PV PERFORM MOD

Help Menu

Version 1.1
2016

Prepared by:
CanmetENERGY - Varennes

November 2016

Contents

Figure list

1. Introduction

This software tool executes an automatic procedure for detecting PV system faults. Faults are defined as periods of abnormally low AC power production, when the system produces less electricity than it should at given operating conditions – solar irradiance and PV panel temperature.

The fault detection procedure consists in comparing the measured alternative current (AC) power of the PV system to the AC power that system should have under normal (fault-free) operating conditions. Significant differences between those values – with respect to pre-determined normal operation limits – are considered as faults.

Fault-free power productions are calculated by a model computing the expected (normal) system AC power production. The model consists of one equation that uses solar irradiance and PV panel temperature measurements to predict the AC power production.

The performance ratio is also automatically calculated; the PR evaluates the efficiency of the PV system by comparing its real electricity production to the ideal (rated) production. The performance ratio complements the model-based fault detection approach, by keeping track of the long-term performance of the PV system.

The fault detection procedure follows the following steps:

1. data cleaning to remove, prior to modelling, observations not representative of a normal operation

2. development of the model predicting the AC power that the system should have under fault-free operation

3. calculation of the PV system normal operation limits

4. identification of faults

1.1. *Model* and *Analysis* tabs

The ***Model*** tab of the software tool allows the user to specify characteristics of the PV system, upload a file containing PV system measurements, visualize those measurements and automatically clean the data, calculate a model predicting the AC power output of the model and calculate normal operation limits.

The ***Analysis*** tab of the software tool allows the user to upload a file containing new PV system measurements from the same system that was used for modelling and analyze the system performance using the model and normal operation limits calculated in the *Model* tab. The modelled AC power and measurements deemed as faults by the model are automatically calculated. The performance ratio of the PV system is also automatically calculated in the *Analysis* tab.

1.2. Required PV system measurements

The following PV system measurements are required for the calculations carried out by the software tool:

- AC power production (kW)
- solar irradiance in the PV system plane (W/m^2)
- PV panel temperature (^{0}C)

The rated direct current (DC) power (kW) of the PV system is required for calculating the performance ratio.

It is important that the units for these measurements (as indicated in brackets) are respected.

1.3. Methodology

Although some information regarding the calculations is provided in this *Help* guide, please refer to the *Methodology* document for a complete description of the data cleaning process, AC power model development, calculation of the normal operation limits and calculation of the performance ratio.

2. Menu

2.1. File

The **File** feature of the Menu is shown in Figure 1. It allows the user to

- save the current project (1)
- open an existing file (2)
- export calculation results (3)
- access the help file (4)

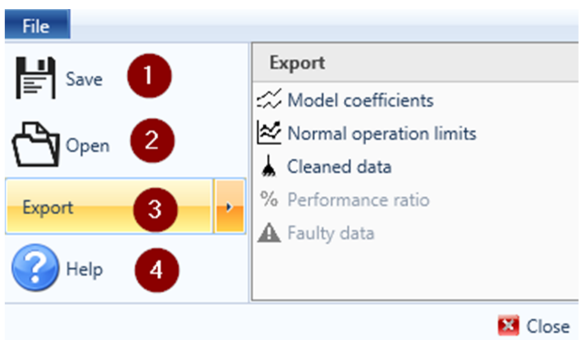

Figure 1: File feature

The work is saved in a default location. To save the project in a different location, select another folder in the list of folders. The work is saved as a file with the extension *afd*. An existing saved project can be loaded using the ***Open*** option.

The following calculation results can be exported, as *.csv* files, for use in another program:

- coefficients of the model predicting the AC power production
- normal operation limits
- cleaned and faulty
- performance ratios

2.2. Quick menu

The **Quick menu** feature is shown in Figure 2. It allows the user to

- save the project (1)
- open an existing project (2)

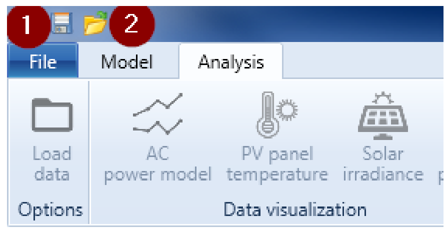

Figure 2: Quick menu: save and open buttons

3. Zooming in and out of charts

In case of a scatter plot (see example in Figure 3), there are 4 different ways to zoom into the chart area:

1. select the white square  and drag it to zoom the *x* axis (1)
2. select the white square  and drag it to zoom the *y* axis (2)
3. click and drag, right or left on the chart, to select the area to zoom (3)
4. point a zone in the chart area with the mouse and roll the wheel to zoom in and out (4)

In order to see the numerical values of a certain point in the graph line, point the mouse on the desired location on the chart. The numerical values associated with this point will be displayed below the chart legend (5).

