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Comprehensive Review on Renewable Energy Sources in Egypt–Current Status, Grid Codes and Future Vision

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ABSTRACT The development of the energy sector in Egypt is considered an urgent issue due to the rapid population rise rate. In particular, renewable energy sources (RESs) applications play an essential role in the coverage of energy demand. Therefore, Egypt has ambitious plans towards RESs to combine a sustainable energy future with economic growth. Egypt has high potentiality for RESs and their applications, nevertheless, the study of this modality remains below the required level. Due to the widespread use of RESs, communities are facing stability issues as the power converters-based RESs create a significant lack of power inertia, causing system instability and power blackouts as well as issues of power quality such as harmonics or resonances due to the power converters and their interactions with the system. This work presents a recent review supported by a statistical analysis about the current situation in Egypt according to the last data carried out from local/global reports. In addition, this review discusses specifications of technical design standards, terms, and equipment parameters for connecting small, medium, and large-scale solar plants, respectively to the Egyptian grid in accordance with the Electricity Distribution Code (EDC), Solar Energy Grid Connection Code (SEGCC), and the Grid Code (GC). Interestingly, the use of hydropower and emergent solar energy is considered the most promising RES variant, besides the wind energy at the coastal sites. This review characterizes the progress in Egypt and classifies interest areas for RESs recent study, e.g., photovoltaic (PV), solar chimney (SC), concentrated solar plant (CSP), and wind energy in Egypt. To maximize the RES hosting capacity in Egypt, various energy storage systems are required to be integrated into the distribution networks. Finally, a view of existing gaps, future visions and projects, and visible recommendations are defined for the Egyptian grid.

INDEX TERMS Egyptian grid, renewable energy sources, grid connection codes, concentrated solar plant, solar chimney, wind energy, energy storage systems.

I. INTRODUCTION

The International Energy Agency (IEA) has set annual reviews for global energy produced in April/year. It provides data and statics about energy, energy efficiency, helps guarantee energy security, and keep track of clean energy transitions according to the IEA‘s recent report in 2021 [1], global carbon dioxide CO_2 emissions fell by 5.8% in 2020 (almost 2 Gigatons CO_2), but the global energy-related CO_2 emissions remain at exactly 31.5 Gt in the atmosphere.

Advanced renewable energy technologies integrated into the power grid in Egypt have been of great interest to researchers over the past ten years. To illustrate this trend, Fig. 1 shows the growth of research articles in six renewable

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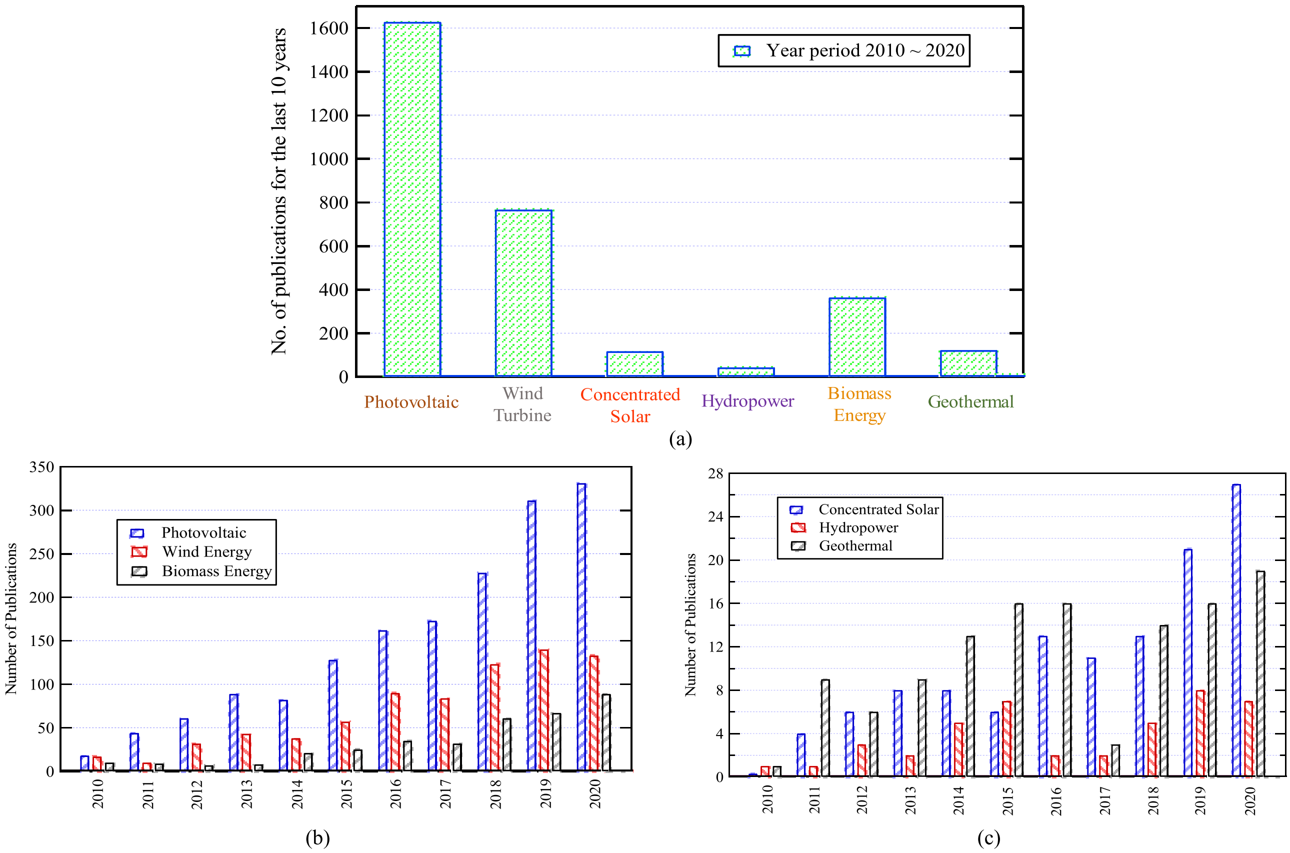

FIGURE 1. **Annual publications in Egypt for different RES variants according to Web of Science database; (a) total numbers of publications for the last 10 years of RES, (b) annual publications for photovoltaic, wind, and biomass energy, and (c) annual publications for concentrated solar, hydropower, and geothermal energy.**

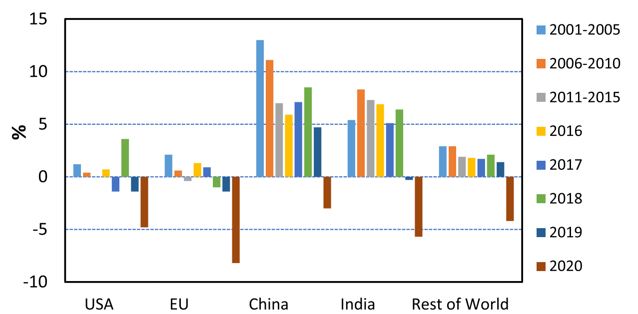

FIGURE 2. **The growth rate of electricity demand over the last 20 years for selected regions of the world.**

energy sources (RESs) types (i.e., photovoltaic, wind, biomass, concentrated solar, hydropower, and geothermal energies) in the last 10 years according to the Web of Science database. It is obvious that there is an expanding trend in the number of research papers reporting on these technologies, which implies their importance for both academy and industry sides. Another notice is that photovoltaic, wind, and biomass energies have taken more attention in the last decay compared to the other RESs types in Egypt.

Moreover, the growth rate of electricity demand over the past 20 years for various regions reveals a significant decline in 2020 according to the IEA energy review [2], and is shown in Fig. 2. Figure 3 states the incremental of power generation from RESs since 1970s for several countries according to [1].

Current expansion plans of generation of different nations foresee an increased share of RESs in the electricity generation mix. For example, Egypt is identified as one of the next eleven world largest economies [3].

In this regard, the electricity sector in Egypt had an averaged installed capacity growth rate of 14.5% per year since 2013, and the total installed capacity is around 61 GW so far in 2021 according to the African energy report [4]. By the end of 2019, the generation capacity was 58.4 GW which mainly consisted of combined-cycle plants (55.7%), the total demand load carried about 31.4 GW according to the Egyptian Electricity Holding Company (EEHC) [5]. However, the share of RESs nowadays, including wind farms (WF) and PV, only represents 3.8% of the total generation capacity. Thus, the Egyptian government in assertion with the Integrated Sustainable Energy Strategy (ISES) 2035, has set targets for RESs to reach 20% of the overall energy required for electricity production by 2022 and 42% by 2035 [5], [6].

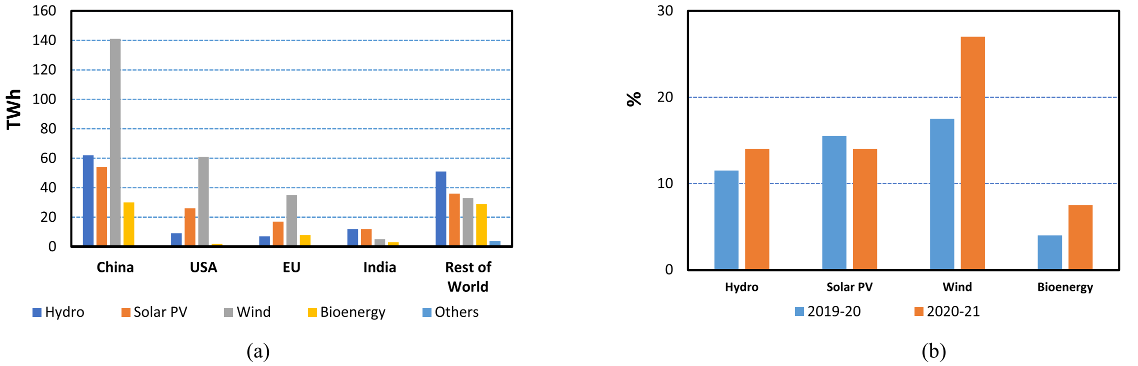

FIGURE 3. Power generation incremental from Renewable a) Country and region, b) Global by period and source according to the IEA report.

