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Dynamic Modelling and Performance Analysis for a Grid-Connected PV System under LabVIEW

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Abstract— **In this paper, we propose a methodology based on virtual instrumentation (VI) using an interactive user-interface under LabVIEW environment, in order to model and analyze the performance dynamically for a grid connected Photovoltaic system (GCPVS) at "Centre de Développement des Energies Renouvelables" (CDER), Algiers, which is running since 2004.**

The present work deals with the electrical modeling of the PV array and the inverter validated by the experimental data, and then evaluating the performance parameters as an energy output, energy yields, performance ration and other parameters according to the standards. Subsequently, the electrical models and the all calculations are written with C language under LabVIEW code diagram.

The Performances of the PV system are evaluated and displayed through a convivial user-interface, with all useful information, leading to a creation of a database and report.

Keywords*—*Photovoltaic; Modelling; Performance; LabVIEW;

I. INTRODUCTION

Renewable power generating capacity in the world not including hydropower saw its largest annual increase ever in 2016, with 161 gigawatts (GW) of capacity added, leading a total installed capacity of 921GW [1].

Faced with this great energy transition in the world, Algeria on its part has launched an ambitious program, with an aim to install a power of renewable origin with a range of 22 GW for the period 2015-2030. The aforesaid program is about large-scale development of photovoltaic and wind. Incorporating the solar thermal (CSP), as well as the sectors of biomass, cogeneration and geothermal.

The photovoltaic with an integration power of 13.5 GW, took the lion's share of the program, and this comes back to the new relevant facts on the energy scene, it should be mentioned: the better knowledge of solar potentials, technological maturity and competitive costs [2].

The performance of the PV system depends on many parameters, including weather, efficiency of PV modules and inverter. In the literature many authors carried out studies dealing with the behavioral modelization of PV system [3]–[7], several works have been published on the performance analysis of grid connected PV system with different characteristics in different locations using different techniques [8]–[15] .

Many LabVIEW applications for performance analysis of PV systems have been reported in the literature [16]–[19]. This work is the continuity of an article [16], whose present article is dedicated for improvement and integration of new model, data processing, dynamic simulation and display.

The objective of this work is to evaluate the performances of a PV system connected to low voltage grid using LabVIEW platform. In this paper, a description will be given for each step leading us for the design of such program. Our task is to model and evaluate different yields and other parameters for a PV system. In this study, we put emphasis on how to develop a friendly interface, which includes all information gathered from the PV system.

In the same interface, another part is dedicated to the results obtained from simulations we have performed using the called platform.

II. PV SYSTEM DESCRIPTION

Our Grid Connected PV system consists of a PV array of 90 modules ISOFOTON 106W 12V. The PV array is made up of three (3) identical PV sub-array of 3.18 kWp (2 branches in parallel of 15 PV modules in series) (TABLE I). The PV sub-array is connected to a single-phase inverter, and each inverter is connected to low voltage grid 230V-50Hz (TABLE II).

TABLE I. MAIN CHARACTERISTIC OF THE PV ARRAY

PV array	
Max. DC power	9.54 kWp.
Geographical characteristics	Latitude: 36.8°N. Longitude: 03.03 °E. Altitude: 345 m.
Tilt /azimuth	27°/+15°S.
Num. PV sub-array & Inverter	3
PV Sub-array	
Max. DC power	3.18 kWp
Num. PV modules in series	15
Num. string in parallel	2

PV Module ISOFOTON I-106/12	
PV Cell Tech.	Mono-crystalline SI
Num. cell in (series/parallel)	36/2
Max. power	106 Wp
Isc_/Impp	6.54 / 6.1 A
Voc / Vmpp	21.6 / 17.4 V

TABLE II. MAIN CHARACTERISTIC OF THE INVERTER

Inverter Fronus IG 30	
AC nominal power	2.5 kW
MPP voltage range	150-400 V
Efficiency	92.7-94.3 %
Grid voltage range	195-253 V
Frequency range	49.8-50.2 Hz

The performance analysis is applied at the moment on one PV sub-system, it's mainly based on measured meteorological data (irradiance and temperature) and measured electrical data (current and voltage).

