Using NI CompactRIO to Design a Maximum Power Point Tracking Controller for Solar Energy Applications

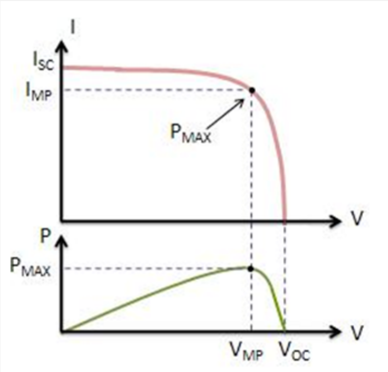

Figure1. The maximum power (PMAX) of a solar cell occurs when the product of voltage (V) and current (I) reaches its peak.

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- Ru-Min Chao, Electromechanical Research Institute, National Cheng Kung University

The Challenge:
Developing a power electronics control system to locate and track the maximum power point of a photovoltaic (PV) array and efficiently transfer power from the solar cells to the load under varying environmental conditions.

The Solution:
Developing a real-time solar cell measurement and control system to ensure that the maximum power output is achieved in a variety of environmental conditions.

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Solar cells have an optimization point, known as the maximum power point, where the power transfer from the cell to the load is optimal. This maximum power point varies with environmental conditions such as the temperature and amount of sunlight illumination. If the output voltage of the solar array is fixed, the maximum power output cannot be continuously generated. We use maximum power point tracking (MPPT) algorithms to increase the overall power generation efficiency by continuously locating and tracking the maximum power point by adjusting the voltage output of the array using a DC to DC converter. MPPT techniques reduce PV array system costs by reducing the number of solar panels needed to obtain a given amount of output power.

To improve the control design of solar cell MPPT, we developed an MPPT system that fits a quadratic equation to the power-voltage curve of the cell and calculates the maximum value of the quadratic function to locate the maximum power point. The system must produce high-speed pulse-width modulation (PWM) signals to control the voltage converter and provide high-speed data acquisition. In addition, we wanted to develop a portable, embedded maximum power point calculation system to ship for future applications.

We used NI CompactRIO with the NI LabVIEW FPGA Module to develop a stable, efficient, and integrated system. To minimize the power consumption, the CompactRIO system also contains a power switch controlled by a turn-on timer. We used analog measurements and actual test results to validate the feasibility of the system to develop an MPPT controller.

Application

We designed a solar energy MPPT device using LabVIEW software for user interface development and to generate new algorithms. We used the LabVIEW FPGA Module to acquire high-speed signals and transfer them to the processor using DMA data transfer. We also used the LabVIEW Real-Time Module to program the processor to execute the MPPT algorithms, and the CompactRIO embedded system to obtain the slower solar cell current (I) and voltage (V) values and transfer the data to the real-time processor for calculations. Then, the FPGA generates the desired PWM duty cycle signals for the step-down buck converter circuit to produce output voltage at the maximum power point. In addition, we can conduct real-time MPPT calculations for other loads such as the battery power supply and motor using this system.

System Architecture

A 25 W solar cell and the step-down buck converter supplies electric energy, which we store in the chargeable 6 V, 10 AH lead acid battery cells and the loaded motor, as shown in the system architecture diagram in Figure 2. In the loaded motor, we used the PWM switch signals provided by the NI 9474 high-speed sourcing C Series digital output module for the voltage scaling of the converter input and output. After we measured the solar cell output power using the NI 9221 C Series module and acquired the data with the NI cRIO-9101 four-slot 1M gate reconfigurable embedded chassis, the NI cRIO-9002 embedded real-time controller calculated the power-voltage curve for MPPT calculation using the acquired data and computed the desired PWM command signal to obtain the maximum solar cell output power.

As shown in Figure 3, the algorithm involves calculating the maximum power point using a quadratic equation. We mapped the characteristic voltage-current curve of the cell to check if the duty cycle obtained from the MPPT calculation is the maximum power point at the solar illumination level. Then, we performed MPPT and compared the two duty cycles, identifying the power difference for MPPT efficiency. Using this system, we understood the actual MPPT performance including the charging process.

