Časopis
pre elektrotechniku,
elektroenergetiku,
informačné a komunikačné
technológie
ročník 18, október 2012
mimoriadne číslo

ELEKTROTECHNIKA, INFORMATIKA A TELEKOMUNIKÁCIE 2012

09.-12. október 2012

Fakulta elektrotechniky a informatiky

Slovenskej technickej univerzity v Bratislave

Zväz elektrotechnického priemyslu SR

EXPO CENTER a.s.

MIMORIADNE ČÍSLO, 2012, KONFERENCIA "ELEKTROTECHNIKA, INFORMATIKA A TELEKOMUNIKÁCIE 2012"

EE – časopis pre elektrotechniku, elektroenergetiku, informačné a komunikačné technológie,
ročník 18, október 2012,
mimoriadne číslo – vydanie ku konferencii s medzinárodnou účasťou Elektrotechnika, Informatika a Telekomunikácie 2012

Vydáva

Spolok absolventov a priateľov FEI STU (EF SVŠT)
v Bratislave, Ilkovičova 3, 812 19 Bratislava 1

v spolupráci s

Fakulta elektrotechniky a informatiky STU v Bratislave
Zväzom elektrotechnického priemyslu SR
EXPO CENTER a.s.

Programový výbor

Gabriel Juhás, – *predseda*, Ivan Baroňák, Anton Beláň, Ján Badžgoň, Zdeněk Diviš, Daniel Donoval, Martin Foltin, Otokar Grošek, František Janíček, Justín Murín, Ján Murgaš, Oldřich Ondráček, Miloš Orgoň, Jiří Sýkora, Boris Šimák, František Uherek, Erik Vavrinský

Odborný garant konferencie

Gabriel Juhás, dekan FEI STU v Bratislave

Redakcia

Ivan Sedlár, šéfredaktor
Viera Danišová, manažérka redakcie

Redakčné úpravy

Martin Šoka

Všetky príspevky boli odborne recenzované.

Toto mimoriadne číslo Časopisu EE vychádza pri príležitosti veľtrhu ELOSYS 2012 a konferencie Elektrotechnika, Informatika a Telekomunikácie 2012
Tlač: Nakladateľstvo STU v Bratislave

Adresa redakcie

Časopis EE, Ilkovičova 3, 812 19 Bratislava 1
tel.: 02/60 29 15 74, tel./fax: 02/65 42 58 21
e-mail: sedlar@casopisee.sk, danisova@casopisee.sk
www.casopisee.sk

Pretlač je dovolená s písomným súhlasom redakcie ● Nevyžiadané rukopisy sa nevracajú ● 6 vydaní ročne ● Zaregistrované MK SR pod číslom EV 3135/09 ● Podávanie novinových zásielok povolené RPP v Bratislave č. r. 571-RPP/95 zo dňa 16.5.1995 ● ISSN 1335-2547

Telekomunikácie

Elektronika a jej vplyv na kvalitu života

Aplikovaná informatika a sieťové riadenie

Elektroenergetika a aplikovaná elktrotechnika

Časopis EE, VOL 18. NO 5/S, 2012, 178-181

DYNAMIC PARAMETERS OF SOLAR CELLS UNDER ILLUMINATED CONDITIONS

Vladimír Ďurman* — Milan Perný* — Vladimír Šály*

The goal of this work is to present a new improvement of the complex impedance technique and its application on the solar cell/module study. By means of a new complex impedance technique the solar cell static and dynamic parameters (dynamic resistance, parallel capacitance and minority carrier lifetime) can be detected from the measured data. The obtained dynamic parameters, especially the minority carrier lifetime under illuminated conditions around a maximum power point, are important in research and development of solar cells. The measurements (marked as Fourier transform (FT) approach) were performed using digital oscilloscope connected with signal generator. Suitable software (Matlab in our case) was used to analyse harmonic components of the input/output signal by Fourier transform.

