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# VERIFICATION OF IEEE STANDARDS 929-2000 AND 1547-2003 TO A SMALL PHOTOVOLTAIC SYSTEM CONNECTED TO BEER ELABD DISTRIBUTION GRID-NORTH SINAI-EGYPT

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**Abstract**: This paper studies the power quality of grid connected photovoltaic (PV) system by verification of IEEE standards 929-2000 and 1547-2003 for a small PV system connected to a grid. For practical considerations, the PV system data extracted from a real standalone PV system and the distribution grid is simulated based on real data extracted from North Sinai distribution network. The Suggested system is simulated under different climate conditions to get real simulation of solar irradiation. A 10 KW grid connected PV system is modeled and simulated by using Matlab/Simulink software and the power quality parameters are studied under different levels of irradiance for the proposed system according to IEEE standards. System operated under normal and abnormal utility conditions. Results show a good compatibility with IEEE standards for subsystem proposed system in case of normal utility operation. In case of abnormal utility conditions, the PV system must island for protection issues.

**Keywords**: Boost Converter, IEEE standard, inverter, MPPT, MATLAB/Simulink, PV system

## I. Introduction

Renewable energy (RE) sources play an important role in electric power generation. Since global warming and environmental pollution are nowadays two of the main worldwide concerns. Renewable energy can play a significant role on the reduction of environmental problems and delay of fossil fuel depletion.

Solar energy is widely used due to its simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts [1].

Egypt belongs to the global sun-belt that means its geographical position is advantageous. In 1991 solar atlas for Egypt was issued indicating that the country enjoys 2900-

3200 hours of sunshine annually with annual direct normal energy density 1970-3200 kWh/m2 [2]. North Sinai is a remote location in Egypt which is rich of sun irradiance most time of the year. Despite the fact that Egypt located in Sun Belt, the use of PV cells does not reflect that fact. Sometimes it is also difficult to transmit power to the remote and hilly places which are far away for the main generating station. Long distance transmission lines are one of the main causes for electrical power losses. So, emphasis on distributed generation (DG) networks with integration of RE systems into the national grid, leads economic and environmental benefits [3]. PV system can be stand alone, grid connected systems or hybrid system according to its operation. Also PV system can be stationary or use solar tracking system [4].

Solar energy is expected to play a great role in the grid's future infrastructure as a distributed source, due to the fact that it is an easily available renewable source of energy.

Grid connected PV system become one of the most preferable environmental solutions [1].

The installation of (PV) equipment is governed by a number of industry codes and standards. Electrical contractors need

to be aware of the codes and standards to ensure safe and functional PV installation.

Different utilities, even with adjacent service areas, often have different policies and requirements for connecting on-site distributed generation to their systems. The problem is that the standards can easily verify for large systems on the contrary the small systems. Two standards have been developed by the IEEE aimed at standardizing the requirements for interconnecting PV systems with the serving utility's system: 1547-2003 and 929-2000. IEEE standards cover the PV system operation at normal and abnormal utility conditions.

This paper discusses the verification of IEEE standard for a 10 KW PV system connected to North Sinai distribution network. The distribution grid is simulated based on real data extracted from North Sinai distribution network. PV system MPPT is studied and simulated. Boost converter (P & O) algorithms is used for control process. Suggested system is simulated under different climate conditions to get real simulation of solar irradiation. Power quality, nominal voltage ranges and voltage flicker are studied for the proposed system according to IEEE standards. System operated under normal and abnormal utility conditions. Results show a good compatibility with IEEE standard for subsystem proposed in case of normal operation. All simulations are performed using MATLAB/Simulink software with real time data obtained from Beer Elabd distribution network.

## II. system description and modeling

Several components are needed to construct a grid connected PV system to perform the power generation and conversion functions. Fig 1 shows the power converter structure used to interface the photovoltaic array with the grid. The first stage is the boost converter, which will raise the relatively low solar voltage to a level suitable (500 V) for the dc link directly connected to the inverter. The second stage is the DC to AC inverter that operates in a current controlled mode which will inject unity power factor current to the grid. The inverter should be able to supply a continuous power from the dc link bus to a three phase utility line (250 V / 50 Hz). An output L filter is employed to reduce the ripple components due to PWM switching operation. The system tied to the grid through 0.25 / 22 KV power transformer.

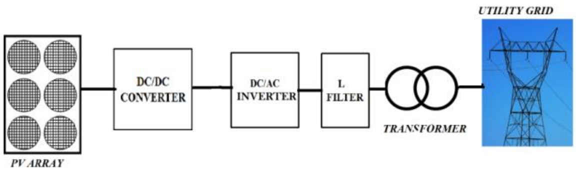


**Fig 1. Components of a Grid Connected PV System**

### A. PV system modeling

#### *1 )* Single PV cell modeling

The PV cell is usually represented by the single diode model. The single diode equivalent circuit of a solar cell is as shown in Figure 2 [5] [6].

