RECOMMENDATIONS FOR UPDATING THE ELECTRICITY DISTRIBUTION CODE AND SOLAR PLANTS GRID CONNECTION CODES IN EGYPT

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ABSTRACT

Electricity sector in Egypt has witnessed major developments in generation, transmission and distribution systems since 2015 due to increasing renewable energy integration, electric vehicles and electricity market reform. As a result, codes and standards have to be updated to guarantee secure and reliable operation of current and future power system. This paper suggests recommendations for updating the Egyptian electricity distribution code and solar power plants grid connection codes via a comparison among technical requirements for corresponding codes in other countries. The major similarities and differences among electricity distribution codes are clarified. Then, a detailed comparison of solar power plants connection codes is presented. The comparison includes voltage and frequency deviations, active and reactive power control, power factor control and fault ride through. Finally, proposed recommendations to update the Egyptian codes are listed.

1- INTRODUCTION

A programme of gradual electricity market reform in Egypt was initiated with law 87/2015 [1]; targeting transition from a traditional, vertically integrated, regulated state monopoly model to a fully competitive market. In addition, Egypt possesses significant renewable potential and is committed to capture the full value of these indigenous resources. For wind and Photovoltaic (PV), regulatory frameworks have been issued since 2014 [2-5].

Recently, waste to energy projects are introduced as the issuance of degree 41/2019 [6] published by the ministries cabinet. In 2013, a decree was issued by the Shura Council (consultative council) of Egypt providing electric vehicles (EV) with a 100% exemption from custom duties and this exemption was maintained in the recent presidential decree for import tariffs, issued on September 9th, 2018 [7] and EV charging station was implemented. Concerning new urban communities, the new administrative capital is being developed with the intention to highlight leading sustainability concepts, including EV charging infrastructure.

Based on the new requirements as mentioned, there appears to be a clear need for updating various electricity codes. Connecting distributed energy resource (DER) to both distribution and transmission network becomes crucial to effectively use the existing infrastructure as well as to guarantee overall system stability. Due to DER requirements, numerous countries in Europe have already upgraded their national grid codes to provide, steady state and dynamic voltage support, frequency support or on-demand response via remote control and communication [8]. The essential services commission (Victoria's energy regulator) did changes to the technical provisions of the Electricity Distribution Code (EDC) to enable uptake of DER [9].

PV is the most common DER, which is connected to distribution networks. Detailed review of Egyptian Small-Scale Photovoltaic Code (SSPVC) and case study for a 200 kW photovoltaic (PV) plant was presented in [10]. An overview of various international standards for Low Voltage (LV) PV systems grid integration was presented in [11], showing the discrepancies between them. In addition, a comparison among Germany, France and Spain codes for Medium Voltage (MV) PV integration was presented. The current Vietnamese technical and administrative framework for connecting PV plants to the LV and Medium Voltage (MV) grids was examined in [12] including a comparison with the relevant Italian technical and administrative framework. European grid-code requirements for PV power plant installations to LV and MV is described in [13]. PV power integration related grid codes are collected and compared in [14] for different

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countries (China, Europe, North America). Detailed technical requirements for connecting solar power plants to electricity networks were presented in [15]. It included a brief comparison of solar power plants connection codes of Egypt, UK, Germany, and USA.

This paper suggests recommendation for the Egyptian EDC and solar connection codes. A comparison with the major similarities and differences among codes in different countries is used as a guide for the recommendations. The structure of this paper is as follow: Requirements for electricity distribution codes in different countries are discussed in Section II. A detailed comparison of medium-scale solar power plants grid connection codes in different countries is presented in Section III. Small-scale PV network connection code is presented in Section IV. Finally, comparative analysis and suggested recommendations of the Egyptian Distribution code and solar codes are introduced.

2 - ELECTRICITY DISTRIBUTION CODES

Electricity distribution codes regulate distributing and connecting electricity to customers. It also covers embedded generating units and transferring electricity among distribution systems. In this section, different EDCs are discussed including Egyptian Electricity Distribution Code (EEDC) [16], the British Distribution Code (BDC) [17], Saudi Arabian Distribution Code (SADC) [18], Germany Medium Voltage Code (GMVC) [19], Sultanate of Oman Distribution Code (ODC) [20] and Nigeria Distribution Code (NDC) [21].