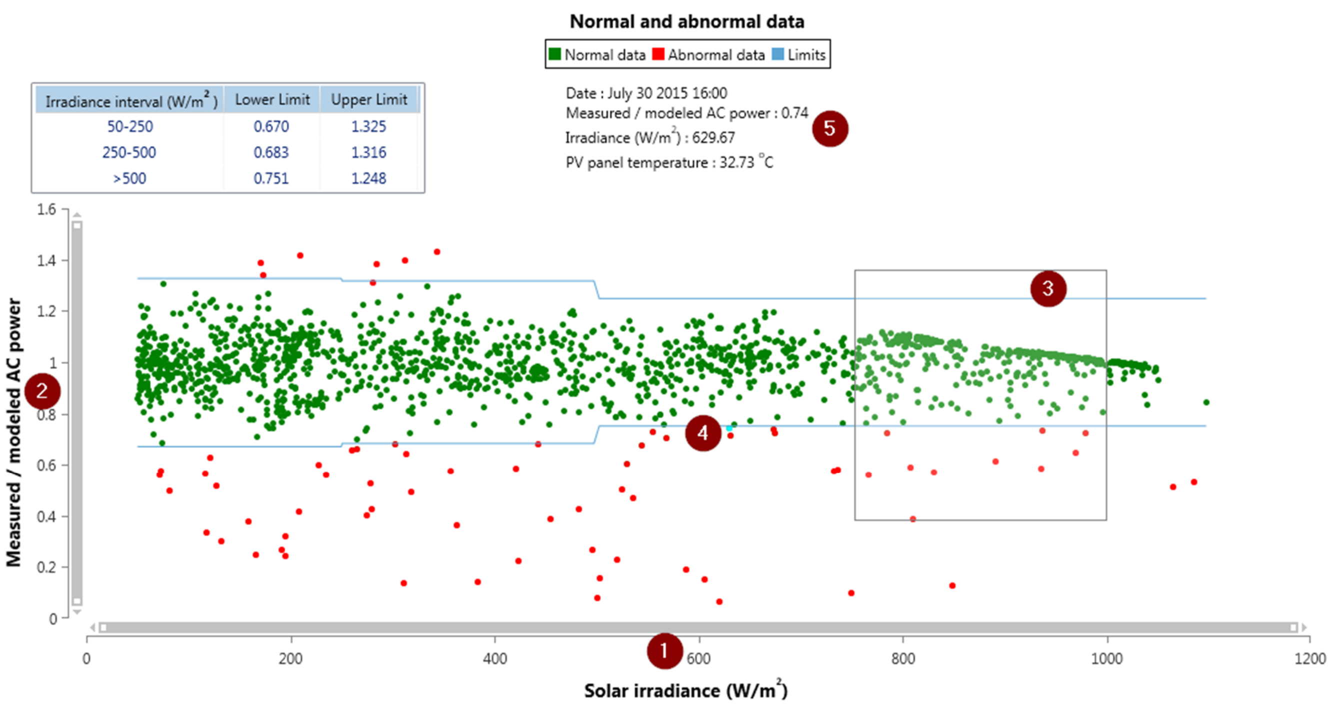

Figure 3: Scatter plot example

In case of a line plot (see example in Figure 4), there are 3 different ways to zoom into the chart area:

1. select the white square  and drag it to zoom the *x* axis (1)
2. click and drag, right or left on the chart, to select the area to zoom (2)
3. point a zone in the chart area with the mouse and roll the wheel to zoom in and out

In order to see the numerical values of a certain point in the graph line, point the mouse on the desired location on the chart. The numerical values associated with this point will be displayed below the chart legend (3).

