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APPLICATION OF A HIGH-PRECISION MPPT CONTROLLER FOR THIN-FILM CADMIUM TELLURIDE PHOTOVOLTAIC DEVICES

Introduction

The efficiency of modern photovoltaic systems is determined not only by the conversion efficiency of photovoltaic devices, but also by their ability to operate under dynamically changing weather conditions and partial shading while ensuring maximum power output [1]. Due to the nonlinear nature of the I-V and P-V characteristics, the MPP coordinates continuously shift, which leads to a mismatch between the equivalent resistance of the photovoltaic modules at the operating point and the equivalent load resistance; as a result, part of the output power is lost. The use of a maximum power point tracking (MPPT) controller enables dynamic adjustment of the system's input resistance, keeping the operating point continuously in the vicinity of the maximum power point. Modern MPPT controllers provide high MPPT tracking efficiency, typically in the range of 95-99% [2,3]. By using an MPPT controller, the overall system efficiency is improved; moreover, it can ensure an optimal battery-charging regime, which positively affects the operational stability of the photovoltaic system. When investigating the stability of laboratory-fabricated CdTe-based photovoltaic (PV) cell samples under real operating conditions, it is necessary to match the load resistance to the sample resistance. Consequently, research aimed at evaluating the effectiveness of MPPT algorithms for low-power PV cells remains highly relevant.

Materials and Methods

To obtain the performance characteristics of CdTe-based photovoltaic devices, numerical simulations were performed using the SCAPS software (Fig. 1) [4]. The parameters of the CdTe/CdS/ITO and CdTe/CdS/ZnO heterostructures on glass substrates (Table 1) were determined according to ref. [5-7]. The thickness of the CdTe absorber layer was set to 2,5 μm, which is generally regarded as an optimal value, as it provides strong light absorption while keeping recombination-related losses at a low level [5].

Table 1

SCAPS model parameters based on literature data [5-7]

Parameters	p-CdTe	n-CdS	ITO	ZnO
thickness, μm	2,5	0,01	0,01	0,01
bandgap (eV)	1,5	2,4	3,72	3,3
electron affinity (eV)	4	4,5	4,5	4,6
dielectric permittivity (relative)	9,4	10	9,4	9,0
CB effective density of states (1/cm3)	$8\cdot10^{17}$	$2,2\cdot10^{18}$	$4\cdot10^{19}$	$2,2\cdot10^{18}$
VB effective density of states (1/cm3)	$1,8\cdot10^{19}$	$1,8\cdot10^{19}$	$1\cdot10^{18}$	$1,8\cdot10^{19}$
electron thermal velocity (cm/s)	$1,0\cdot10^{7}$	$1,0\cdot10^{7}$	$2,0\cdot10^{7}$	$1,0\cdot10^{7}$
hole thermal velocity (cm/s)	$1,0\cdot10^{7}$	$1,0\cdot10^{7}$	$1,0\cdot10^{7}$	$1,0\cdot10^{7}$
electron mobility (cm²/Vs)	$3,2\cdot10^{2}$	50	30	$1,0\cdot10^{2}$
hole mobility (cm²/Vs)	$4\cdot10^{1}$	20	5	25
shallow uniform donor density N_D (1/cm3)	0	$1\cdot10^{18}$	$1\cdot10^{21}$	$1\cdot10^{18}$
shallow uniform acceptor density N_A (1/cm3)	$2\cdot10^{14}$	0	0	0