A- Voltage Range

The Distribution Network Operator (DNO) preserves the limits of the contracted nominal voltage change at supply point. Table I presents the operation voltage range in the codes.

All codes defined operation voltage range with in ±5% or ±6% but in EEDC; the range of voltage for medium voltage is ±10 % for aerial networks due to longer distances.

B - Frequency Range

The Distribution Network Operator (DNO) takes the necessary measures to preserve the network frequency, while taking into consideration the changes allowed within the grid code. Table II presents the operation frequency range in various codes.

Table I- Limits of Operating Voltage

Code	Requirements in the code
EEDC	Low nominal voltages: voltages up to 0.4 kV. Medium nominal voltages: voltages higher than 0.4 kV and up till less than 33 kV. Voltage Operation Range For Low Voltage = ± 5 % For Medium Voltage For underground cables = ± 5 %. For aerial networks = ± 10 %. In the Egyptian Electricity law [1], voltage level is defined as follows: 'Low Voltage: voltages up to 1 kV. Medium voltage: voltages higher than 1 kV and up till less than 33 kV.'
BDC	Low Voltage: In relation to alternating current, a voltage exceeding 50 volts but not exceeding 1 kV. Medium Voltage: voltage exceeding 1 kV. Voltage Operation Range: For Low Voltage = ± 5 % For Medium Voltage = ± 5 %
SADC	Low Voltage: voltage used for the supply of electricity, the upper limit of nominal RMS value of which does not exceed 1 kV. Medium Voltage: voltage used for the supply of electricity, the nominal value of which is between 11 kV and 36 kV. Voltage Operation Range For Low Voltage = ± 5 %. For Medium Voltage = ± 5 %.
GMVC	Not mentioned.
ODC	For low voltages: 415/240 V, Voltage Operation Range = ± 6 %. For Medium voltages: 33/11 kV, Voltage Operation Range = ± 6 %.
NDC	For low voltage: 415/230 V, Voltage Operation Range = ± 6 %. For Medium voltage: 11/16 kV, Voltage Operation Range = ± 5%. 33 kV, Voltage Operation Range = ± 6 %.

All codes defined operation voltage range with in ±5% or ±6% but in EEDC; the range of voltage for medium voltage is ±10 % for aerial networks due to longer distances.

Table II- Limits of Operating Frequency

Code	Requirements in the code
EEDC	Normal Operation Frequency = 50 Hz. Frequency Operation Range The licensed distributor is obliged to follow the instructions given to him from the National Control Centre.
BDC	Normal Operation Frequency = 50 Hz. Frequency Operation Range shall normally be controlled within the limits of 49.5 - 50.5 Hz.
SADC	Not mentioned.
GMVC	Normal Operation Frequency = 50 Hz. Frequency Range 49.5-50.25Hz.
ODC	Normal Operation Frequency = 50 Hz. During exceptional steady state conditions, Frequency deviations will not exceed 49.90Hz to 50.10Hz. Under disturbed conditions, System Frequency could rise transiently to 51.50 Hz or fall to 48.00 Hz.
NDC	Not mentioned.

The BDC, GMVC and ODC defined the operation frequency range but EEDC did not define the range, however it should follow the instruction of the National Control Centre.

C- Fault Level Consideration: The short circuit rating of user's equipment at the connection point should be not less than the design fault level of the distribution network operator's distribution system to which it is connected. Table III shows the necessity of not exced the short circuit level at the connection point.

Table III- Short Circuit Rating of User's Equipment

Code	Requirements in the code
EEDC	When designing and operating the scattered production unit it should be taken into consideration short circuit level shall not exceed limits in the code.
BDC	The short circuit rating of User's Equipment at the Connection Point should be not less than the design fault level of the DNO's Distribution System to which it is connected. The DNO in the design of its system will take into account the contribution to fault level of the user's connected system and apparatus.
SADC	Not mentioned.
GMVC	Electric installations must be designed, constructed and erected in such a way that they reliably withstand mechanical and thermal effects of a short-circuit current. The connection owner shall furnish proof of the short-circuit current capability for the entire transfer station.
ODC	Not mentioned.
NDC	Not mentioned.

