2022 IEEE 63rd International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON) | 978-1-6654-6558-8/22/$31.00 ©2022 IEEE | DOI: 10.1109/RTUCON56726.2022.9978866



# Effect of New Renewable Energy National Projects on Voltage profile and Reliability of 500 kV Egyptian Power System

Mahmoud Aref,
Department of Electrical Engineering, Assiut University, Assiut, Egypt;
Ural Federal University, Yekaterinburg, Russia
mahmoud.aref@eng.aun.edu.eg

Vladislav P. Oboskalov
SEC «Reliability and Safety of Large Systems and Machines» UB RAS, Ural Federal University
Yekaterinburg, Russia
VPO1704@mail.ru

Anatolijs Mahnitko
Power Engineering Institute, Riga Technical University
Riga, Latvia
mahno@eef.rtu.lv

Aleksandrs Gavrilovs
Network Development Function
JSC Sadales tikls
Riga, Latvia
aleksandrs.gavrilovs@sadalestikls.lv

***Abstract*—Currently, renewable energy sources such as solar and wind energies are increasingly used in the Egyptian power system. However, the large-scale renewable energy source of the intermittent type requires better management with a proper understanding of the changing characteristics of the grid and its protection systems. Knowledge of the reliability of distribution networks is an important factor in system planning and operation for the development and improvement of power distribution systems. To achieve minimal interruptions in consumers' work, utilities must strive to improve reliability at a low cost. Most customer service outages are known to be caused by a malfunction in the distribution system. This article examines the impact of new national renewable energy projects in Egypt on the voltage profile and reliability indices of the Egyptian 500 kV power system. The Electrical Transient Analysis Program (ETAP) was used for investigations.**

***Keywords—Voltage profile; Reliability; Egypt; PV; Wind***

## I. Introduction

Due to the adaptation to the new way of life, the demand for energy in the energy sector is growing rapidly day by day. Overloading the distribution system and its consequences in the form of higher voltage deviations, overloading of feeders and increased losses in the distribution system have a negative effect on the quality of the system. Global warming and dwindling fossil fuels also make it necessary to find more efficient alternatives that provide the correct operating level of energy loss and voltage profile at different points in the distribution network. Renewable distributed generators (DGs) can be considered as the most suitable step-up devices for distribution systems, which reduce both pollution and energy losses, resulting in an improved voltage profile. Egypt has an excellent wind regime with wind speeds of around 10 m/s in many areas. The disadvantage of wind energy is its seasonality. Therefore, if wind power is to supply an important portion of the demand, either standby power or electrical energy storage system (EESS) will be required to provide reliable power to the loads. The integration of renewable distributed generators, such as photovoltaic (PV) systems and wind turbines (WT) into distribution networks, can be considered an excellent and efficient solution to meet the growing demand for energy.

Many research papers are being studied the Egyptian power system. In a literature review, solutions were used to improve the voltage profile of the Egyptian Delta power grid to achieve voltage quality by applying voltage levels (66, 11, 6.6, 0.4) kV in the Egyptian Delta grid with four different scenarios: power flow during normal operation, automatic Tap Changer (ATC) for transformers, a Static Volt Ampere Reactive (VAR) System(SVS) with (ATC) and a (SVS), (ATC) and shunt reactive power compensation devices (parallel capacitor/inductor) presented in [1]. The optimal placement of CBs, DGs and AVRs on a part of a real old, long, bad and heavily loaded Egyptian distribution system with high power losses (about 29% of the system load) and poor voltage regulation (about 30%) has been investigated in terms of reducing energy losses and reducing investment costs [2]. In ref. [3], Optimizing wind hybrid power distribution together with a proton exchange membrane fuel cell (WE/PEMFC) system was used to improve the performance of an electrical power distribution system (EDS). The system load demand was expected to reach by 2022 for the city of Marsa Matruh as part of the Egyptian distribution network, and a hybrid WE/PEMFC system design was being implemented.

Three multi-objective optimization methodologies were presented as a solution to improve the traditional technical and economic performance of EDS by integrating DG from different classes [4]. A review of the hybrid power system and a detailed analysis of steady-state and transient stability were presented. The isolated hybrid system consists of WTs, PV array, EESS, backup diesel generator, and system analysis battery. The hybrid wind-solar electric power system was designed according to the ETAP program [5].

