JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 15, No. 5- 6, May – June 2013, p. 559 - 564

# Operation and performance of grid-connected solar photovoltaic power system in Kocaeli university

AHMET AKTAS, ENGIN OZDEMIR[a*], ABDULHAKIM KARAKAYA[b], MEHMET UCAR[c]
*Kocaeli University, Natural and Applied Science, Department of Energy Engineering, 41380, Umuttepe, Kocaeli*
*[a]Kocaeli University, Technology Faculty, Department of Energy Systems Engineering, 41380, Umuttepe, Kocaeli*
*[b]Kocaeli University, Technical Education Faculty, Electrical Education Department, 41380, Umuttepe, Kocaeli*
*[c]Duzce University, Duzce Vocational School, Electrical and Energy Department, 81010, Duzce*

In this study, operation and performance of grid-connected solar photovoltaic (PV) power system installed in Kocaeli University are presented. The grid-connected PV power system consists of 720 Wp thin-film PV panels, a 1 kW grid-connected inverter and a WebBox for internet connection. The PV system has been installed first 360 Wp in March 2010 and upgraded for 720 Wp in August 2011. Each has a power of 60 Wp Kaneka thin-film solar panels are installed in the PV system. The SMA Sunny Boy single-phase 1 kW grid-connected inverter is connected to perform the conversion of the direct current generated by the PV panels into mains standard alternating current. The power, voltage and current harmonic values at grid side of the inverter have been measured using Fluke 434 power quality analyzer. After March 2012, the PV system has internet connection via SMA Sunny WebBox. The produced PV electric energy amount can be monitored in our department website (http://enerji.kocaeli.edu.tr) in hourly, daily and monthly basis.

(Received December 18, 2012; accepted June 12, 2013)

*Keywords:* Grid-connected, Inverter, Photovoltaic (PV) system, Solar energy

## 1. Introduction

Photovoltaics (PV), the technology which converts sunlight into electricity, is one of the fastest growing sectors of the renewable energy industry. The PV technology can be used in several types of applications. PV systems can be grouped into stand-alone systems (such as rural electrification, pumping water equipments and industrial applications) and grid-connected systems (such as domestic systems and power plants). Stand-alone systems are not connected to the grid and consist of PV panels and of a storage system which guarantees electric energy supply also when lighting is poor or when it is dark. In grid-connected systems the public electricity grid functions as a big accumulator [1].

Globally, 29.7 GW of PV systems were connected to the grid in 2011, up from 16.8 GW in 2010. Total installed PV capacity world-wide reached over 69 GW at the end of 2011. Thus, PV is the third most important renewable energy in terms of globally installed capacity after hydro and wind power [2]. Fig. 1 shows the evolution of global cumulative installed capacity 2000-2011 (MW). The generally world-wide PV markets, both in terms of newly connected capacity during 2010 and 2011 and cumulative installed capacity at the end of the year 2010 and 2011 is given in Table 1 [2].

