REMOTE MONITORING OF ENERGY PRODUCTION AND EFFICIENCY OF AN OFF-GRIDD PHOTOVOLTAIC SYSTEM
/
MONITORIZAREA DE LA DISTANTA A PRODUCTIEI DE ENERGIE SI A EFICIENTEI UNUI SISTEM FOTOVOLTAIC OFF-GRIDD

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ABSTRACT

In remote locations where people are required to live, such as weather stations in mountain areas, astronomical observatories etc., it is necessary to provide electricity for the operation of equipment and for domestic needs. The optimal solution is the use of photovoltaic energy. Owners of solar systems can remotely monitor the operation of the photovoltaic plant via the Internet (LTE, LoRa). The operating parameters of the solar installation can be seen in real time or can be adjusted. The article presents theoretical aspects, the hardware structure of monitoring equipment and remote monitoring software, which allow the analysis of the production and efficiency of the photovoltaic (PV) installation.

REZUMAT

În locațiile îndepărtate în care oamenii trebuie să locuiască, cum ar fi stațiile meteo din zonele montane, observatoarele astronomice etc., este necesar să se furnizeze energie electrică pentru funcționarea echipamentelor și pentru nevoile casnice Soluția optimă este utilizarea energiei fotovoltaice. Proprietarii de sisteme solare pot monitoriza de la distanță funcționarea centralei fotovoltaice prin Internet (LTE, LoRa). Parametrii de funcționare ai instalației solare pot fi vizualizați în timp real sau pot fi reglați. Articolul prezintă aspecte teoretice, legate de structura hardware a echipamentelor de monitorizare și software-ul de monitorizare la distanță, care permit analiza producției și a eficienței instalației fotovoltaice.

INTRODUCTION

Monitoring of the photovoltaic systems is useful for maintenance or for improving the performances of energy production. In order to be able to monitor the operation of the solar system, the equipment (e.g. solar charger, inverter) must be provided with communication interfaces. By means of additional hardware equipment and software applications, remote monitoring can be performed directly through the local network or through the Internet (LTE, LoRa). In other papers that addressed the monitoring of PV systems, the authors used wireless systems (Andreoni et al., 2012) or data acquisition system (DAS) (Meyer et al., 2020) for remote monitoring and control for microgrid applications. In the first mentioned work, the authors present a flexible, robust and reliable measurement and control system based on wireless sensor network (WSN) architecture. The wireless communication technology utilizes a full duplex digital system using the ZigBee protocol, based on the IEEE 802.15.4 standard for Wireless Personal Area Network (WPAN). In the second paper, the authors present a data acquisition system (DAS) for monitoring electrical and meteorological parameters for a microgrid system composed of three PV systems. Electrical and meteorological data are automatically recorded using two data loggers, and the data is periodically downloaded via Wi-Fi to a personal computer for analysis.

In this article, the authors present the hardware structure of a monitoring equipment and a virtual instrument developed for monitoring a PV system from a remote location. The photovoltaic system is located on a mooring pontoon in the Danube Delta. For the purpose of remote monitoring, the equipment is connected to the internet via a Venus GX unit from Victron Energy. At the location of the pontoon, the internet was provided with an LTE router.

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MATERIALS AND METHODS

Photovoltaic system

In Romania there are favourable conditions for the production of solar energy, the potential being on average 1500 kWh /m^2/an. *(***)*

A solar installation installed by the authors on a mooring pontoon (Fig. 1) in an isolated area of the Danube Delta is equipped with a remote monitoring system of operating parameters. Through the monitoring system, the operating parameters of the PV system can be seen or the system parameters can be changed.

The parameters of the PV installation are: solar power, solar voltage and current, voltage, current and battery temperature. The system parameters can be: AC input current limit, battery monitor, DC input low shut-down, DC input pre-alarm, shut-down on SOC (state of charge) limit, absorption voltage, float voltage, charge current, ESS (energy storage system) grid set point and others. The area of photovoltaic panels is dimensioned, by the amount of electrical energy to be supplied by photovoltaic panels in one day so that to supply electrical loads in the amount of 1.1 kW. 1.1 kW ·24 h = 26.4 kWh.

In order to achieve a 27 kWh average production capacity in any season during a calendar year, 30 photovoltaic panels of 265 W are needed. The electricity produced during the day is stored in 12 batteries with the following characteristics: voltage U = 12 V, capacity C = 220 Ah. The energy stored by them is E = U [V]· C [Ah] · 12 = 12 V · 220 Ah · 12 = 31680 Wh. To prolong the battery life to 1000 discharge cycles specific to gel batteries, the battery state of charge must be maintained at 60%. Then, the available battery energy is E_b = 31.68 kWh · 40% = 12.67 kWh, which can ensure consumption for about 12 hours without sun. For batteries charging, a charger model SmartSolar 250/100 produced by Victron Energy is used, and for energy management and for DC/AC conversion (inverter), a Quattro 48/8000 unit also from Victron Energy is used.

