1ESTIMATION PERFORMANCE OF A PHOTOVOLTAIC SYSTEM CONNECTED TO THE GRID BY USING EVANS AND DURISCH MODELS

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Abstract

The paper is focused on analyzing a first grid connected PV system recently installed in the building of Institute of Geosciences, Energy, Water and Environment, composed by two sets of 12 panels of crystalline silicon modules connected in parallel with open circuit voltage 44.8 V DC and nominal power is 195 Wp. The objective of the study is finding a suitable empirical method to calculate electrical energy output of the system. Meteorological data (temperature, solar radiation, etc.) used for the calculation of electrical energy output for both methods are taken from the meteorological DAVIS station of the Experimental Laboratory of Faculty of Electrical Engineering, Polytechnic University of Tirana. A MATLAB code was developed to compare the results of each empirical method regarding to efficiency and productivity of electrical energy output. Comparison of experimental data of electrical energy output from a grid connected PV system and calculated values using two different empirical methods, Evans method and Durisch method, showed a consistence difference. Both empirical methods give greater values of output electrical energy than experimental ones. Good linear correlation between three sets of data, demonstrate that the greater part of differences originate from loses in electrical system of PV system. Modifying Evans method and Durisch method with respective linear approximation equations defined experimentally offers a good empirical equation which can be used in analytical analysis and modeling of the PV system. Not very good correlation coefficients show that further experimental data are needed.

Keywords**:** *photovoltaic system, empirical method, electrical energy output, grid connected, meteorological data.*

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1. Introduction

Both research and technological development in the area of renewable energy sources are necessary to account for the increase in energy demand and environment problems in the world. Stand-alone photovoltaic systems are the best solutions for such a communication system. Generally there exist two types of models for photovoltaic installations, electric and energetic models. The electrical model is equivalent to one or two diode model. The energetic model is used for measuring the output power of photovoltaic system, in such a given conditions. The purpose of using the models for photovoltaic installations is on calculations of the energy produced by the system, it is not important if the modeling is related to the solar radiations or the modeling of the tension and courant and for consequences the electric power. The aim of this work is to determine the best model of efficiency for photovoltaic installation in the climatic conditions of Tirana. The installation is in grid operation, grid-connected solar power cogeneration system that means no storage system as batteries is integrated in the building of Institute of Geoscience, Energy Water and Environment. The photovoltaic system is completed by the modules photovoltaic and the inverter, which is used to convert the courant from continuous current into the alternative current. The data for solar radiation are taken from the Experimental Laboratory of Faculty of Electrical Engineering, Polytechnic University of Tirana. The meteorological station which is installed in the building of Faculty of Electrical Engineering is a “Davis” one.

2. The efficiency models

Typical Meteorological Year data files include three solar radiation values: total horizontal, direct beam, and horizontal diffuse radiation. A radiation model is required to translate these energy values into the energy incident upon the PV module. PV module manufacturers provide performance data for their products only for fixed standard conditions of solar irradiance and operating temperature. This production of electric energy is depending from several factors:

- PV array peak power $P_{pv, peak}$;
- solar irradiation on PV module plane G_{β};
- PV module temperature cell θ_{cell};
- inverter efficiency and size $P_{inv, rated}$;
- PV module technology;
- inverter type;
- PV module inclination; and
- location of the PV system

In a first part, the hourly production for various PV module technologies is estimated using a model elaborated by Durisch et. al., Evans et al. [1, 2, 3] in optimal conditions (maximal power point conditions, MPP) because the PV array is supposed connected to an inverter integrating a maximum power point tracking losses (MPPT). The role of the inverter in the efficiency of the energy is out of this paper.

