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LABVIEW SIMULATION OF A MATHEMATICAL MODEL FOR RAPID VARIATIONS OF AMBIENTAL CONDITIONS ON A PHOTOVOLTAIC CELL

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Abstract: *This article presents a mathematical model used to anticipate the module temperature which is based on real parameters measurements of the photovoltaic ensemble such as: ambient temperature, wind velocity, wind direction and relative humidity. The adopted mathematical model is capable to generate the temperature of the photovoltaic model using only three of the input data.*
The results obtained after running the chosen mathematical model in the LabView simulation program shows that the cell generated current and power are proportionally rising with the wind velocity. Also, the variation of the output power produced by the photovoltaic cell between the extreme values of the wind velocity is 0.021W and also, the higher current is produced, as it was accepted, at the highest wind velocity.
Key words*: LabView, mathematical model, wind influence, wind velocity*

INTRODUCTION

In order to anticipate the output electrical energy of an electrical photovoltaic module, we must anticipate, first, the module temperature function of the environment temperature, wind speed and direction, total irradiation and not in the last place the relative humidity.

This article presents a mathematical model that can anticipate the module temperature and this is based on measurements of the real parameters of the photovoltaic ensemble such as: environment temperature, wind speed and direction and also the relative humidity. The Electrical and Electronics Engineering Institute standard (IEEE), requests the photovoltaic module temperature in order to anticipate the output voltage based on the environment temperature, the wind speed and direction, total irradiation and relative humidity.

Because all the thermal properties of a photovoltaic module can vary in time, it is necessary the implementation of an universal mathematical model which can provide a pattern for the analysis and also to provide the photovoltaic ensemble temperature.

DATA COLLECTION ABOVE THE MODULE

In order to obtain the environment conditions, a weather station which can provide the environment temperature, the relative humidity and also the wind speed and direction was installed near the photovoltaic module. The data is read at every five seconds and then is realized an average value for each five minutes. The photovoltaic module used in the research program are presented in table nr. 1.

Table 1 – Module information

	Cell Technology	**Module Number**
1.	a-Si	3

RESULTS AND INTERPRETATIONS

The first challenge achieved was the development of a mathematical model capable to generate the photovoltaic module temperature based on five input parameters: the environment temperature, the relative humidity, wind speed and direction and the global irradiation. The wanted equation for the module temperature generation being:

$$T_{module} = w_1 \times T_{ambient} + w_2 \times Irradiance + w_3 \times WindSpd + w_4 \times WindDir + w_5 \times Humidity + Const \quad (1)$$

The second challenge was to develop a mathematical model that can provide the photovoltaic temperature based only on three input parameters: the environment temperature, the wind speed and the global irradiation. The wanted equation for the module temperature generation being:

$$T_{module} = w_1 \times T_{ambient} + w_2 \times Irradiance + w_3 \times WindSpd + Const \quad (2)$$

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Table 2 – Data for the five parameters equation

Technology	Module	Tamb w1	Irradiance w2 (°C/W.m^{-2})	WindSpd w3 (°C/ms^{-1})	WindDir w4 (°C/deg)	Humidity w5 (°C/RH%)	const (°C)
Amorphous Si	1PTL	0.945	0.025	-1.255	0.009	0.181	-2.1
	2PTL	0.946	0.025	-1.304	0.010	0.158	-1.8
	3PTL	0.981	0.028	-1.647	-0.007	0.102	3.1
	4PTL	0.993	0.028	-1.697	-0.016	0.090	4.7
	5NREL	0.979	0.023	-1.280	-0.001	0.018	3.2
	6NREL	0.959	0.029	-1.433	-0.006	0.006	5.7
	7NREL	0.947	0.026	-1.222	-0.001	0.015	4.6
	Average	0.964	0.026	-1.406	-0.002	0.082	2.5

Table 3 – Data for the three parameters equation

Technology	Module	Tamb w1	Irradiance w2 (°C/W.m^{2})	WindSpd w3 (°C/m.s^{-1})	const (°C)
Amorphous Si	1PTL	0.930	0.025	-1.321	2.7
	2PTL	0.937	0.025	-1.373	2.7
	3PTL	0.947	0.027	-1.610	4.1
	4PTL	0.943	0.027	-1.605	4.2
	5NREL	0.958	0.023	-1.353	4.4
	6NREL	0.952	0.029	-1.604	5.4
	7NREL	0.930	0.026	-1.288	5.5
	Average	0.943	0.026	-1.450	4.1