All codes, except ODC and NDC, clarify the limits of short circuit level at the connection point, which shall not exceed certain limits by the user's equipment, and these limits are different according to the different construction of the networks.

D- Voltage Phase Unbalance

Voltage phase unbalance is defined as the ratio between the rms values of the negative sequence component and the positive sequence components of the voltage. Table IV shows the limits of voltage phase balance in each code.

Table IV- Voltage Phase Unbalance

Code	Requirements in the code
EEDC	Load Balance: The subscriber is to verify the balance of his loads so that the current of each phase does not deviate from the average of the measured three-phase - whatever the applied calculation method is or the measuring device. At normal case, LV unbalance= 2 % and MV unbalance = 5 %. At emergency less than 2 minutes, LV unbalance= 10 % and MV unbalance = 4 %.
BDC	The voltage unbalance should not exceed 1.3 % for systems with a nominal voltage below 33 kV.
SADC	Not mentioned.
GMVC	The customer facility must not exceed a resultant degree of unbalance KU,i = 0.7% with averaging over 10 minutes.
ODC	A maximum value of 2.0% is permitted for phase unbalance.
NDC	Not mentioned.

The BDC, GMVC and ODC define the allowed percentage of voltage phase unbalance. EEDC defines the allowed percentage of current phase unbalance.

E- Power Factor

The ratio of active power to apparent power is the power factor. Table V defined the power factor of the user.

Table V- User's Power Factor

Code	Requirements in the code
EEDC	The subscriber of 10 kW power and more is obliged to keep the average power factor at 0.90. In case the factor increases above 0.92, the subscriber then deserves a reduction of the invoice value according to the electrical current supply contracts that have been approved by the Authority. In tariff calculation by the Egyptian Electricity regulator [22], The tariff is calculated to loads with 0.92 power factor.
BDC	Not mentioned.
SADC	Not mentioned.
GMVC	The displacement factor cos φ of the customer facility must be between 0.9 inductive and 0.9 capacitive. The network operator may determine closer limits for its network.
ODC	Not mentioned.
NDC	All MV users shall maintain a power factor not less than 0.85 lagging at the connection point, unless a different value has been agreed in the connection agreement.

The GMVC allows the customer facility to be between 0.9 inductive and 0.9 capacitive. While EEDC obliged the customer to keep the average power factor at 0.90 but the exact billing is at average power factor 0.92 every three months [22].

3 - MEDIUM SCALE SOLAR CODES

Medium Scale Solar Code (MSSC) stipulates the technical requirements and specifications of integrating Medium Scale PV (MSPV) power plants or Medium Scale thermal power plant to the medium voltage distribution networks. It includes technical requirements and limits of system performances such as frequency and active power control, voltage and reactive power control, and fault ride through. This section presents a comparison between Egyptian Solar Energy Plants Grid Connection Code (EMSSC) [23], British generating plant connection (BMSSC) [24], Germany grid code for connecting PV systems to the medium voltage power grid (GMSPVC) [25], Grid connection code for renewable power plant connected to the electricity transmission system or the distribution system in South Africa (SAMSC) [26], California Requirements for Large Generator (CMSSC) [27] and Sultanate of Oman Technical

Guidelines for medium scale PV (OMSPVC) [28].

A- The Frequency and Active Power Control

The main reason for the active power control is to ensure frequency within range. Table VI shows how the renewable station can help in controlling the active power.

B- Reactive Power Control

Consumption and generating of reactive power must be matched in order to maintain a stable system voltage. Table VII shows the contribution of reactive power to overcome voltage decrease. The GMSPVC mentioned that the facility must be capable of feeding required reactive power within 20 ms while the EMSSC requires 250 ms of reactive current injection. The range of reactive power within 0.95 leading to 0.95 lagging power factor at rated active power in medium voltage codes except for SAMSSC and OMSPVC.