Fig. 1 - Solar installation located on a mooring pontoon in the Danube Delta

For the purpose of remote monitoring, the pieces of equipment are connected to the internet via a Venus GX unit. At the site of the pontoon, the internet was provided with an LTE router.

Theoretical aspects

The current – voltage curves of a PV module describes the ability to convert energy under given conditions of irradiance and temperature. A PV cell is a p-n junction with features similar to a diode *(*)*. When the cell is illuminated, photons excite electrons in it and a current is generated. This is known as the photovoltaic effect. The current of a PV cell can be modeled:

$$I = I_0 \left[exp\left(\frac{qV}{nkT}\right) - 1\right] - I_L \tag{1}$$

The parameters used to characterize the output of solar cells are the short circuit current (I_{sc}) - current with zero voltage and the open circuit voltage (V_{oc}) - maximum voltage with zero current *(Mori et al., 2020)*. This value increases logarithmically with increased sunlight. At $I = 0$:

$$V_{OC} = \frac{nkT}{q} \ln\left(\frac{I_L}{I_0} + 1\right) \tag{2}$$

The current – voltage curve is characterized by the following parameters *(Moulin et al., 2019; *****)*:

- Maximum power point (MPP) - designated as the rated power of a photovoltaic cell, is the point on the current-voltage curve at which it operates at maximum power. For MPP, both the rated current (I_{MPP}) and the rated voltage (V_{MPP}) are specified.

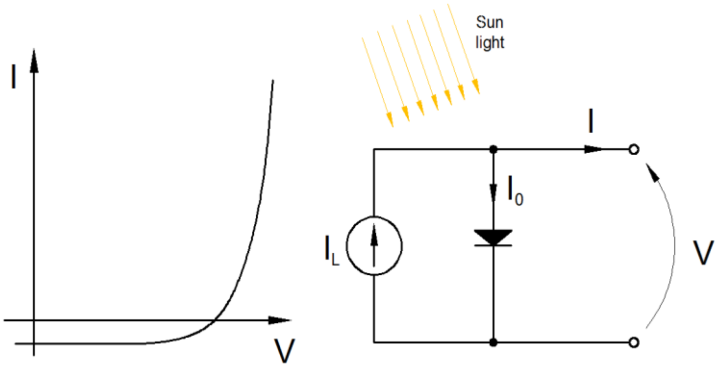


Fig. 2 - Current – voltage characteristics of a p-n junction subject to illumination

- The short-circuit current (I_{SC}), which varies depending on the technology used to build the cell. An important feature of the short-circuit current of the cell is that it is linearly dependent on irradiance.

- Open Circuit Voltage (V_{OC}) - represents the voltage at the terminals of the cell when it has no load. V_{OC} is also dependent on the material from which the cell is made.

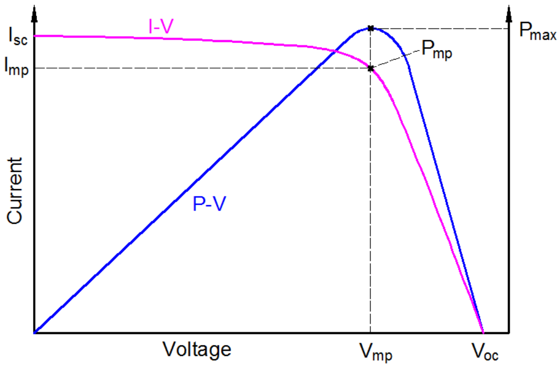


Fig. 3 - The current – voltage and P – V curves of a photovoltaic cell

The solar irradiance incident to a solar panel is the most important factor in amount of power a solar cell can generate. The amount of irradiation affects the short-circuit current drastically, while the open-circuit voltage remains almost unchanged. The maximum power point MPP tracks very closely with the irradiance incident to the solar cell and it is proportional to the irradiance *(****)*.

