Power Quality Measurement Campaign at a Jordan LV Grid and Determination of the Influence of a Large PV Plant

Daniel Masendorf
Energynautics GmbH
Darmstadt, Germany
d.masendorf@energynautics.com

Eckehard Tröster
Energynautics GmbH
Darmstadt, Germany
e.troester@energynautics.com

Stanko Jankovic
International Energy Consultants GmbH
Bad Homburg, Germany
stanko.jankovic@gopa-intec.de

***Abstract*—Power Quality has been measured at several points in the LV grid of a Jordan refugee camp over a period of more than 1 year. During the measurement campaign a 12.9 MWp PV plant was connected closeby to the upstream MV grid. The power quality in the grid, the influence of the PV plant and its method of operation on the power quality and lessons learned during the measurement campaign are described in this paper. The focus of the analyses was put on the voltage magnitude, unbalances, THD and flicker.**

I. Project background

As a result of the Syrian civil war millions of Syrians have fled from their country. The neighboring countries Jordan and Lebanon have accomodated a large share of them. In the North of Jordan, close to the border, around 70 000 refugees live in Al Zaatari camp, which is operated by UNHCR. The electricity supply of this number of people in the middle of the desert is challenging regarding infrastructure and budget. The refugees live mainly in containers and are supplied with electricity by an LV grid. To reduce the electricity bill, the refugees have power only during the night for several hours, which is of course not a desirable state. To improve the living standard of the people there, the hours of available electricity should be extended. For this reason, a 12.9 MWp PV plant, funded by the German development bank KfW, was built next to the camp and connected to the upstream MV-grid. Applying net metering, this power plant is supposed to reduce the annual electricity bill by 5 million Euro and thus UNHCR was able to increase the duration of electricity supply for the refugees [1].

However, there were concerns that the PV plant might have a negative influence on the power quality. So, to determine the impact of the PV plant the measurement campaign that is described here, was conducted. Hence, the measurement campaign conducted by Energynautics on behalf of GOPA - intec is an integral part of the large project of refugee camp electrification.

II. Measurement campaign

Main objective of the measurement campaign is to determine the influence of the PV plant on the power quality of the low voltage grid (230 V rated voltage) of the nearby refugee camp. Besides, the consumption of the refugee camp is observed in detail, so UNHCR can determine possibilities to save energy. However, this paper only deals with the power quality aspects of the measurement campaign.

The camp is separated into 12 districts which all have their own transformer (rated power: 9 times 630 kVA, 3 times 1 MVA) connecting it to the upstream medium voltage grid. As mentioned before, the power supply of these transformers is switched on only several hours during night and evening. There are additional transformers for consumers with continuous power supply such as the registration of the camp, the offices of UNHCR, hospitals and other facilities.

Altogether 13 Power Quality Analyzers (PQA) have been installed, one at the low voltage side of each of the 12 transformers inside the refugee camp and one at the transformer (rated power: 125 kVA) of UNHCR registration. It was not possible to install a PQA directly at the PV plant. The used measurement devices do not only measure power quality data and record them on an internal storage memory, but also measure and record power and consumption. Since the electricity is only switched on at night (as well as the PQAs) it is impossiple to observe an influence of the PV plant on power quality using the measurement devices inside the camp. Consequently, these PQAs are mainly used to observe the consumption of the refugees and to do basic power quality analyses. For the analysis of the influence of the PV plant mainly the PQA at UNHCR registration was used, as this has continuous power supply. This measurement device is a class S PQA according to IEC 61000-4-30 [2]. EN 50160 [3] was used to assess the power quality.

A. *Requirements of EN 50160*

The focus in the power quality analyses of this project was put on voltage magnitude, total harmonic distortion (THD), unbalance (u_2) and flicker (P_{lt}). EN 50160 analyzes 10 min average values for one week for each of the quantities and checks, if a certain percentage of measured values is within certain limits. The requirements are summarized in table I. The following formulas are used to calculate power quality indices [3], [4], [5]:

$$THD = \frac{\sqrt{\sum_{h=2}^{40}(U_h^2)}}{U_1}\,, \qquad (1)$$

where U_h is the magnitude of h_{th} harmonic voltage.

$$u_2 = \frac{U_2}{U_1} \cdot 100\,, \qquad (2)$$

where U_2 is the magnitude of negative sequence voltage and U_1 is the magnitude of positive sequence voltage.

$$P_{\text{lt}} = \frac{\sqrt[3]{\sum_{i=1}^{12}(P_{\text{st},i}^3)}}{12}, \quad (3)$$

where P_{st} are short term flickers, calculated for 10 min and P_{lt} are long term flickers calculated for 2 h using a moving average.
For more information refer to [3].