An analysis was made on an amorphous-Si photovoltaic module using the parameters from tables 2 and 3. The graphic interpretation revealed the fact that the mathematical model based only on three input parameters it is superior to the one with five input parameters. The reason why is happening this abnormality is that the errors caused by the last two parameters have a major impact on the final result, in the circumstances that we can neglect them.
These readings show us that the three parameters mathematical model can be used in order to generate the module temperature in the manner that the next equation describes it:

$$T_{module}\,(°C) = \quad 0.943 \times T_{ambient} + 0.028 \times Irradiance - 1.528 \times WindSpd + 4.3 \qquad (3)$$

Where the measurement unit for $T_{ambient}$ is "°C", for irradiance is W/m^2 and the measurement unit for the wind speed is m/s. A short analysis on the parameters values presented in tables 2 and 3 shows that the photovoltaic module temperature is signified determinate by the environment temperature an irradiation. The environment temperature generate the module temperature and the irradiation generates the module ΔT rising which is around the 0.028 °C per W/m^2. On the other side, the module temperature decreases approximately with 1.45 °C when the wind speed is rising with 1m/s.

MATHEMATICAL MODEL OF EMBARKED PV MODULE

The simulation purpose of a PV cell function to rapid irradiations variations, which more accurate means, to a variation of the tilt angle once with the oscillations moves of the ship, is to implement the mathematic model of the ship oscillatory movements into a PV cell mathematic model. Because the only ranging parameter that is swinging in the same time with the tilt angle is the solar irradiation, which is always taken like a freestanding value in most of the mathematic models of the PV modules, we chose to use for the simulation the model with only one diode.
For the calculations simplification and also because the simulation take place only once a day with constant irradiation, we considered that the direct irradiation (4) and the diffuse one (5) are

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constant, and the albedo irradiation(6) varies with the tilt angle of the PV module.

$$Beam_{Inc} = Beam_{Hor} \cdot \sin H_{soli}/H_{sol} \qquad (4)$$

$$Diff_{Inc} = Diff_{Hor} \cdot \left[(1-K_B)\cdot\frac{(1+\cos i)}{2} + K_B \cdot \sin\frac{H_{soli}}{H_{sol}}\right] \qquad (5)$$

$$Alb_{Inc} = \rho \cdot Glob_{Hor} \cdot \frac{(1-\cos i)}{2} \qquad (6)$$

where: i – tilt angle, H_{sol} – Sun high measured from the horizon, H_{soli} – Sun high measured from the tilt plane (equals with 90°-incidental angle), K_B – clearness irradiation beam index (6), I_o – solar constant, ρ – albedo.

$$K_B = Beam_{Hor}/I_o \cdot \sin H_{sol} \qquad (7)$$

In this way, the incident irradiation on the PV module collector plan is equal with the global horizontal irradiation, specific with the projection on the surface of the collector plan. As the PV module oscillates in the same time with the ship, the incident solar irradiation will have a reference value for a horizontal orientation and will vary directly proportional with the cosine of the tilt angle of the ship.

The embarked PV cell model relations for roll and pitch are:

$$\begin{cases}\varphi = \varphi_A \cos(\omega_\varphi t - \beta_\varphi)\\ \theta = \theta_A \cos(\omega_\theta t - \beta_\theta)\end{cases} \qquad (8)$$

where: φ – roll angle [rad], θ – pitch angle [rad], φ_A, θ_A– maximum roll and pitch angle, ω_φ ,ω_θ– circular frequencies for roll and pitch, β_φ, β_θ–initial phase of roll and pitch angles.

$$I = [I_{SC} + K_i \cdot (T - T_r)] \cdot \frac{S \cdot \cos(\varphi_A \cos(\omega_\varphi t - \beta_\varphi))}{S_R} - I_0 \cdot \left(e^{\frac{qV}{kT}} - 1\right)$$

$$I = [I_{SC} + K_i \cdot (T - T_r)] \cdot \frac{S \cdot \cos(\theta_A \cos(\omega_\theta t - \beta_\theta))}{S_R} - I_0 \cdot \left(e^{\frac{qV}{kT}} - 1\right)$$

(9), (10)

Realations (9) and (10) were used in simulation of embarked PV cell characterization at fast irradiation variation produced by ship's movements.