Success with NI Products and Support

Compared to other hardware platforms, developing with CompactRIO was much more time-efficient. The developed system is comparable with other systems created in Very High-Speed Integrated Circuit (VHSIC) Hardware Description Language (VHDL), but the LabVIEW FPGA tools simplify many complicated steps. We used the internal 40 MHz operation frequency to provide the 20 kHz PWM output signals and voltage/current measurement required for MPPT calculation. In addition, we synchronized functions such as display and recording for user reference, while the cRIO-9002 embedded real-time controller provided real-time calculation and further strengthened the stability of MPPT system operation.

After we completed our application, we continued to receive service from NI applications engineers. We approached them with our maintenance and technical problems, and the annual forums and cost-free tuition were helpful. With NI products and assistance, we successfully developed our MPPT system for real-time solar cell calculation, ensuring that the maximum power output is achieved in variable ambient environments. We can apply this MPPT calculation method for power tracking in other solar power generation systems in the future.

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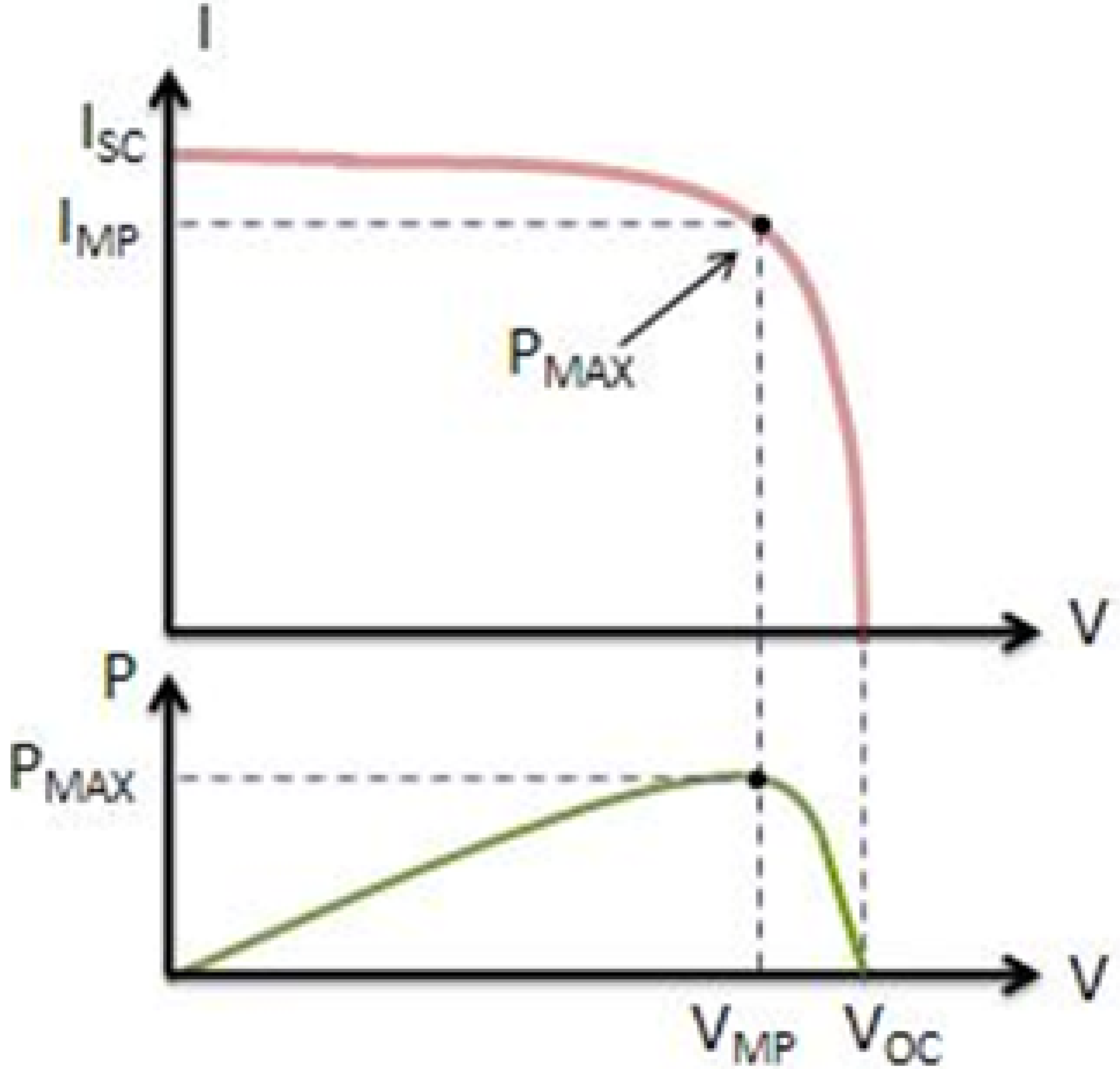