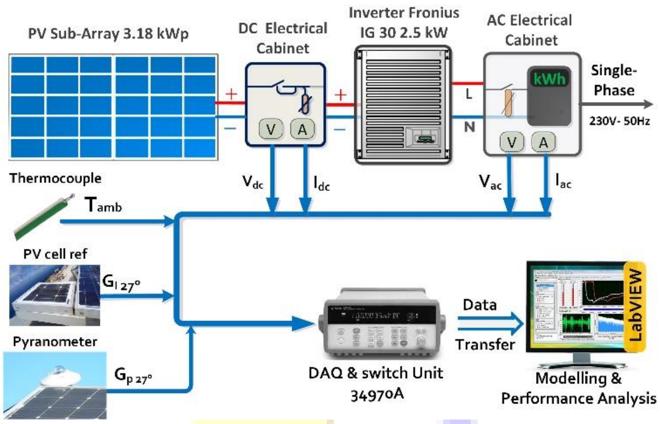


Fig. 1. Synoptic scheme of a one PV subsystem with monitoring system

III. MODELING AND SIMULATION OF PV SYSTEM

The objective of the simulation of the grid connected PV system is to obtain expected evolution of voltages and currents at the DC side, and the AC power at the inverter output.

Meanwhile, simulation results will give the expected behaviour, in a dynamic way of the whole system taking into account real climatic conditions.

The simulation of the whole grid connected PV system is based on the models presented below for both PV array and inverter, is carried out in LabVIEW environment.

A. PV cell temperature model

The formula used to determine the temperature of PV cell $\mathrm{T_{cell}}$ from both, ambient temperature $\mathrm{T_{amb}}$ and tilted Global irradiance is given by the following expression [3].

$$\mathrm{T_{cell}} = \mathrm{T_{amb}} + 0.03\, G_{I,m} \qquad (1)$$

B. PV array model

The inverters recommended for PV systems connected to the grid are equipped with a Maximum Power Point Tracking (MPPT) search, even an algorithm for fault detection citing for example the inverters of: SMA, ABB, Fronius. However, the research method as well as the developed algorithm are generally unknown; different from one manufacturer to another. For this reason, our model is a behavioral type whose input parameters of the model of the simulation are the instantaneous radiation $\mathrm{G_{I,c}}$ and temperature $\mathrm{T_{cell}}$ as mentioned in Figure 2.

The DC current dynamic model of the PV array at MPP $\mathrm{I_{DC,sim}}$ follows the relationship below[20] .

$$\mathrm{I_{DC,sim}} = \mathrm{N_p}.\,\mathrm{I_{m,ref}}.\,\frac{\mathrm{G_{I,m}}}{\mathrm{G_{ref}}} \qquad (2)$$

With:

$\mathrm{N_p}$: Number of PV string in parallel (2)
$G_{I,m}$: Global irradiance measured on tilted plane (27°)
$\mathrm{G_{ref}}$: Global irradiance in standard conditions (STC), 1000W/m^2
$\mathrm{I_{m,ref}}$: DC current at MPP in STC for PV module (5.9A)

Using Linear Reoriented Coordinates Method (LRCM), The DC voltage model of the PV array $V_{DC,sim}$ at the MPP follows the relationship below [21]

$$\mathrm{V_{DC,sim}} = \mathrm{V_x} + \mathrm{b}.\,\mathrm{V_x}.\ln\left(\mathrm{b} - \mathrm{b}.\exp\left(\frac{-1}{\mathrm{b}}\right)\right) \qquad (3)$$

With:

$\mathrm{V_x}$: open-circuit voltage at any given G and T
b : PV module aging factor 0.01<b<0.18

C. Inverter model

Conversion from DC to AC power allows this power to be tied to the AC grid. This conversion can be accomplished with high efficiencies but there are energy losses that need to be estimated. The following equations define the behavioral model developed by Sandia National Laboratories [22]. As independent variables, both simulated DC power and voltage are used to calculate the AC power of the inverter, as shown in the Figure 2.