The fill factor FF is a qualitative size used to characterize solar cells. Assuming an ideal I-V curve, rectangular in shape, in which the point of maximum power is obtained by multiplying the values of the short-circuit current and the open-circuit voltage, the filling factor represents the deviation of the real characteristic from the ideal one. From a geometric point of view, the filling factor represents the ratio between the surfaces formed by the two characteristics in the system of orthogonal axes. The value for fill factor FF has the following calculation formula:

$$FF = \frac{P_{MPP}}{V_{OC} \cdot I_{SC}} = \frac{\eta \cdot A_C \cdot E}{V_{OC} \cdot I_{SC}} \tag{3}$$

Solar Cells Efficiency

The conversion efficiency of photovoltaic cells represents their electricity flow in relation to the energy absorbed by the incident solar radiation *(Mehmet and Furkan, 2011; Cristescu et al., 2017; Meyer et al., 2020)*. This is calculated by dividing the peak electric power of the cell expressed in W by the power density of the incident radiation when the maximum power is reached expressed in W/m^2 and at the cell surface expressed in m^2:

$$\eta = \frac{P_{MPP}}{A_C \cdot E} \tag{4}$$

In the production of photovoltaic cells, given the dependence of their electrical characteristics on temperature and radiation spectrum, the conversion efficiency is determined according to standardized test conditions STC - Standard Test Conditions *(**)*. These assume a temperature of 25°C with a tolerance of ±

2°C, the incident irradiance of 1000W/m^2 and the spectral distribution of the radiation corresponding to an air mass index AM 1.5. The STC’s correspond to a clear day in which the Sun has an elevation angle of 41.81° and the cell is oriented towards it, at an angle of 37°.

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$P_{MPP} = V_{OC} \cdot I_{SC} \cdot FF \tag{5}$$

where: V_{OC} is the open circuit voltage;

I_{sc} is the short circuit voltage;

FF is the fill factor

$$\eta = \frac{V_{OC} \cdot I_{SC} \cdot FF}{P_{in}} \tag{6}$$

The power of incident solar radiation can be measured using a light sensor placed locally or from a nearby weather station. (Fig. 4).

The efficiency of a photovoltaic installation can be determined in real time with a software algorithm that takes into account the surface of the photovoltaic installation, rated power of solar panels and the locally measured temperature and sun luminosity *(Attari et al., 2016; Filippo et al., 2013; Nanjannavar, 2013; Suresh et al. 2014).*

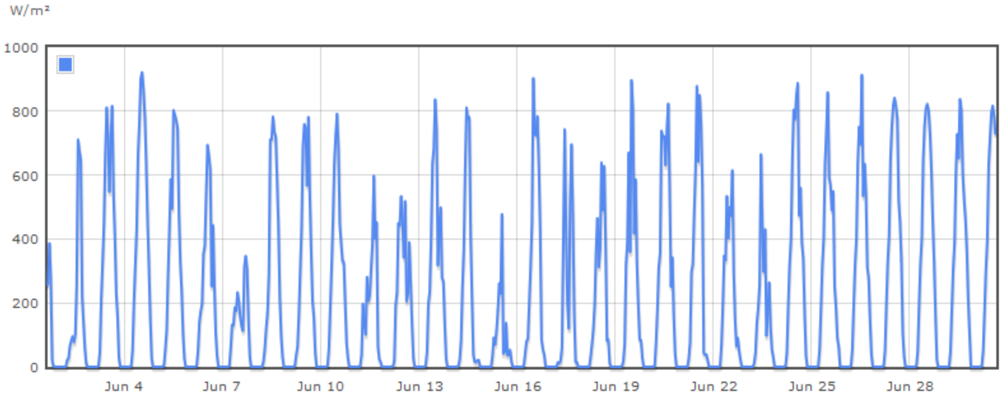


Fig. 4 - Records of the solar power peak for June 2020 at PV plant location (aprs.fi/weather Luminosity)

PV system monitoring

High-performance equipment for solar installations such as solar chargers or inverters have Serial, Ethernet, CAN or Modbus communication ports. These devices can be connected to the internet through gateways. Some companies producing equipment for solar photovoltaic systems also provide modules for transmitting operating parameters via the Internet. The equipment of the solar installation transmits data in real time by means of these communication devices, thus being able to monitor the state of charge of the batteries, the voltage and the current delivered by the solar panels, the temperature of the batteries and the state of operation of the inverter *(Andreoni et al., 2012)*. Through a console, the operating parameters of the solar system can be changed or one can upload configuration files.

Individual equipment equipped with a communication port can also be connected to the internet. Thus, an MPPT solar charger from Victron Energy (Fig. 5) can be connected to the Internet via a gateway module. In Figure 6 it can be seen the realization of a communication module for a solar charger. Serial data from the pins of VE.Direct port of the charger are converted to RS232 and connected to an RS232-Ethernet gateway module, model WIZ110SR from Wiznet.

