Modelling a grid connected Photovoltaic system with an aerogenerator through labVIEW

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Abstract – In this paper, we propose a methodology based on virtual instrumentation in order to model a grid connected PV system of the “Centre de Développement des Energies Renouvelables” (CDER), Algiers, which is running since 2004, a wind energy system was also considered for the study. Note that this task was achieved under LabVIEW environment. It can be seen that data-acquisition systems are widely used in renewable energy source (RES) applications in order to collect data regarding the installed system (radiometric and electrical), for evaluation purposes. Therefore, a datalogger (Agilent 34970 A) was setup in order to monitor the whole installation, in view to evaluate its performance.

Our system is able to store and display both PV plant electrical output measurements and collected variables environmental data. Performance of the PV system are then evaluated and displayed through an attractive and convivial user-interface.

The first part of this work concerns the extraction of electrical and radiometric data in text format file, already measured with a data acquisition; afterwards implementing model including PV system connected to the grid and the wind generator equations under LabVIEW.

The second part of the work is devoted to the development of a graphical program that evaluates the energy balance, the performance of the PV system. This program will allow us to create a user-friendly interface with all useful information, leading to a creation of a database.

Keywords – Meteorological Data, LabVIEW; Measurements, Virtual Instrument, Database; PV System, Monitoring

I. INTRODUCTION

The analysis of data including their monitoring and treatment has become more friendly, flexible and attractive with the development of modern instruments and testing technology such as LabVIEW (Laboratory Virtual Instrument Engineering Workbench). LabVIEW is a graphical programming language by National Instruments that uses icons instead of lines of text to create applications. It should be noted that several laboratories use this kind of technology since it offers several advantages.

Therefore, the conception of virtual instruments has become a popular program tool for test and measurement domain, in particular for photovoltaic (PV) systems. The aim of this work is to evaluate the performance of the grid connected system installed at the level of the CDER, using LabVIEW platform.

Many applications of LabVIEW for monitoring PV systems have been reported before in the literature [1-5]. In this paper, a description will be given for each step leading us for the design of such program. Our task is to monitor data which are needed in order to calculate the different characteristics of the installation such as different yields and other parameters. 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. EXPERIMENTAL DETAILS

A. Wind energy modelling

A precise determination of the mean wind speed is crucial for the evaluation of the wind potential, since this last depends on the cube of the mean wind speed.

1) Weibull distribution

In order to calculate the mean power from a wind turbine over a range of mean wind speeds, a statistical expression which gives a good fit to wind data known as the Weibull distribution was used.

In non-dimensional form, this can be written as:

\[
f(v) = \frac{k}{c} \left( \frac{v}{c} \right)^{k-1} \exp \left[ -\left( \frac{v}{c} \right)^k \right]
\]  

(1)

v: is the wind speed, k is the shape factor and c is the scale factor.

The mean wind velocity can be obtained by the expression:

\[
\langle v \rangle = c \Gamma \left( 1 + \frac{1}{k} \right)
\]  

(2)

Also, the available power in the wind can be expressed as:

\[
P = \frac{1}{2} \rho \langle v \rangle^3
\]  

(3)

Where \( \rho \) is the air density, equal to 1,225 kg/m³.

B. PV system modelling

The objective of the simulation of the grid connected PV system is to obtain expected evolution of voltages and currents at the DC side of the system as well as at the AC side and at the inverter output. Therefore,
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 modules and for the inverter and is carried out in LabVIEW environment. The flowchart of the simulation process is illustrated in figure 1.

Fig.1: Simulation process

1) Photovoltaic module modelling

The model proposed [7-8] was used. It’s takes into consideration the manufacturer data sheet, the air temperature, and the irradiation value, it’s possible to model the generation system for a photovoltaic installation.

It is expected that this model will be used for future applications in the area of power systems where most of the existing models cannot be used to calculate power flow, harmonic analysis, optimal load for maximization of the power, etc.

The current - voltage relationship is given by:

\[ I(V) = \frac{I_{sc,x}}{1-e^{\frac{V}{E_i}}[1-e^{\frac{V}{E_i}}]} \]

(4)

The model includes a short circuit current \( I_{sc,x} \) at any solar irradiance and temperature conditions, an open circuit voltage \( V_{oc,x} \) at any solar irradiance and temperature condition and an I-V characteristic constant \( b \) which is defined between 0.01 and 0.18, where smaller is the \( b \), greater is the produced power.

\( I_{sc,x} \) and \( V_{oc,x} \) can be obtained using equations:

\[ V_{oc,x} = s \frac{E_i}{E_{in}} TCv(T_{cell} - T_n) + s V_{oc,max} - s(V_{oc,max} - s(V_{oc,max} - \frac{E_i}{E_{in}} ln(\frac{V_{oc,x} - V_{oc_ref}}{V_{oc_ref}}))) \]

(5)

\[ I_{sc,x} = p \frac{E_i}{E_{in}} \left[I_{sc,ref} + TCi(T_{cell} - T_n)\right] \]

(6)

\( I_{sc,ref} \) and \( V_{oc,ref} \) are the short circuit current and open circuit voltage at Standard Test Conditions (25°C and 1000W/m²) respectively.

\( V_{oc,max} \) is the open-circuit voltage at 25°C and more than 1200W/m² (slightly superior to \( V_{oc,ref} \)).

\( T_{cell} \) is the solar cell temperature in °C with nominal temperature \( T_n = 25°C \).