Power produced by the PV installations is given by:

$$P_{mp} = I_{mp} \times V_{mp} \qquad (2.1)$$

This expression is direct for calculation of the power, where the values for tension and courant are maximal. [7]

3.1 Durisch Model

Durisch et al. developed semi-empirical efficiency formulation usable for four PV technologies introducing the relative air mass AM. The experiment was based in four types of PV installations, mSi, pSi, aSi, CiS. The parameter AM is important in this model. This model is to be estimated in different local areas where, this model is closed to the real measurements for some types of climatic conditions. [1]
The empiric model of Durisch is given below:

$$\eta_{PV} = p\left[q\frac{G_\beta}{G_{\beta,0}} + \left(\frac{G_\beta}{G_{\beta,0}}\right)^m\right]\times\left[1 + r\frac{\theta_{cell}}{\theta_{cell,0}} + s\frac{AM}{AM_0} + \left(\frac{AM}{AM_0}\right)^u\right] \qquad (3.1)$$

Where G_β is the solar irradiance on the PV module tilted from β^0 have high effects on the PV efficiency, $G_{\beta,0}$=1000W/m^2, $\theta_{cell,0}$=25^{0}C and AM is the relative mass of air [5], in the normal conditions is AM_0=1.5.

$$AM = \frac{1}{\left[\cos\theta_z + 0.50572\left(96.07995 - \theta_z\right)^{-1.6364}\right]} \qquad (3.2)$$

With θ_z in degrees.
The parameters p, q, m, r, s and u have been determined for m-Si and are available in Ref. [1].

The temperature of cellules is calculated by the Ross formula [4]:

$$\theta_{cell} = \theta_a + hG \qquad (3.3)$$

θ_a is the ambient temperature and h is the Ross coefficient available in Ref. [4].

The efficiency of PV cell initially increases with increase of solar insolation and then, after achieving a maximum, starts to decrease with increase of solar insolation. The effect is explained with two different mechanisms related with increase of value of solar insolation acting simultaneously in PV cell. Initially increase of solar insolation increase energy absorbed in PV cell followed by an increase of electrical energy output of PV cell. A part of absorbed solar energy remains to PV cell causing increase of its temperature. It is a known fact that increase of temperature of PV cell decrease its of electrical energy output, resulting in a decrease of efficiency. [6]

3.2 Evans Model

The most known model for the efficiency of the photovoltaic module is:

$$\eta_{PV} = \eta_{ref}\left[1 - \beta\left(\theta_{cell} - \theta_{cell,ref}\right) + \gamma\log\left(\frac{G_\beta}{G_{\beta,ref}}\right)\right] \qquad (3.4)$$

With θ_{cell} the PV cell temperature, η_{ref} = 14.88 % the reference module efficiency at a PV cell temperature $\theta_{cell,ref}$ (25^0C) and for a solar irradiance G_β onto the module (1000W/m^2). γ and β' are the solar irradiance and temperature coefficients. ($\theta_{cell,ref}$, η_{ref}, β', γ) are given by PV manufacturers, γ and β depend on PV module material. Evans (2) utilize β'=0.0048^0C^{-1}, and γ=0.12 for the mono crystalline silica. Most often this equation is seen with γ=0 (3).

The above presented equations require a large number of input parameters that need to be determined. (2), (3)

4 Experimental results

We have calculated the electrical power output of PV system by:

$$\mathbf{P_{mp} = \eta_{PV}\, G_\beta\, A} \qquad (4.1)$$

Where η_{PV} is the efficiency of the PV system; A is the area (m^2) of PV module; G_β is the solar insolation in kW/m^2. The PV maximum electrical power output can be also calculated using measured values of V_{mp} (maximal output voltage) and I_{mp} (maximal output current) using:

$$P_{mp} = I_{mp} \times V_{mp} \qquad (4.2)$$

Two models for P_{mp} calculation for crystalline silicon modules are tested:
- The first one developed by Borowy and Salameh (8, 9) using manufacturer data in standard conditions:

Where:

$$I_{mp} = I_{sc,ref}\left\{1 - C_1\left[\exp\left(\frac{V_{mp,ref}}{C_2 V_{oc,ref}}\right)\right]\right\} + \Delta I \qquad (4.2.1)$$

And:

$$V_{mp} = V_{mp,ref}\left[1 + 0.0539\log_{10}\left(\frac{G}{G_{,ref}}\right)\right] + {}_0\Delta^{-} \qquad (4.2.2)$$

- The second one developed by Labbe ́ (10) and based on an empirical formula is:

$$P_{\max} = \left(\frac{G}{G_{,ref}}\right)\left[P_{mp,ref} + ¥_0\left(^{-}_{cell} - ^{-}_{cell,ref}\right)\right] \qquad (4.2.3)$$

With γ_0 the module power temperature coefficient.

