Measurement and Evaluation of Solar Panel Data Via DC Power Line

Nihat DALDAL
Department of Electrical and Electronics Engineering, Faculty of Engineering
Bolu Abant Izzet Baysal University
Bolu, Türkiye
nihatdaldal@ibu.edu.tr

Berat UZUN
Department of Electrical and Electronics Engineering, Faculty of Engineering
Bolu Abant Izzet Baysal University
Bolu, Türkiye
uzunberat@gmail.com

Erdal BEKİROĞLU
Department of Electrical and Electronics Engineering, Faculty of Engineering
Bolu Abant Izzet Baysal University
Bolu, Türkiye
bekiroglu_e@ibu.edu.tr

***Abstract*—Today, it is important to monitor the data first of all in order to increase the efficiency of solar panels. In this study, parameters affecting the efficiency of photovoltaic panels , such as ambient temperature, panel temperature, humidity, light ratio, panel current, panel voltage were measured at certain time intervals. The data was then transferred to the computer via the PV panel (Power Line Communication, PLC) using the existing photovoltaic panel DC power line with the FSK modulator-demodulator, which was converted into a serial information package and designed, and the data was recorded. Here the panel data is collected entirely via its own energy cable without the use of any lines or wireless units. With Python-based software, graphs of panel parameters were created, the data obtained were analyzed and the factors affecting energy production were examined.**

Keywords—Powerline Communication; Photovoltaic Solar Panel; FSK Modulation and Demodulation; Frequency-shift keying (FSK)

1. INTRODUCTION

The development of technology and the continuous increase of the world's population means the need for energy. In today's world, the reduction of fossil fuels, which are the source of conventional energy makes clean and reliable energy more important [1]. Developed countries have aimed to develop energy policies in order to meet the emerging energy needs and to increase the share of clean energy in total energy production. Among renewable energies, especially solar and wind power plants have become the most popular and developed systems [2].

Nowadays, solar and wind energy, which is identified with the concept of nature-friendly green energy, is abundant and unlimited, and production facilities are continuously improving in efficiency [3]. Solar energy system technologies have made great progress especially in the last 20 years and production facilities have increased gradually [4-5].

The production of energy derived from factors such as solar and wind varies according to time. Solar panels need to be continuously monitored and managed for stable power generation. Communication over the Power Line (PLC) method is preferred in intelligent production systems due to the use of the existing power line and the low cost of hardware.

When the recent studies are examined;

Dubey et al. [6] investigated the effect of working temperature and photovoltaic modulus on the electrical performance of crystalline photovoltaic modules. In the system created by Napoli et al. [7], an innovative topology is provided which performs a power line communication (PLC) on the DC bus with serial connected photovoltaic modules.

Han et al. [8] proposes a user-friendly PV monitoring system based on low-cost power line communication (PLC). For cost reduction, the PLC module was developed without a communication modem. a transmitter is added to each panel. Measured current voltage and temperature values were transferred to receiver PLC system by ASK digital modulation. It was transferred from the main system to the mobile phone with the help of wireless. Duc Ma et al. [9] Digital Filter and Line Filter are designed as Detection filter using ASK based PLC system. It has created DC-PLC based monitoring system which shows voltage, current and temperature values. Eke et al [10] In this study, the effects of light spectrum on outdoor performance of photovoltaic modules were investigated. Soyer G. [11] In this study, the current, voltage, power and simultaneous radiation-temperature values produced by photovoltaic panels were recorded into SD Memory Card depending on time and their efficiency was examined according to these values.

When the studies have been examined, heat, current, voltage and light intensity of solar panels have been measured in general. In addition, in several studies that made measurements via the panel line, PLC modules were used as products and ASK modulation was used in communication.

In this study, ambient temperature, panel temperature, light intensity, panel current and voltage and ambient humidity value were measured and these values were sent over the existing panel energy cable. The system that communicates over the line has been realized with FSK modulator and demodulator design, and the communication circuit structure has been designed to be cheaper and more quality communication with FSK modulation. Then, graphs were plotted and interpreted to examine the effects of the obtained data on panel yield.

2. Power Line Communication (PLC)

Recently, the need for communication systems has increased the interest of research communities in so-called power line communication (PLC) systems. Power line communication (PLC) technologies use an existing infrastructure (power cables) as a communication medium and can also be an interesting low-cost solution for the M2M communications scenario. [11-13]. PLC systems communicate by transmitting the information signal over the power lines by means of a carrier signal through the modulation process [14]. Different modulation techniques have been designed to prevent noise and signal distortion. Modulation and demulation is performed by devices connected to the electricity grid [15]. In solar panels, receiving panel data over the existing power line will also prevent the use of extra communication cables or RF modules.

