THE EFFECT OF PHOTOVOLTAIC ROOFTOP SYSTEMS ON GRID POWER QUALITY

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ABSTRACT

In recent years, both demand for electricity and fossil fuel have grown rapidly and energy security concerns and global warming issues are becoming more important. These concerns are directing energy research attention towards renewable energy sources, such as solar and wind energy in order to contribute to the growing energy demands and reduce the need for fossil fuels. Moreover, cost reduction of PV panels and technical progress in power electronic conversion and semiconductor devices make photovoltaic (PV) systems one of the most promising renewable energy sources.

In December 2013 the Egyptian Supreme Council of Energy has declared a resolution to install 1000 Photovoltaic Rooftop systems, PVRS, on Governmental buildings as a pilot project to encourage large consumers to install PVRS.

A large number of grid connected PV generators connected to distribution networks through PV inverters are potentially able to cause harmonic problems.

In general, a harmonic problem can be defined as a particular disturbance, which is created by the presence of non-linear components in the electrical system that determines a permanent modification of the voltage and current sinusoidal wave shapes in terms of sinusoidal components at a frequency different from the fundamental.

Alexandria Electricity Distribution Company (AEDC) installed its first monocrystal PVRS 32 kWp on its building, there were many measurements carried out for electric energy parameters before and after PVRS installation to assure the IEC standard.

This paper presents and evaluates measurements based on power quality indices obtained from the PV site. Also, the power quality parameters measured on different solar irradiance level in order to determine how power quality quantities are affected by changes in solar irradiance. The analysis of measurements revealed high current total harmonic distortion during low solar irradiance conditions.

INTRODUCTION

The Solar Atlas was issued, and indicated that Egypt is endowed with high intensity of direct solar radiation ranging between 2000 – 3200 kwh/m2/year from North to South. The sun shine duration ranges between 9-11 h/day from North to South, with very few cloudy days as shown in Fig.1.

Electricity demand has increased rapidly in Egypt over the past decade, accompanied by a significant shift to summer peaks, driven largely by increased air conditioner usage. To overcome this increase of energy demand Egypt should spend billions over the next decade in new generation plants, including significant expenditure on peak load plants, and on new and upgraded network assets. Electricity generation in Egypt is still largely sourced from fossil fuels, which causes the release of harmful gases into the atmosphere including CO2.

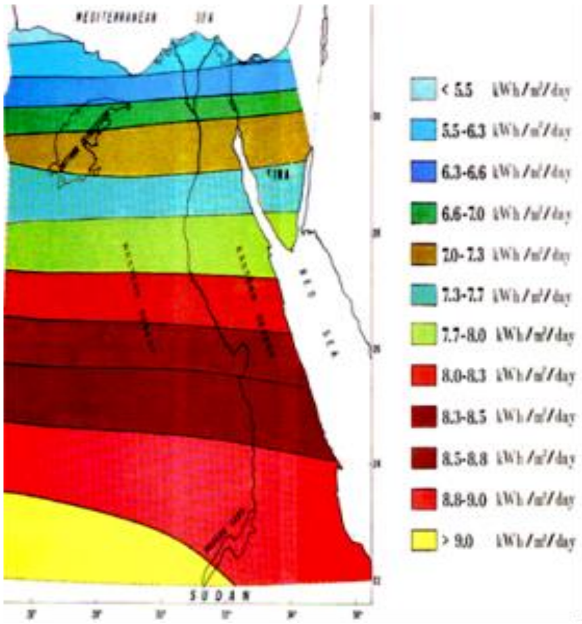

Fig.1 Global Irradiation Solar Map for Egypt.

The use of PV systems and other types of renewable energy sources like wind turbines and hydroelectric units will help to reduce the need of fossil fuel and decrease the gas emissions thereby helping government to achieve 20% of its energy from renewable sources to meet their binding 2020 target. The government offers incentives in order to encourage the PV industry to achieve its target and at the same time, issued a small scale PV (ssPV) code specifies the technical requirement for connecting ssPV to the low voltage distribution network. This code obligate that the total current harmonic distortion from customer's PV system shall be less than 5 % at rated generator output in accordance with IEC 61727.

