The generation from photovoltaic plants are becoming more and more important part of the renewable energy sources, due to their advantages of environmental impact, low maintenance cost, quiet energy generation etc. Production of energy from photovoltaic plants is of great interest today because of the reduced classical energy sources. Naturally, the use of this renewable energy is at high cost, which demands the working conditional of photovoltaic plant at high performance level. Today the photovoltaic plants are connected to a different host of various loads. A photovoltaic plant can produce electricity at any point of the volt-ampere characteristic of the module, points that can be appointed as the working point of the photovoltaic plant. The coordinates of this point are voltage and current of working photovoltaic plant. A single point located at the knee of the VI characteristic curve is considered as the maximum power point (MPP), points on which module works with the maximum efficiency and power generation. Building V-I and P-V characteristics in experimental way helps us in determining the point on which the installation works closer to maximum power point. Maintenance cost can be reduced by periodic V-I characterization of the photovoltaic plans when preventive intervention are requested.

The model of a FV Cell

The main element of a FV plant is the photovoltaic cell. A photovoltaic plant that is subject to a uniform solar radiation, displays a characteristic voltage-current with a maximum power point (MPP) in which the plant produces the maximum power at output. This maximum power is dependent on the changing of solar radiation as well as on the temperature of photovoltaic panels.

A simple circuit that represents the photovoltaic cell is shown in Figure 1, where the equivalent circuit consists of a source stream that represents the current generated by the cell, a diode that represents the behavior of FV in dark conditions, a series Rs resistance that represents the parasitic resistance of the cell and which includes the resistance of two constituent layers of the cell as well as the resistance of the contacts, the shunt resistance Rsh, as a representing of all losses verified inside the cell, as an affect of the parasitic currents.

Based on circuit shown in Figure 1 and by applying Kirchoff’s laws we can determine the voltage-ampere dependency of the photovoltaic cell and write the following equation

\[ I = I_L - I_D - I_{Rsh}, \]

When \( I_L \) - is current generated by solar illumination The current that will pass through
the cell we declare as \( I_d \) while its analytical expression is declared as in (2)

\[
I_d = I_o \left( \frac{qV}{kNKT} - 1 \right), \tag{2}
\]

Where \( q \) - is the electron charge; \( I_o \) - the saturated current; \( N \) - coefficient without dimension, \( K \) - the Boltzmann constant and \( T \) the temperature in Kelvin.

As a result the characteristic equation of the illuminated cell takes the following form

\[
I = I_L - I_d - I_{Rsh} = I_L - I_o \left( e^{\frac{q(V-I \cdot R_s)}{kNKT}} - 1 \right) - \frac{V + I \cdot R_s}{R_{sh}}, \tag{3}
\]

Where \( R_s \) series resistance; \( R_{sh} \) shunt resistance; \( I_o \) - the saturated current; \( N \) - coefficient without dimension, \( K \) - the Boltzmann constant and \( T \) the temperature in Kelvin.

**Photovoltaic module V-I and P-V characterization**

Determination of the V-I characteristic of FV for a photovoltaic panel, of silicon multicrystalline type, for various conditions of natural or artificial radiation source, require artificial radiation sources, variable load resistance as well as a measuring system and data storage. Nowadays due to the lack of an artificial light source at our laboratory, VI characteristics are extracted based on solar radiation conditions. In order to get all the characteristic and to determine its extreme points, a group of resistances of \( 2 \times 7.5 \) Ohm and \( 130 \) Ohm are set in.

The system designed for the characterization of a FV module that enables the measurement and extraction of V-I characteristic is shown in Figure 3 and 4. Two HP Agilent voltmeters, HP34401 A and HP 34410A, are connected to the personal computer via GPIB interfaces working as system controller. An MatLab script is prepared in order to run in cyclic loop measurement of the V-I parameters tension and current, through the shunt resistance, for each value of the load manually changed. The Instrumentation Control Toolkit of MatLab Software is used for the controlling of the data and commands flow between the instrument and the controller. Temperature and solar radiation is measured by thermocouple of type K and meteorological station, respectively.

Figure 5.a shows two different sets of measurement of the V-I characteristics respectively in constant and non constant solar radiations that shows for high currents the downward slope is different from the characteristics compared with the characteristic of Figure 5.b that shows a more normal downward slope. This change is due to the changes in radiation during the process of extracting of the feature, which reinforces the need of their extraction through the use of an artificial radiation source in order to get the family of the features of FV module for different radiation conditions. Figure 6, shows the P-V characteristics of the photovoltaic panel.
calculated based on the values of V and I measured directly by the system.

From the build of these features we can extract a number of performance parameters of FV panel such as: short circuit current $I_{sc}$, the voltage of open circuit $V_{oc}$, the current and voltage of the maximum power point $V_{mp}$ and $I_{mp}$, the filling factor FF that determines the quality of the photovoltaic module, and the performance $\eta$ of the work of FV module based on the definitions of the standard of the S SH EN 61829:2005 family.

Conclusion

Most of the factors affecting the degradation of FV modules directly affect the V-I feature of the V-I characteristic of panel, therefore a continuous monitoring of this feature allows us to identify any likely performance degradation of FV module. Analysis of data obtained allows us to understand the mechanism of degradation, as well as the method and the time to preventive intervene in the correction and maintenance of FV plants.

In addition, this system gives us the opportunity to automatically collect data for a long period of time, with minimum need for human intervention, used in the future in additional research on FV modules.

The process of combining the automated extraction of V-I and V-P features with the theoretical simulations in Matlab, provides additional opportunities for the students to acquire better knowledge in the field of FV plants.
Appendix

**Figure 1. The model of a FV cell**

![The model of a FV cell](image1)

**Figure 2. V-I and V-P of PV cell**

![V-I and V-P of PV cell](image2)
FIGURE 3. HARDWARE USED FOR THE PV CHARACTERIZATION

FIGURE 4. HARDWARE USED FOR THE PV CHARACTERIZATION
FIGURE 5. V-I OF FV MODULE

a) in the case when the solar radiation varies

b) In the case when the solar radiation remains almost unchanged

FIGURE 6. P-V characteristic of the PV module