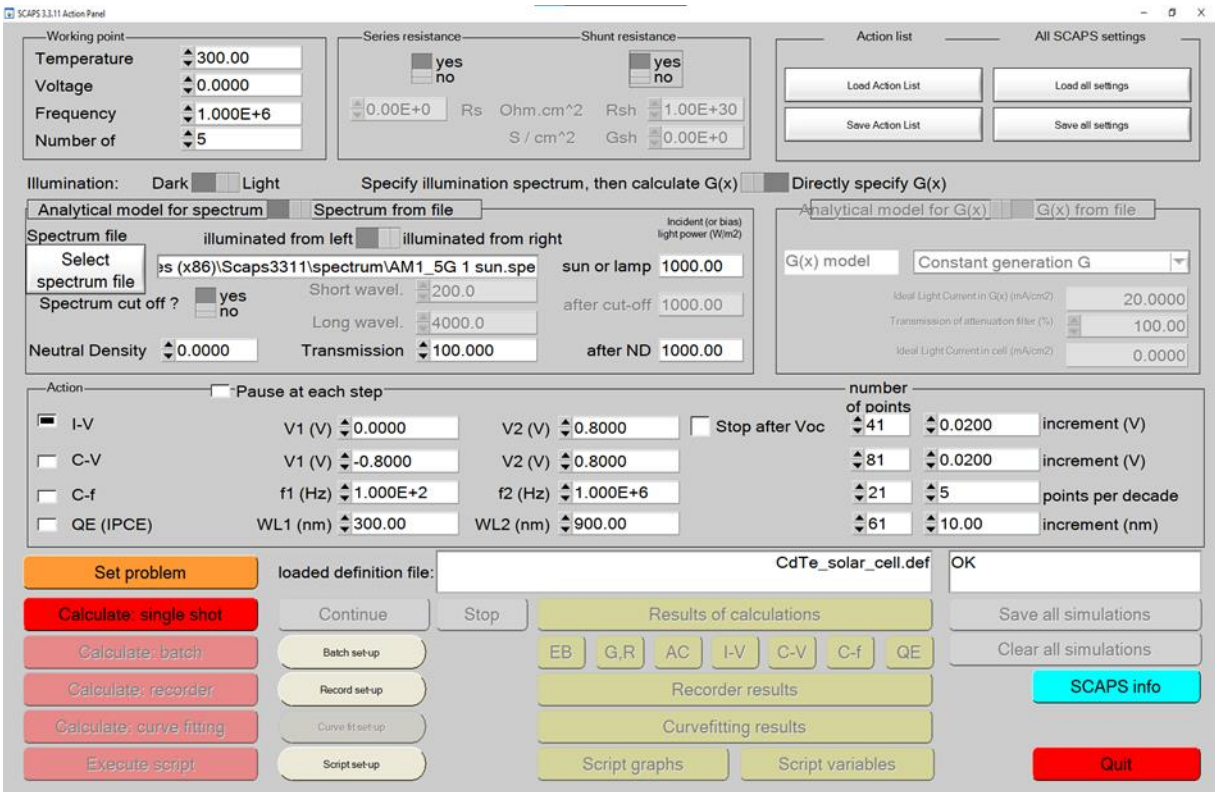

Fig. 1. SCAPS program window

For the practical implementation of the incremental conductance algorithm for thin-film CdTe/CdS heterostructures, an MPPT controller concept was developed based on a precision current regulator built around an operational amplifier (Fig. 2).

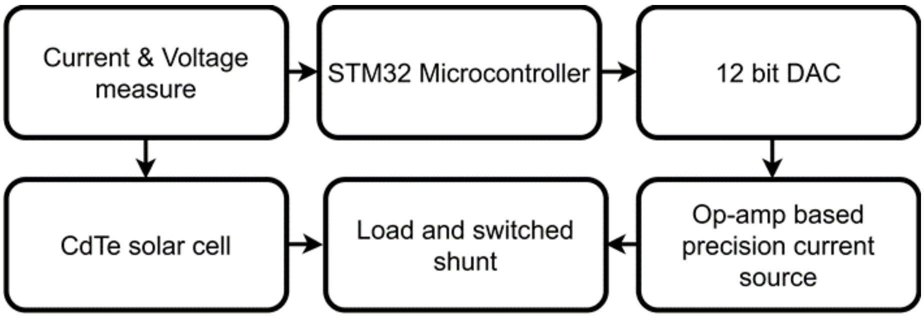

Fig. 2. Block diagram of the MPPT controller

The practical implementation of the proposed concept made it possible to develop a test setup adapted to laboratory samples of photovoltaic converters, enabling the characterization of devices with power ratings from several tens of milliwatts up to a few watts. The maximum sample voltage ranges from 0 to ~20 V and the current from 1 µA to 3 A, taking into account the maximum allowable power dissipation in the power transistor.

Results and Discussion

The results of SCAPS simulations for the CdTe/CdS/ITO and CdTe/CdS/ZnO semiconductor structures are presented in Table 2.

Based on the De Soto equations [9], a mathematical model of the incremental conductance MPPT algorithm operation over one year was developed using Python programming tools. The simulation results of the MPPT algorithm for the specified structures are shown in Fig. 3. It should be noted that the heterostructure parameters obtained from SCAPS simulations differ only slightly; therefore, Fig. 3 presents result only for the CdTe/CdS/ITO structure.