Alexandria Electricity Distribution Company (AEDC) installed its first monocrystal PVRS 32 kWp on its building roof as shown in Fig.2. . The PVRS is connected to the distribution network via three phase inverter.AEDC focused on measuring the electrical parameters before and after installing PVRS at different solar irradiance levels.

Fig.2 View of Rooftop Photovoltaic System Installed by AEDC

MEASUREMENT PROTOCOLS

The AEDC Headquarter building is fed from 500 kVA transformer which is supplying other domestic loads. Work time in the headquarter building from 8am till 2:30pm. Measurements for electrical parameters have been carried out before installing PVRS and after installing PVRS. Also, the power quality parameters measured on different solar irradiance levels in order to determine how power quality indices are affected by changes in solar irradiance.

Case Study (A)

Before installing the PVRS, measurements of electrical parameters have been performed for the transformer low voltage side and for the cable which feeding the building for one week in summer. The measured voltage values for the transformer and cable were within the IEEE limits. The measured total voltage harmonic values were within the IEEE limits for the two measurements. Fig.3 shows the measured current values for the transformer varies from 197.1A to 454.15 A. The total current harmonic distortion values for the transformer-LV side were within the limits as shown in Fig.5 . The measured current values for the building loads varies from 17A to 48.4 A. The total current harmonic distortion values for the cable were over the limit due to the air condition loads in summer as shown in Fig.6. The measurements have shown current unbalance reached to30.5% at low building loads as shown in Fig.7. This problem was solved by redistributing the loads at maximum load for the building.

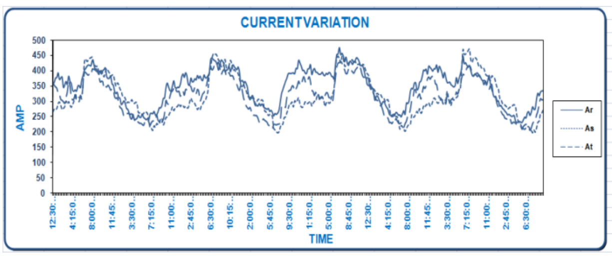

Fig.3 Current Profile with Time at Transformer LV side

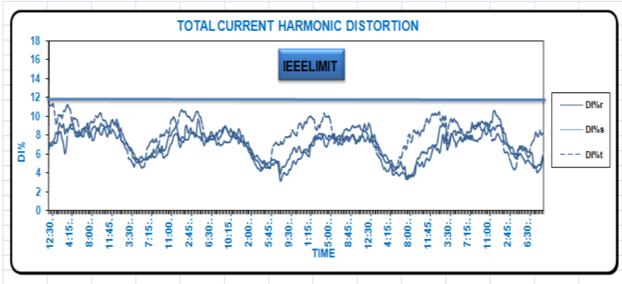

Fig.4 Total Current Harmonic Distortion with time for transformer LV side

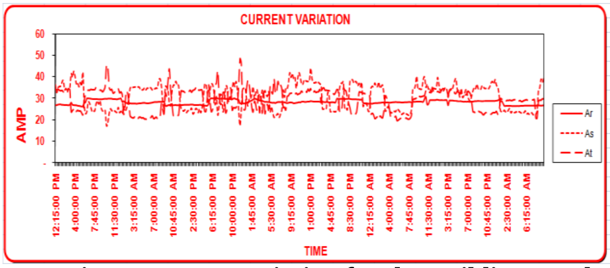

Fig.5 Current Variation for the Building Loads

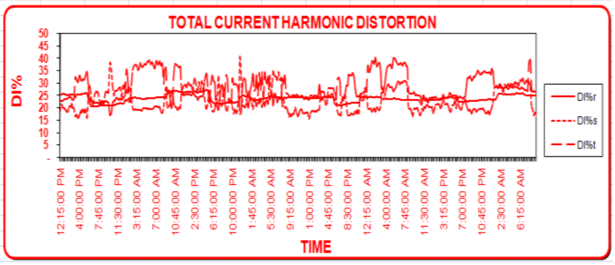

Fig.6 Total Current Harmonic Distortion with Time for Building loads

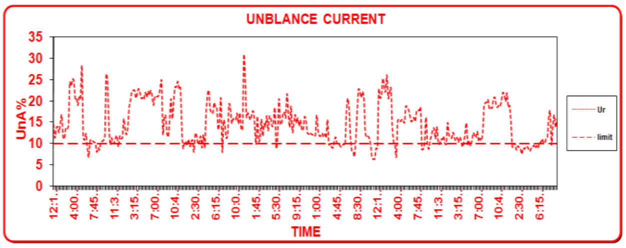

Fig.7 Current Unbalance with Time for Building loads

Case Study (B)

