18èmes Journées Internationales de Thermique (JITH 2017)
Monastir (Tunisie), 25 - 27 Octobre 2017

Study and Simulation of Photovoltaic Installation for Energy Efficient Buildings

S. Ben Mabrouk (*) , H. Oueslati, A. Ben Mabrouk,
Research and Technology Centre of Energy, CRTEn
P.Box : 95 Hammam-Life 2050, Tunisia.
salah.benmabrouk@crten.rnrt.tn
L. Dusonchet, S. Favuzza, D. La Cascia, F. Massaro, G. Zizzo
DEIM – Department of Energy, Engineering Information and Mathematical models
University of Palermo; Palermo, Italy.
dusonchet@dieet.unipa.it

Abstract: In the present paper, a new approach to the management of energy resources in a research laboratory is proposed and evaluated by a simulation for the PV installation realized for the Tunisian-Italian cooperation project DE.DU.ENER.T, using renewable energy and economic criteria.
The aim of this project is to improve energy efficiency order to minimize the electricity cost consumed at the laboratory. According to the bills of electricity received we noticed that there is a high consumption of electrical current, from the STEG grid, and especially by the energy intensive equipment such as drying ovens and all the workstations. So, we targeted to install a photovoltaic field of 12KWc to reduce these bills by using the sustainable, green and clean sources.
In addition, a theoretical study of the PV system sizing realized manually in order to know in the first hand the compatibility between the different equipment of this installation and to compare the results with those found by the SMA Sunny Design and PV*SOL software in the second hand.
We designed and managed these systems optimally to promote the self-consumption of the electric energy in the building of LPT Research laboratory. We will focus on the use of the PV system by evaluating the impacts of electricity generation using renewable energy levied on electricity grid (energy injection and extraction) and the economies that can be achieved during the hours Operating. Then, we present the different result obtained by the simulation of our installation using a PV-SYST simulation software.

Keywords: Heat Transfer, Hybrid Energ System, Renewable Energy, Photovoltaic panel, Simulation.

1. Introduction

Hybrid Energy System (HES) is an electric energy system, which is made up of a single or many electric sources. These sources could be renewable, traditional, or mixed and works in off-grid or connected to the grid [1-3]. If this HES system contain only the renewable energy sources it will be name by a Hybrid Renewable Energy System (HRES) such as the photovoltaic, the wind turbine and so they can address emissions, reliability, efficiency, and economical limitations of single renewable energy source [3].
The HRES systems are becoming famous for standalone power generation in not isolated and isolated area due to the growing, the improvement and efficiency in renewable energy technologies [4]. This hybrid system have many advantages for our country such as protect the environmental, reduce the emission of gas especially CO2 and other pollutants emissions like the green house gas due to the not consumption of fuel or natural gas. The cost of solar and wind energy can be competitive with the classical grid installation and the diversity of natural resources who are renewable, clean and inexhaustible [5]. Most of this equipment can be easily installed and deployed for other utilizations. Financially, these sources are free and there costs are predictable and not influenced by fuel price [5-8]. However, the most disadvantage of the hybrid system photovoltaic PV–Wind is

there dependence on climatic changes and weather. Then they must be oversized to make their standalone systems reliable and to satisfy the load [9-10].

Various hybrid renewable energy systems have been installed in different countries because many domains are concerned with the uses of the HRES. Buildings consume about 40% of the overall energy consumption worldwide and correspondingly are responsible for carbon emissions. Since, last decade efforts have been made to reduce this share of CO2 emissions by energy conservation and efficient measures [10]. One of this area is the research and development actions [1, 10] which have focused on the performance analysis of demonstration systems, the development of efficient power photovoltaic panel and the innovation of new types of PV panel and wind turbine. For exploring the opportunities given by HRES generators coupled with innovative storage systems, the authors have built two different prototypes in Valderice (Italy) and in Borj-Cédriya Techno Park (Tunisia) in the framework of the international cooperation project DE.DU.ENER.T Erreur ! Source du renvoi introuvable.. Both prototypes comprise:

- an electric consumption center;
- a photovoltaic generator;
- a micro-wind generator;
- a battery energy storage system (BESS).

Other researches focused on the battery and the storages systems [7]. This work will focus only on the study and the sizing of the PV installation for this DE .DU.ENER.T Project [8].