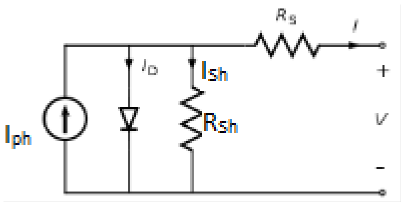


**Fig 2. solar cell equivalent circuit**

It primarily consists of a current source that generates photo-current (Iph), which is a function of incident solar irradiation and cell temperature and a diode that represents p–n junction of the solar cell. In practical solar cells, the voltage loss on the way to the external contacts is observed. This voltage loss is expressed by a series resistance $R_S$. Furthermore, leakage current is described by a parallel resistance $R_{sh}$. The voltage-current characteristic equation of a solar cell is given as follows:

$I_{sh}$ Short circuit current is the maximum possible current in the circuit, at zero voltage [7].

Short circuit current

$$I=I_{ph}-I_d-I_{sh} \qquad (1)$$

$$I=Iph-Io\{exp[\frac{q[V+IRs]}{AKTc}]-1\}-\frac{V+IRs}{Rsh} \qquad (2)$$

Where $I_O$ is the saturation current (representing the diode), $R_s$ series resistance, A is diode ideality factor, k (= 1.38 ×$10^{-23}$ w/m$^2$k) is Boltzmann‟s constant, q (=1.6×$10^{-19}$ C) is the magnitude of charge on an electron and $T_C$ is working cell temperature.

Open circuit voltage:

$$Voc=\left(\frac{AKTc}{e}\right)\ln\left(\frac{Iph}{Io}\right)=Vt\ln\left(\frac{Iph}{Io}\right) \qquad (3)$$

Maximum power point:

$$P_{max}=I_{max}.V_{max} \qquad (4)$$

#### *2 )* Multiple PV cells "Module"

The PV module is the result of associating a group of PV cells in series (Ns) and parallel (Np), with their protection devices, and it represents the conversion unit in this generation system. The manufacturer supply PV cells in modules, consisting of NPM parallel branches, each with NSM solar cells in series shown in Fig.3. The voltage-current characteristic equation of a solar cell array is given in equation 5: [8] [15] [7].

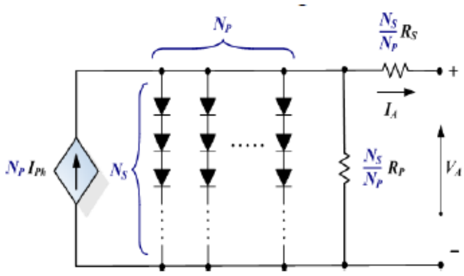


**Fig 3. PV module equivalent circuit**

$$I_A=N_pI_{ph}-N_pI_{Rs}\{\exp[\frac{q}{AKTc}(\frac{Va}{Ns}+\frac{IaRs}{Np})]-1\}-\frac{Np}{Rp}\{\frac{Va}{Ns}+\frac{IaRs}{Np}\} \quad (5)$$

Where: $I_A$: PV array output current, $V_A$: PV array output voltage and $I_{Ph}$: Solar cell photocurrent

**B. DC-DC Converter modelling**

A DC-DC converter acts as an interface between the PV and the load, and by varying the duty cycle the point of operation of the module is adjusted. It makes the PV system to operate at maximum power point [14].

This paper uses the classical boost converter which operates in the continuous conduction mode to implement the MPPT algorithm.

Classical boost converter has an output voltage which always higher than the input PV cell voltage. The topology for classical boost converter is simple, easy to implement, and has high efficiency [10] [11] [12] [13].

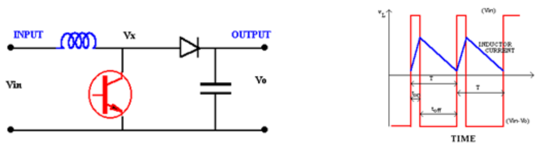


**Fig 4. DC-DC boost converter**

$$Vo=\frac{1}{1-D}\,Vin \quad (6)$$

Where $V_{out}$ is the output voltage, D is duty cycle, and $V_{in}$ is input voltage which in this case will be the solar panel voltage.

**C. MPPT**

MPPT algorithm is important in PV systems because it reduces the PV array cost by reducing the number of PV panels required to achieve the desired output power. MPPT increase the efficiency of photovoltaic systems [15] [16].

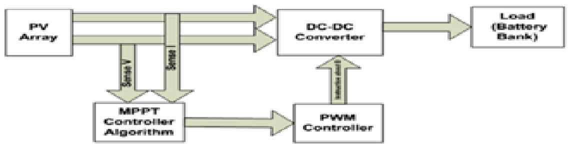


**Fig 5. Block diagram of the complete PV structure with MPPT algorithm**

There are many techniques concerning MPPT. Among various algorithms, P&O algorithm is used in this work for the MPP tracking. A scheme of the algorithm is shown in Figure 6 below [17] [18] [19].

