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A LABWIEW™ BASED PHOTOVOLTAIC CELLS VIRTUAL INSTRUMENTAL SYSTEM FOR EDUCATIONAL PURPOSE

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Abstract. *This paper aims to establish a virtual instrumental system to measure the characteristics of photovoltaic (PV) cells with instrumentation software LabVIEW™. The basic principles behind PV cells are explored in detail. The important characteristics of PV cells, including irradiation, open-circuit voltage, short-circuit current, and current-voltage curve, under different conditions are discussed. These characteristics are embedded in the LabVIEW™-based PV virtual instrumental system, which was created using graphical language and relative instrumental equipment. This system can be used to both measure and learn the basic configuration and characteristics of PV cells.*
Keywords: LabVIEW, Photovoltaic cell, Measurement system, I-V curve of a PV cell, PV characteristics

1. **Introduction.** In traditional power systems, the input energy of large-scale thermal generation units usually comes from fossil fuels. Coal is the most widely used of these fuels in Taiwan, accounting for 40.3% of all power plant input energy. The CO_2 emission of these thermal units is the most significant factor for increased global warming. Connecting renewable distributed energy resource units to distribution networks can both provide clean energy to customers nearby and reduce energy losses to mitigate the greenhouse effect. The most widely used commercial operating renewable units are solar and wind energy generation systems, particularly the photovoltaic (PV) generation system. Thus, the mechanisms and characteristics of PV cells should be thoroughly examined. PV cells can be divided into three types according to materials: single-crystal, polycrystalline, and amorphous silicon PV cells. The efficiencies and applications of these cells are listed in Table 1. These characteristics indicate the advantages and disadvantages of different PV cell technologies. The conversion of energy from sunlight to electrical power by PV cells depends on several critical parameters that affect their output voltage, current, and power. Thus, the electrical characteristics of PV cells under different conditions should be determined by theoretical discussion and verification of measurements. Specifically, an accurate and efficient measurement system should be developed. One such system is the virtual instrumental system established by LabVIEW™. Related to other LabVIEW™ applications, this technique and its equipment have been successfully applied to various engineering fields, such as in biomedical [2-4] and electrical engineering [5-9]. LabVIEW™ can be used to establish a virtual instrumental system for PV cells. Thus, this paper aims to establish a LabVIEW™-based PV cell virtual instrumental system that measures the

Table 1. Various PV cell technologies and their characteristics

Material		Theory Efficiency	Real Efficiency	Application
Single Crystal Si		25-30% 34% (Concentrated Type)	24% (Laboratory Level) 14-17% (Commercial Level)	Aerospace Power, Center Generation System, Independent Power Source, Electronic Products
Multicrystaline Si		20%	17.7% (Laboratory Level) 11-14% (Commercial Level)	Independent Power Source, Electronic Products
III-V Family (GaAs, InP)		35%	27.8% (Laboratory Level)	Aerospace Power
Thin-Film PV	Amorphous	15%	13.5% (Laboratory Level) 5-7% (Commercial Level)	Independent Power Source, Electronic Products
	II-V Family (CdS, CdTe, CuInSc2)	17-18%	15.8% (Laboratory Level)	Independent Power Source, Electronic Products

related electrical characteristics of PV cells. The established system not only effectively replaces the traditional measurement system but also exemplifies the use of green energy technology for educational purposes. This paper has four sections: Section 1 provides an introduction; Section 2 describes the measurement system; Section 3 discusses the test results; and Section 4 concludes.

2. The Measurement System.

2.1. Electrical characteristics of PV cells.

PV systems are devices that convert the energy contained in photons of light into electrical voltage and current. In other words, PV systems use semiconductor materials to convert sunlight into electricity. The basic principle behind PV systems is that the vicinity of a *p-n* junction is exposed to sunlight, the photons of which are absorbed; thus, hole-electron pairs are formed. If these mobile charge carriers reach the vicinity of the junction, the electric field in the depletion region pushes the holes into the *p*-side and pushes the electrons into the *n*-side. Therefore, the *p*-side accumulates holes, and the *n*-side accumulates electrons, creating a voltage that can be used to deliver current to a load. Figure 1 shows a generalized PV equivalent circuit with both series and parallel resistances. Applying Kirchhoff's current law to the node above the diode derives Equation (1) for the relationship between the current and voltage.