2. TUNISIAN PROTOTYPE

2.1. Description of the prototype

The Tunisian prototype of the DE.DU.ENER.T Project installed near the Laboratory of Thermal Processes, a part of the Research and Technology Centre of Energy CRTEn (Borj Cedriya Techno Park), to reduce the energy consumption consumed from the grid by this laboratory, and it composed by a 12KWc of photovoltaic field and a 1KW of wind turbine.

(a) (b)

Figure 1. the laboratory LPT (a) and the platform of our installation (b)

2.2. Work methodology and laboratory equipment

Because of the unavailability of an electrical consumption meter dedicated to the laboratory (LPT), we made an estimation of the energy consumption of the latter. To make this estimation, we conducted census of electrical equipment used by one local of this laboratory.

This local contain three type of Equipment:

- Laboratory equipment such as drying oven, desiccators and precision balance,
- Workstations and laser printer,
- Lighting equipment

Then we extrapolated this consumption for the remainder of locals and offices for this laboratory. Finally, we have refined our extrapolation by an error margin of 10%.

After identifying the different equipment of the laboratory, we tried to identify the optimal operating mode (number of unit, operating hours...) and identified the different electrical characteristics (current, voltage, power...) for each appliance to determine the real power consumption in this laboratory and the higher energy consuming equipment.

The power consumed by each equipment is calculated as follows:

$$\begin{aligned}
&\text{Total Power} = \text{Unit power x Quantity}\\
&\text{Daily Power} = \text{Total Power x Hours Operating / day}\\
&\text{Mounthly Power} = \text{Daily Power x Number of day per mounth}\\
&\text{Annualy Power} = \text{Mounthly Power x Number of mounth}\ .
\end{aligned} \tag{1}$$

The development of control strategies asks for a computationally efficient energy model of a building under study. Consequently, after determining these powers, the photovoltaic power to install is determined by the following expression:

$$\text{PV Power} = \sum \text{Annualy Power} \Big/ \text{Basic Consumption} \tag{2}$$

The following figures follow the consumption profile of different equipment.

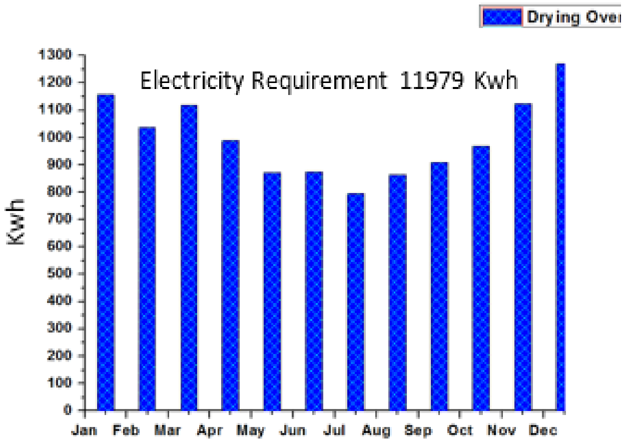


Figure 2. Consumption profile of the drying oven.

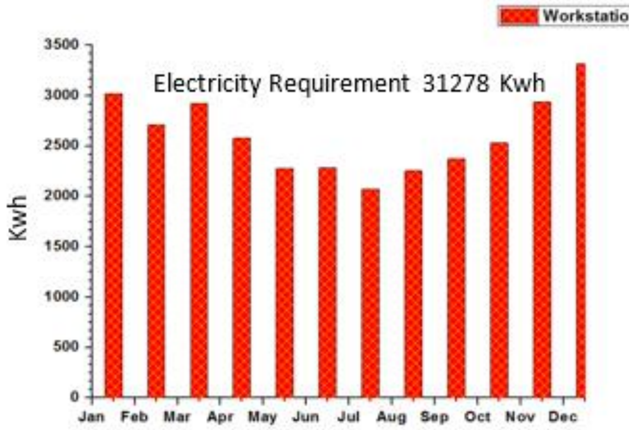


Figure 3. Consumption profile of the workstations.