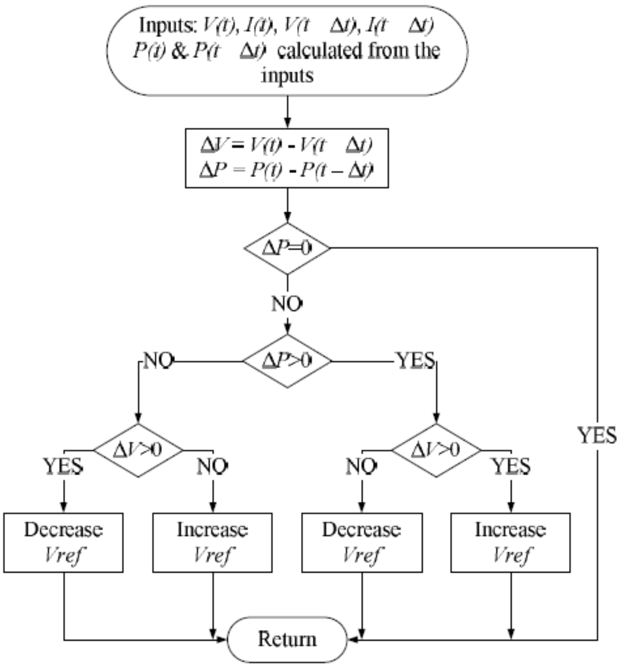


**Fig.6 Flow chart for P& O MPPT algorithm**

**D. Inverter**

The grid-connected inverter is important to connect the PV generator to utility system. It acts as bridge to transfer the power that produces from PV cells to utility. However, the inverters must produce good-quality sine-wave output, must follow the frequency and voltage of the grid. The inverter must observe the phase of the grid, and inverter output must be controlled both voltage and frequency variation [20]. The Inverter used is three-level neutral point clamped inverter (NPC) type Voltage source inverter (VSI) which is controlled using synchronous d-q reference frame to inject a controlled current into the load, figure 7. Phase lock loop (PLL) is used to lock grid frequency and phase [21]. The Three-Level Bridge block implements a three-level power converter that consists of one, two, or three arms of power switching devices. Each arm consists of four switching devices along with their anti parallel diodes and two neutral clamping diodes [22] [23].

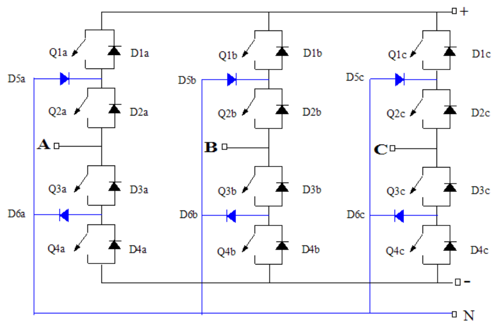


**Fig 7. Three phase three level voltage source inverter**

**E. Grid**

The grid in this work is section of distribution grid with 22 KV line to line voltage. The frequency is 50 HZ. The grid part of Beer Elabd, North Sinai, Egypt. The source of the DR at beer Elabd from the transmission line through power transformer 66 / 22 KV. In this work we presented the power source as three phase source.

## III. ieee standard for grid connected PV system

A major barrier to grid-connected PV has been the lack of standards for interconnecting the facility's PV system with the utility's system. Different utilities, even with adjacent service areas, often have different policies and requirements for connecting on-site distributed generation to their systems. Two standards have been developed by the IEEE aimed to

standardizing the requirements for interconnecting PV systems with the serving utility's system: [24] [25] [26] [28] [29].

929-2000: Recommended Practice for Utility Interface of Residential and Intermediate PV Systems. &1547-2003: Standard for Interconnecting Distributed Resources (DR) with Electric Power Systems.

The proposed system is investigated to show consistence with IEEE standards.

## IV. Simulation and results

A complete Simulink-Matlab simulation of the closed loop PV system including the global and command previously studied has been carried out with the following parameters shown in table 1:

Characteristics measured under standard test conditions (STC: irradiance 1000 w/m$^2$, cell temperature=25 deg. C)

**Table1.PV system data**

| Vs | 0.6 VDC | Ns series cells per module | 72 |
|---|---|---|---|
| KI short circuit current coefficient | 0.037 | Np parallel modules | 60:600 |
| Rs series resistance | 3.95x10-4 ohm | Isc module short circuit current | 4.9 A |
| Rp parallel resistance | 99.32ohm | Module power | 160 W |

### A. System data

In this case the PV system connected to the grid load by boost converter, inverter and transformer. The Boost converter boosts the entire voltage of PV system to be 500. The DC /AC inverter convert the DC voltage to AC voltage (inverter output voltage is 250 VAC and 50 HZ). The transformer step up the voltage to 22 KV. The complete simulink model of PV module is shown in Figure 8.