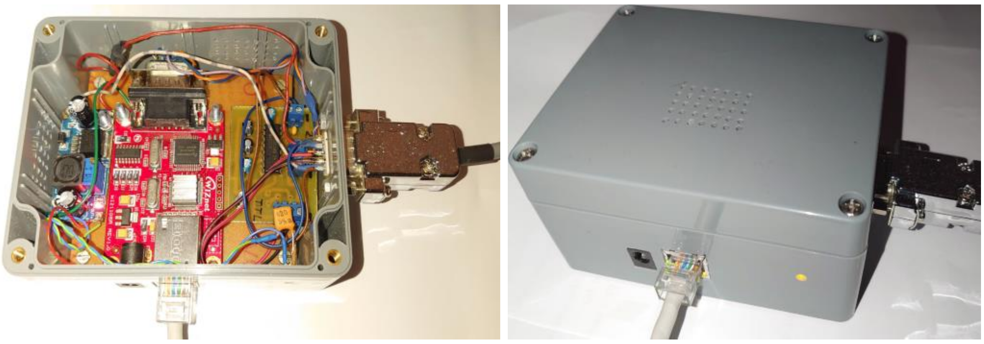
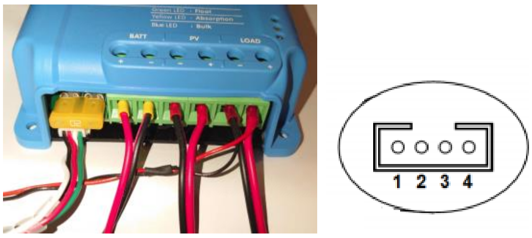


Fig. 5 - TCP/IP gateway module for solar charger



Pin	Function
1	GND
2	VE.Direct-TX
3	VE.Direct-RX
4	Power +

Fig. 6 - VE. Direct serial port on Victron solar charger

The gateway module connects to the internet via a router (Fig. 7) which is configured with port forwarding. The gateway module is configured as TCP server mode, has an IP configured, an ethernet communication port and the COM port through which the communication with the solar charger is made.

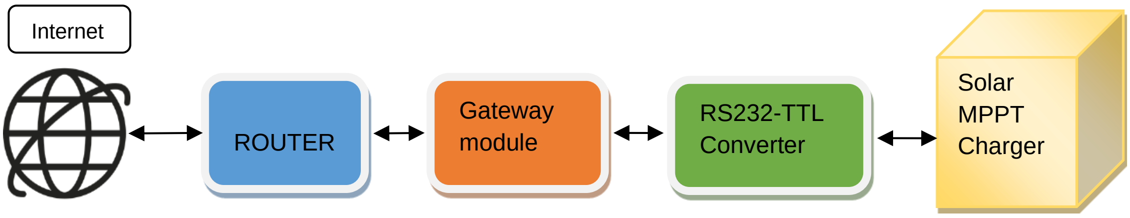
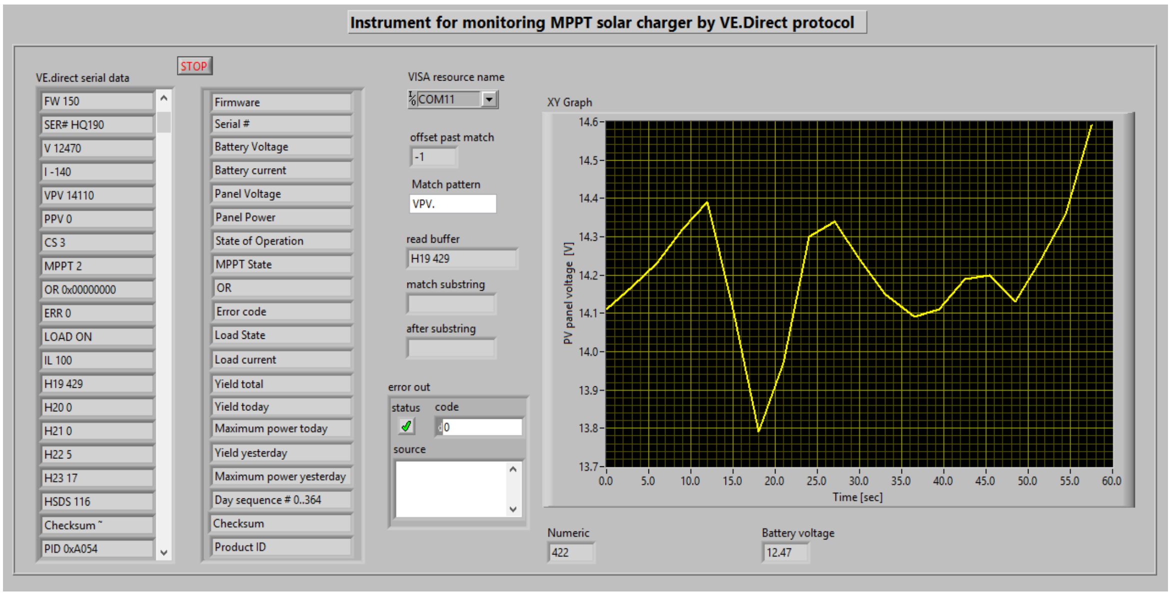


Fig. 7 - The way to connect the solar charger to the internet

The authors have developed a software tool in the LabView environment with which the parameters provided by the solar charger by serial port (Fig. 8) can be monitored, via the Internet. It has an interface through which the header of the monitored values can be set. Values with the correct pattern are represented graphically. For example, the "VPV" parameter which is the voltage from the solar panel has the value transmitted serially: 14110 (mV).


