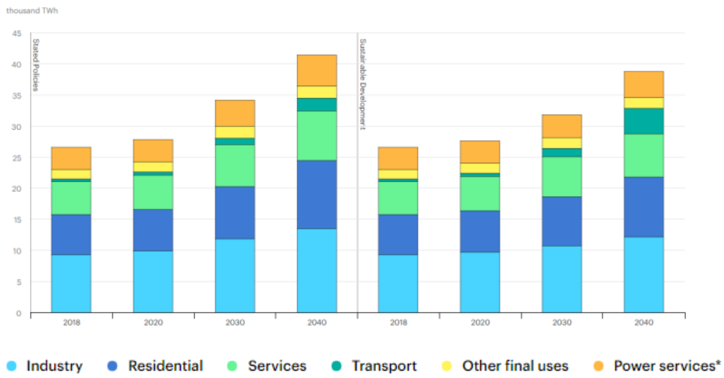

Fig - 1: Global demand of electricity by sector from 2018 till 2040 (projected) [2]

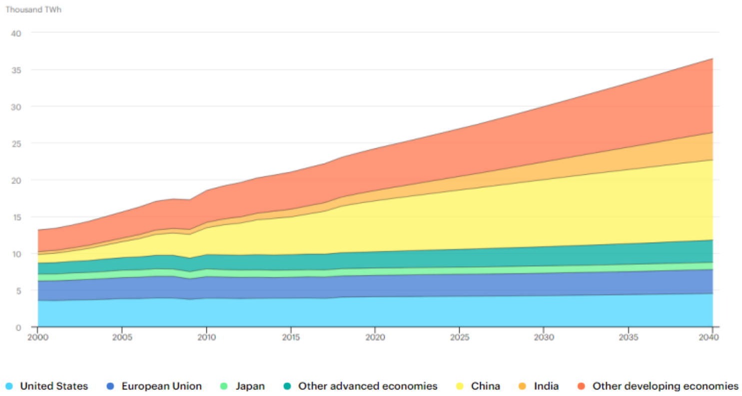

Fig - 2: Global demand of electricity by region from 2000 till 2040 (projected) [3]

The current scenario is that the energy demand contracts by 6%, which is the largest percentage in the last 70 years [4]. Figure 3 presents the annual growth rate of electricity demand over the last 20 years for various regions of the world revealing the significant declination in 2020. Despite that, it is worth noting that in most economies an increase in the residential electricity demand was observed. This is due to the lockdown measures where many people stayed home most of the time, and due to the increased indoor activities as telecommuting. Though, this reduction in energy and electricity demand is projected for the rest of 2020, a recovery is expected, and an increase for energy demand in the near future is estimated as it was earlier predicted before the pandemic.

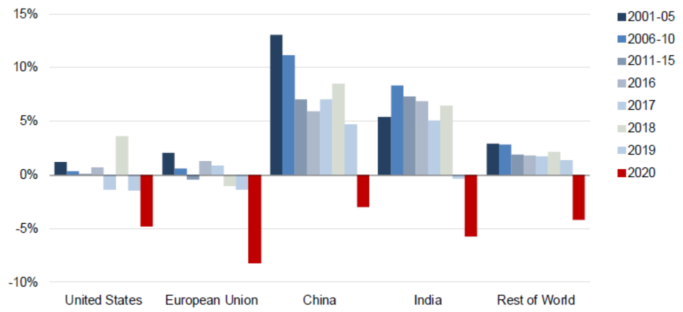

Fig - 3: Annual rate of electricity demand growth over the last 20 years for selected regions of the world [4]

Egypt is definitely one of the countries which experienced this pandemic similarly concerning the energy and electricity usage and demand. Even though, the energy sector in Egypt is impacted adversely due to the pandemic it is totally believed nationally, that this is not the end for Egypt's smart grid initiatives taken or renewable energy renaissance. Actually, a top Egyptian leader in the industry and energy sectors stated that "The drive will pick up again in around 18 months. As the economy and the population continue to grow, demand for electricity will rise with it. Long term, the recovery will give most investors and governments space to think about where to invest in the future of energy" [5, 6].

Definitely, the expansion of the Egyptian cities and the growth of population bring challenges associated with the increase in energy and electricity utilization. Accordingly, meeting the reliability in the Egyptian national unified grid currently has several challenges to face, this is due to the congestion of the grid, the increased electricity consumption, the power systems ageing infrastructure, the increased energy transfer over longer distances, and the increased peak demand. The development of the smart grid will provide many benefits including reduction of the power outages, reduction of the CO_2 emissions, enhancement of the energy efficiency, reduction of the electricity bills, improvement/enhancement of the reliability of the power system, optimization and increase of the renewables utilization, and reduction of the overall system losses. The amount of greenhouse gas emissions in Egypt are considered one of the highest in the world. Thus to face the dual issues of increased energy demand and increased emissions, Egypt is taking impressive steps to develop its smart grid and to optimize its potential for renewable energies utilization [7, 8]. Egypt totally believes that in order to achieve and rapidly accomplish sustainability as a developing country, the smart grid should be introduced and developed. This implies the deployment of smart meters, usage of advanced metering infrastructure, automated monitoring, measurement, and control systems, and integration of advanced ICT in the electrical power system grid. Smart grid also implies a new perspective for viewing the electricity consumers; they are to be considered as a hub acting both as consumers and producers of renewable clean energy. Integration and penetration of distributed renewable energy resources is another aspect of the smart grid development in the country [9, 10].

The paper aims to highlight how the smart grid poses a great opportunity for Egypt as a developing country; optimizing the use of its potentials and resources and enhancing the performance of its electrical power system via new advanced technologies. This paper also aims to shed the light on the initial steps taken in Egypt for the emergence, evolution, and development of the smart grid, so as to modernize the unified national grid and enhance the Egyptian power system as a whole. The rest of the sections are arranged as follows: Section 2 introduces the smart grid concept and development, giving a brief background of the smart grid and its definitions, and explaining its drivers, advantages, components, and technologies. Section 3 presents the smart grid studies with an interest of the Egyptian perspective for the smart grid concept development in the country. Section 4 gives an idea of the 3 main elements of the electricity sector in Egypt; generation, transmission, and distribution. Section 5 introduces the preliminary steps currently taken to implement the smart grid in Egypt. Section 6 concludes the paper.

2. SMART GRID CONCEPT AND DEVELOPMENT

This section gives a background of the smart grid and presents its definitions. Moreover, it introduces the key drivers for the development of the smart grid and its various advantages. In addition, it describes the components and technologies adopted for the smart grid evolution. Finally, a brief analogy of the smart grid and the human body is presented.