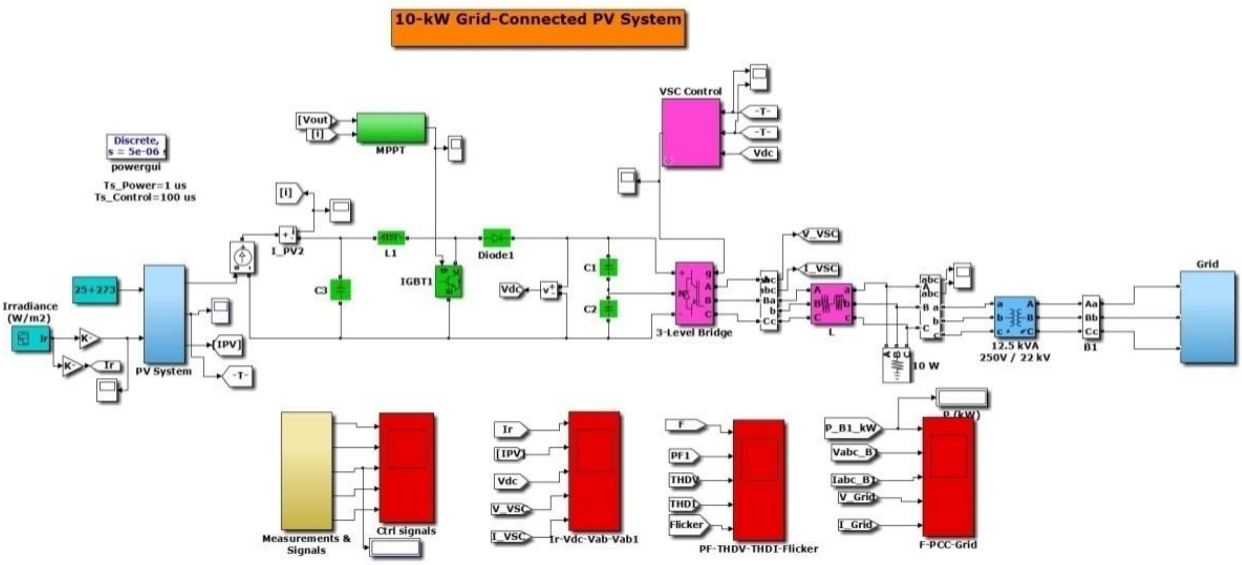


**Fig 8. Simulink model for PV system connected to grid**

### B. Parameters

According to IEEE standards 929-2000 and 1547-2003 PV system has to achieve the values mentioned in that standards when connect with the grid.

#### 1 ) Voltage Flicker

The International Union for the Application of Electricity (UIE), which was formerly known as the International Union for Electro heat, adopted a standard assessment methodology that is based on the previously developed flicker meters proposed in 1979, taking into account the following facts: [27]

- Specification of the design and function characteristics of the measurement device (flicker meter)
- Specification of the statistical assessment of the flicker phenomenon

#### 2 ) Power factor

The power factor definition is the ratio between the applied active (true) power - and the apparent power, and can in general be expressed as: [30]

$$PF = P / S \qquad (7)$$

Where, PF = power factor, P: active (true or real) power (Watts) and S: apparent power (VA, volts amps)

### 3 ) Total Harmonic Distortion

Total harmonic distortion (THD), is the summation of all harmonic components of the voltage or current wave form compared against the fundamental component of the voltage or current wave: [30]

$$\mathbf{THD\ (voltage)} = \frac{\sqrt{\mathbf{V2^2+V3^2+V42......+Vn^2}}}{\mathbf{V1}} * \mathbf{100}\ \% \qquad \mathbf{(8)}$$

$$\mathbf{THD\ (current)} = \frac{\sqrt{\mathbf{I2^2+I3^2+I4^2......+In^2}}}{\mathbf{I1}} * \mathbf{100}\ \% \qquad \mathbf{(9)}$$

### 4 ) Frequency

Frequency can be obtained from the phase locked loop control.

## C. System simulation results

The system described is simulated in MATLAB/Simulink to evaluate its operational characteristics. The system is evaluated over a 1-secondfor studying system behavior under different circumstances over a complete sunny day. This time-span is chosen to get fast results. Temperature input set at 25 °C. The results of the system parameters using the methods and models outlined previously were completed using a various simulation packages.

Here the simulation is carried out by two cases Normal and abnormal utility conditions.

Figure 9 and 10 obtained the I-V and P-V characteristics of PV module.