Robust and efficient new methods have been proposed, such as hybrid particle swarm optimization, as well as the gravity search algorithm (PSOGSA) and Moth-Flame Optimization (MFO), to determine the optimal location with appropriate capacity for DG units to reduce system power loss and operating costs and improving voltage profile and voltage stability [6]. MFO was chosen to solve the problems of the Egyptian distribution network in the Middle East as a practical example with optimal integration of DG.

The development of a digital model to simulate the Egyptian power grid at 500 kV and 220 kV levels were presented in [7]. The system includes various types of power plants such as thermal, hydro and wind farms. The Egyptian performance code is briefly described and used to evaluate system performance in various operating scenarios, including stable and transient analysis. The use of combined treatment procedures, especially during peak hours, is in most cases a necessary solution and the use of conventional capacitors to add reactive power, combined with other proposed methods, is very helpful as a cheap remedy. It is known that increasing voltage levels in the power system reduces losses [8].

The application of a sequential algorithm was used to detect and quantify distributed generation resources in a realistic Egyptian distribution network of 47 buses located south of Cairo. The algorithm was implemented using ETAP software and genetic algorithms (GA) to reduce overall active power loss and improve the voltage profile by placing one, two and three DGs in ideal locations with optimal dimensions. Investing in small power projects may be financially feasible for independent power producers (IPPs) and developing countries should encourage this approach to alternative sources of funding other than traditional corporate or national lending [9].

For a 500 kV substation of Egyptian power system, an indirect controller based on a 48-pulse multilevel neutral point source voltage converter SSSC was implemented to pump a controlled compensation voltage in series with the transmission line. Approximately 20% increased power flow can be achieved by using the proposed economical SSSC controller [10].

This paper aims to investigate the effect of new renewable energy projects of PV and wind energies on the 500 kV Egyptian power system. The voltage profile and reliability indices are calculated to measure the effect of new renewable energy projects. These projects are executed in different years while the consumption load increases. The annual increase in consumption load is taken about 7 % of the total load. The new renewable energy generators are added to the Egyptian power system to feed the increase in load. ETAP program is used to simulate the 500 kV Egyptian power system to calculate its voltage profile and reliability.

## II. Research Method

### A. Power Flow Analysis

Power flow analysis is used in power systems for operating and planning. The power flow model of the power system is built using the relevant grid, load, and generation data. The output of the power flow model includes the voltages on the different buses, the power flow of the lines in the power system, and the losses in the system. These outputs obtained by solving the nonlinear nodal power balance equations using iterative methods like Newton-Raphson, Gauss-Seidel, and fast-chopping methods are commonly used to solve this problem.

### B. Methods of Reliability Assessment

Power system reliability indicators can be calculated using various methods. The two main methods are analytical and simulation. The analytical method represents the system as a mathematical model and evaluates the reliability indices for this model using numerical solutions. Typically, they provide predictive indices in a relatively short computation time. The simulation method evaluates reliability performance by simulating the real process and random behavior of the system. Thus, the method solves the problem through a series of real experiments.

Reliability is a measure of the ability of a power system to supply electricity to all points of consumption within acceptable limits and in the amount required, for a certain period of time under the intended operating conditions. Adequacy refers to the presence in the system of sufficient capacity to constantly meet the demand for the load of the consumer; Accounting for planned / unplanned breaks.

The reliability indices are defined as follows [11]:

- Energy not supplied (ENS) index. It refers to the energy not supplied to the system loads as a result of line failures (MWh/year).
- Average energy not supplied (AENS) index. It represents the ratio of ENS to the total number of customers served Np at load point p over the year (kWh/customer/year).
- System average interruption frequency index (SAIFI). It refers to the average number of the interruptions that a customer experience (interruptions /customer/year).
- System average interruption duration index (SAIDI). It refers to the average outage duration time that a customer experiences (hours/ customer/year).
- Customer average interruption duration index (CAIDI). It refers to the average time required for restoration the power supply after outage occurrence (hours/customer/ interruptions).
- Average service unavailability index (ASUI). It refers to the time span for which power as demanded by customers was unavailable during a specified amount.

