EMPIRICAL MODELS FOR ENERGY YIELD OF A PHOTOVOLTAIC SYSTEM CONNECTED TO THE GRID

Study Purpose

- The purpose of this study is to find a suitable empirical model to calculate electrical energy yield of a PV system.

- For the realization of this study we have worked on two empirical models and on experimental electrical energy data obtained from our grid connected PV system.

Introduction

- Technological developments in the field of renewable energy sources have opened new horizons in solving major problems related to the continued growth of the demands for energy and most important issue as it is environmental protection.
- PV systems connected to the network offer an option in the continuing expansion of solar energy to produce electricity.
- Analytical description of the energy supplied by a PV system on the network depending on technological and meteorological parameters is the first step towards the use of intelligent networks.

Energetic Empirical Models

- Meteorological data of solar radiation should include three indicators of the solar radiation intensity:
  1. on horizontal surface,
  2. on slope surface and
  3. the diffused radiation

- Production of electricity from PV systems depends on many factors, such as:
  - $P_{PV,\ peak}$ the array peak power of the PV modules,
  - G_{β} the intensity of solar radiation on the PV module,

Energetic Empirical Models

- θcell the cell temperature of the PV module,
- Inverter efficiency and size,
- PV module technology,
- PV module inclination, and
- Location of the PV system, etc.

- An empirical model must translate these values to the energy produced by the PV module.

Evans Model

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

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

Where, θ_{cell} is the PV cell temperature, η_{ref} = 14.88 % the reference module efficiency at a PV cell temperature $\theta_{cell,ref}$ (25°C) and for a solar irradiance G_β onto the module (1000W/m²), γ and β' are the solar irradiance and temperature coefficients.

- Evans utilize $\beta'=0.0048\,^0C^{-1}$, and γ=0.12 for the mono crystalline silica.

Durisch Model

- Durisch et al. developed semi-empirical efficiency formulation usable for four PV technologies mSi, pSi, aSi, CiS.

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

Where, G_β is the solar irradiance on the PV module tilted from β_0, $G_{\beta,0}=1000 W/m^2$, $\theta_{cell,0}=25°C$ and AM is the relative mass of air, in the normal conditions is $AM_0=1.5$.

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

Where, θ_z is the latitude of the region where the PV module is installed, in degrees.

Durisch Model

- The parameters p, q, m, r, s and u have been determined for p-Si and are p=15.39, q=0.177, m=0.0794, r=0.09736, s=0.8998, u=0.9324.

- The temperature of cellules is calculated by the Ross formula:

$$\theta_{cell} = \theta_a + hG_\beta$$

Where, θ_a is the ambient temperature and h is the Ross coefficient h=0.026.

Experimental results

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

$$P_{mp}=\eta_{PV} X G_{\beta} X A$$

Where, η_{PV} is the efficiency of the PV system, A is the area of the PV module, G_{β} is the solar insolation in titled surface.

- 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):

$$P_{mp}= I_{mp} X V_{mp}$$

Experimental results

- In our case the PV system 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 is 190 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 obtain by the PV modules to adapt the system to the electric network.

Experimental results

➢The parameters that we used to calculate output electrical energy of PV system for both models 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,
-Maximum elevation angle of sun for the region and
- The azimuth angle of the PV module.

