Sanal Fotovoltaik Panel Karakteristiklerine Uygulanan LabVIEW-tabanlı İzleme Sistemi[1]

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Özet
Fotovoltaik güç santrallerinde izleme sistemi, tüm sistem arayüzünü gerçekleştirmek için çok önemlidir ve sorun giderme işlemlerinin gerçek zamanlı olması gerektiğinden bazı durumlarda analiz için kritik öneme sahiptir. Bu makale, mühendislik laboratuvarlarında sanal eğitim platformu olarak yeni bir teknik olarak fotovoltaik panel karakteristikleri için bir sanal cihaz önermektedir. Önerilen sistem, analiz ve veri işleme uygulamalarında yüksek performansa sahip NI-LabVIEW ortamına dayalıdır. Benzetim işleminin istenen eğitim analitiğine uygun olarak sanal eğitim platformu ile gerçekleştirilmesi için alt sanal cihazlar yoluyla tüm veriler LabVIEW arayüzüne girilmiştir. Önerilen çalışma, LabVIEW ile projeye yönelik mühendislik eğitimini desteklemek için dijital becerilere dayanan temel kavramları kullanarak fotovoltaik panel karakteristiklerinin eksiksiz şekilde anlaşılmasına yönelik bir tasarımdır.

Anahtar Kelimeler: Fotovoltaik, LabVIEW, MPPT, Sanal Eğitim, Mühendislik Laboratuvarları

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LabVIEW Based Monitoring System Applied for Virtual Photovoltaic Modules Characteristics

Abstract
The monitoring system in photovoltaic (PV) power plants is very important to interface the whole system and critical in some cases for analyzing since it has to be in real-time for troubleshooting responses. This paper proposes a virtual instrumentation for photovoltaic module characteristics to provide a new technique in engineering laboratories as a virtual learning environment platform. The proposed system is based on the NI-LabVIEW environment which has high performance in analysis and data acquisition applications. All data are presented in LabVIEW's interface which is provided via sub virtual instruments to implement the simulation process according to the requested educational analytics via virtual learning environment platforms. The proposed design presents a solid understanding of photovoltaic modules characteristics using the basic concepts depending on digital skills in order to support the project-oriented engineering education by LabVIEW.

Keywords: Photovoltaic, LabVIEW, MPPT, Virtual Learning, Engineering Laboratories

INTRODUCTION

Photovoltaics is the process of converting sunlight directly into electricity using solar cells. Though expensive to implement, solar energy offers a clean, renewable energy source. When contemplating to use the produced energy from the solar photovoltaic system, it is important to know how much energy can be produced according to location, temperature and conversion efficiency. Solar energy is the technology used to make use of the sun's energy. The energy which is delivered from the photovoltaic system which consists of one or more photovoltaic modules is dependent on its characteristics and the current which is drawn from its solar cells. Using a monitoring system to analyze the performance has the main role to be able to track the amount of energy which is produced by the photovoltaic system in real-time, and to ensure the forecasted conversion efficiency can continue tracking the maximum power point most of the time. In this paper, the proposed monitoring system is designed and implemented to simulate photovoltaic module characteristics based on LabVIEW environment (Laboratory Virtual Instrument Engineering Workbench) which is a graphical programming language from National Instruments (NI). It includes tools that engineers and students can use to create a multitude of applications in much less time using parallel programming language platform. A model of a solar module is developed using LabVIEW software in order to simulate and analyze the operation of the photovoltaic (PV) module. The PV cell output current is calculated with an explicit equation developed by an approximation using a Taylor series. The effect of weather conditions on the operation of the PV module is analyzed through variations in cell temperature and solar irradiation which will be compared as a result with a real reference solar module. One of the keys to comprehending maximum power point tracking is understanding how the incremental conductance (IC) method is managed by calculation of the most suitable load at the maximum power point.

