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# IDENTIFICATION OF PHOTOVOLTAIC MATRIX IN REAL TIME

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**Abstract**: *This paper describes the adaptation of the modified method of opinion the residuums in identification of state the photovoltaic cell. It was introduced the "window classifier" of conditions of work the tested the photovoltaic matrix as well as define the liminal coefficient of efficiency. Comparison got residuum with acceptable coefficient allow on effective opinion of state photo-cell in real time.*

**Key words**: *residuum, classification, photovoltaic, real time.*

## INTRODUCTION

During recent years the interest in the use of solar energy grew permanently. The use of photocell sets in the form of photovoltaic matrices constantly increases.

Practical use of photovoltaic cells increases. They are applied in low power equipment (watches, calculators, signaling lamps, lighted road signs, car park automates, emergency highway points, toys, chargers, electronic thermometers), middle power (automatic weather stations, building integrated roofs, solar facades, spaceships, pumps, fountains, sea beacons, automatic monitoring), and high power (photovoltaic PV power stations connected to the power net) [1]. The most ambitious solutions foresee construction of satellite solar power stations. Such solar batteries should be more efficient, as solar radiation would reach them continuously, without overcoming the atmospheric barrier.

Important in diagnostic and identification of state the photo-cell are the changes resulting from natural environmental conditions mainly. In exploitation of photovoltaic matrix one should call attention on temperature of environment $T$ and quality of lighting $D$, which value exerts the largest influence on voltage of photo-cell - example - non-linear element [2,3].

The photovoltaic matrix, taking into account the environment it operates in, is an example of a part particularly exposed to changing environment conditions that affect its efficiency and quality of the voltage signal emitted by it.

The identification of state be described many the methods eg with domain of statistics. The authors propose the adaptation of the residuums method extended with classification of conditions of work.

## 1 THE METHOD OF RESIDUES

In the method of residues the measurement result denoted as $y$ is compared to the signal $\hat{y}$ generated by the residue generating model (1).

$$r = y - \hat{y} \qquad (1)$$

In an ideal case, under correct operation of the object, value of the residue should be equal to zero, while once a damage or failure arises, its value is non-zero (Fig. 1).

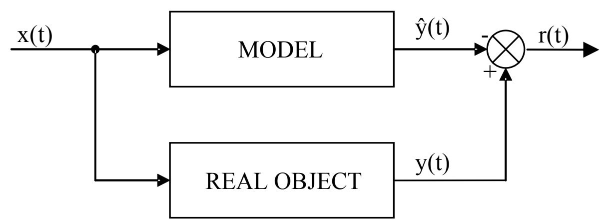


*Fig.1: Schematic diagram of the method of residue assessment: x(t) – the excitation in given moment of time*

The authors in the presented paper make a proposal to call an instantaneous voltage signal *y(t)* the tested signal, and the $\hat{y}(t)$ the pattern signal, derived from the measurements carried out earlier in order to be used as the reference pattern measurements. It should be noticed that the pattern signal is not derived from the mathematical model but is selected from the database of the archived pattern measurements. The database includes average values of the pattern voltages for definite "classifier" windows. Additionally, the assumption of keeping a constant load level during all the test trials has been met.

## 2 A WINDOW CLASSIFIER OF OPERATION CONDITIONS

In order to "settle" the results of identification obtained with the use of the method of residues in the appropriate range of the operation conditions the theory of statistical classification was used.

The statistical classification is a kind of a statistical algorithm assigning the objects among particular classes, basing on the attributes (features) of the objects. In a formal way, the problem may be presented as follows: for a given file of training data $\{(a_1,b),\ldots,(a_n,b)\}$ such a classifier $h$: $a \to b$, should be found that assigns a class $b \in B$ to the $a \in A$ object. For example, should the problem be related to filtering the measurement conditions, the $a_i$ is for representation of the measurement while $b$ is a respective area of the measurement conditions. Taking into account that the measurement conditions are delimited to two parameters (light intensity is represented by the lighting quality $D$[%], temperature $T$[ºC]), a file of $b$ classes should be determined that correspond to certain ranges of variability of the parameters. In this case the archived samples of current-voltage characteristics of the photovoltaic matrix must be properly sorted with regard to appropriate classes $b$.

