Supplementary Materials: Use of the Maximum Power Point Tracking Method in Portable Lithium-Ion Solar Battery Charger

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1. PV Modelling

In order to create a model of a silicon PV cell, a single-diode PV cell model was used [1-6]. Designations used:

I—PV cell terminal current, proportional to solar radiation;
I_{ph}—photo-generated current;
I_o—saturation current;
I_D—diode current;
V_{sh}—shunt voltage drop
I_{sh}—current diverted through shunt resistor (R_{sh}) of a PV cell;
V_D—diode voltage;
l_s—solar factor;
N_s—number of PV cells connected in series;
N_p—number of PV cells connected in parallel;
G_o—maximum solar irradiance;
G—solar irradiance.

Physical constants:

$k = 1.38 \cdot 10^{-23} (\frac{J}{K})$—the Boltzman constant;

$q = 1.6 \cdot 10^{-19} (C)$—electron charge;
$V_q = 1.1q \cdot \frac{V}{c}$—rectangular potential barrier;
$T_o = 298.15(K)$—25°C temperature;
$G_o = 1000\ (\frac{W}{m^2})$—maximum solar irradiance.

- PV cell terminal current:

$$I = I_{ph} - I_D - I_{sh} \tag{S1}$$

- Photo-generated current:

$$I_{ph} = I_{sc} + k_i \cdot (T - T_n) \cdot \frac{G}{G_0} \tag{S2}$$

- Saturation current:

$$I_0 = I_{rs} \cdot \ (\frac{T}{T_n})^3 \ \cdot e^{(\frac{q \cdot E_{g0} \cdot (\frac{1}{T_n} - \frac{1}{T})}{n \cdot K})} \tag{S3}$$

- Reverse saturation current:

$$I_{rs} = \frac{I_{sc}}{-1 + e^{(\frac{q \cdot V_{0c}}{n \cdot N_S \cdot K \cdot T})}} \tag{S4}$$

- Current flowing through shunt resistance:

$$I_{sh} = \frac{V + I \cdot R_S}{R_{sh}} \tag{S5}$$

- PV cell terminal current:

$$I = I_{ph} - I_0 \cdot (e^{\left(\frac{q\cdot(V+I\cdot R_S)}{n\cdot N_S\cdot K\cdot T}\right)} - 1) - I_{sh} \quad (S6)$$

- Equation taking into account the number of series and parallel-connected PV cells:

$$I_{out} = N_p \cdot I_{ph} - N_p \cdot I_0 \cdot (e^{\left(\frac{q\cdot(V+I\cdot R_S)}{n\cdot N_S\cdot K\cdot T}\right)} - 1) - I_{sh} \quad (S7)$$

All the equations of the PV panel mathematical model were implemented in the MATLAB/Simulink R2018b (MathWorks,Natick,MA,USA) (Figure S1).

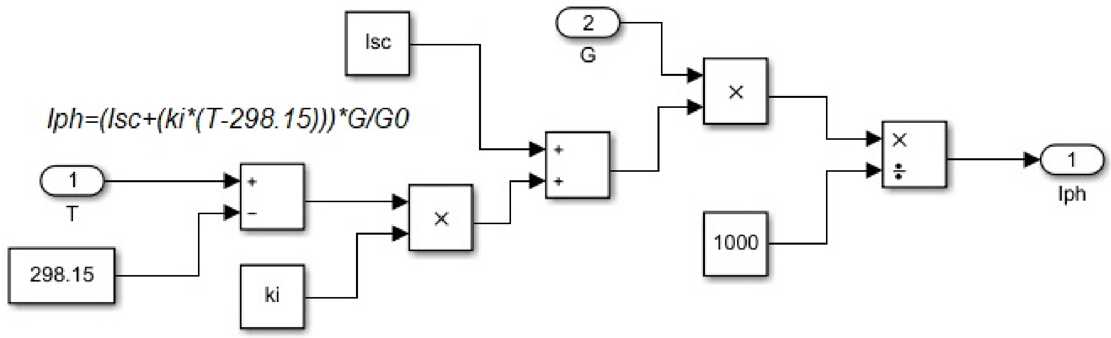

Figure S1. Implementation of the equation describing photogenerated current using MATLAB software.