2.1 Smart Grid Definitions and Background

There is no consensus reached for a single definition of a Smart Grid. Despite the fact that several entities and organizations have set definitions for the smart grid such as the U.S. department of energy, the IEC, the IEEE, the European technology platform, and others, it cannot be stated that there is a single standard definition for the smart grid. This is mostly due to being a concept that is still under development [11-13]. The smart grid is an advanced modernized digitalized power system that allows bi-directional power flow. It has several characteristics such as resiliency, adaptability, self-healing, and sustainability under different uncertainties. It is also characterized with its interoperability and scalability having components and devices that are secured against cyber-attacks [11]. The smart grid concept brings together a number of technologies, presents many consumer solutions, and addresses a variety of drivers for regulations and policy. The vision of the smart grid is to maintain a system with efficient smart components and devices so as to reduce peak demand and power losses, a system that can determine and eliminate power outages by isolating and alleviating disturbances that might cause blackout of the grid [12]. Different components that a smart grid comprises are depicted in Figure 4. The smart components as numbered in the figure are 1. offshore wind farm, 2. electric vehicle, 3. residential consumers, 4. rooftop photovoltaic, 5. prosumer (producer and consumer), 6. industrial consumer, 7. data control center, 8. thermal power plant, 9. photovoltaic power plant, 10. small scale wind farm, 11. commercial consumer, 12. electric energy storage, 13. transmission network, and 14. distribution system. Thus, a modern smart grid is capable of accommodating renewable energy sources efficiently with a high level of energy management via automation and high tech telecommunications. A huge amount of data and information should be handled, transmitted, and controlled. A constant continuous control and efficient energy management are required for renewable energy sources so as to assure proper allocation of energy. This implies that the operation of the smart grid should be responsive in a real time manner and more efficient when it comes to generating, transmitting, and distributing energy. Hence, the role of advanced and modern technologies in a smart grid is extremely vital [14].

Fig - 4: Smart grid basic structure [14]

2.2 Smart Grid Drivers and Advantages

There are several drivers which are considered motivations for the smart grid development, some of these drivers are expressed as the need to:

- Assure energy sustainability and improve energy efficiency
- Enhance the reliability and security of the power system and attain an efficient control system
- Increase the integration of renewable energy resources and reduce the greenhouse emissions [11, 12]
- Meet the increased electrical energy demand and alleviate the increased electricity charge
- Improve the customers' services by providing easy access to pricing information and permitting the customers' control over their energy usage [12]
- Take advantage of the advancement in the information and communication technologies (ICT) to upgrade the electrical grid [11]

These drivers will boost the deployment of smart grid to modernize the conventional grid, which in turn means several advantages to the customers and utilities such as [12]:

- Reduction of utility bills
- Reduction of peak demand
- Reduction of the customer bills due to improved pricing strategies
- Business development and economic growth
- Renewables increased integration
- Increase of system reliability via self-governing control
- Enhancement Capacity and efficiency
- Increased resiliency against attacks
- Integration of several types of energy storage
- Provision of two way communication between utilities and customers
- Improvement of facilities utilization and deferral of new power stations building
- Accommodation of decentralized electrical power generation units
- Automation of both maintenance and operation of the power system
- Empowerment of forecasted maintenance and self-healing
- Reduction of greenhouse gas emissions

2.3 Smart Grid Components and Technologies

Smart Grid involves advanced products and services integrated with intelligent control, ICT, monitoring and self-curing technologies. What makes the smart grids stand out from the conventional grid is its utilization of sophisticated instruments, equipment, and devices; moreover, the intelligent services that it provides [11, 12]. The smart grid comprises several components and many technologies such as Telecommunication Systems, ICT integration for modernized protection systems, Smart management units, Energy storage units, Smart meters, Automated meter reading, Smart sensor, Phasor measurement units, Cloud architecture of smart grid. Highlights on some of these significant technologies that enabled the smart grid into reality are as follows:

2.3.1 Telecommunication Systems

The traditional communication network used for the conventional power grid control and monitor system depends mainly on communication means such as dial-up lines, wireless radio connection, and Ethernet. These means need to be upgraded to be able to avoid the congestion of high volume of data flow in a smart grid. Thus a wireless communication system structure is to be employed for a smart grid as it is more advantageous over wired communication, and will be reliable and available to handle huge amount of data flow. Moreover, it is an affordable economic communication system that provides high level of security of data transformed. In addition, satellite communication is capable of offering a full coverage and fast placement making it an advantageous communication system for a smart grid. However, some wired based communication systems are expected to be deployed into a smart grid such as, power line fiber optics communications. Figure 5 shows the telecommunication connections and the power networks connections within a smart grid.

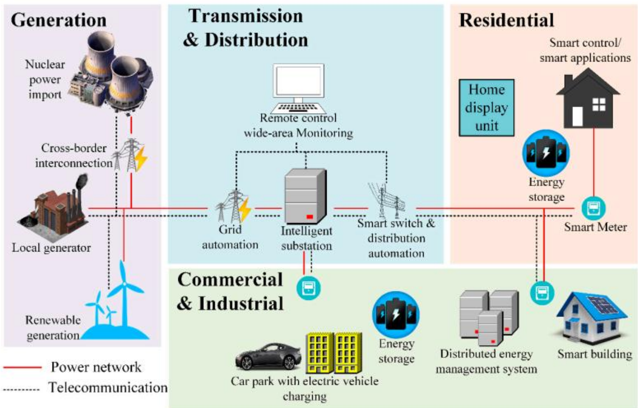

Fig - 5: Telecommunication and power network connections in a smart grid [12]

2.3.2 ICT integration for modernized protection systems

For a smart grid, a protection system should respond to unplanned unexpected cyber-attacks in addition to responding to conventional grid faults. A layer based ICT infrastructure has been proposed in [15] to be integrated in a smart grid protection control system to enable it to be resilient during a cyber-attack. Such attacks include but are not limited to purposely corrupt or change data in a smart grid, spy on targeted consumer's data, cause delay in data transmittal, and make exchange of information inaccessible. Figure 6 presents a schematic diagram for an ICT structure of a modernized protection system in a smart grid.

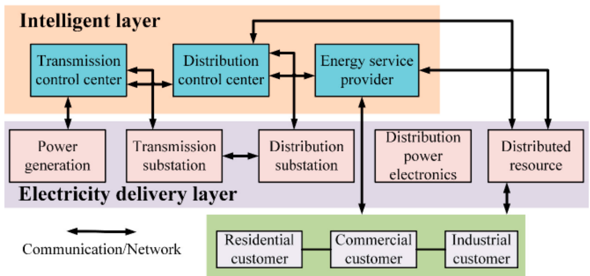

Fig - 6: Schematic diagram for an ICT structure of a modernized protection system in a smart grid [12]

2.3.3 Smart meters

The automated meter reading was primarily employed at the distribution level to enable the utilities to remotely read the consumers' consumption, alarms, and the status. As it is a one way communication, it was not that effective in taking corrective actions from the utilities side. Thus, automated/advanced meter reading were not that promising for a smart grid development. Hence, the smart meters were used in smart grids to overcome the advanced meter reading drawbacks. The smart meters have two main functions. First, they provide the customers with information about their energy consumption and this enables the consumers to have control over their energy usage. Second, the smart meters send information to the utilities allowing for load factor control and pricing strategies development. Proper implementation of smart meters can provide more than just recording the consumers' energy consumption, they can provide several benefits such as detection of lost energy possibly by fraud, early detection of probable blackouts, and fast detection of contingencies. Smart meters deployment will enable the application of demand response and demand side management schemes for efficiently using and saving energy. Research and development about smart meters has widely increased recently. Furthermore, addition of smart meters in several countries has also increased worldwide since early 2000s [11][16].