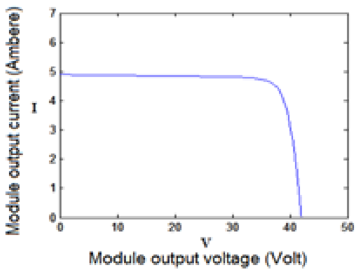


**Fig. 9.I-V characteristic for PV Module**

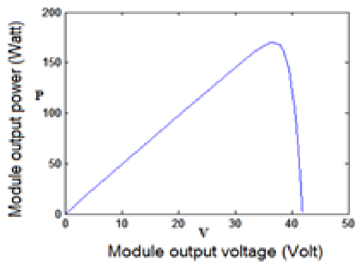


**Fig 10. P-V characteristic for PV Module**

### 1 ) Normal operation

Assuming solar irradiance changes as shown in figure 11. The irradiance figure covers different solar changes from zero to 1000 $w/m^2$, ramp and sudden change. The PV output current changed with the solar radiation changes. The DC bus regulator must act to maintain the DC bus Voltage constant (at 500 V) figures 11, this to makes PV system able to feed the inverter and the load. The voltage output of DC/AC inverter constant at 250 V, but the inverter output current changed with the variation of solar irradiance as obtained in figure 11. At the begging of the simulation the voltage and current raised to 0.1 second. This is due to simulation starting and reaches to steady state operation. The voltage and current raise causes deviation for all parameters at that time.

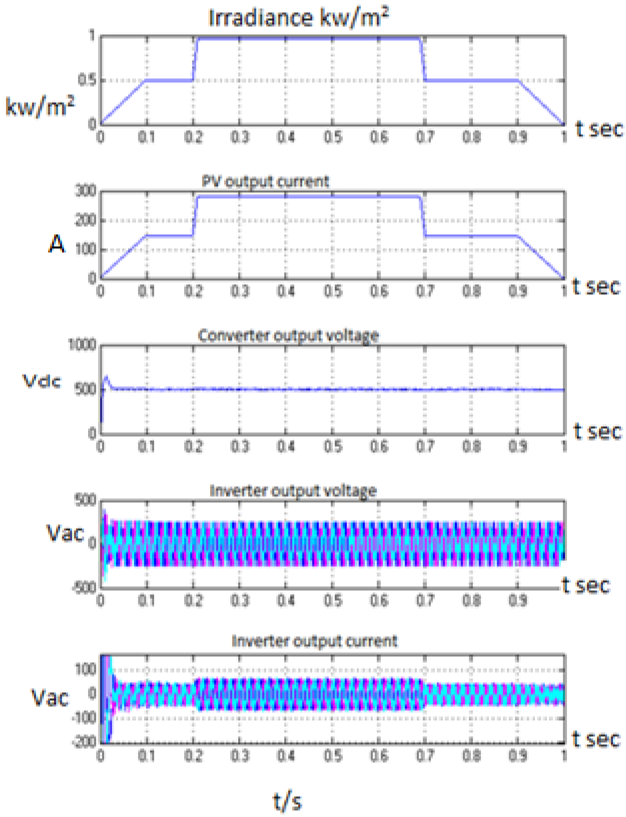


**Fig 11. Input irradiance, PV output current , converter output voltage,Inverter output voltage and current during normal operation**

The PV system supply power to the grid via a power transformer 0.25/22 KV. The delivered voltage and current at PCC shown in figure 12. Voltage and current of the grid obtained in figure 12. Grid voltage and Transformer output voltage are the same values but the transformer current which injected to the grid is variable due to irradiance change. The produced power (KW) which delivered to the grid matching with the changes of the irradiance as appeared in figure 12.

The frequency, power factor, voltage THD, current THD and weighted voltage flicker obtained in figure 13.

The frequency maximum value 50.2 HZ and minimum value 49.7 HZ. Power factor nearest to unity value all the time. Voltage and current THD less than 5%. The maximum value of the weighted voltage flicker is 0.1 over time less than 0.1 second. The parameters obtained in figure 14 achieved with IEEE standards.

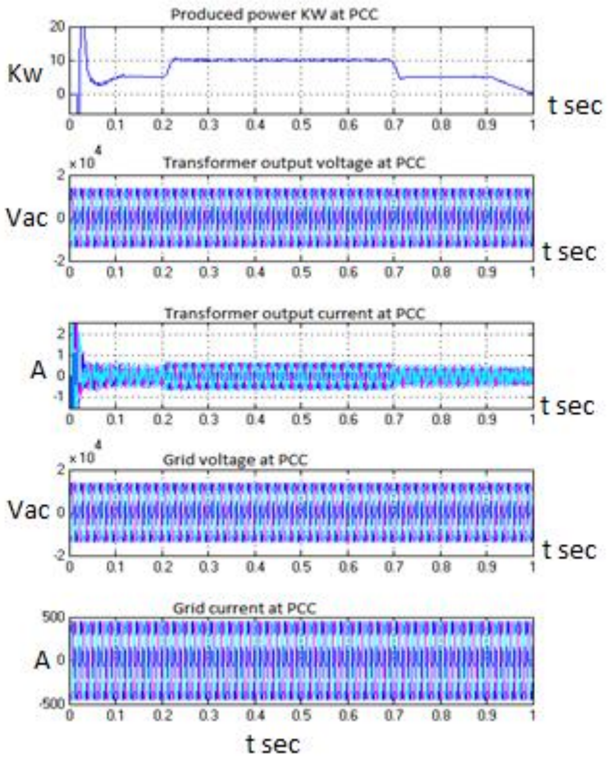


Fig 12. Produced power delivered to the grid, Grid voltage and current Transformer output voltage and current at PCC