Figure1. The maximum power (PMAX) of a solar cell occurs when the product of voltage (V) and current (I) reaches its peak.

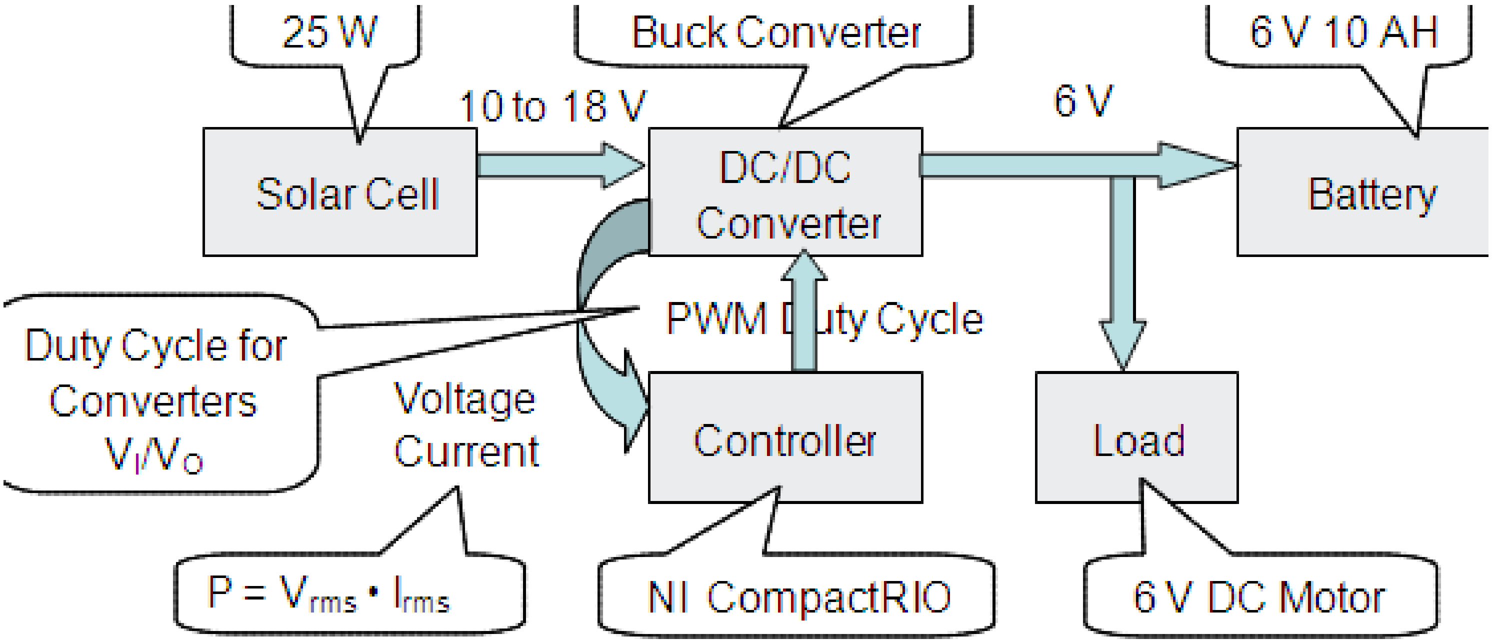