3. Structure of The Designed System

The structure of the designed and implemented system is shown in Figure 1. The current and voltage values of PV Panel, air temperature, panel temperature, humidity, light value are measured at certain time intervals and given to microcontroller inputs. The microcontroller receives the data from the serial communication (UART) module RX output to the FSK modulator circuit. The FSK Modulator sends the modulated information from the panel's existing DC power line through the coupling capacitor.

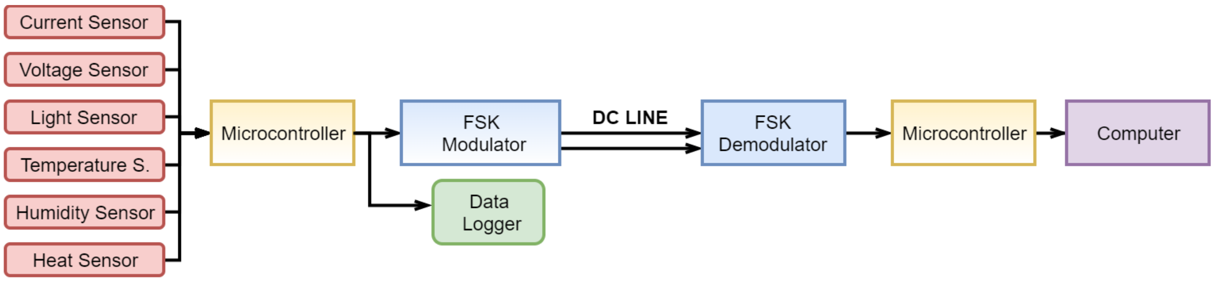


Figure 1. Measurement of PV data and transmission over the existing power line

The FSK Demodulator circuit located at the end of the DC line converts the signal received from the coupling capacitor into a baseband signal and sends it to the RX input of the serial communication (UART) of the microcontroller. The microcontroller transfers the recieved data to the computer via USB. The program, written in Python language on the computer, creates instant graphics by saving the received data. Figure 1 shows the block diagram of the study.

3.1. Measurement of sensor data via solar panel power line

The data on the Panel was measured with a microcontroller and applied to the designed FSK modulator circuit. The FSK modulator circuit produces 110kHZ for the value of logic 1, while the signal produces 90kHZ for the value of logic 0. The FSK signals produced were applied to the panel DC line through coupling.

3.2 Measurement and transmitter system structure

In the installed system, BH1750 (light sensor) and STH3X (temperature and humidity sensor) are connected to I2C communication protocol pins (SCL, SDA). The DTH11 (humidity and temperature sensor) is connected to pin Digital-7 of the microcontroller, ACS712 (current sensor) Analog-0 and MAX471 (voltage sensor) are connected to pin Analog-1. As shown in Figure 2, the sensor information from the TX port which is the output of the microcontroller UART module is superimposed on the DC line by the coupling capacitor by the FSK transmitter circuit.

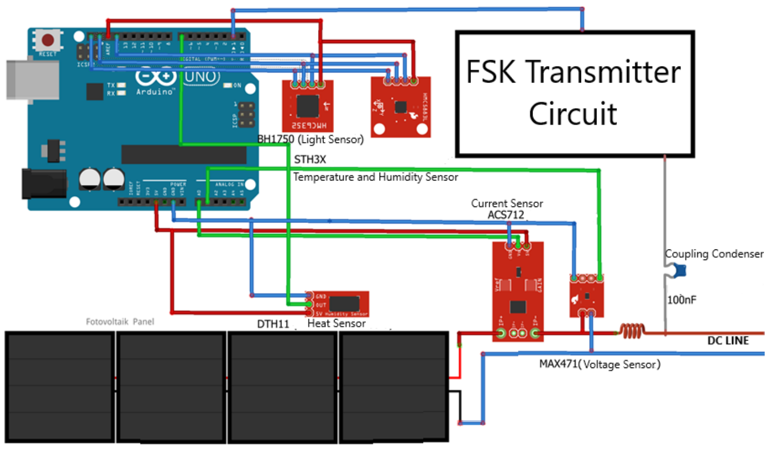


Figure 2. System Sensor Circuit.

A coil is placed on the line to prevent the high frequency signal from entering the source and microcontroller system . In addition, a 12V 7Ah battery is included in the system so that the power consumed by the microcontroller does not affect the characteristics to be measured. The connections of the sensor circuit are shown in Figure 3.

