Şebeke Bağlantılı Fotovoltaik Sistemin Enerji Hasatı Analizi: Kampüs Çalışması

Energy Harvesting Analysis of an On-Grid Photovoltaic System: A Study for Campus Area

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Özet

Evirici şebeke bağımlı yada otonom fotovoltaik (PV) sistemlerin önemli bir bileşenidir. Bu projede, büyük ölçekli bir evirici kullanılmasına rağmen genellikle diğer sistemlerde % 30 PV dizisinin anma gücünün %30'u kadar altında nominal AC çıkış gücü ile boyutlandırılır. Tipik olarak, bir eviricinin nominal çalışma ışınım değerleri 200W/m^2-1100W/m^2 arasındadır. Fakat yüksek enerji hasatı için 6W/m^2-200W/m^2 ışınım değerleri arasında çalışan eviriciler olmalıdır. Bu ışınım değerlerinde çalışan DC-DC çeviriciler sayesinde aküler şarj edilebilir veya akülerin soğutulması amacı ile eviriciler kullanılabilir. Bu çalışmada, bir fotovoltaik sistemden elde edilen enerji hasatı ortalama saatlik değerler yerine anlık (15 sn.) değerler kullanılarak optimum enerji hasatını ifade etmektedir. Bu veriler Beykoz, ilçesinde (41 ° 08'31.1 "N 29 ° 06'00.6" E, İstanbul, Türkiye) kullandığımız sistemin hesaplamaları sonucu elde edilmiştir.

Abstract

The inverter is a major component of photovoltaic (PV) systems either autonomous or grid connected. Inverters are usually sized with a nominal AC output power some 30% below the PV array nominal power whereas in this project, an oversized inverter is used. Typically, the nominal operation radiation values of an inverter is between 200W/m2-1100W/m2. There must be also inverters which are operated between 6W/m2-200W/m2 in order to harvest energy. This idle energy can be used with the help of DC-DC converter for charging the batteries or with the help of an inverter for air conditioning the rooms where the batteries must be cared well. In this paper we present a photovoltaic energy harvesting possibilities and demonstrate that using instant (15 s) values instead of average hourly values leads to considerable differences in optimal energy harvesting. We perform these calculations for data sets from inverter readings in Beykoz (41°08'31.1"N 29°06'00.6"E, Istanbul, Turkey).

1. Introduction

The PV system will feed into a number of different existing buildings on the campus. The project has significant LEED aspirations, which indicated that a large array size would be preferred; however, challenges with utility interconnection and existing building electrical equipment required significant review to determine optimal system sizes. The average size of our project to date is approximately 1.7kW, with 10 PV panels. Our example power plant consists of an outdoor installation of PV panels, a dc collection network, an indoor installation of inverters, and high-voltage ac switchgear to connect to the electric utility grid. Nominal Power (3200W) of SF-WR-3203 inverter was used in this project. In Turkey, the frequency limits are between 47.50Hz and 50.20Hz, minimum input voltage for grid-feeding is 250V and rated input voltage is 410V. Power losses of inverter in nighttime operation is less than 3W and maximum efficiency is about 98.6%. Own consumption of the inverter is less than 8W and includes 1x RJ45 socket (Ethernet for TCP/IP network) for communication, e. g. with a central data server. The data in the plot comes from the SF-WR-3203 in June, 2016 where the inverter temperature is about between 45-50°C. However, as shown in Fig. 1, the inverter is in "energy laboratory" under the roof and the temperature differences between winter and summer are not as drastic as they would be for inverters located outside.

Figure 1. Donated PV Panels Solar Frontier 170 Watt, SF 170-S) and Inverter (Solar Frontier SF-WR-3203) (at the left side is inverter, at the right side is the dc/ac collection network)

Table 1. Electrical Performance at Nominal Operating Cell Temperature (NOCT) Conditions*

* Nominal Operating Cell Temperature Conditions: Module operating temperature at 800 W/m2 irradiance, air temperature 20 °C, wind speed 1 m/s and open circuit condition.

Parameters	Value
Nominal power (Pmax)	126 W
Power tolerance	+5 W / 0 W
Open circuit voltage (Voc)	102 V
Short circuit current (Isc)	1.76 A
Voltage at nominal power (Vmpp)	82.1 V
Current at nominal power (Impp)	1.55 A

Each array is also protected by a fuse and a blocking diode. The peak DC output of 5 PV panels is 595V, output current 3.14A, and rated output power is 1.7kW. Fuses and the blocking diodes for each panel are located in a DC collection box. The installed PV system is shown in Figure 2.