Keywords: Solar cells, capacitance, Fourier transform, minority carrier lifetime, maximum power point

1 INTRODUCTION

Increase in photovoltaic industry activates demand for fast, accurate and relatively simple testing of solar cells and modules. The solar cell tests can be accomplished in the form of DC or AC measurements. As we cannot obtain the dynamic parameters by the DC methods, obviously, the AC methods are preferred. AC measurements are suitable tool for determination of the solar cell static (series resistance, shunt resistance) and dynamic (dynamic resistance, parallel capacitance, minority carrier lifetime τ) parameters. Monitoring of the lifetime of minority carriers in the process of research and manufacturing is important due to its effect on potential cell efficiency. Determination of the parallel capacity of the photovoltaic (PV) module/cell is required for design of the control unit (charge controller), which controls the flow of current in an electrical circuit. A usual way of the AC measurement is the impedance method. Nowadays, the impulse voltage method provides a good alternative to the conventional impedance AC measurements. In our contribution we present the use of this enhanced method for monitoring of static and dynamic parameters under illumination in the maximum power point (MPP) and its surrounding.

2 SOLAR CELL DYNAMIC PARAMETERS

Description of the dynamic behaviour of PV cell is usually based on AC equivalent circuit (Fig. 1.). In this circuit, similar to the static (DC) model I_{ph} represents photogenerated current, series resistance R_s represents several partial contributions but especially the emitter/base resistance, the contact resistance and the resistance of the top and rear metal contacts, the shunt resistance R_{sh} represents power losses in solar cells by providing an alternate current path for the light-generated current. The dynamic model also includes additive components as capacitance C_{diff} which arises from the rearrangement of the minority carriers injected into the quasi-neutral region, capacitance C_{depl}, which expresses the capacity behaviour of pn junction, dynamic resistance R_d related to non ideality of pn junction, and grid inductance L_{grid}, which is the inductance of the metal fingers and wires. Generally, in the real conditions under illumination in MPP and its surrounding, the shunt resistance is substantially greater than the dynamic resistance. It implies that parallel resistance $R_p = R_{sh} \parallel R_d$ is close to R_d. In addition, the width of the depletion region appears to diminish and the depletion capacitance at the same time becomes negligible. That is, $C_{depl} << C_{diff}$ [1].

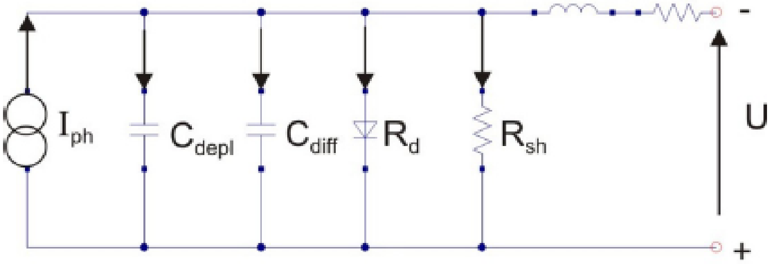

Fig. 1. AC circuit model of a crystalline silicon solar cell.

---

* Institute of Power and Applied Electrical Engineering, Slovak University of Technology, Faculty of Electrical Engineering and Information Technology, Ilkovičova 3, 812 19 Bratislava, Slovakia; vladimir.durman@stuba.sk

According to [2, 3], in the dynamic model the diffusion capacity and its relation to the minority carrier lifetime τ for low frequencies (ωτ<<1) can be defined as

$$C_{diff} = \frac{1}{2}\frac{\tau q}{k_B m} I_0 e^{\frac{qU}{mk_BT}} \quad (1)$$

Diffusion capacity and its relation to the minority carrier lifetime τ for high frequencies (ωτ>>1) can be defined as

$$C_{diff} = \left(\frac{\tau}{2\omega}\right)^{1/2} \frac{q}{k_B m} I_0 e^{\frac{qU}{mk_BT}} \quad (2)$$

where q is the elementary charge, k_B Boltzmann constant, m the diode factor, T the temperature and U is the applied DC voltage. The diffusion capacitance depends on the voltage and the frequency as it is seen from Eq. 1, 2.

