

Economic Sizing of a Grid-Connected Photovoltaic System: Case of GISER research project in Morocco

M Khanfara¹, R EL Bachtiri², M Boussetta³ and K EL Hammoumi⁴

^{1,2,4}CED STI, FST, PERE Laboratory EST-USMBA, Fez, Morocco

³FSDM, LESSI Laboratory, REPEER Group EST-USMBA, Fez, Morocco

maha.khanfara@usmba.ac.ma

Abstract. This paper is within the framework of the GISER (Gestion Intelligent des Systèmes d'Energies Renouvelables). It's a project about 3kVA hybrid energy management in PERE Laboratory (Procédés des Energies Renouvelables) of EST fez Morocco. We present a sizing study and a cost analysis of a photovoltaic system using simulation results with Sunny Design software. The goal of our work is to compute and optimize the dimensioning of a photovoltaic installation in order to find the best configuration of the system. We have considered a PV installation connected to the grid with 2.5kWp through an inverter. We have taken into account meteorological conditions in the installation site (radiation and temperature). Our optimization approach considers the operation of each part of the installation, including energy production, energy consumption and the overall quality/price of the installation.

1. Introduction

The rapid depletion of fossil-fuel resources on a worldwide basis has necessitated an urgent search for alternative energy sources. Photovoltaic and wind energy are considered as promising toward meeting the continually increasing demand for energy. The solar energy is inexhaustible and pollution-free. With the growing world population, electrical network become nonoperational due to redundant and overstressed infrastructure. Micro-grids are a promising solution to provide local energy generation and management [1].

Generated energy from PV systems depends mainly on solar energy available at selected site. Geographical location, ambient temperature, clearness index, tilt angle and orientation of PV panel. In order to efficiently and economically use of PV array system sizing and economic analysis is necessary [2].

Several researches, deal with system cost optimization of either grid-connected or stand-alone using HOMER optimization software which is based on the analytical simulation and storage system with anaerobic digestion biogas Power Plants [3]- [5]. Others [6][7] have developed heuristic methodologies, relying on evolutionary algorithms to optimize micro grids or HRESs size according to cost, environmental, or reliability parameters. However, few of them

deal with solar-, wind-, and biomass-resource hybridization in a grid-connected scheme [8] – [11].

In [12] the authors showed that the Moroccan climate is very favorable for the installation of grid-connected microgrid in several regions of the country. In [13] a grid coupling and injection into isolated grid networks with a proposed method to eliminate the first harmonics using a multilevel inverter. The photovoltaic systems, particularly those linked to the grid, have been developed in reply to an increasing demand of a renewable and clean energy [14], the aim is that the system must be economically attractive, the components for PV installation have a great influence on the system cost and its lifetime, and thus each part of the system must be well optimized and configured [15] [16].



The goal of this work is to find the optimal configuration of the 2.5kWp PV installation connected to grid for a research project in Morocco. The main contribution of this paper is to discuss an economic study and optimize the dimensioning of a photovoltaic installation compared to simulation results.

The optimal PV sizing depends on climatic data based in Fez. We have identified the optimal configuration between all the possible structures of a microgrid based on the power peak of the system which defines our project, thus on real climatic data of the region of Fez where we intend to realize our system.

We have found as a best configuration: Trina Solar Energy TSM-250PC05A for the PV panel. SB 2.5-1VL_40 for the inverter which have been chosen for its best performance and its compatibility with the PV module. We have also computed cable section, economic sizing and compared the results with Sunny Design Software simulations. We have found that the total investment including PV modules, inverter and lines is equal to 28,049 MAD.

2. Studied system

The studied system is a 3 kVA hybrid system developed within the framework of the CNRST-funded GISER project about the management of renewable energies consisting 2.5 kW peak PV module, 1.5 kVA wind turbine, 1 kW battery pack in order to ensure the electrical energy needs during the night and 1.5 kVA diesel generator as a backup power supply in the absence of PV-wind generation and if the batteries are discharged as shown in figure 1.