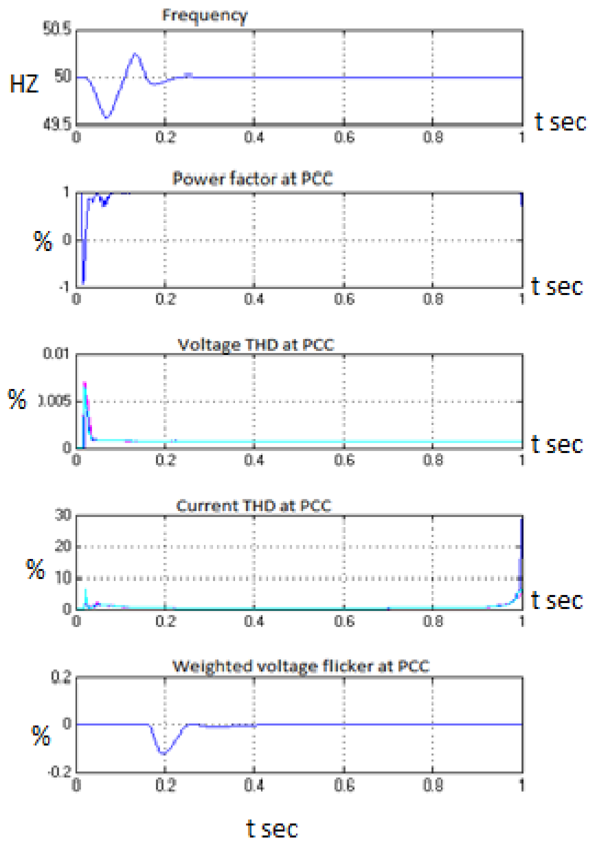


Fig 13. Frequency, P.F, Voltage THD, Current THD and weighted voltage flicker

## 2 ) Abnormal operation

The common faults are line to ground (L-G) , line to line (L-L) faults, line to line to ground (L-L-G) and three line to line (L-L-L). Here we assume fault occur at time 0.1 till 0.35 seconds.

- *L-G Fault*

During (L-G) the voltage sag will occur on the phase A and it remains for 0.25 second. Figure 14 showed the parameters during (L-G) fault. The frequency reaches 49.5 HZ as minimum value and 50.4 HZ for maximum value. The power factor fluctuated during fault time then back to unity value after fault clearance. THD for voltage is greater and reach about 15% at the begging of the fault and at the end of fault time, the current THD maximum value is 10%. Due to the sudden change of the voltage in phase A, voltage fluctuation occurred with percentage about 0.2%.

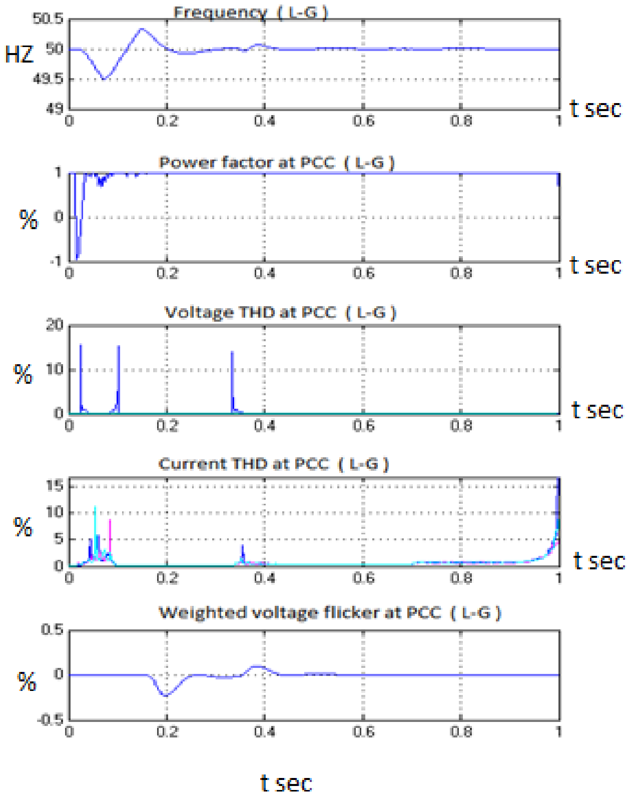


**Fig 14. Parameters at L-G fault**

- L-L-G Fault

As the results of the PV system parameters in case of L-G Fault, assume that L-L-G fault occurred at time 0.1 till 0.35 second figure 15. The frequency in this case fluctuate more the in case of L-G fault but within limits. The power factor values minimum value 0.7 during fault time and unity for the remaining time. THD for voltage exceed 20% and THD for current exceed 15%. The weighted voltage fluctuation changed two times during fault time.