$$\mathrm{P_{AC,SIM}} = \{(\mathrm{P_{ACO}}/(\mathrm{A}-\mathrm{B})) - \mathrm{C}.(\mathrm{A}-\mathrm{B})\}\,(\mathrm{P_{DC,SIM}}-\mathrm{B}) + \mathrm{C}.\,(\mathrm{P_{DC,SIM}}-\mathrm{B})^2 \qquad (4)$$

$$\mathrm{A} = \mathrm{P_{dco}}.\{1 + \mathrm{C_1}.(\mathrm{V_{DC,sim}} - \mathrm{V_{dco}})\} \qquad (5)$$

$$\mathrm{B} = \mathrm{P_{so}}.\{1 + \mathrm{C_2}.(\mathrm{V_{DC,sim}} - \mathrm{V_{dco}})\} \qquad (6)$$

$$\mathrm{C} = \mathrm{C_o}.\{1 + \mathrm{C_3}.(\mathrm{V_{DC,sim}} - \mathrm{V_{dco}})\} \qquad (7)$$

Definition of the Performance Parameter are available in the Sandia report for inverter [22].

The values of the parameters characterizing the model of the Fronuis IG 30 inverter and other inverters are given in an excel database with the PV_LIB Toolbox developed at Sandia National Laboratories [23].

IV. PERFORMANCE ANALYSIS OF PV SYSTEM.

In this part, performance analysis is applied for a period of eight (8) days from 16 to 23 July, this analysis consists to calculating [12] [13]:

The daily energy received E_r in (kWh/m2/day) measured on the horizontal and tilted planes as indicated by the equation below:

$$\mathrm{E_r} = ((\mathrm{G_r}.\Delta_\mathrm{t}) + \mathrm{E_{r-1}}.\mathrm{b_{id}})/1000 \qquad (8)$$

The average temperature $\mathrm{T_a}$ for ambient and PV cell each day according to the following equation:

$$\mathrm{T_{av}} = ((\mathrm{T}.\Delta_\mathrm{t}) + \mathrm{T_{av-1}}.\mathrm{b_{id}})/\mathrm{N_s} \qquad (9)$$

The DC and AC daily electrical energy $\mathrm{E_e}$ in (kWh /day) measured and simulated are represented by the following equation

$$\mathrm{E_e} = ((\mathrm{P}.\Delta_\mathrm{t}) + \mathrm{E_{e-1}}.\mathrm{b_{id}})/1000 \qquad (10)$$

with :

Δ_t : sampling time in hours
$\mathrm{b_{id}}$: Daily Initialization Bit
$\mathrm{N_s}$: Number of samples during the day

The yields of the PV system are expressed as: reference yield (Y_r), array yield (Y_a) and final yield (Y_f) given in [hr], as well as the performance ratio (*PR*) expressed in [%], they can be obtained from the simulation results using the following formulas which are used in accordance the IEC 61724 standard to evaluate the performance of a grid connected PV installation. [15] [13]:

$$Y_r = \frac{\int_0^{\Delta t} G_h}{G_0} \qquad (11)$$

$$Y_a = \frac{\int_0^{\Delta t} E_{dc}}{P_0} \qquad (12)$$

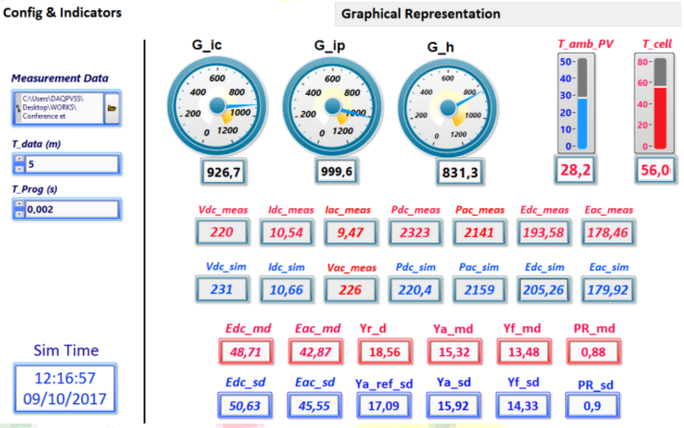
$$Y_f = \frac{\int_0^{\Delta t} E_{ac}}{P_0} \qquad (13)$$