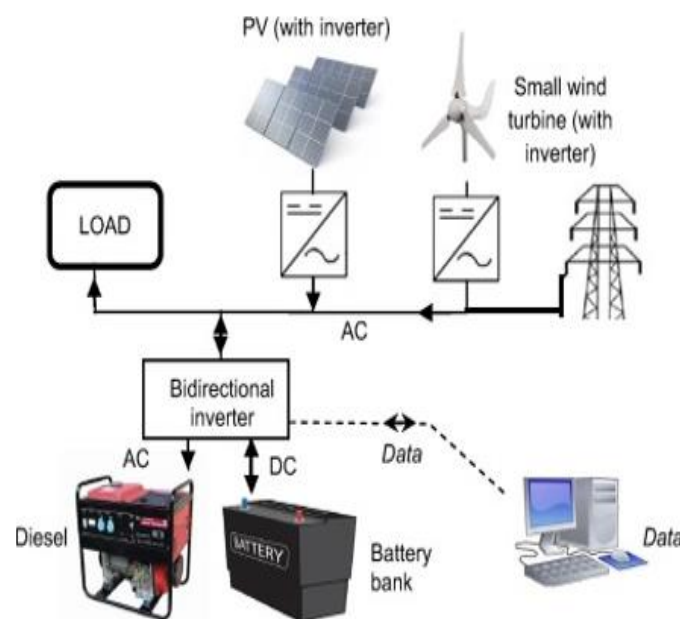


Figure 1. Hybrid Power System

2.1 Location of the site

The performance of a photovoltaic panels depends on climatic data which are principally solar radiation and temperature. To cater for a given load profile, the system size increases when climate resources are low [14]. Information required for this study was collected based on a project in Fez city of Morocco.

2.2 Meteorological DATA

Global irradiation of the location is 1.982 kWh/m² per year. The performance of PV modules is strongly depending on the sun light condition and temperature [15].

Figure. 2 and 3 give data of global irradiation and global temperature per month for Fez site.

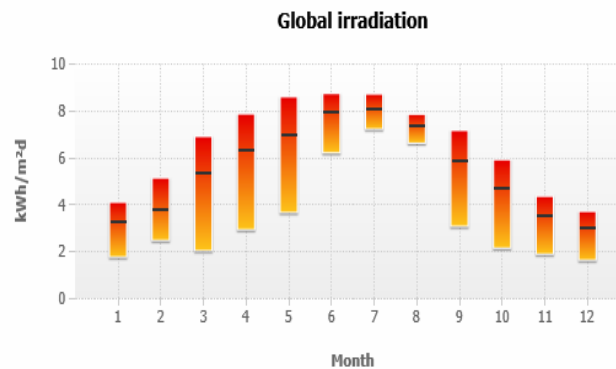


Figure 2. Global irradiation per month

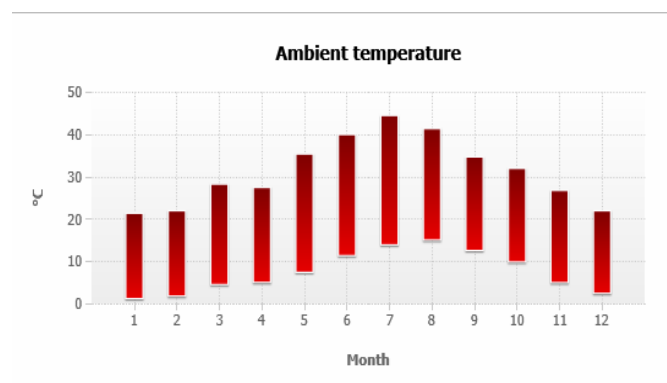


Figure 3. Global temperature per month

3. System Configuration

After the data input of the project (location and information on the PV power installation (Peak power, Orientation/Mounting type) the software proposes the following configuration:

3.1 Photovoltaic design data

Figure 4. Shows the information design of the PV array

10 x Trina Solar Energy TSM-250PC05A (35mm) , Azimuth angle: 0 °, Tilt angle: 25 °, Mounting type: Ground mount	
Number of strings:	1
PV modules per string:	10
Peak power (input):	2.50 kWp
Typical PV voltage:	280 V
Min. PV voltage:	254 V
Min. DC voltage (Grid voltage 230 V):	50 V
Max. PV voltage:	410 V
Max. DC voltage:	600 V
Max. MPP current of PV array:	8.3 A
Max. operating input current per MPPT:	10 A
Max. input short-circuit current per MPPT:	18 A
Photovoltaic Output Circuit Current:	8.8 A

Figure 4. PV array configuration

The important technical requirement which characterize the PV is the efficiency:

$$\mu = \frac{P}{E \cdot S} \quad (1)$$

P= Power peak of the PV

E= Irradiation

S= Area of the PV

$$\mu = \frac{250}{1000 \times 1.6368} = 15.27\%$$

3.2 Inverter

The sizing of the inverters will impose the way of cabling the modules between them. figure 5. Shows the inverter configuration proposed.

1 x SB 2.5-1VL-40 (PV system section 1)	
Peak power:	2.50 kWp
Total number of PV modules:	10
Number of PV inverters:	1
Max. DC power (cos φ = 1):	2.65 kW
Max. AC active power (cos φ = 1):	2.50 kW
Grid voltage:	230V (230V / 400V)
Nominal power ratio:	106 %
Dimensioning factor:	100 %
Displacement power factor cos φ :	1

Figure 5. Inverter configuration

The Sunny Boy is a transformerless photovoltaic inverter that converts the direct current of the photovoltaic generator into grid-compliant alternating current and feeds it into the grid.

Figure.6. shows the performance and the compatibility between the inverter and PV modules.

The choice of inverters is based on three requirements: Power Compatibility, Voltage Compatibility and Current Compatibility.

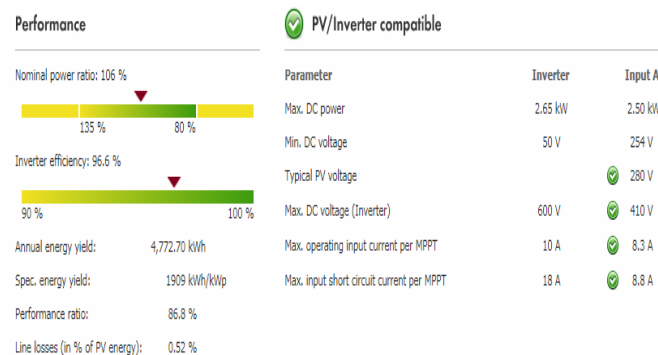


Figure 6. Performance and PV Inverter compatibility

3.3 Lines

The choice of the cables section on DC side is carried out according two important requirements:

The permissible current maximal in the cable I_{max} and the voltage drop in line. In [17] the permissible current through the lines must be equal to or greater than 1.25 times of the PV string short-circuit current.

$$I_{max} \geq 1.25 * I_{cc} \quad (2)$$

Voltage drop in the cable should be less than 3% and ideally to equal to 1%.

$$S = \frac{2 * \rho * L * I}{\epsilon * U} \quad (3)$$

S: Cable section

ρ : Resistivity of the semiconductor = 0.02314 $\Omega\text{mm}^2/\text{m}$

L: Cable length = 15 m

I: Current flowing in the cable = $I_{mpp} = 8.27 \text{ A}$

ϵ : Voltage drop

U: Voltage at the origin of the cable = $U_{mpp} = 30.3 \text{ V}$

$$S = \frac{2 * 0.02314 * 15 * 8.27}{0.03 * 10 * 30.3} = 0.63 \text{ mm}^2 \cong 1.5 \text{ mm}^2$$

In [17] I'UTC C15-712-1 contains a table giving the value of the permissible current as a function of cable cross-section, installation mode, the temperature.