TABLE I. Requirements of EN 50160 for the examined quantities

Quantitiy	Requirements
Voltage magnitude	95 % of values within ± 10 % of rated voltage 100 % of values within +10 % / -15 % of rated voltage
THD	95 % of values below 8 %
Unbalance	95 % of values below 2 %
Flicker (P_{lt})	95 % of values below 1

III. Power Quality Analysis

The PQA at the registration was installed on July 30th, 2017 and records data since then. The PV plant was put into operation on October 22nd, 2017. In this paper mainly the power quality of the ”base state” from August 2017 is compared with the same days exactly one year later.
As mentioned before the focus was put on voltage magnitude, unbalances, THD and flicker. These quantities were examined and compared with technical requirements defined in EN 50160. It turned out that the requirements of the standard were fulfilled all the time in the considered weeks in 2017 as well as in the considered weeks in 2018. To get a deeper insight into the observed quantities, additionally, their average values, maximum and for magnitude also minumum values were calculated for August 2017 and 2018 (see table II). To get a better understanding of these values and to see the influence of the PV plant, the characteristics of all these quantities have been examined for the period from August 2017 until August 2018. Each quantity is analyzed and described in detail in the following chapters.

TABLE II. Maximal, minimal and average voltage, THD, unbalance and flicker for three phases during August 2017 and 2018

		Phase	08.2017	08.2018
Magnitude [V]	Max	1	239.82	243.6
		2	239.89	245.11
		3	241.74	245.52
	Min	1	220.70	214.06
		2	221.16	214.99
		3	223.29	217.53
	Ave	1	231.15	229.05
		2	231.58	230.07
		3	233.59	231.60
THD [%]	Max	1	3.66	4.52
		2	3.57	4.36
		3	3.64	3.99
	Ave	1	2.33	2.41
		2	2.29	2.31
		3	2.38	2.22
Unbalance [%]	Max	-	1.03	1.06
	Ave	-	0.72	0.65
Flicker [-]	Max	1	3.72	3.91
		2	3.72	3.79
		3	3.77	3.73
	Ave	1	0.38	0.37
		2	0.38	0.42
		3	0.38	0.37

A. Voltage

In table II it can be seen that the maximal voltage values in August 2018 are higher than in 2017, while the minimal values are lower. The average of 2018 is slightly lower than 2017. Exemplary voltage curves of August 2017 and 2018 are shown in figure 1. It can be seen that the voltages behave very similar in both cases.
Besides, it can be seen that voltage is significantly lower during the night than during the day. This is due to the activation of the power supply of the refugee camp during the night, which is a significant load that drags the voltage down. In August 2017 the refeguee power supply was switched on for seven to eight hours per night, while the duration was increased to twelve hours per night in August 2018. Hence, the period with low voltages during the night was increased, leading to lower average values for voltage magnitude.
In figure 2, voltage at the registration and active power of the PV plant are shown for the time period, when the PV plant was put into operation. There, it can be seen that the active power dispatch of the PV plant further lifts the daytime voltage. The peaks of the days around noon directly after the PV plant was connected are around 4 V higher (approximately 0.017 p.u.) than during the days before the PV plant was connected.
In the following months, especially in summer, there were complaints by consumers in the camp about overvoltages. Unfortunately, no reliable measurement data were recorded during that time, due to a measurement device connection problem probably caused by construction works in the