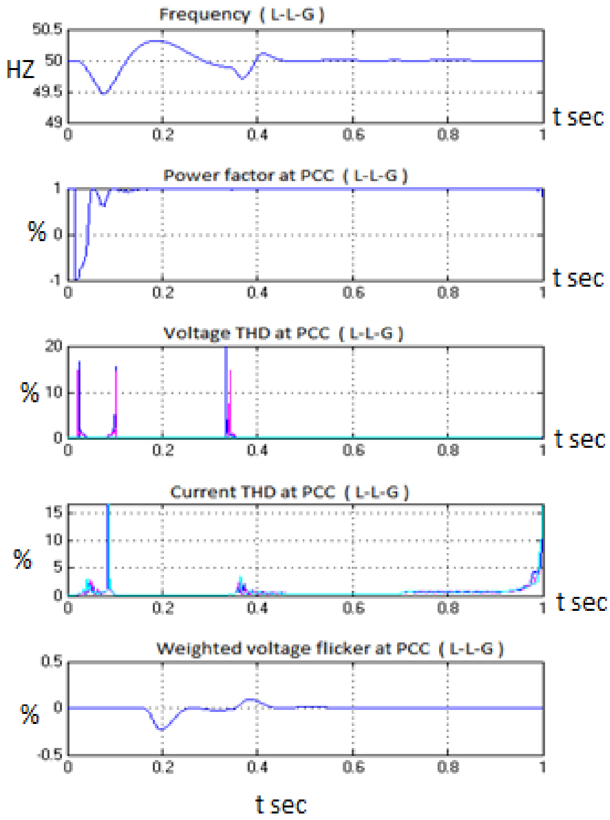


**Fig 15. Parameters at L-L-G fault**

- L-L Fault

The parameters during L-L fault shown in figure 16. Fault time 0.1 till 0.35 second. The frequency in this case reaches to 49.5 HZ minimum value and 50.2 HZ as maximum value. The power factor values minimum value 0.7 during fault time and unity for the remaining time. THD for voltage not exceed 2% and THD for current exceed 15%. The weighted voltage fluctuation changed two times during fault time.

- L-L-L Fault

The parameters during L-L-L fault shown in figure 17. Fault time 0.1 till 0.35 second. The frequency in this case reaches to 49.3 HZ minimum value and 50.1 HZ as maximum value. The power factor values minimum value 0 during fault time and unity for the remaining time. THD for voltage not exceed 20% and THD for current exceed 15%. The weighted voltage fluctuation changed two times during fault time.