Experimental results

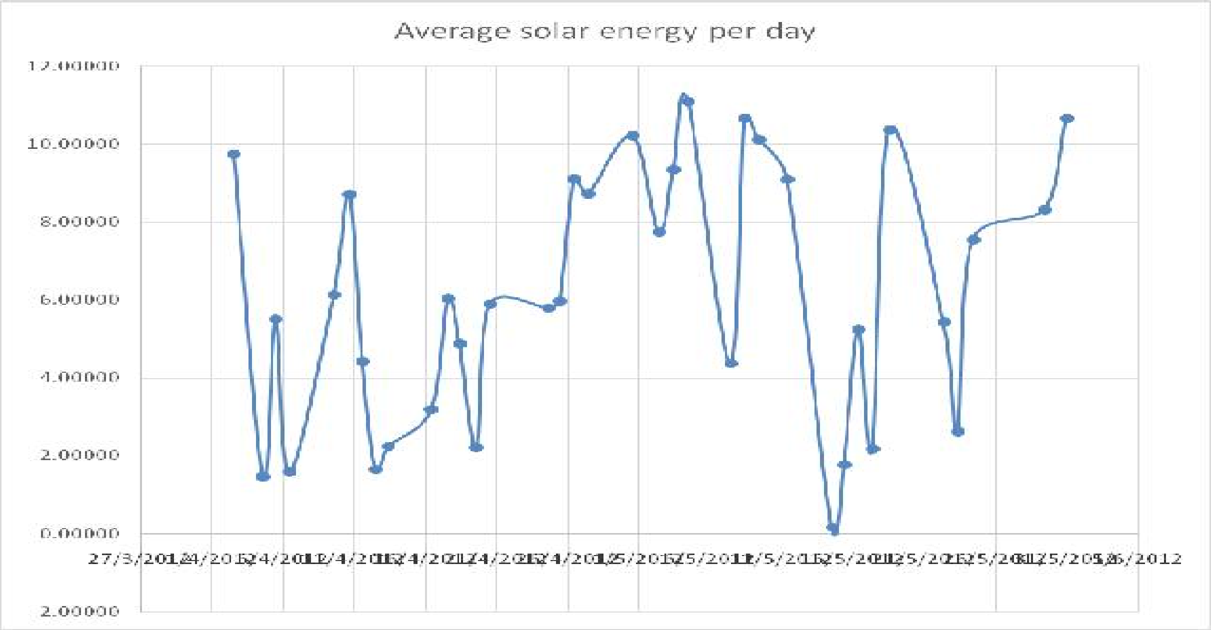

Figure 1: The average daily solar insolation energy in $kWh/m^2/day$ for period April - May 2012.

- In figure 1 is shown daily DC output energy generated by PV array during a specific period April- May 2012.
- It linearly depends on the irradiance except for the nonlinear characteristics range of lower irradiance.
- The daily energy varies from one day to the other not only due to change of insolation but also due to changes of efficiency of PV module with increase of its temperature.