Recently, electricity subventions in Egypt have waned gradually, which has encouraged the consumers to own PV systems. Incorporating large PV amounts is not an easy mission due to several economic and technical constraints [7]–[9]. Therefore, the grid protection infrastructure and the system's compatibility should be guaranteed. Egyptera has the authority to develop the electrical tariff structures and codes in Egypt such as Electricity Distribution Code (EDC) and Grid Code (GC) [10].

Several significant challenges have occurred due to the intermittency and uncertainty of integrating RESs into the grids such as lack of inertia and frequency deviations [8], [11]–[14], thus Energy utilities and regulators have issued administrative roles for interfacing RESs at the distribution and transmission levels. A detailed recent GCs outline for PV integration is stated in [15]. North Carolina Solar Centre, Interstate Renewable Energy Council, and the USA have developed a guide on PV interfacing issues [16]. German codes for interfacing PV systems to MV grids are portrayed in [17]. Several forms for PV system integration are discussed by California and Germany in [18]. The practice code guidelines for grid-connected PV systems have been created by the Institution of Engineering and Technology (IET) [19]. The South African National Energy Regulator has affirmed the "GC connection for renewable energy power plants associated to the Transmission or Distribution electrical Systems" [20].

On the other hand, as the growth of wind power generation increases, its penetration and its commitment to the overall power supply increases [21], [22]. The installed capacity of wind power by 2019 was 650.8 GW globally, including 59.7 GW added in the same year [23], [24]. The installed wind capacity is anticipated to become 664.5 GW by the end of 2019, with an extra 65.4 GW, up about 17.4% by 2018 [25]. Figure 4 states the global development of wind power over the past decade, and wind turbines (WTs) geological share around the world, with Asia leading the list, followed by North America, Europe, and then rest of the world shown in Fig. 5.

Concentrated solar plant (CSP) is a type of solar thermal energy utilized to convey electricity by energy concentration

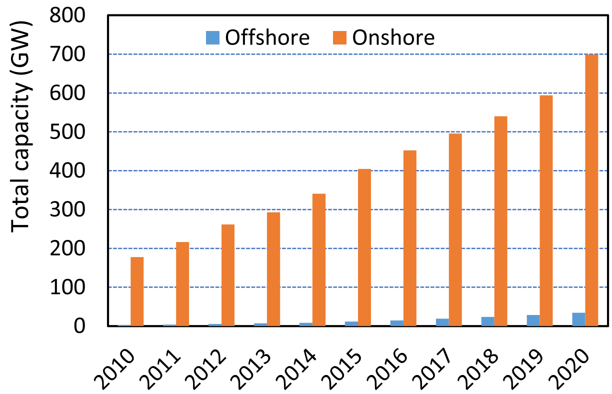

FIGURE 4. Worldwide trend for wind power capacity (IRENA 2019).

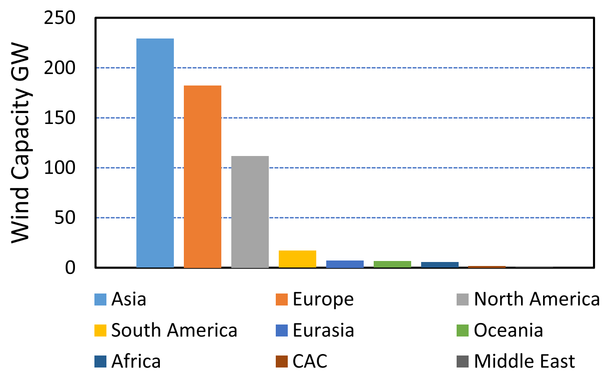

FIGURE 5. Wind capacity in 2018 by region.

by the sun in a single focal point [26], and is considered the foremost powerful and convenient option for its ability to outfit heat and electrical energy [27]. The minimum direct normal irradiance DNI for economically viable CSP plants at current rates is 2000 kWh/m^2/y. Referring to [3], [28]–[30], there are 4- CSP technology types currently use. These include power tower, dish and trough parabolic, linear Fresnel reflectors (LFRs).

Among the solar technologies, solar chimney SC is also a committing for the use of large-scale solar energy and was first developed by Schaich [31] in the 1980s.

TABLE 1. Technical Indicators of Hydro Generators according to EEHC annual report 2019.

Description		High Dam	Aswan 1	Aswan 2	Esna	Naga-Hamady	Assiut	2018/2019
Generation Energy	(GWh)	8893	1410	1594	471	446	247	13121
Peak Load	(MW)	2160	276	270	80	67	40	2827
Max. daily generated energy	(GWh)	43.4	6.5	6.6	1.9	1.6	0.9	57.5
Min. daily generated energy	(GWh)	9.4	1.5	2.4	0.5	0.5	0.01	16.4
Efficiency	(%)	83.6	85.4	90.1	83	85	86	-

It has numerous advantages such as a passive ventilation system that is based on natural driving force [32], simple structure, low environmental pollution, and renewable power generation [33], but it is still far from being widely marketed. Also, SC has several issues that are considered major barriers experienced such as low efficiency, high bulk size requirement, and its dependency on solar irradiation [34].

The solar plant connection ought to fulfill the SEGCC prerequisites [10] and meanwhile, the provider should obey the EDC prerequisites [10]/GC [35]. The specialized details of coordinating small-scale solar plants (SSSPs), medium-scale (MSSPs), and large-scale (LSSPs) to the transmission/distribution networks are discussed in this work. Moreover, Wind farms and solar power plants (SPPs) include operating limits, capability prerequisites, etc. will illustrate in this review work.

The contributions of this research are:

i. Depict the last RESs circumstance in Egypt.
ii. Characterize the current progress of RESs (e.g., PV, SC, CSP, and WT) in Egypt.
iii. Provide a full background on the specifications of technical standards design, terms, and equipment parameters to associate solar and wind farms to the Egyptian grid.
iv. Statistical analysis, futuristic plans, and projects, and recommendations for research are formulated.

II. CONVENTIONAL ENERGY IN EGYPT

Egypt is one of the countries that have great natural resources potentials such as coal, oil, natural gas, and fossil fuel sources; approximately 4189 billion reserves barrels of oil and 77200 billion cubic meters of natural gas, in the form of deposits on the coastal and mainland [36].

Outside of OPEC in Africa, Egypt is the largest region in oil province and third in dry natural gas, following Algeria and Nigeria with accordance to Energy Information Administration (EIA) [37].

About 90 % of Egypt's power generation comes only from natural gas and oil (divided into 77.37% of natural gas, 12.64% of other fossil fuels), with 6.49% hydroelectric power, and 3.6% from RESs as reported by Hannah R. *et al.* in [38]. On the other side, the EEHC 2019 report states that the hydro energy sharing is around 4.8 %, and RESs are about 3.8%, with a total generation capacity of 58.558 GW as mentioned in [5]. The technical and development indicators from Hydro plants for the last 5 years in Egypt are stated in Fig. 6 and Table 1.

Consumed fuel is found in several applications such as commissioning tests, BOOT, and EEHC power plants. For BOOT plants, the fuel consumed for natural gas is 2888 million m^3 (equivalent to 2469 K toe), with an add up to 5128 K toe of natural gas in EEHC plants and summing to 30.2 K toe excluding consumed fuel in isolated plants. The fuel consumption development in Egypt is shown in Fig. 7.

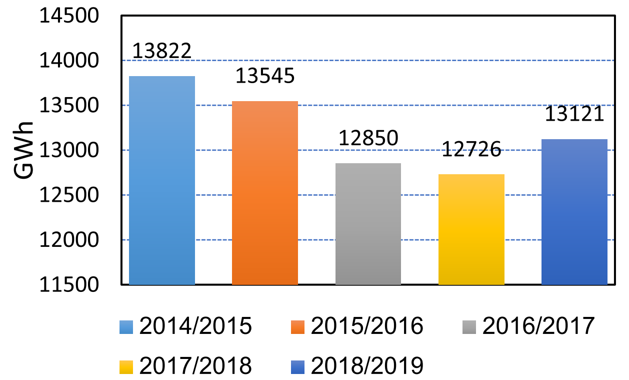

FIGURE 6. Hydropower generated Development (GWh).

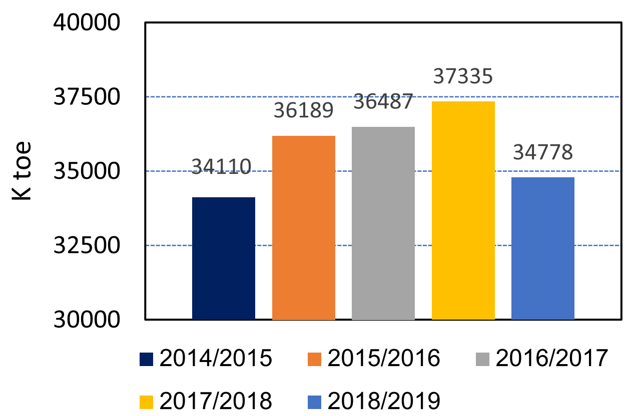

FIGURE 7. Development of total fuel consumption for 5 years in Egypt.