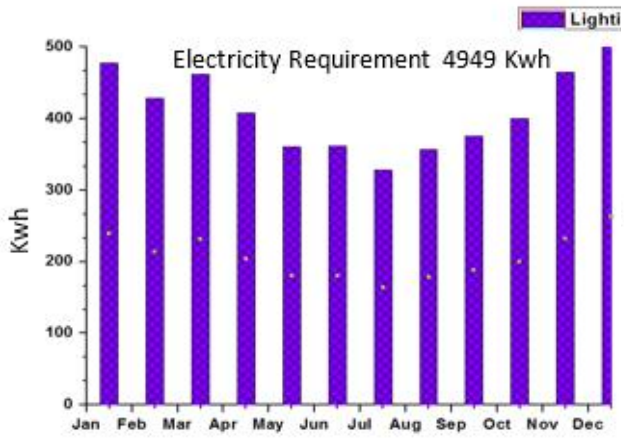


Figure 4. Consumption profile of the lighting system

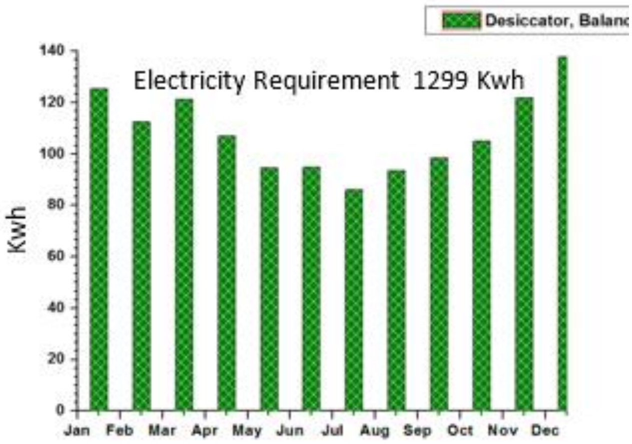


Figure 5. Consumption profile of the laboratory equipments

According to the previous figures, we can conclude that there are two types of energy consuming equipment that are drying oven (Figure 2) and the workstations (Figure 3).

2.3. Theoretical sizing of the Equipment

– Photovoltaic Panel

We have chosen to install Yingli Solar monocrystalline photovoltaic panels of 250 Wc, tinted in black because in this case it becomes more selective and we will have a maximum yield of 15.3%.

TABLE I. Electrical characteristics of PV panel

Characteristics	*Units*	*STC Conditions*	*NOCT Conditions*
Maximum Power	W	250	181.6
Voltage at Pmax	V	28.9	26.4
Current at Pmax	A	8.66	6.91
Open circuit voltage	V	37.6	34.8
Short circuit cuurent	A	9.29	7.50

TABLE II. Thermal characteristics of PV panel

Characteristics	*Symbol*	*Units*	*Value*
Nominal Temperature of cell		*°C*	***46 +/- 2***
Temperature coefficient for Pmax	*γ*	*%/°C*	***-0.42***
Temperature coefficient for Voc	*βVoc*	*%/°C*	***-0.31***
Temperature coefficient for Isc	*αIsc*	*%/°C*	***0.04***
Temperature coefficient for Vmpp	*βVmpp*	*%/°C*	***-0.41***

– Converter

For our installation of 12 Kwp with a type of exposure and incline of 36°, using a single inverter is sufficient. But, for larger installation the installation of multiple inverters can reduce the risk of outages. The selected inverter is a Sunny Tripower 12000 TL-20 whose technical characteristics are presented in the following tables:

TABLE III. Electrical characteristics of Inverter

Characteristics	*Symbol*	*Units*	*Value*
Maximum DC Power	$\mathbf{P}_{max}$	W	12 275
Maximum Input Voltage	$\mathbf{V}_{max}$	V	1 000
MPP Voltage range	$\mathbf{U}_{mppt}$	V	400-800
Maximum Input Current A/ B	$\mathbf{I}_{max}$	A	18 A / 10 A
Number of independnt MPP Input A/ B			A : 2 / B : 2
Grid Frequency		**Hz**	50-60
Maximum Output current		**A**	17.4

We must make sure that voltage delivered by the PV field belongs to the MPPT voltage range of the inverter. If it does not, the installation may have a power loss. This MPPT voltage range will also have an impact on the number of PV panels in string.