$$PR = \frac{Y_f}{Y_r} = \frac{E_{ac}}{E_{dc}} \qquad (14)$$

All behavioral models and mathematical expressions are integrated under LabVIEW code diagram using a graphical program, this is called a virtual instrument (VI).

V. RESULTS AND DISCUSSION.

The layout of the developed VI can be viewed in front panel for an interactive user-interface, including different tabs shown in figure 2 and 3.



Measurement Data: C:\Users\DAQPVSS\Desktop\WORKS\Conference et
T_data (m): 5
T_Prog (s): 0,002
Sim Time: 12:16:57 09/10/2017
G_ic: 926,7
G_ip: 999,6
G_h: 831,3
T_amb_PV: 28,2
T_cell: 56,0
Vdc_meas: 220
Idc_meas: 10,54
Iac_meas: 9,47
Pdc_meas: 2323
Pac_meas: 2141
Edc_meas: 193,58
Eac_meas: 178,46
Vdc_sim: 231
Idc_sim: 10,66
Vac_meas: 226
Pdc_sim: 220,4
Pac_sim: 2159
Edc_sim: 205,26
Eac_sim: 179,92
Edc_md: 48,71
Eac_md: 42,87
Yr_d: 18,56
Ya_md: 15,32
Yf_md: 13,48
PR_md: 0,88
Edc_sd: 50,63
Eac_sd: 45,55
Ya_ref_sd: 17,09
Ya_sd: 15,92
Yf_sd: 14,33
PR_sd: 0,9

Fig. 2. User-interface designed under labview_config and control tab.

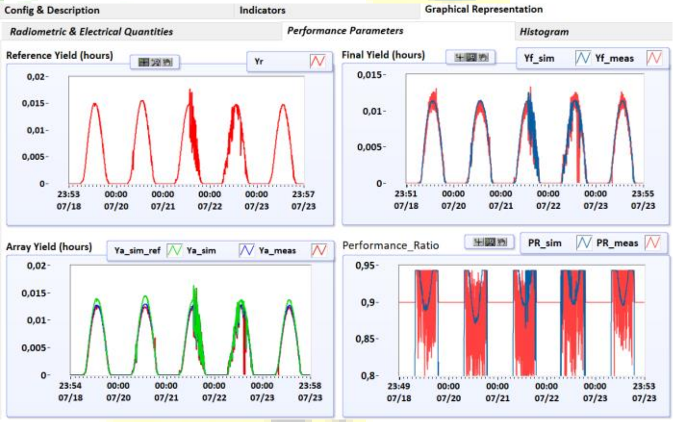


Fig. 3. Graphical representation tab under labview.

In the waveform below, the measurement and simulation results are presented for one typical day (July 19th), with a sampling interval Δ_t= 1 min.

- meteorological quantities

The following figures 4 and 5 show the display of the meteorological data measurement (irradiance and temperature) under LabVIEW

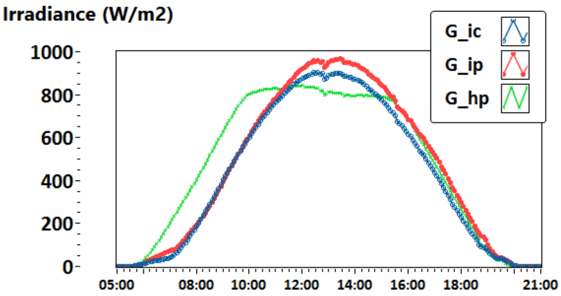


Fig. 4. Daily waveform – Display measured Irradiance.