Taking into account the need of clear assignment of a measurement series $a$ to the classes of measurement conditions $b$ a window classifier of conditions of the photovoltaic matrix operation was designed, the classes of which are represented by the rectangles of variability of the parameters $D$ and $T$ (Fig. 2).

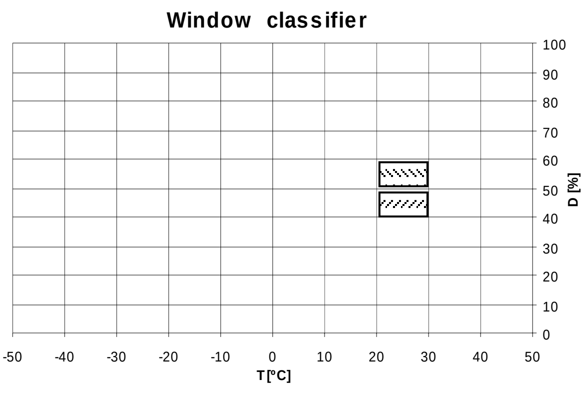


*Fig.2: The window classifier Y of variability of the parameters T and D*

Attachment of a given measurement series to a definite classifier class enables minimizing the errors caused by slowly varying operation conditions. All the pattern data (voltage values) corresponding to faultless operation will be assigned to respective classes. It was decided to create 100 classes denoted as $y_{DT}$, where $dt$ is for consecutive row ($d$) and column ($t$) numbers, to which a proper rectangle is assigned that is related to the ($D,T$) parameters resulting from the operation conditions.

In order to formulate a representative family of pattern voltage signals a decision was made to determine averaged voltage values for each of the classifier "windows", respectively. Taking into account the experimental data it was assumed that maximal deviation of voltage values of the diagnosed module as compared to the average level of a given window, does not exceed $\delta U_{\max} = 25\%$.

The definite threshold $\delta U$ allows for defining the efficiency degree (with the method of residues) of the surveyed photovoltaic matrix. The matrix is considered as efficient provided that the following condition is met:

$$r < \Delta U_{\max} \qquad (2),$$

where $\Delta U_{max}$ is for maximal absolute voltage deviation from its average value for a given measurement window.

## 3 EQUIVALENT SCHEME OF A PHOTOCELL

In order to assess the effect of the temperature $T$ and the quality of lighting $D$ on the current efficiency of the photocell a standard equivalent scheme has been selected for a model of three parameters (Fig. 3), the mathematical description of which allows for accounting the effect of considered environmental conditions on the current generated.

Taking the following denotations: $I_0$ – the diode "dark" (saturation) current; $q$ – elementary charge ($1.6\cdot10^{-19}$As), $k$ – the Boltzmann constant ($8.65\cdot10^{-5}$eV/K); $T$ – temperature [ºC], one can formulate the following expression for the output current (3) [3].

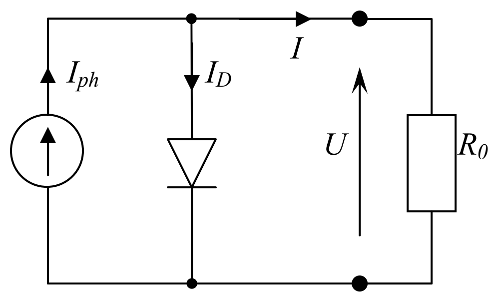


*Fig.3: An ideal equivalent scheme of a photocell in case of a three-parameters model: $R_0$ – resistance of the load; $I_{ph}$ – the current flowing through the irradiated cell; $I_D$ – the current flowing through a large-surface diode; I – the load current; U – voltage drop [V] at the receiver $R_0$ [3]*

$$I = I_{ph} - I_D = I_{ph} - I_0\left[\exp\left(\frac{qU}{k(T+293.15)}\right)-1\right] \quad (3)$$

The effect of temperature $T$ is directly visible in the formula (2), while the $I_{ph}$ current is proportional to the lighting quality $D$. According to the scheme of the Figure 3, the lighting quality $D$ significantly affects the current efficiency of the photocell, while the temperature $T$ (apart from the load) considerably influences the diode current $I_D$.