## III. System Under Study

An actual Egyptian distribution network is considered for the present study. Fig. 1 shows single line diagram of the 500 kV Egyptian network simulated in ETAP without new renewable projects. The simulated 500 kV Egyptian grid consists of 25 single-circuit structure 500 kV transmission lines. The Egyptian transmission grid is fed from the power stations listed in Table. I based on 2022 data. The total installed generation capacity and peak load of the Egyptian power system were about 26890 MW and 17733.2 MW in 2022 respectively. The ACSR conductor type is used in the 500 kV Egyptian power system. The length and specifications of the transmission line are reported by The Ministry of Electricity and Renewable Energy on its website.

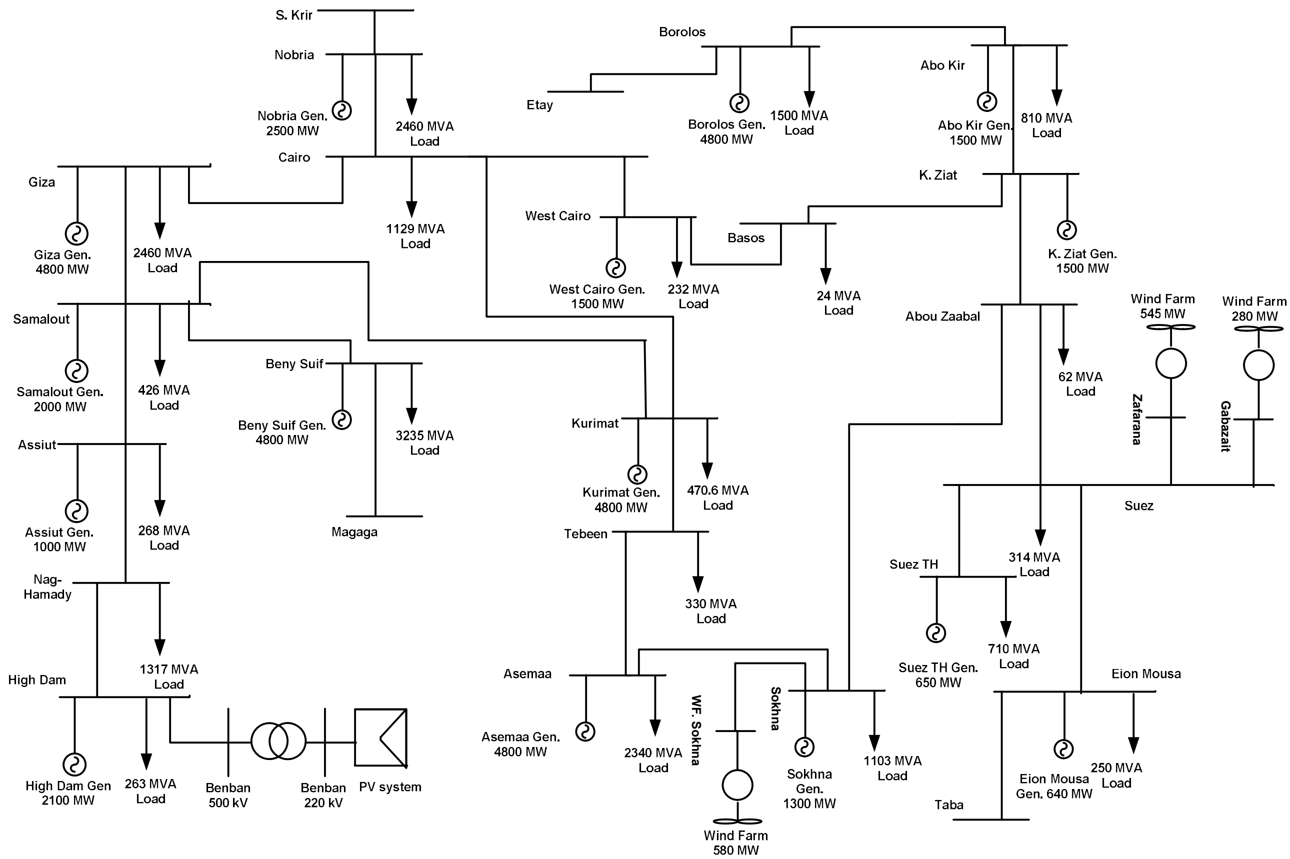


Fig. 1 Egyptian power system without new renewable energy projects.