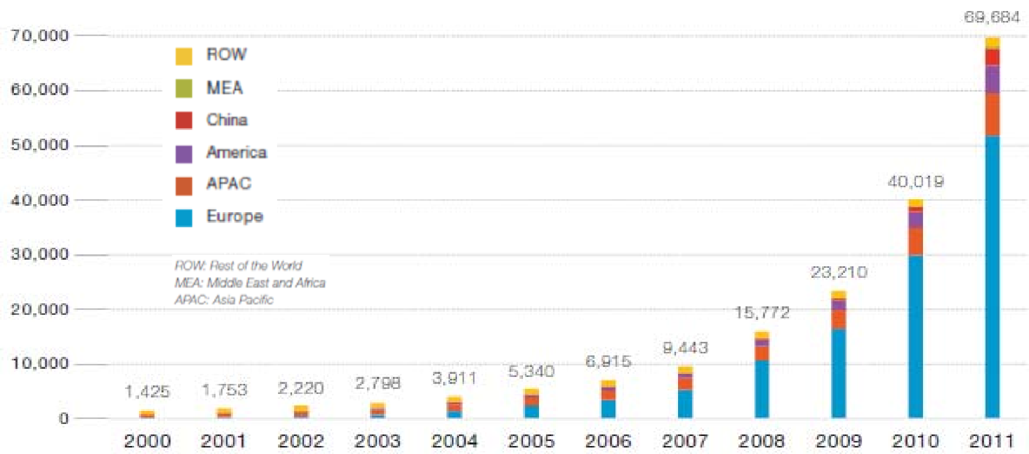



*Fig. 1. Evolution of global cumulative installed capacity 2000-2011 (MW).*

*Table 1. World-wide PV markets and capacities 2000-2011 (MW).*

| Country | Newly 2010 | Cumulative 2010 | Newly 2011 | Cumulative 2011 |
|---|---|---|---|---|
| Italy | 2,326 | 3,470 | 9,284 | 12,754 |
| Germany | 7,408 | 17,193 | 7,485 | 24,678 |
| China | 520 | 893 | 2,200 | 3,093 |
| USA | 878 | 2,528 | 1,855 | 4,383 |
| France | 719 | 988 | 1,671 | 2,659 |
| Japan | 991 | 3,618 | 1,296 | 4,914 |
| Australia | 387 | 524 | 774 | 1,298 |
| United Kingdom | 62 | 91 | 784 | 875 |
| Belgium[a] | 417 | 1,044 | 974 | 2,018 |
| Spain[a] | 441 | 4,029 | 372 | 4,400 |
| Greece | 150 | 205 | 426 | 631 |
| Slovakia | 145 | 148 | 321 | 468 |
| Canada | 105 | 200 | 364 | 563 |
| India | 60 | 161 | 300 | 461 |
| Turkey[b] | 0.1 | 1 | 5 | 6 |

[a] Data here are installations in AC power, as officially reported, [b] 2011 data are provisional

21.9 GW of PV systems was connected in Europe in 2011, compared to 13.4 GW in 2010. In terms of global cumulative installed capacity, Europe still leads the way with more than 51 GW installed as of 2011. Europe still accounts for the predominant share of the global PV market, with 75% of all new capacity in 2011. Italy was the top market in 2011, with 9.3 GW connected, followed by Germany with 7.5 GW; Italy and Germany accounted for nearly 60% of global market growth during 2010. Italy, Germany, France, China, Japan and USA PV markets achieved more than 1 GW of additional PV capacity in 2011. China was the top non-European PV market in 2011, with 2.2 GW installed, and followed by USA with 1.9 GW. Many of the markets outside Europe, in particular China, the USA and Japan, but also Australia (1.3 GW) and India (0.46 GW), have addressed only a very small part of their enormous potential; several countries from large sunbelt regions like Africa, the Middle East, South East Asia and Latin America are on the brink of starting their development [2].

The Energy Market Regulatory Authority (EMRA) regulates and controls the energy market in Turkey. The Law on the Utilization of Renewable Energy Resources for the Purposes of Electricity Generation came into force on dated 10.05.2005 and numbered 5346. The regulation was prepared again and published as the Amending Law to the Law on Utilization of Renewable Energy Resources for the Purposes of Electricity Generation dated 29.12.2010 and numbered 6094. According to this Law, the electric power generated by PV solar energy generation plants will be purchased 13.3 USA dollar cent/kWh with support for a period of ten years by the state. In case of mechanical and/or electro-mechanical equipment used in generation plants has been manufactured in the country, additional support will be provided for integration of PV panels and manufacture of solar structural mechanics 0.8, PV modules 1.3, PV cells that make up the module 3.5, inverter 0.6 and material that focuses sunlight on the PV module 0.5 USA dollar cent/kWh for a period of five years [3].

Regulation on Exempted Generation in the Electricity Market of the EMRA was published in the Official Gazette dated 03.12.2010 and numbered 27774. The regulation was prepared again and published in the Official Gazette dated 21.07.2011 and numbered 28001 and amending regulation to dated 10.03.2012 and numbered 28229. Accordingly, natural and legal persons establishing a maximum of 500 kW generation plant based on renewable energy sources with micro-cogeneration plant were exempt from obligation obtaining a license and setting up a company. Anyone who has electricity customers can establish exempted power generation plant and produced more electricity can be sold to the distribution company [4].