PV CHARACTERISTICS

PV Cell Model

The photovoltaic solar cell is an electronic device that consists of a double side of semiconductor materials connected together as a P-N junction to form an equivalent electronic element of regular diode. It has gray side which has positive charges and blue side which has negative ones. The main concept of the solar cells is to connect them in series to increase the voltage which basically reaches 30V as a maximum voltage for the module. The equivalent circuit of the solar cell illustrated in Figure (1) makes it possible to consider it as a current source connected with the diode and the two resistors.

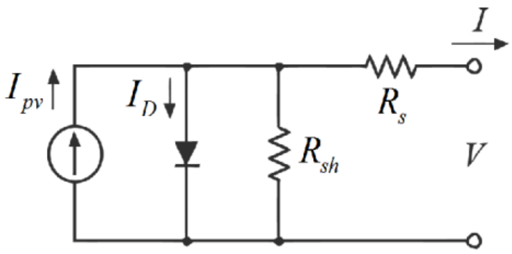

Figure 1. Equivalent circuit of a silicon solar cell

Here:

- I is saturation current, which will be according to the cell temperature
- V is the cell voltage
- n is the ideality factor of p-n junction
- Tc is the cell operating temperature (K)
- $q = 1.6 * 10^{-19}$ electron’s charge
- $k = 1.38 * 10^{-23}$ J/K Boltzmann constant

The simple model of a solar cell has been illustrated in Figure (1). The series resistance "R_s" is coordinated with the solar cell or solar module which consists of a series of equivalent cells. We can calculate the value of the series resistance (R_s) depending on equation (1) and I-V measurements. Figure (2) illustrates that "R_s" varies with the reciprocal of irradiance.

$$I = I_{ph} - I_0 * \left(e^{\frac{q*(V+I.Rs)}{nkT}} - 1\right) - \frac{V+I.Rs}{Rp} \qquad (1)$$

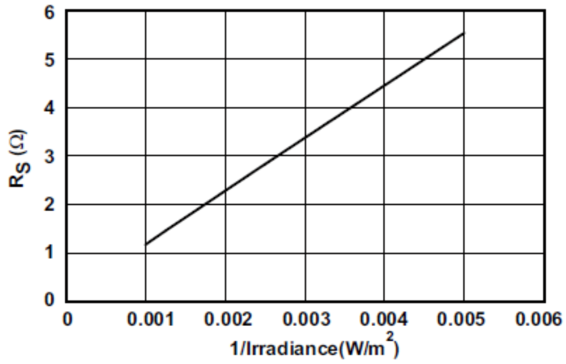

Figure 2. R_s vs reciprocal of irradiance for 215 Wp solar module

Parallel leakage resistance (R_p) is larger than 100 kΩ in most types of solar cells. We can ignore the value of this resistance in many applications. The current value through this solar cell's "equivalent diode" is represented by Equation (2).

$$I = I_0 * \left(e^{\frac{q*(V+I.Rs)}{nkT}} - 1\right) \qquad (2)$$

While choosing the appropriate solar module, the following parameters will represent the performance of this module and its maximum power.

- V_{oc} : Output voltage which represents the open circuit voltage
- I_{sc} : Output current which represents the short circuit current
- V_{mpp} : Output voltage at the maximum power point
- I_{mpp} : Output current at the maximum power

These values have been tested according to standard test condition (STC) at 25°C and 1000W/m^2. Figure (3) illustrates the variation of I-V curves and power curves for different values of irradiance.