The Egyptian power system in this study is a real multi-source power system where the power plants can be classified into 3 categories: a) non-reheat power plants are represented by gas-turbine power plants and a few numbers of steam power plants, b) Reheat power plants are mainly represented by thermal power plants or combined cycle power plants and c) Hydraulic power plants such as High Dam in Aswan city. Recently, the Egyptian power system included several RESs such as wind and solar energies (e.g., photovoltaics solar power and Concentrated Solar Power (CSP)).

TABLE I. THE EGYPTIAN TRANSMISSION GRID POWER STATIONS LISTED BASED ON 2022 DATA

| **No.** | **Name** | **Pg** | **Qg** | **Pl** | **Ql** |
|---|---|---|---|---|---|
| 1 | West cairo | 1500 | 0 | 208.8 | 101.26 |
| 2 | Cairo | 2100 | 1309.41 | 1016.1 | 492.12 |
| 3 | Nobira | 2500 | 1558.82 | 2214 | 1072.3 |
| 4 | S krir | 0 | 0 | 0 | 0 |
| 5 | Giza | 4800 | 2992.94 | 2214 | 1072.3 |
| 6 | Samalut | 0 | 0 | 383.4 | 185.7 |
| 7 | Assiut | 0 | 0 | 241.2 | 116.8 |
| 8 | Nag-hammady | 0 | 0 | 1185.3 | 574.1 |
| 9 | High damn | 2100 | 1309.4 | 236.7 | 114.6 |
| 10 | Beniswif | 4800 | 2992.9 | 2911.5 | 1410.1 |
| 11 | Magaga | 0 | 0 | 0 | 0 |
| 12 | Kurimat | 4800 | 2992.9 | 423.5 | 205.1 |
| 13 | Tebeen | 0 | 0 | 297 | 143.8 |
| 14 | Assemaa | 4800 | 2992.9 | 2106 | 1020 |
| 15 | Sokhna | 1300 | 810.59 | 992.7 | 480.8 |
| 16 | Bassos | 0 | 0 | 21.6 | 10.5 |
| 17 | Abo zabaal | 0 | 0 | 55.8 | 27 |
| 18 | K zaiat | 1500 | 935.29 | 0 | 0 |
| 19 | Abo kir | 1500 | 935.29 | 729 | 353 |
| 20 | Borolos | 4800 | 2992.9 | 1350 | 653.8 |
| 21 | ETAY | 0 | | 0 | 0 |
| 22 | Suez | 0 | 0 | 282.6 | 136.9 |
| 23 | Suez th | 650 | 405.29 | 639 | 309.5 |
| 24 | Ein Mousa | 640 | 399.059 | 225 | 109 |
| 25 | Taba | 0 | 0 | 0 | 0 |

### *A. New Renewable Energy Projects in Egypt*

In Egypt, there are new renewable energy technologies now applied, which are PV systems and wind farms.

#### *1) PV projects*

Egypt enjoys favorable solar radiation intensity. In 1991, the solar atlas for Egypt was issued indicating that the country enjoys between 2900 and 3200 hours of sunshine annually, with annual direct normal intensity of 1970-3200 kWh/$m^2$ and a total radiation intensity varying between 2000 and 3200 kWh/$m^2$/year from the north to the south of Egypt. IRENA's Global Atlas platform combines recent irradiation potential and includes a new solar atlas released in 2016, thus reiterating Egypt's high solar potential. On a global scale, Egypt is one of the most appropriate regions for exploiting solar energy both for electricity generation and thermal heating applications. Since the early 1980s, solar PV systems have been demonstrated in Egypt for different applications, including pumping, lighting, advertising, cold storage and desalination. Table II shows the new PV projects in Egypt.