$$I = I_{SC} - I_o\left(e^{\frac{qV_D}{kT}} - 1\right) - \frac{V_d}{R_P} \tag{1}$$

where I_o is the reverse saturation current (A), q is the electron charge (1.602×10^{-19} C), k is Boltzmann's constant (1.381×10^{-23}J/°K), T is the junction temperature (K), and R_P is the parallel resistance. One PV cell produces only about 0.6 V and is thus insufficient for application. Therefore, a module consisting of several pre-wired cells in series should be built. A typical module has about 36 cells in series and is designed as a 12-V module; a 24-V module has 72 cells in series or 12-V modules with two parallel strings each having 36 cells in series. For any application, therefore, PV modules can be wired in series to increase voltage and in parallel to increase current. Output voltage and current can be expressed as (2) and (3); the product of both is power. A PV panel with many modules connected in series and in parallel can be created to deliver the desired amount of energy. Combinations of such panels called an array are an important element

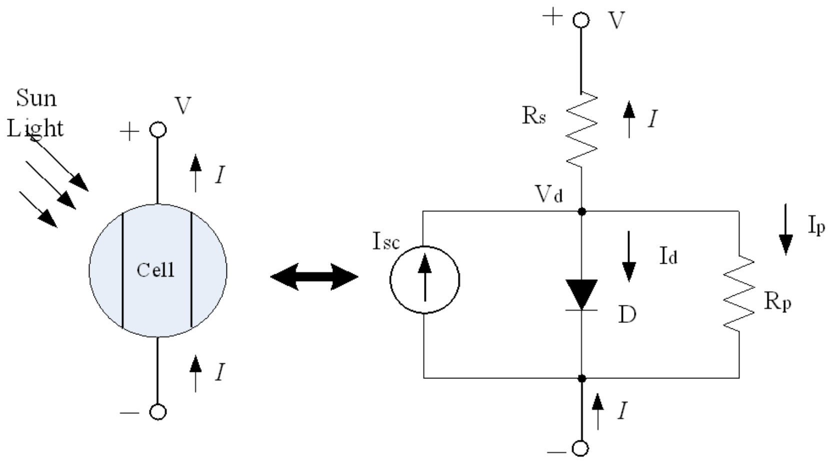

FIGURE 1. Equivalent circuit for PV cell with both parallel and series resistances

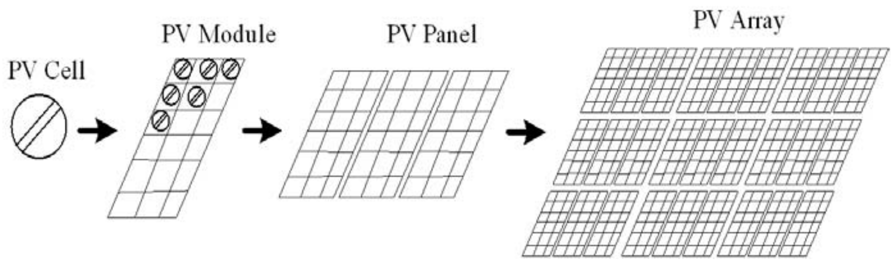

FIGURE 2. PV cells, modules, panels and arrays

FIGURE 3. Schematic diagram of developed PV cell virtual instrumental system

in PV system design. The distinction between cells, modules, panels and arrays is shown in Figure 2.

$$V_{pv,\, \mathrm{mod}\, ule} = N_s \cdot V \tag{2}$$

$$I_{pv,\, \mathrm{mod}\, ule} = N_p \cdot I \tag{3}$$

where N_s and N_p are the number of cells in series and in parallel, respectively, in a PV module.

The electrical characteristics of PV cells depend on the PV material, temperature, and insolation. Thus, this paper aims to determine PV output current, voltage, and power by measuring the correlative characteristics under different conditions. Instead of traditional measurement instruments, a virtual instrumental system based on LabVIEW™ is established and used in this paper.