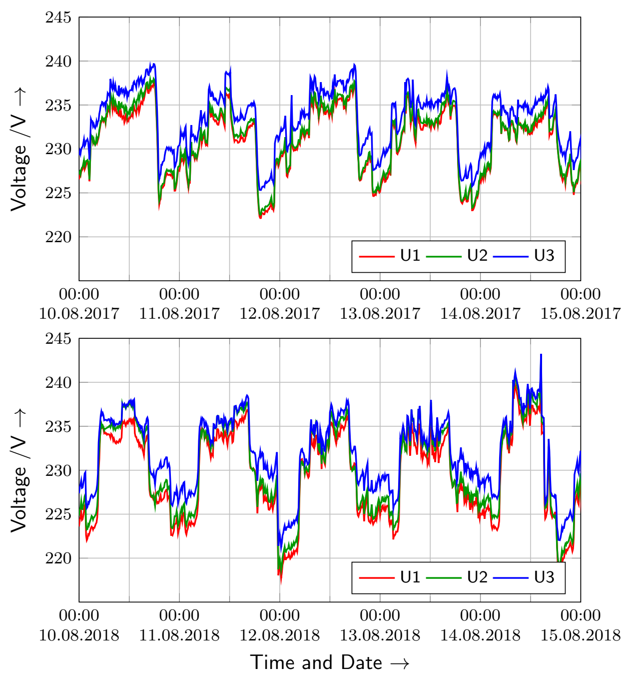

Fig. 1: 3-phase voltage at registration at exemplary days in August 2017 and 2018

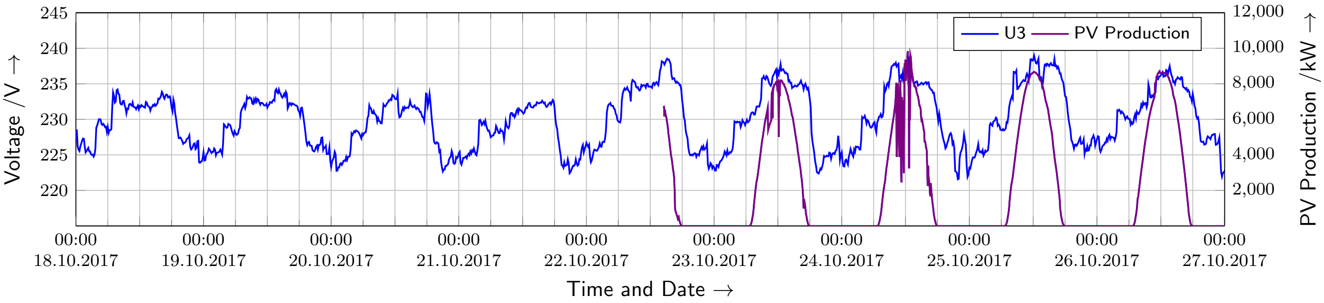

Fig. 2: Influence of production of the PV plant on the voltage at the registration

substation. Hence, these overvoltages could not be observed well and no evaluation according to EN 50160 was done. However, in June 2018, it was decided to operate the PV plant at a power factor of 0.9 to decrease the voltage, when the PV plant is dispatching power. The time period, in which the operation mode was changed is shown in figure 3. Voltage of phase 3 is shown exemplary for the voltage at all phases.

First it was accidently reactive power dispatched instead of consumed, resulting in an extra high voltage peak during the day. This error was corrected after a few hours, by switching from power factor 0.9 overexcited to power factor 0.9 underexcited. At the point in time, when the operation mode changed, the voltage immediately dropped by approximately 8 V (ca. 0.035 p.u.). The peaks of the voltage during the days directly after the operation mode was changed are lower than during the days before. Hence, the method of controlling voltage with the power factor is certainly effective and compensates the increased voltage induced by the active power dispatch of the PV plant.

However, it can be observed that the active power peaks of the PV plant are lower since it is operated with cosphi = 0.9 underexcited, because the inverter current limit is reached sooner. Thus, the drawback of this method is that less energy is produced. An improvement for this could be achieved by using a Q(U) characteristic instead of a constant cosphi setpoint for the power plant, so the active power would only be curtailed, when necessary.

B. Harmonics

In figure 4, it can be seen that the voltage THD during the night is significantly higher than during the day. EN 50160 specifies that the THD should be below 8 % for 95 % of the time. This requirement is fulfilled during the day as well as during the night.

There are many LEDs installed in the camp which have a high emission of harmonics [6]. These harmonics (especially a high fifth harmonic was observed) also affect the MV grid and are transmitted to the LV grid of the registration leading to a higher THD there.

It can be observed that the period with high THD is increased in 2018 compared to 2017. The reason for this is the longer duration of electricity supply of the camp. It can also be seen that higher values are reached every night, resulting in higher maximal observed values in August 2018 (see table II). During the day lower values are observed in 2018 than in 2017. Thus, a negative influence of the PV plant can absolutely not be observed.

C. Unbalance

The unbalance is shown for exemplary days in August 2017 and 2018 in figure 5. Like harmonics, the unbalances are higher during the night, which implies a correlation with the power supply of the camp. The maximal observed values in August 2017 are similar to the ones in August 2018, but the average in 2018 is lower than 2017, which is due to lower unbalances during the day.

