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A wireless monitoring system for monocrystalline PV system

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Abstract. Photovoltaic systems are progressively attached importance and their installed capacity increases day by day because of their reliability, decremented installation and operating cost and simple construction structure. Generated power obtained from a photovoltaic system changes depending upon regional distinctness, and It can be estimated approximately by taking into consideration mean global radiation amount, temperature and humidity. However, there may be different regional negative or positive factors like dust, air pollution, desert powder which affect generated power. The best reliable data for a region can be obtained from the existing photovoltaic system in the region. For this purpose, a monitoring system for 1000W monocrystalline photovoltaic system constructed at Kocaeli University Uzunciftlik Nuh Cimento Vocational High Scholl is prepared. The installed monitoring system shows and records real values generated from the photovoltaic system and environmental data. In the study, Instantaneous data obtained from the monitoring system for October 2018 and 7th October 2018 is given within figures. Additionally, daily and monthly total energy productions of the photovoltaic system are given for October 2018 and date interval between July 2018 and March 2018, respectively.

Keywords: PV systems; monitoring

1. Introduction

Photovoltaic (PV) systems are one of the most important renewable energy sources (RES). PV systems consist of integrated solar cells invert solar radiation into electricity. When solar cells absorb sunlight, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light (photons) to electricity (voltage) is called the photovoltaic (PV) effect. Energy production of a PV system depends on directly the solar irradiance and negatively working temperature, humidity and pollution of air. During the operation of the PV cell, only around 15% of solar radiation is converted to electricity and residual energy is converted to heat. The electrical efficiency will decrease when the operating temperature of the PV module increases (Teo *et al.* 2012).

PV systems can be separated into two classes as standalone and on-grid systems. Standalone

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systems are generally preferred in remote areas where accessing the utility power is economically and physically challenging. Battery charging, lighting, and water pumping are some applications of standalone systems. Grid-connected PV systems allow any surplus of energy harvested from a PV system to be fed into the grid. Grid-connected systems can be installed with or without batteries. Grid-connected PV systems without batteries procure energy from the grid when the PV system cannot yield energy depending on time zone or weather condition. A grid-connected system with batteries, also called grid-tie PV system, is stored the harvested energy. The stored energy is converted to AC with correct frequency and amplitude before it is synchronized to and integrated with the low-voltage utility grid. The most important advantage of this system can supply energy depending on battery capability when energy is cut on the grid or the PV system cannot produce energy due to time zone or weather condition (Naeem *et al.* 2011). As it is seen from given that grid-connected system with batteries, grid-tie PV system, is the best reliable PV structure with regard to energy continuity. However, it is the least preferred PV system due to the cost of batteries. Amount of energy produced from grid-connected PV plants has been reported as the third largest source of renewable energy after hydro energy source and wind energy source, with an estimated increment in future years. PV technologies have the highest rate of growth in the world-wide power technology because of simple and easily understandable installation structure, the flexibility of its applicability, high reliability, zero fuel costs, pretty maintenance costs, and the lack of noise due to the absence of moving parts (Moreno-Garcia *et al.* 2015). Additionally, solar energy has been indicated as the most reliable and viable solutions among all Renewable Energy Source (RES) for tropical countries. Electrical energy generation sector using PV technology has seen a rapid evolution during the past few decades because of the developments in PV technologies and various financial subsidies being provided by the government. This is evident from the increase in cumulative installed PV capacity (MW) of countries participating in International Energy Agency- Photovoltaic Power Systems Programme (IEA-PVPS), from 103MW in 1992 to 139.8GW in 2014 (Madeti and Singh 2017). According to the Global Market Outlook (GMO) 2016, the most likely scenario of total global solar capacity in 2020 will be 613 GW (Polo *et al.* 2017). This foresight brings forth the necessity of accurate prediction of energy production in order to provide solar energy more reliable and preferable. To build an accurate PV model and visualize monitoring for commercially available PV module supplies suitable environment to predict energy production and effectively assess the harness the instantaneous output power and annual electricity generation of a PV system in the field operation (Le *et al.* 2016).