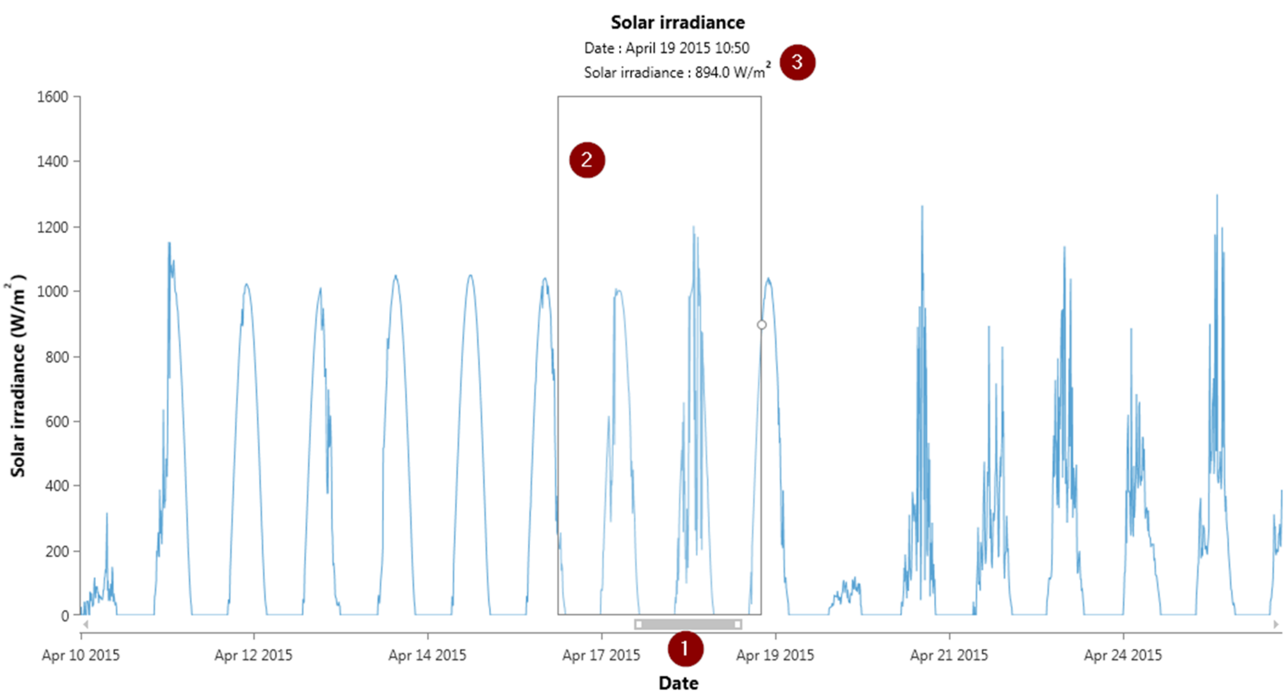

Figure 4: Line plot example

4. Model tab

The ***Model*** tab allows the user to:

- specify the characteristics of the PV system to be analyzed
- upload a file containing PV system measurements
- visualize those measurements
- automatically perform the modelling required for fault detection

4.1. PV system

The PV system section allows the user to:

- specify the characteristics of the PV system to be analyzed
- upload a file containing PV system measurements
- redo the calculations on the same dataset as currently loaded

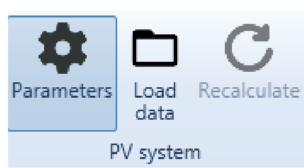

Figure 5: PV system section

4.1.1. Parameters

The user can select the following parameters, as it can be seen in Figure 6:

- PV system type (1)
- maximum PV panel temperature (2)
- maximum AC power produced by the system (3)
- minimum irradiance – power linearity (4)
- language in which the user interface is displayed (5)