Instrument for monitoring MPPT solar charger by VE.Direct protocol

VE.direct serial data	
FW 150	Firmware
SER# HQ190	Serial #
V 12470	Battery Voltage
I -140	Battery current
VPV 14110	Panel Voltage
PPV 0	Panel Power
CS 3	State of Operation
MPPT 2	MPPT State
OR 0x00000000	OR
ERR 0	Error code
LOAD ON	Load State
IL 100	Load current
H19 429	Yield total
H20 0	Yield today
H21 0	Maximum power today
H22 5	Yield yesterday
H23 17	Maximum power yesterday
HSDS 116	Day sequence # 0..364
Checksum ˜	Checksum
PID 0xA054	Product ID

VISA resource name: COM11
offset past match: -1
Match pattern: VPV.
read buffer: H19 429
match substring:
after substring:
error out: status ✓ code 0
source:
Numeric: 422
Battery voltage: 12.47

Fig. 8 - Software tool for monitoring the solar charger

Solar installations connected to the Internet through a monitoring system equipped with Modbus TCP service can be monitored using software applications that read the values of the registers from remote units ID's. A GX monitoring system from Victron Energy has the unit ID and services in Table 1.

Table 1

Modbus TCP services	
com.victronenergy.hub4 com.victronenergy.hub4	Unit ID: 100
BlueSolar Charger MPPT com.victronenergy.solarcharger	Unit ID: 239
com.victronenergy.system com.victronenergy.system	Unit ID: 100
MultiPlus Com.victronenergy.vebus	Unit ID: 246

By unit ID 246, VE.Bus state (0=Off; 1=Low Power; 2=Fault; 3=Bulk; 4=Absorption; 5=Float; 6=Storage; 7=Equalize; 8=Passthru; 9=Inverting; 10=Power assist; 11=Power supply; 252=Bulk protection) and battery temperature can be monitored. By unit ID 239, MPPT charger status, PV voltage; PV power and PV current can be monitored. By Unit ID 100, battery voltage, battery current, battery power and SOC – state of charge can be monitored *(Sivagami and Jothiswaroopan, 2020; Vargas et al., 2019)*.

An application for the complete monitoring of the photovoltaic system was also developed, in the LabView environment which monitor the PV system via Modbus TCP. The virtual instrument has the block diagram in Figure 9 and the front panel from Figure 10. In the application window the user can select the parameters that can be displayed on the graph and the recorded data can be saved in files.

The block diagram of the instrument for monitoring the photovoltaic installation uses a TCP master function through which unit IDs of the PV system are accessed, and on the basis of the registers the operating parameters of the photovoltaic system for electricity production are read. The data read from the devices are processed and displayed on the dials and on the graph. The curves displayed on the graph can be selected by means of a selection block made with the "case structure" function.