Some circumstances as daily and seasonal weather conditions, intermittent component failure, operating conditions, air pollution and component degradation determine the performance of PV systems. In order to ensure performance and long term projections of PV systems, monitoring is critical. While monitoring systems are used for long-term data monitoring, they are also used to investigate the efficiency of PV systems under special conditions. An experimental performance analysis has been performed for a cold region stationary PV system (Choi *et al.* 2016). An data acquisition and FPGA based power control system has been studied for distributed PV system under partial shading condition (Chao 2013). Some experimental studies in order to determine impacts of air pollution like red soil, limestone and ash, and temperature and wind speed on PV system efficiency have been studied (Kaldellis and Fragos 2011, Kaldellis *et al.* 2011, Kaldellis *et al.* 2014). Another monitoring system has been constituted to estimate global solar radiation and performance of solar power plant (Srivastava *et al.* 2019).

In this study, a microcontroller based real-time PV monitoring system is prepared and presented. The 1000W monocrystalline PV system was constructed at Kocaeli University Uzunciftlik Nuh Cimento VHS. Energy yielded from the PV system is stored in four series-connected 6V-180Ah batteries during day time and used to lighten garden of the school at night. Our monitoring system hardware consists of STM32F4 discovery card, a SP110 pyranometer, current sensor, SHT75 temperature and humidity sensor, HC-05 Bluetooth module, a signal conditioning circuit to reduce voltage and read adjusted value by the microcontroller. The software of the system is prepared by using LabVIEW. In the next section, studies for monitoring prepared and presented in literature, the methods and technologies used in these systems are summarized. Our monitoring system is detailed in section 3 and outputs obtained and monitored from the PV power generation system are given section 4. The study ends with the summary and future works.

2. Background

As mentioned above, monitoring of PV system performance is essential to ensure performance and long term projections of the system. The most significant components of monitoring systems to collect valuable data on PV system inputs and outputs are pyranometers, thermocouples, and voltage/current/power sensors. Quality and reliability of data collecting by the aid of monitoring systems can help support operations and maintenance over the lifetime of the system. When collecting massive amounts of data, automated data quality control and performance monitoring can enable system operators to rapidly sense performance issues (Klise and Stein 2016). In addition to significant components of monitoring systems, as pyranometers, thermocouples, and voltage/current/power sensors, some electrical and meteorological sensors as humidity sensors, wind speed, and wind direction sensors can be used on monitoring systems. The parameters measured by suitable sensors are selected according to British Standard BS IEC 61724 (Madeti and Singh 2017). The parameters measured by monitoring systems are determined according to the PV system being grid connected or standalone, with battery or without battery. On the other hand, meteorological parameters except solar irradiance can be monitored with respect to the effect of the related parameter on energy production.

PV monitoring systems aim to predict/sense different undesirable situations, which can cause to drop energy production levels from expected level by the aid of measured solar irradiation. Unexpected problems, occurred on the energy production system and dropped energy production level, can be caused by the control system, design of PV system, climatic conditions, surrounding objects, and geographical locations, etc. It was reported that the annual energy loss due to partial shading is about 10–20%. Additionally, production losses associated with the occurrence of each of grid fault can occur. Problems on renewable energy source systems vary because of the region or the system, and they need individual solutions. For this purpose, it is necessary to develop techniques to monitor weather conditions, energy production and estimate the real potential power of RES in the settled area in real-time. The primary objective of a PV monitoring system is to maximize the operational reliability of a PV system with minimum system costs. In brief PV monitoring systems provide and report information about the energy potential or solar irradiance, energy production, environment and operating temperature, analysis of different of faults that might occur and energy loss associated with them. The data obtained from the monitoring system can also be used for early detection/warning, evaluating the climatic changes, etc. (Madeti and Singh 2017). The monitoring system has a significant impact to test the performance and to detect any undesirable failing of installed PV system and panels. As mentioned above, a monitoring system is constituted for a specific purpose or monitoring several electrical and meteorological parameters. While the PV system generates power for a certain period during daylight, energy consumption can change within day for a particular sector. While office, factory or school need power mostly day time, residential consumers need night time. Without a monitoring system, the energy amount yield from the PV system is observed from meter-reading or the inverter display. Owning a monitoring system that can be accessed from anywhere is appropriate and financially efficient (Rahman *et al.* 2017). With a pessimistic scenario, it is possible to meet unwelcome high electric bill if any problem at the PV power generation system is not noticed on time. This is one of the economic benefits of owning a monitoring system (Rahman *et al.* 2017).