2.3.4 Smart sensors

Smart sensors are sensors that have the capability to process the recorded signals as analog signals then present them digitally. In addition, smart sensors address and transfer digital data via a bi-directional bus. It can also manipulate and compute the sensor derived data. Smart sensors automates the collection of data thus, more accurate collection and less errors in recording. Moreover, it embeds intelligence to process raw data to actionable information and therefore it enables taking corrective and predictive actions in real time manner [11].

2.3.5 Phasor measurement units

Phasor measurement units are devices that measures the branch currents and the bus voltages while using a general time source for synchronization. This allows for instantaneous synchronized measurement of different remote points on the grid. Phasor measurement units are considered to be of the key measuring devices in the future of smart grid systems. They are vital for monitoring and controlling voltage stability; additionally, they can alleviate and prevent blackouts and congestions. Phasor measurements units are incorporated with smart grid communications technologies, they will provide the smart grid with real time measurements that will in turn enhance the power delivery system [11].

2.3.6 Energy storage Units

Energy storage units are key elements in a smart grid. The usage of energy storage units in a grid has many benefits such as energy management, peak shaving, load shifting, frequency support…etc. Moreover, they assist in increasing the penetration of intermittent renewable energy resources as solar and wind energy within the smart grid. There are several types of energy storage units like electrochemical, electromechanical, electrostatic, and electromagnetic battery storage units [12].

2.4 An Analogy for a Smart Grid

In this section, an analogy of the smart grid and the human body adopted in [11] is presented. The evolution of the smart grid involves addition of 1- nerves, 2- brains, 3- muscles, and 4- bones. Addition of the nerves implies the addition of the sensors, metering, and measuring devices at the customer level and the grid level. The main aim here is to relay data from one smart entity in the system to the entire system. Examples of a customer level nerve system are smart meters and advanced metering infrastructure (AMI). And on the grid level advanced visualization technologies (such as synchro-phasors that measure current and voltage of transmission lines) are presented for both distribution and transmission grids to monitor the grid status widely and in real time. This enables optimum operation for the power system as well as fast response to problems occurring in the system. Moreover, addition of the brains implies the processing performed on the data sensed by the nerves and the effective use of the information. An example is the demand response at the consumer level via dynamic pricing, where the consumers change their consumption in response to signals received from the utilities. Furthermore, addition of the muscles implies the addition of distributed energy resources (DERs), energy storage units, and combined heat and power (CHP) plants and storage devices so as to increase the reliability and security of the grid. Also, the addition of the bones implies improving the transmission (via superconducting for example) and distribution lines to enable the communication of the power line and facilitate the DERs integration [11].

3. SMART GRID FOR EGYPT IN THE LITERATURE

Smart grid application is lagging behind in the developing countries when compared to developed countries. Yet, some developing nations started exploring the potential for smart grid application recently. Egypt is one of those developing countries which look forward to upgrading the existing power system grid and outlook the deployment of the smart grid [17]. There has been an overall increase in the number of publications over the past years in all categories and aspects of smart grid research globally [14]. Similarly, research interest in the smart grid has greatly increased recently in Egypt. Egypt was adopted as the study case in several research work such as [9, 18-30]. Reference [9] investigated an approach to upgrade the existing conventional grid to a smarter grid. The authors proposed a decentralized PID controller based on particle swarm optimization for a realistic power system in Egypt.

It was shown that the proposed decentralized controller performs similar to the centralized one; however, it is more robust and effective in case of large disturbances when compared to the centralized controller. Thus, the aggregated controller design is recommended for a more flexible control in the advanced smarter grid. Moreover, [18] proposed steps to alleviate the challenges facing the smart grid concerning the infrastructure investments of the renewable energy resources integration into an evolving smart grid via development of the associated regulatory standpoints. The steps to be taken into consideration when integrating renewable energy resources into the Egyptian grid were presented and assessed, bearing in mind lessons learnt from successful international examples and experiences. These were presented and recommended to regulatory entities as workable regulatory aspects for the implementation of the smart grid concepts. Furthermore, [19] reviewed the main features and concepts of a smart grid discussing the challenges facing its implementation in Egypt, and offering a perspective of the possible opportunities to be utilized to facilitate the evolution of the smart grid and its deployment in Egypt. Additionally, [20] focused on a proposed implementation of a demand response program in Egypt, which is one of the smart grid features. The paper investigated and compared a direct load control program to a pay-back program. The simulations were made using actual data from customers living in Cairo, Egypt. The results revealed that the proposed pay-back program is more efficient than the direct load control program, it was also shown that the proposed program can be implemented in Egypt. Moreover, [21] proposed an optimization algorithm for demand side management as a smart grid application in Egypt. It is a firefly based algorithm with an objective of minimizing the operational cost including consumed, generated, unserved, and lost energy costs. A day-ahead unit commitment for thermal generating unit and an economic dispatch of the committed units were also considered. This study used a real life 66kV, 45 bus distribution system of the Egyptian network in Alexandria city for verification of the proposed algorithm. This distribution network has several integrated distributed generating units. Also, [22] investigated the integration of a distributed generator wind turbine in a real distribution network of Tala City in Egypt. The impact of adding a distributed static compensator with the wind turbine is studied in regards to minimizing power losses. The optimal ratings and locations of the distributed generator and the compensator are determined using the enhanced gray wolf optimization technique. The study is performed taking into consideration the uncertainty in load demand changes. Furthermore, [23] reviewed the concept of the smart grid with a special focus on the Egyptian case. The technical and environmental benefits of applying the smart grid technologies to the electric power system in Egypt is presented. Opportunities especially those relevant to increasing the renewables as well as making good use of the geographical area for interconnecting with neighboring countries were elaborated; moreover, challenges as those relevant to investments, policies and aging infrastructure were also clarified. Likewise, [24] developed a digital model simulating the electric power grid of Egypt at 500kV level and 220kV level. The model was used to evaluate the system performance for steady state stability and transient stability at different operating scenarios. The grid performance compliance to the Egyptian Grid Code was also cross checked. Furthermore, [25] addressed the stabilization of the frequency of renewable energy system by proposing a model predictive control technique and comparing it to a PI controller based algorithm that uses particle swarm for optimization. The proposed technique is verified using the Egyptian power system grid composed of conventional generating resources and wind turbines, this was simulated using Matlab/Simulink. Additionally, [26] proposed an optimization plan for a residential area of a peak load equals to 160.2 kW and an annual energy consumption of 430 MWh in New Assiut city in Egypt. A hybrid energy system composed of photovoltaic, wind generators, fuel cell, diesel generator, hydrogen fuel, electrolyzer, and battery storage system. The size of these different generators are optimized using genetic algorithm rejecting no loads and selling the excess energy generated to the grid. The optimum economic (minimum cost of energy) and environmental (minimum CO2 emissions) configuration of the hybrid energy units was determined. Moreover, [27] presented a broadband power line communication system as an application for a smart grid. The proposed system is implemented over a typical medium voltage and low voltage power system in a new residential area in Egypt. The hardware for installing the broadband power line communication is addressed using noise filters to block unwanted signals produced from different residential devices and equipment.