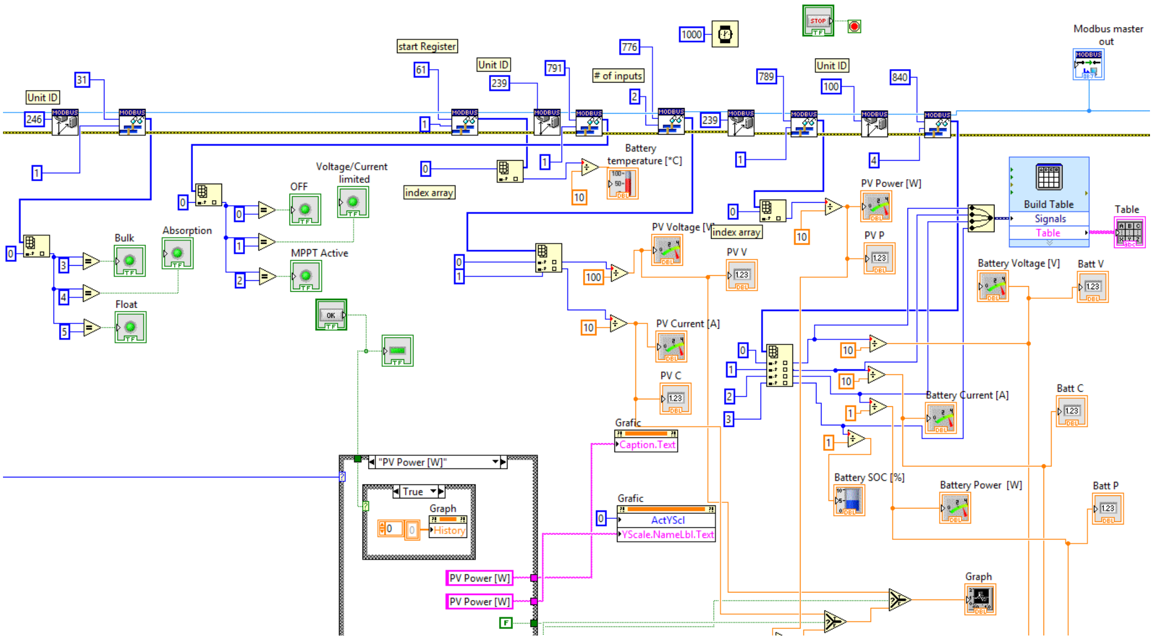
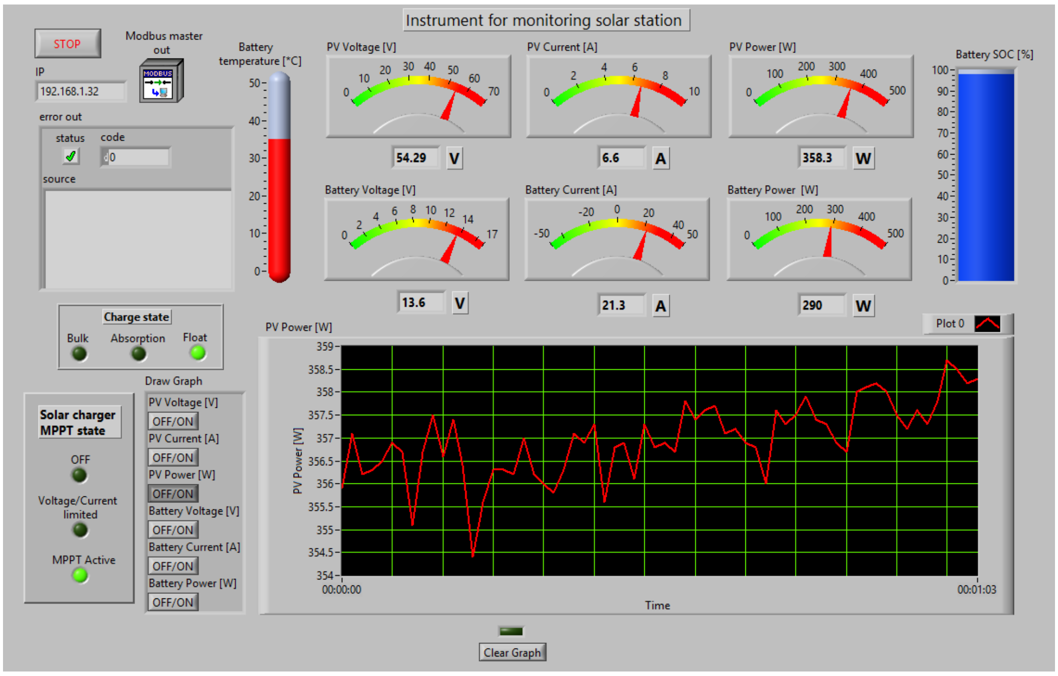


Fig. 9 - Block diagram of the instrument for monitoring PV installation made in LabView



IP 192.168.1.32
status ✓ code 0
PV Voltage [V] 54.29 V
PV Current [A] 6.6 A
PV Power [W] 358.3 W
Battery Voltage [V] 13.6 V
Battery Current [A] 21.3 A
Battery Power [W] 290 W

Fig. 10 - Front panel of the virtual instrument for monitoring PV installation

The block diagram of the instrument for monitoring the photovoltaic installation uses a TCP master function through which unit IDs of the PV system are accessed, and on the basis of the registers the operating parameters of the photovoltaic system for electricity production are read. The data read from the devices are processed and displayed on the dials and on the graph. The curves displayed on the graph can be selected by means of a selection block made with the "case structure" function.

RESULTS

The following is the data recorded for June 2020 by monitoring the remote PV plant. Figure 11 shows the curves drawn for the production of solar energy and PV power. The graph shows that in the middle of the month, productions of 10 kWh were obtained.