Figure 2. Hardware System Architecture Diagram

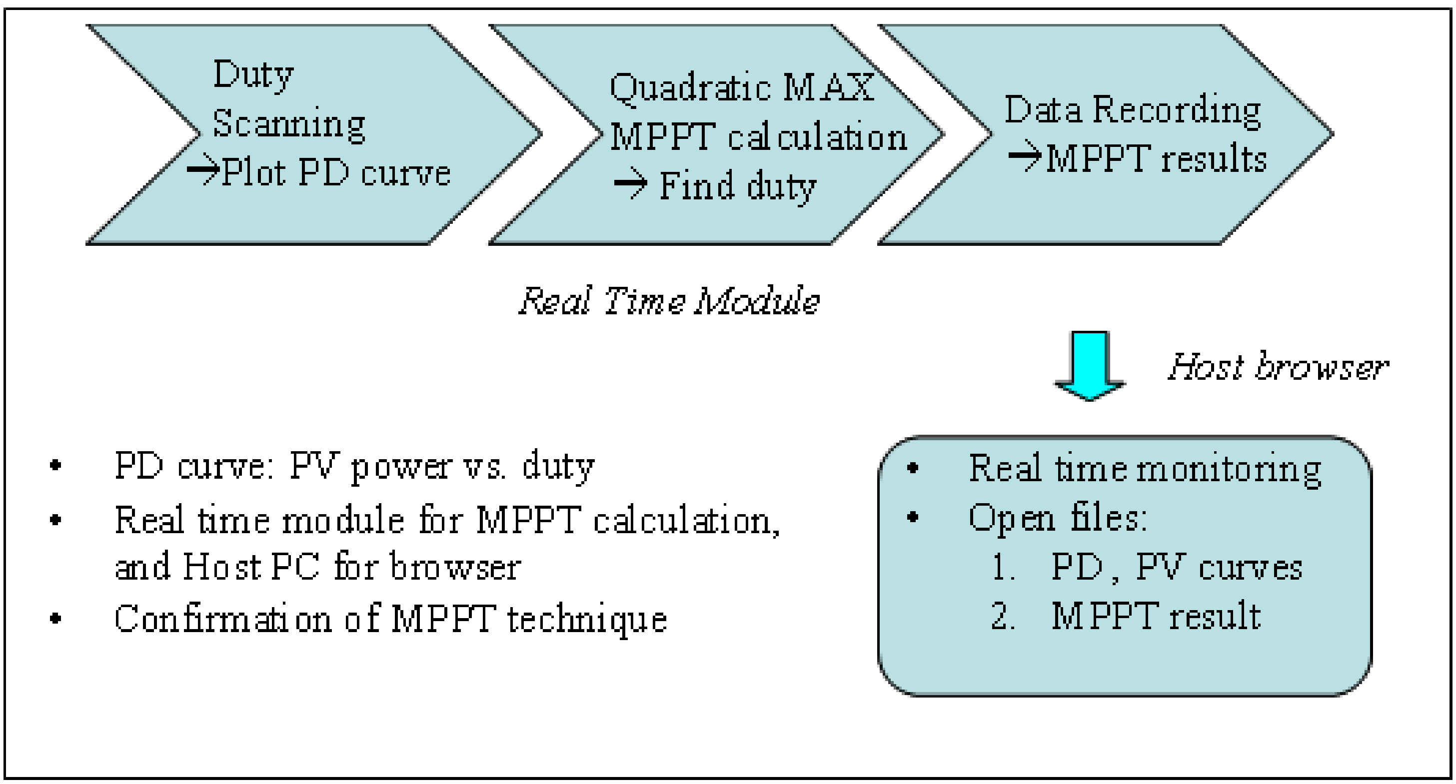

Figure 3. MPPT Process Flow

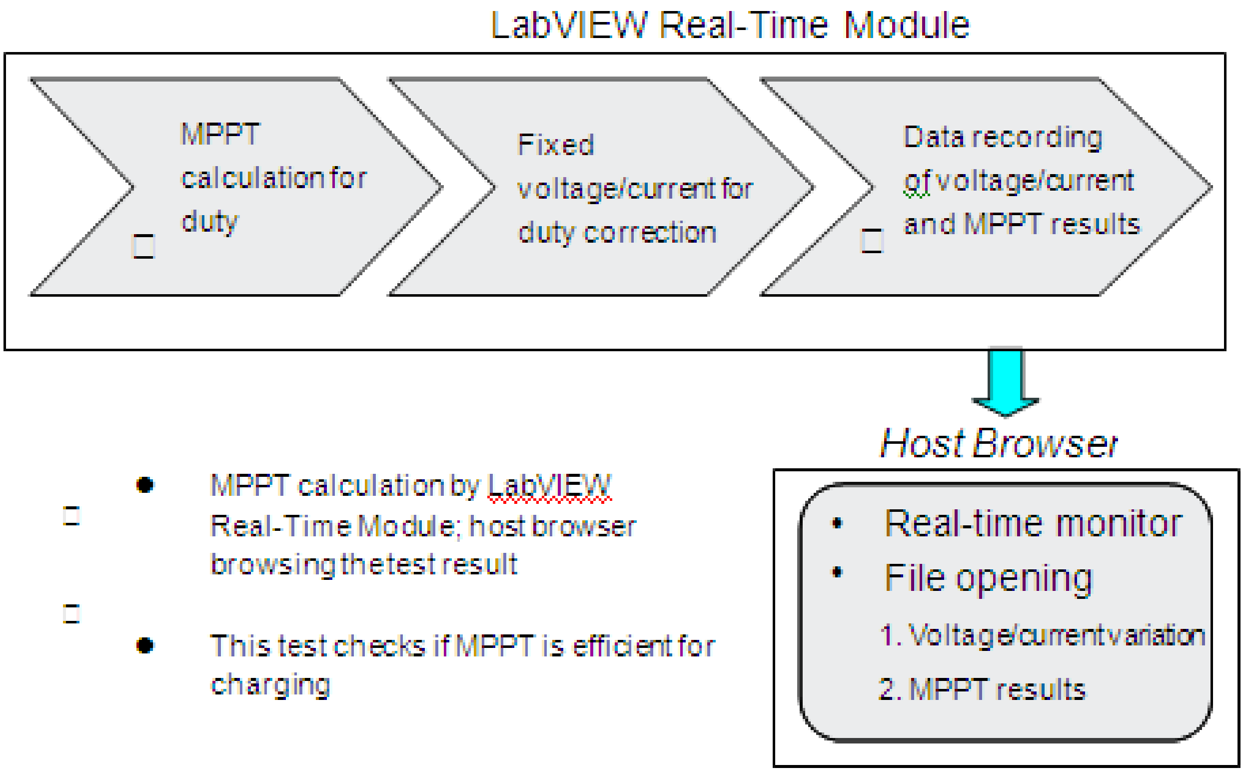

Figure 4. Charge Test Process Flow