In addition to the interest in smart grid research work elaborated up here, there is also an interest and potential shown from regulatory bodies and entities in charge of the electricity sector in Egypt towards the smart grid, where steps are being taken towards empowering the implementation of smart grid technologies. This will be elaborated more in the following sections specifically in section 5.

4. ELECTRIC POWER SECTOR IN EGYPT

Egypt is the 3rd most populous country in Africa, and has the largest population in North Africa, reaching over 100 million people [31]. Egypt has natural gas and oil as depleting resources; moreover, it has high potential for renewable energy through its promising wind and solar resources. The increase in the demand for electricity is increasing at an annual rate of 7% and a growth is expected to continue at this rate for the future [7, 18]. According to the Ministry of Electricity and Renewable Energy latest annual report of the fiscal year 2017/2018 [32], the Egyptian electricity sector companies are structured as depicted in Figure 7. The objectives and achievements of the generation, transmission, and distribution companies are elaborated in the following subsections.

4.1 Electricity Generation

The generation companies produce electrical energy at the affiliated power plants. The generation company is also responsible for managing, operating, and maintaining the affiliated power plants. The generation companies sell the produced energy to the transmission company, and also to the distribution companies at medium voltages. Electrical energy is generated from different types of resources. The installed capacity in MW of each source of these different resources are shown in Figure 8 for the 5 fiscal years from 2013/2014 till 2017/2018. It is shown that they increase with a 14.5% annual average growth rate for the shown

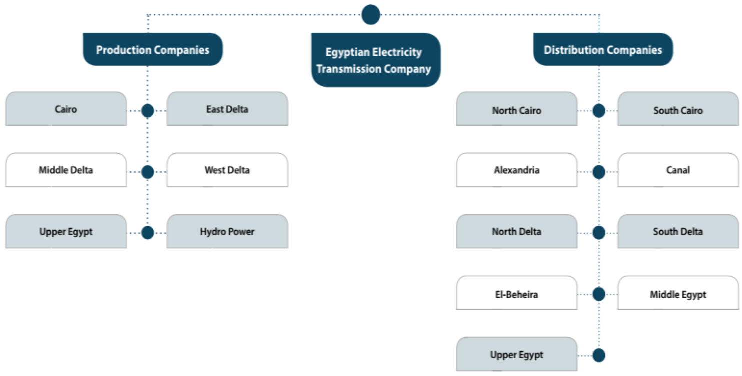

Fig - 7: Structure of the companies affiliated with the Egyptian electricity [32]

period. Figure 9 depicts the percentage of the capacity installed for each one of these various generation resources till 2017/2018.

The generation from renewables includes solar units of 50 MW of PV in Benban, Aswan. It also includes a solar-thermal power plant of 140 MW (with a solar unit of 20 MW). In addition, it includes a wind farm generation capacity of 967 MW. A 226 MW isolated and reserve units are also considered. These isolated power plants in addition to a 5 MW wind farm in Hurgada are not connected to the unified national grid. They are built to fulfil the load of some remote areas and some touristic places.

The total energy generated in 2017/2018 reached 196,760 GWh, and the peak load to be satisfied in 2017/2018 reached 30,800 MW. The increase in peak load during the same 5 years duration is illustrated in Figure 10. It is noticed that an annual average increase rate of peak load is 4.2% [32].

There is a number of planned future projects (2022-2027). Some of these are: 2250 MW combined cycle power plant in Luxor, 2640 MW clean coal power plant in Oyoun Mousa, 6600 MW steam power plant in Hamrawein, and a 2400 MW pumped storage hydro power plant on Attaqa mountain in Suez [32-34].

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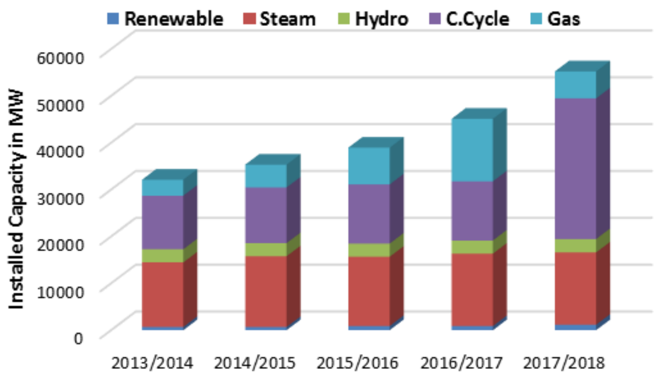

Fig - 8: Development of installed capacity for various types of generation in MW

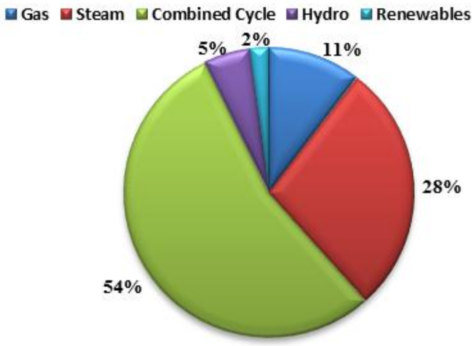

Fig - 9: Installed capacity percentage by the type of generation till 2017/2018

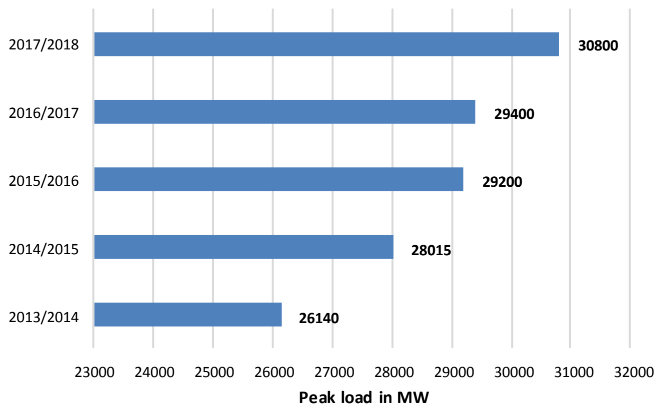

Fig - 10: Development of peak load in MW

4.2 Electricity Transmission

The Egyptian Electricity Transmission Company objective is to manage, operate and maintain electricity transmission over high and ultra-high voltages to the whole country. It organizes the loads over the grid via the national dispatch center and other regional dispatch centers. The company is also responsible for selling and buying the electricity over the high voltage grid as well as to the distribution companies. As per the transmission statistics for the year 2017/2018 [32], the total transmission transformers capacity reached 130,868 MVA with a total number of 670 substations and 2612 transformers. The total length of the high voltages and ultra-high voltages transmission lines reached 46,890 km. The transmission lines operates at different voltage levels. Figures 11-13 present the transmission capacity in MVA for the last 2 fiscal years announced, the total line lengths for the last 5 years, and the percentage of the lines lengths for each voltage level on the transmission grid [32].