After installing the PVRS, many measurements were carried out to evaluate power quality indices obtained from the PV site. The measurements were performed in summer when solar irradiance level is high case study (B-1) and in winter when solar irradiance level is low case study (B-2) for:

a- The transformer LV side.

b-The cable feeding the building

c- The inverter output cable

Case study (B-1)

The measurements were performed in summer when solar irradiance level is high for five days. The measured voltage values for the transformer and cable were within the IEEE limits. The measured total harmonics voltage values were within the IEEE limit for the two measurements. Fig.8 shows the measured current values for the transformer which varies from 157.1A to 546.15 A. The total current harmonic distortion values for the transformer-LV side were approximately within the limits except a few points at low loads as shown in Fig.9. The measured current values for the building loads varies from 4A to 100.6 A as shown in Fig.10. The total current harmonic distortion values for the building loads were over the limit due to the air condition loads in summer and at low loads as shown in Fig.11. The measured generated current values for the PVRS varies from 0.1A to 48 A as shown in Fig.12. The total current harmonic distortion values emitted from the inverter were over the limit at few points as shown in Fig.13.

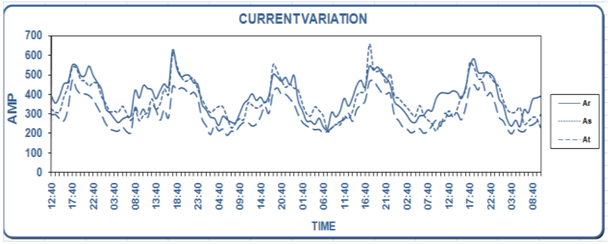

Fig.8 Current Profile with Time at Transformer LV side (Case Study (B-1))

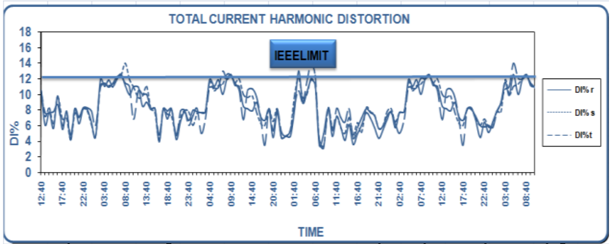

Fig.9 Total Current Harmonic Distortion with time for transformer LV side (Case Study (B-1))