Table VI- Control of Active Power for Frequency Regulations

Code	Requirements in the code
EMSSC	For grid frequencies in the range from 50.2 Hz to 51.5 Hz the solar plant has to reduce active power (Installed capacity from 500 kW to 50MW). The output power must be reduced by: $\Delta P = 0.4 \times PM \times (\Delta f/Hz)$ The output power is allowed to increase again as soon as the frequency becomes below 50.2 Hz.
BMSSC	Be able to control the active power for frequency regulations (Installed capacity 50MW).
GMSPVC	Be capable of operation at reduced power output (if PCC rated voltage 10kV). All generating units have to reduce their power output above a system frequency of 50.2 Hz. The power has to reduce with a gradient of 40%/ Hz of the instantaneously available power. The output power is only allowed to increase again as soon as the frequency becomes below 50.05 Hz.
SAMSSC	When the *frequency* on the network exceeds 50.5 Hz, the renewable power plant shall reduce the active power as a function of the change in frequency. Once the frequency exceed 51.5 Hz for longer than 4 seconds the renewable power plant shall be tripped.
CMSSC	The plant is set to operate at a curtailed power level that is 10% lower than the available estimated peak power. The upper limit of the droop curve is the available plant power, and the lower limit is at a level that is 20% below the then-available peak power. The implemented droop curve also had a ±36 mHz frequency dead band.
OMSPVC	The frequency shall be between 49-50.3 Hz. For overfrequency, the power droop shall be 4.4 %. For underfrequency, reduction rate of the power shall be 10 % (per 1 Hz for frequency below 49 Hz) of the rated power at 50 Hz.

C- Fault Ride Through

Fault ride through ability means that the grid-connected photovoltaic power station could remain online when the point of common coupling voltage is higher than the prescribed critical low voltage curve and lower than the critical high voltage curve during various faults and their clearance. Fault ride through is illustrated in Table VIII as shown in Fig. 1.

Table VII- Reactive Power Contribution

Code	Requirements in the code
EMSSC	For 3-phase faults, the solar plant must inject reactive current for the time period 250ms after the beginning of the fault until fault clearance. For unsymmetrical faults, it is not permissible that during the duration of the fault, reactive currents be fed into the grid, which will give rise to voltages higher than 110% nominal voltage in non-faulty phases at the grid connection point. The solar plant must be able to control reactive power at the grid connection point in a range of 0.95 lagging to 0.95 leading at maximum active power to 20% of active power.
BMSSC	Not mentioned.
GMSPVC	In the event of voltage, drop of more than 10% the reactive current contribution of at least 2% of the rated current per percent of the voltage drop. The facility must be capable of feeding required reactive power within 20 ms.
SAMSSC	The reactive power capability of renewable power plant shall be available within the parameters: Voltage (p.u): 0.20-0.80, power factor: -0.95:0.95. Voltage (p.u): 0.80-1.10, power factor: -0.975:0.975.
CMSSC	For the asynchronous generating facility, provide reactive power at 0.95 lagging power factor when voltage levels are between 0.95–1 p.u. Likewise, it should be able to absorb reactive power at 0.95 leading power factor when voltage levels are between 1–1.05 p.u.
OMSPVC	The provision of reactive current during a fault is currently not required. But it might be introduced in the future with growing PV penetration. Power factor is varying between 0.90 lagging and 0.90 leading.

Table VIII- Fault Ride Through

Code	Requirements in the code
EMSSC	The Solar Plant shall trip if all phase-to-phase voltages are below the curve in Fig. 1.
BMSSC	Any generation set or power station connected to the DNO’s distribution system, where it has been agreed between the DNO and the generator that the generator’s power station will contribute to the DNO’s distribution system security, may be required to withstand, without tripping, the effects of a close up three phase fault and the phase (voltage) unbalance imposed during the clearance of a close-up phase-to-phase fault, in both cases cleared by the DNO’s main protection.
GMSPVC	Fig. 1 shows the limiting curve of plants during faults. They must not disconnect during voltage drop down to 0%Uc with duration of ≤ 150 ms. Underneath the blue line; there are no requirements to remain grid connection.
SAMSSC	Fig. 1 for SAMSPVC shows the combinations of voltage and time that renewable power plant shall be able to endure. 'Must Remain Connected Area' is between upper and lower bounds.