## 4 LABORATORY RESEARCH STAND

It is assumed that the matrix is described with the help of the parameters of known probability distributions [4].

The laboratory measuring stand includes (Fig. 4): a photovoltaic module Shell ST20 of outer size 748×328×35mm (the weight of 4100g), a decade resistor D14 kl. 0.1, a TH-03 converter (3-channels, the dimensions 125×60×30, computer communication through a series port COM; $T$ temperature measurement: an EL015 sensor of resolution of $\pm 0.01^{\circ}C$; $D$ lighting quality measurement: two EL031 sensors of resolution of $\pm 0.1\%$), the conductors with plugs, a PC computer with a software developed by manufacturer of the Pico measurement converters (temperature and lighting quality measurement), microcontroller PIC18F8722 (an AC-converter: voltage measurement with the help of a voltage divider, current measurement with a shunt), digital meters (verification of accuracy of the AC-converter read-out); an intermediate I/O system (including a voltage divider provided with a Zener diode, protecting the AC converter against overvoltage and a shunt for current measurement) designed for physical connecting the photovoltaic module, resistor, meters, and microcontroller.

Reception, processing, and transmission (RS232) of the measured values at the microcontroller level have been implemented with the help of C Language. The final application (developed in the Delphi environment) fulfils many functions, among others ensures two-directional communication with the microcontroller (e.g. possible changes in signal sampling frequency). The application computes average value of the illumination quality $D$, plots the I=f(U) characteristics, and allows for exporting the measurement results to the Excell Sheet or recording them in the form of a graphic plot. It is provided with an approximation function, etc.

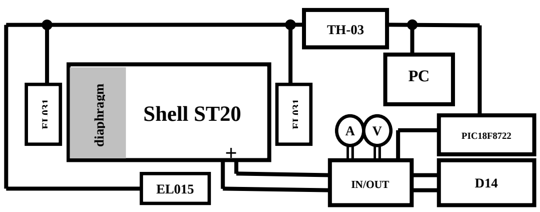


*Fig.4: Block diagram of a laboratory measuring stand*

## 5 SIMULATION OF OPERATION CONDITIONS

Usefulness of laboratory measurements results from possible simulating of real conditions in a laboratory room. Such an action speeds up the rate of measurement procedure and eliminates the effect of poorly foreseeable weather conditions. Additionally, dynamics of the conditions changes, like the quality of lighting (illumination) or temperature does not deviate from feasible real variations of the parameters, provided that proper attempts are made.

During execution of the laboratory measurements the natural conditions of the module operation are simulated by:

- changing the quality of lighting (e.g. by switching on and off artificial light sources, except for the sources emitting a pulsating light, for example the fluorescent lamps [3]),
- changing temperature (e.g. by ventilation of the room or heating the module and its environment with a flow of heated air or applying crumbled ice to the module surface),
- switching off a part of the module (simulation of a failure or shading, by full covering of a part of working surface of the module).

Advantage of the simulation study (as opposed to the measurement performed in natural environment) consists in possibility of free imposing the preferred changes in working conditions of the module.

## 6 RESULTS OF MEASUREMENTS

The measurements included the following trials:

- recording of the output voltage patterns $U$ [V] of the module of several seconds duration, the lighting quality $D$ (in the range $0 \div 100\%$), and temperature $T$ [ºC]. The trials were three times repeated in short time intervals, thus minimizing possible changes in the measurement conditions, under varying load and faultless operation,
- recording as above but with a part of the module surface switched off (simulation of failures of the photovoltaic cells).

The measurements have been carried out for a constant load resistance $R_0$=1000Ω, constant temperature T≈16.46ºC, and varying illumination quality $D$ resulting from dynamic weather pattern on the testing day (quickly varying cloud cover). Several series of sample voltage sample records have been made, with the recording frequency f=2s.

Fig. 5 shows the voltage pattern with regard to the illumination quality $D$.