III. WHY RENEWABLE ENERGY?

Africa has been designated by the United Nations as one of the landmasses most susceptible to the climatic variation impacts variation due to populace growth and related human activities, low resilience to alter, and looming water crises. It is still vulnerable to the fossil fuel vicissitudes oriented for developed countries that are exported crude oil to [39]–[41].

For Egypt, the energy use is rising by 6.5-10 % per year, but the imbalance in reliance on finite gas and other traditional resources has set the Egyptian energy sustainability future at risk. Egypt has recognized a critical need to mimic carbon emissions. In addition to Egypt's wealth of wind and sunlight, it can move well towards relying on RESs. Lack of access to electricity in rural regions is an issue faced by the destitute of worlds, so RESs in Egypt can be key to alleviating poverty within the country.

Renewable energy has the benefit of employment creation, vicinity to load, and in numerous situations its reliance on a concentrated power source [8], [42], [43]. Therefore, Egypt has set a target to reach 20% of total capacity from RESs by 2022, and 42% by 2035. For further details about the recent and future development of the private sector and RES projects in Egypt, see Tables 10 and 11 at the end of this review.

IV. RENEWABLE ENERGY SOURCES IN EGYPT: AN OVERVIEW AND THE RECENT SITUATION

According to [5], there is ongoing coordination between the Egyptian Electricity Transmission Company (EETC) and the New & Renewable Energy Authority (NREA), under the supervision of the EEHC, for signing the following renewable energy purchase agreements [6]: (1) a total capacity of 1965 MW (500 MW from WFs and 1465 MW from solar energy). (2) 200 MW PV plant project at Kom Ombo. (3) 250 MW wind farms and 900 MW PV in the Western Menia Governorate region. Construction of the first and second stages of solar (PV) plant was completed in Benban region, Aswan, Egypt by November 2019, with a capacity of 1465 MW out of the 1800 MW, which is one of the biggest PV farms in the world [44], [45]. Currently, 1820 MW of wind energy is being negotiated and contracted with several alliances, and 750 MW of solar energy with several alliances.

Consequently, Egypt needs to deploy large-scale renewable resources to attain a sustainable energy future with economic growth [46]. In addition, Egypt tries to replace fuel-based cars with electric cars. A Chinese team recently visited Egypt to start preparing the basic project infrastructure and put a plan to produce 25,000 electric cars annually starting from 2021. A thousand fast-charging stations will be established in Egypt per year with a capacity of 50 kW for 3 years [47], [48]. Here, we are going to give a brief survey in the following subsections about RESs in Egypt.

A. SOLAR ENERGY IN EGYPT

This subsection is divided into 2-major's categories as follow:

1) SOLAR POWER PLANTS IN EGYPT

The converting energy process from sunlight into electricity is called solar energy. It can be done directly by PV, or indirectly with CSP or a combination. Egypt is one of the nations that have the most elevated sun-oriented radiation. the solar average direct radiation in kWh/m^2/day in different areas in Egypt is stated in [49], [50]. High solar radiation is found in the south compared to the northern coastal areas.

Currently, Egypt is constructed several solar plants stations concerning the last annual reports in [5], [50] such as Kom-Ombo with 200 MW, Kuraymat with 140 MW (consists of 20 MW solar plant and 120 MW combined cycle), and the world's largest PV power plant in Benban, Aswan, Egypt with approximately 1.85 GW. The Benban farm comprises 39 stations each around 50 MW. Other types for solar plant application called solar chimney and concentrated solar plant are discussed in detail below.

2) SOLAR CHIMNEY

Solar chimney (SC) power generation is done by converting solar energy into heat energy in the collector and then be converted back into mechanical energy to spin the turbine to generate electricity. Solar chimney power plant (SCPP) comprises a roof collector covering flowing air that is heated by the radiant energy of the sun, and an updraft chimney located in the collector center, causing hot air to flow through the chimney by the lower glass cover of the collector. SC system has several advantages such as the simplicity of operation, low maintenance cost, and system durability.

Several pieces of research [51]–[54] were conducted in various countries and geographical locations to introduce different amendments to the traditional SC and investigate the feasibility and performance of SCPP. Table 2 gives an overview of the feasibility and experimental studies in specific SCPPs sites.

Many researchers were investigated SCs because of the potential points of interest in terms of economic impacts, energy prerequisites, and environmental benefits. In [55]–[58], passive cooling was used in arid and hot regions to supply internal thermal comfort and mimic residential energy consumption. Recently works that examined the SC performance when coordinated with a solar cell to deliver additional energy utilized in buildings are presented in [59]–[61].

A real small-scale SCPP project was designed and constructed at the Faculty of Energy Engineering, Aswan, Egypt [27]. It comprises four main parts: WT, generator, tall tower, and air collector as shown in Fig. 8. The collector is suspended from 2-20 m above the ground surrounding the tower. Compared with PV systems, the SC has the benefits of working 24 hours a day even after sunset.

3) CONCENTRATED SOLAR POWER PLANT

CSP technology uses mirrors to reflect sunlight and concentrate it to a single point on a receiver where it heats a

TABLE 2. SCPP experimental and feasibility studies based on geographic locations in different countries.

Site	Authors	Type of study	Site	Authors	Type of study
Lanzhou, China	Cao et al. [62]	Feasibility	Pacific Island Countries	Ahmed et al. [78]	Empirical
Spain	Cuce, et al. [63]	Feasibility	Florida, USA	Pasumarthi et al.[79]	Empirical
Nepal	Baral, S. [64]	Feasibility	Wuhan, China	Zhou et al. [80]	Empirical
India	Akhtar and Rao [65]	Feasibility	Bundoora, Aust.	Akbarzade et al. [81]	Empirical
Saudi Arabia	Mostafa et al. [66]	Feasibility	Karak, Jordan	Al-Dabbas [82]	Empirical
Nigeria	Okoye et al. [67]	Feasibility	Algeria	Azizia et al. [83]	Empirical
Lebanon	Bayeh et al. [68]	Feasibility	Iraq	Amori, et al. [84]	Empirical
Northern Cyprus	Okoye et.al. [69]	Feasibility	Fukuoka, Japan	Okada et al. [85]	Empirical
Iran	Sangi [70]	Feasibility	Qinghai, China	Guo et al. [86]	Empirical
Libya	Abuashe, et al. [71]	Feasibility	Kota, India	Lal et al. [87]	Empirical
Egypt	El-Haroun et al. [72]	Feasibility	Tehran, Iran	Ghalam et al. [87–89]	Empirical
Tunisia	Bouabidi et al. [73]	Feasibility	Damascus, Syria	Kalash et al. [90]	Empirical
UAE	Hamdan [74]	Feasibility	Texas, USA	Raney et al. [91]	Empirical
Algeria	Ali et al. [75]	Feasibility	Aswan, Egypt	Fathy et al. [27]	Empirical
Botswana	Ketlogets et al. [76]	Feasibility			
Mediterranean region	Nizetic et al. [77]	Feasibility			

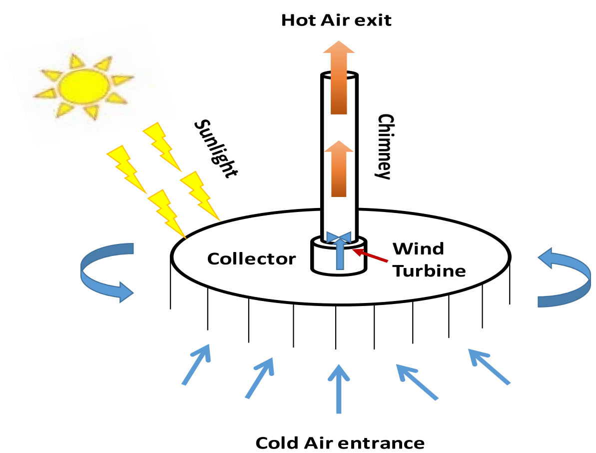

FIGURE 8. Main parts of solar chimney.

transfer fluid to a high degree of temperature. This energy is directly used after being transferred in the process of spinning a turbine or an engine to generate electricity through a generator.

Recently, Egypt faced many difficulties economically and socially with the population increment that increased the demand for electricity, which surpassed 6% annually [92]. Following the Ministry of Electricity and Renewable Energy by 2035, Egypt will turn into a merchant of gas and oil country. To get rid of these issues, the government has developed a mixed energy plan to install 2550 MW of CSP technology [93]. This strategy can accomplish economic and social merits, particularly for rural electrification [94], and with conditioning local manufacturing procedures for components of power plants [95].

A real CSP station is established in the Kuraymat region, Egypt, in 2011. It is considered an integrated solar combined-cycle (ISCC) technology that blends the merits of solar energy and combined cycle [3], [96]–[98]. The power capacity is 140 MW was established in the Kuraymat site. It includes a gas-fired combined cycle with 120 MW and 20 MW as solar PV plants. Table 3 describes the main components and data for the El-Kuraymat power plant.

with the knowledge that Egypt has one of the most worldwide sunny regions [99]–[101]. Ten sites have been chosen in this work to analyze the reference power plant in Egypt. The direct normal irradiation DNI for these locations differs between 3069 $kWh/m^2/y$ in Janub Sina' and 1890 $kWh/m^2/y$ in Alexandria, additionally, you can determine the Global horizontal irradiation (GHI), Global tilted irradiation (GTI), and Diffuse horizontal irradiation (DIF) from Table 4. The Global Solar Atlas of the Arab Republic of Egypt is shown in Fig. 9. (See [49] for details).

B. SOLAR ENERGY GRID CONNECTION CODES AND REQUIREMENTS IN EGYPT

Two standard codes for interfacing solar plants with the Egyptian utility grid are described as follows:

i. A small-scale PV (ssPV) code was released by Egyptera and became operative in 2014 [102]. It indicates the requirements technically for interconnecting ssPV systems (with rating < 500 kW) to low voltage networks to regulate the connections of distributed generators DGs units with the distribution network.

ii. The SEGCC [10] specifies the terms of interconnection between MSSPs and LSSPs, and these requirements will be discussed in Section 4.1.2.2.

