

Investigation of Power Quality Indices in Jordan University of Science and Technology Grid-Tie Photovoltaic Plant

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Abstract—In this paper, the effects of the grid-tie photovoltaic plant (PV) are analyzed on the power factor and the voltage harmonic distortion in the power quality aspect of the distribution network. The conditions for the total harmonic distortion (THD) in the power grid related to the photovoltaic power station connected to the user side are also summarized. Based on MATLAB/SIMSCAPE software, one string of the photovoltaic system at the Jordan University of Science and Technology (JUST) was simulated and hence, compared its results with the real results of the system. Measurement and simulation results illustrate that the voltage harmonic distortions to the power grid do not exceed the recommended levels, but the photovoltaic system needs to have a capacitor bank to get a unity power factor.

Index Terms—Power quality, Power factor, THD, Photovoltaic, PV Module, and MATLAB/SIMSCAPE.

I INTRODUCTION

Photovoltaic is considered a promising technology, and it has witnessed rapid growth in recent years, especially after increasing the costs of fossil fuel. In the case of Jordan, shrinking resources and a reasonable energy crisis severely constrain economic prospects and industrial growth. Therefore, it is more urgent to increase the use of renewable energy.

Despite the great benefits that can be obtained from connecting the PV system with the power grid, new challenges on the grid designing and protection can emerge. Power flow direction and power quality (harmonics and voltage fluctuation) at the user side are affected after the PV system connected to the distribution network [1].

The energy extracted from the PV panel depends on various factors such as temperature, irradiance, and climate conditions. However, the sun irradiation strongly affects the performance of the power system due to continuous changes in the amount of radiation falling and leading to voltage flickering and fluctuation. The larger the capacity of the PV power system connected to the electrical grid, the higher the dynamic power quality problems resulting from photovoltaic power generation like frequency variation, voltage sag ...etc [2, 3].

Power systems designed to function at the fundamental frequency, which is 50-Hz in Jordan, are prone to unsatisfactory operation and, at times, failure when subjected to voltages and currents that contain substantial harmonic frequency elements. Many problems can be caused by harmonics such as over-voltage, over-current, resonance, loss of transmission lines, and protection faults. Ensuring the voltage level and the power quality at the joint coupling point of the photovoltaic system is very important to achieve the best possible power system performance [4,

5].

In the Jordan University of Science and Technology (JUST) PV plant, SMA inverters are used due to the capability of providing reactive power and voltage adjustment. In many PV plants, the reactive power could be adjusted by external types of equipment like reactive power compensation systems, but it is better to use inverters that can adjust reactive power values [6].

If an immediate change in voltage happens, then this leads to the cause of what is known as a voltage flicker. Despite the voltage flicker usually happened at the user side, it affects the sinusoidal voltage waveform of the power grid. In the case of grid-tie PV plants, continuous changes in the amount of solar radiation leading to voltage flickering. Such distortions can disturb the user's equipment and cause the inrush current. Moreover, it affects the mechanism of the network impedance and leads to a sudden rise of voltage or sudden fall and hence, the causes of the voltage flicker [7].

The voltage flicker limits are contained in the following documents [8]:

(a) IEC/TR3 61000-3-7 (1996) "Assessment of emission limits for fluctuating loads in MV and HV power systems."

(b) IEC 868 / Engineering Recommendations P28 (pg 17) "Limits on voltage flicker short term and long-term severity values."

Harmonics are typically produced by the user's apparatus generating waveforms that distort the fundamental 50 Hz wave. Such harmonic generation can damage user apparatus and can fail transmission network apparatus. The limits for harmonic distortion levels are given in the following documents:

- (a) BS EN 50160:2000 “Voltage characteristics of electricity supplied by public distribution systems.”
 - (b) UK Engineering Recommendation G5/4, February 2001 “Planning levels for harmonic voltage distortion and the connection of non-linear equipment to transmission systems and distribution networks.”
 - (c) IEC/TR3 61000-3-6 (1996) “Assessment of emission limits for distorting loads in MV and HV power systems.”
- All the requirements mentioned above and standards are essential for the power quality of the electrical grid, and there are always taken into account to ensure the energy quality of the Jordanian power system [9].