The following equations are used to determine the minimum and maximum number of PV panels in string [13]:

$$\text{Maximum number of panels} = E\left(\frac{\text{Umppt, max}}{\text{Umpp*1,15}}\right) \quad \textbf{(3)}$$

$$\text{Minimum number of panels} = E\left(\frac{Umppt,\min}{Umpp*0,95}\right) \quad \textbf{(4)}$$

The theoretical calculation has given us a minimum number of 16 panels and a maximum number of 24 panels, and we will connect to the A input of the inverter 32 panels according to 2 strings and to the B input 16 panels into a single string.

The sizing of an inverter per string is based on three criteria: power compatibility, Maximum voltage compatibility, current compatibility.

The power of the inverter must be significantly different to the power of the field that is why this power must be undervalued approximately by 5-15% and be increased by 10-20% relatively to the maximum power of the field [13].

$$0.85 < \frac{\text{Maximum power of inverter}}{\text{Field power}} < 1.2 \quad (5)$$

An inverter is characterized by a maximum input voltage equal to 1000V and if the voltage delivered by the PV panels exceeds this value the inverter may be damaged.

The following equations are used to verify this compatibility [12]:

$$\Delta V = \beta V_{OC} * V_{string} * \Delta T \quad (6)$$

$$V_{max} = V_{string} + \Delta V \quad (7)$$

An inverter is characterized by a maximum input current. So when the DC input current exceeds the maximum current admissible by the inverter it continues to operate, but provides to the grid the corresponding power at peak current.

This compatibility is verified by the following expression:

$$I_{string\ input} = \text{Number of string} * I_{Mpp} \quad (8)$$

– Voltage drop

To properly sizing our facility, we must have a voltage drop not exceeding than 3% of the AC or DC part. For this, we must calculate these two voltage drops according to NF C 15-100 and NF C 14-100 norms by these following expressions [14].

$$U = \left(\frac{I*\rho*L}{S} \right) \quad (9)$$

$$u = b*\left(\rho_1 \frac{L}{S} \cos\cos\varphi + \lambda L \sin\sin\varphi \right)*I_b \quad (10)$$

$$\Delta u = \left(\frac{U}{U_0} \right)*100 \quad (11)$$

3. Results

3.1. Simulation by SMA Sunny Design and PV SOL software

In this part, we realized a simple simulation for the photovoltaic installation by the SMA Sunny Design [15], which is photovoltaic software for SMA inverters like our inverter.

The important object for this sizing is to compare the results for the power, voltage and the current compatibility, which are found theoretically with those found by this software.

The following figure presents the compatibility for the voltage range and the input current between the out photovoltaic field and the input of the inverter.

	Input A:	Input B:
Number of strings:	2	1
PV modules per string:	16	16
Peak power (input):	8.00 kWp	4.00 kWp
Typical PV voltage:	432 V	432 V
Min. PV voltage:	387 V	387 V
Min. DC voltage (Grid voltage 220 V):	150 V	150 V
Max. PV voltage:	647 V	647 V
Max. DC voltage:	1000 V	1000 V
Max. current of PV array:	17.3 A	8.7 A
Max. DC current:	18 A	10 A

Figure 6. Compatibility of the electrical caracterestics of our sizing

The following figure presents the consumption profile for our system by using some battery to storage some energy for lighting at night, and the effect of this installation to reduce the quantity of electricity purchased from the grid.

We know that the energy consumed by our laboratory per year is equal 49505 KWh and with results of this profile of self-consumption, we can conclude that the self-sufficiency quota is equal 32.2% (in percentage of PV Energy) and the self-consumption quota is equal 82.4% (in percentage of Energy Consumption per year).