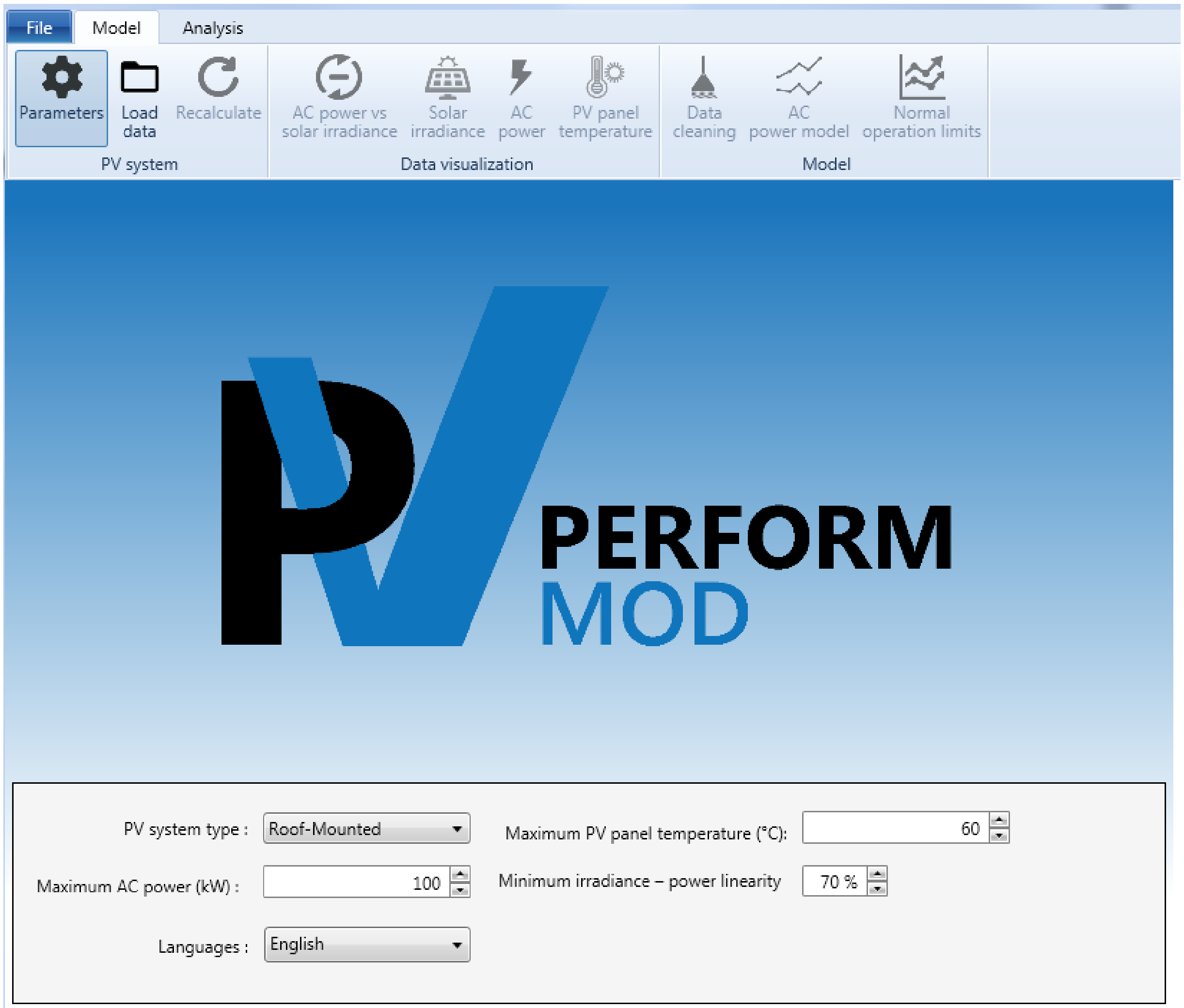

Figure 6: PV system parameters

PV system type

The PV system type can be selected as either roof-mounted or building integrated.

Maximum PV panel temperature (^{0}C)

The default values for the maximum PV panel temperature are 60^{0}C for roof-mounted systems and 90^{0}C for building integrated systems; the user can change these values. These temperature values are used in the data cleaning process to eliminate abnormally high PV panel temperatures.

Maximum AC power (kW)

The value of the maximum AC power that the PV system is producing is used in the data cleaning process to eliminate abnormally high AC power values. It is entered by the user.

Minimum irradiance – power linearity

The minimum irradiance – power linearity is used in the data cleaning process to identify measurements not representative of a normal operation – under normal operating conditions, the solar irradiance and electricity production follow a strong linear relationship. The default value is set at 70%, but the user can change it. Datasets having an irradiance – power linearity bellow this value will not be modeled, and a warning message will be displayed. Lowering the minimum irradiance – power linearity value can result in inaccurate models, and it is therefore recommended to maintain a value of at least 70%.

4.1.2. Load data

The user selects a file containing PV system measurements. The file has to contain measurements of AC power production, solar irradiance in the PV system plane and PV panel temperature.

The file must meet the following requirements (please see examples in Figure 7 and Figure 8):

- it must be a .csv file or a Excel file
- the .csv file must be semi-coma ";" separated
- the Excel file must contain only 1 tab
- the headers must contains "DataTime", "ACProduction", "SolarIrradiance" and "SensorTemperature" (*The order is not important*)
- the time must follow the format "mm/dd/yyyy hh:mm"

```
DataTime;ACProduction;SolarIrradiance;SensorTemperature
01/08/2014 00:00;;0;17.7
01/08/2014 00:10;0;0;17.6
01/08/2014 00:20;0;0;17.5
01/08/2014 00:30;0;0;17.3
01/08/2014 00:40;0;0;17.2
```

Figure 7: Example of the .csv format in which the data has to be loaded

	A	B	C	D
1	DataTime	ACProduction	SolarIrradiance	SensorTemperature
2	2014-08-01 07:00	18.08	152.17	20.38
3	2014-08-01 08:00	45.07	359.17	29.07
4	2014-08-01 09:00	69.42	569.00	37.65
5	2014-08-01 10:00	85.34	748.00	44.83
6	2014-08-01 11:00	79.55	811.33	45.95

Figure 8: Example of the Excel format in which the data has to be loaded

4.1.3. Recalculate

This option allows the user to change the values from the *Parameters* section and redo the calculations on the same dataset as currently loaded.