The value of the maximal permissible current I_{max} at a given ambient temperature is defined by the following formula:

$$(4) \quad I_{max} = I_{120} * k$$

I_{120} : permissible current in an ambient temperature

So $I_{max} = 22 * 0.82 = 18.04 \text{ A}$

We must verify if the permissible current of the lines are equal to or greater than 1.25 times of the PV string short-circuit current.

$$I_{max} \geq 1.25 * I_{CC}$$

we notice that $I_{max} \geq 10.987$

The cable section on AC side as follow:

$$S = \frac{b * \rho * L * I * \cos \varphi}{\epsilon * V_n} \quad (5)$$

S: Cable section

b: Coefficient equal to 1 for one phase and 2 for 3 phases

ρ : Resistivity of the semiconductor = $0.02314 \Omega \text{ mm}^2/\text{m}$

L: Cable length = 25 m

I: Reverse Current = $I = 1.25 * 8.27 \text{ A}$

ϵ : Voltage drop

V_n : Nominal Voltage = $V_n = 220 \text{ V}$

$$S = \frac{2 * 0.02314 * 25 * 8.79 * 1}{0.03 * 220} = 1.54 \text{ mm}^2$$

Figure.7. shows wire sizing

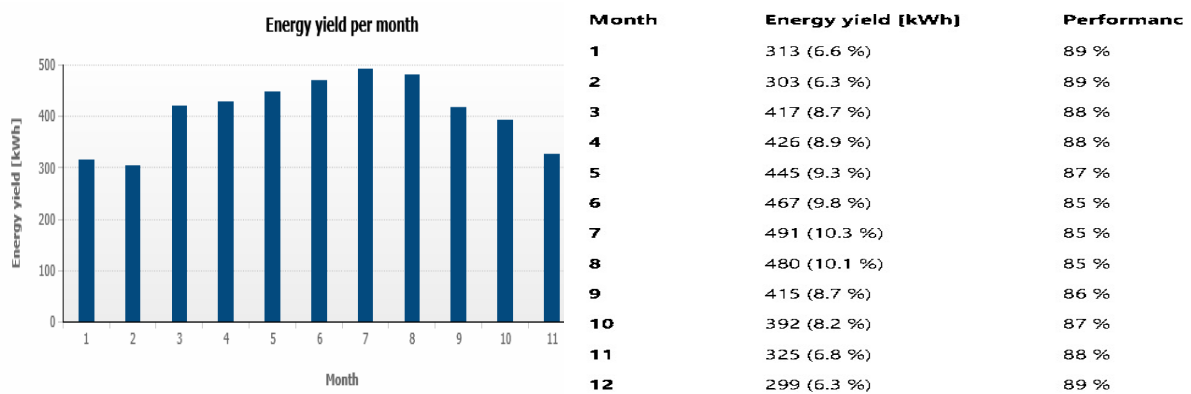
We notice that the section of cables that have been proposed are equal to that calculated.

	✓ DC	⚠ LV	✓ Total
Power loss at nominal operation	17.27 W	27.10 W	44.36 W
Rel. power loss at rated nominal operation	0.65 %	1.08 %	1.74 %
Total cable length	20.00 m	10.00 m	30.00 m
Cable cross-sections	1,5 mm ²	1,5 mm ²	1,5 mm ²

Figure 7. Line section

The energy yield contains two major elements: the target yield is the theoretical annual energy production (on the DC side of the module), only taking into account the energy of the incoming light and the module's nominal efficiency and The Performance Ratio is the ratio between actual yield (i.e. annual production of electricity delivered at AC) and the target yield, it takes into account all pre-conversion losses, inverter losses, thermal losses and conduction losses.

figure 8 shows that the energy yield and the performance ratio of the PV system.

**Figure 8.** PV energy yield and the performance ratio per month

3.4 Profitability analysis

This section shows the economic analysis for the project.

	The total costs
PV modules`	2,143.80 USD
Inverter	808.00 USD
Lines	19.75 USD
Investment	2,971.5528 USD
Specific investment (CapEx / kWp)	1,180.72 USD/kWp

4. Conclusion

This paper presents a technical economic study and a dimensioning of a PV system Trina. The dimensioning was realized with two methods, theoretically and by using the sunny design software, the results shows that we have found the best configuration of the system which consist: 10 of Trina Solar Energy TSM-250PC05A and one inverter SB 2.5-1VL_40. The Total investment is 2,971.5528 USD, and the total revenue from grid feed-in after 20 years is 11687 USD.