Experimental results

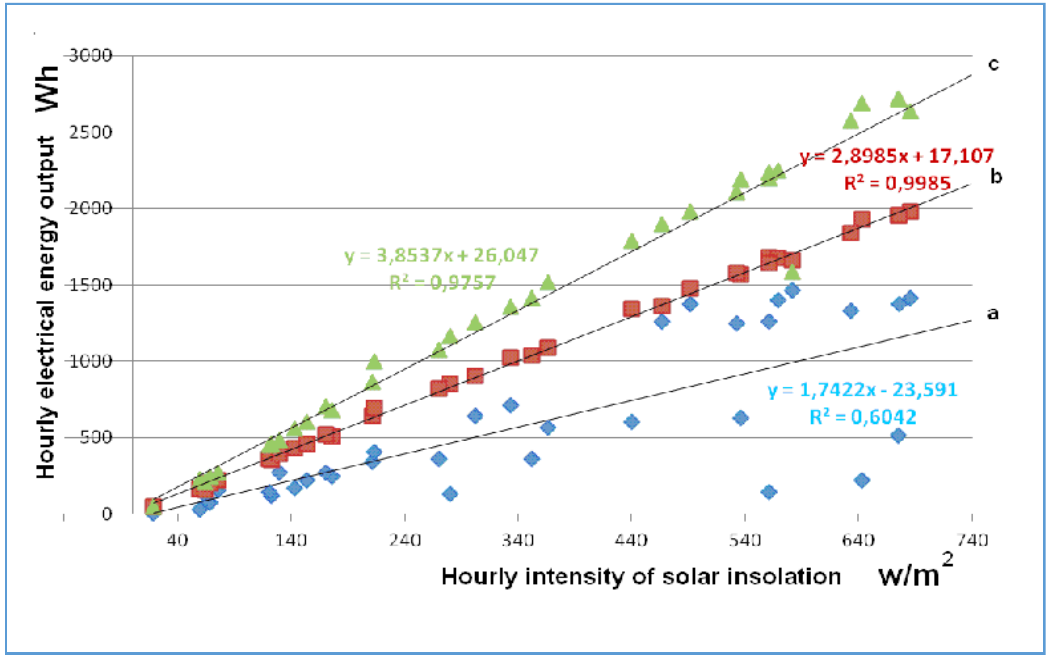

Figure 2: Variation of hourly electrical energy output from PV system with hourly intensity of solar insolation together with regression equations and correlation coefficients: a- measured output energy, b - calculated output energy using Evans model and c- calculated output energy using Durisch model.

- In the Figure 2 are shown variations of the 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 model and y = 3,8537x + 26,047 and R^2 = 0,9757 for Durisch model.
- Correlation coefficients between solar insolation and calculated values of output electrical energy are really good for both models.

Experimental results

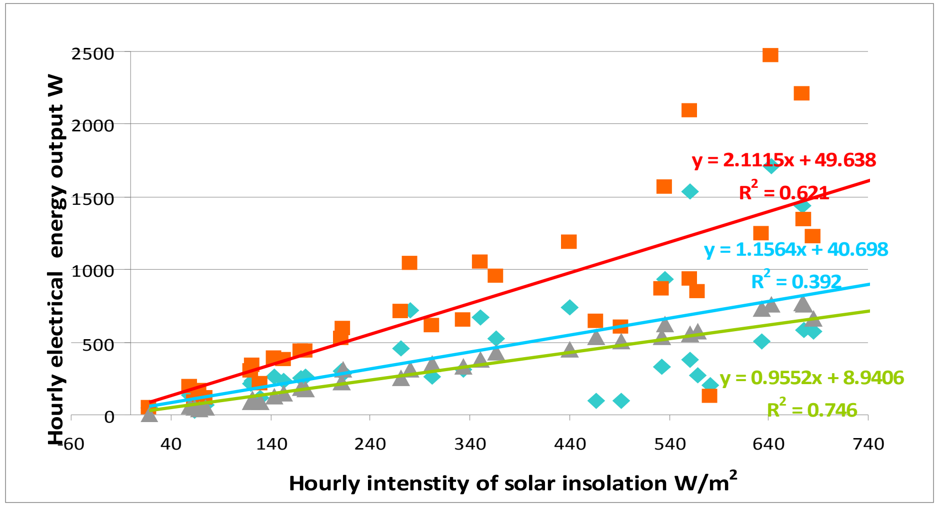

Figure 3. Differences between calculated data and experimentaly measured data of output electrical energy. a- brown line and markers difference between calculated data for output energy using Durisch model and experimental data, b- blue line and markers difference between calculated data for output energy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

- However it is a sustainable difference between experimental data and calculated data.
- Both Evans model and Durisch model calculate greater output energy than experimental measurements show.
- There is a sustainable difference between calculated data using Evans model and calculated data when Durisch model 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.

Conclusions

- Comparison of experimental data of electrical energy output from a grid connected PV system and calculated values using two different empirical models, Evans and Durisch model, showed a consistence difference between the experimental data and those provided by each model.
- Both energetic empirical models give greater values of output electrical energy than experimental ones; however the Evans model is more close to the measured experimental data.
- Good linear correlation between three sets of data, demonstrate that the greater part of differences originate from loses in electrical system of PV system.

Conclusions

- Careful adjustment of parameters of Evans and Durisch models defined in controlled laboratory conditions can significantly improve their compliance with the provisions of experimental results in a concrete case.
- To realize such a study, are needed more experimental measurement and rigorous control of the results to avoid the effects of the different factors that are not related to the physical processes that are studied.

Reference

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THANK YOU ☺