The transmission GC in Egypt [35] levels: EHV more than 132 kV, HV of 33 to 132 kV, and MV starting from 11 to 22 kV. The SEGCC is associated with the following codes:

TABLE 3. SCPP experimental and feasibility studies based on geographic locations in different countries.

Parameters	Value	Parameters	Value
Solar total Aperture Area	130800 m^2	Max. Solar Field Thermal Power Output	61 MW
No. of Collectors	160	Nominal Capacity	20 MW
No. of Loops	40 per collector	Solar Resource	2154
No. of modules	12 per Collector	Receiver Inlet Temperature	293 C°
Design Irradiation	700 W/m^2	Receiver Outlet Temperature	393 C°
Types of models and general data			
Receiver Model	PTR 70	Technology	Hybrid, Parabolic Trough
Turbine Model	SST-900	Developer	NREA
Mirror Model	RP3	Receiver Working Fluid	Biphenyl/Diphenyl oxide: Therminol VP-1
Collector/Helio-stat Model	SKAL ET-150	Cooling type	Wet

TABLE 4. Global solar radiation specifications in Egypt.

Parameters	Interval	Al Bahr El Ahmar	Elgizah	CAIRO	Shamal Sina'	Janub Sina'	Al Wadi El Jadid	Aswan	Asyut	Matrouh	Alexandria
DNI	Min	5.98	5.43	5.53	5.50	6.00	5.86	5.69	5.94	5.31	5.17
	Max	7.56	6.75	6.28	7.64	8.41	7.33	6.73	7.44	6.39	6.00
GHI	Min	6.15	5.68	5.74	5.54	5.90	6.16	6.30	6.10	5.53	5.51
	Max	6.56	6.20	6.01	6.30	6.62	6.74	6.53	6.48	6.17	5.84
DFI	Min	1.56	1.80	1.90	1.43	1.17	1.89	2.00	1.68	1.88	1.94
	Max	2.30	2.10	2.10	1.98	1.99	2.37	2.43	2.18	2.11	2.11
GTI	Min	6.75	6.22	6.29	6.12	6.52	6.81	6.74	6.66	6.10	6.02
	Max	7.24	6.90	6.69	7.09	7.41	7.37	7.12	7.23	6.90	6.50
Unit		$kWh/m^2/day$									

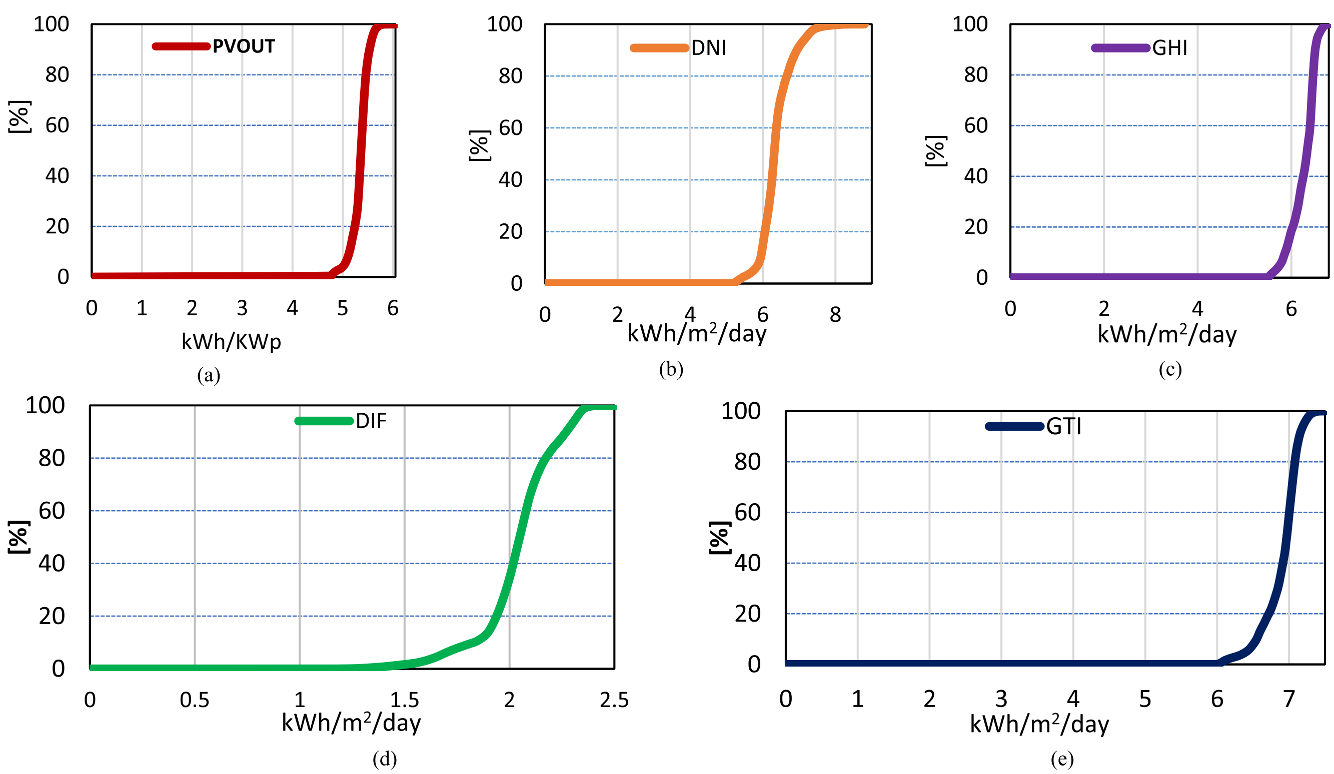

FIGURE 9. The solar irradiation per day in Egypt: (a) photovoltaic power output (PVOUT), (b) DNI, (c) GHI, (d) DIF, (e) GTI.

TABLE 5. The technical specifications and conditions for ssPV.

Type	Conditions
Utility Compatibility	• The design of PV system must be linked as a balanced 3-phase units. • The feeder voltage at furthest point ought not to surpass +10% of its nominal value in case of Max. Load.
System Parameters	• The customer should keep the limit of operating voltage variations at $\pm$10%. • PV system must operate in parallel with the utility grid within (48.5 → 51) Hz. • The total flicker severity at PCC should be ≤ 0.8 and ≤ 1.0 for long-term and short-term respectively. • For THD harmonic distortion, the total current produced by the PV must be $< 5\%$ for the odd current harmonics limits according to the IEC 61727-2004 standard. • The synchronization process of the PV system must be carried out with the network through the static inverter in the state of $\Delta f \leq 0.3$ Hz, $\Delta v \leq 0.5\%$, and $\Delta\delta \leq 20^o$.
Safety and Protection	• PV system should be automatically switched off from the grid in case of loss situations, the injection of DC current surpasses the limit of threshold, and voltage and frequency are out the rated ranges. • PV system must be stopped when the utility distribution grid is energized, the frequency is out of the range (48.5-51 Hz) or when the voltage veers off the exterior specified conditions (*). • The PV short circuit protection should follow the IEC 60364-7-712 code.
Earthing	• The earthing system for ssPV electrical installation must comply with the SANS requirements 10142-1: Code of Practice Wiring of Premises.
Islanding	• To comply with the ssPV connections code requirements, an unintended island condition must be prevented according to the IEC 62116 code.
Metering	• Two metering schemes are discussed by ssPV code: the first is Feed-In-Tariff that uses a one-way meter and the second is the Net-Metering which utilizes a bi-directional meter.

(*) The following conditions shall be met, with voltages in r.m.s referred to the nominal voltage: $V < 50\%$ with Max. trip 0.2 s, $50\% \leq V \leq 85\%$ at 2 s, $85\% \leq V \leq 110\%$ with continous trip, $110\% < V < 120\%$ at 2 s, and finally $120\% \leq V$ the Max. trip occured at 0.16 s.

i. The EDC [10] identifies the fundamental strategies and rules for regulating the relationship between the distribution networks users and facilities.

ii. The Egyptian Transmission System Code, known as the " GC" [35] defines the relations between the transmission operator and the users in legal and technical form.

1) A SMALL-SCALE PV CONNECTION TO LV NETWORKS

SSSPs capacity range is less than 500kW, which can be associated with LV distribution networks. Table 5 presents the specialized details that might be considered for ssPV. The size of the ssPV system is limited to a CB rating at the supply point, and voltage permissible range on the transformer LV side (MV/LV), and the voltage at the feeder farthest point [103].

Several works to link ssPV systems involved in financial and economic analyses are discussed in [102], [104], [105]. In addition, measurements provide a process for a PV plant capacity of 200 kW in [106] to state the compatibility of both ssPV and EDC codes including frequency, voltage, and harmonic distortions using a power analyser tool for 7 days.

2) MEDIUM AND LARGE-SCALE PV CONNECTION TO MV/HV NETWORKS

The specifications of technical design standards and equipment parameters were concerned to associate MSSPs and LSSPs with the Egyptian grids. The MSSPs capacity range is (0.5 → 20)MW, whereas the range of LSSP is $\geq$ 20 MW. MSSPs can be associated with MV distribution or HV transmission networks, while LSSPs are typically linked with the HV/EHV transmission network [10], [107]. The SEGCC [10] specifies the prerequisites for interfacing SPPs to MV distribution or HV/EHV transmission networks. In addition, it indicates the SPPs operational limits to be linked with the grid, plant capability prerequisites, synchronization, safety measures, protection settings, active and reactive power control systems, etc. For medium and large SPPs, SEGCC must be provided to all of them to be associated with the transmission grid. The technical requirements for MV/HV scale are stated in Table 6.