Figure 2. Base construction for ground-mounted systems

2. Monitoring

2.1. Remote Control

Today, monitoring and performance analysis of solar PV plants has become extremely critical due to the increasing cost of operation and maintenance as well as reducing yield due to performance degradation during the lifecycle of the plant equipment. This means that the use of a monitoring system can become essential to ensure high performance, low downtime, and fault detection of a solar PV power plant during the entire lifecycle. [1] In fact, monitoring of basic parameters is available as a standard feature on most inverters on the market today. Most inverters are connected via Bluetooth, Wi-Fi, Ethernet, or serial networks. There is a wide array of systems that collect the data including simple PC-based systems, "black boxes," and Internet-connected devices. Remote control and monitoring is more real-time and is typically performed by USB for local monitoring, and RS-485 and power line for inverter interconnection. Certain data is stored in the internal memory (EEPROM) and some of this data is shown on the display and as described below:

1. Voltage and current of the solar generator

2. Power and current fed into the grid

3. Voltage and frequency of the power grid

4. Energy yields on a daily, monthly and annual basis

5. Error conditions, events

6. Version information

The entire system is configured to perform the following series of tasks:

• Remote logging – all data is logged as 15-seconds averages at the web page of http://95.183.236.21/page.measurements.html;

• Data collection and storage – all data is transmitted both in real-time (every 15 seconds) and in “excel files” (pre-defined data packages for academicians at the end of every day);

• Data publishing services – academicians can easily tap into historical data sets that can be automatically preset or manually prepared; The map interactive feature allows for reading of yield values and also shows maxima and minima of energy, average energy and environmental savings such as CO_2, number of saved trees, over the entire Istanbul land area [2].

2.2. Network (TCP/IP)

The device can transfer yield data and event messages every 10 seconds via the TCP/IP interface to the Internet portal server (*http://public.solarmonitoring.net/dashboard/system/YY1RI/1m7Kho75QV*) and the yield data can be displayed graphically. Inverter data derived from the inverter is available through the browser and is required to work in interaction with the Python language. Using “Beautifulsoup” and “Selenium” libraries, interaction between python and browser was performed and the data was loaded into the table with JavaScript which was extracted through beatifulsoup library and was recorded into a CSV file and a data set has been created.

2.3. Grid Related Shutdowns

Usual inverters do operate above 450V voltage and between 200W/m^2-1100W/m^2 radiation values. At sunrise and sunset, where the DC voltage is under inverter operation voltage, the inverters do not allow the energy feed in grid. Solar Frontier SF-WR-3203 senses the utility frequency and voltage and will shut down if it senses conditions outside the range expected for utility power. Typically, between 22.03.2016 - 15.06.201, 6 shutdowns of Solar Frontier SF-WR-3203 inverter exist when “Islanding (23 times)”, “ENS Grid Voltage too low (21 times)”, “ENS Grid Frequency too low (6 times)” and “ENS Grid Frequency too high (7 times)” problems occur.

Table 2. Event table of the inverter (SF-WR-3203)

Name	**Start Time**	**End Time**
Islanding	14.06.2016 10:27:34	14.06.2016 10:27:39
ENS Grid Voltage too low	14.06.2016 10:27:34	14.06.2016 10:27:39
ENS Grid Frequency too low	29.05.2016 10:43:44	29.05.2016 10:43:50
ENS Grid Frequency too high	29.05.2016 10:43:44	29.05.2016 10:43:50

Dropouts take usually 6 seconds and typically last at least 5-minutes before the inverter tries to re-sync with the utility grid. The dropouts don't look sharp in 5-minute data plots because the dropouts rarely happen on the exact minute and some normal performance values are averaged in data when the problem starts or ends. Sometimes this problem can persist over hours, but shorter time intervals are more typical. With very short time interval data, one can see that the power actually goes to zero within about a cycle and the inverter takes five minutes or more before it attempts to start operating again [3].