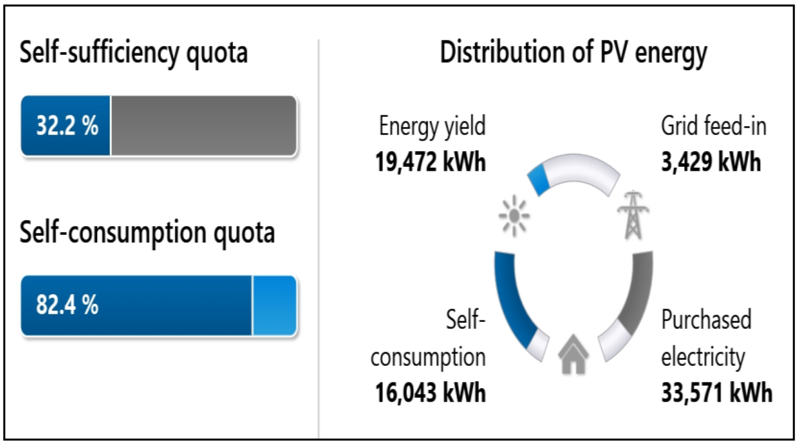


Figure 7. Self Consumption profile

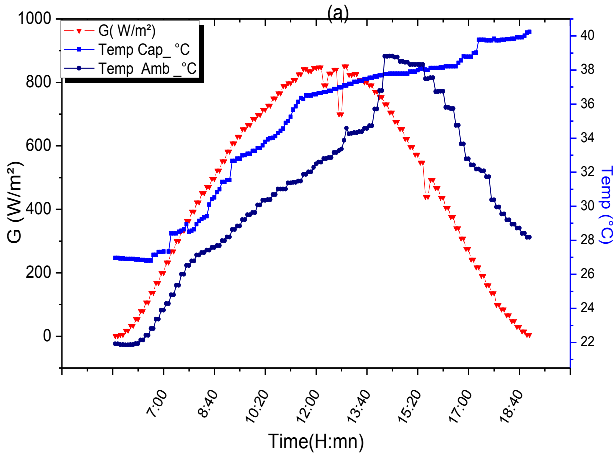
In this part we realized a simulation for our photovoltaic installation by the PV*SOL software to have some idea about the efficiency for this system and to compare some results with the others results given by SMA Sunny Design software.

Figure 8. Self Monthly Production profile

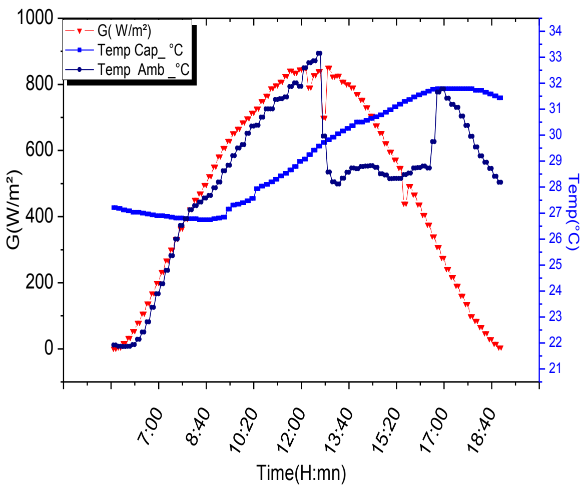
We noted that by summing each monthly power produced by the HRES (Fig. 8), we find a very similar value to that found previously by using the SMA Sunny Design software (fig.7). This small variation is due to the difference between the values of each weather databases [15].

3.2. *Temperature profiles*

In the following figures, we present the profile of the panel temperatures using the meteorological database of 2016 for Techno Park site of Borj Cedriya (south of Tunis City) that allows to accurate data for solar irradiation, wind, temperature and more weather parameters. We noted that these profiles are proportional and that the peak temperature appears in the summer with a maximum of outside temperature equal to 38°C and a maximum of PV panel temperature equal to 40°C.



(***a***)



(***b***)

Figure 9. Temporal evolution of solar irradiation (G), ambiant temperature (Temp-Amb) and PV Panel temperature (Temp-Cap) for a typical day of July 2016 (***a***) and May 2016 (***b***).

1.1. Performance Ratio (PR)

The performance ratio (PR) is indicated in percentage and is the ratio between the real and the theoretical yield of the photovoltaic system.

If the value of this ratio approaches of 100%, we consider that this photovoltaic system has an efficient operation. However, it is not possible to reach the value of 100% in practice because the operation of the photovoltaic system always generates inevitable losses such as the thermal and conduction losses. The performance ratio is calculated as follows [14]:

$$\text{Performance Ratio} = \text{Real yield} \big/ \text{Theorical yield} \qquad (12)$$

In the following figure 10, we present the profile of this performance ratio. We noted that our installation is effective because it have a higher performance ratio (more than 80%) and we deduct that this value is fluctuating because of some conditions such as panel temperature, shading, solar irradiation and the energy losses.