Hence, no negative influence of the PV plant can be observed.

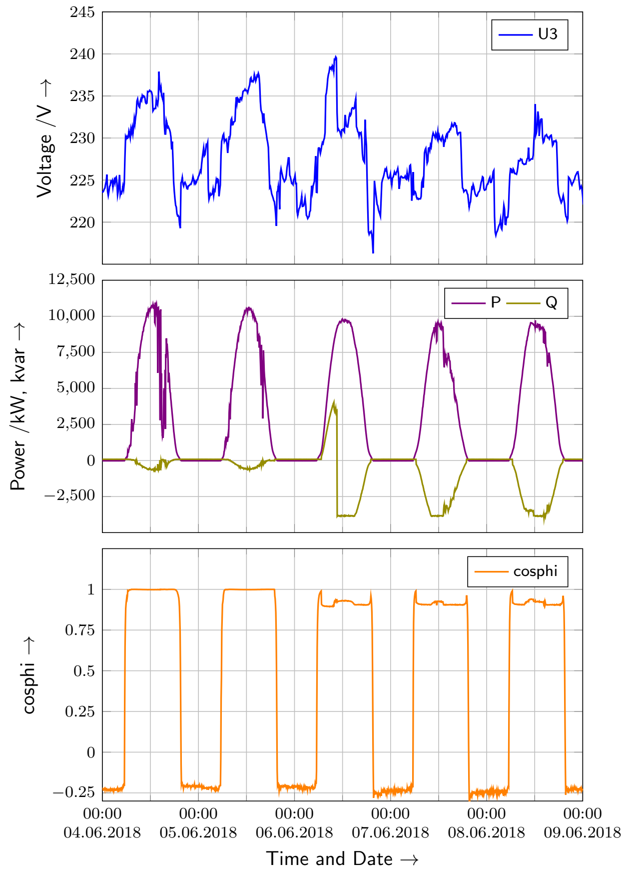

Fig. 3: Influence of different power factors of the PV plant on the voltage at registration. From top to bottom: Voltage at registration, active and reactive power of PV plant, cosphi of PV plant

