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Study for the Extension of the Oued el Kebrit Photovoltaic power plant to 24 MWp

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ABSTRACT

Technological and industrial development as well as population growth have greatly increased the world's demand for electricity. The latter is an important factor for national development. In fact, a large part of the world's energy production, ensured by fossil sources, has led to global warming and increased pollution and depletion of conventional natural resources. Accordingly, the use of renewable energies, especially photovoltaics, has become a necessity to boost the production rate of electricity from non-fossil, sustainable and non-polluting resources. To that end, research center's main emphasis has moved towards working on the optimization of photovoltaic systems. The present work aims to expose the potential of solar energy in Algeria. A presentation of the national program of renewable energy and energy efficiency of Algeria, consolidated by a thorough case study of a real PV power plant in Algeria is offered, which exposed a considerable deficit in achieving the desired objectives caused by both economic and health crisis in the entire world in recent years. The increase in this power plant power was chosen as an objective. Therefore, the effectiveness of the proposed solution could be determined based on sizing simulations, using PVSyst software, after the extension of the power plant.

دراسة لرفع قدرة محطة الطاقة الكهروضوئية بوادي الكبريت إلى 24 ميجاوات

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الكلمات المفتاحية:
متصلة بالشبكة
كهروضوئية
محطة توليد الطاقة
زيادة الطاقة
دراسة

الملخص

أدى التطور التكنولوجي والصناعي وكذلك النمو السكاني إلى زيادة الطلب العالمي على الكهرباء بشكل كبير. وهذا الأخير عامل مهم للتنمية الوطنية. والواقع أن جزءًا كبيرًا من إنتاج الطاقة في العالم، والذي يتم تأمينه من مصادر الطاقة الأحفورية، أدى إلى الاحتباس الحراري وزيادة التلوث واستنزاف الموارد الطبيعية التقليدية. وبناءً على ذلك، أصبح استخدام الطاقات المتجددة، وخاصةً الطاقة الكهروضوئية، ضرورة لزيادة معدل إنتاج الكهرباء من مصادر غير أحفورية ومستدامة وغير ملوثة. وتحقيقًا لهذه الغاية، اتجه التركيز الرئيسي لمركز الأبحاث نحو العمل على تحسين الأنظمة الكهروضوئية. يهدف هذا العمل إلى الكشف عن إمكانات الطاقة الشمسية في الجزائر. يتم تقديم عرض للبرنامج الوطني للطاقات المتجددة وكفاءة الطاقة في الجزائر، مدعومًا بدراسة حالة شاملة لمحطة توليد الطاقة الكهروضوئية الحقيقية في الجزائر، والتي كشفت عن عجز كبير في تحقيق الأهداف المرجوة بسبب الأزمة الاقتصادية والصحية في العالم كله في السنوات الأخيرة. تم اختيار الزيادة في طاقة محطة الطاقة هذه كهدف. لذلك، يمكن تحديد فعالية الحل المقترح بناءً على محاكاة التحجيم، باستخدام برنامج PVSyst، بعد توسيع محطة توليد الطاقة

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1. Introduction

Undoubtedly, solar energy is a great asset for our country. Indeed, Algeria has one of the largest solar deposits in the Mediterranean basin. With a surface area of more than two million km², Algeria receives a very large amount of sunshine daily to produce maximum energy. This is why the Algerian government put a national program that envisaged 30% of national production by 2030 based on renewable with even plans for energy export.

However, because of the economic and health (COVID-19) crisis, Algeria, like all countries in the world, has experienced a considerable delay in achieving these investment objectives in the field of PV power plants.

The new vision of planning and development has given rise to a brand new ministry dedicated to renewable energies and sustainable development, (National Renewable Energy and Energy Efficiency Program).

Consequently, and taking into consideration all the constraints, the reflection on a techno-economic solution to help the realization of the national program already mentioned at a lower cost is essential and becomes a concern of the government as well as for the research centers.

In this work, we propose an extension study (power increase) of a real case of a photovoltaic power plant namely wadi el Kebrit 15 MWp as one of the solutions that meets the criteria and requirements of the current situation.

2. Photovoltaic energy potential in Algeria

Algeria, given its geographical position, has one of the highest solar deposits in the world. The duration of insolation on almost the entire national territory exceeds 2000 hours annually and can even reach 3,900 hours, particularly in the highlands and the Sahara. Thus, over the entire territory, the overall solar energy received per day on a horizontal area of one square meter varies between 5.1 KWh in the North and 6.6 KWh in the Great South, i.e. nearly 1860 kWh/m²/year in the North and 2409 kWh/m²/year in the South of the country [5].