3. Monitoring systems

A monitoring system is a Data Acquisition (DAQ) system which is used widely in RES to acquire data from several sensors on the system and sent them to a central computer for further process and controls the data. Data acquisition is the process of gathering information from the real world in analog form and digitalizes the signal for presentation, analysis, and storage on a personal computer. This process involves several stages including sensors, signal conditioning, ADC and signals transferring method. The basic block diagram of a simple DAQ system is shown in Fig. 1 (Madeti and Singh 2017).

There are several studies about RES, PV or meteorological monitoring system in literature. Some of these studies are summarized and listed in tables in the studies (Madeti and Singh 2017, Rahman *et al.* 2017, Dhimish *et al.* 2016, Triki-Lahiani *et al.* 2017). For remote areas or regions in developing countries, an Arduino based data logger was developed to monitor photovoltaic (PV) systems at low-cost only 60€ (Fuentes *et al.* 2014). Another monitoring system also measured wind speed and ambient temperature performed in (Polo *et al.* 2017). The system uses three different devices: a thermopile pyranometer (Kipp and Zonen CMP11) and reference modules of CIS and CdTe in short-circuit in order to analyze the differences in modeling small scale PV systems when using different irradiance measuring devices. A wireless PV visualized monitoring, evaluation, and fault detection system was presented in (Le *et al.* 2016). The system is visualizing not only irradiance using a Si-based pyranometer JSP-215 with a sensitivity of 4 mV/(W/m^2) and the maximum measurement radiation of 1205 W/m^2, but also cell temperature, voltage, and current of a PV module under practical operation conditions, includes the DAQ interface circuitry with a STM32F4DISCOVERY board, an HC-05 Bluetooth slave module, and a MATLAB/Simulink programming platform. In the study (Yahyaoui and Segatto 2017), the authors present a different and useful method to monitor and to detect faults related to short-circuit currents, open-circuit voltage, and partial-shading. The monitoring system used in this PV system contains an Agilent HP 6063B programmable electronic load for the data acquisition and a reference solar cell to

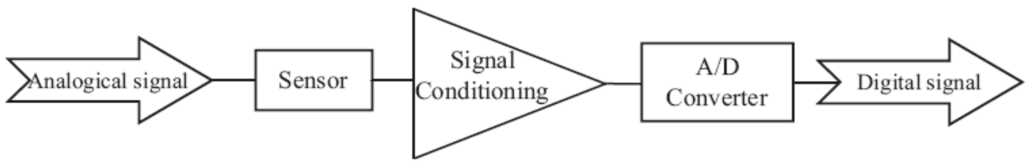

Fig. 1 The basic block diagram of a simple DAQ system

measure the solar radiance. In real time, the current and voltage indicators are utilized to analyze the faults connected to open-circuits, short-circuits or partial shading in a PV plant. The evolution analysis of the indicators enables differentiating these faults. Additionally, the presented technique enables us to determine the number of bypassed modules and open-circuit strings. Another simple, low-cost and open source real-time monitoring system based on a microcontroller Atmega328P-PU is given in (Caruso *et al.* 2016). In the study, it is provided high flexibility to the proposed system by using wireless communication between the components. Alternative inexpensive Arduino Uno microcontroller module is presented for real-time monitoring of existing 1.6 kWp single-phase grid-connected PV systems in Electrical Energy Conversion Research Laboratory (EECRL), School of Electrical Engineering and Informatics (SEEI), Institute of Technology Bandung (ITB) (Iskandar *et al.* 2016). The data logger stores measured data, voltage, current, and power, during the measurement with Arduino Uno module using battery-powered, internal memory for data storage and LCD displaying the measurement from sensors. The system allows users to access the monitored data quickly from the data logger and data retrieval online or offline. Wireless communication based on a radio frequency is used, and Human-computer interface for online monitoring is prepared in the system.