V. COMPARISON OF SOLAR ENERGY GRID CONNECTION CODES

SEGCC can be issued as an approved standard in different nations or by system administrators [108]. In Table 8, some bases and rules for comparisons in Germany PV GCs [108], [109], Denmark [110]–[113], the UK [114], [115], the USA [116], [117], and Egypt [10], [107] are explained. They include the rules of power, frequency, and reactive power control.

As evidenced by [118], the specified benchmarks of Egyptian and European have taken the same direction. Various items such as grounding, short circuits, THD current are the same in the case of the European and Egyptian standards. Furthermore, subjects such as harmonics, flicker restrictions, voltage, injection DC power, islanding, and time to reconnect represent similitudes across the criteria provided. This comparison showed that the main contrasts between Egyptian codes (ssPV and SEGCC), European

TABLE 6. The technical specifications and conditions for MV/HV scale.

Type of Requirements	Conditions
Point of common coupling (PCC)	The SPP is linked to the grid at this point.
Range of voltage	The SPP grid-connection shall has the ability to convey its actual power (P) when the voltage in the PCC is within: • (0.85 → 1.1) pu for unlimited runtime and (1.1 → 1.15) pu for 30 min.
Range of frequency	The solar plant conditions in case of: • $f < 50$ Hz , it shall inject active power to below 47.5 Hz. • 50 Hz $\leq f <$ 50.2 Hz , it must maintain 100 % of active power. • $f >$ 50.2 Hz , it shall inject power up to 51.5 Hz in accordance with the active power control terms as mentioned below in this table.
Starting up SPPs	It shall be connected to the grid if: • Frequency at PCC is 48 Hz $\leq f <$ 51Hz and Voltage at PCC is 0.9 pu $\leq V <$ 1.1 pu . • The active power should increment by 10% /min of rated active power during the start-up condition.
Power quality	• SPPs should strive to preserve the quality waveform of voltage at the PCC. • SPPs should obey with the GC/EDC determinations. • If a fault happened within the grid, solar plants have to ride-through the grid fault without disconnection from the Grid. Further details included in section 5.3 in the Egyptian GC.
Harmonic distortion	• Max. Distortion Levels of harmonics at the PCC must comply with the provisions of the IEEE 519-2014 standard as described in (section 5.3.7 of GC). The limits for individual and total harmonics of current and voltage waveforms are given in Table VII.
Flicker severity	• The total flicker severity in PCC should be $\Delta P_{lt} \leq 0.25$ for long-term (2 hours) and $\Delta P_{st} \leq 0.35$ for short-term (10 min.) in accordance with IEC 61000-3-7.
Voltage unbalance and fluctuations	• Voltage imbalance shall be resisted by SPPs until 2 % at least 30 secs as illustrated in section 5.3.5 of the GC. • SPP voltage variances within the PCC should reach 3 % of the normal voltage.
Active and reactive power (Q) control	• SPP should continue providing power within (47.5 → 50.2) Hz or range of grid voltage at the PCC for the given time periods in Fig. 10a. • For grid frequencies from (50.2 → 51.5)Hz, the SPP has to mimic the active power referring to $\Delta P = 0.4 \times P_m \times (\Delta f/Hz)$, and $\Delta V = V\text{-}V_o$ as shown in Fig.10b. • SPP should able to control Q at PCC in arrange of 0.95 lagging to 0.95 leading power as shown in Fig. 10c, and as follows: set-point control of Q, power factor control (cos φ), power factor as a function in solar plant output power cos φ (P), and Q as a function of voltage, Q (V). • For 3-φ faults, the SPP must inject reactive current for 250 ms after the starting of fault until clearance.
Protection	• The grid protection settings for the SPP at PCC must be commissioned concerning the GC code of protection. • The grid protection setting at the solar inverter generators depends on the incidents such as over/under voltage and frequency. • The recommendation setting for under/over frequency will be (47.5 Hz level with ≤ 500 ms, and 51.5 with ≤ 100 ms) respectively. For over/under voltage, the recommended setting will be ($1.15 \times V_n$ in ≤ 3 s, and $0.3 \times V_n$ in 1 s) respectively.

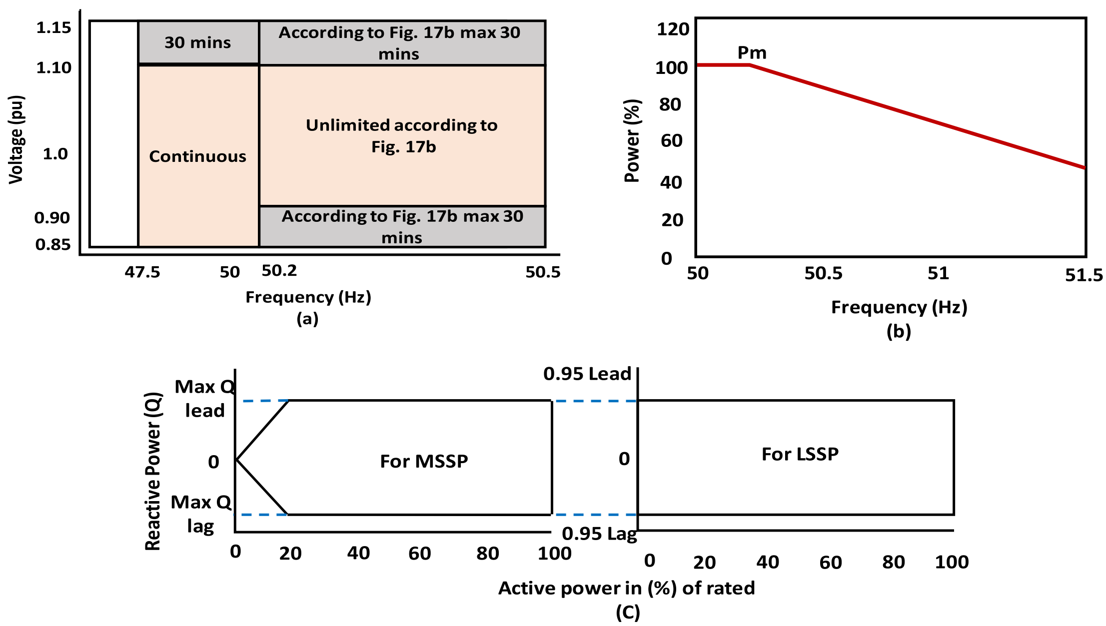

FIGURE 10. a) Voltage, frequency, and SPP operation time ranges (quasi-stationary observation), b) Active power reduction due to over-frequency, and c) P-Q Diagram for MSSP and LSSP.

TABLE 7. Limits of current and voltage harmonics distortion transmission at the PCC.

Voltage level (KV)	Level of harmonic voltage distortion (%)					
	Odd harmonic limits			Total harmonic limits		
$V < 1$	5.0			8.0		
$1 \leq V < 69$	3.0			5.0		
$69 \leq V \leq 161$	1.50			2.50		
$V > 161$	1.0			1.50		
Harmonic distortion current level for 69 kV voltage transmission and below.						
Short circuit ratio I_{sc}/I_L	Max. integer distortion of harmonic current as ratio of I_L					
	Odd harmonic distortion					TDD
	<11	11 to <1 7	17 to <23	23 to < 35	> 35	
$ratio(r) < 20$	4.0	2.0	1.5	0.6	0.3	5
$20 < 50$	7.0	3.0	2.5	2.5	0.5	8
$50 < 100$	10.0	4.5	4.0	4.0	0.7	12
$100 < 1000$	12.0	5.5	5.0	5.0	1.0	15
$r > 1000$	15.0	7.0	6.0	6.0	1.4	20
Harmonic distortion current level between (69 → 161)kV.						
$r < 20$	2.0	1.0	0.75	0.3	0.15	2.5
$20 < 50$	3.5	1.75	1.25	0.5	0.25	4
$50 < 100$	5.0	2.25	2.0	0.75	0.35	6
$100 < 1000$	6.0	2.75	2.5	1.0	0.5	7.5
$r > 1000$	7.5	3.5	3.0	1.25	0.7	10
Harmonic distortion current level for above 161 kV.						
$r < 25$	1.0	0.5	0.38	0.15	0.1	1.5
$r < 50$	2.0	1.0	0.75	0.3	0.15	2.5
$r \geq 50$	3.0	1.5	1.15	0.45	0.22	3.75

Where I_{SC}, I_L are short-circuited and demand load currents at the PCC respectively.
*All power generation equipment is restricted to current distortion values, in any case of actual I_{SC}/I_L.
**The even harmonics limits are 25% comparing to odd harmonics limits that recorded within the table.

(IEC 61727), and North American (IEEE 1547) code standards are common requirements for power quality, protection, and security.

VI. WIND ENERGY: A BRIEF REVIEW

The International Electro-technical Commission (IEC) is developed a standard 4 type model to be like their electrical power system partners [119]. Comprehensive reviews were published in[30], [120]–[126] for further clarifications on the generic/standard software and modeling developed for the purposes of analysis and stability studies.

Several challenges make operators worried, including, voltage/reactive power support, power quality problems, power prediction, frequency stability, harmonics, protection, the capability of LV ride-through, small-signal stability, electricity market, and other challenges. All previous challenges arising from integrating wind energy systems into grids were summarized in [30]. Similar to the connection of solar energy requirements discussed before, a comparison was made in [30] to summarize the compliance of existing WTs types to grid integration requirements and their components.