4.2. Data visualization

The *Data visualization* group allows the user to visualize the data contained in the file uploaded in the *Load data* feature. A plot representing AC power versus solar irradiance can be displayed, as well as time series plots of the solar irradiance, AC power and PV panel temperature – see Figure 9.

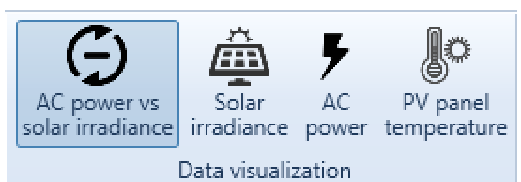

Figure 9: Data visualization group

4.3. **Model**

The *Model* feature allows the user to

1. automatically clean the data (eliminate measurements not representative of a normal PV system operation)

2. calculate a model predicting the AC power output of the model

3. calculate normal operation limits

These operations have to be carried in the order shown above: data has to be cleaned before calculating the AC power model, and then the normal operation limits can be computed. Each operation is carried out by clicking on its corresponding button. The Model options are shown in Figure 10.

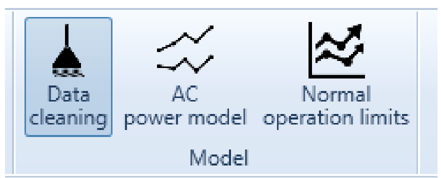

Figure 10: Model group

The values of the cleaned data, the coefficients of the model predicting the expected AC power production under normal operating conditions and the normal operation limits of the PV system can be exported as csv. files (see Section 2.1 – *File* for more details).

4.3.1. Data cleaning

This feature automatically identifies measurements not representative of a normal PV system operation. The steps carried out are the following:

- the measurements are averaged on an hourly basis

- observations corresponding to PV panel temperatures higher than the value entered in the *Parameters* section are eliminated

- observations corresponding to AC power productions higher than the value entered in the *Parameters* section are eliminated

- observations corresponding to solar irradiances higher than 1,250 W/m^2 are eliminated – the maximum solar irradiance in space, before entering Earth's atmosphere, is slightly superior to 1,300 W/m^2

- observations corresponding to irradiance levels less than 50 W/m^2 are eliminated – the measurement accuracy is significantly reduced at very low sunlight levels.

- the linear relationship between solar irradiance and AC power production is used to identify measurements representative of a normal operation: measurements located closed to the line representing this linear relationship are considered representative of a normal operation. This linearity is represented by the R^2 factor – an R^2 value of 100% indicates perfect linearity

Due to the technological quality of the solar modules, the efficiency of a PV system is dependent on the light intensity levels. At low irradiance levels – generally below 300 W/m^2 – the efficiency is low; the efficiency increases with the sunlight levels, and remains relatively stable until the irradiance reaches higher values, after which the efficiency slightly drops. In order to capture the behavior of the PV system according to different sunlight levels, the data cleaning procedure is carried out for the following irradiance intervals: 50-250, 250-500 and greater than 500 W/m^2.

The measurements are represented on a plot showing the AC power production versus solar irradiance: normal operation data is shown in green, while the abnormal operation data is shown in red. The values of the R^2 factor of the original and cleaned data are shown, as well as the number of observations eliminated from the original data during the data cleaning process (see Figure 11).