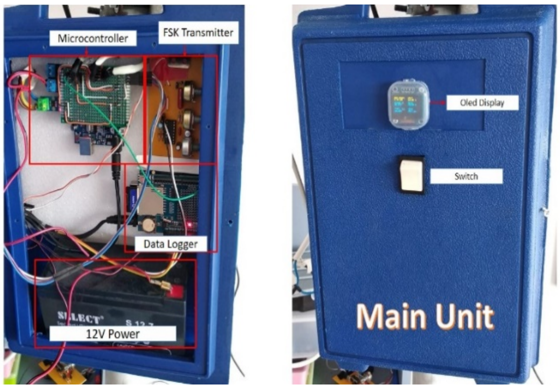


Figure 3. Internal and External View of the Transmitter Unit.

4. Receiver System Structure

In the designed system, the FSK signal received from the coupling capacitor before the load added to the end of the DC line was converted to digital information by the FSK Demodulator and given to the RX port of the UART module of the microcontroller. The data obtained were transferred to the computer via USB cable by serial communication port [9]. An SD-Card module has been added to record sensor and time information between 7-20 hours. 100w polycrystalline panel is connected to 5Ω rheostat as a load. Python coding language is selected for the software designed for the system. 6 different sensor information coming from the serial port is transferred to the computer as a single text. Figure 9 shows the block diagram of the software.

In addition, the Oled display has been added to the receiver circuit to see the information. A switch is included to shut down the system at any time. Figure 4 shows the internal structure and external appearance of the receiving system.

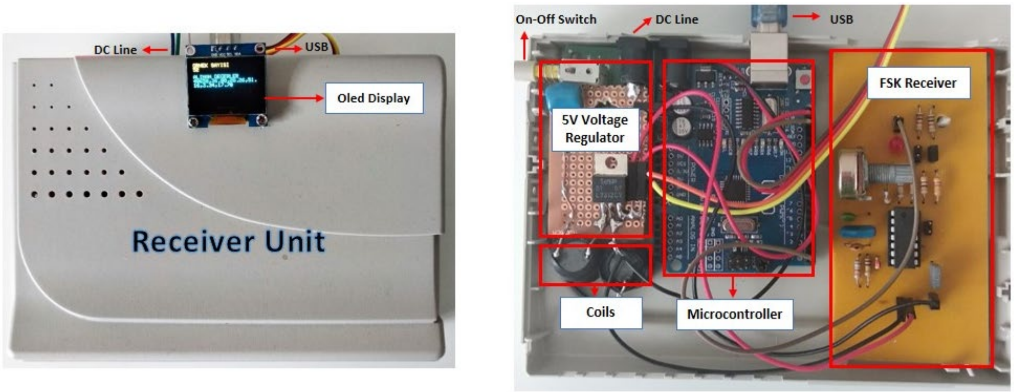
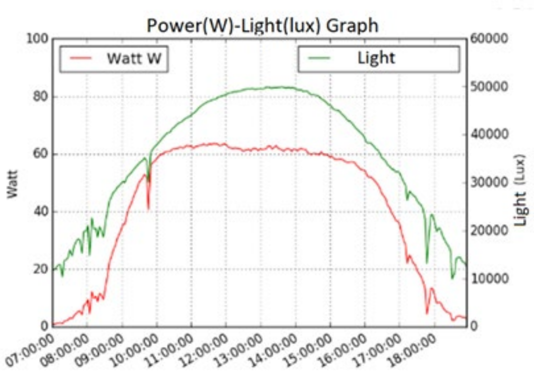
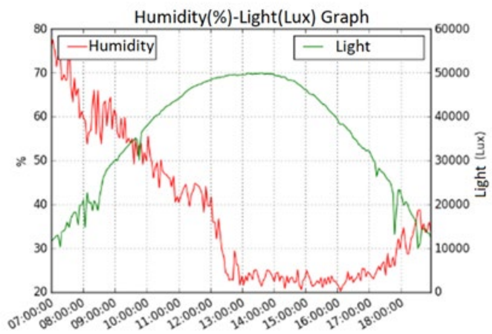


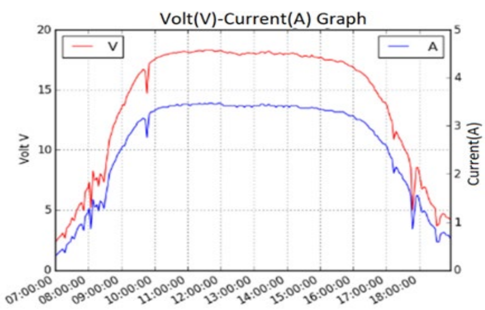
Figure 4. Internal Structure and Exterior View of the Receiver Circuit.