Table 2.

Results of SCAPS simulations CdTe based solar cell

Structure	V_{oc}, V	J_{sc}, mA/cm2	FF, %	η, %
CdTe/CdS/ITO	0,93	28,58	69,9	18,74
CdTe/CdS/ZnO	0,92	28,58	70,15	18,5

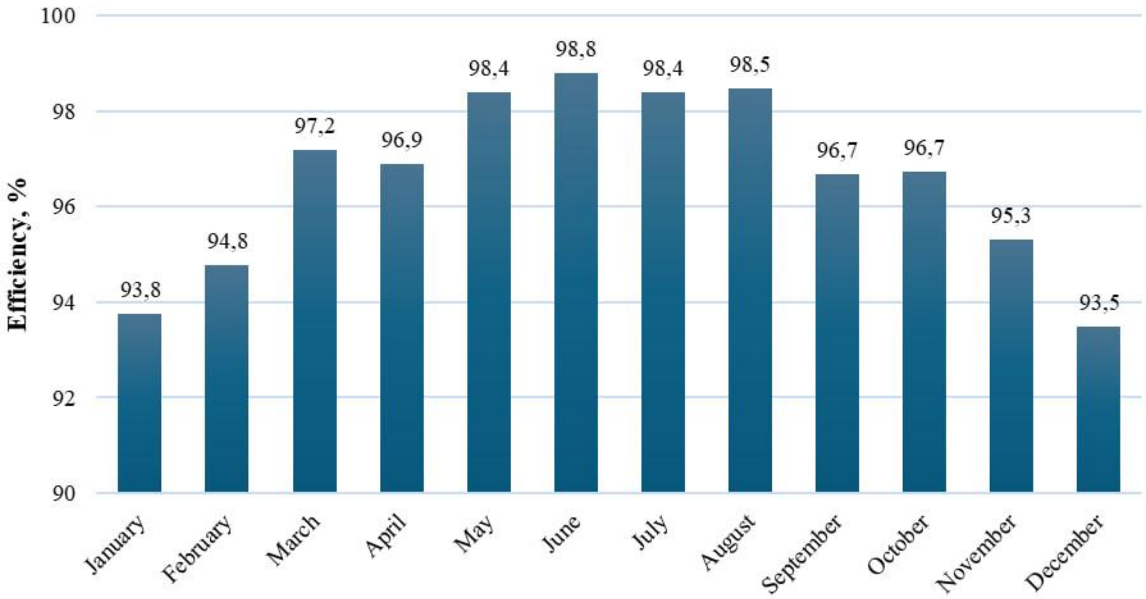

Fig. 3. Results of simulation of the incremental conductance MPPT algorithm for the CdTe/CdS/ITO structure over a one-year period

The monthly efficiency was evaluated using the following formula:

$$\eta_{mppt} = \frac{\sum\left(P_{op} \cdot \Delta t\right)}{\sum\left(P_{true\_mppt} \cdot \Delta t\right)} 100\% \quad (1)$$

where: P_{op} is the actual power obtained by the system using the MPPT algorithm;

P_{true_mppt} is theoretical maximum power of the photovoltaic cell;

Δt is the time interval between measurements.

Overall, the simulation results indicate a high efficiency of the incremental conductance MPPT algorithm for the considered low-power laboratory samples of CdTe/CdS/ITO and CdTe/CdS/ZnO semiconductor structures. The short-circuit current of the model was calculated for a sample area of 25 mm², which corresponds to 7,1 mA under standard test conditions.

Conclusions

SCAPS modeling was performed and the operating parameters of cadmium telluride (CdTe) thin-film photovoltaic energy converters were determined. The short-circuit currents were calculated and normalized to the area of the actual sample. Based on the obtained data, a concept and a block/structural diagram of an MPPT controller were developed, which will ensure operation of the measurement setup within a sample voltage range of 0 to ~20 V and a current range of 1 μA to 3 A.

A year-long simulation of the Incremental Conductance MPPT algorithm was conducted, which demonstrated high efficiency of the applied algorithm when used with low-power photovoltaic converters. The average annual tracking efficiency was 96,6% of the theoretical maximum.

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