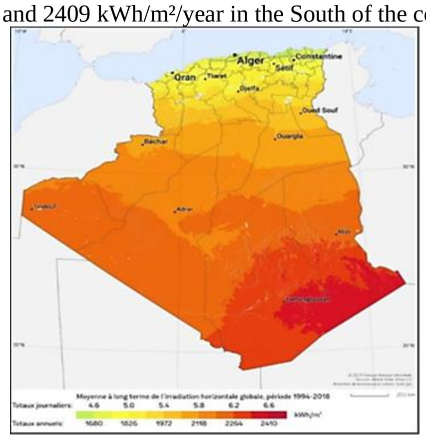


Fig. 1: Photovoltaic energy potential in Algeria [17]

- National Programme for the Development of Renewable Energies and Energy Efficiency (PNEREE) :

The program for the development of renewable energies and energy efficiency divided into five areas [18]:

1. The development of renewable energies;
2. The development of energy efficiency and energy saving;
3. The industrial capacities to be developed to support the program;
4. Research and development;
5. The legal and regulatory framework and incentives.

A report by IRENA, In 2020, cumulative PV power reached 423 MW compared to only 49.1 MW in 2015. Figure.2 shows the evolution of the installed photovoltaic capacity for the period from 2010 to 2020 in Algeria, which confirms the increase in the energy produced by solar photovoltaics, which reached 373.6 GWh in 2018 compared to 13.7 GWh in 2010 [8].

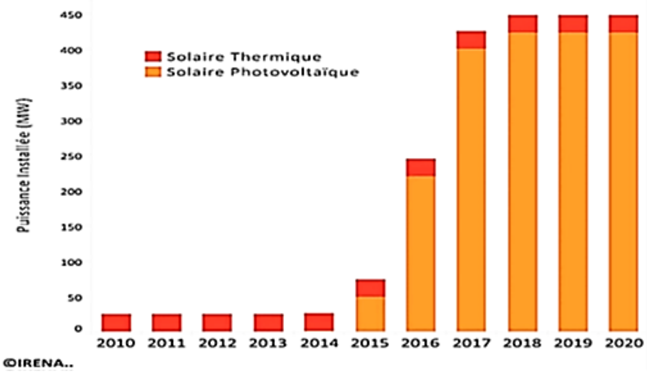


Fig. 2: Installed capacity in Algeria (2010-2020) [18]

According to the latest report by the Algerian Commission for Renewable Energy and Energy Efficiency (CEREFE), at the end of December 2022, the total installed capacity in renewable energy amounted to only 589.7 MW, of which 460.8 MW excluding hydroelectricity includes 422.6 MW connected to the grid and 38.2 MW off-grid.

- The new national program "Production of 2000 MWp of solar electricity"

On January 30, 2022, Sonelgaz revealed that the group has been "officially" tasked the public authorities with the realization of 15,000 MW in renewable energies, and that will launch a national and international call for tenders before the end of the first quarter of 2023 for the study and commissioning of 15 solar PV plants, with a total capacity of 2000 MW divided into 15 lots as the first phase.

Sonelgaz-Energies Renewables launched the call for tenders; the publishing and advertising company BAOSEM published it on Monday, February 27, 2023 [24].

Table 1: List of sites for the 2000 MWp batch PV power plants indicated by the availability of the spans [24]

Site	Wilaya	Capacités [MWc]	Superficies [H]	Poste raccordement	Tension [KV]
Abadla	Bechar	80	160	Abadla 60/30KV	60
Kenadsa		120	240	Bechar 220/60KV	220
Aflou	Laghouat	200	400	Aflou 220/60KV	220
Nakhla	El oued	200	400	Oued El Allenda 220/60KV	220
Taleb Larbi		80	160	Taleb Larbi 60/30KV	60
Touggourt	Touggourt	130	260	Tamacine 2 220/60KV	220
Leghrous	Biskra	200	400	Tolga 220/60KV	220
Tolga		80	160	Tolga 220/60KV	60
Khenguet Sidi Nadji		150	300	Bade 220/60KV	220
Batmete	M'Sila	220	440	El Hamel 220/60KV	220
M'Ghaier	M'Ghaier	220	440	M'Ghaier 220/30KV	220
Guerrara	Ghardaia	80	160	Guerrara 60/30KV	60
Ras El Oued	B.B.Arreridj	80	160	Ras El Oued 60/30KV	60
Merouana	Batna	80	160	Merouana 60.30KV	60
Frenda	Tiaret	80	160	Frenda 60/30KV	60

3. The Oued el Kebrit power plant

- OKP 12MWp Plant Presentation
  - The Oued Kebrit photovoltaic power plant is located 65 km south of the capital of the Wilaya of Souk Ahras. And 07 km north of the daïra of El Aouinet, Wilaya of Tébessa.

