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Estimating the Input Power of a Power Plant Using the Efficiency of the Inverter

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Abstract

The study focuses on estimating the input power of a power plant from available data, using the theoretical inverter efficiency as the key parameter. The paper addresses the problem of missing data in power generation systems and proposes an approach based on the efficiency formula widely documented in the literature. In the absence of input data, this method makes it possible to estimate the plant's input power using data extracted from the site, in particular that provided by the Ministry of the Environment. The importance of this study lies in the need to accurately determine the input power in order to assess the overall performance of the energy system.

Keywords

Estimation, Data, Missing, Input, Power, Efficiency, Inverter

1. Introduction

The efficient operation of power plants requires accurate knowledge of their input power, which is crucial for assessing their overall performance. However, in many cases [1]-[7], the input data is incomplete or missing, which represents a significant challenge for power plant managers. Many missing data techniques exist in the literature, such as simple imputations, model-based methods, interpolations, K-nearest neighbours (KNN), etc. These different techniques require a minimum of existing data. However, given the immense size of our missing data, these different techniques seem inefficient. With this in mind, this work investi-

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gates a new approach to estimating the input power of a power plant using inverter efficiency as the key parameter. The main objective of this study is to overcome the lack of input data by exploiting the relationship between the theoretical efficiency of the inverter and the input power, in order to provide a reliable estimate of the latter. This approach offers a practical and effective solution for assessing the overall performance of power plants, thereby facilitating their operation and optimisation. In this introduction, we will detail the basic principles of this method and highlight its importance for the power industry.

2. Modeling

2.1. The Study Site

The installation studied is a grid-connected PV system located at the Ministry of the Environment in Burkina Faso.

- a field of modules located on the roof;
- an array of grid-connected inverters
- a data acquisition system;
- the electrical network;
- electrical loads.

Description of the PV field

The PV array consists of 380 AT solar 205 W modules. It has the following characteristics

- a peak power of 80 kWp;
- an overall surface area of 486 m^2;
- a nominal yield η_0 of 13%.
- The PV array faces due south at an angle of 15˚.

Description of the inverter park

The inverter park consists of eight (08) Sunny Tripower 10000TL-10 inverters, each with the following characteristics:

- a nominal output power of 10,000 W;
- a maximum efficiency η_0 of 98.1%;
- the ability to search for the maximum power point (MPP).

Figure 1 shows the efficiency curve of the inverters. It shows that the efficiency of the inverters falls dramatically when the AC power is less than around 500 W.

These inverters incorporate an acquisition system that allows PV system parameters to be measured and displayed on a computer, mobile phone, etc.

Description of the acquisition system

A data acquisition station integrated into the inverters monitors the system's main electrical parameters (voltage, current and frequency). The system is also equipped with radiation and temperature sensors. Thanks to SMA's Sunny Portal (System-, Mess- und Anlagentechnik), a measurement and equipment technology system, data can be recorded and consulted at any time and from any location using a protected access account. For our study, we had a username and

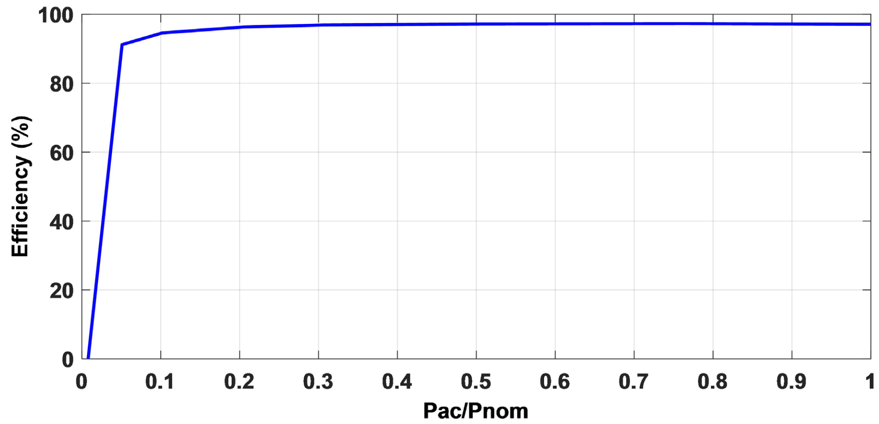

Figure 1. Inverter efficiency.

password for access. The access allowed us to view and extract meteorological data such as ambient temperature, module temperature, solar radiation and also all the electrical parameters such as DC and AC voltage, inverter frequency, DC and AC power as well as the energy produced, in an Excel file [4] [5].