The energy regions for generation of electricity using solar energy were determined by the Ministry of Energy and Natural Resources of the Republic of Turkey [5]. The 38 city at a total of 27 regions was allowed and encouraged for electric generation. While the highest capacity was granted to Konya with 82 MW of electricity, Van follows with 77, Mersin 35 and Karaman were granted the rights to apply for up to 38 MW. There is a 600 MW limit to investments throughout Turkey.

## 2. Solar pv power system configuration

A 720 Wp grid-connected PV power generation system was carried out with support from the Scientific Research Projects Unit of Kocaeli University. The solar panels installed in the garden of the Faculty of Technology at Kocaeli University. A single-phase 1 kW grid-connected inverter was established in building of the Faculty of Technology and connected to the distribution panel. The system was designed to generate power that would be injected directly to the electric grid as show in

Fig. 2. It consisted of 3 main parts are solar PV power panels, grid-connected inverter and monitoring system.

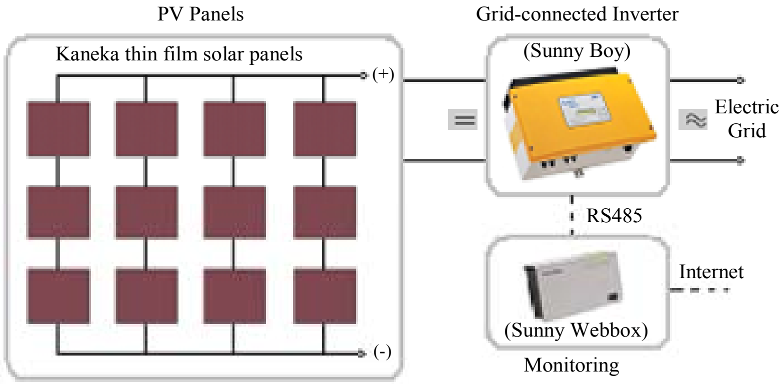



*Fig.2 The system block diagram.*

### 2.1 Solar PV Power Panels

A 720 Wp solar PV power system was comprised of 12 Kaneka solar PV thin-film panels. Each panel has a power of 60 Wp and a nominal voltage of 67 V. Solar PV panel parameters are given in Table 2 [6]. The panels are connected in series strings of three groups of four parallel-connected modules, for nominal voltage of 201 V dc. Fig. 3 shows photograph of the 720 Wp PV power panels involved in this study.

*Table 2 Solar PV panel specifications.*

| Parameters | Values |
|---|---|
| $P_{MAX}$ | 60 W |
| $V_{OC}$ | 91.8 V |
| $I_{SC}$ | 1.19 A |
| $V_{PM}$ | 67 V |
| $I_{PM}$ | 0.9 A |

*Fig. 3 Photograph of the 720 Wp solar PV power panels*

### 2.2 Grid-connected Inverter and Monitoring System

The grid-connected inverters are used to convert dc power from PV array to AC power on grid. The output of solar PV power panels was connected to a Sunny Boy single-phase 1 kW grid-connected inverter. The inverter is turned on in the morning and will automatically synchronize to the electric grid. After that it is operated all day until the evening, it will just automatically shut down. The grid-connected inverter needs to have the electric grid all the time. If the electric grid has a problem like shut down or unusual problem, the grid-connected inverter stops operation for operator safety. The electrical data are measured by measurement function of the inverter. The inverter shows on the screen, PV system power transmitted to the electric grid, system voltage, total amount of produced energy, amount of produced energy during the day and total run time [7].

Since the modules voltage and current vary considerably depending upon the weather conditions, the inverter needs to move its working point in order to function optimally. In order to feed the maximum power into the electricity grid, the inverter must work in the maximum power point (MPP) of the PV array [8]. In the used inverter, an MPP tracker ensures that the inverter is adjusted to the MPP point and the greatest possible power is fed into the mains electricity grid. Table 3 shows the SMA Sunny Boy single-phase grid-connected inverter parameters [7].