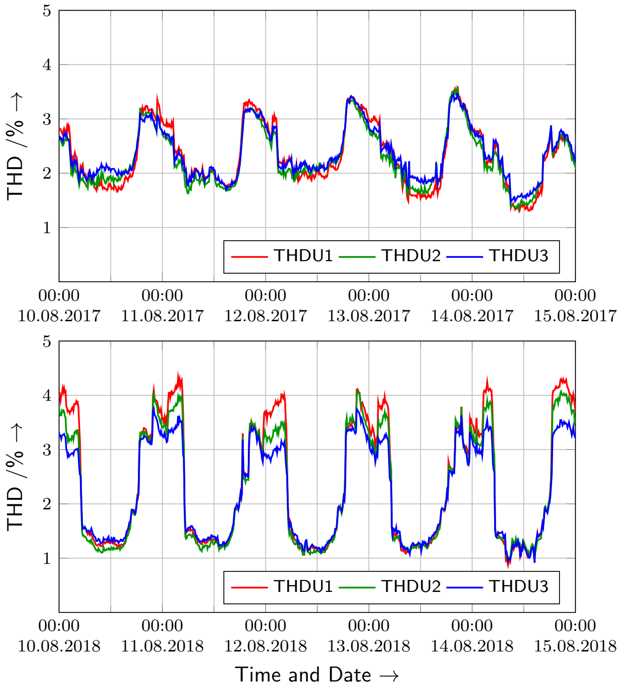

Fig. 4: 3-phase THD at registration at exemplary days in August 2017 and 2018

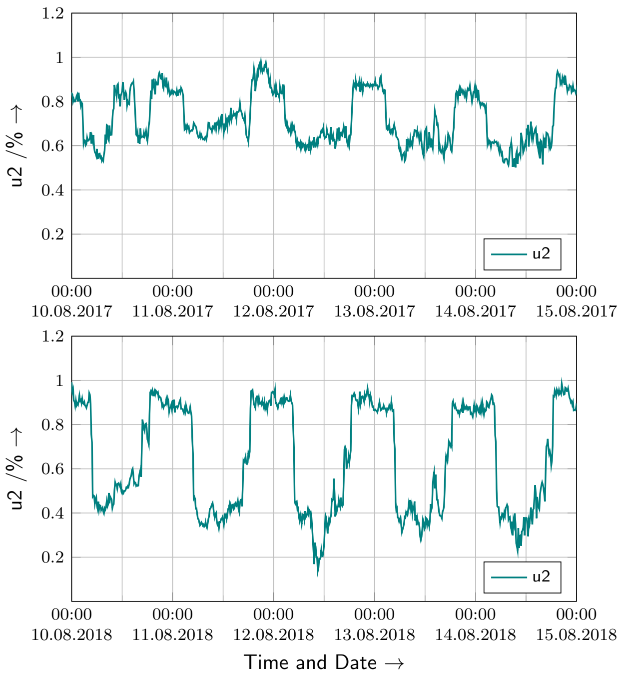

Fig. 5: Negative sequence of voltage in percentage of positive sequence at registration at exemplary days in August 2017 and 2018

D. *Flicker*

In table II no real difference between August 2017 and 2018 can be observed. Detailed graphs of the flickers of each phase are shown in figure 6. Since one value for P_{lt} is calculated every 10 min using the P_{st} values of the 2 h before, each point in the curves depends on the 2 h before that moment (see equation 3). It can be seen that P_{lt} is usually well below 1 in all 3 phases. There are some points

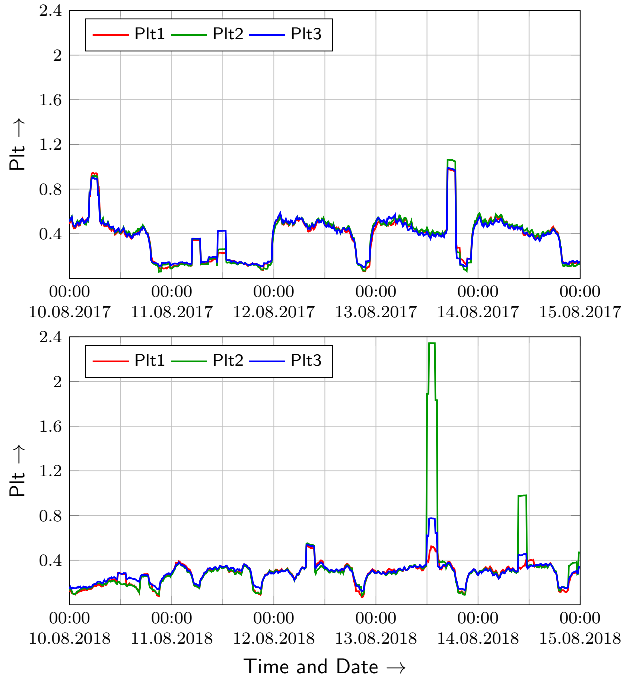

Fig. 6: 3-phase flickers at registration at exemplary days in August 2017 and 2018

in time where this limit is exceeded, but in none of the weeks examined here less than 95 % have been within the limit, so requirements of EN 50160 are still fulfilled.

In the graphs of figure 6 it can be seen that there are significant differences between some of the days. There seems to be a periodic behavior, but it is not as clear as in the other observed quantities. Stochastically occuring events, such as voltage dips have a large influence on flickers. For example, at 13th August 2018 a voltage dip in phase 2 occured leading to high flicker values for a short time.

On the days in 2018 shown here, the flickers are usually slightly lower than in the corresponding days in 2017. Thus, no negative influence of the PV plant can be observed. Also no correlation between flickers and cloudy/sunny days could be observed, when analyzing a larger period of data (not shown here).

IV. Conclusion

In this paper the power quality in the low voltage grid of a Jordan refugee camp has been described and the influence of a PV plant has been determined. First the quantities voltage magnitude, THD, unbalance and flicker have been analyzed according to EN 50160 befoore and after the PV plant was connected. In both cases the requirements of EN 50160 were totally fulfilled. Hence, a more detailed analysis was necessary to see the influence of the PV plant. Average, maximal and minimal values of the examined quantities were determined and a closer look on the curves of each quantity was taken.

No influence of the PV plant on THD, unbalance and flickers could be observed. But it was seen, that the PV plant lifts the voltage, when dispatching active power. Consequently, overvoltages in the low voltage grid have been observed. As remedial measure, the PV plant operates with a power factor of 0.9 underexcited since June 2018. This operation mode is able to compensate the voltage increase by the active power, but the drawback is that the inverter current limit is reached sooner due to the reactive component and thus less active power can be dispatched during peak hours.

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