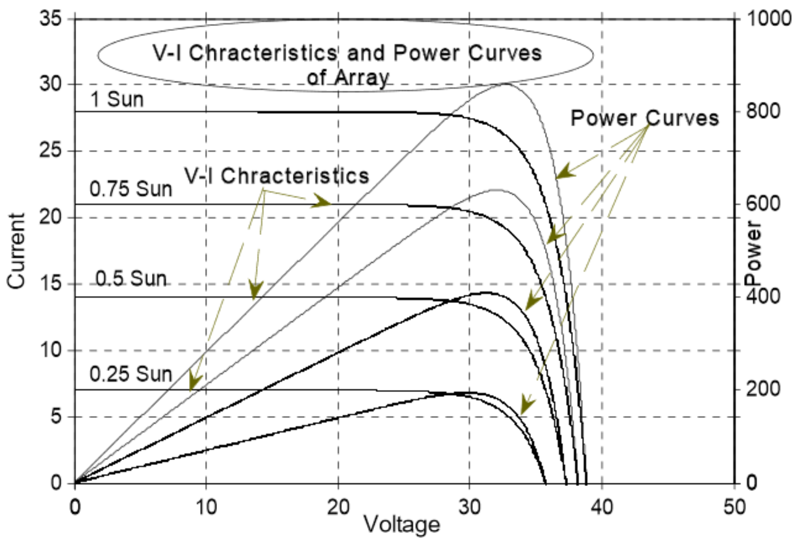

Figure 3. The differences between I-V curves and power curves at different values of irradiance

PV MODULE MODEL

Photovoltaic modules consist of multi solar cells connected in serial and parallel determined by the voltage or current requirements. The equivalent circuit of the solar module formed by (N_p) parallel and (N_s) series identical cells which is shown in Figure(4). The power supplied by a PV system of one or more photovoltaic cells is determined by the irradiance, temperature, and the load current drawn from the cells. Connecting the solar cells in parallel will keep the total voltage value equals to the voltage of one solar cell, which increases the output current which is the sum of the values of the current of each of the solar cells. Most of the silicon solar cells have close values for voltage and current which is around 0.7 V for each cell allowing about 4 A to pass through. So most of the solar modules have a series connection for the cells to increase the voltage and the current remains the same for each cell.

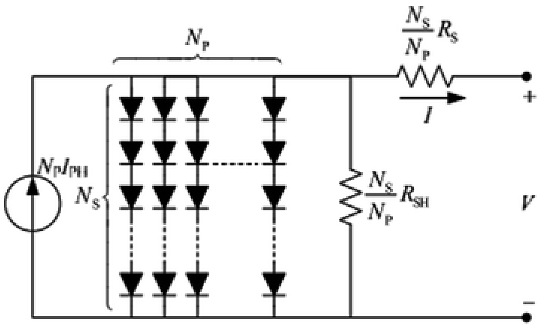

Figure 4. Equivalent circuit of a silicon solar module

$$I = N_p.I_{ph} - N_p.I_0\left(e^{\frac{q\left(\frac{V}{Ns}+\frac{I.Rs}{Np}\right)}{k.Tc.n}} - 1\right) - \frac{\frac{Np.V}{Ns}+I.R_S}{R_p} \qquad (3)$$

$$R_s(T) = \frac{Ns}{Np}.R_s \qquad R_p(T) = \frac{Np}{Ns}.R_p \qquad (4)$$

Since equation (3) does not have an analytical solution, numerical methods such as the Newton-Raphson's method have been largely adopted for the solution. In this paper, a different approach is made in order to establish an explicit form of equation (3). When a Taylor series is utilized to represent the function $f(x) = e^x$ as a power series, the approximation is given in the following equation:

$$f(x) = e^x = \sum_{n=0}^{\infty}\frac{x^n}{n!} = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots \qquad (5)$$

If the same Taylor series representation is used for Equation(3), taking into account only the first two parts of the series (first order approximation - FOA), the PV module output current can be determined by solving the linear Equation(3), assuming that R_S is given by the PV module manufacturer or otherwise previously determined and $R_p = \infty$.

MAXIMUM POWER POINT TRACKING (MPPT)

Maximum power point tracker is an electronic device that operates the PV panels using some smart methods to let the PV system produce the maximum power that they are capable of. In spite of the fact that the maximum power point tracking will be implemented using incremental method, it does not mean that the tracking system is a mechanical which physically moves the solar panels to make them point more directly to the sun. MPPT devices are smart electronic systems which manipulate the electrical operating point of the solar panels so that the modules are able to deliver maximum available power from the sun. The main structure of the maximum power point tracker is an electronic DC-DC converter that optimizes the match between the photovoltaic modules, and the battery bank or utility grid. One of the main parameters in the photovoltaic module is (V_m) which produces the maximum output power (P_{max}) depending on the irradiance level and the solar cell temperature. The basic idea consists of setting P_{max} when dP/dV=0. The control is achieved by adjusting the output current through changes in the equivalent load impedance. In this work, we have presented 40 methods for MPPT as suggestions for engineering education plan to be implemented in engineering laboratories. We have presented the incremental conductance (IC) method which is extensively used and several methods have been represented for MPPT implementation and Table 1 shows these 40 suggestions (Karami, Moubayed, & Outbib, 2017).