*Table 3 Grid-connected inverter parameters.*

| Parameters | Values |
|---|---|
| $V_{DCmax}$ | 400 V |
| $V_{DCmpp}$ | 139 - 400V |
| $I_{DCmax}$ | 10 A |
| $V_{ACnom}$ | 230 V |
| $f_{ACnom}$ | 50/60 Hz |
| $P_{ACnom}$ | 1 kW |
| $I_{ACnom}$ | 4.4 A |
| $\cos\varphi$ | 1 |

A monitoring system selected for the project consist of the SMA Sunny WebBox, continuously records the performance of solar PV power system. The grid-connected inverter is connected via RS485 with the WebBox [7]. The WebBox can access the internet via network connections. The measured values and the current energy yield are visualized and archived in the internet, through the sunny web portal in Kocaeli University Department of Energy Systems Engineering website (http://enerji.kocaeli.edu.tr/fotovoltaik.php). The grid-connected inverter and the monitoring system are showed in Fig. 4.


*Fig. 4 Grid-connected inverter and monitoring system.*

## 3. Performance analysis

The solar PV power system has been installed first 360 Wp in March 2010 and upgraded for 720 Wp in August 2011. This section presents operation and performance results obtained from monitoring the 720 Wp grid-connected PV power system. The system was monitored after March 2012 by the Sunny WebBox. Hourly, monthly and annual performance parameters of the PV system evaluated. The 720 Wp system generated electric power of 950 kWh between August 2011 and August 2012. Fig. 5 shows the hourly energy production of solar PV system for 11 September 2012. Monthly energy production is showed in Fig. 6. Monthly generated energy was over 100 kWh for months June, July and August 2012.

The grid-side electrical parameters of the inverter were measured using Fluke 434 power quality analyzer. Fig. 7 shows the grid-side voltage and current waveforms and grid-side power and energy values. The grid-side voltage 218.5 V, current 2.4 A, power 0.53 kW and power factor 1.0 was measured.