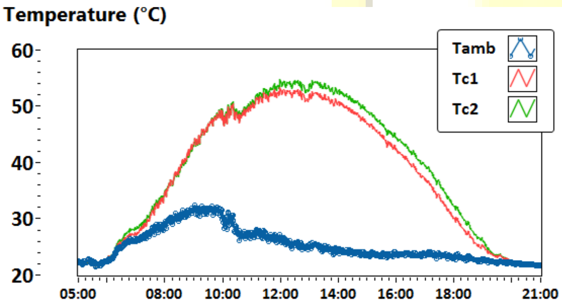


Fig. 5. Daily waveform – Temprerature.

- measured and simulated electrical quantities

The measured and simulated electrical quantities are represented respectively by charts in the figures (6-9).

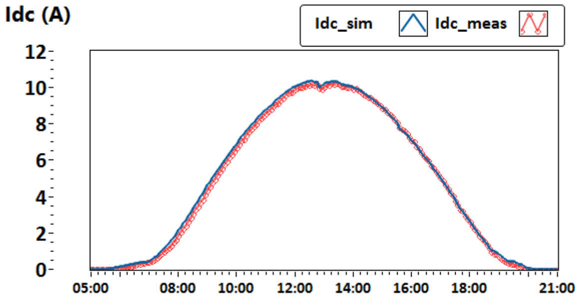


Fig. 6. Daily waveform –DC current.

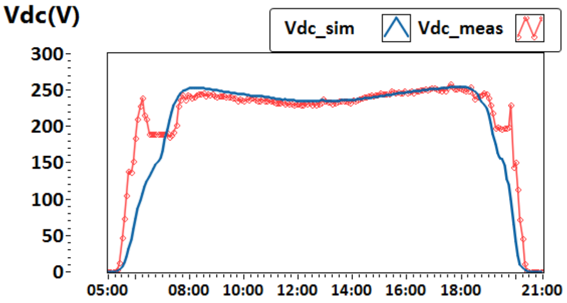


Fig. 7. Daily waveform –DC Voltage.

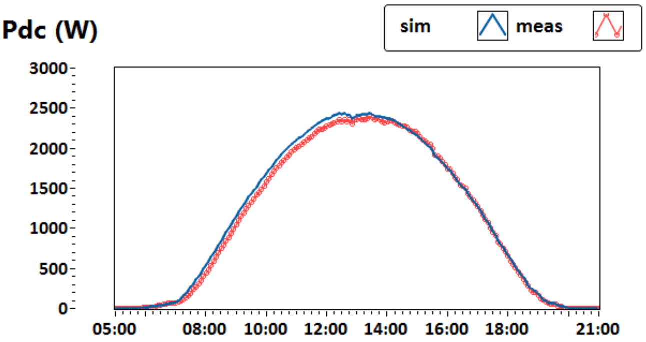


Fig. 8. Daily waveform –DC power.

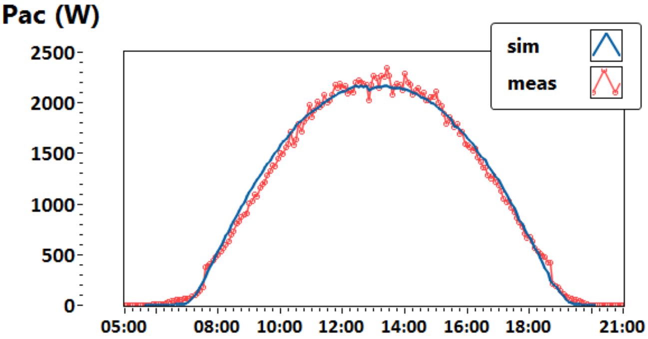


Fig. 9. Daily waveform –AC power.

According to our results, it can be seen that the simulated graphs are perfectly in accordance with the measurement graphs.