There is no direct physical meaning of the time-integral of voltage. The capacitance may be defined by the voltage-current relationship:

$$i = C\frac{dv}{dt} \tag{1}$$

The capacitor voltage may be expressed in terms of the current by integrating the above equation

$$dv = \frac{1}{C}i(t)dt \tag{2}$$

The above Equation can be integrated between the times t_0 (before the sunrise or before the sunset) and t_1 (after the sunrise or after the sunset) and between the corresponding voltages $v(t_0)$ and $v(t_1)$

$$v(t) = \frac{1}{C}\int_{to}^{t1} i(t)dt + v(to) \tag{3}$$

The power delivered to the capacitor is

$$p = v.i = Cv\frac{dv}{dt} \tag{4}$$

3. Results and Discussions

In this study, energy harvesting analysis of an on-grid PV system is performed with 7 days DC voltage, phase currents and phase power data. The measurement was taken 1,5 hours before the sunrise and 1,5 hours after the sunset.

Using instant (15 s) irradiation values instead of average hourly irradiation values leads to considerable differences in using the idle energy during the sunrise and sunset. The monitoring system relies on the measurement capabilities of the inverter and no additional hardware is required. The measurement data is collected over the internet directly from the inverter. The experimental results, obtained from a prototype of the system, demonstrate the feasibility of a fully integrated photovoltaic energy harvesting possibilities. In the future work, the model will be then continuously fed with local weather data and calculates in real time what would be the correct energy production at 100% of plant capacity. The automatic comparison between the calculated and the real production figures (supplied by the already mentioned data logger) will give a precise indication of the plant performance or plant health every minute or less.

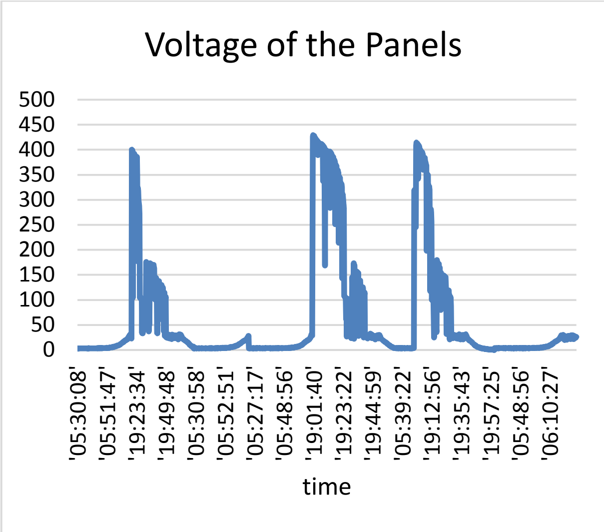

Figure 3. Sunrise and Sunset (3-day measurements)

The open circuit (Thevenin) voltage of the panels starting from 3V to 400V at 05:51 a.m. and 07:21 a.m. respectively can not be fed into grid (Figure 3). This unused energy, which is calculated in formula (4), may be stored in the batteries with different capacity (12V, 24V). If compared to total daily energy derived from the system, this harvested ebergy could be used for air-conditioning the rooms of the batteries or/and the rooms of the security staff.

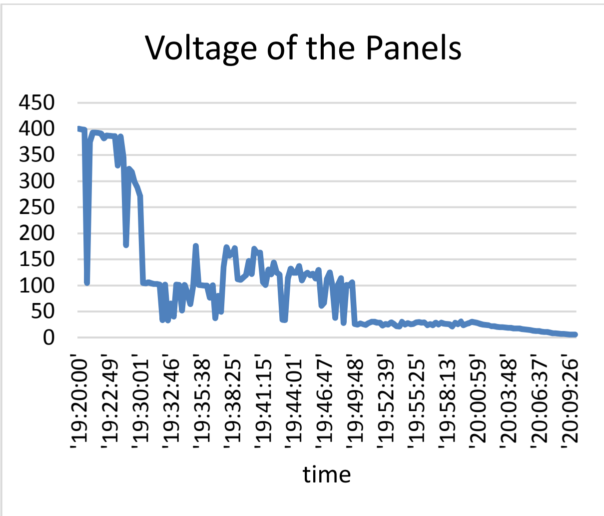

Figure 4. Sunrise and Sunset (1-day measurement)

As seen in Figure 4, the inverter shuts down at 19:30 where the voltage decrease below 400V and PV panels still produce voltage until 20:09. When we take into account the middle voltage (MV) and high voltage (HV) levels of PV systems, yearly yield of potentially harvested energy will reduce the pay-back time.

4. Acknowledgments

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5. Literature

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[3] Frank Vignola, “Performance of PV Inverters”, *Solar Radiation Monitoring Laboratory Department of Physics* 1274 – University of Oregon Eugene,