Finally, from the designated equivalent circuit elements (R_d, C_{diff}) we can calculate the minority carrier lifetime τ as

$$\tau = \frac{R_d C_{diff}}{2} \quad (3)$$

3 EXPERIMENT

In our previous work we found that the dielectric spectroscopy of a solar cell can be accomplished by a special method with help of a high-speed memory oscilloscope [4]. It is based on acquiring the impedance data by a separate measurement of the voltage and the current through the solar object and calculation of the impedance from their ratio. Under these conditions, the measurement could be faster if the input voltage has the shape of a square wave [5-7]. When choosing the method, we must take into account, except of its speed, also precision and availability of the individual measuring instruments.

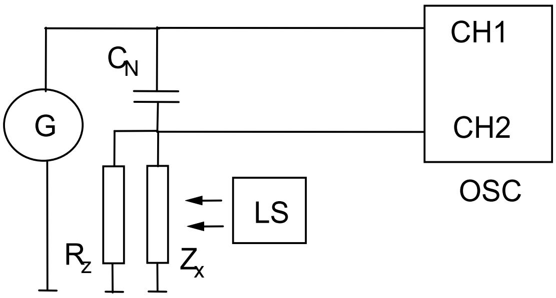

Fig. 2. Schematic of the measuring circuit.

In addition, in the case of solar cells we have to ensure the measurements with a bias superposition onto the periodic sinusoidal or impulse voltage.

Our measurements were performed with help of equipments according to the scheme in Fig. 2. Here, the impulse signal was applied from the DG 2021A RIGOL generator (assigned as G) to the capacitance divider consisting of the normal capacitance C_N (190 nF) and the solar cell impedance Z_x connected in series. The cell was loaded with the resistance R_Z. The impulse voltages on the both parts of divider were sampled separately through the two channels CH1, CH2 of the DSO 3062A Agilent oscilloscope (assigned as OSC). The sampling was synchronized with the generator through its special trigger output. Each result was an average from 256 consecutive measurements. The instruments were controlled by a PC with help of the GPIB connection. The impulse voltages on the capacitance divider were analysed by the Fourier transform. The frequency dependence of the solar cell impedance was computed from the first 5 harmonics. The amplitude of the square wave was 75 mV. All measurements were carried out on the mono crystalline silicon solar cell with standard front grid electrode system at room temperature. The cell was exposed to the radiation from the light source (LS) with power of 50 mW cm^{-1}.

4 RESULTS

Before realization of the impedance measurements, the current-voltage characteristic of illuminated specimen was examined at five loading resistances. This is depicted in Fig. 3. Then the impedance measurements were performed with the same light and load conditions as in the case of current-voltage characteristic.

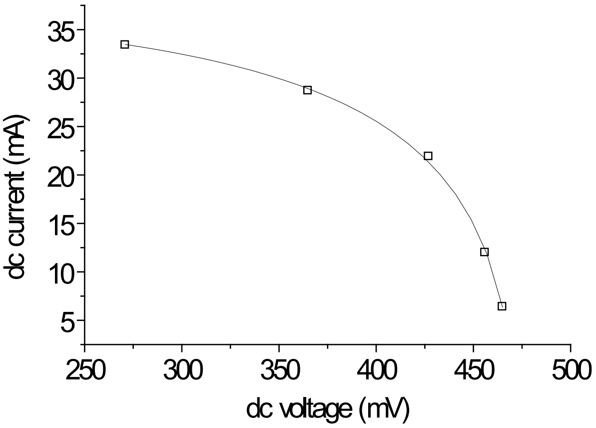

Fig. 3. Current-voltage characteristic of the solar cell.