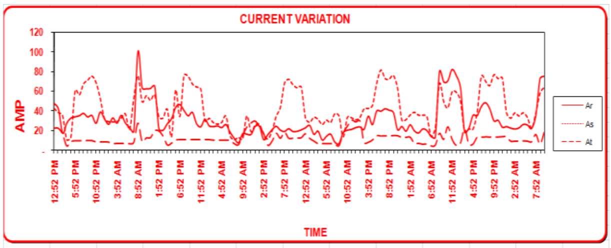

Fig.10 Current Variation for the Building Loads

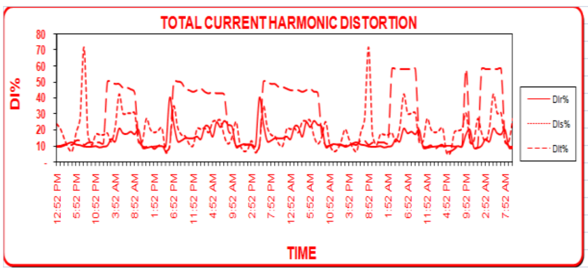

Fig.11 Total Current Harmonic Distortion with Time for Building loads

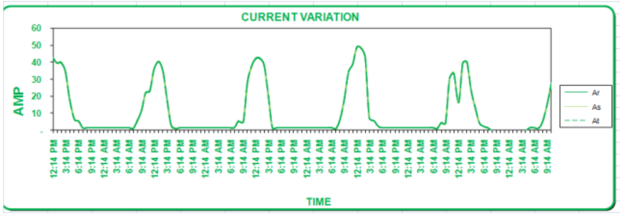

Fig.12 Current Generated from PVRS

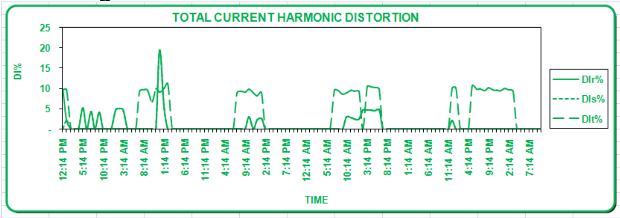

Fig.13 Total Current Harmonic Distortion emitted from inverter side

Case study (B-2)

The measurements were performed in winter when solar irradiance level is low for cloudy sky for three days. The measured voltage values for the transformer and cable were within the IEEE limits. The measured total harmonics voltage values were within the IEEE limit for the two measurements. Fig.14 shows the measured current values for the transformer which varies from 155.1A to 480.15 A. The total current harmonic distortion values for the transformer-LV side were within the IEEE limits as shown in Fig.15. The measured current values for the building loads varies from 22A to 73 A as shown in Fig.16. Fig.17 shows the active power delivered from the PVRS to the LV grid after working hours. The total current harmonic distortion values for the building loads were over the limit due to at low loads as shown in Fig.18. The measured generated current values for the PVRS varies from 0.1A to 48 A as shown in Fig.19. The total current harmonic distortion values emitted from the inverter were over the limit at no solar irradiation as shown in Fig.20.

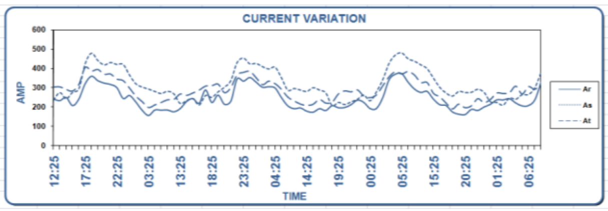

Fig.14 Current Profile with Time at Transformer LV side (Case Study (B-2))

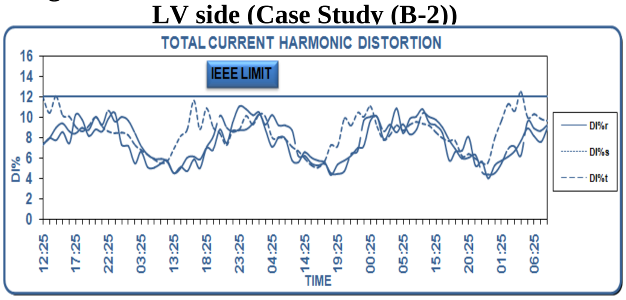

Fig.15 Total Current Harmonic Distortion with time for transformer LV side (Case Study (B-2))

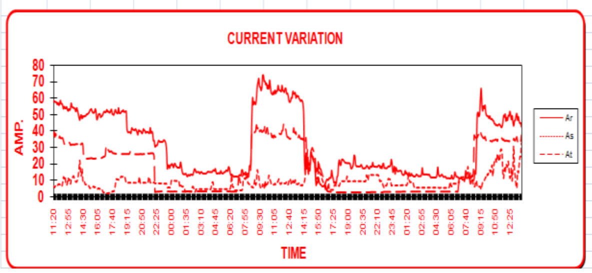

Fig.16 Current Variation for the Building Loads

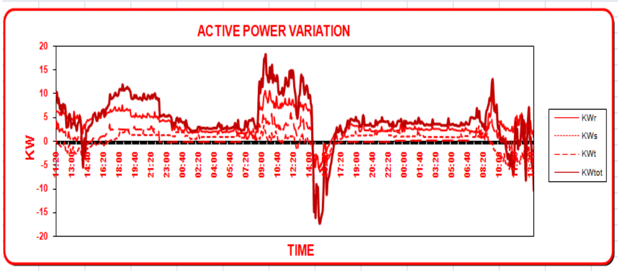

Fig.17 Active Power Consumed in the Building and Delivered from the Building to LV Side