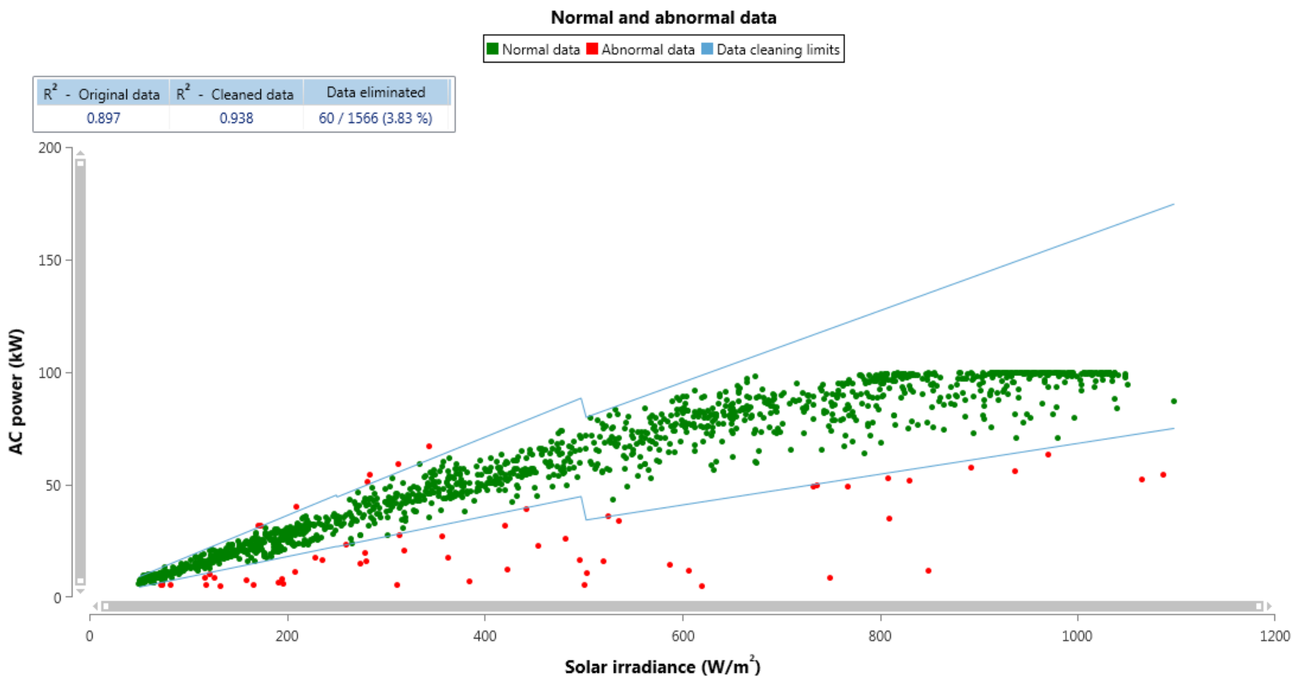

Figure 11: Cleaned data

4.3.2. AC power model

The dataset in the previous step is used to calculate the model predicting the expected AC power under normal operation conditions. The model is based on a parametric approach to PV system modelling which calculates the AC power as follows:

$$P_{AC} = Irrad. \times [a_1 + a_2\, Irrad + a_3 \log(Irrad)] \times [1 + a_4(T_{module} - 25)]$$

where P_{AC} = AC power (W)

$Irrad$ = solar irradiance (W/m^2)

T_{module} = PV module temperature (^{0}C)

a_1, a_2, a_3 and a_4 = parameters calculated so the model result is as close as possible to the measured data

In order to capture the behavior of the PV system according to sunlight levels, models for following irradiance intervals were developed: 50-250, 250-500 and greater than 500 W/m^2. Models developed for those irradiance intervals are more accurate than one global model that covers the complete irradiance range.

The measured and modeled AC powers are shown in a plot. The coefficients for each model, as well as the modelling errors – corresponding to an irradiance interval – are also shown. Periods of time where AC values are not present may exist: these periods correspond to observations eliminated during the data cleaning (see Figure 12).