The impedances were divided into their real and imaginary parts. The results of this stage of experiments are in Figs. 4–5. The impedances in the mentioned figures depend on the loading resistance, which is indicated with the dc voltage as the line parameter. The measured values of impedances $\mathbf{Z}$ were then fitted by the following formulae for the real (Re) and imaginary (Im) parts:

$$\mathrm{Re}(\mathbf{Z}) = \frac{R_p}{1+\omega^2 T^2} + R_s, \quad (4)$$

$$\mathrm{Im}(Z) = -\frac{\omega T R_p}{1+\omega^2 T^2}, \quad (5)$$

where ω is the angular frequency, R_p is the resistance of the parallel RC equivalent circuit, C is the capacitance of the equivalent circuit, T is the time constant ($T=CR_p$), and R_s is the series resistance.

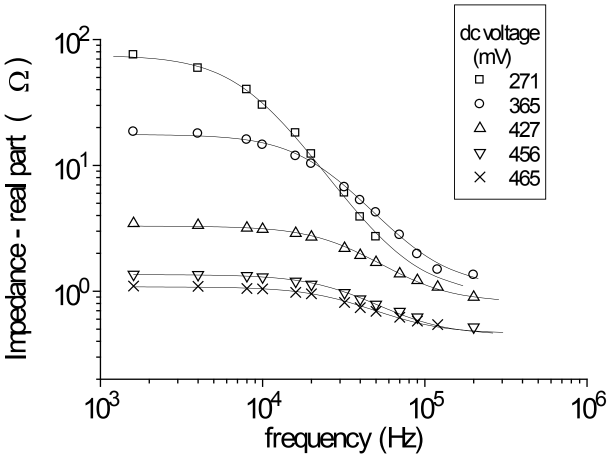

Fig. 4. Frequency dependence of the real part of impedance (points - measured data, lines - calculated data).

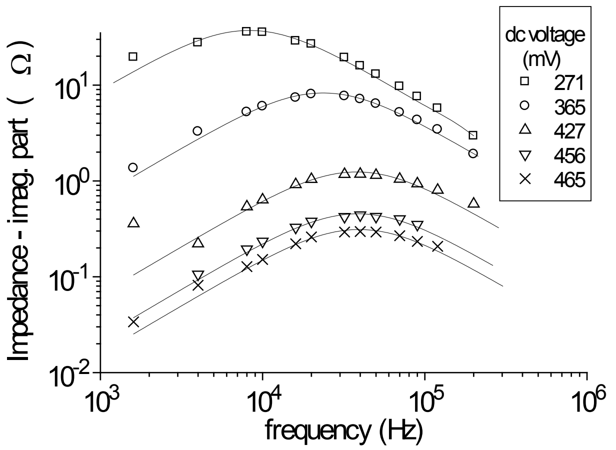

Fig. 5. Frequency dependence of the imaginary part of impedance (points - measured data, lines - calculated data).

The calculated values of R_p and C are shown in Fig. 6 with the same x co-ordinate as in the current-voltage characteristic.

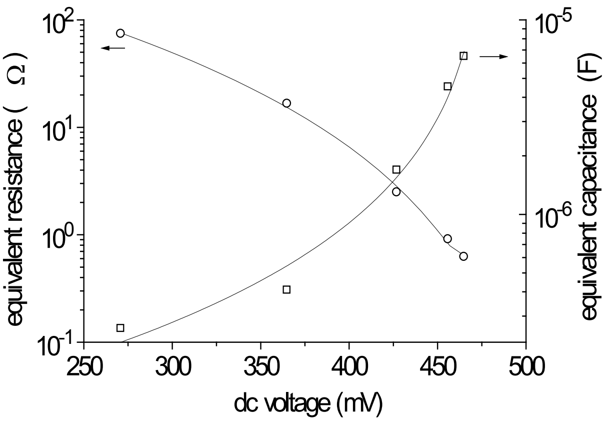

Fig. 6. Variation of C and R_p with loading conditions.