2.2. **The developed virtual instrumental system.** Figure 3 shows a schematic diagram of the developed system. This system can be divided into three parts: PV cells, data acquisition (DAQ) card, and a LabVIEW™-based graphical user interface (GUI)

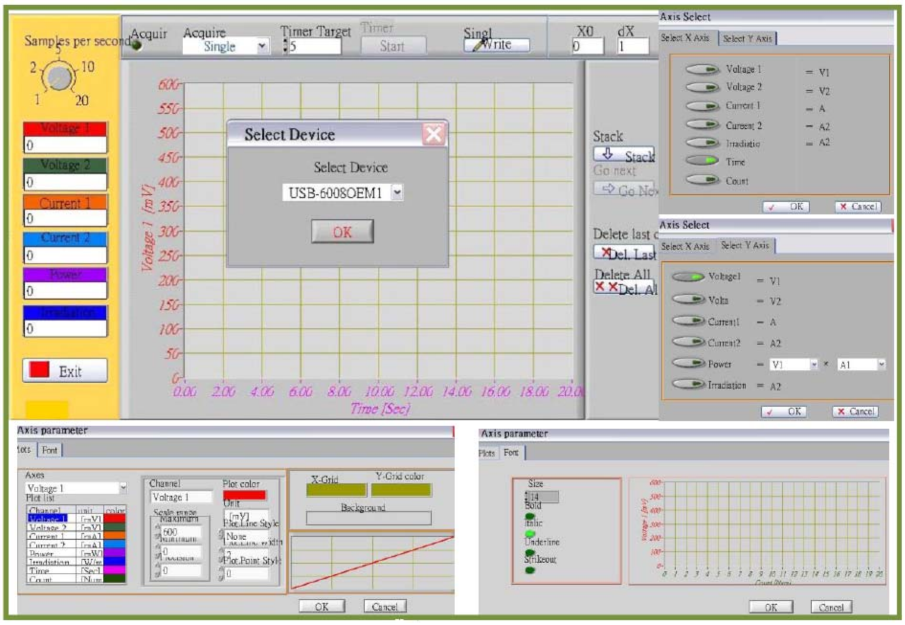

FIGURE 4. LabVIEW^{TM}-based graphical user interface

program. The system was developed to measure PV cells, modules, and/or systems. The front panel of LabVIEW^{TM} is shown in Figure 4. This system measures three parameters:

(1) The current-voltage (I-V) curve of PV cells
(2) The irradiation of various light sources
(3) The shading effect on the open-circuit voltage and short-circuit current of PV cells

The developed system can be used to not only measure but also learn the basic configuration and characteristics of PV cells.

3. **Test Results.** A PV cell is usually represented by an equivalent circuit (Figure 1). Thus, irradiation and temperature are the major factors that affect the output characteristics of PV cells. Thus, this study has two objectives: (1) to determine the I-V curve of a PV cell and (2) clarify the effect of shading on PV cell performance. The I-V and output voltage/current curves are measured; the results are shown on the front panel of the developed LabVIEW^{TM} GUI software (Figure 5). The I-V characteristic of a PV cell and the irradiation increment are nonlinear. The open-circuit voltage and short-circuit current also tend to increase. The test results are identical to the theoretical results, suggesting that data processing in the developed measurement system is valid. The effects of shading on the output voltage/current and open-circuit voltage/short-circuit current of PV cells are shown in Figures 6 and 7. The output voltage and current of the PV cells are significantly different under various shading conditions. The test results indicate a severe voltage drop, which can be corrected by adding a bypass diode across each cell.

4. **Conclusions.** Based on LabVIEW^{TM}, DAQ card and essential circuits, a virtual instrumental system that measures the characteristics of PV cells is designed and implemented in this study. This system can be used to measure irradiation, open-circuit voltage, short-circuit current, I-V curve, and output voltage/current/power under different conditions for educational purposes. The developed technique can be used to monitor and collect data for PV generation systems.