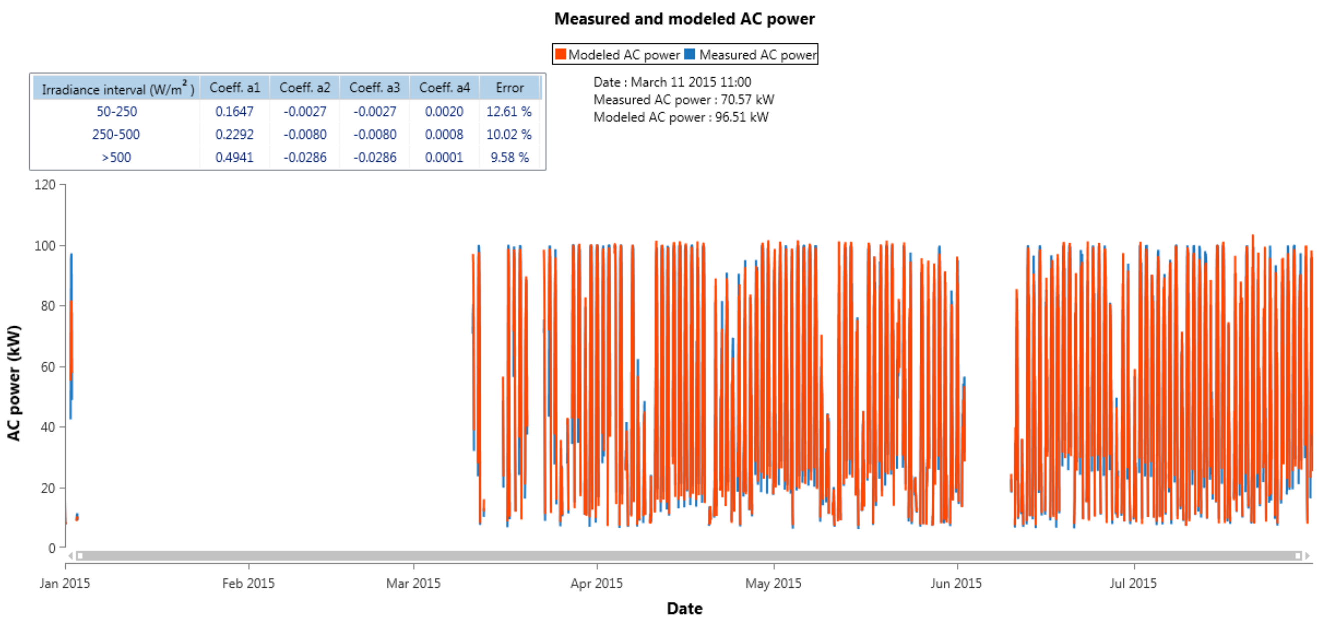

Figure 12: AC power model

5. Analysis tab

The ***Analysis*** tab of the software tool allows the user to upload a file containing PV system measurements from the same system that was used in the *Modelling* tab. The model and the normal operation limits calculated in the *Modeling* tab are applied to the data to detect faults and evaluate the PV system performance.

5.1. Load data

The user selects a file containing PV system measurements. The Load data button is shown in Figure 13.

The file has to follow the same format specified for the *Modelling* tab:

- it must be a .csv file or a Excel file
- the .csv file must be semi-coma ";" separated
- the Excel file must contain only 1 tab
- the headers must contains "DataTime", "ACProduction", "SolarIrradiance" and "SensorTemperature" (*The order is not important*)
- the time must follow the format "mm/dd/yyyy hh:mm"

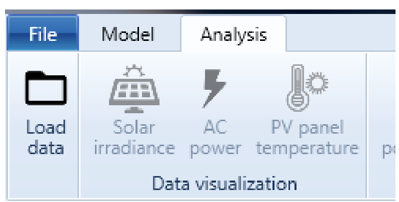

Figure 13: Load data button

5.2. **Data visualization**

This feature allows the user to visualize the data contained in the file uploaded in the *Load data* feature. Plots of the solar irradiance, AC power and PV panel temperature can be visualized. The data visualization options are shown in Figure 14.

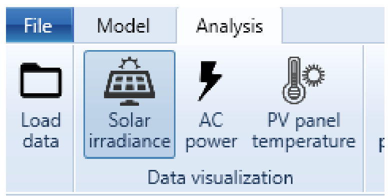

Figure 14: Data visualization

5.3. **Analysis**

5.3.1. AC power model and faulty data

This feature allows the user to apply the AC predictive model and the normal operation limits calculated in the *Modelling* tab to the previously loaded dataset, in order to determine faulty measurements. The modeled AC power values are automatically calculated by clicking on the *AC power model* button, while faulty measurements are identified by clicking on the *Faulty data* button. The modeled AC power values and the faulty measurements can be exported as .csv files.

The *Analysis* options are shown in Figure 15.

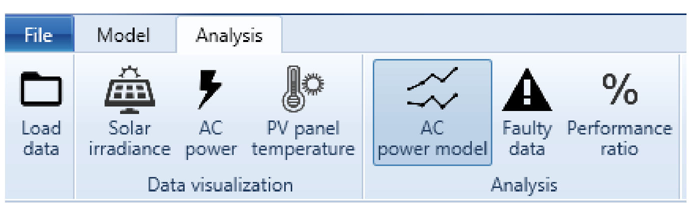

Figure 15: Analysis group

5.3.2. Performance ratio

The performance ratio (PR) evaluates the efficiency of the PV system by comparing its real production to the ideal production at Standard Test Condition (STC) of 1,000 W/m^2 solar irradiance and 25^{0}C PV module temperature – this is the rated (design) DC power output of the system. The PR is calculated over a specified period of time, and is used to monitor the system performance over time; it takes into account the electricity output and the amount of sunlight received over that period. The performance ratio *PR* is calculated as follows:

$$PR = \frac{\text{Total AC electricity production (kWh)}}{\text{Rated DC power (kW) x Total insolation (Wh/m}^2\text{) / 1,000 (W/m}^2\text{)}}$$

where *Total AC Electricity Production* = AC energy (kWh) produced over the interval for which the performance ratio is calculated

Rated DC Power = DC power at STC (rated, or design, DC power of the PV system, kW)

Total insolation = total solar energy received by the PV system over the interval for which the performance ratio is calculated (Wh/m^2); the total insolation is divided by 1,000 W/m^2 since this is the irradiance for which the design power is specified.