- Daily performance parameters

The next figures (10-11), represent the continuous daily representation for performance parameters and all energy yield

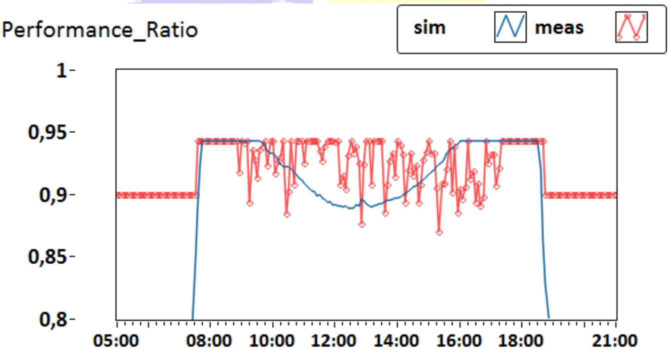


Fig. 10. Daily waveform – Performance ratio.

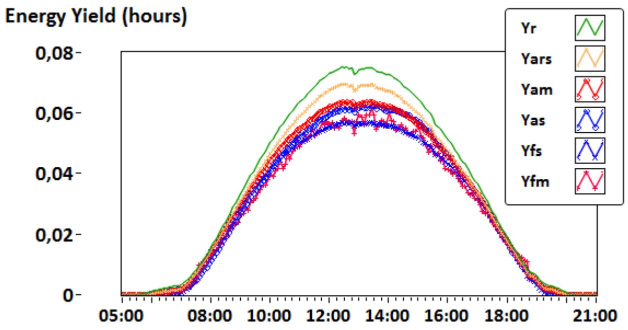


Fig. 11. Daily waveform – All energy Yields.

- Weekly performance parameters

In this part the performance parameters are represented in histograms for the periode 16th to 23th July under LabVIEW interface as shown in the following figures (12-17).

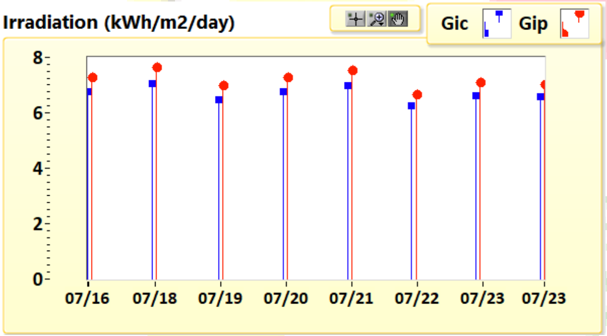


Fig. 12. Histogram –Irradiation received on tilt plane 27° .

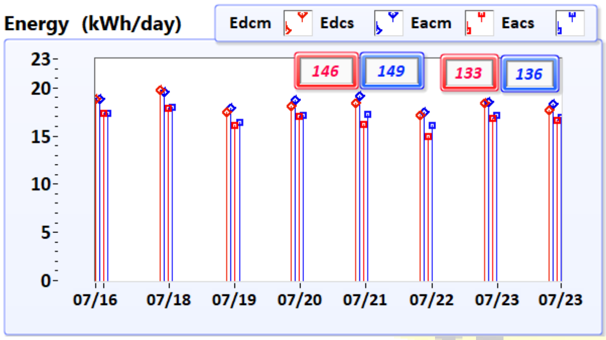


Fig. 13. DC and AC Energy for PV System.

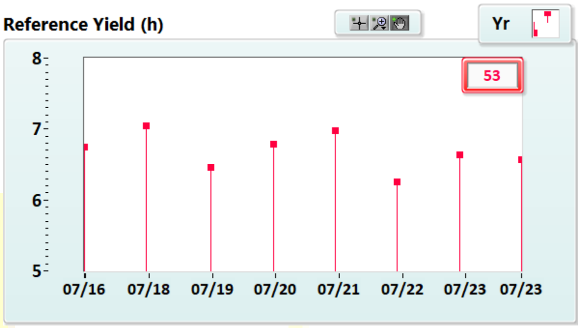


Fig. 14. Histogram – Reference Yield.