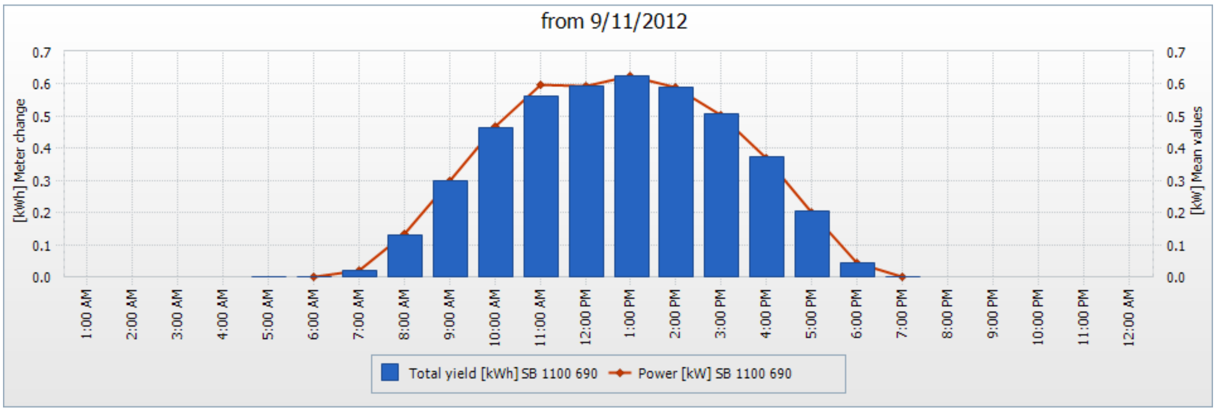



*Fig. 5 Hourly energy production.*

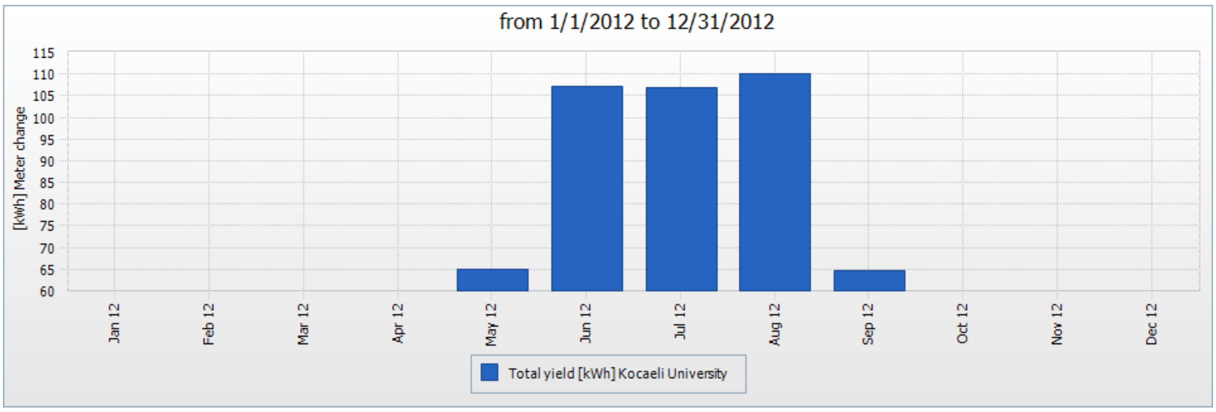
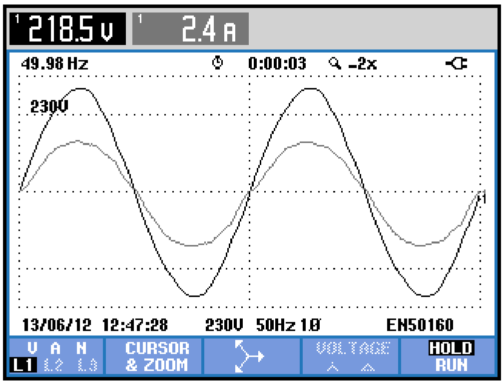
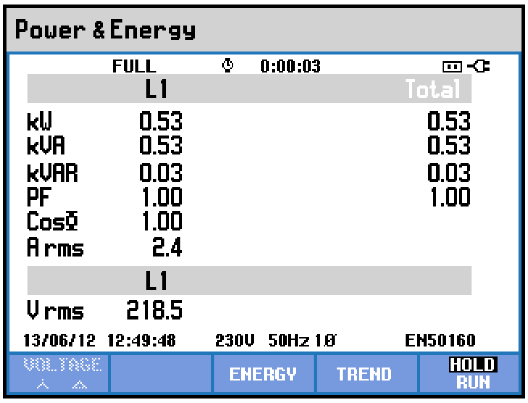



*Fig. 6 Monthly energy production.*

The grid-side voltage and current harmonics spectrum and harmonics table are showed in Fig. 8 and Fig. 9, respectively. The grid-side inverter voltage total harmonic distortion (THD) value was 2.5% and current THD value was 4.8%. These values are quite close to the limit value of 5% specified in the IEEE 519-1992 standard.

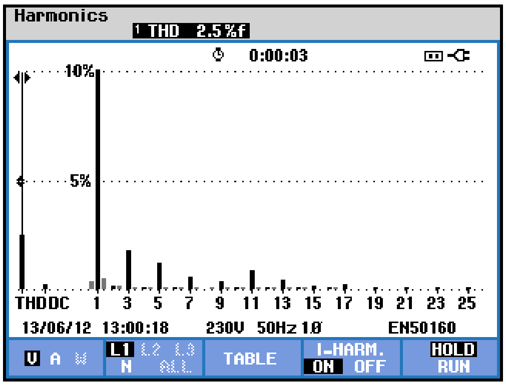



(a)