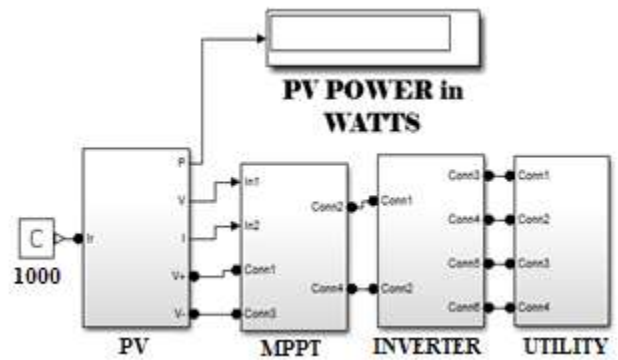


Fig. 1. MATLAB /SIMSCAPE model of the photovoltaic system.

II PV SYSTEM MODELING

The whole model of the PV system is built by MATLAB/SIMSACPE simulation software. The injection current, which comes from the photovoltaic generation system to the grid, could be transferred into essential components. The frequency of the inverter is the same as the power grid frequency, and its capacity is related to the output power of the PV system [10-12].

PV systems are like any other electrical power generation system, with only different components and hence, different physical properties. Although a PV array produces power when exposed to sunlight, several other components are required to conduct correctly, control, convert, distribute, and store the energy produced by the array. Depending on the functional and operational requirements of the system, the specific components required may include significant entities such as DC-AC power inverter, battery bank, etc.

The essential element of a PV module is called a PV cell. In SIMSCAPE workspace, a PV cell block can be used to precisely simulate the behavior of a real PV cell. More than one PV cell block can be used to make a PV module out of series and parallel connected cells. The module will have one input, irradiance in W/m^2 , and two voltage polarity outputs, +V and -V. The whole PV system, which consists of PV modules, MPPT controller, DC-DC converter and utility can be easily modeled using SIMSCAPE, as shown in Figure 1.

The adopted PV Cell specifications are as shown in Table 1 below

TABLE 1
The PV Cell Specifications

Number of PV module	220
Number of PV module in series	22
Open circuit voltage	38.6V
Short circuit current	9.03A
Voltage at MPP	31.4V
Current at MPP	8.44A
Maximum power	265W
Number of inverters	1
Inverter power	60000W

III CASE ANALYSIS

At the JUST PV plant, one string is simulated in MATLAB/SIMSCAPE environment. Two hundred and twenty PV modules are connected, every 22 PV modules connected in series with total voltage about 850VDC, these PV panels are combined in a DC combiner box. DC combiner box is directly connected to an SMA 60KW grid-tie inverter.

The following figures show the practical characteristics of the system during 2018, where the figures show the feasibility of installing such projects in Jordan. In Figure 2, which shows the amount of solar radiation during the year, it is clear that the majority of the year has a very high level of solar radiation, which significantly increases the efficiency of the system and reduces the cost of project recovery.

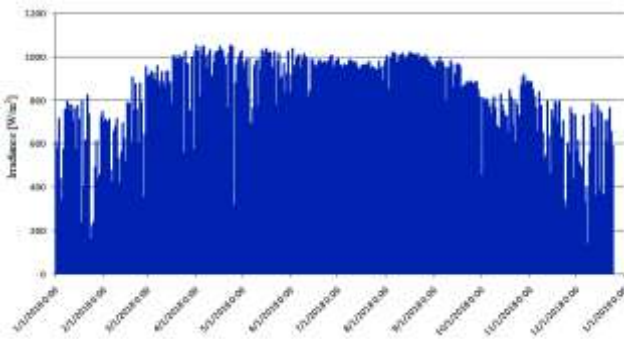


Fig. 2. Irradiation in JUST PV plant during the year 2018

The following tables show the differences between simulation and actual results in the same operating conditions.