The remaining equations have been implemented in accordance with the example presented in Figure S1. The following are assumed as input parameters in the model:

- solar irradiance obtained;
- ambient temperature;
- number of PV cells connected in series;
- number of parallel-connected PV cells;
- series resistance value;
- shunt resistance;
- open circuit voltage;
- short-circuit current.

The simulated PV panel model is presented in Figure S2.

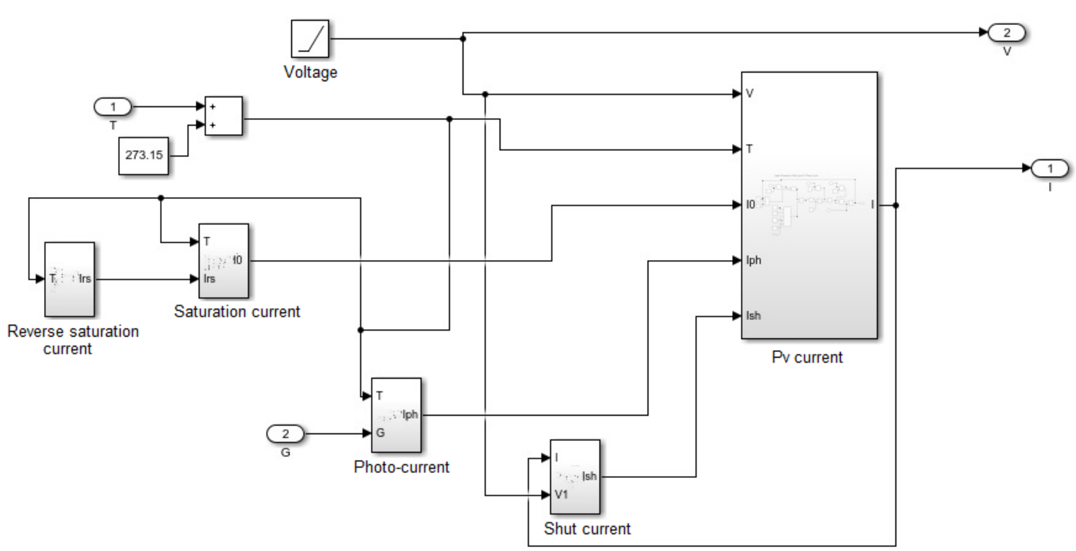

Figure S2. PV panel model.

During the simulation, the solar irradiance and the operating temperature values were entered into the model of the PV panel. The voltage was applied in an incremental, time-dependent manner to determine the maximum panel power (Figure S3). The obtained output current and voltage values allowed the current–voltage and power–voltage characteristics to be drawn.