\( E_i \) is the effective solar irradiation in W/m² with nominal effective solar irradiance \( E_{in} = 1000W/m^2 \).

\( TCv \) is the temperature coefficient of \( V_{oc} \) in V/°C.

\( TCi \) is the temperature coefficient of \( I_{sc} \) in A/°C.

\( \epsilon \) is the maximum allowed error to stop the iteration.

While:

\[ |b_{n+1} - b_n| > \epsilon \]

\[ b_{n+1} = \frac{v_{oc,ref} - V_{oc,ref}}{v_{oc,ref} ln(1 - \frac{V_{sc,ref}(1-exp(1/L))}{v_{sc,ref}})} \]

(7)

Using Linear Reoriented Coordinates Method (LRCM) [9-10], the current and voltage equations at the maximum power point (MPP) are given as follows:

\[ I_{mpp} = I_{sc,ref} \frac{1-b+b \exp(-\frac{1}{b})}{1-\exp(-\frac{1}{b})} \]

(8)

\[ V_{mpp} = V_{oc,ref} + b.V_{oc,ref} \ln(1-b.b \exp(-\frac{1}{b})) \]

(9)

2) Inverter model

The following equations define the behavioural model developed by Sandia National Laboratories [11,12]. As independent variables, the both DC power and DC voltage are used to calculate the inverter AC power. The parameters with the “o” subscript are constant values that define a reference or nominal operating condition.

\[ P_{dc} = \left[ (P_{aco}/(A-B)) - C \cdot (A-B) \right] \cdot (P_{dc}-B) + C \cdot (P_{dc}-B)^2 \]

(10)
Where:

\[ A = P_{dc0} \times [1 + C_4 (V_{dc} - V_{dco})] \]  
(11)

\[ B = P_{so} \times [1 + C_2 (V_{dc} - V_{dco})] \]  
(12)

\[ C = C_3 [1 + C_3 (V_{dc} - V_{dco})] \]  
(13)

The values of performance parameters given by recognized testing laboratory (SANDIA, CEC, Spec...) are shown in table II [13-1].

### TABLEAU II
**INVERTER PERFORMANCE PARAMETER, SANDIA NATIONAL LABORATORIES DATABASE**

<table>
<thead>
<tr>
<th>Parameters of inverter model</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximum AC-power at reference operating condition, ( P_{dc0} ) [W]</td>
<td>2700</td>
</tr>
<tr>
<td>DC-power level at which the AC-power is achieved at the reference operating condition ( P_{dco} ) [W]</td>
<td>2879</td>
</tr>
<tr>
<td>DC-voltage level at which the AC-power is achieved at the reference operating condition ( V_{dco} ) [V]</td>
<td>277</td>
</tr>
<tr>
<td>self-consumption by inverter, ( P_{so} ) [W]</td>
<td>27.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Constant parameters of inverter model</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_0 ) [1/W]</td>
<td>-1.009e-5</td>
</tr>
<tr>
<td>( C_1 ) [1/V]</td>
<td>-1.367e-5</td>
</tr>
<tr>
<td>( C_2 ) [1/V]</td>
<td>-3.587e-5</td>
</tr>
<tr>
<td>( C_3 ) [1/V]</td>
<td>-3.421e-3</td>
</tr>
</tbody>
</table>

#### 1. C. PV system performance

The yields of the PV system are expressed as reference yield \( (Y_r) \), given in [hr], array yield \( (Y_a) \) given in [hr] 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 [14]

\[ Y_r = \frac{\int_0^t \Delta P_{ac} (W/m^2) dt}{g_0} \]  
(14)

\[ Y_a = \frac{\int_0^t E_{ac} (kWh)}{P_0} \]  
(15)

\[ Y_f = \frac{\int_0^t E_{ac} (kWh)}{P_0} \]  
(16)

\[ PR = \frac{E_{ac}}{E_{dc}} \]  
(17)

#### III. RESULTS & DISCUSSION

The layout of the developed virtual instrument can be viewed in front panel format for an interactive user interface, including the weather station, PV system & wind energy analysis. In figure 2, is shown the interface devoted to the description of the PV system and its configuration.

![Fig. 2 PV system description panel including configuration](image)

![Fig. 3 Measured and simulated data represented in indicators.](image)
Meanwhile, in figure 4, is presented the interface where indicators displaying all the radiometric data measured with electrical data measured and simulated including the gain in CO₂ emission.

Simulated DC and AC power are shown in figure (4.a) and (4.b), as we notice a good agreement between data obtained from simulation and those obtained from measurements.

Concerning the performance ratio, the graphical presentation is given in figure 5, a good agreement is found between simulation results and monitored data.

For the wind energy part, the Weibull distribution estimation is given with simulation performed using an aerogenerators, the results of these simulations are given respectively in figures 6 and 7.
IV. CONCLUSION

The PV system and the weather station existing at the level of our establishment was monitored, modelled and performance were computed thanks to the reliable and friendly LabVIEW platform.

The results obtained by the simulation were validated using measured data; the comparison has shown a good agreement, approving then the models we have chosen.

By developing a platform under LabVIEW has enabled us the acquisition and control of data for the PV system.

A friendly display has made the platform more attractive. The aim was also to create a data base for measurements which are performed since 2004, giving a huge amount of recordings, currently existing at the level of our laboratory, for future utilization.

Furthermore, the work will be exploited in future for web page design.

V. REFERENCES

[9] Ortiz-Rivera E., Modelling and Analysis of Solar Distributed Generation, PhD, 2006, East Lansing, MI, USA.