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References

- [1] Gungor V C, Lu B, and Hancke G P 2010 *Opportunities and Challenges of Wireless Sensor Networks in Smart Grid (IEEE Transactions on Industrial Electronics vol 57)*pp. 3557–3564
- [2] Zhou W, Lou C, Li Z, Lu L, and Yang H 2010 *Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems (Applied Energy vol 87) no. 2, pp. 380–389*
- [3] Montuori L, Alcázar-Ortega M, Álvarez-Bel C, and Domijan A 2014 *Integration of renewable energy in microgrids coordinated with demand response resources: Economic evaluation of a biomass gasification plant by Homer Simulator (Applied Energy vol 132) pp. 15–22, Nov. 2014.*
- [4] Ma T, Yang H, and Lu L 2014 *A feasibility study of a stand-alone hybrid solar–wind–battery system for a remote island (Applied Energy vol 121)pp. 149–158*
- [5] Lai C S and McCulloch M D 2017 *Sizing of Stand-Alone Solar PV and Storage System With Anaerobic Digestion Biogas Power Plants(IEEE Transactions on Industrial Electronics vol 64) pp. 2112–2121*
- [6] Zhao B, Zhang X, Li P, Wang K, Xue M, and Wang C 2014 *Optimal sizing, operating strategy and operational experience of a stand-alone micro grid on Dongfushan Island (Applied Energy vol 113)pp. 1656–1666*
- [7] Ma T, Yang H, Lu L, and Peng J 2015 *Pumped storage-based standalone photovoltaic power generation system: Modeling and techno-economic optimization (Applied Energy vol. 137)pp. 649–659*
- [8] González A, Riba J R, and Rius A 2015 *Optimal Sizing of a Hybrid Grid-Connected Photovoltaic–Wind–Biomass Power System (Sustainability vol 7)pp. 12787–12806*
- [9] Yazdani A, Bhuiyan F A, and Primak S L 2015 *Optimal sizing approach for islanded microgrids (IET Renewable Power Generation vol 9)pp. 166–175*
- [10] Tazi K, Abbou F M, Bannour Chaka A, and Abdi F 2017 *Modeling and simulation of a residential microgrid supplied with PV/batteries in connected/disconnected modes—Case of Morocco (Journal of Renewable and Sustainable Energy vol 9)p. 025503*
- [11] Mondol J D, Yohanis Y G, and Norton B 2006 *Optimal sizing of array and inverter for grid-connected photovoltaic systems (Solar Energy vol 80) pp. 1517–1539*
- [12] Boussett M, El Bachtiri R, Khanfara M, and El Hammoumi K 2017 *Assessing the potential of hybrid PV–Wind systems to cover public facilities loads under different Moroccan climate conditions (Sustainable Energy Technologies and Assessments vol 22)pp 74–82*
- [13] Khanfara M, Elbachtiri R, El hammoumi K, Boussetta M 2016 *A Multicarrier PWM Technique for Five Level Inverter connected to the grid (International Conference on Information Technology for Organization Development (IT40D)) 978-1-4673-7689-1/16\$31.00*
- [14] Nordin N D and Rahman H A 2014 *Design and economic analysis in stand-alone photovoltaic system (in Energy Conversion CENCON IEEE Conference) pp. 152–157*
- [15] Kolhe M 2009 *Techno-Economic Optimum Sizing of a Stand-Alone Solar Photovoltaic System (IEEE Transactions on Energy Conversion vol. 24) pp. 511–519*
- [16] Boussetta M, Elbachtiri R, El hammoumi K, and Khanfara M 2016 *optimal sizing of grid-connected pv-wind system case study: agricultural farm in morocco (Journal of Theoretical and Applied Information Technology vol 86) p. 196*
- [17] GUIDE PRATIQUE *Installations photovoltaïques*, UTC C15-712