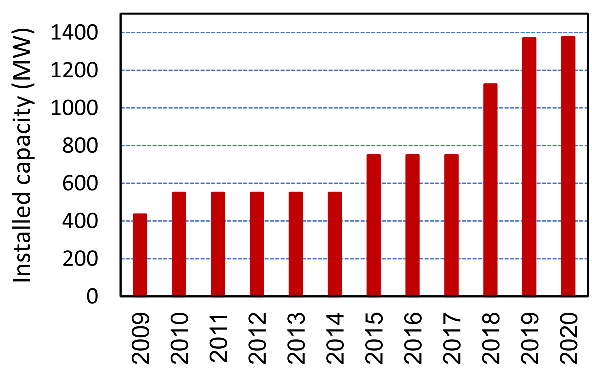

FIGURE 11. The annual last decade growth of wind energy in Egypt.

A. WIND ENERGY IN EGYPT

Historically, the first WF was constructed at Ras Ghareb on the Red Sea Coast, Egypt in 1988s. It comprises 4 Wincon

TABLE 8. Comparison between active and reactive power control regarding to SEGCC requirements for various countries.

Code	Code requirements	
	Active power control	Reactive power control
Germany	• Capable of operating at low output power (if PCC rated voltage is 10 kV) • All generators ought to mimic the gradient output power of 40 %/Hz in the event of a frequency 50.2 Hz • The generator yield control is permitted to be expanded as it were one more time below 50.05 Hz.	• When a drop by more than 10 % in voltage happened, the reactive current contribution is 2 % of the rated current per drop percentage in voltage, and the facility should be able to supply the desired Q within 20 milliseconds.
Denmark	The power-generating plants requirements are divided into three basic types (B, C, D) based on the plant's active power capacity (MV/HV): • A power-generating plant shall be competent of a persistent uninterrupted generation in the frequency range $(49 \rightarrow 51)$Hz for type B and $(49.8 \rightarrow 49.5)$ Hz for types C, D, and when the voltage at the Point of Connection (POC) is within the range$(90 \rightarrow 110)$% of normal operating voltage. • Control must be performed with an accuracy of ± 2 % of power plant's nominal active power (P). The active power must follow the droop with a deviation of 5 % of nominal active power.	• The control precision may be less than ± 2 % of rated power when active power generation is below10 % of plant's nominal apparent power. However, the Q-uncontrolled exchange shall not be more prominent than 10 % of the nominal plant apparent power. • A power-generating plant shall be able to execute Q-control and power factor (PF) control allowing the reactive power to be controlled by a constant PF.
USA	• It is much essential to provide a frequency response with 5 and 3 % droop settings for solar plant governor control loop. The droop control definition for PV plant is like that for traditional units: $\frac{1}{Droop} = \frac{\Delta P / P_{rated}}{\Delta f / 60Hz}$ • The droop curve dead band is $\pm$ 36 mHz.	• FERC Order 661-A can be applied to SPPs, and the desired PF range is 0.95 measured at (POC). • The CAISO reactive power prerequisite states the operating voltage for PV plants to supply Q at 0.95 PF lagging when the POC's voltage within $(0.95 \rightarrow 1)$pu. In addition, the SPP should be able to absorb Q at 0.95 PF leading when the POC's voltage within $(1 \rightarrow 1.05)$pu.
UK	• The GC in UK requires the output power to remain constant at lower frequencies to support system frequency. Generating units must constantly maintain the output active power between$(49.5 \rightarrow 50.5)$ Hz. • The frequency regulation range shall be no more than ± 0.015 Hz and a droop$(3 \rightarrow 5)$%..	• The generating units should be competent in providing $(50 \rightarrow 100)$ % of rated power within 0.95 leading to 0.95 lagging PF • Consumption requirement of Q (leading PF) linearly mimics the power outputs between$(20 \rightarrow 50)$% of power rated while 0.95 lagging limit keep constant. Underneath 20 % of rated power production, the Q limit is of ± 5 %or approximately $0.999 < PF < 1$.
Egypt	• SPP must diminish the active power (installed capacity from 500 to 50 MW) in case of the grid frequency is within $(50.2 \rightarrow 51.5)$ Hz, • The output power ought to be minimized by $\Delta P = 0.4 \times PM \times (\Delta f / Hz)$. • The output power is permitted to increment once the frequency is less than 50.2 Hz	• For 3-φ faults, the SPP must inject reactive current for 250 ms after the starting of fault until clearance. • For unsymmetrical faults, reactive currents should not be fed into the grid during the duration of the fault, resulting in voltages increases above of 110 % of its nominal value at the grid POC. • The Q of SPP should be $\leq$ the consumption of Q before the fault occurs.

TABLE 9. Wind farms in Egypt installations size and distribution.

Wind farm region	Capacity MW	No. of turbines	Year of operation	Wind farm region	Capacity MW	No. of turbines	Year of operation
Ras Ghareb	0.4	4	1988	Zafarana 8	119.85	141	2010
Hurghada	5.2	42	1993	Gabal El-Zayt 1	240	120	2010
Zafarana 1	30	50	2001	Gabal El-Zayt 2	220	110	2018
Zafarana 2	33	55	2001	Gabal El-Zayt 3	120	60	Under Construction
Zafarana 3	30.36	46	2003	Ras Ghareb	262.5	125	2019
Zafarana 4	46.86	71	2004	Gulf of Suez1	250	125	Under Construction
Zafarana 5	85	100	2005	West Bakr	252	96	Under Construction
Zafarana 6	79.9	94	2007	Gulf of Suez	500	173	Under Construction
Zafarana 7	119.85	141	2009	West Nile	250	Cancelled in August 2020	

Danish WTs with a capacity of 100 KW each. The second WF, consisting of 42 WTs with a capacity of 5 MW was established in Hurghada in 1993 [127]. The third WF in Egypt contains 698 WTs with 545 MW as a total capacity and has been built in Zafarana in several stages since 2001. In addition, there are wide areas that have high wind resources

TABLE 10. Development of private sector current projects in Egypt.

Technology	Installed				Under Construction		Under Development			
	Wind	PV		Bio	Wind	Bio	Wind	PV		Bio
		FIT	Metering							
Project Name	Ras Gareb	Benban Solar	Net Metering	Bio Energy	West Bakr	Bio Energy	Private Sector	Private Sector		Private Sector
Capacity MW	250	1465	100	12	250	3	200	500		51
Plant Name							Nowais	Siemens	Priv. Sec.	
Capacity MW							500	500	700	
Sum	250	1465	100	12	250	3	700	1700		51
Sub total	1827				253		2451			
Total in MW	4531									

TABLE 11. The recent development of renewable energy projects in Egypt.

Technology	Installed					Under Construct		Under Development		
	Wind		Solar			Wind	CSP	PV		
			PV		CSP					
Project Name	Zafarana Wind Complex	Gulf Of Zeit Wind Complex	Roof-top and Central PV plants Off Grid	PV Plant Kom Ombo	Kuraymat Concentrated Solar Cell	Gulf Of Seuz 1	Kom Ombo PV plant	PV Plant Hurghada	PV Plant Kom Ombo	PV Plant Zafarana
Capacity MW	545	580	32.00	26.00	140	250	200	20	50	50
Developer Parties	German - Denmark – Spain - Japan	EU - Germany - Spain - Japan	United Arab Emirates	France (AFD)	EU – Germany	AFD - JICA	NREA-AFD	Japan - Spain	Arab Fund	German (KFW)
Sum (MW)	1125		58.00		140	450		120		
Total	1893									

with an average speed of 7 to 8 m/s. these areas are located along the Nile Valley in Assuit, Minia, and Beni-Suef. Moreover, the Gabel El-Zeit region along the Red Sea coast is richly endowed with wind energy reaching 200 MW with an average speed of 9 m/s at a height of 10 m [128], [129]. In this manner, within the Gabel El-Zeit area, two WFs large-scale projects were constructed. The first consists of 120 WTs with a capacity of 240 MW, which was built in 2010 and is called Gabal El-Zeit 1. The second project, which comprises 110 WTs with a capacity of 220 MW completed in July 2018, is called Gabel El-Zeit 2 [130], [131]. Table 9 states the WFs capacity and installed size data, and the growth in wind from 2009 to 2020 is shown in Fig. 11.

B. PROGRESS IN EGYPT: RECENT PROJECTS

Egypt has started a series of projects for both private and government sectors to support wind energy growth such as State-owned projects, Competitive bids, and Feed-in Tariffs. The private sector and NREA install, maintain and operate these projects through commercial funds. Also, an integrated framework has been created for incentives to stimulate the international and domestic private sector for investing in wind energy [50], [128].

According to [50], there are many installed projects, under construction, and underdevelopment with the help of different development parties which are depicted in detail in Tables 10 and 11. Figure 12 shows the locations of RESs projects in Egypt.

Several works related to wind power have been introduced in various sites along the Mediterranean coast, Red Sea coast to assess the same regions in Egypt [129], [132]–[137].

The average monthly speed of wind appears at a height of 10 m and the annual wind power set at various heights of 10, 70, 100 m are portrayed in Fig. 13.

VII. ROLE OF ENERGY STORAGE SYSTEMS IN EGYPT

Energy storage systems (ESSs) can assist in the transition of energy from hydrocarbon fuels to renewable sources. In addition, they are essential to regulate fluctuating wind and solar energies [8], [138], [139]. Today, several types of electrical storage applications can be classified as mechanical, electrochemical, chemical, and thermal storage systems. Figure 14 provides the detailed classifications of the different types of ESSs.