- Geographical coordinates: 35°55'N and 7°52'E.
- Area: Thirty-one (31) Hectares.

Fig. 3: Site plan of the OKP power plant

The following table summarizes some information about the OKP PV plant:

Table 2: Overview of the OKP plant

Puissance Installée	15 000 kWc
Tension d'injection au réseau	30 kV
Constructeur	Groupement (YINGLI-SINOHYDRO-HYDROCHINA)
Délais de réalisation	08 mois
Date de Mise Sous Tension	24/04/2016
Montant Global Du Projet	2 880 660 881,14 DA
Coût du kWh	12,99 DA/kWh
Coût du kWc Installé	2,500$/kWc
Production Estimée	24,4 GWh/An
Gain en CO2	15 200 Tonnes CO2/An

- Technical and economic constraint of the plant

Complete isolation of the power plant from the power grid if a fault occurs on the injection line. (Missing emergency line)

• The production of the plant is limited to 12MWp because it transmits energy on a 30kV line with a conductor cross-section of 93.3mm2 which has a thermal limit of 270 A.

• Power limitation of inverters to 93% so that production does not exceed 12 MWp.

• An available energy of 03MWp not produced and not consumed.

• The need for participation in the realization of the PNEREE of 4000 MW by 2030.

• The high cost of commissioning a new power plant, as well as the global economic crisis.

4. Study for the extension of the Oued el Kebrit power plant to 24 mwp

In this paper, we explain the design of the proposed extension 09 MWP. Then the simulation in PVSyst environment for study the efficiency of the project.

- Extension Advantage

• Continuity of service in the event of unavailability of one of the two lines.
• Recovery of the 3 MWp of power not produced and not consumed since the commissioning of the plant in 2016.
• Cancel the power limitation of the inverters.
• Avoid being at the thermal limit of the starting cables (load balancing between the two 30 KV feeders).

- Choice of equipment

We chose the "Jinko Solar" solar panel 400Wp for the following reasons:

✓ Jinko is simply the largest producer of solar panels in the world. A true behemoth of the industry, it produced no less than 14.2 GW in 2019!

The inverter is an essential part of our solar installation. Choosing the right inverter model is therefore essential. So to make the right choice, you must take into account these criteria: • The technical characteristics of the inverter (power and efficiency) • The warranty and lifespan • The features • The best price

• According to the selection criteria mentioned, a three-phase inverter with the reference SUNGROW (SG 1250) was chosen. The inverter has a power of 1260 kW in accordance with that of the existing power plant.

- Photovoltaic sizing of the OKP 9MWp extension

The design of the extension based on theoretical calculations is done as follows:

- Calculate the number of panels

$$N = \frac{P_T[W]..}{P_{Pv}[W]..} = \frac{9000000}{400} = 22500 \quad \text{Panels}$$

With N: number of panels
PT : Total power of new extension
Ppv : Panel power

- Voltage compatibility

a) Number of PV modules

- Number of PV modules in series: NSmin

$$NSmin = \frac{U_{min}[V]..}{U_{mpp}[V]..\times 0.85} = \frac{520}{41.70 \times 0.85} = 14.67 \approx 15$$

With Umin : Minimum Input voltage of inverter
Umpp : Maximum power point voltage of panel

- Number of PV modules in series : NSmax

$$NS_{max} = \frac{U_{max}[V]..}{U_{mpp}[V]..\times 1.15} = \frac{850}{41.70 \times 1.15} = 17.73 \approx 18$$

With U_{max} : Maximum Input voltage of inverter
U_{mpp} : Maximum power point voltage of panel

Voltage compatibility check

The maximum voltage that can be supply by a PV string composed of 19 modules in series is calculate by the following expression:

$$NS_{max} \times U_{mpp}[V]..\times 1.15 = 18 \times 41.70 \times 1.15 = 863.19\,V < U_{ond\ max} = 1000\,V$$

With: $U_{ond\ max}$: Maximum input voltage of inverter

This voltage is lower than the maximum allowable voltage at the inverter's input

- Power compatibility (current)
  - Number of parallel channels :NP

$$NP = \frac{I_{max}}{I_{sc} \times 1.25} = \frac{2222}{10.36 \times 1.25} = 171.58 \approx 172\ parallel\ channels$$

With: I_{max}: Maximum input current of inverter
I_{sc} : Panel short circuit current

Verification of power compatibility

We calculate the maximum power that can be provide by a PV subfield composed of **172 strings** in parallel with 18 modules in series per string with the following expression:

$$P_{branchemt} = NS_{max} \times NP \times P_{Pv} = 18 \times 172 \times 400 = 1238.4\,KW < Pinverter = 1260\,KW$$

$$0.7 < \frac{P_{inverter}}{P_{branchement}} = \frac{1260}{1238.4} = 1.017 < 1.2$$

This power is less than the maximum permissible power at the inverter's input.