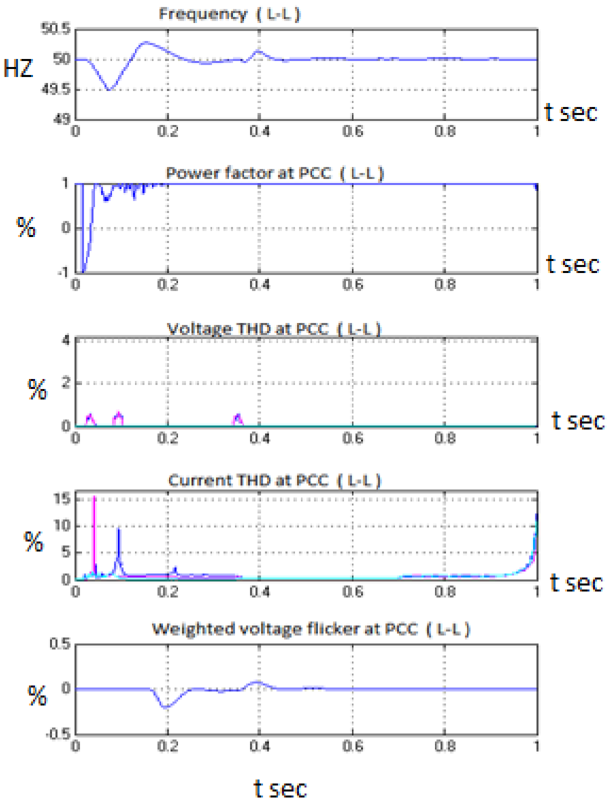


**Fig 16.Parameters at L-L fault**

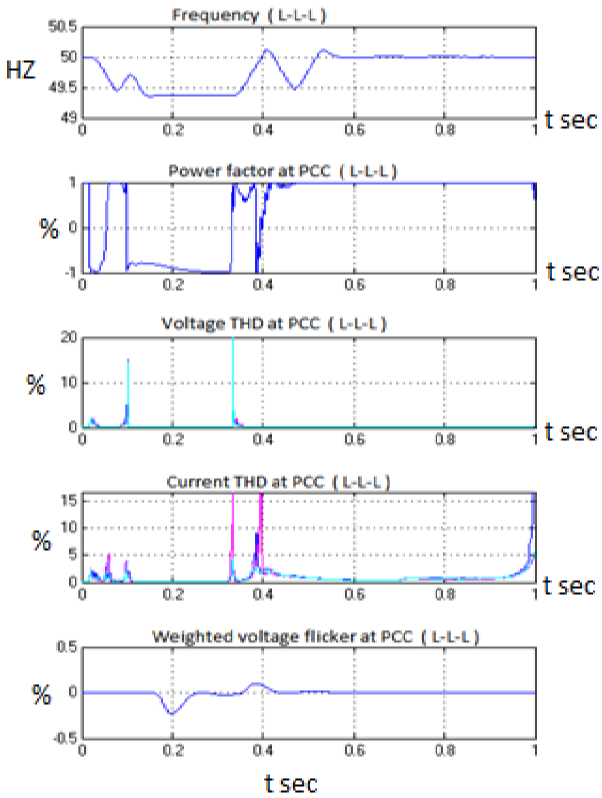


**Fig 17. Parameters at L-L-L fault**

## V. Comparison between obtained results and ieee standards

At normal operation all the measured parameters at the point of common coupling are achieved with IEEE standards.

At abnormal operation, the power factor, nominal voltage and THD are out of limits during fault time. The frequency out of limits during L-L-L fault and within limits during the other faults. Voltage flicker within limit for all type of faults.

According to IEEE standards, when fault occurred in the grid and the inverter sense abnormal conditions, the inverter in this case must disconnect from supply power to the grid. The control system remains connected to monitor grid parameters for reconnection after fault clearance.

When the fault cleared the inverter supply power to the grid with normal operation and the parameters return back to its normal values.

## VI. Conclusion

Photovoltaic (PV) generation represents currently one of the most promising sources of renewable green energy. Due to the environmental and economic benefits, PV generation is preferred over other renewable energy sources, since they are clean, inexhaustible and require little maintenance. Egypt belongs to the global sun-belt. The country's geographical position is advantageous with solar energy. PV system components are discussed i.e. Converter, inverter, MPPT are mentioned. PV system connected to grid type discussed and simulated by Matlab/Simulink. The simulation contains PV system and its components with the grid connection. There are standards form IEEE which identified the margin values of the power factor, voltage, voltage flicker, THD and nominal voltage. This paper verified the standards of IEEE on the operation of PV system with grid tied for normal operation. Operation of the system under abnormal utility conditions L-G, L-L ,L-L-G and L-L-L faults discussed and simulated. According to IEEE standards the PV system must isolated during fault occurrence. This paper describes the required specification of 10:100 KW PV system to tie in distribution resources in Beer Elabd, North Sinai, Egypt.

## VII.RECOMMENDATIONS

This research study will be helpful for utilities and customers in future to estimate the level of impacts of PQ factors in distribution network while integrating large scale PV in to the network. It's recommended to continue improvement and study the PQ for large scale of photovoltaic systems.

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**الملخص**: يقدم هذا البحث دراسة عن جودة الطاقة لنظام الشبكة الضوئية الموصلة ((PV من خلال تحقيق معايير معهد الهندسة الكهربية والالكترونية 2000-929 (IEEE) و 1547-2003 لنظام خلايا شمسية صغير متصل بشبكة توزيع. وللاعتبارات العملية، يتم محاكاة بيانات نظام الطاقة الكهروضوئية المستخرجة من نظام للخلايا الشمسية تعمل بشكل مستقل حقيقي وشبكة التوزيع استنادا إلى بيانات حقيقية مستخلصة من شبكة توزيع شمال سيناء. ويتم محاكاة النظام المقترح في ظل ظروف مناخية مختلفة للحصول على محاكاة حقيقية للتشعيع الشمسي. تم تصميم نموذج 10 ك واط من الشبكة الكهروضوئية الموصولة ومحاكاة باستخدام برنامج ماتلاب / سيمولينك وتدرس معايير جودة الطاقة تحت مستويات مختلفة من الإشعاع للنظام المقترح وفقا لمعايير معاييرمعهد الهندسة الكهربية والالكترونية .(IEEE) يعمل النظام تحت ظروف العادية وغير الطبيعية لشبكة التوزيع. وتظهر النتائج توافق جيد مع معايير معهد الهندسة الكهربية والالكترونية للنظام المقترح في حالة التشغيل في الظروف العادية. في حالة ظروف الشبكة غير الطبيعية، يجب أن يتم فصل المنظومة الشمسية لقضايا الحماية.

**الكلمات المفتاحية:** منظم جهد مستمر، معايير معهد الهندسة الكهربية والالكترونية، نظام خلايا كهروضوئية، تكنولوجيا تعقب نقطة القدرة العظمي، المحاكة بالماتلاب ، محول الجهد من مستمر الي متردد.