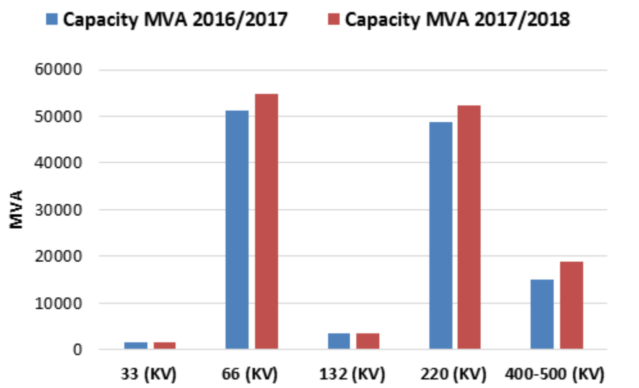

Fig - 11: Total MVA capacity for different transmission voltage levels in the Egyptian Grid

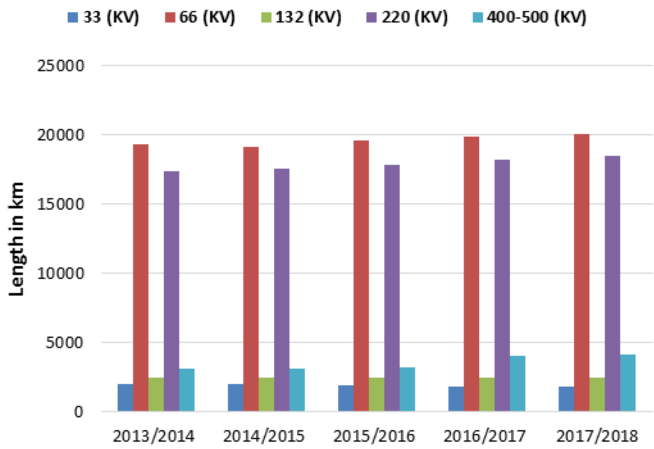

Fig - 12: Total line lengths for different transmission voltage levels in the Egyptian Grid

4.3 Electricity Distribution

Distribution companies sell the electrical power obtained from the transmission company to customers on medium and low voltage levels. It also manages, operates, and maintain the distribution grid as guided by the dispatch centers. Moreover, it performs load forecasting studies as well as economic and financial studies. The Egyptian distribution companies sold 131,150 GWh of energy for the year 2017/2018, to a total number of 35.1 million subscribers.

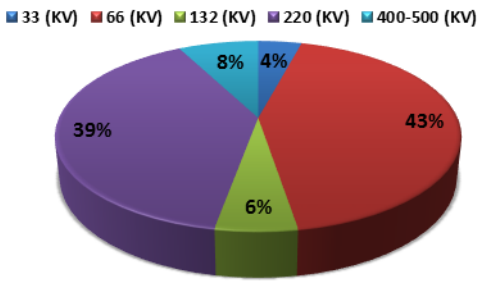

Fig - 13: Percentage of line lengths for each transmission voltage level in the Egyptian Grid

The increase in number of subscribers is depicted in Figure 14, showing an annual average increase rate of 3.5%. The total length of MV distribution network lines and cables is 197,741 km and for the LV lines they reached 288,867 km by 2017/2018. The development in the capacity of distribution transformers in MVA is presented in Figure 15, and that of the total distribution circuit lengths in km is shown in Figure 16.

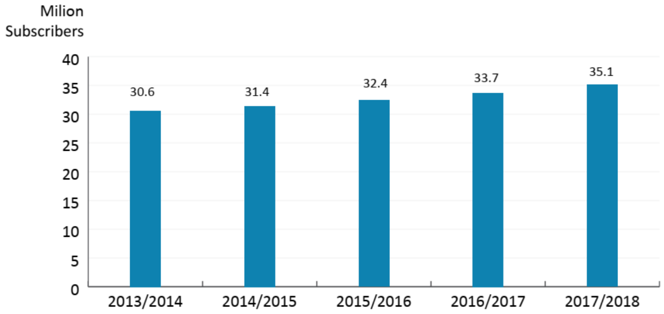

Fig -14: Number of subscribers in the distribution companies [32]

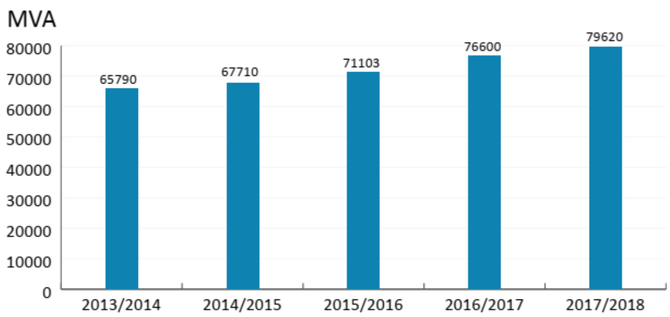

Fig - 15: Distribution transformers capacity in MVA on medium and low voltages [32]

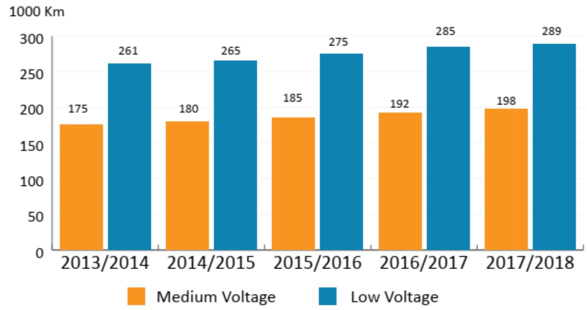

Fig - 16: Total distribution lines lengths on medium and low voltages [32]

5. CHALLENGES AND POTENTIALS FOR A SMART GRID IN EGYPT

The electric smart grid is regarded as a modernized network that is mostly composed of control via automation, energy storage systems, distributed generation resources, reliable efficient data communication, advanced metering, cyber security devices, advanced sensors, energy management systems, demand side management, demand response programs, and demand optimization tools [12]. The smart grid global perspective is almost identical; however, each country focuses on different aspects of the smart grid depending on its needs, capabilities, and resources. This section presents the challenges facing Egypt towards smart grid implementation and the preliminary steps taken by the country to overcome those challenges and promote the smart grid development.

5.1 Challenges for Smart Grid Deployment

Main challenges that Egypt is facing for deploying the smart grid technologies are infrastructure investment challenges, and regulations compliance challenges. Some of the examples for infrastructure challenges are the capital infrastructure expenditure for the smart grid, high costs of technologies relevant to smart grid implementation as sensors and advanced metering infrastructure, and huge data communication systems required. In additions, expenses are also needed to enhance the aging infrastructure. Moreover, there are challenges concerning the regulatory bodies as lack of experience among decision makers concerning the smart grid concepts implementation, and lack of coordination between relevant authorities in the electrical power sector [18].