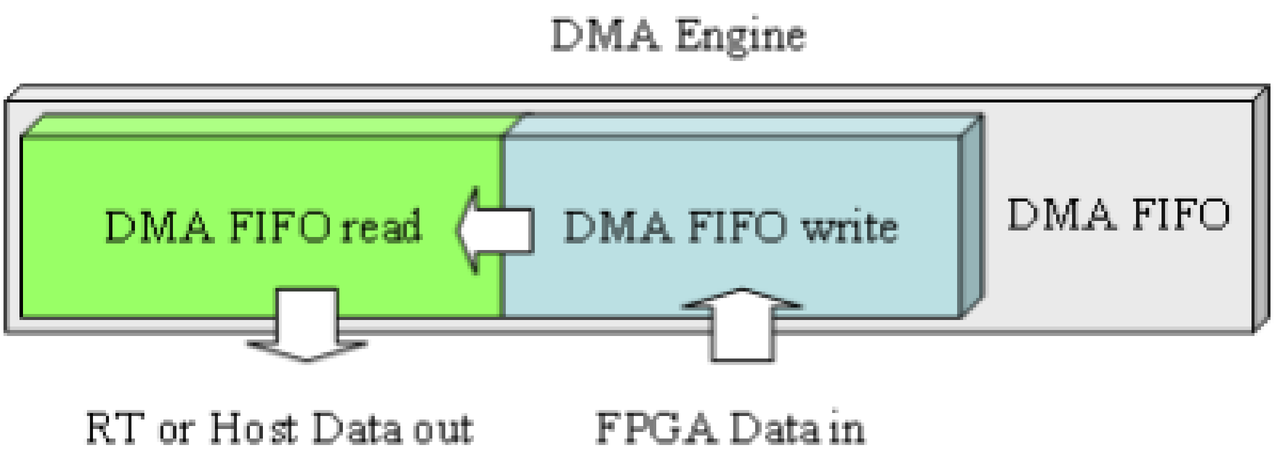

Figure 5. Diagram showing how high speed data is transferred from the CompactRIO FPGA to the real-time processor