In order to produce a fast and low-cost prototype, a microcontroller-based data acquisition system was prepared by using a 10-bit 16F877 microcontroller and applied to remote PV water pumping systems in (Mahjoubi *et al.* 2011). In this system, the information obtained from the sensors goes to the microcontroller, where it is processed and later sent to an external EEPROM memory and passed on to a personal computer via a Global System of Mobile Communication (GSM) network and, in particular, using the Short text Message Service (SMS). Another PIC 16F877 microcontroller based low-cost PV monitoring system was set up to acquire the data on remote areas and transfer the information via high frequency (HF) wireless connection to a personal computer (PC) for analysis and interpretation in (Benghanem 2009). It is presented in the study that it is possible to control the functioning of PV system and also to give the I–V curve of PV modules in real conditions and to study the performances of the PV system in real time. A data logger prototype based on a low-cost solution using Atmel Atmega 8 microcontroller, Dallas DS 1307 Real Time Clock and 64 k serial EEPROM from microchip was designed in (Purwadi *et al.* 2011). A data satellite transmission based a monitoring system which records data of irradiance, PV generation, state of the battery and load was developed in a remote fishing village called Apiques near Baleia, in the Northeastern state of Ceara, Brazil (Krauter and Depping 2004). The data obtained from the system is sent to the ARGOS-SCD satellite, and the satellite data is transferred from the receiving ground station to the Internet, providing worldwide access via WWW.

The Lab-VIEW software interface is prepared and presented for displaying, storing, and processing the obtained monitoring data at the University Mechanical Engineering Umech, Moscow, Russia (Rezk *et al.* 2017). The system enables the user to display in a PC screen the instantaneous values of any of the operational output parameters of the PV system and graphs of the I-V and P-V characteristics of PV panel. The Internet of Things (IoT) and Cloud computing principles based Renewable Energy Monitoring System which includes three main parts: 1. Analog/Digital Converter Embedded System (ADCES) which utilizes a SanUSB microcontroller, based on free software and hardware tool with the PIC18Fxx5x family including native USB interface, 2. Raspberry Pi (RPi) Embedded Linux System (ELS), 3. Online Web Monitor for real-time cloud monitoring, is presented in (Pereira *et al.* 2018). The system gives a new concept on data acquisition, and transmission systems (DATS) applied to real-time cloud monitoring of a decentralized photovoltaic (PV) plant. A new PV monitoring study is prepared to introduce the normalized efficiency and its longer-term average for screening and system analysis purposes and show the similarity of this metric to the Performance Ratio (Herteleer *et al.* 2017). A user interface to store meteorological and electrical data measured by sensors per second with NI 9205/9206 analog voltage measurement cards and monitor to the user is prepared at LabVIEW. A calibrated Kipp&Zonen CMP11 pyranometer and a Mencke&Tegtmeyer Si- 420TC-T reference cell in the plane-of-array and Pt100 temperature sensors for ambient and module temperatures are used in the system. In (Rohit *et al.* 2017), a real-time data acquisition and monitoring system of solar photovoltaic modules are presented. A graphical program to obtain efficiency and fill factor of the solar PV module is developed in LabVIEW. The data consisting of voltage, current, solar radiation, ambient temperature, humidity and power acquired from sensors is displayed on the front panel in real time. The data is acquired, stored and converted using NI DAQ module and LabVIEW software.