References [17] and [35] suggested some main elements to be considered by the developing countries so as to facilitate the deployment of the smart grid. These are: 1-Redesign the transmission and substations system so as to reduce the energy losses due to the long transmission lines. 2-Redesign the distribution system such as to include intelligent control comprising flexible switches and smart sensors. 3-Integrate the renewable distributed generation intelligently using smart elements so as to maintain power quality against intermittent generation. 4-Apply load side management to lessen the load shedding using load control switches. 5-Supply electricity to rural communities via local charging stations. 6-Provide billing services via mobile phone and online payment. 7-Apply intelligent control through two-way flow of information by providing reliable efficient information system infrastructure. 8-High level of investment and financing is needed from the government and regulatory bodies. A pattern to be followed was also recommended so that when applied by the developing nations, they will accelerate the smart grid development. This pattern includes comprehending and realizing the necessity for smart grid, government and regulatory bodies support and investment, pilot project adoption, and integration of renewable energies.

Egypt is one of the developing countries that have tried to push the nation towards the modernization of the electrical power grid [17]. Though Egypt faces a lot of challenges concerning the renewable energy integration and the smart grid infrastructure, Egypt is working hard towards alleviating and overcoming such challenges. Some examples of these challenges which are specifically relevant to the smart grid infrastructure and renewable energies integration are the lack of the grid access, grid capacity limitations, high cost of connecting to the grid, lack of technical standardizations and certification, lack of maintenance facilities, need for developing an infrastructure and regulatory strategy, need for expertise in decision making, need for restructuring the electricity market, need for capital expenditure for the infrastructure, and the need for renewable energies assessment [18].

5.2 Steps Taken to Promote the Smart Grid in Egypt

Other than North America and the West of Europe, most of the world are at their early stages of developing their regulatory frameworks for smart grid implementation. In Egypt, the regulator has made adjustments to regulatory framework and worked with other government agencies to promote the smart grid deployment [7]. Policies are initiated and regularly updated to accommodate with the needs for the smart grid development. These policies yielded exceptional achievements, mainly is the great increase in the total installed capacity connected to the national electricity grid which reached up to 55,213 MW. Moreover, the peak load that reached 30,800 MW and was steadily met. In addition, stability of the electricity supply was maintained to all types of consumers who are about 35.1 million subscribers by the end of the fiscal year 2017/2018. In addition, a significant enhancement in the average rate of fuel consumption was achieved at the thermal power plants; this reached 206.3 g/KWh (generated). This in return resulted in reducing the CO_2 emissions by about 2.2 million tons/year. Furthermore, the availability of the power plants increased to 88.7%. Also, significant development of the electrical power network is accomplished at various voltage levels; hence, praise and recognition of the electricity sector was observed in all forums for its continuous contribution to the country's welfare [32]. This section sheds the light on several aspects of how the Egyptian electricity sector is working to promote and boost the development of the smart grid.

5.2.1 Encouraging and Enabling Integration of Renewables Technologies

Smart Grid concepts can accomplish the security in supplying the required electricity demand and also other benefits while paying less in electricity traditional infrastructure investment. Smart grid promotes renewables, thus achieving the supply security via integrating renewable energy resources smoothly in the country's unified grid. Egypt is planning and is taking preliminary steps to transform its traditional grid to a smart one by integrating renewables to the Egyptian unified grid learning the lessons from the international experience in this respect [18]. According to [7] Egypt has realized the necessity for a supportive regulatory system to advance and boost renewable energies in a positive sustainable way. The Electricity Utility and Consumer Protection Regulatory Agency (EgyptERA) has for the past few years had a major role in getting the framework and the sector ready for the broad integration and penetration of renewable energy resources. Egypt efforts to create this supporting frameworks to promote renewables are significant, this is due to her strong belief that renewables can be a means to alleviate poverty by providing almost free running cost energy source for lighting and cooking. Furthermore, to address both issues; the increase in demand and increase in CO_2 emissions, Egypt is moving with remarkable steps towards developing its renewable energy potential. Though Egypt is facing many challenges to bring the wind and solar energy to market, it is tackling those issues by working towards advancing its regulatory framework.

The Egyptian electricity sector set a strategy that is mainly focused on diversifying the resources for energy generation with an expansion for renewables utilization. It also targets to rationalize the conventional energy generation and encourage Egyptian investors as well as international ones from all over the world to invest in the development of renewables projects. Furthermore, it motivates and encourage the local industrial sector to explore and implement the manufacturing of renewable energy technologies and associated technologies. According to [32], "The new & renewable energy strategy aims to increase the share of energy generated from renewable sources to 20% of the total generated energy in Egypt by 2022, out of which 6% from hydro power and 14 % from wind and solar energy (photovoltaic cell systems)." There is continuous cooperation between different entities including the Egyptian Electricity Transmission Company (EETC) and the New and Renewable Energy Authority (NREA) to assure facilitating the increase in the renewables share in the energy generation, some aspects of this cooperation is represented in the plans set for the electrical grids to confirm and assure the efficient use of the electrical energy generated from the integrated renewable energies.

Moreover, plans are set to generate power from renewables via projects established by the government as well as projects established by the private sector. The coordination is also there to sign the Power Purchase Agreements of the energy generated by the private sector with a capacity of 1850 MW from:

- "A 250 MW Wind farm at the Gulf of Suez", "A 200 MW Solar Power Plant Project at Kom Ombo", and "A 250 MW wind farm project at Suez Gulf".
- 1150 MW at the Nile River west region from: "A 250 MW wind farm", "A 200 MW photo voltaic (PV) solar plant and another one with capacity of 600 MW", and "A 100 MW from solar power plants (CSP)".

A project adopted to install grid connected PV solar panels on the roof of buildings have reached about 23.5 MW to date. The total amount of energy generated from renewables in Egypt reached 47.2 GWh during the fiscal year 2017/2018. Figure 17 and Figure 18 present the installed power capacity and the total energy generated from renewable energy resources in the duration from 2013 till 2018. It is observed that from 2013 till 2018 the annual average growth rate is 16.7% for the energy generated from renewable energy resources.

It is worth noting that a solar/thermal plant with a capacity of 140 MW (with 20 MW solar unit) entered commercial operation in Kuriemat as the first one of its type in the country. Furthermore, the first grid connected PV power plant with a capacity of 50 MW was operated in Benban in Aswan city and was integrated to the national grid in 2018.