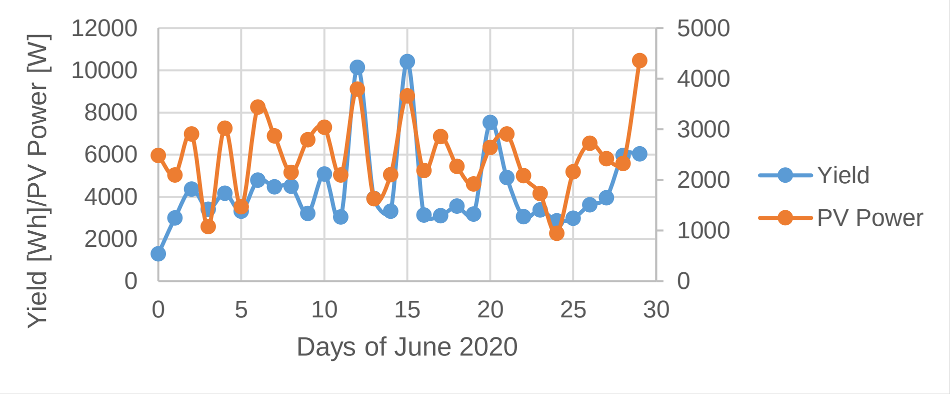


Fig. 11 - Solar Yield / PV Power

Figure 12 shows the voltage variation provided by the solar panels for June 2020.

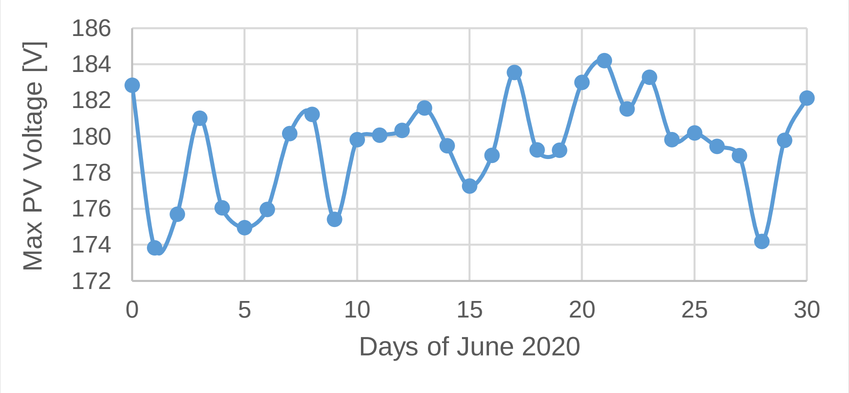


Fig. 12 - Maximum PV Voltage

The variation curve of the maximum battery voltage can be found in figure 13. It can be seen that once in 7 days the battery charging system raises the voltage to ~ 14.5 V when the batteries enter Cycle service with absorption mode.

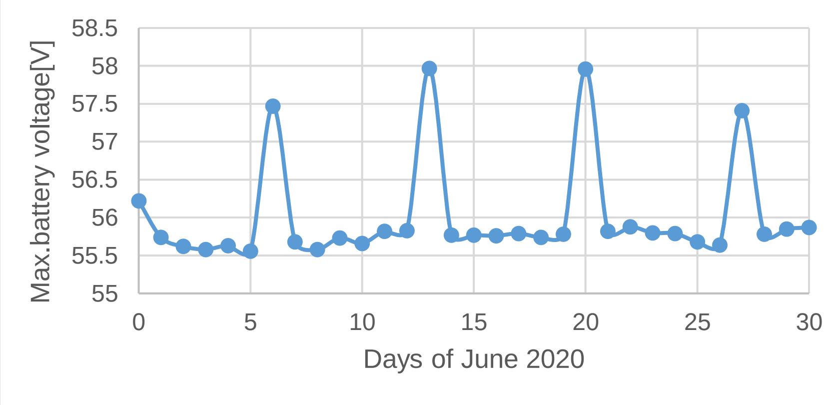


Fig. 13 - Maximum battery voltage

Figure 14 shows the variation of the battery temperature for June 2020. The temperature of the batteries oscillates by a few degrees between night and day when the batteries are charged. It is found that the temperature of the batteries has an increasing trend towards the end of the month with the warming of the weather.