The list of all experimental data can be found in Tab. 1.

Tab. 1. Summary of the measured and calculated results

dc voltage (V)	dc current (mA)	C (10^{-7}F)	R_s (Ω)	R_p (Ω)	τ (10^{-6}s)
0.271	33.4	2.58	0.93	74.2	-
0.365	28.7	4.07	1.06	16.5	3.36
0.427	21.9	16.8	0.81	2.48	2.08
0.456	11.9	45.1	0.44	0.90	2.03
0.465	6.40	64.8	0.46	0.62	2.01

5 CONCLUSION

The impulse voltage method provides a good alternative to the conventional impedance measurements. It could be used mainly in the case, when a proper precise LCR meter is not available or in the case when there is a demand on quick measurements with lower precision. The precision in our case was also influenced by a small (8-bit) resolution of the dual channel oscilloscope. It must be also mentioned, that in contrast with the LCR meter measurements, the amplitudes of the individual harmonics at impulse voltage are not constant. They decrease in inverse proportion to their order, which can be an obstacle at examination of voltage sensible specimens. The consequence of a rapid decrease of the amplitudes is a small usability of higher harmonics. Moreover, the impulse voltage generates only odd harmonics. This factor terminates the speed of entire equipment. Despite of the mentioned disadvantages, the method can be successfully applied also in such a special case, as is the impedance measurement of a solar cell in illuminated stage. Our results proved a rapid increase of the solar cell equivalent capacitance in order of two decades and also the same rapid decrease of the equivalent resistance. The series resistance varies approximately between the values of 0.5 and 1 Ω, but we cannot make any definite conclusion about its course because of the measurement uncertainty. Namely, any junction resistance of the connecting wires can reach the value of about 0.1 Ω. The results of measurements were also used for calculation of minority carrier lifetime in maximum power point conditions under illumination. We found that the minority carrier lifetime is nearly constant around MPP. The physical background of the observed phenomena at the interfaces in the solar cell structure will be treated in a separate paper.

Acknowledgement

This contribution/publication is the result of the project implementation Wind and solar Electrical Accumulation System, ITMS 26220220133 supported by the Research & Development Operational Programme funded by the ERDF.

REFERENCES

[1] LUCIA, M. L. - HERNANDEZ-ROJAS, J. L. – LEON, C. - MÁRTIL, I.: Capacitance measurements of p-n junctions: depletion layer and diffusion contributions, Eur. J. Phys. **14** No. 86 (1993), 86-89

[2] MILLMAN, J., - HALKIAS, C. C.: Integrated Electronics, McGraw-Hill, New York, 1972

[3] KUMAR, R. A. - SURESH, M. S. - NAGARAJU, J.: Silicon (BSFR) solar cell AC parameters at different temperatures. In: Solar Energy Materials & Solar Cells **85** No. 3. (2005), 397-406

[4] ĎURMAN, V. - PERNÝ, M. - ŠÁLY, V.: Impedance spectroscopy of solar cells, Renewable energy sources 2012, Tatranské Matliare Slovak Republic, May 15-17, 2012

[5] KUMAR, R. A. - SURESH, M. S. - NAGARAJU, J.: Measurement of AC parameters for gallium arsenide (GaAs/Ge) solar cell by impedance spectroscopy, IEEE Trans. Electron Devices **48** No. 9 (2001), 2177–2179

[6] SURESH, M. S.: Measurement of solar cell parameters using impedance spectroscopy, Solar Energy Materials and Solar Cells **43** No. 1 (1996), 21-28

[7] CHENVIDHYA, D. - KIRTIKARA, K. - JIVACATE, J.: A new characterization method for solar cell dynamic impedance, Solar Energy Materials and Solar Cells **80** No. 4 (2003), 459-464