2.2. PV Field Efficiency

Experimentally, the efficiency of the PV array is determined by the relationship in Equation (1):

$$\eta_{Experimental\_field} = \frac{P_{PV}}{S * G} \tag{1}$$

where P_{PV} is the power of the PV array (W), G is the irradiance in the plane of the collectors (W/m^2) and the area of the PV array (m^2).

The theoretical yield is determined from formula (2) [4] [6] [7] [8]:

$$\eta_{pv,literature} = \eta_{ref}\left[1-\beta\left(T_p - T_{ref}\right)\right] \tag{2}$$

where η_{ref} is the reference efficiency of the field as:

$$\eta_{ref} = \eta_{ref,modules} * \eta_{loss} \tag{3}$$

η_{loss} is the estimated efficiency linked to losses within the field (cables, diodes, etc.) [7]. In our case, $\eta_{ref} = 0.13 \times 0.95 = 0.123$, T_p is the panel temperature and T_{ref} is the reference temperature (T_{ref} = 25˚C); β is the temperature coefficient (to be determined or supplied by the manufacturer). The literature [4] [7] indicates that β varies between 0.0025 and 0.008 K^{-1}. The parameter β was determined from experimental measurements and is 0.0061.

2.3. Inverter Efficiency

The inverter is an essential component for any PV system that has to supply electrical energy in alternating current or be connected to the electricity grid. It is generally characterised by:

- its input voltage
- its rated power;

- its efficiency
- output signal quality and harmonic content;
- no-load consumption.

All eight inverters are of the Sunny Tripower 10000TL-10 type. The UPv input voltage ranges from 150 V to 800 V. Their rated power is equal to 10,000 W, their efficiency is 98.1% and they supply a 50 Hz signal. In this work, we will characterise the inverter by its efficiency.

The instantaneous value of the experimental efficiency ηond depends on the ratio of the output power Psortie to the input power Pentrée of the inverter. It can be written as [8]-[14]:

$$\eta_{ond} = \frac{P_{output}}{P_{input}} \tag{4}$$

To calculate the theoretical efficiency, we take into account the power lost by the inverter, which is written as:

$$P_{loss} = P_{input} - P_{output} \tag{5}$$

Dividing (5) by the rated power of the inverter $P_{nom/inv}$ gives:

$$\frac{P_{loss}}{P_{nom/inv}} = \frac{1}{P_{nom/inv}}\left[P_{input} - P_{output}\right] \tag{6}$$

$$\frac{P_{output}}{P_{nom/inv}}\left[\frac{P_{input}}{P_{output}} - 1\right] \tag{7}$$

$$\eta \times \left[\frac{1}{\eta_{ond}} - 1\right] \tag{8}$$

$$\text{With} \quad \eta = \frac{P_{output}}{P_{nom/inv}}$$

$$\text{By appealing} \quad \eta_{loss} = \frac{P_{loss}}{P_{nom/inv}}$$

$$\text{We have} \quad \eta_{loss} = \eta \times \left[\frac{1}{\eta_{ond}} - 1\right] \tag{9}$$

$$\text{Thus} \quad \eta_{ond} = \frac{\eta}{\eta + \eta_{loss}} \tag{10}$$

The losses (η_{loss}) can be described to a good approximation using Equation (11) [8] [9]:

$$H_{loss} = \eta_o + k\eta^2 \tag{11}$$

where η_o is a no-load inverter constant and k is a constant related to resistive losses.

Finally, we deduce the theoretical efficiency of the inverter expressed by:

$$\eta_{ond} = \frac{\eta}{\eta + \eta_o + k\eta^2} \tag{12}$$

The values of η_o and k can be determined from the inverter efficiency curve.