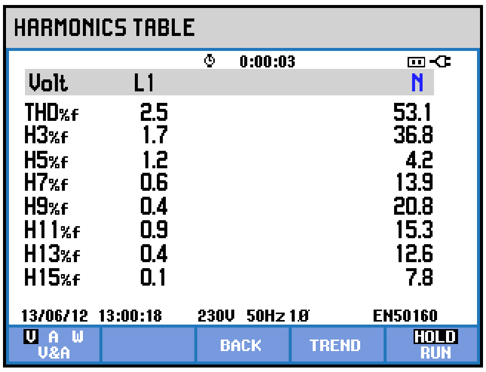



(b)

*Fig. 7 (a) Grid-side voltage and current waveforms (b) grid-side power and energy values*

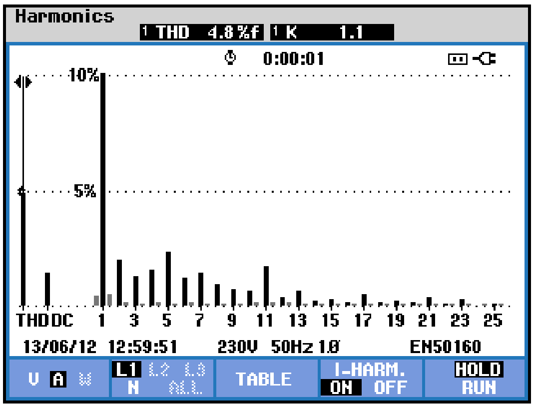



(a)

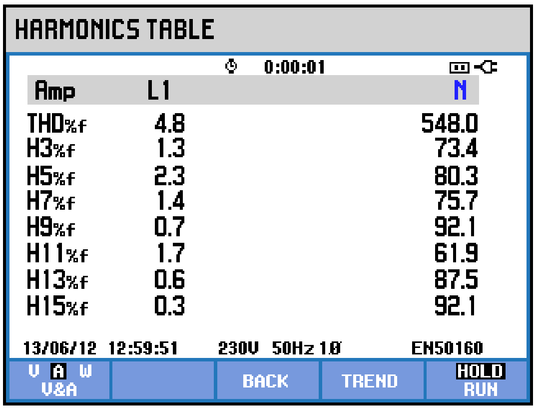



(b)

*Fig. 8 Grid-side voltage, (a) harmonics spectrum, (b) harmonics table.*




(a)




(b)

*Fig. 9 Grid-side current, (a) harmonics spectrum, (b) harmonics table.*

## 4. Conclusions

Solar PV power systems are becoming more popular with the increase of energy demand and the concern of environmental pollution around the world. A 720 Wp grid-connected PV power system installed in the garden of the Faculty of Technology at Kocaeli University. The system monitored after March 2012 and its operation and performance parameters were evaluated on hourly, monthly and annual basis. The grid-side electrical values are measured by using power quality analyzer. The installed grid-connected solar PV power system works efficiently as shown the presented results. Also, solar irradiation is found good enough to produce electrical energy.

### Acknowledgements

This study was supported by the Scientific Research Projects Unit of Kocaeli University.

## References

[1] ABB, Technical Application Papers No.10, Photovoltaic plants.

[2] Global Market Outlook for Photovoltaics until 2016, European Photovoltaic Industry Association (EPIA), May 2012.
[3] Amending Law to the Law on Utilization of Renewable Energy Resources for the Purposes of Electricity Generation, Law No: 6094, dated 29.12.2010.
[4] Amending Regulation to the Regulation on Exempted Generation in the Electricity Market Official Gazette No: 28229, dated 10.03.2012.
[5] The connection capacity of transformer centers for electricity generation plants based on solar energy, from http://www.enerji.gov.tr.
[6] Kaneka Corporation, from http://www.kaneka-solar.com.
[7] SMA Solar Technology, from http://www.sma.de.
[8] Kjaer S.B., Pedersen J.K. and Blaabjerg F., A review of single-phase grid-connected inverters for photovoltaic modules, IEEE Transactions on Industry Applications, **41**(5), 1292 (2005).

*Corresponding author: eozdemir@kocaeli.edu.tr