Table 1. MPPT comparative methods

Tracking methods			
1	Constant voltage method	21	Array Reconfiguration Method
2	Open-circuit voltage method	22	MPPT with a variable inductor
3	Short-circuit current method	23	State-based MPPT method
4	Open-circuit voltage pilot PV cell method	24	Linear reoriented coordinates method
5	Temperature Gradient (TG) Algorithm	25	Curve-fitting method
6	Temperature Parametric (TP) Method	26	Differentiation method
7	Feedback voltage or current method	27	Slide control method
8	P-N junction drop voltage tracking technique	28	Current sweep method
9	Look-up table method	29	dP/dV or dP/dI feedback control
10	Load current or load voltage maximization	30	Incremental Conductance method
11	Linear current control method	31	Variable step incremental conductance method
12	The only-current photovoltaic method	32	Variable step-size incrementalresistance method
13	PV Output Senseless (POS) control method	33	Parasitic capacitance (PC) method
14	Perturb and Observe (P & O) method	34	β method
15	Modified P & O with fixed perturbation step	35	IMPP and VMPP computation method
16	Conventional P & O with adaptive perturbation	36	Methods by modulation
17	Modified P & O with adaptive perturbation	37	Ripple correlation control
18	Three-point weight comparison method	38	Fuzzy logic control
19	On-Line MPP search algorithm	39	Neural network
20	DC-Link capacitor droop control	40	Biological swarm chasing algorithm

INCREMENTAL CONDUCTANCE METHOD

The essential feature of incremental conductance (IC) method is differentiating the PV power with respect to voltage. Maximum power point lays in where the differentiation result is zero. Therefore, The MPPT controller solves the power using the following equations:

$$\frac{\mathrm{d}P_{pv}}{\mathrm{d}V_{pv}} = \frac{\mathrm{d}(V_{pv}.I_{pv})}{\mathrm{d}V_{pv}} = I_{pv} + V_{pv}\frac{\mathrm{d}I_{pv}}{\mathrm{d}V_{pv}} = 0 \quad (6)$$

Hence, $\frac{V_{pv}}{I_{pv}} = -\frac{\mathrm{d}V_{pv}}{\mathrm{d}I_{pv}}$ (7)

Incremental conductance (IC) locates the maximum power point when:

$$\frac{\mathrm{d}I_{pv}}{\mathrm{d}V_{pv}} + \frac{I_{pv}}{V_{pv}} = 0 \quad (8)$$

The incremental conductance method uses a search technique that edit the duty cycle so that the voltage of the solar module is changed in order to search for the condition of equation (8). MPPT has been found according to that condition which stops the scanning. This incremental conductance method will continue to calculate ($\mathrm{d}I_{pv}$) until the result is no longer zero. In some cases, a non-zero value is used for comparison so the search will not be triggered by noise. When the left side of equation (8) is bigger than zero, the search will increment V_{pv}. When the left side of equation (8) is less than zero, the search will decrement V_{pv}. Figure (5) shows the IC algorithm steps:

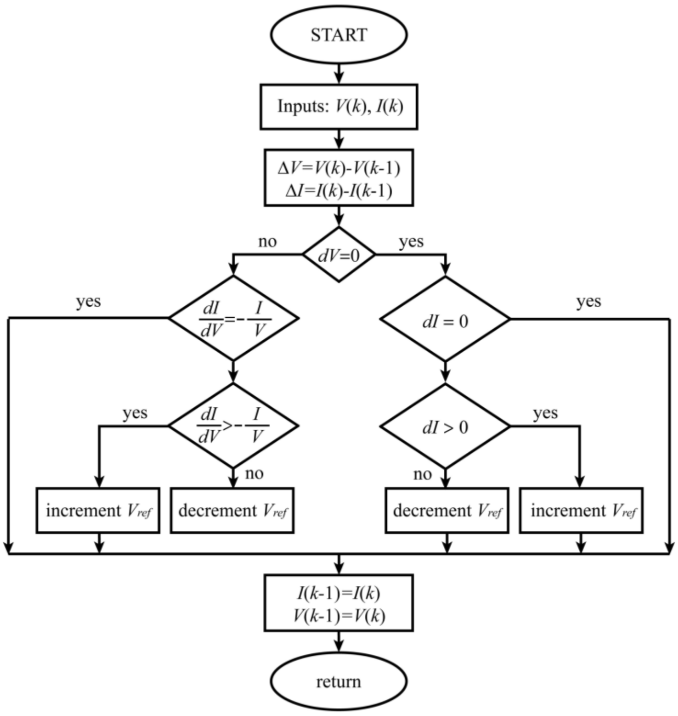

Figure 5. Incremental Conductance Algorithm

One of the main advantages of the incremental conductance algorithm is that it offers a perfect adaptive method due to rapidly changing atmospheric conditions, but it requires an advanced control circuit to implement.

LABVIEW ENVIRONMENT

The key feature of LabVIEW's graphical programming is the ease with which LabVIEW can program parallel operations. The front panel of LabVIEW is very convenient for building programs as it has a good graphical user interface. For all programming work in LabVIEW, the programmer does not need to enter any textual codes, except annotations of design elements. The graphical representation of the program flow increases readability at least for projects that are not too extensive. In this work, integrating several types of instruments and multi sub-virtual instruments (sub-VIs) make the system very popular. In the proposed system, the advantages of NI software is combined with the robust and reliable method to present virtual learning environment platform for PV modules. A design approach for 40 different methods is also presented in table(1) to increase digital teaching in engineering laboratories. LabVIEW environment platform manages communication between CPU and the I/O modules. LabVIEW has smart tools to create channels, tasks, interfaces, scales, and virtual instruments. The serial instrument includes software utilities and hardware drivers for communication protocol and includes the documentation on the stop bits, parity bits, baud rates, and packet size that the instrument used. In LabVIEW environment, computer's processor can compile the scenario which belongs to the block diagram side as the icons are connected together, and then will be converted to machine code. The voltage and current points are taken and captured along the I-V curve starting from open circuit load to short circuit load. The subsequent P-V curve points are captured simultaneously while the load resistance is being varied. Since the incremental conductance algorithm has multi conditions for (dV=0), the sub-VI for those conditions has been built as a ready libraries in a block diagram as shown in Figure (6).