In our case the maximal value of output voltage of the PV array is 600V DC (The PV is composed by two sets of 12 panels of crystalline silicon modules connected in parallel with open circuit voltage 44.8 V DC and nominal power

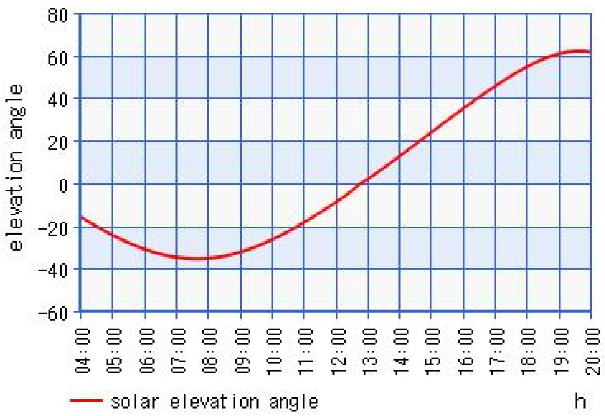

Figure 1: Variation of azimuth angle of the sun during a typical day

is 195 Wp.) The PV grid-connected system that we used for our study is of trade type CNCB connected to SG5K inverter series which automatically adjusts PV array load to provide maximum efficiency of the solar panels.

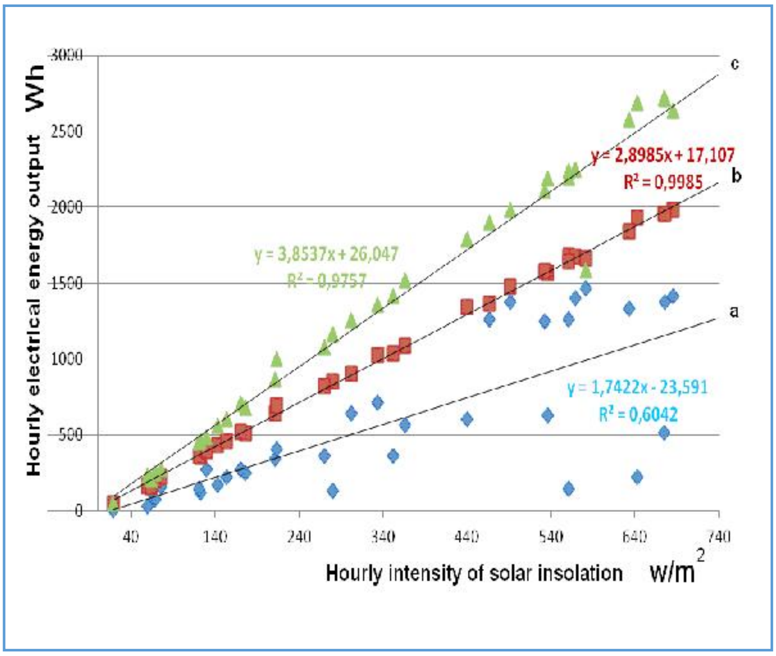

Figure 2: Variation of hourly electrical energy output from PV system with hourly intensity of solar insolation together with regression equations and correlation coefficients: a- measured output energy, b - calculated output energy using Evans model and c- calculated output energy using Durisch model.

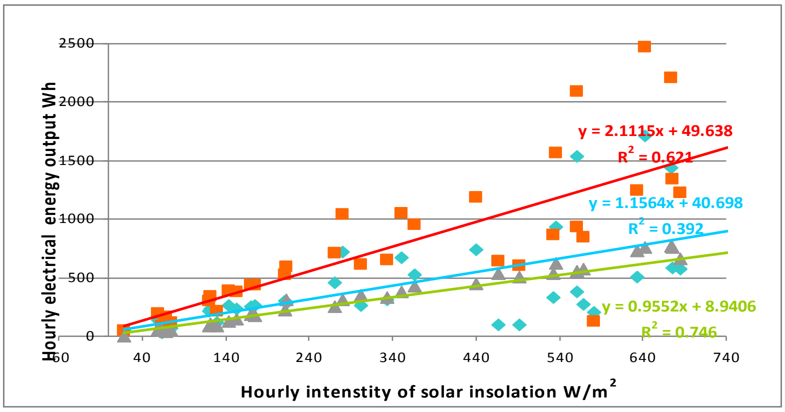

Figure 3. Differences between calculated data and experimentaly measured data of output electrical energy. a- brown line and markers difference between calculated data for output energy using Durisch method and experimental data, b- blue line and markers difference between calculated data for output energy using Evans method and experimental data and c- green line and markers difference between calculated data for output energy using Durisch method and calculated data using Evans method.