4. Monitoring system of 1000W PV system

In this study, a microcontroller based real-time PV monitoring system for 1000W monocrystalline PV system was constructed at Kocaeli University Uzunciftlik Nuh Cimento VHS, 40° 45' 03.2"N-30° 03' 17.0"E. The system is an off-grid system. The PV system consists of five 200W monocrystalline PV modules with 37.10V (voltage at maximum power), 5.40A (current at maximum power), 44.70V open circuit voltage (V_{OC}), 5.70A short circuit current (I_{SC}) and 1580x808x35mm dimensions. Energy yielded from the PV system during day time is stored in four series-connected 6V-180h traction batteries and used to light garden of the school with three 100W LED projector at night. The five monocrystalline PV module has been settled boths side of the existing grid-connected 500W thin-film solar system as seen in Fig 2.

In the study, it is aimed to track, monitor and record the energy yielded from the PV system and stored in batteries according to irradiance with temperature and humidity of the environment. An interface is designed in LabVIEW for this purpose. The system has two electrical data, voltage and current, and three meteorological data, global irradiance, temperature and humidity of the environment. The current and irradiance sensors produce an analog signal and the output voltage of the PV power generation system is also an analog signal.

The temperature and humidity of the environment are taken from the digital sensor. The analog signals and digital signals taken from sensors and conditioner circuit is processed on STM32F4 discovery card and sent via HC-05 Bluetooth module to a personal computer. The output current of the PV system is measured by ACS715 current sensor with 185mV/A sensitivity. The output voltage of the PV system is measured via signal conditioning circuit installed by using cascade connected two inverter operational amplifier with gains of -0.0738 (for reducing the output voltage) and -1 (for obtaining positive voltage to microcontroller input). The solar irradiance is measured by SP110 pyranometer with $5mV/Wm^2$.

The STM32F4 discovery microcontroller has 16 channels used as an analog to digital converter (ADC) with 12-bit. Three of these channels are used for converting analog signals to the digital signal. The temperature and humidity of the environment are measured by SHT75 digital sensor and sent to the microcontroller by using I^2C communication. The sensor is faultlessly coupled to a 14bit ADC and a serial interface circuit. This results in superior signal quality, fast response time and insensitivity to external disturbances.

Fig. 2 The PV system constructed at Kocaeli University Uzunciftlik Nuh Cimento VHS

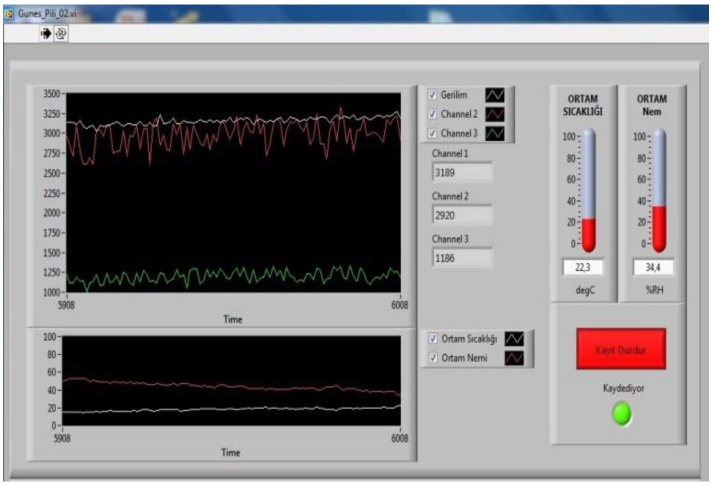

Fig. 3 The user interface prepared on LabVIEW

There are several wired and wireless transmission techniques such as power line communication system, fiber optic, coaxial cable and satellite, Bluetooth, Wi-Fi, Zigbee, GSM-GPRS, RFID, Wireless Local Area Networking (WLAN), Wireless Sensor Network(WSN). In this study, the electrical and meteorological data obtained from sensors and conditioning circuit is processed on STM32F407VG Cortex M4 microcontroller from ST Microelectronics and then, sent to the personal computer via HC-05 Bluetooth module. Bluetooth is one of the most suitable methods for short-distance data transmission. Bluetooth technology is a kind of global wireless communication standard that enables to connect devices together over a certain distance simply. Besides, the Bluetooth device includes two most common implementations of the specification are Bluetooth Basic Rate/Enhanced Data Rate, which was adopted as version 2.0/2.1 and Bluetooth with low energy, which was adopted as version 4.0/4.1/4.2. The maximum baud rate varies from 115 kbps to 960 kbps, and the maximum transmission is in the range 10-100 m (Le *et al.* 2016). The data transmitted through Bluetooth is monitored and recorded via a user interface prepared on LabVIEW. The user interface is given in Fig. 3.