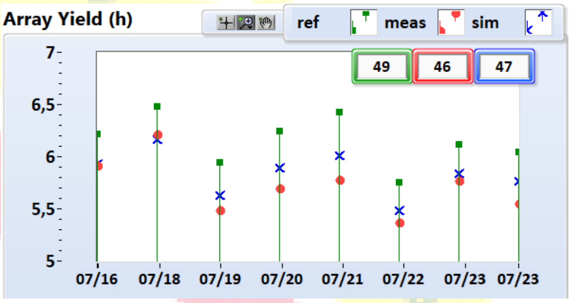


Fig. 15. Histogram –Array Yield.

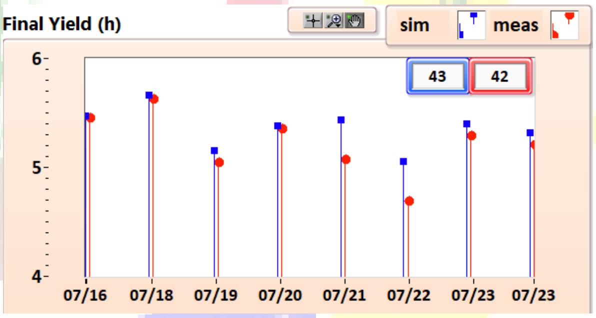


Fig. 16. Histogram – Final Yield.

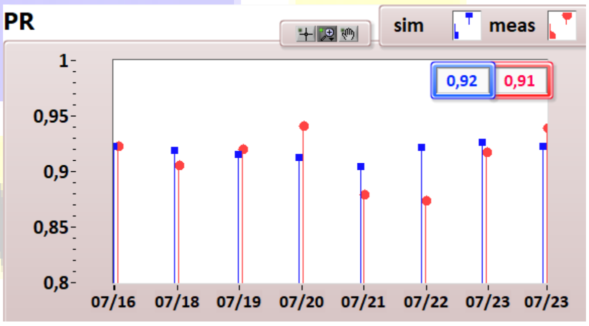


Fig. 17. Histogram – Performance Ratio.

The measurement and simulated efficiency of the PV system are represented in figure 18 for eight days.

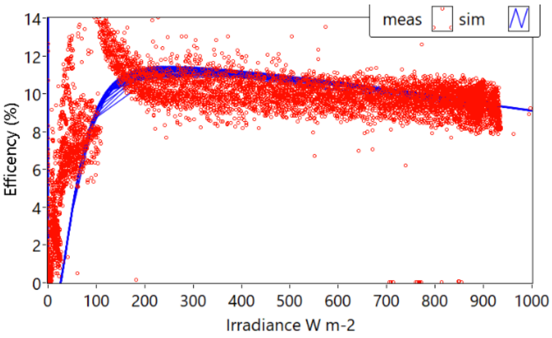


Fig. 18. Efficiency for PV system.

According to our graph, we can tell that the performance ratio of our grid connected PV system are above 85 %, the mean value is around 90%. The PV system efficiency varies between 8% and 12% from 200 W/m^2 up to 1000 W/m^2, and the comparison of efficiency between the experimental and the simulation, showed a good agreement especially for irradiance higher than 1000 W/m^2. Furthermore, simulation values agree well with measured ones, in general.

VI. CONCLUSION

This works was achieved in LabVIEW environment for the modelling and the performance analysis of our grid-connected PV systems using a convivial user-interface.

For the dynamic behavior modelling of the PV system, an accurate models are included allows to predict DC power produced by PV array, and the AC power at the inverter output.

The results obtained by simulation were validated using data measurement; the comparison has shown a good agreement, and the good representation of results for performance calculations, which approve the choice of the models we have used. The developed user-interface allows calculating the performance ratio and energy yields of the PV system, create an XLS report files and visualize all these data and information dynamically with different scenario.

The deviations between the simulated and measured values represents a detection of the operation anomaly of PV system.

Note that the user-interface created is extensible to integrate multiple PV model (DC & AC side) and to analyze data using advanced techniques we quote for example: Machine Learning, statistical methods and other many methods for performances analysis and faults detection in a PV system.

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وحدة البحث التطبيقي في الطاقات المتجددة
U R A E R