The parameters that we used to calculate output electrical energy of PV system for both methods are the following: Output voltage of PV system, output current of PV system, mean hourly solar insolation on the PV module, mean hourly temperature of the surrounding atmosphere and of PV module, the maximum elevation angle of sun for the region and the azimuth angle of the PV module. At solar noon, the sun is always directed to south in the northern hemisphere and north in the southern hemisphere. The elevation angle varies throughout the day as shown in the Figure 1 above. At the equinoxes, the sun rises at east point and goes down at west point; it is at azimuth angles 90° at sunrise and 270° at sunset.

In the Figure 2 are shown variations of output energy from PV system with solar insolation for experimental data of measured energy, for calculated energy using Evans model and for calculated energy using Durisch model. In all cases, output energy changes linearly with solar insolation. Regression equations and correlation coefficients are y = 2,8985x + 17,107 and R^2 = 0,9985 for Evans method and y = 3,8537x + 26,047 and R^2 = 0,9757 for Durisch method. Correlation coefficients between solar insolation and calculated values of output electrical energy are really good for both methods. However it is a sustainable difference between experimental data and calculated data. Both Evans method and Durisch method calculate greater output energy than experimental measurements show. Also there is a sustainable difference between calculated data using Evans method and calculated data when Durisch method is used. Differences between calculated output energy and experimental data in all cases increase linearly with increase of solar insolation. However correlation coefficients in these cases are smaller. (Figure 3) These differences demonstrate that in both methods must be made some correction to better consider real losses and fluctuations on output electrical energy of PV system.

Table 1: Measured hourly output electrical energy produces by PV system together calculated electrical energy output using Evans and Durisch models for different hourly mean solar insolation intensities.

Measured output Energy (Wh)	Calculated energy output using Evans model (Wh)	Calculated energy output using Durisch model (Wh**)**	Hourly solar insolation in horizontal surface (W/m2)
1636.32	2133	2947	743.67
117.40	354.8	458.51	122.33
565.77	1089	1516	366.67
145.35	362	448.3	121.00
604.24	1345	1789	439.67
218.04	1931	2686	643.00
361.59	1036	1411	351.67
167.32	429.6	559.87	143.33
340.51	642	863	211.67
128.44	851	1167	280.33
1376.37	1475	1978	491.67
272.54	391.3	483	129.33
222.75	456.9	602.6	153.67
710.12	1023	1358	333.67
628.92	1566	2192.7	536.33
26.78	1636.9	2256.6	59.33
1412.96	1678	2234.4	561.00
1402.89	1677	2247.4	568.67
1464.01	1665	1588.13	581.33
1243.33	1579	2108.3	64.00
1246.67	1576	2111	532.67
1411.15	1982	2639	685.33
245.64	508	681.08	175.67
1332.19	1842	2575.8	633.00
1262.32	1644	2199.6	561.00
1260.27	1360	1899	466.67
1.42	49.93	50.037	18.67
159.91	223.5	272.99	75.33
364.17	817.7	1075.37	270.33
272.32	523.5	707.7	171.00
948.98	2262	2758	788.33
75.60	201.6	244.09	68.67
407.92	689.9	999.16	213.33
644.09	905	1255.58	302.67
514.03	1956.8	2720.54	674.67
1373.29	1952.8	2711.88	676.00

Conclusions

Comparison of experimental data of electrical energy output from a grid connected PV system and calculated values using two different empirical methods, Evans methods and Durisch method, showed a consistence difference. Both empirical methods give greater values of output electrical energy than experimental ones. Good linear correlation between three sets of data, demonstrate that the greater part of differences originate from loses in electrical system of PV system. Modifying Evans method and Durisch method with respective linear approximation equations defined experimentally offers a good empirical equation which can be used in analytical analysis and modeling of the PV system. Not very good correlation coefficients show that further experimental data are needed.

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