SIMULATION RESULTS

The most-known program for simulation PV cells and modules is Simulink from Matlab.Because of the fact that the data acquisitions programs, used in experiments with onboard PV panels, were realized in LabView, that will recognize in the future the Matlab-Simulink products, we realized the simulation of an embarked PV module function at rapid changes of irradiation, also in this program.

In figure 1 it is presented the LabView program's block diagram of an embarked PV module function at rapid changes of wind speed, constant irradiation and no ship's movements.

As it is presented above, the incident irradiation on the PV module plan it is composed of the direct and indirect irradiation to whom is added the irradiation from the albedo. So, the virtual instrument *Formula* computes the expression(6) and then it is added to the cosines of the total horizontal irradiation. Also on this block, the total incident irradiation of the PV module is reported to the reference irradiation value (1000W/m^2).

The values that can be introduced to this block are the albedo's and the total horizontal irradiation's ones. The simulation continues for the expression (8). The block *Iscr* computes the short-circuit current for a PV cell at a certain temperature according to the between-brackets expression from (1) relation. The reference temperature T_r is equal with 25°C (298°K) according with STC. The short-circuit temperature coefficient K_i (Kelvin) was settled to 0,0017 A/°C. The short-circuit current I_{scr} it is settled to the value of 0,63 A according with the table data of the 10 Wp PV panel, used in the next chapter for validation experiments. The PV temperature must be introduced by the operator in °C.

In order to check the mathematic model proposed and implemented in LabView, we realized a simulations with the input data of characteristics provided by the manufacturer for a 10Wp PV panel (Table 4)

Technical data of a 10Wp PV panel used in simulation and experiments

PV cell number	9
Rated power	10 W
Tension	17,85 V
Current	0,56 A
Free tension	22,18 V
Short-circut current	0.63 A

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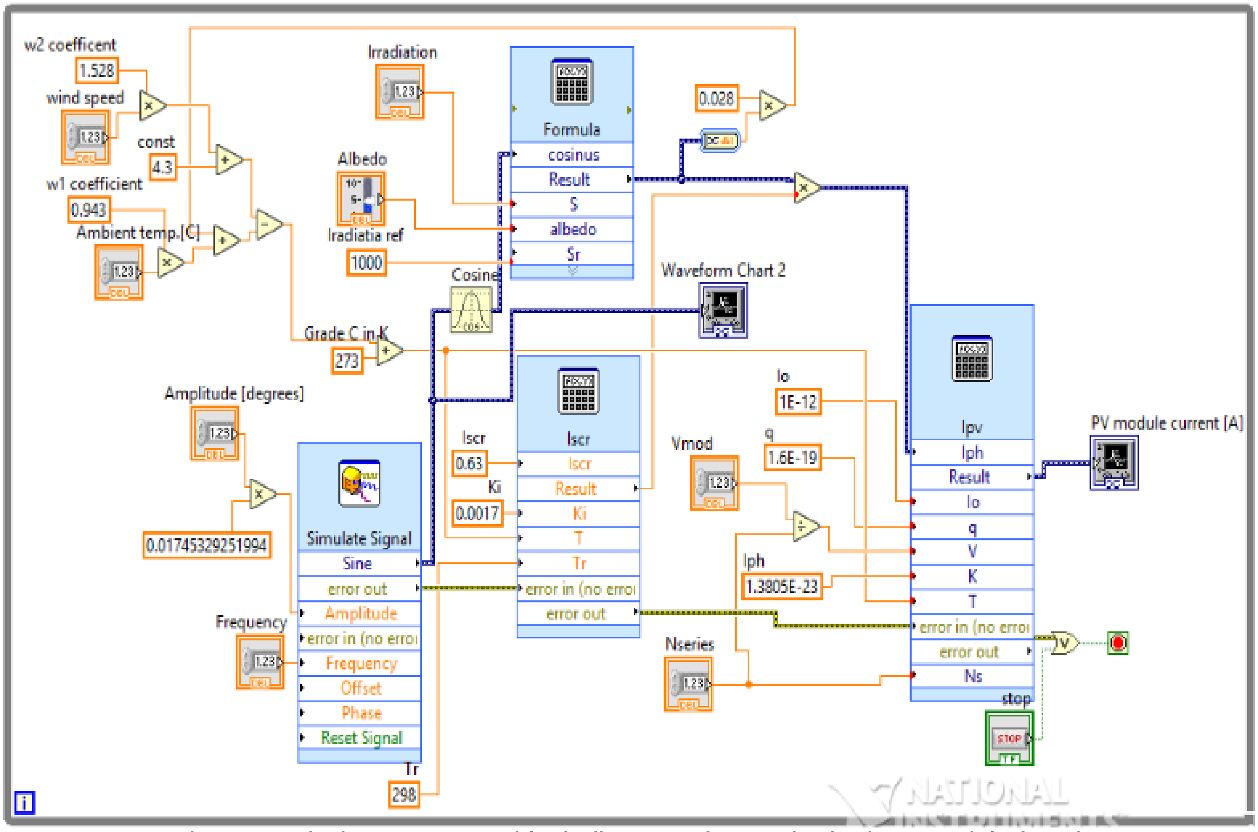