Let η_i be the efficiency of the inverter at i% load ($0 < i < 100$), we have:

$$\eta_i = \frac{i/100}{i/100 + \eta_{i,loss}} \tag{13}$$

The expression for η_i is taken from (13), which gives:

$$\eta_{i,loss} = \frac{i}{100} \times \left(\frac{1}{\eta_{i,ond}} - 1\right) \tag{14}$$

According to Equation (11) we have:

$$\eta_{i,loss} = \eta_o + k\left(i/100\right)^2 \tag{15}$$

Equating Equation (14) with Equation (15) gives:

$$\eta_o + k\left(\frac{i}{100}\right)^2 = \frac{i}{100}\left(\frac{1}{\eta_i} - 1\right)$$

Solving this equation gives:

$$k = \left(\frac{100}{i}\right)^2 \times \left[\frac{i}{100}\left(\frac{1}{\eta_i} - 1\right) - \eta_o\right] \tag{16}$$

Considering a second state of charge j we have:

$$k = \left(\frac{100}{j}\right)^2 \times \left[\frac{j}{100}\left(\frac{1}{\eta_j} - 1\right) - \eta_o\right] \tag{17}$$

Solving for equality between Equations (16) and (17) gives:

$$\eta_o = \frac{i \times j}{100 \times \left(i^2 - j^2\right)} \times \left[i \times \left(\frac{1}{\eta_j} - 1\right) - j \times \left(\frac{1}{\eta_i} - 1\right)\right] \tag{18}$$

If we consider the efficiency at 10% of rated power η_{10} and the efficiency at 100% of rated power η_{100} we obtain:

$$k = \frac{1}{\eta_{100}} - \eta_o - 1 \tag{19}$$

$$\eta_o = \frac{1}{99}\left(\frac{10}{\eta_{10}} - \frac{1}{\eta_{100}} - 9\right) \tag{20}$$

In our study we obtain $\eta_o = 0.0062$ and $k = 0.0227$.

3. Results and Discussion

Figure 2 shows the experimental and theoretical yields $\eta_{Experimental\_field}$ and $\eta_{Theoretical\_field}$.

Between 12 pm and 2 pm, irradiance reaches its peak (around 1000 W/m^2). The same applies to temperature (60˚C). At the same time, however, the yield reaches a minimum value (10%). As the temperature rises throughout the day, the field's yield decreases from 13% at 9 a.m. to 10% at 12 noon. Then, as the temperature drops, the yield increases.

Equation (2) correctly reproduces the field yield over the course of the day, except at the beginning and end of the day when irradiance values are low. The correlation rate is around 0.7687.

Using the values of η_o and k in Equation (12), we obtain the inverter efficiency in Figure 3, where we plot the evolution of the simulated and measured efficiency over the course of a day.

The efficiency measured varies throughout the day. It rises from 70% at 7 am to 97% at 9 am, and then remains constant until 7pm, before falling at the end of the day.

There is also a strong correlation (0.9882) between simulated and measured efficiency. On the basis of these findings, we can say that Equation (12) reproduces the inverter's efficiency during the day satisfactorily.

We will use the inverter efficiency to estimate the field input power because it is independent of temperature and its correlation rate (0.9882) is much higher than that of the field efficiency (0.7687).

For some days, or inverter input power data is missing. They can therefore be estimated using the theoretical inverter efficiency given by equations 4 and 12. Comparison of the estimated input powers with the measured input powers shows that there is a strong correlation (0.9998) as shown in Figure 4.

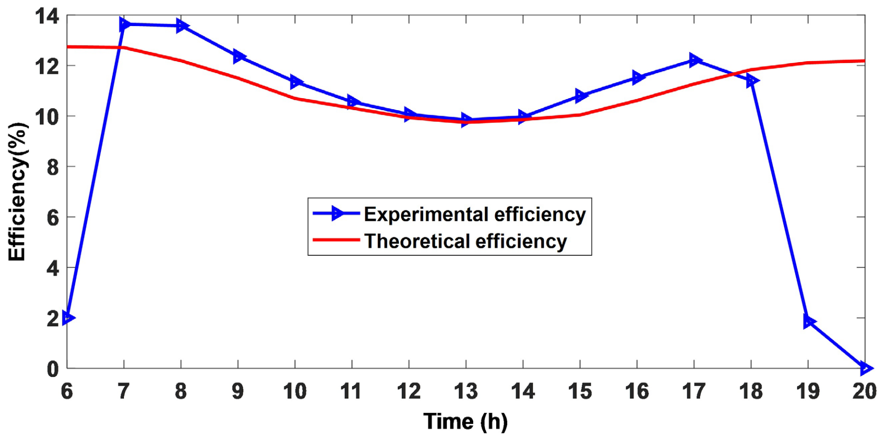

Figure 2. Changes in experimental and theoretical yield in the field on 07/07/2016.