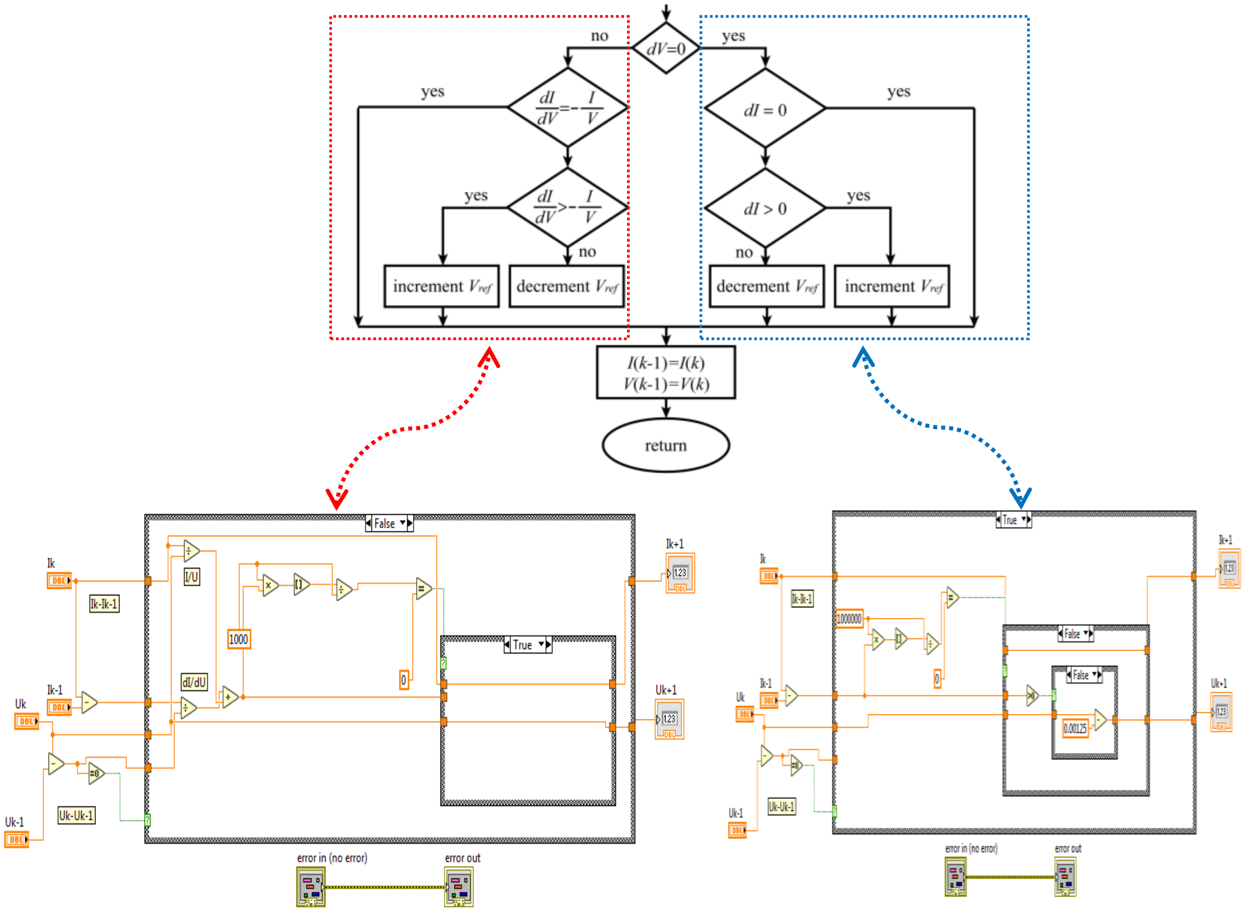

Figure 6. Multi sub-VIs block diagram

In this work, a mathematical model of the solar panel was presented based on incremental conductance method for MPPT using learning environments for engineering instructional platforms. After creating the sub-VIs as a libraries, the next step is to call them as a programming functions inside the block diagram. The main loop is the gray rectangle which is infinite loop controlled by a stop icon located in front panel. Inside this infinite loop all sub-VIs functions will be called and connected together to form a graphical programming structure. While compiling these strcuture, the voltage and current values will be calculated which consequently leads to the value of the solar modules power. Collecting the data points in an array helps us to reduce the development efforts to build the corresponding (X,Y) axis. The implemented block diagram design is shown in the following Figure (7).

All labVIEW designs are based on the coordination between the block diagram and front panel which has the control buttons for data collection. The block diagram side is normally used to develop all scenarios of the application whereas the front panel becomes an indicators for all updated data in real time. The characteristics of I-V and P-V curves will be represented in the front panel as shown in Figure (8).