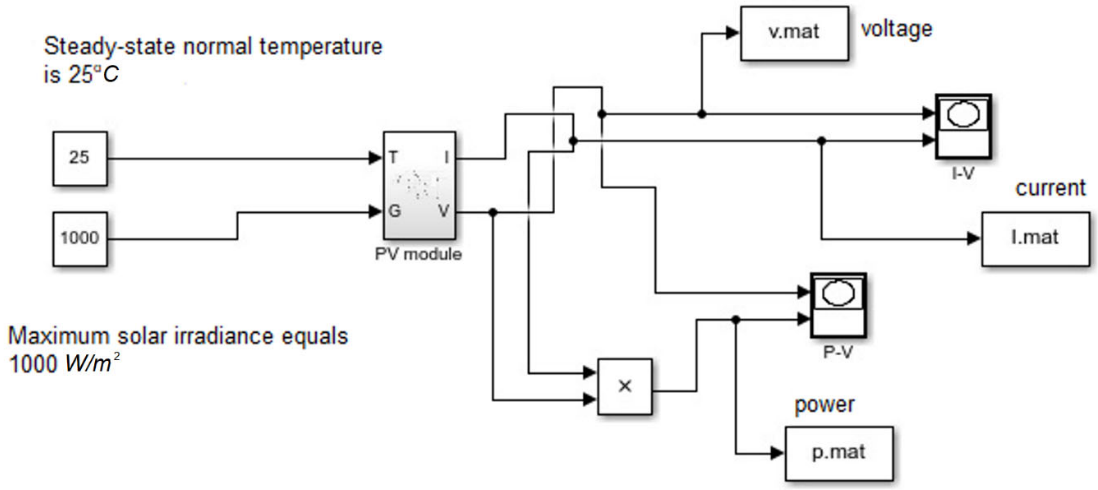

Figure S3. Simulated PV module.

In a simulation model of a solar panel, KC200GT of the company Kyocera (Kyoto, Japan) was used. The technical details supplied by the manufacturer is presented in Table S1 [7].The current–voltage characteristics,, both in conditions of constant sunlight and variable cell operating temperature and for constant cell temperature under variable solar conditions, were drafted by the authors, basing on the data by the manufacturer, and serve as an example (Figure S4).

Table S1. Parameters of KC200GT solar panel.

Parameters	Value
Isc	8.21 *A*
Voc	32.9 *V*
Pmax	200.143 *W*
Ns	54
Rp	415.405 *Ω*
Rs	0.221 *Ω*
a	1.3

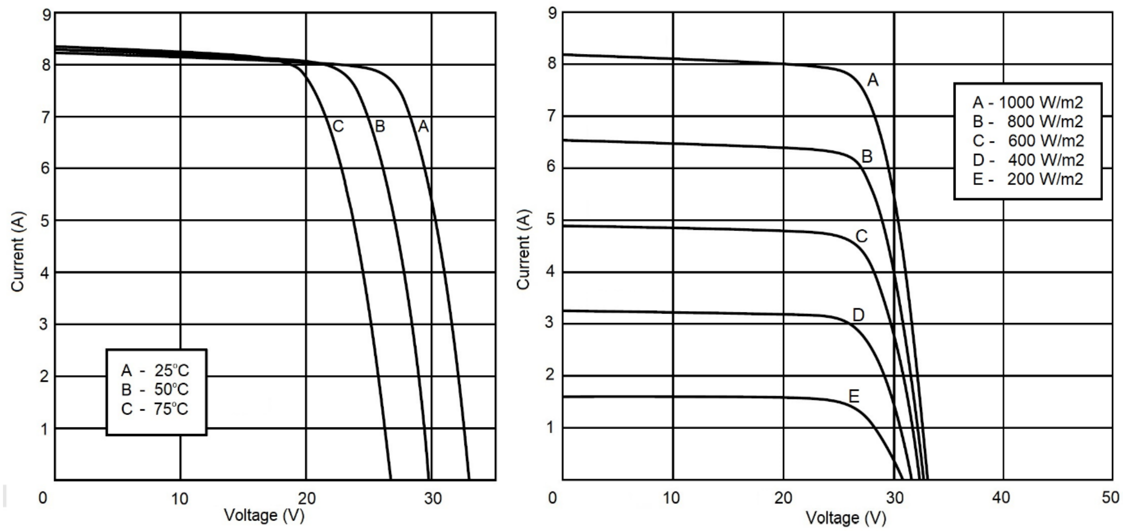

Figure S4. Current–voltage characteristics for Kyocera KC200GT PV module — constant irradiance (1 kW/m^2) and variable cell temperatures on the left, and constant cell temperature (25°C) and variable irradiance on the right .

2. Selection Microcontroller According to the Schematic Requirements

The number of microcontrollers available is quite substantial; therefore, a microcontroller needs to be selected in such a way as to meet all the design principles. Due to the exceptionally good parameters of the Cortex™ cores, it was decided that a STMicroelectronics company's ultra-low power series microcontroller would be selected. The analysis of the available peripherals of the microcontroller allowed the implementation of the MPP algorithm. To this end, analogue-to-digital converters were used to measure the voltage. Communication with the AD5245 evaluation board and the e-link display is conducted via the I2C bus. The microcontroller itself has the capability of being put to sleep mode to save energy. A microcontroller equipped with Cortex™-M0+ in TSSOP20 outline package, which takes little space on the PCB, while providing a sufficient number of inputs and outputs along with extensive range of enhanced peripherals, was selected (Figure S5).