Figure 1.LabView program's block diagram of an embarked PV module function at rapid changes of wind speed

The simulation allows the view of results in real time as graphic charts and numbers. In other train of thoughts, in order to realize an analysis above the wind influence on a photovoltaic module we did a number of fifteen simulations considering only the ambient temperature (25 /°C) and the wind speed that is rising from 1m/s to 15m/s.

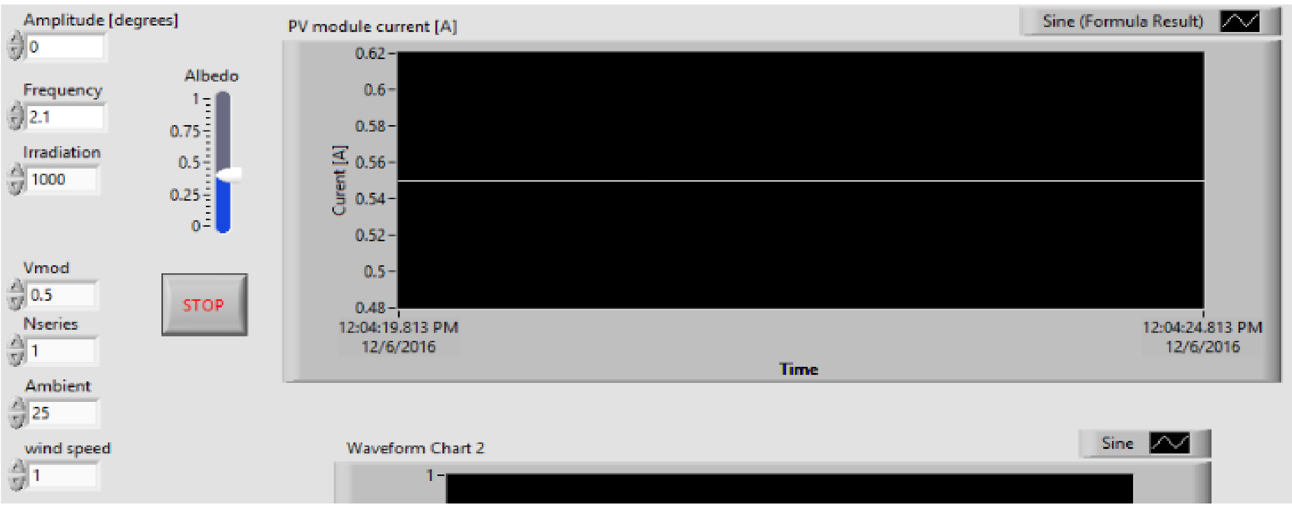

Figure 2.LabView program's front panel of an embarked PV module function at a wind speed of 1m/s

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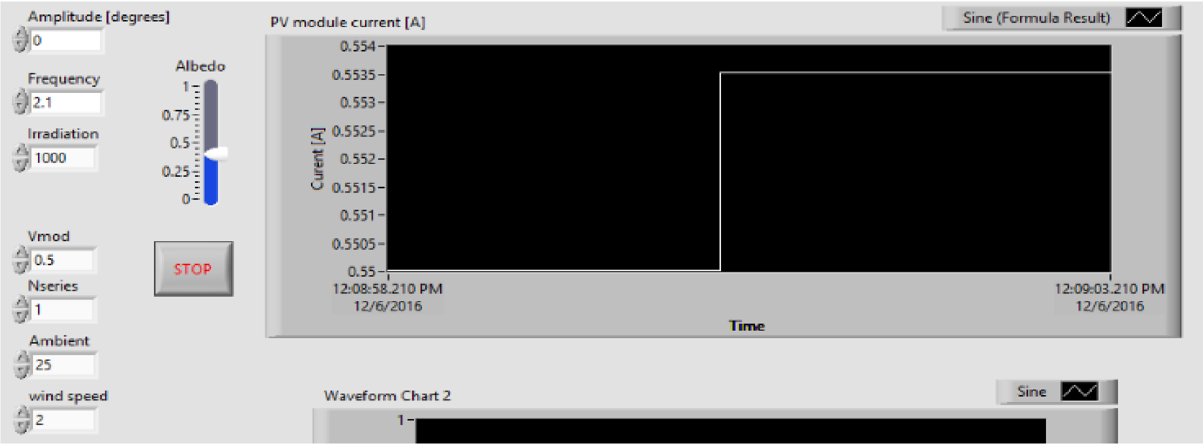