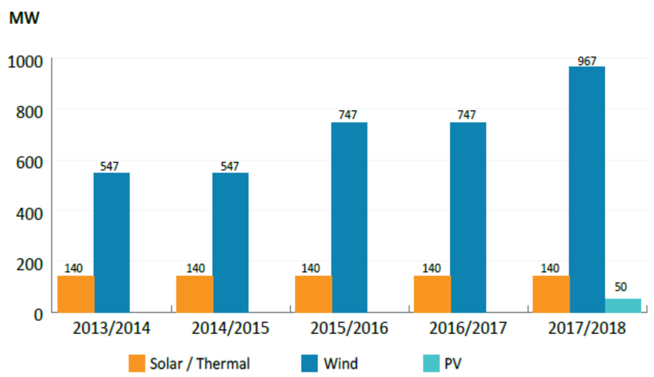

Fig - 17: Total installed capacity from various renewable energy resources in Egypt (excluding a 5 MW wind plant at Hurghada) [32]

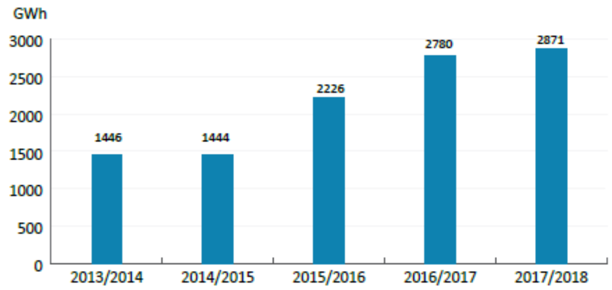

Fig - 18: Total energy generated in GWh from various renewable energy resources in Egypt [32]

5.2.2 Demand Response Programs Initiation

Currently, the demand response (DR) program that is applied in Egypt is similar to a direct load control (DLC) in the sense that it is based on shutting down and cutting off loads and shifting the supply of the electricity to the consumers by the operator/utility. The DLC tries to reduce the participant load demand via direct control from the utility of the participant/customer loads.

In the DLC there is a contact between the customer and the operator where the customer prioritize the devices and report that to the operator so as to consider it when shutting down the electricity. Due to the lack of advanced technology implementation; unfortunately, this type of DR is not deployed yet in Egypt. Hence, the electricity is completely shut down randomly in various areas/regions according to peak load and peak time. The network operators in Egypt directly disconnect the supply without any prior notifications. Thus, currently the electricity sector applies the DLC with no agreements or contacts with the consumers, and cut off the supply anytime and anywhere [20].

The planned advancement in the electricity infrastructure and the initiatives taken to implement automation for monitoring and controlling of the power system grid, and also starting the deployment of smart meters in various cities in Egypt will pave the way for the proper and correct application of DR programs in the near future. Table 1 shows the planned tariffs for selling electricity, the prices are assigned based on a 92% power factor. According to the report [32] published by the Ministry of Electricity & Renewable Energy for the fiscal year 2017/2018, "The ToU tariff is applied in accordance with the smart meter application program, and the peak hour duration is 4 hours starting at a time defined by the Ministry of Electricity & Renewable Energy". Tables 2 and 3 present the tariff for the electricity usage in both residential and commercial buildings respectively. It is shown by the set tariffs how the government motivates the customers to reduce their energy consumption in order to pay a lower monthly tariff [20, 32].

Table - 1: Electricity selling tariffs for different customers at different voltage levels in Egypt [32]

Purpose of use	price of capacity(1) EGP/KW month	Average price of energy(2) Pt./KWh	Off-peak(3) Pt./KWh	On-peak(3) Pt./KWh	Customer service EGP/customer-month
Ultra-High Voltage(132-220 KV)					
Kima	-	60.00	-	-	
Subway	-	85.00	-	-	35
Rest of customers	30	96.4	89	133.5	
High Voltage(22-66 KV)					
Subway	-	90.00	-	-	35
Rest of customers	40	101.5	93.7	140.5	
Medium Voltage(11-22 KV)					
Irrigation	30	80	74	111	
Water and Sanitation Co's	0	115	0.0	0.00	35
Rest of customers	50	105	96.9	145.4	
Low Voltage(380V)					
Irrigation	-	50	-	-	4
Water and Sanitation Co's	-	110	-	-	
Rest of customers	-	110	-	-	-
Public lighting	-	110	-	-	

5.2.3 Electrical Transmission Interconnection

Egypt has an objective of being a central hub for energy. It is adopting new policies for trading energy at regional as well as international levels via electrical transmission interconnection with neighboring countries and by being a part of energy pools both regionally and internationally. Egypt has a 400 kV interconnection with Jordan and a 220 kV interconnection with Libya with a total sold and exported energy in 2017/2018 of 225 GWh and 170 GWh to each country respectively.

Table - 2: Electricity selling tariffs for residential customers [32]

Consumption brackets (KWh/ month)	Pt./KWh	Customer service EGP/ customer-month
0-50	22.0	1
51-100	30.0	2
0-200	36.0	6
201-350	70.0	11
351-650	90.0	15
651-1000	135.0	25
0 - more than 1000	145.0	40
Read by Zero	-	9

Table - 3: Electricity selling tariffs for commercial customers [32]

Consumption brackets (KWh/ month)	Pt./KWh	Customer service EGP/ customer-month
0-100	55	5
0-250	100	15
0-600	115	20
601-1000	145	25
0-more than 1000	150	40
Read by Zero	-	9

Figure 19 shows the exported and imported electrical energy over these interconnections in the last 5 years. A 500 kV interconnection with KSA will have a capability of transmitting 300 MW over a HVDC bipolar transmission connection is under construction. Moreover, a 220 kV interconnection with Sudan for transmitting 300 MW is also planned and studied. In addition, among its effort to be an energy hub in the region, Egypt is working on being a part of the Eastern Africa Power Pool countries. It also joined several entities and organizations such as the Association of Mediterranean Transmission System Operators (MED-TSO), the Union for the Mediterranean (UFM) and some other international organizations. Furthermore, the interconnection between Egypt, Cyprus, and Greece is under study. Figure 20 presents the Egyptian perspective for being an energy hub of the region.

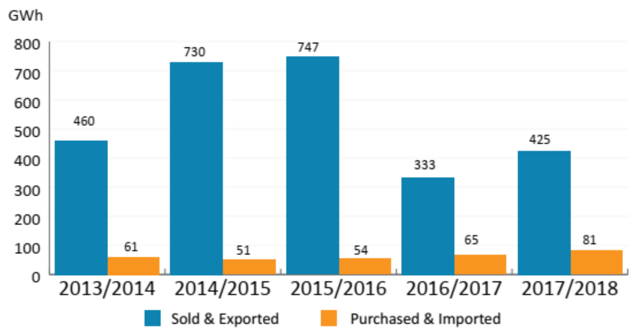

Fig - 19: Total exported and imported energy over the Jordanian and Libyan interconnections [32]

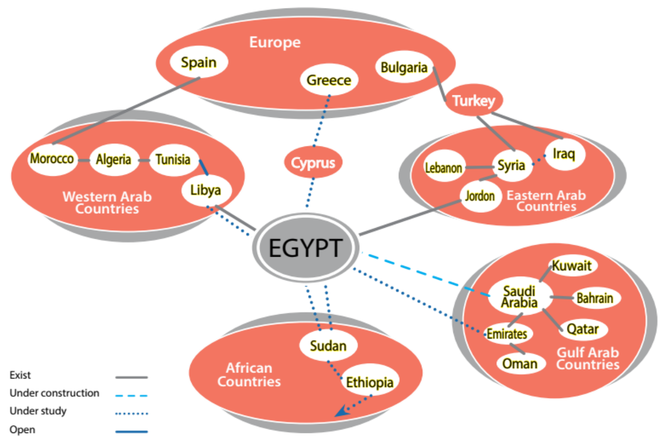

Fig - 20: Egypt as a central energy hub of the region [32]

5.2.4 Distribution Networks Energy Efficiency Improvement

The Egyptian Ministry of Electricity and Renewable Energy signed an agreement with a Japanese agency to fund a project for establishing a smart network within 3 distribution companies with a total fund of 24.762 billion Japanese Yen. The aim of this integrated smart grid at the distribution level is enhancing the network performance efficiency, reducing the thermal emissions and CO_2 emissions, and decreasing the electric energy losses. The project planned implementation duration is 60 months. The agreement contract was signed in 2016 and came into force in 2017 [32].