The proposed simulation performance is tested under two conditions, the first condition at 1000W/m²solar radiation and temperature of 17.94 C°, the second condition at 615W/m²solar radiation, and temperature of 16.86 C°. According to the following results, it's evident that the simulation results are very close to the real readings of the photovoltaic system at the same operating conditions.

TABLE 2

Differences between simulation results and actual results at 1000 W/m², 17.94 C°

	Real system results	Simulation results
Irradiance	1000 W/m ²	1000 W/m ²
Temperature	17.94 C°	17.94 C°
Maximum DC Power	50.04 KW	58.30 KW
Maximum DC Voltage	619.4 V	690.8 V
Active Power	47.69 KW	58.30 KW
Power Factor	0.93	1
Maximum AC current L1	74.7 A	84.49 A
Maximum AC current L2	74.8 A	84.49 A
Maximum AC current L3	74.6 A	84.49 A
Maximum AC voltage L1	242.95 V	230 V
Maximum AC voltage L2	240.57 V	230 V
Maximum AC voltage L3	240.23 V	230 V

TABLE 3

Differences between simulation results and actual results at 615 W/m², 16.86 C°

	Real system results	Simulation results
Irradiance	615 W/m ²	615 W/m ²
Temperature	16.86 C°	16.86 C°
Maximum DC Power	30.95 KW	36.80 KW
Maximum DC Voltage	640.8 V	400 V
Active Power	30.47 KW	36.80 KW
Power Factor	0.92	1
Maximum AC current L1	46.5 A	53.30 A
Maximum AC current L2	46.6 A	53.30 A
Maximum AC current L3	46.5 A	53.30 A
Maximum AC voltage L1	239.04 V	230 V
Maximum AC voltage L2	236.74 V	230 V
Maximum AC voltage L3	236.17 V	230 V

These values in the tables show the differences between the real values of the solar system and the simulation values when modeling the solar system through a MATLAB/SIMSCAPE program. Many values, such as the value of solar radiation and temperature are assumed to be constant. However, these values are constantly changing, resulting in differences between actual values and simulation values. Another reason may strongly affect the difference in readings between actual and simulated values, which is partial shading. In the case of partial shading, the actual power values of the PV system less than the simulation values. The simulation programs cannot consider the impact of all operating conditions, but it is clear that its results are very close to the actual values and this indicates the strength of the simulation program.

THD in the output voltage is illustrated in Figure 3.

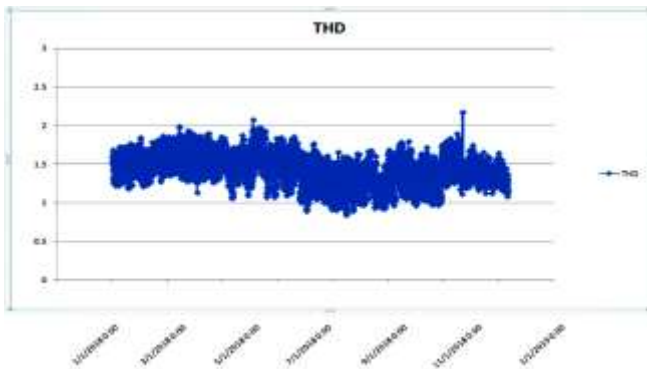


Fig. 3. THD in the output voltage.

It's evident from the previous figure that the THD over a whole year was very few and within the recommended levels in international standards rules. On the other hand, the simulation result illustrates that the THD=0.02, MATLAB/SIMSCAPE software, provides an FFT command window. This command window is used to make many analysis features like THD.

The terms of calculation and assessment of the reactive power of the grid-tie PV systems are [13]:

- 1) The voltage levels of the electrical grid must remain stable and within normal range with PV power generation.
- 2) The reactive power exchange between PV generation and grid on the point of common coupling is zero.