Forecast Production with consumption

In the following figure 11, we present the quantity of the energy produced by the PV installation, the energy consumed from the grid and a little quantity of energy stored by using batteries (Fig. 11).

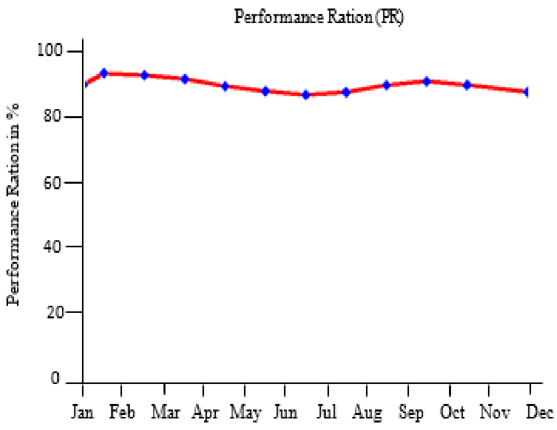
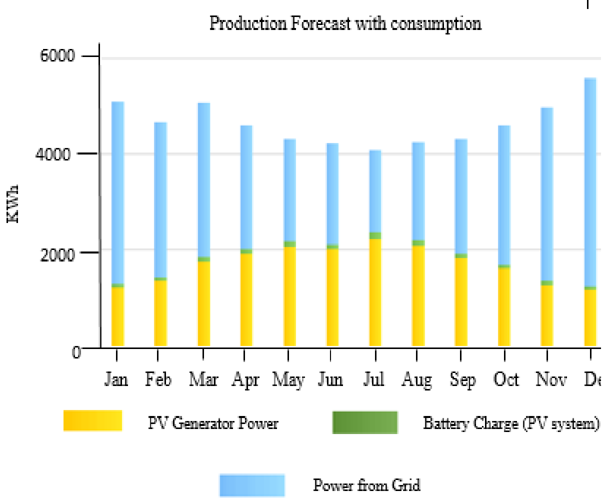


Figure 10. Performance ratio



- Figure 11. Production forcast with consumption

We noted that by summing each monthly power produced or purchased (Fig. 11), we find a very similar value to that found previously by using the SMA Sunny Design software (fig.7). This small variation is due to the heat dissipation for each weather databases [15].

4. Conclusion

This document is an evaluation for our DE.DU.ENER.T project funded in the framework of the trans-frontier cooperation program ENPI CT Italia-Tunisia 2007-2013.

First, it shows the approach used to realize our theoretical sizing study. Next, we performed simulations by means of professional software for photovoltaic installations in order to have an idea about the profitability of our system and to compare the results found. Finally, we conclude that the results are very similar and they show the efficiency of our system, then this installation will allow us to reduce the cost of electricity purchased from the grid.

Recent results of the simulation study realized by some industrial software such as PV*Syst and PV*SOL indicate that the hybrid electric system could provide about 39% of the total consumption of the electricity for our laboratory. Our solar devices allow the order of 4500 KWh energy saving and CO2 emissions reduction of about 2600 Kg per year.

After the connection of this hybrid system to the electricity distribution grid, some measurements and data will be extracted to use it for the Capitalization and Monitoring study.

NOMENCLATURE

Symbol	Description	Unit
$U_{mppt,max}$	Maximum input Dc voltage to the inverter	V
$U_{mppt,min}$	Minimum input Dc voltage to the inverter	V
U_{mpp}	Maximum voltage of the PV panel	V
U	DC Voltage drop	V
I, I_{Mpp}	Maximum current of the panel	A
L	Cable length	m
u	AC Voltage drop	V
b	Coefficient	No unit
s	Cable section	mm²
$cos\phi$	Power factor	No unit

λ	Linear reactance	Ω/m
I_b	Maximum output current of the inverter	A
Δu	Relative voltage drop	V
U_0	Nominal voltage	V
ΔV	Voltage difference	V
βV_{0C}	Temperature coefficient	%/°C
V_{string}	String voltage	V
ΔT	Temperature difference	°C
V_{max}	Maximum input voltage to the inverter	V
$I_{string\ input}$	Maximum input current per string	A
ρ, ρ_1	Resistivity of the conductive wire	$\Omega.mm^2/m$