CMSSC	**The plant should withstand zero voltage up to 150 msec and according to Fig. 1.**
OMSPVC	**PV shall be capable to stay connected as long as the voltage at the Point of Coupling (PoC) above the voltage time diagram in Fig. 1.**

Time of withstanding fault is different in the codes for: 150 ms, 200 ms or 250 ms and the operation areas are totally different.

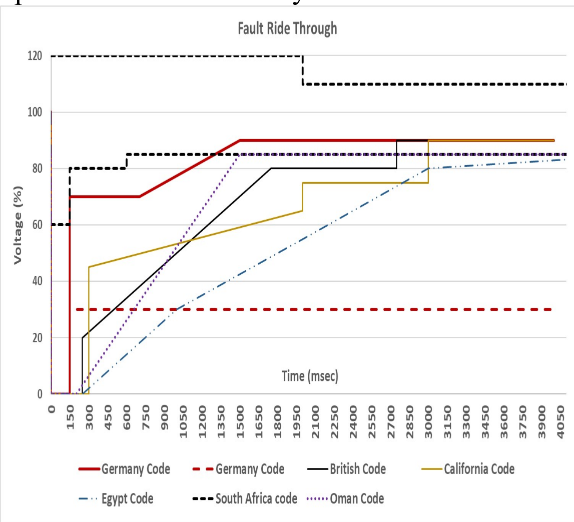

Fig. 1- Fault Ride Through for Germany, British, California, Egyptian, South Africa and Oman codes

4- Small Scale Photovoltaic Code

Small Scale Photovoltaic Code (SSPVC) specifies the technical requirement for integrating small scale PV (SSPV) plant to the low voltage distribution network. In this section, the comparison includes Egyptian Technical Requirements for Connecting Small Scale PV Systems to Low Voltage Distribution Networks (ESSPVC) [29, 30], the British small scale embedded generator connection PV (BSSPVC) [31], Germany Technical Conditions for the Connection to the low voltage network (GSSPVC) [32] and Sultanate of Oman Technical Guidelines for medium scale PV (OSSPVC) [28].

A- Voltage Range

PV integration may increase the system voltage so it is so important to limit the maximum voltage. Table IX presents the range of the voltage.

Table IX- Voltage Range

Code	Requirements in the code
ESSPVC	In accordance to Distribution Code 4-1-1 "Quality of electrical supply voltage", the DNO shall maintain the limits of the voltage variation in the range of +/- 10% of the nominal voltage.
BSSPVC	Voltage limits (119% to 87%) of nominal voltage
GSSPVC	Voltage limits (110% to 80%) of nominal voltage
OSSPVC	Voltage range: 85 -110 % of rated voltage.

B- Frequency Range

PV that operates in parallel with utility system shall operate within the frequency limits. If the system frequency exceeds these limits, the PV system should disconnect until the system returns to normal frequency operation range. Table X presents the frequency limits.

C- Power Factor

According to power factor, the PV will inject or absorb reactive power to the network, which affects the voltage of the network. Table XI presents the required power factor.

Table X- Frequency Range

Code	Requirements in the code
ESSPVC	An SSPV that operates in parallel with the utility system shall operate within the frequency trip limits in accordance to the Distribution Code 4-1-3 (48.5Hz -51 Hz).
BSSPVC	SSPV shall operate within the frequency trip limits (47.5-51.5 Hz)
GSSPVC	Disconnection at over-frequency: Inverter manufacturers have to implement threshold values between 50.3 Hz and 51.5 Hz (uniformly distributed)
OSSPVC	Frequency range: (47.5-52.5 Hz).