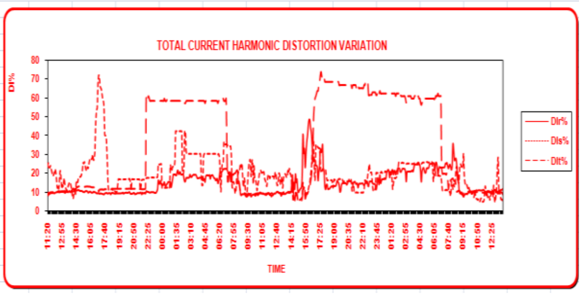

Fig.18Total Current Harmonic Distortion with Time for Building loads

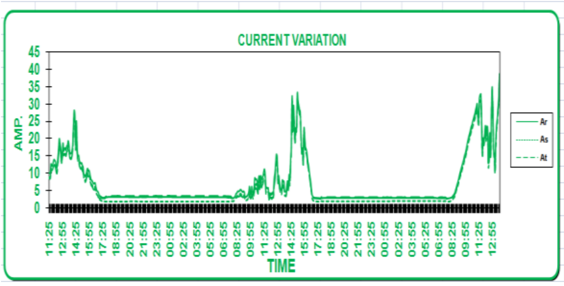

Fig.19 Current Generated from PVRS

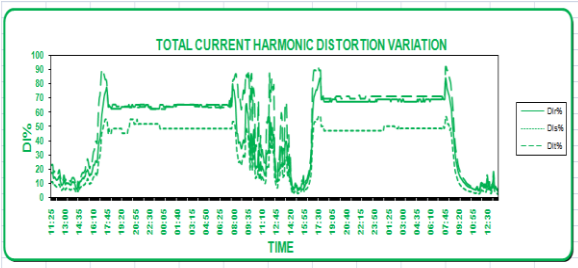

Fig.20 Total Current Harmonic Distortion emitted from inverter side

RESULTS AND ANALYSIS

In this paper, many measurements were carried out before and after installing PVRS in different circumstances. The results were as follow:

1- The measured voltage values at LV transformer side were within the limits ±5%, and haven't been affected by installing PVRS.
2- The Total voltage harmonic distortions have been within the limits before and after installing PVRS.
3- The total current harmonic distortions for the transformer LV side have been within the limits before and after installing PVRS except few points at low loads conditions.
4- The current unbalance for the building loads is above the limits and the loads need to be redistributed.
5- The total current harmonic distortions for the building loads have been over the limits before and after installing PVRS. A portion of these harmonics is due to low load conditions after working hours. The total current harmonics were around 15% at load.
6- The total current harmonic distortions emitted from the inverters were over the IEC limits which is 5%
7- The total current harmonic distortions emitted from the inverters depend on the current generated from PV. When the ratio of the generated power to the maximum generated power from the PV increases the total harmonics current decrease as shown in Fig.21

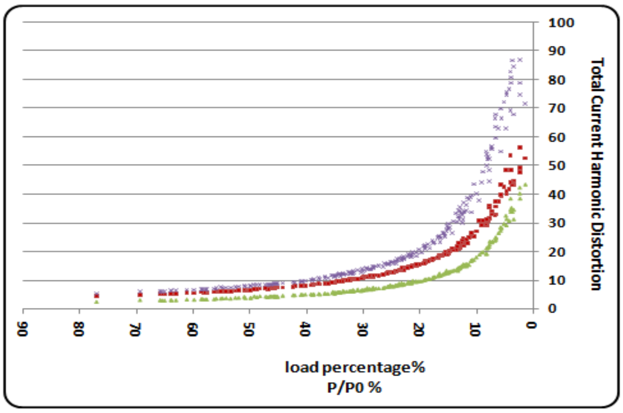

Fig.21 Total Current Harmonics Distortion with Respect to Load Percentage Ratio

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[1] U.S. Department of Energy (2009): *Workshop Report on High Penetration of Photovoltaic (PV) Systems into the Distribution Grid*, Ontario, CA, February 24- 25, 2009.

[2] Chicco, G.; Schlabbach, J.; Spertino, F.: "Characterisation of the harmonic emission of grid-connected PV-systems. *Proc. of IEEE-Conference PowerTech 2005*. St. Petersburg, Russia (June, 27-30, 2005), paper 66