ESSs are designed to keep unexpected occurrences during peak and off-peak periods. The integration of ESSs with other energy generation sources significantly reduces

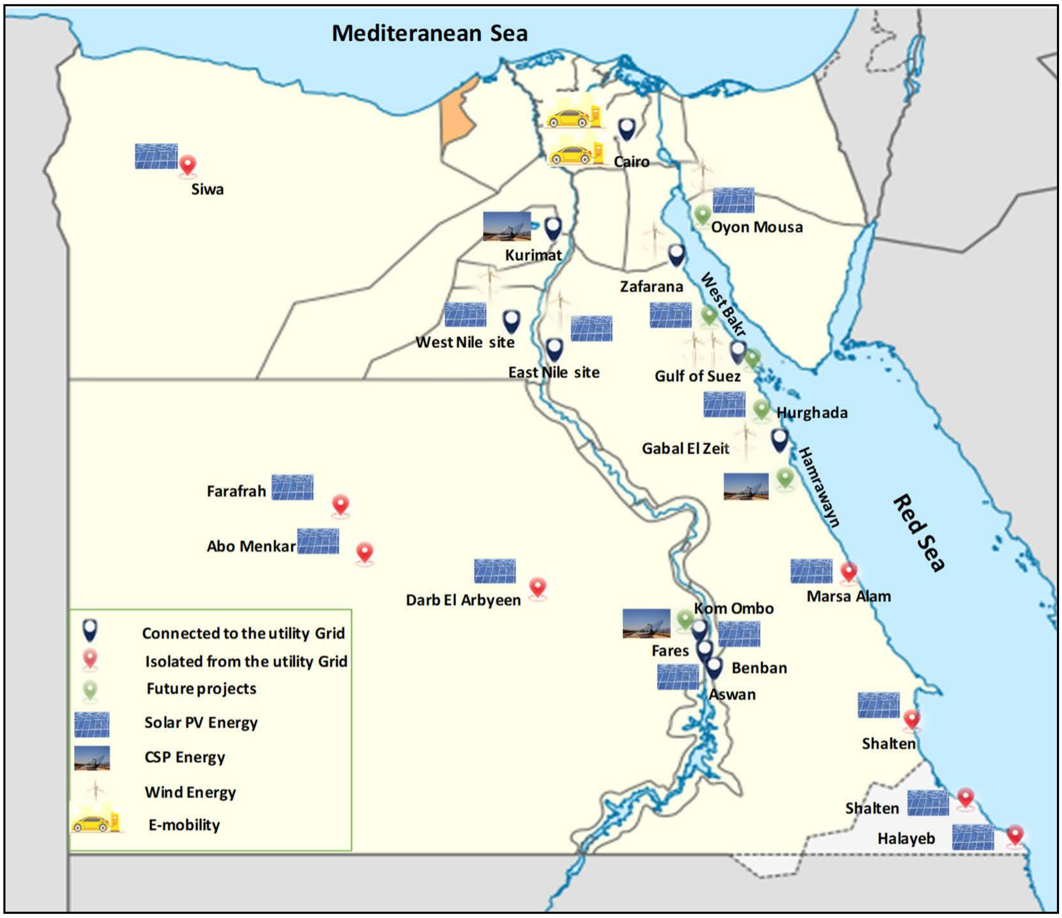

FIGURE 12. The present and future sites of renewable energy sources projects in Egypt.

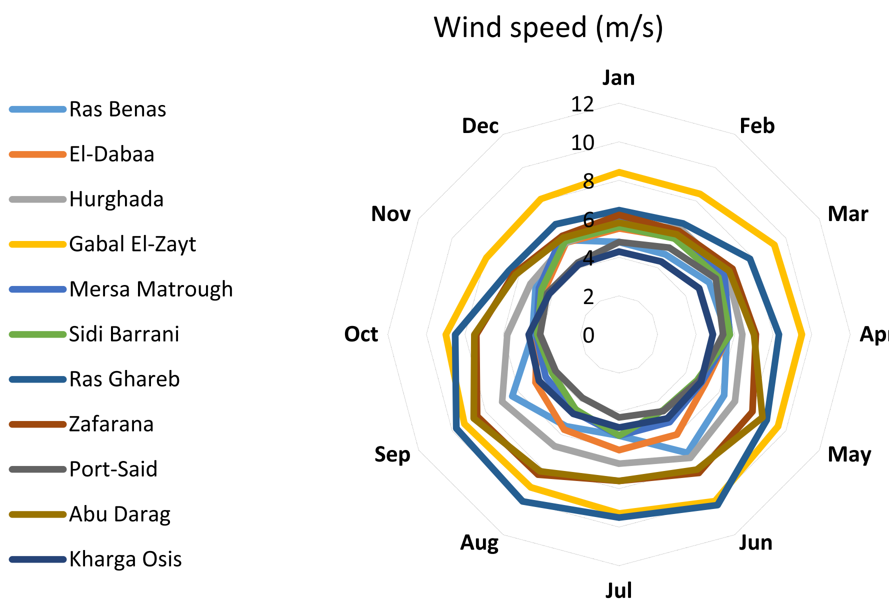

FIGURE 13. The average monthly speed of wind at 10 m height.

electricity production [8]. In addition, they have acritical implications for the power generation benefits discussed in detail in [140].

Currently, there are several barriers and challenges for a 100% energy transition to find alternative technologies capable of mitigating the CO_2 problem through zero

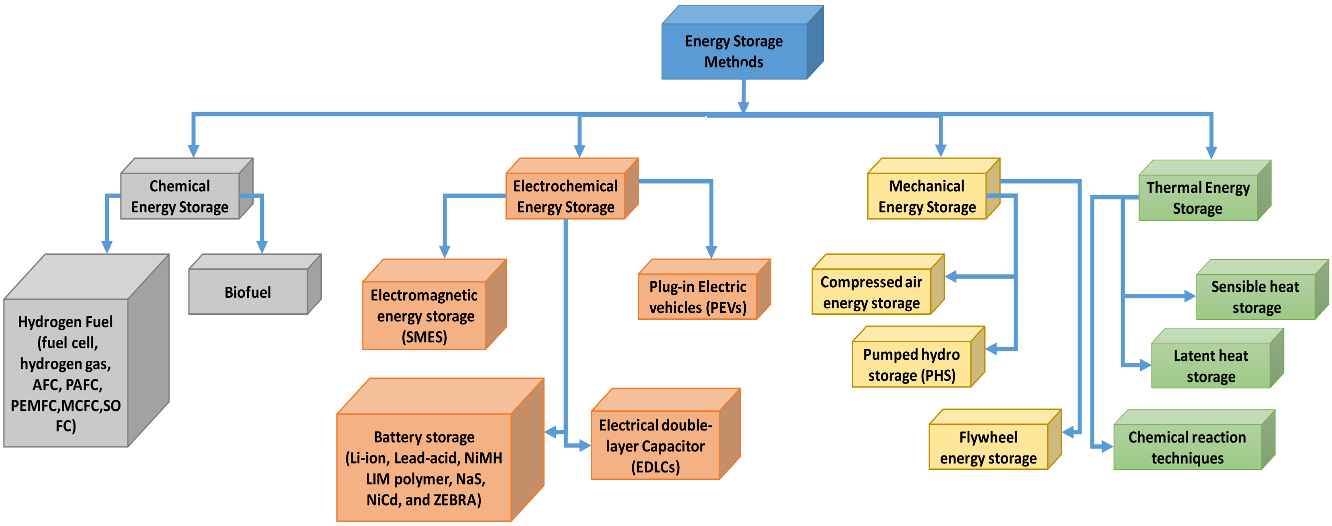

FIGURE 14. Different ESSs classification.

emissions or indiscriminate use of CO_2 in the air such as fuel-like photosynthesis [141]. In addition, batteries still represent the biggest obstacles due to their cost and short lifespan, as most countries are now turning to use electric vehicle charger stations (EVCSs) to make the environment clean [8], [142]–[146]. Taking into account the case study conducted in this review, Egypt is one of the mixed energies of developing countries, made up of natural gas (77.3%), other fossil fuels (12.64%), hydro (6.49%), and RESs (3.6%). In this regard, Egypt has drawn up a plan to reach 42% of total capacity from RESs by 2035 [5], [50]. In addition, it put a future vision for the implementations of several projects to achieve the goal; for example, Attaqa Mountain pumped storage power plant is a 2.4 GW hydroelectric power project planned for development in Suez that is scheduled for commissioning in 2024. It will be the first power plant in Egypt to generate electricity using water storage and pumping during peak times. For more details on the other projects in Egypt, they are described in the following section.

VIII. FUTURE PLAN AND PROJECTS IN EGYPT

There are several scenarios for energy and load growth, and in light of this, a strategy for future generation projects plans that corresponded to the load scenarios has been developed [5]:

A. RENEWABLE ENERGY SOURCES PRIORITIES

1) PRIMARY PRIORITY

- A Power Combined Cycle Project with a capacity of 2250 MW, which is being implemented in Luxor by Aqua Power based on BOO. It consists of two modules, the first is scheduled to operate with a capacity of 750 MW by the end of 2023, and the last with a capacity of 1500 MW is scheduled to operate in July 2024.
- A 2400 MW pumping and storage power project in Gabal Al-Ataqa, Suez, to be executed on the basis of (EPC+Finance) with 2.7 billion US dollars as an initial cost.

2) SECOND PRIORITY

- A 750 MW of RESs will be added on the BOO basis in Oyoun Moussa instead of the coal-fired power station in coordination with the Emirati investor.
- A Final construction decision on a (6 × 1000) MW thermal coal-fired power plant will be taken in Hamrawein, Red Sea, on the basis of "EPC + Finance", or part of it.
- A 100 MW CSP project located in Upper Egypt at Kom Ombo, Aswan will be developed. The aim is to reach 3% of total power-sharing by 2035. A 1 x 200 MW PV plant using bi-facial technology will be included in this project with a total area of 5 km^2 and powered by Saudi Arabia's Acwa power company.
- Four VVER-1200 / V-529 reactors with a capacity of 4.8 GW (1.2 per unit) for a nuclear power plant in Dabaa, Matrouh Governorate, Egypt, are waiting for the construction license. The essential target is to share about 4% of the Egyptian grid installed capacity by 2035.