TABLE II. NEW PV PROJECTS IN EGYPT

| Project | Size | Contract |
|---|---|---|
| Kom ombo | 200MW | BOO SCHEME |
| West Nile | 600 MW | Sky power and EETC BOO |
| West Nile | 200 MW | EETC BOO |
| West Nile | 600 MW | BOO scheme |
| FIT | 50 MW | EETC PPA |
| FIT | 1415 MW | EETC PPA |
| hurghada | 20 MW | NREA-JICA EPC scheme |
| Zaafarana | 50 MW | NREA-AFD EPC scheme |
| Kom ombo | 26 MW | NREA-AFD EPC scheme |
| Kom ombo | 50 MW | NREA-AFD EPC scheme |

#### *2) Wind Energy projects*

In Egypt, there exist several regions with high wind speed. The red seashores and the Gulf of Suez are the most prominent of these regions. It was estimated that 20 GW of wind farms can be housed in the Gulf of Suez area. Other candidate areas for wind farm construction are located at Faiyoum, Beni sweif, Minya and Kharga oasis. Also, Egypt works to build new wind farm stations:

- A wind power plant project with a capacity of 250 megawatts, a private sector (Lakela Company), is under construction, and many BOO "Build, own and operate" projects with a 750 MW.
- Ras Ghareb Wind farm (262 MW); Wind project being developed near the Gulf of Suez, approximately 30 km north-west of Ras Ghareb, Egypt.
- A wind power plant in West Nile (200 MW).

## IV RESULTS AND DISCUSSION

The 500 kV Egyptian power system without and with new renewable energy projects, shown in Fig. 1, is simulated using ETAP program and calculate the power flow analysis and reliability indices. Fig. 2 shows the voltage profile of 500 kV Egyptian power system without and with new renewable energy projects. Fig. 3 shows EENS of 500 kV Egyptian power system without and with new renewable energy projects. Table III shows the reliability indices of 500 kV Egyptian power system without and with new renewable energy projects.

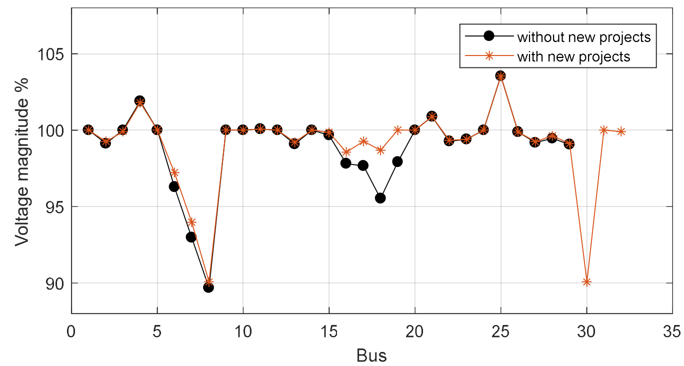


Fig. 2 Voltage profile of 500 kV Egyptian power system without and with new renewable energy projects.

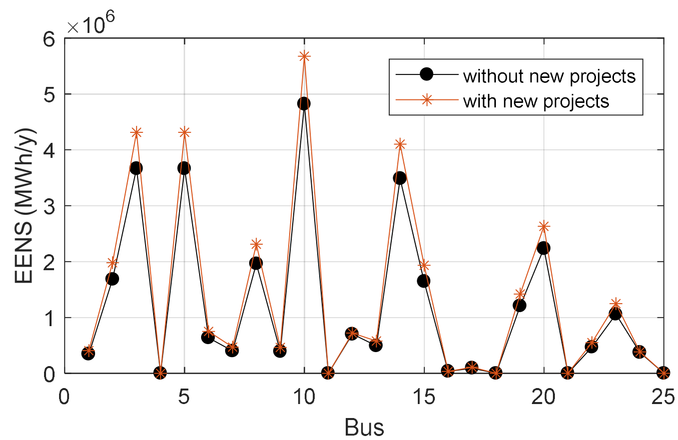


Fig. 3 EENS of 500 kV Egyptian power system without and with new renewable energy projects.

From the results, as shown in Fig. 2, the new renewable energy projects improve the voltage profile of the 500 kV Egyptian power system. The voltages of buses Bassos , Abo Zabaal, K. zaiat and Abo Kir are increased more than 98 % as well as the voltages of Samalout, Assiut and Nag-Hamady are improved by increasing about 2%.