Acknowledgments : The Project has been funded by "Programme Instrument Européen de Voisinage et de Partenariat (IEVP) Coopération Transfrontalière (CT) - Programme ENPI Italie-Tunisie 2007- 2013 Projet DE.DU.ENER.T. " Le Développement durable dans la production énergétique dans le territoire" Ps 2.3.005 CUP : C17D13000000006 - Progetto cofinanziato dall'Unione Europea - "Sfide comuni, obiettivi condivisi" - Assistenza Tecnico-scientifica Ares s.r.l. - Soggetti: Comune di Valderice, Centre de Recherches et des Technologies de l'Energie (CRTEn) - Technopole de Borj Cedria -Tunisia, Consorzio Universitario della Provincia di Trapani, Libero Consorzio Comunale di Trapani".

References

1. Sudhakar K. Tulika S. Kavali J. Matlab Modeling and Simulation of Solar Photovoltaïc Panel; LAMBERT Academic Publicshing.
2. Bajpai P, Dash V. Hybrid renewable energy systems for power generationin stand-alone applications: Areview.Renew Sustain Energy Rev 2012; 16:2926– 39.
3. Erdinc O, Uzunoglu M. Optimum design of hybrid renewable energy systems: Overview of different approaches. Renew Sustain Energy Rev 2012; 16:1412– 25.
4. Marques AJ, Boccaletti C, Ribeiro EFF. Uninterruptible Energy Production in Standalone Power Systems for Telecommunications presented at the International Conference on Renewable Energies and Power Quality (ICREPQ'09) Valencia (Spain), 2009.
5. W.T. Chong, M.S. Naghavi, S.C. Poh, T.M.I. Mahlia, K.C. Pan. Techno-economic analysis of a wind–PV hybrid renewable energy system with rain water collection feature for urban high-rise application. Appl Energy 2011; 88:4067–77.
6. Kazem HA. Renewable energy in Oman: status and future prospects. Renew Sustain Energy Rev2011; 15:3465–9.
7. Zachariah Iverson, Ajit Achuthan, Pier Marzocca, Daryush Aidun. Optimal design of hybrid renewable energy systems (HRES) using hydrogen storage technology for data center applications. Renew Energy 2013; 52:79–87.
8. S. Ben mabrouk, A. Ben Mabrouk, K.Harzli, D. La Cascia , H.Oueslati, G. Zizzo, L. Dusonchet, S. Favuzza, M.G. Ippolito, F. Massaro. Experimentation of Sustainable Energy Microsystems: the DE.DU.ENER.T. Resaerch Project. 4th International Conference on Renewable Energy Research and Applications (ICRERA2015) , 22-25 November 2015 Palermo, Italy.
9. Kazem HA, Khatib T. Techno-economical assessment of grid connected photovoltaic power systems productivity in Sohar, Oman. Sustain Energy Tech- nol Assess 2013; 3:61–5.
10. Kabalci E. Design and analysis of a hybrid renewable energy plant with solar and wind power. Energy Convers Manag 2013; 72:51–9.
11. Harish V.S.K.V, Kumar A. A review on modeling and simulation of building energy systems. Renewab and Sustain Energy Reviews, 2016; 56: 1272 – 1292.
12. Paiva JE, Carvalho AS. Controllable hybrid power system based on renewable energy sources for modern electrical grids. Renew Energy 2013; 53: 271–279.
13. A. Labouret, M. Villoz, Installations photovoltaïques : Conception et dimensionnement d'installations raccordées au réseau, 5ed, Edition le Monter, DUNOD : Paris, 2012, pp.127-139.

14. Unio Technique de l'Electricité (UTE), UTE C 15-105 Guide Pratique : Détermination des sections de conducteurs et choix des dispositifs de protection, Méthodes pratiques, Edition UTE, CEDEX, 2003, pp.83-91.
15. H. Oueslati, S. Ben Mabrouk, A. Ben Mabrouk, D. La Cascia,G. Zizzo, L. Dusonchet, S. Favuzza, F. Massaro. "Feasibility analysis and study of a grid-connected hybrid electric system: Application in the building sector", 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), pp. 1-6, 7-10 June 2016, Florence (Italy), DOI: 10.1109/EEEIC.2016.7555660.