The analog voltage, current, and irradiance data are given as ADC output data in the upper waveform chart. These values are quantized before recorded. Temperature and humidity values are obtained as real values from the sensor and showed graphically right side of the interface. The data taken from microcontroller can be tracked utilizing the user interface and also recorded at specified intervals. Sampling time intervals are not standard in the literature. It is reported in (Fuentes *et al.* 2014) that Mukaro *et al.* was developed low-cost hardware for solar radiation monitoring and then for environmental monitoring and they were sampled and stored the data in 10-min intervals.

It is suggested in (Madeti and Singh 2017) that averaged values of data should be stored within a 5–15 min. In (Polo *et al.* 2017), All measurements are stored by the data acquisition system with 5-min timestamp. Output power is monitored and displayed in the MATLAB/Simulink platform at an interval of 1 min in (Le *et al.* 2016). The current and voltage measurements are performed in a short time, less than 5 min (Yahyaoui and Segatto 2017). Measurements obtained from a low-cost PIC microcontroller based data acquisition and transmission system are carried out in 10 min intervals using a real-time clock and stored in local EEPROM memories in (Pereira *et al.* 2018). The acquisition software for a solar radiation monitoring system operates with a time step of 50 s in (Balan *et al.* 2008). On the other hand, by basing on the IEC 61724 standard, data acquisition and recording interval should be determined depending on parameter types. For example, for parameters that depend on irradiance, the sampling period should be 1 min or less, and for parameters with high time sample, it should be between 1 and 5 min (Triki-Lahiani *et al.* 2017). In our system, in order to take more sensitive data, the time interval of data acquisition and recording is selected as 30 s. The data taken from microcontroller and time is recorded as a text file. The data obtained from the installed system is presented in the next section.

5. Experimental results

The recorded data as a text file is read by using MATLAB 2016B and presented through figures in this section. The 1000W PV system was installed in August 2015, but the monitoring