3) THIRD PRIORITY

A total of 570 stations with a capacity of 36.1 MW were set up as follows:

- A 2.3 MW form 122 stations on top of buildings of the EEHC and its subsidiaries.
- An 11 MW from 69 stations that subscribers have installed to the Feed-in-Tariff system.
- A 22.8 MW from 379 stations that subscribers have installed to the Net-Metering system.
- A 30 MW from another 8 stations granted by Emirati (executed by MASDAR Co.) have been implemented as funded remote isolated plants.

The procedures of contracting and negotiation are currently being carried out and conducted to establish several alliances:

TABLE 12. The share of energy consumption in Egypt for the past decade.

Energy Consumption (EJ)										
Year	Oil	Gas	Coal	Solar	Hydro	Nuclear	Wind	Geo Biomass	Biofuels (TWh)
2011	405.11467	477.59288	5.126368	0.242561	33.66313	0	4.265018	0	0
2012	424.01739	506.37165	4.541821	0.149651	33.55570	0	4.590786	0	0
2013	428.64757	495.01414	4.487148	0.151310	33.88865	0	3.950250	0	0
2014	459.36988	462.18786	4.524073	0.105613	34.57772	0	2.866021	0	0
2015	477.55980	460.18807	9.544475	0.165446	34.61602	0	4.733556	0	0
2016	490.17401	493.54151	14.52134	0.262989	33.95601	0	6.351876	0	0
2017	454.87882	559.34186	14.03808	1.504876	32.80283	0	5.275432	0	0
2018	425.17771	595.94656	25.03845	3.754139	33.21744	0	5.045117	0	0
2019	417.74839	589.45312	23.09410	9.105088	33.15867	0	6.912793	0	0
2020	446.19511	573.80926	23.09410	10.87705	33.22098	0	7.229271	0.000432	0

TABLE 13. The share of energy production in Egypt for the last decade.

Energy Production (% Electricity)							
Year	Gas	Hydro	Solar	Wind	Oil	Nuclear	Other renewables
2011	74.87741	9.288127	0.148138	1.078676	14.38183	0	0.225803
2012	77.08815	9.383541	0.163415	1.113860	12.02019	0	0.230832
2013	76.73544	9.147525	0.166894	0.790813	12.94031	0	0.219005
2014	73.50766	9.081583	0.147031	0.915166	16.13144	0	0.217111
2015	71.41414	9.003324	0.160538	0.9500731	18.26072	0	0.211200
2016	70.47530	8.197490	0.102697	1.2580489	19.77206	0	0.194392
2017	72.61376	7.584674	0.345787	1.3116084	17.95875	0	0.185413
2018	76.55592	7.196911	0.342744	1.3332755	14.39540	0	0.175738
2019	76.48878	6.920820	0.818357	1.2790229	14.32779	0	0.165218
2020	77.37126	6.487689	1.901354	1.4425492	12.64189	0	0.155245

- WFs with a capacity of 1820 MW under the BOO scheme by (Toyota/Orascom/Engie - AlNowais - Italgen- Siemens/Gamesa).
- SPP with a capacity of 750 MW under the BOO scheme by (Eni of Italy, AlNowais of UAE, SkyPower of USA).

B. ELECTRIC VEHICLE (E-MOBILITY)

The NREA [50] is collaborating with several international bodies such as (i.e. World Bank, GIZ, and KfW) to investigate the entry possibility for EVCSs to the market and decide on the RESs share. This collaboration will incorporate the studying feasibility of the project, infrastructure, market research, and charging stations.

The Egyptian Military Production Ministry cooperated with China sit a strategy for EVCSs manufacture into 3-phases by 2040. The first phase starts from 2019-2024, the second from 2025-2030, and the last phase starts from 2031-2040 according to the EEHC.

Egypt will set up 1,000 fast-charging stations per year with a capacity of 50 kW for 3 years at least [47], [48]. Therefore, some pillars have been set as a strategy for industrialization and promotion for using EVCSs as:-

- Establishing the local manufacturing including public and private charging units and preparing the infrastructure.
- Increasing the Egyptian market share of EVCSs by 2% at 2030 and 5% by 2040. This also requires raising the grid capacity to handle high loads
- Acquire EVCS industrialization technology with 65% by the end of 2030.
- Increasing the industrial output rate to 50%, enhancing the existing vehicles, and substituting obsolete cars.
- Reducing environmental and health risks arising from fossil fuel utilization to 75% by 2040.

IX. CONCLUSION AND RECOMMENDATION

Egypt has a promising plan for using renewable energy sources RESs. One of the basis visions is to pay serious attention, make great efforts in research to abuse the maximum amount of RESs, and help in facing future challenges that may affect the Egyptian grid. In the past decade, Egypt has implemented more RESs plants to mimic the dependence of conventional energy sources. Statistical Analysis to clarify energy consumption and production sharing by source in Egypt has presented in Tables 11 and 12. It is noticed that the RESs are increasing slowly and still far away, so several projects will be constructed in Egypt to reach 42% of its capacity by 2035.

In this study, a quick insight into the state of energy in Egypt is provided. Also, a review of recent projects and research directions are being discussed related to WT and solar energy such as (PV, CSP, and SC). In addition, a shot on recent topics that investigate the energy transition and the integration of life-supporting systems to maximize the hosting capacity of RESs in Egypt using various Energy storage systems ESSs is provided in this study.

The Egyptian energy sector has recently faced significant challenges due to the intermittence and uncertainty of RES integration into the utility grid, lack of inertia, frequency deviations, and increases significant problems related to the power quality such as harmonics or resonance, changes in voltage and dip, and flickering. However, currently, it is difficult to take corrective action to overcome this situation.

Egypt has progressed in establishing an empowering policy, institutional framework, and regulatory for the deployment of RESs, besides possessing expertise in executing large-scale projects for renewable, especially for the generation of electricity from wind and solar.

Recommended actions to accelerate country adoption of RESs:

- Modernization of the strategies of the power sector to mirror the increased financial cost and the merits of other RESs.
- Reflect the biomass potential upgrades in future energy strategy through the development of a robust administrative framework and support schemes linked with it.
- Clarify organization roles and simplify regulations with responsibilities in wind and solar development. In addition, organize comprehensive campaigns to measure the wind and solar energy potential.
- Compilation of RESs projects to mitigate risks and guarantee the viability of their finances.
- Re-evaluate the potential for coal and nuclear to be incorporated into the mixed power supply in light of the energy security, environmental, and climate concerns posed by nuclear and coal.
- Adoption of a major plan to strengthen the capabilities of local manufacturing and the creation of a domestic industry vibrant using RESs.
- Develop a lawful framework for the management of solid organic waste with an emphasis on institutional responsibilities for selecting locations for the process of recycling and waste treatment.
- Mapping RESs and their integration to the grid by conducting cost-effective and high potential areas to develop a RE project, in order to feed the energy sector.
- Understanding and maximizing the RESs benefits deployment. Encourage consumers to install distributed thermal systems and RESs by improving technical and financial regulations and procedures. The process of moving towards a net metering schema for deployed solar PV systems should be facilitated.
- Maximize the RES hosting capacity in Egypt using ESSs to be incorporated into the distribution networks.
- Advanced infrastructure and smart meters are necessary tools to accelerate investments in RES technology, thereby promoting energy efficiency.
- The utilization of hydropower and emergent solar energy is considered the most promising RES variant, as well as the wind energy at the coastal locations.

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DECLARATION OF COMPETING INTEREST

The authors declare no conflicts of interest concerning this work.

NOMENCLATURE

INDEXES

Δf	Grid frequency minus 50.2 Hz
Δv	Change in voltage (V)
ΔP	Active power change W)
P_m	Active output power (W)
ΔP_{st}	Short term flicker factor
ΔP_{lt}	Long term flicker factor
ΔV_o	The pre-fault voltage
ΔV	Change in voltage during fault
V_n	Rated voltage
I_{SC}	Short circuit current (A)
I_L	Demand load current (A)
P	Active power (W)
Q	Reactive power (VAR)

ACRONYMS

PF	Power factor
PCC	Point of common coupling
THD	Total distortion harmonics
RESs	Renewable energy sources
EVCS	Electric vehicle charger station
SCPP	Solar chimney power plant
CSP	Concentrated solar plant
WF	Wind Farm
PV	Photovoltaics
DGs	Distributed generators
SPP	Solar power plant
SCPP	Solar chimney power plant
SSSP	Small scale solar plant
MSSP	Medium scale solar plant
LSSP	Large scale solar plant
LV	Low voltage
MV	Medium voltage

HV/EHV	High/Extra-high voltage
EEHC	Egyptian Electricity Holding Company
EETC	Egyptian Electricity Transmission Company
IEA	International Energy Agency
IEC	International Electro-technical Commission
EIA	Energy Information Administration
ISES	Integrated Sustainable Energy Strategy
NREA	New and Renewable Energy Authority
EDC	Electricity Distribution Code
GC	Grid Code
SEGCC	Solar Energy Grid Connection Code
GHI	Global horizontal irradiation
DNI	Direct normal irradiation
DIF	Diffuse horizontal irradiation
GTI	Global tilted irradiation
OPEC	Organization of the Petroleum Exporting Countries
BOOT	Build Own Operate & Transfer
POC	Point of Connection
ESSs	Energy storage systems

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