Figure 3.LabView program’s front panel of an embarked PV module function at a wind speed of 2m/s

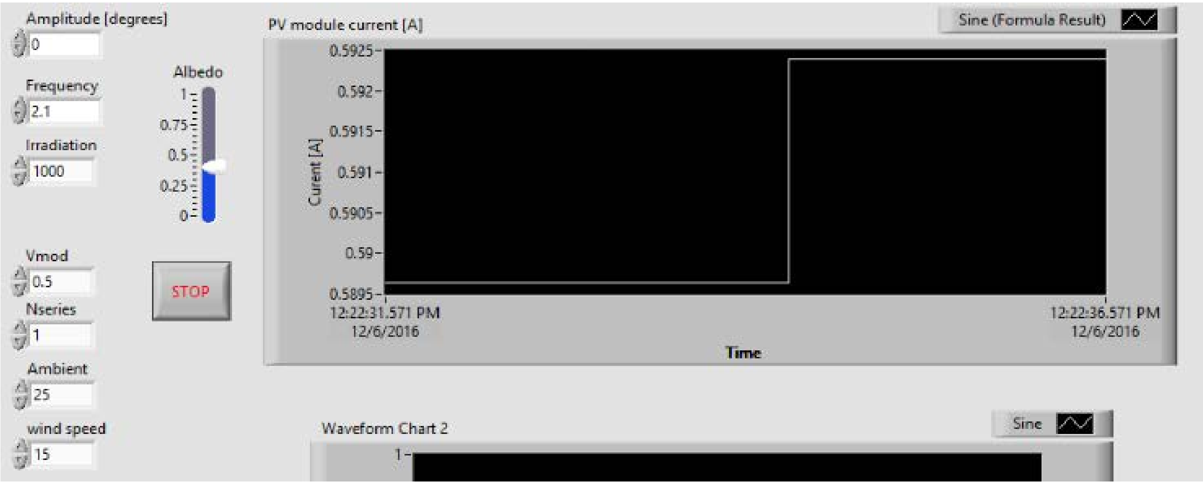

Figure 4.LabView program’s front panel of an embarked PV module function at a wind speed of 15m/s

Table 5 - Simulation results of an embarked 10Wp PV module

Ship tilt	Wind m/s	Voltage V	Current A	Power W
0	1	0.5	0.55	0.275
0	2	0.5	0.5535	0.2767
0	3	0.5	0.557	0.2785
0	4	0.5	0.5605	0.2802
0	5	0.5	0.5635	0.2817
0	6	0.5	0.567	0.2835
0	7	0.5	0.57	0.285
0	8	0.5	0.5725	0.2862
0	9	0.5	0.5755	0.2877
0	10	0.5	0.5785	0.2892
0	11	0.5	0.5815	0.2907
0	12	0.5	0.5845	0.2922
0	13	0.5	0.587	0.2935
0	14	0.5	0.59	0.295
0	15	0.5	0.5925	0.2962

After the simulation of an embarked 10Wp PV module function at different wind speeds and constant irradiation, we obtained the results presented in table 5. Analyzing the obtained data we can observe that the electric current produced by the photovoltaic cell and implicit it’s power are

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rising proportionally with the rising of the wind speed. The power variation of the cell between the extreme values of the wind speed was 0,021W and the maxim current is produced as it was accepted at the highest wind speed value

Conclusions

The conclusions of the study presented in this paper, shows that the implementation of renewable energy in naval domain should be made with a rigorous documentation and research, in order to obtain the best solution and effectiveness. Further research should be made on real onboard conditions and using more complex mathematical models for PV cells and ships' oscillations.

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