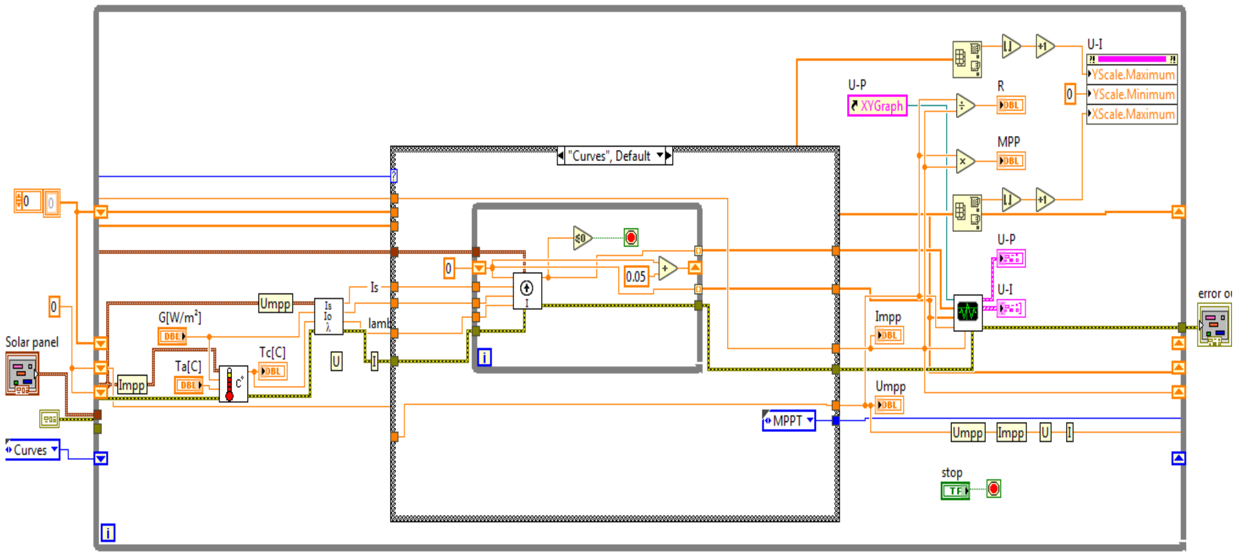

Figure 7. The implemented block diagram

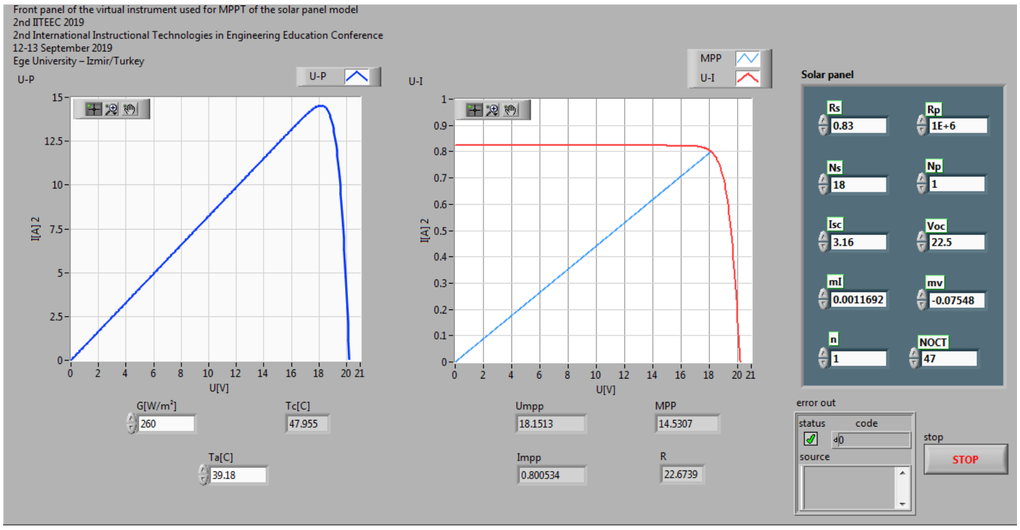

Figure 8. Front Panel

CONCLUSIONS

The presented work helps us to understand the operating of every equipment in photovoltaic modules and its characteristics which is concerned with manipulating PV parameters. There are many approaches to track the maximum power point for PV cells and groups of cells. Additional MPPT methods are presented in table 1 as 40 different suggestions for projects oriented engineering education which can be implemented in engineering laboratories as a virtual learning environment platform. Using the data points in arrays and implementing those kind of mathematical equations using the digital platforms help a lot to build the incremental conductance algorithm which means the ability of building the other methods in the same way which ensures a robust stability of the maximum power point tracking and leads to wide range of comparisons between those kind of systems.

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