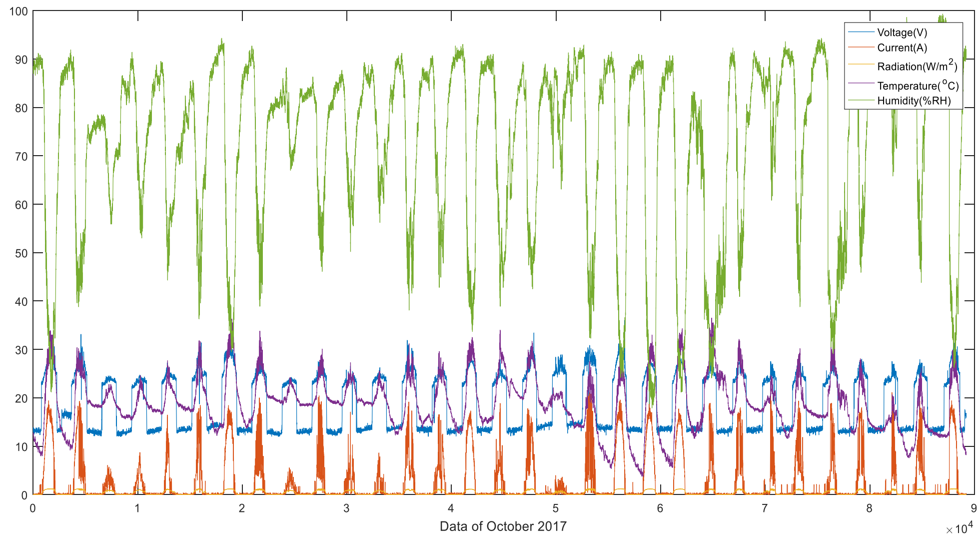

Fig. 4 Data of October 2018 obtained from the system

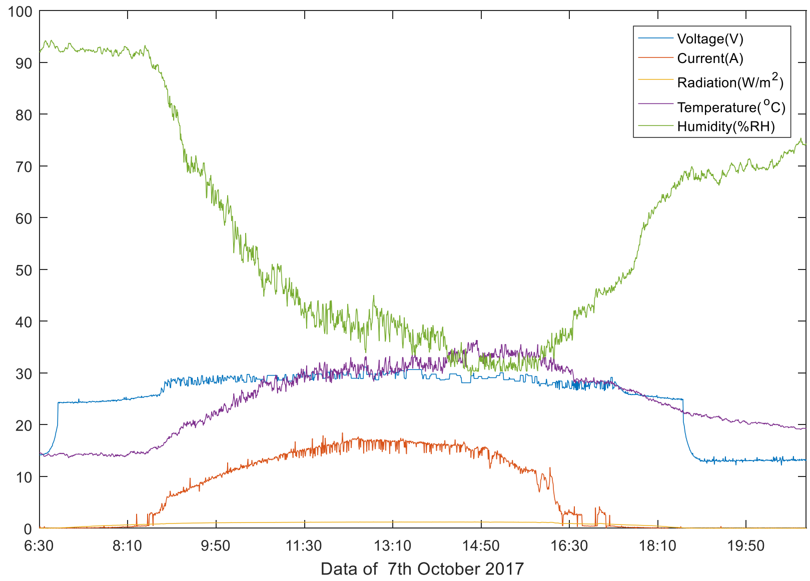

Fig. 5 Data obtained on 7th October 2018

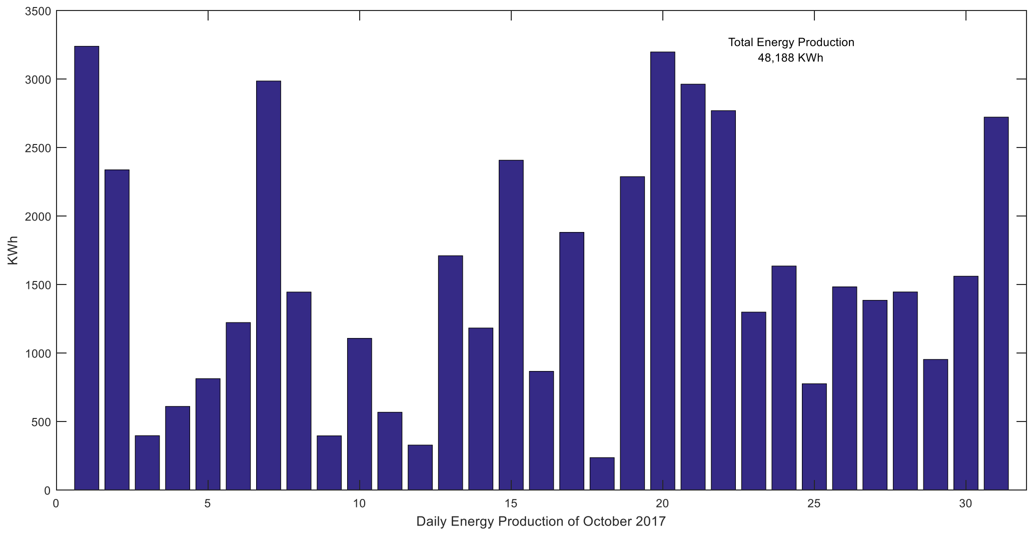

Fig. 6 Daily energy production of October 2018

system was installed in June 2018 and started to record data at the helm of July 2018. In Fig. 4, open data obtained from the system on October 2018 is given. The horizontal axis in the figure represents the number of data points recorded during the month. The common vertical axis shows voltage in Volt, current in Amper, radiation in Watt/meter^2, temperature in centigrade degree, humidity in percentage humidity with blue, red, orange, purple, green, respectively.