As mentioned previously, the inverters used in the PV power system are of type SMA; this type can compensate for the reactive power values. Moreover, it is allowing the power factor values to stay within the normal range. The following picture illustrates the power factor values during 2018.

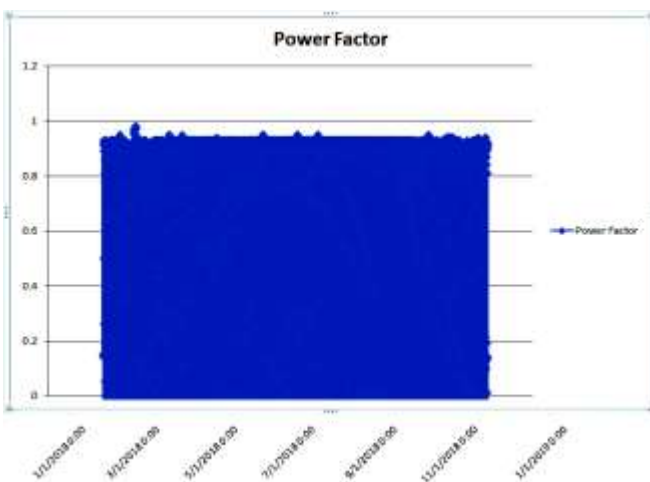


Fig. 4. Power factor values in 2018.

It's evident from the previous figure that the power factor of the grid-tie photoelectric system is equal to 0.9 at most times and this is considered very well. To access a unity power factor using MATLAB/SIMSCAPE software. The values in Tables 2 and 3 are taken into account. Moreover, the power factor correction is:

$$kVAr = Power (KW)(Tan (\phi_A - \phi_B)),$$

Where,

$$\phi_A = \cos^{-1} (\text{initial power factor})$$

$$\phi_B = \cos^{-1} (\text{required power factor})$$

According to Table 3, $\phi_A = \cos^{-1}(0.92)$, and the required power factor is 1. However, the active power is 30.47KW, so regarding the previous equation, the capacitor bank should be added with a capacity of 20kVAR per string. The following figure illustrates the value of the power factor after the addition of the capacitor bank.

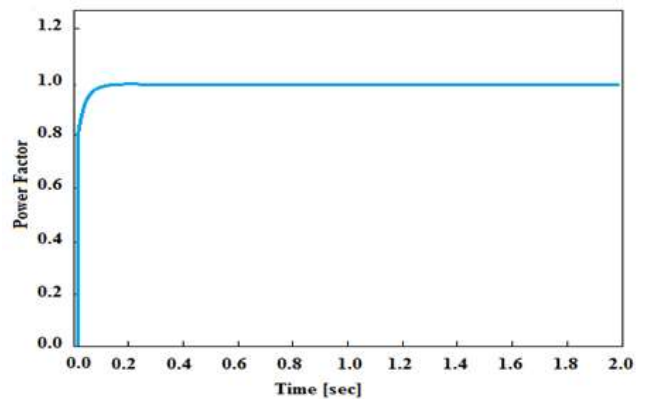


Fig. 5. Power factor simulation result after the addition of compensator.

V CONCLUSION

In this paper, the impact of the grid-tie photovoltaic power system in JUST and the power quality in the distribution network was analyzed and studied. The power quality problems resulting from connecting the photovoltaic power plant to the electrical grid were summarized, and quality standards and requirements for maintaining power quality were mentioned.

Based on the MATLAB/SIMSCAPE simulation software, this paper simulates the THD and power factor in the case of Jordan University of science and technology grid-tie photovoltaic plant.

The result illustrated that

- 1) The THD caused by grid-tie photovoltaic plant injecting into the grid satisfies standards requirements.
- 2) 20KVAR capacitor bank capability per string should be added to the photovoltaic system to obtain a unity power factor.

It is also recommended to study the effect of voltage fluctuation, voltage flickering, and other factors that impact the quality of electrical power.

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