5.2.5 Distribution Companies' Dispatches Development

The performance of the distribution companies and distribution companies was enhanced via the establishment of 14 new dispatch centers at the distribution companies. These dispatch centers use the up to date most recent technologies in control and communication systems used for monitoring and controlling the distributors, the transformers, and the distribution stations medium volt side in a reliable and safe way.

This development of the dispatch centers was deployed in two phases. The first phase comprised the establishment of 5 dispatch centers in about a year and a half in 3 distribution companies in 2 cities; Cairo and Alexandria. Following that 9 more dispatch centers were established in the second phase also in about a year and a half in the rest of the distribution companies [32].

5.2.6 Smart Meters

A protocol of cooperation was signed in 2016 with the National Defense Council to support the security and privacy to develop and establish the information systems and the databases required in the fields of smart meters and their applications, so as to keep the confidentiality of information and data at the electrical distribution companies. In 2017 the contract for supplying, installing, and maintaining the advanced meter infrastructure systems for a pilot project comprising 250,000 smart meters in 6 distribution companies. A total number of 2000 meters was installed in those 6 companies, and the supply of the equipment needed is ongoing to start the preparation of the data centers [32].

5.2.7 Pre-paid Meters Unified Management Program

The expansion of pre-paid meters started in Egypt in 2011 and the number of installed meters reached 6.3 million meters by the end of 2018. The advantages of using the pre-paid meters is to achieve financial liquidity for the utilities from pre-payment of the electricity usage charging amount, and also to avoid the wrong estimation of the energy consumption from the consumer side and to eliminate the high electricity bills.

A project for establishing a Unified Program for the management of pre-paid meters is prepared in cooperation with the Ministry of Defense. The main objectives of such a program is to find a unified central system for charging these meters. Moreover, to obtain standard reports from all companies and utilities so as to assist in the decision making process. In addition, this program will facilitate the card charging services via electronic venues and different charging centers at the distribution companies and even possibly operating new charging center branches. Operation of the Unified Program started in 2 distribution companies and the program implementation is ongoing in the rest of the companies in the country successively [32].

5.2.8 Energy Efficiency Enhancement and Rationalization

Street lighting

The supply and installation of 2.6 million high pressure sodium street lights and 100-150 watts LED luminaries were supported by 4 Egyptian governmental entities including the Ministry of Electricity & Renewable Energy, costing a total of 2.1 billion Egyptian pounds. Until October 2018, the supply of 2.2 million lights was accomplished and 2.1 of them were installed.

Residential lighting

A plan to distribute 13 million energy saving lamps for residential purposes across the country was fulfilled by supplying 13 million lamps by October 2018, and distributing 11.9 million technically tested lamps to the distribution companies.

Governmental, Industrial and Commercial Sectors

Several studies were performed for rationalizing and justifying the electrical energy consumption in the governmental premises, buildings, and public utilities. Moreover, some studies were done in the commercial and industrial sectors, raising the awareness in all the cities all over the country [32].

5.2.9 Electricity Re-Pricing

The Egyptian regulator recognizes well the objectives of the internationally pricing policies and thus the electricity prices are set so as to realize the financial efficiency of the utility, to cover the costs for each supplying voltage accordingly, and to assign electricity usage indicators that properly reflects and consider the social aspects and dimensions of the consumers, this is depicted earlier in Tables 1, 2, and 3 in section 5.2.2. The Electricity Utility and Consumer Protection Regulatory Agency (EgyptERA) reviews the electricity prices/tariffs set by the Ministers' Council via the Electricity Tariff Restructuring Plan for selling electricity, and to report proposal and recommendations for adjusting the set prices so as to provide the balance between the utilities and service providers, and the consumers. The Ministry of Electricity & Renewable Energy issues Decrees to modify the selling tariff of electricity regularly whenever there is a necessity for that [32].

6. CONCLUSION

There is no doubt that the electricity sector has been experiencing and witnessing recently noticeable significant advancement and innovations globally, and Egypt is no exception. The move towards a more sustainable electrical energy system via the transition to a smarter grid is a great challenge for the Egyptian electrical power sector. Smart grid provides great benefits and solutions to the electric power system including the increased system reliability, sustainability, resiliency, and efficiency; moreover, reduction of energy losses and integration of renewable energy resources are also some benefits to name. In this study, a review of the concept and development of the smart grid is presented, where a background of the concept and the definitions of the smart grid are described. Also, the components and the various technologies of the smart grid are explained. To address the application of the smart grid in Egypt, first the research work and the studies in the literature that addressed the smart grid for the last few years in Egypt are reviewed; then, a brief introduction of the electrical power sector in Egypt is presented. Afterwards, the challenges facing Egypt in deploying the smart grid concept and technologies are explained, followed by a detailed description of the various steps and initiatives taken by the government and the regulatory body in Egypt to promote a smarter grid in the country.

Despite being simplified, this review analysis sheds the light on the key barriers/challenges and potential/opportunities for developing a smart grid in Egypt. This review study contributes to a better understanding concerning the Egyptian electrical power sector status and its planned and initiated advancement. This work also aims to build on the efforts of other Egyptian researchers in the field of smart grids in accordance with Egypt's social, economics, and political context.

From this review, it can be concluded that although the challenges that Egypt faces are great ones, Egypt is capable of overcoming those challenges and moving forward towards promoting and developing its smarter grid. This was revealed via determining the steps already taken by the country in that concern including: encouraging and enabling integration of renewables technologies, demand response programs initiation, electrical transmission international interconnection with the neighboring countries, distribution networks energy efficiency improvement, distribution companies' dispatches development, smart meters installations, pre-paid meters unified management program application, energy efficiency enhancement and rationalization, and electricity re-pricing policies.

It has been noted by the research done in the smart cities field that cities become rapidly smarter when the government, regulatory entities, industry, and academia/research institutes communicate, collaborate, and work together for the good of the country [10]. The author plans to work on investigating this matter in Egypt concerning the aspects of collaboration between different entities in the country, and its impact on the process of developing and implementing the smart grid technologies in Egypt.

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