From Fig. 3, EENS increased by small value when the new projects add to 500 kV Egyptian power system because the consumption load increased by 14%. The maximum increased at

Beniswif Bus (No. 10). But the customer interruption decreased from 9.151 hr / customer interruption to 9.098 hr / customer interruption when the new projects add to 500 kV Egyptian power system as shown in Table III. From Table III, the reliability indices affected by new renewable energy projects where the reliability indices increased and increased the energy not served.

TABLE III RELIABILITY INDICES OF 500 KV EGYPTIAN POWER SYSTEM WITHOUT AND WITH NEW RENEWABLE ENERGY PROJECTS

| System indecies | Without new renewable energy projects | With new renewable energy projects |
|---|---|---|
| ACCI | 178175700 kVA / customer | 210018900 kVA / customer |
| AENS | 1467381 MW hr / customer.yr | 1719617 MW hr / customer.yr |
| ALII | 180.86 pu (kVA | 187.09 pu (kVA) |
| ASAI | 0.8111 pu | 0.8057 pu |
| ASUI | 0.18892 pu | 0.19430 pu |
| CAIDI | 9.151 hr / customer interruption | 9.098 hr / customer interruption |
| CTAIDI | 1654.950 hr / customer.yr | 1702.047 hr / customer.yr |
| EENS | 29347620 MW hr / yr | 34392340 MW hr / yr |
| SAIDI | 1654.950 hr / customer.yr | 1702.047 hr / customer.yr |
| SAIFI | 180.8560 f / customer.yr | 187.0860 f / customer.yr |

## V. CONCLUSION

The use of renewable energy sources such as solar and wind energies is increasing in Egypt's energy system. Large-scale intermittent renewable energy projects require better management with a proper understanding of the changing characteristics of the grid and its protection systems. In concluded the results:

- New renewable energy projects are improving the voltage profile of the Egyptian 500 kV power grid. The voltage on Basos, Abu Zabel, K. zaiat and Abu Qir buses is increased more than 98%, while the voltage on Samlout, Assiut and Nag Hammady buses was increased by about 2%.
- EENS increased by a small amount when new projects were added to the Egyptian 500 kV grid as the demand load increased by 14%. Increased the limit on the Beni Swif bus (#10). However, the frequency of customer outages dropped from 9,151 hours per customer to 9,098 hours per customer when new projects added 500 kV to the Egyptian grid.
- Reliability performance has been affected by new renewable energy projects as reliability performance has increased and unreleased energy has increased.

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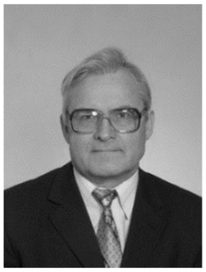
**Mahmoud M.A. Aref** was born in 1984. He received B.Sc and M.Sc from electrical engineering, Assiut university in 2006 and 2012 respectively. Received PhD degree in 2019. He is employing by the Electrical Engineering Dept. of Assiut University, Egypt as professor assistant. His research interests include stability and reliability of renewable sources connected to electrical power systems.

E-mail: mahmoud2006aref@gmail.com.



**Vladislav P. Oboskalov**, born in 19 graduated from UPI (Yekaterinburg) in 19 Received the degree of Candidate of Techn Sciences in 1970, doctor of Technical Scier in 1999. Professor since 2000. Currently working in the Automated Electric Syst Department of Ural Federal University. research interest include Reliabil optimization, operation and economics electric power systems.
E-mail: vpo1704 @mail.ru

**Anatolijs Mahnitko** graduated from Mechanics and Mathematics Faculty of Kiev State University in 1966. In 1972 received scientific degree of technical sciences (Dr. sc. ing.) in the Riga Technical University. He has been working in RTU from 1972 as a senior lecturer, assistant, Associate Professor and Professor of Power Engineering Institute. His research interests include Electrical Power System mathematical simulation and optimization.
E-mail: mahno@eef.rtu.lv

**Aleksandrs Gavrilovs** received B.sc., M.sc. and Ph.D. degrees in electrical engineering from Faculty of Power and Electrical Engineering of Riga Technical University in 2005, 2007 and 2011 respectively. His research field is power system development, planning, optimization and distibuted energy resources integration in electricity distribution network. Currently he is working for Latvian largest electricity distirbution system operator JSC Sadales tikls as project manager in a Network Development Function. E-mail: aleksandrs.gavrilovs@sadalestikls.lv