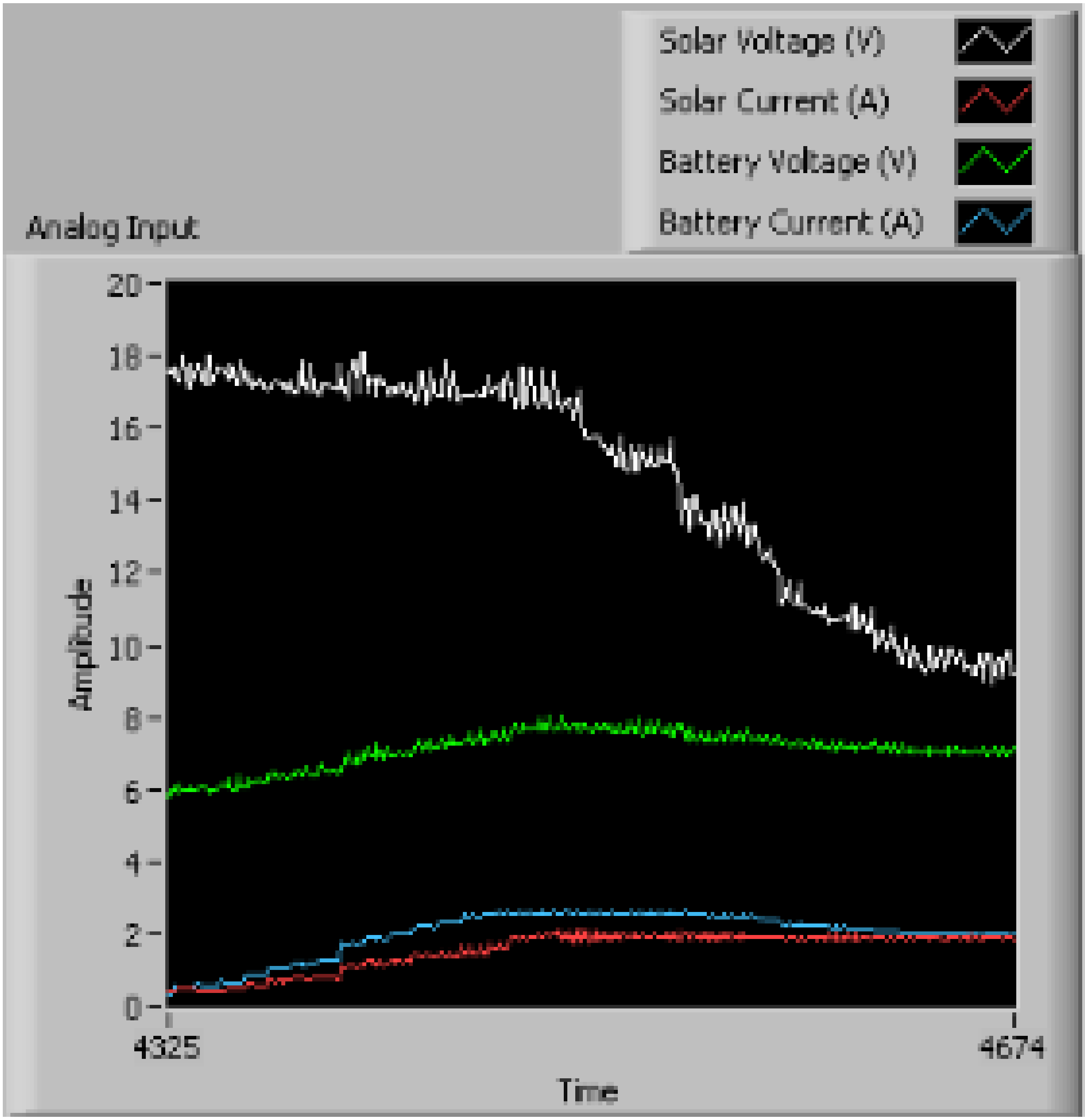

Figure 6. Voltage and current waveforms for the solar cell and battery

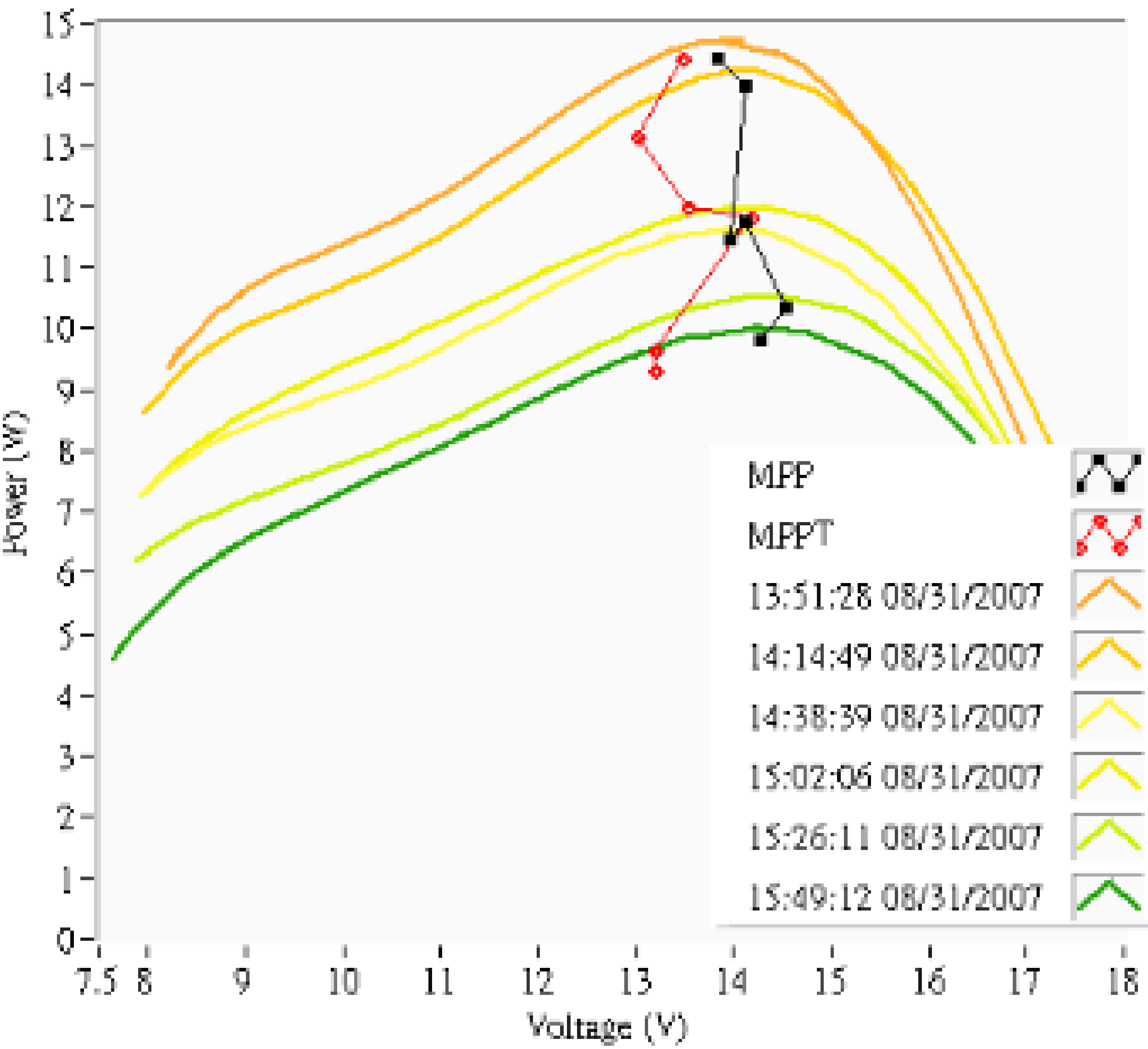

Figure 7. Solar cell power versus voltage (PV) curve based on experimental measurements under different lighting conditions