Table XI- Power factor

Code	Requirements in the code
ESSPVC	"Power factor: The SSPV shall not inject reactive power into the utility network, while the drain of reactive power shall be limited to a power factor of 0.9. This limit applies unless otherwise agreed upon with the utility." The SSPV consumes reactive power.
BSSPVC	SSPV shall operate at a power factor within the range 0.95 lagging to 0.95 leading relative to the voltage waveform unless agreed with the distribution network operator
GSSPVC	For SSPV < 13.8 kVA, power factor 0.95 lead or lag. For SSPV > 13.8 kVA, power factor 0.90 lead or lag.
OSSPVC	Not Mentioned.

5- Recommendation for Egyptian Codes

The Egyptian Electricity Utility and Consumer Protection Agency (Egyptera) is responsible for developing electricity codes and tariff structure. EEDC was published in 2010, SSPVC in 2014 and MSPVC in 2017. SWOT analysis of PV in Egypt was investigated in [33], which illustrate the potential of PV in Egypt.

A- Recommendations for the Electricity Distribution Code

1- Change the definition of voltage in the distribution code to be:

- Low nominal voltages up to 1kV.
- Medium nominal voltages: voltages higher than 1 kV and up till less than 33 kV.

2- Define the frequency operation range to be normally controlled within the limits of 49.5 – 50.5 Hz.

In exceptional circumstances, system frequency could rise transiently to values of the order of 52 Hz or fall to values of the order of 47.5 Hz.
3- Short circuit level shall be added to the planning chapter to be a guide for new equipment installation as well as for scattered units.
4- The power factor for subscriber of 10 Kw power and more shall be harmonized with the tariff.
5- Add notification about technical requirements to connect medium voltage load and diversity factor or refer which are mentioned in periodical book number 1-2020 and periodical book number 4-2020 [34, 35].
6- Add chapter about earthing requirements.
7- Add chapter about communication and SCADA system.
8- Complete the metering chapter to include smart meters and its communication system
9- Add item about losses clarifying the duties of Distribution company:
- Classify system losses into two categories technical losses and non-technical losses;
- Endeavour to keep the distribution losses at economically acceptable levels in compliance with the regulator directives.
10- Harmonics standard should be updated to IEEE-519-2014, and any future updates.

B- Recommendations for Solar Energy Plants Grid Connection Code

1- Harmonics standard should be updated to IEEE-519-2014, and any future updates.
2- Add a part about detailed grid impact study.

C- Recommendations for Small Scale Photovoltaic Code (ESSPVC)

1- At the beginning; the following statement: (This document entitled “Technical Requirements for Connecting ssPV Systems to low voltage Distribution Networks” is all complementary documents that entail obligatory provisions for Customers seeking ssPV installations) should be replace by: (This document entitled “Technical Requirements for Connecting ssPV Systems to Low Voltage Distribution Networks” and the Egyptian Electricity Distribution Code are two complementary documents.)
2- Scope modification: “This document specifies the technical requirement for connecting small scale PV to the low voltage distribution network. It applies to SSPV installed (< 500 kW) at three-phase connections while ensuring compliance of the utility interface with the requirements documented in this specification (and Electricity Distribution Code).”
3- Voltage range in ESSPVC should comply with voltage range in EEDC.
4- Controlling reactive power may control voltage, so SSPV shall operate at a power factor within the range 0.95 lagging to 0.95 leading relative to voltage waveform unless otherwise agreed with the DNO.
5- Harmonics standard should be updated to IEEE-519-2014, and any future updates.
6- Define the connection procedure steps.
7- Define commissioning and acceptance tests.

V- CONCLUSIONS

In this paper, recommendations for Egyptian EDC and solar codes have been suggested based on a comparison among different codes of different countries. The requirements in corresponding codes are compared with each other and comments on major similarities and differences between them have been explored. Connection conditions for solar power plants have been analysed and summarized for each grid connection code. Steady state or normal operations conditions such as voltage and frequency deviations, active and reactive power control, voltage control, and power factor control requirements have been studied. Furthermore, fault ride through requirement during grid disturbance have been discussed

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