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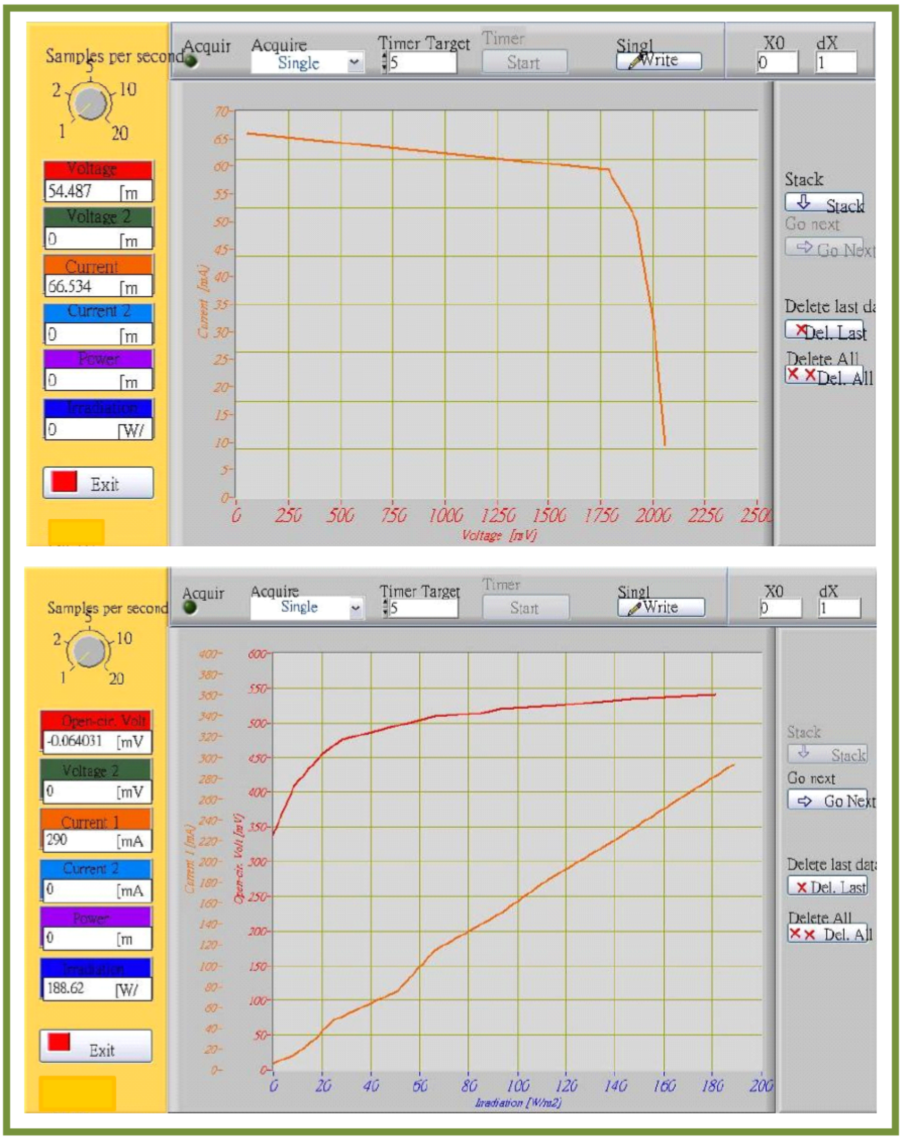

FIGURE 5. I-V and voltage/current-irradiation curves

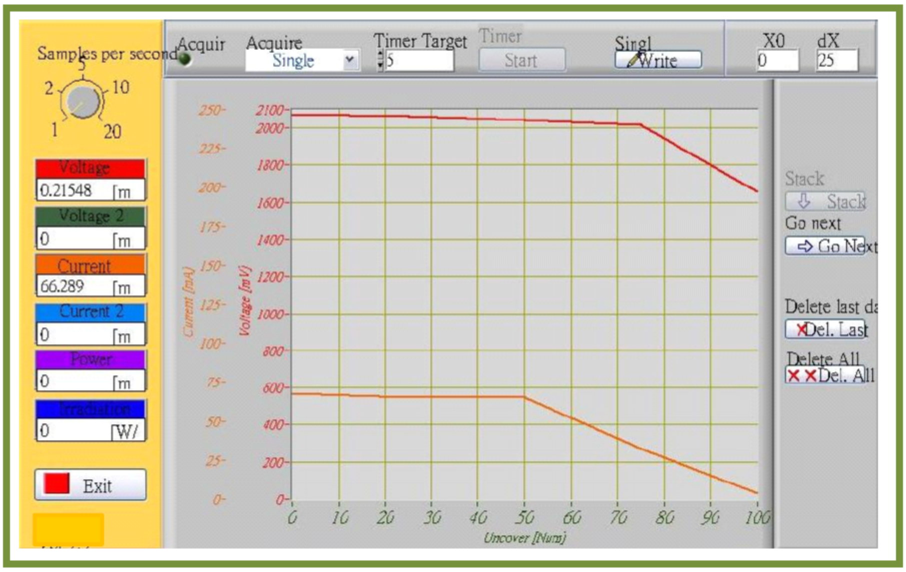

FIGURE 6. Effect of shading on output voltage/current of PV cells

FIGURE 7. Effect of shading on open-circuit voltage/short-circuit current of PV cells

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