As seen in Fig. 4, voltage, current, radiation and temperature values rise in the daytime while humidity decreases. In order to see clearly behavior of the data in the day time, data recorded the hours between 6.30 am and 8.00 pm on 7th October 2018 is given in Fig 5.

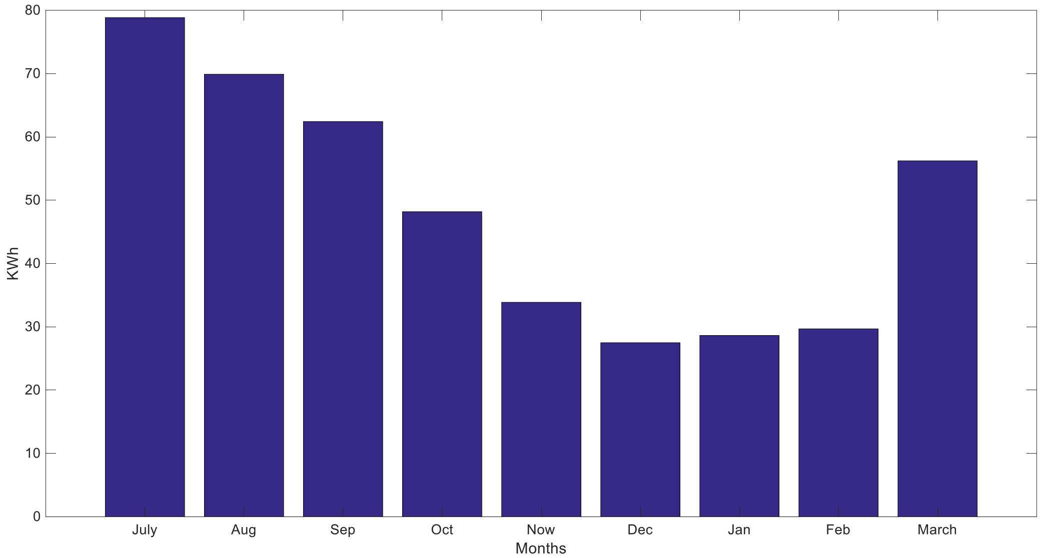

Fig. 7 Monthly energy production of the PV system from July 2018 to March 2019

In Fig. 6, Energy production of 1000W monocrystalline PV system for each day of October is given. The total energy production of the month is calculated as 48,188 KWh. The monthly energy production of the PV system from July 2018 to March 2019 is given In Fig. 7. In this period, 435,258 KWh electric energy was generated from the PV system.

6. Conclusions

In this study, the monitoring system installed for 1000w monocrystalline PV system constructed at Kocaeli University Uzunciftlik Nuh Cimento VHS was presented. The PV system, constructed 40° 45' 03.2"N-30° 03' 17.0"E, consists of five 200W monocrystalline PV modules, four series-connected 6V-180h traction batteries to store generated energy and three 100W LED projector to lighten garden of the school. The monitoring system was installed to monitor and record real values generated from the PV system and environmental data. So the energy efficiency of the region could report with real values. The monitoring system records data, voltage, and current generated by the PV system, global irradiance, temperature and humidity of the environment. Voltage, current, and irradiance data are obtained as analog while temperature and humidity are taken as digital. Analog and digital data collected with STM32F4 discovery card and sent via HC-05 Bluetooth module to a personal computer and recorded here in a text file. Additionally, a user interface on LabVIEW was prepared to monitor instantaneous data. Obtained data from the monitoring system is given in Figures. Instantaneous data belonging to October 2018 and 7^{th} October 2018 was presented in the study. Besides, daily energy production in October 2018 is given as an example. Total energy production in October 2018 is measured by 48,188 KWh. Finally, monthly energy production of the PV system from July 2018 to March 2019 is given in the figure. Total energy generation of the system at related period is 435,258 KWh.

It is planned to prepare a long term report about the energy efficiency of the region in consideration of obtained data from the monitoring system for future study. So, a source will be presented for individual and business financier whom they want to invest solar energy in the region.

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