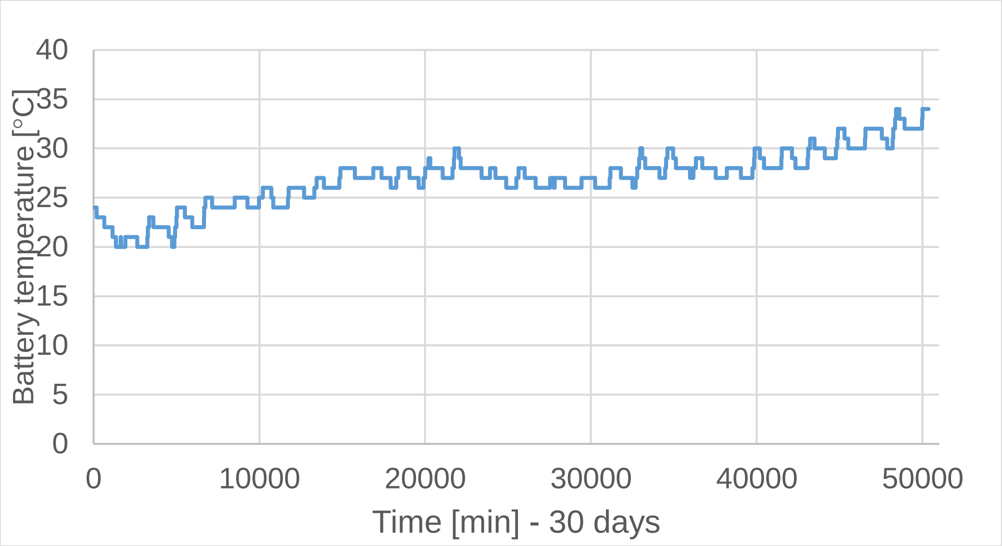


Fig. 14 - Battery temperature variation

In Figure 15 is a diagram with battery voltage, PV current and PV power made with data for a period of 24 days, data that were downloaded from the VRM portal of Victron Energy.

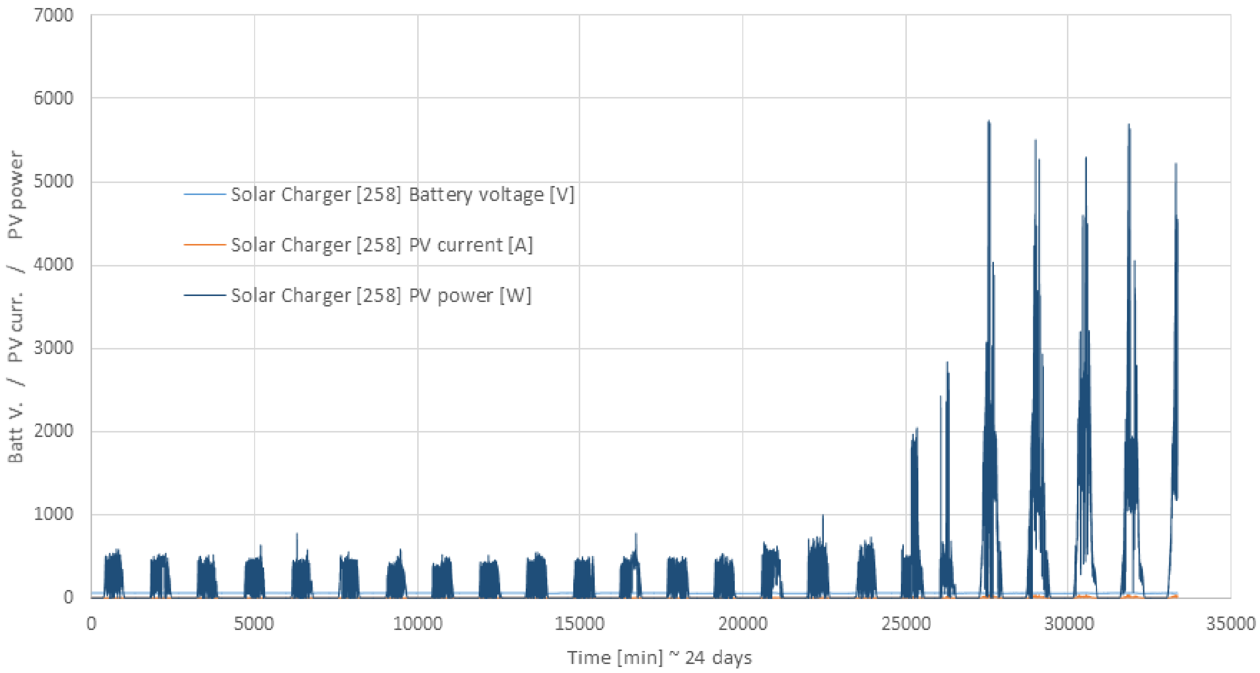


Fig. 15 - Battery voltage, PV current and PV power for 24 days

CONCLUSIONS

In order to be able to optimize the energy production of a photovoltaic installation, it is necessary to monitor the operating parameters. If the installation is located in a remote area and is not serviced by personnel with technical knowledge, monitoring can be done remotely.

By transmitting the operation data of the solar installation to a cloud server, the operation history of the PV installation can be kept.

By remote monitoring, some measures to improve the performances of the installation can be taken. For example, if there is a deterioration in energy production, this may be due to the dirt covering the solar panels and measures may be taken to clean the panels.

By connecting the equipment of the photovoltaic installation to the internet, some operating parameters can be changed remotely and alarms can be received in case of abnormal operation.

With the help of a software instrument, the operation of a photovoltaic plant placed in a remote location can be watched live.

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