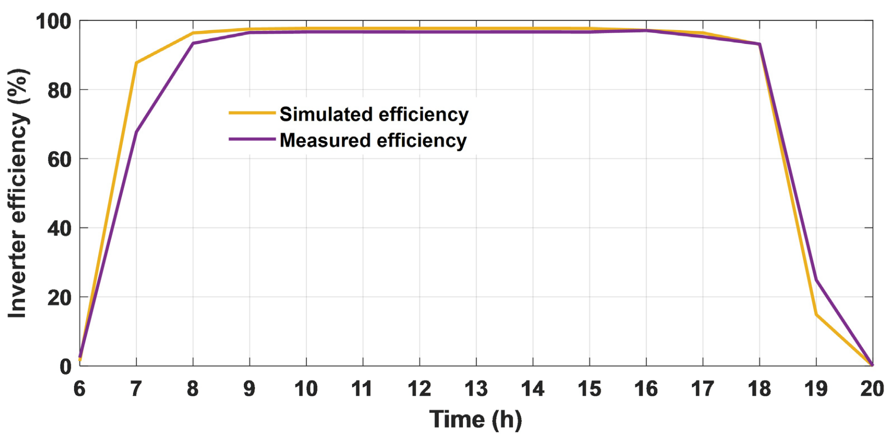

Figure 3. Evolution of simulated and measured inverter efficiency.

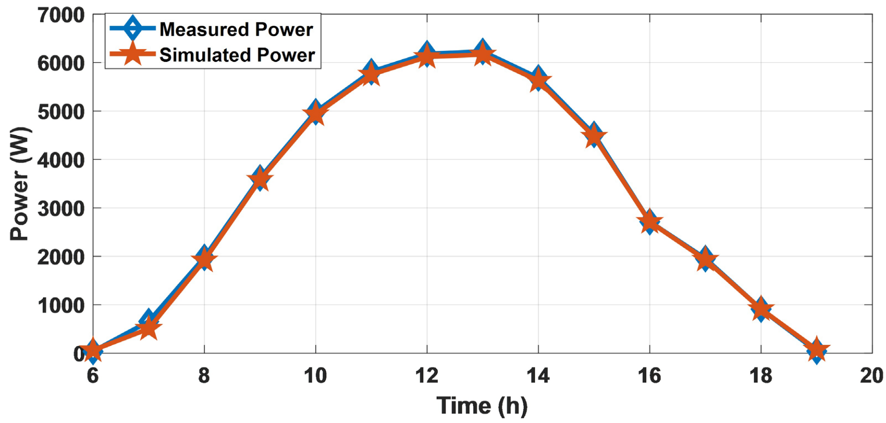

Figure 4. Evolution of measured and simulated input power.

4. Conclusions

The results obtained in this study confirm the robustness of the proposed approach for estimating the input power of a PV plant using inverter efficiency as the key parameter. The high correlation between the theoretical and measured value of the inverter efficiency, reaching 0.9882, attests to the reliability of the efficiency equation obtained. This high correlation suggests that the efficiency equation satisfactorily reproduces the real behaviour of the inverter throughout the day.

Thanks to this efficiency value, the input power could be accurately estimated. The comparison between the estimated and measured input powers reveals a strong correlation, reaching 0.9998, thus demonstrating the effectiveness of the proposed approach for estimating the input power under conditions where the input data is incomplete or missing.

In conclusion, this study paves the way for a practical and reliable method to assess the overall performance of power plants, by providing an accurate estimate of their input power. This approach could be of great use to PV plant managers, enabling them to optimise plant operation and make informed decisions to improve energy efficiency.

The method can also be applied to any system, provided that the experimental coefficients linked to the location can be found.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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