The closer the PR value for PV system approaches 1, the closer the system production is to its ideal, design production. In order to properly calculate the performance ratio, the following steps are automatically performed:

- observations corresponding to irradiances lower than 50 W/m^2 are removed, in order to avoid measurement uncertainty at low sunlight levels
- all missing data is eliminated from the dataset

The user selects the period of time over which the performance ratio is calculated. It is recommended that the minimum period be at least 7 days. The rated DC power of the system must be entered by the user.

For more details please refer to *Performance ratio* section of the *Methodology*.

The performance ratio screen is shown in Figure 16.

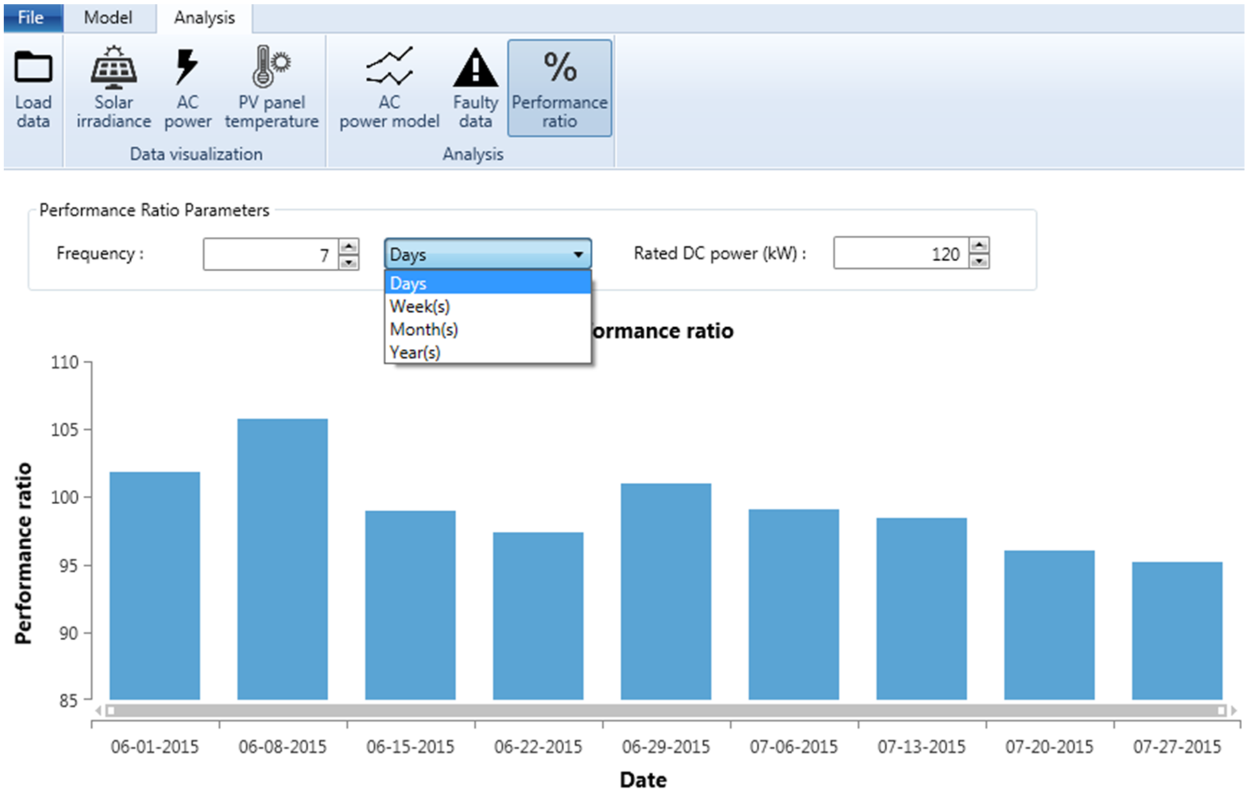

Figure 16: Performance ratio screen

5.3.3. Performance ratio superior to 100%

The performance ratio (PR) cannot be superior to 100%. If such a situation occurs, it is most probably caused by erroneous irradiance measurements – pyrometer miscalibration under-estimating the irradiance level. In this case, the data wrongly indicates that the electricity production of the PV system takes places at lower than actual sunlight levels.