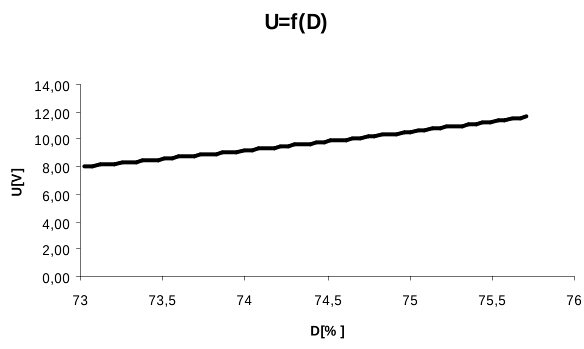


*Fig.5: Dependence of voltage U on the illumination quality D in the $y_{77}$ class*

Average value of voltage in Fig. 5 amounted to $U_{śr}=\hat{y}(t)$=10.29V. Maximal voltage deviation from its average value was equal to $\Delta U_{max}$=2.31V that gives $\delta U_{\max} = 22,45\%$. The data are related to the $y_{77}$ class of the window classifier of operation conditions of the considered photovoltaic matrix. It may be noticed that a slight variation of the *D* parameter results in remarkable changes in the generated voltage.

Fig. 6 presents the dependence U=f(D) for more stable illumination conditions.

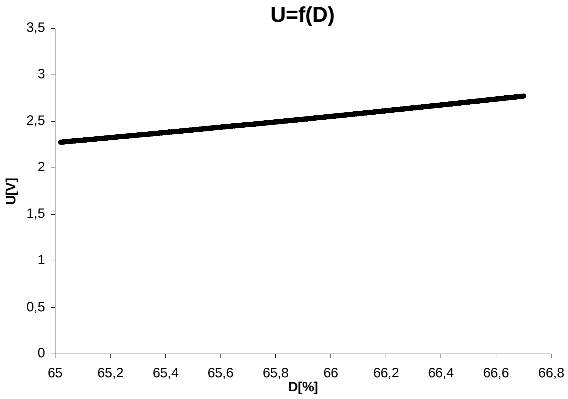


*Fig.6: Dependence of voltage U on the illumination quality D in the* $y_{67}$ *class*

Respective values for the $y_{67}$ class amounted to $U_{śr}=\hat{y}(t)$=2.55V, $\Delta U_{max}$=0.32V, $\delta U_{\max} = 12,55\%$.

For the class $y_{67}$ similar measurements have been performed upon disabling of a part of the matrix surface, using the screen. A percent screening was denoted by $\delta S$. Table 1 shows the results of the experiment.

| $\delta S$ [%] | $U_{śr}=\hat{y}(t)$ [V] | $U_{śr}=y(t)$ [V] | $r$ [V] | $\Delta U_{max}$ [V] |
|---|---|---|---|---|
| 29.1 | 2.55 | 1.76 | 0.79 | 0.32 |
| 12.5 | 2.55 | 2.43 | 0.12 | 0.32 |

*Tab. 1: The effect of disabling of a part of the matrix surface on the residue value in the* $y_{67}$ *class*

The results of the experiment show that in case of a larger screen the method of residues enables detecting the defect of a part of the matrix surface. Unfortunately, for smaller surface the method failed. Nevertheless, the residue level is proportional to the screen surface. The percent value of the residue amounts approximately to 31 in case of disabling 29.1 percent of operating surface of the matrix, and 4.7 percent for the screen of $\delta S$=12.5%. This gives evidence that the rate is not linear, due to quick variations of operation conditions in the considered $y_{67}$ class.

## 7 RESUMES

The modification of residuums method allows to detect the influence of variables of conditions environment on the work of photo-cell. Particular attention should be paid to effectiveness of the presented method in case of the defects of larger surface of photovoltaic matrix. A conclusion should be drawn that for purposes of further research the class ranges of a window classifier should be narrowed and, at the same time, their number should be increased. Then the voltage deviation from its average value in a given window shall take a smaller value and its comparison to the residues should allow for obtaining more reliable diagnostic assessment. Further stage of the research should consist in experimental adaptation of the span of the window classifier to current operation conditions in order to improve assessment accuracy of the considered photovoltaic matrix.

## 8 REFERENCES

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