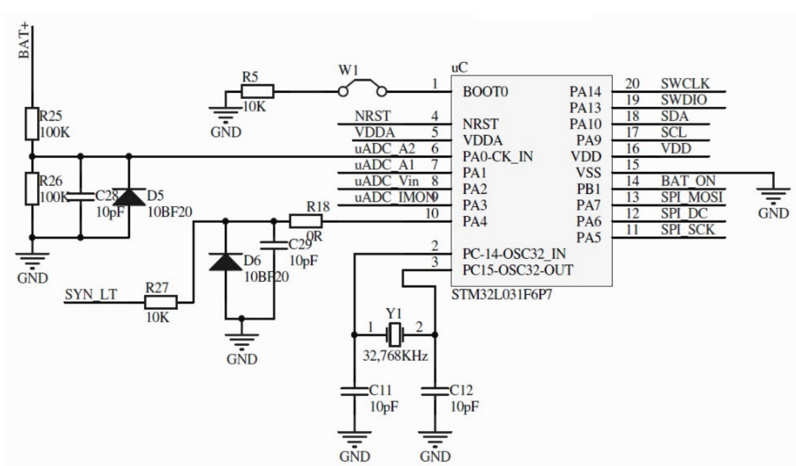

Figure S5. Fragment of a schematic presenting a microcontroller and signals.

Putting the microcontroller into a deep sleep mode, that is, turning off all the peripherals and waking the microcontroller using the signal line, allows for the current consumption to be reduced to only 0.25 μA. When using RAM and a real-time clock (RTC), the current consumption is 0.7 μA in the idle mode. The current consumption during a usual run is approx. 80 μA at 1 MHz. The analog-to-digital converter (ADC) consumes 41 μA at 10ksps. The implemented algorithm performs voltage measurements to determine the operating parameters of the PV panel and the battery being charged. The system controls the operation of the converter and digital potentiometer external control system, used to change and maintain the parameters while the microcontroller is in deep sleep mode to minimise the current consumption that would have to be used by the digital-to-analogue controller (DAC) or pulse width modulation to control the operation of the converter.
PCB was manufactured and soldered, and then all the systems were initiated (Figure S6).

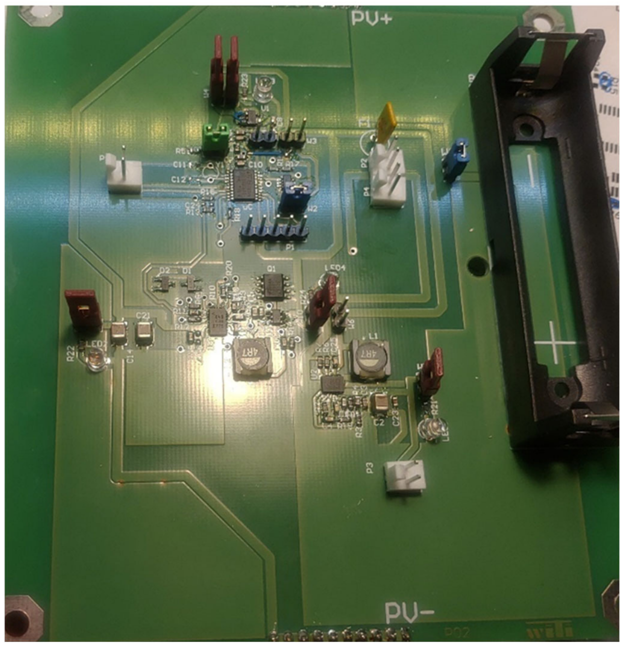

Figure S6. Ready PCB with all the system components.

References

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