5. Graphs of Measured Sensor Data

Date of the day, time, light information (lux), panel temperature (°C), ambient temperature (°C), panel output voltage, output current value, ambient humudity are recorded respectively.







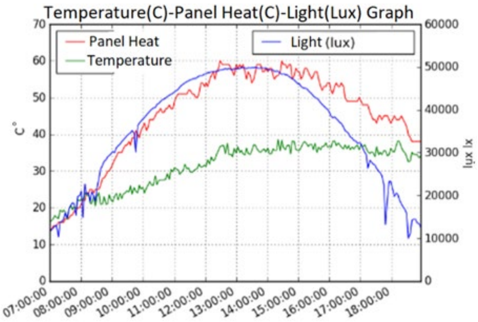


Figure 5. Graphs generated with sensor data

As shown in Figure 5 with the data obtained, the sensor value-time graphs are plotted and the process is continued as long as new information is received.

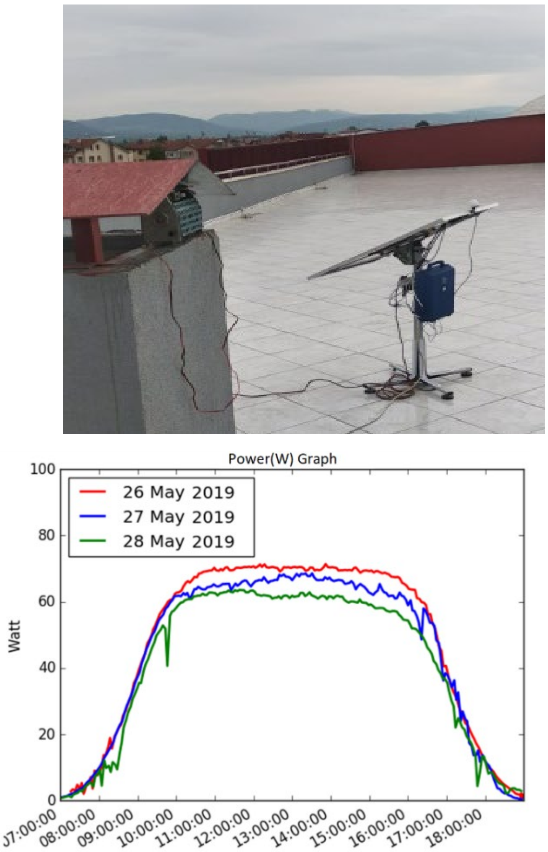


Figure 6. Designed monitoring system and 3-day power graph

Figure 6 shows the panel power values of 3 different days according to time

If the statistical connection between the chart variables is examined, the effects of the variables on the yield can be examined. For this, the correlation (R) between P (Probability; Probability) and variables should be examined. Correlation analysis is a statistical method used to test the linear relationship between two variables or the relationship of a variable with two or more variables, and to measure the degree of this relationship, if any.

Purpose in correlation analysis; when the argument changes, it is to see in which direction the dependent variable will change [16]. As a result of the correlation analysis, whether there is a linear relationship and the degree of this relationship, if any, is calculated by the correlation coefficient. The correlation coefficient is denoted by "R" and takes values between -1 and +1.

P value is a value used to determine the presence of statistical significance and the level of evidence of the difference, if any [17].

When the statistical analysis of the chart values is done, the R and P values of the variables are shown in Table 1. According to Table 1, the R correlation coefficient varies between -1 and 1. Considering the correlation coefficient values, the most effective parameters are panel voltage and light intensity since the P value between the output variable is 0. When the table is analyzed in general, it is concluded that all variables are important since the probability values of all variables are less than 0.05.

Table 1. Probability and correlation values of variables.

• **Variable**	• **P Value**	• **R value**
• PV Voltage	• 0	• 0,987241
• Light	• 0	• 0,969281
• Humudity	• 6,69E-44	• -0,51258
• Temperrature	• 7,83E-17	• 0,322237
• PV Temperature	• 2,28E-86	• 0,676727

6. Conclusion

In this study, a simple and inexpensive FSK transmitter-receiver system was proposed as a communication method over power line. Because the line is DC, the FSK signal is superimposed on the DC supply using capacitive coupling without exposure to noise. The coil is used to protect the supply voltage of the microcontroller and FSK circuit from the generated FSK frequency. Although there is 1 transmitter and 1 receiver in the current system, more PV panels can be monitored by increasing the number of transmitters. Thanks to the developed system, instead of using an extra line or RF wireless communication for monitoring of PV panel data, communication was realized over the DC power line of the panel. Figure 13 shows the monitoring system designed and the 3-day energy production graph.

When the panel temperature-power graph is analyzed, it is observed that although the light ratio remains the same, the panel temperature causes a decrease in the power ratio after 50 degrees. It is determined that the power generation between 09-17 hours is at the desired level under constant load. It was observed that the ambient moisture value decreased depending on the light intensity.

Thanks to the study, the efficiency of the panels in outdoor conditions was monitored over the existing DC power line and the power generation was examined. Monitoring of panel efficiency will increase performance in electricity generation.

In future studies, communication will be realized with different modulation types and measurements will be made over panel cable from further distances and will be compared with the current study. Using long term recorded data and ANN modeling, the effect of variables on yield will be examined with higher accuracy.

References

[1] Lasheen M. at all, "Adaptive reference voltage-based MPPT technique for PV applications," *IET Renew. Power Gener.*, vol. 11, no. 5, pp. 715–722, Apr. 2017, doi: 10.1049/iet-rpg.2016.0749.

[2] M. Marodkar, S. Adhau, M. Sabley, and P. Adhau, "Design and simulation of DC-DC converters for Photovoltaic system based on MATLAB," in *2015 International Conference on Industrial Instrumentation and Control, ICIC 2015*, Jul. 2015, pp. 1478–1483, doi: 10.1109/IIC.2015.7150983.

[3] Sofia Fanourakis, Kevin Wang, Patrick McCarthy, and Lihong (Heidi) Jiao, "Low-Cost Data Acquisition Systems for Photovoltaic System Monitoring and Usage Statistics," J.Energy Power Eng., vol. 11, no. 11, pp. 719–728, 2017, doi: 10.17265/1934-8975/2017.11.005.

[4] Pinto G.b, Plata G., "Measuring the effect of forced irrigation on the front surface of PV panels for warm tropical conditions" Energy Reports, vol. 5, pp. 501–519, 2019, doi: 10.1016/j.egyr.2019.04.010

[5] Soyer G. , "Fotovoltaik Panellerde Güneş Işınımı-Sıcaklık-Akım-Gerilim (gısag) Taşınabilir Veri Kayıt Sistemi Tasarımı ve Uygulaması", Yüksek Lisans Tezi, Marmara Üniversitesi Fen Bilimleri Enstitüsü, İstanbul, 2018

[6] Dubey S., Sarvaiya J.N, Seshadri B., "Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World – A Review", Energy Procedia ,Volume 33, Pages 311-321, 2013

[7] Napoli F, Guerriero P, d'Alessandro V, Daliento S. "A Power Line Communication on DC bus with photovoltaic Strings", 3rd Renewable Power Generation Conference , 24-25, Naples, Italy, Sept. 2014

[8] Han J, Lee I and Kim S (2015) "User-Friendly Monitoring System For Residential Pv System Based On Low-Cost Power Line Communication", Consumer Electronics IEEE Transactions on, vol. 61, 175-180.

[9] Ma Han S, Park M, Kim J. "DC-PLC Modem design for PV module monitoring", Journal of International Council on Electrical Engineering Volume 6- Issue 1, 2016.

[10] Eke R, Betts TR and Gottschalg R (2017) "Spectral Irradiance Effects on the Outdoor Performance of Photovoltaic Modules", Renewable and Sustainable Energy Reviews 69:429–434.

[11] Rabie K.M ."Power Line Communication Systems", Phd Thesis, Engineering and Physical Science, Manchester University, Manchester, 2015

[12] Lampe L, Tonello A.M, Swart T., " Power line communications: Principles, standards and applications from multimedia to smart grid, Second Edition, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom,2016

[13] Pereira S. at all., " Power line communication technology based on morphological filtering for machine-to-machine applications", Computers & Electrical Engineering, Vol. 93, July 2021 ,doi : 10.1016/j.compeleceng.2021.107254

[14] Yousuf M.S ve El-Shafei M., "Power Line Communications: An Overview-Part I", 4th International Conference on Innovations in Information Technology, pp. 218–222, 18-20 , Dubai, Dubai, Nov 2007

[15] Bal G ve Daldal N. "Enerji Hatları Üzerinden Mesaj Gönderme Sisteminin Tasarımı ve Gerçekleştirilmesi", Gazi Ün.. Müh. Mim. Fak. Dergisi, Cilt 29, No 2:415-424, 2014

[16] Rosner B. Fundamentals of Biostatistics, 7th edition. , Brooks/Cole. 2010.

[17] Dawson B, Trapp RG. Basic & Clinical Biostatistics (LANGE Basic Science),McGraw-Hill Medical. 2004.