To have the necessary number of inverters, we must estimate the total power by the power supplied by a subfield:

$$N_{Inverter} = \frac{P_T}{P_{branche}} = \frac{9000}{1238.4} = 7.27 \approx 7\ Inverter$$

5. Simulation results

The simulation of this expansion will done with PVSyst. The design is detail in the following figure:

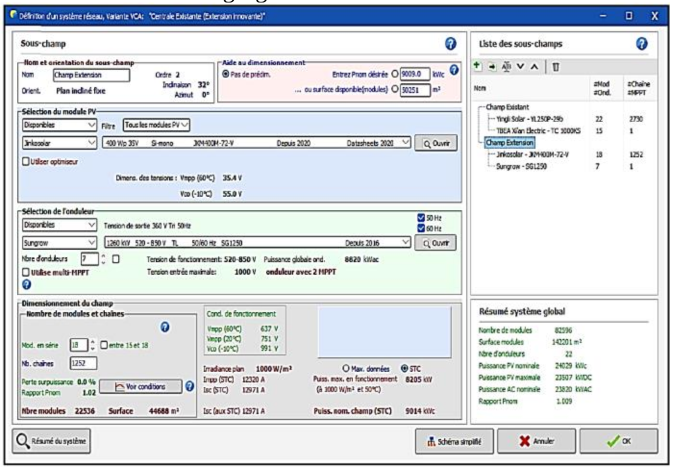
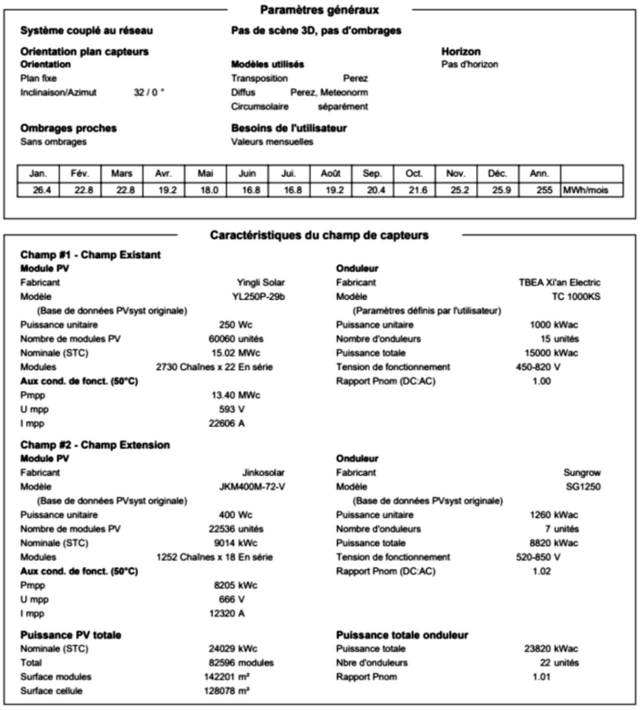


Fig. 4: System dashboard by simulation of an extension variant

After the validation of the system, we launch the simulation to analyze the results.



Paramètres généraux

Système couplé au réseau — Pas de scène 3D, pas d'ombrages

Orientation plan capteurs
Orientation: Plan fixe; Inclinaison/Azimut 32 / 0 °
Modèles utilisés: Transposition Perez; Diffus Perez, Meteonorm; Circumsolaire séparément
Horizon: Pas d'horizon
Ombrages proches: Sans ombrages
Besoins de l'utilisateur: Valeurs mensuelles

Jan.	Fév.	Mars	Avr.	Mai	Juin	Jui.	Août	Sep.	Oct.	Nov.	Déc.	Ann.	
26.4	22.8	22.8	19.2	18.0	16.8	16.8	19.2	20.4	21.6	25.2	25.9	255	MWh/mois

Caractéristiques du champ de capteurs

Champ #1 - Champ Existant

Module PV		Onduleur	
Fabricant	Yingli Solar	Fabricant	TBEA Xi'an Electric
Modèle	YL250P-29b	Modèle	TC 1000KS
(Base de données PVsyst originale)		(Paramètres définis par l'utilisateur)	
Puissance unitaire	250 Wc	Puissance unitaire	1000 kWac
Nombre de modules PV	60060 unités	Nombre d'onduleurs	15 unités
Nominale (STC)	15.02 MWc	Puissance totale	15000 kWac
Modules	2730 Chaînes x 22 En série	Tension de fonctionnement	450-820 V
Aux cond. de fonct. (50°C)		Rapport Pnom (DC:AC)	1.00
Pmpp	13.40 MWc		
U mpp	593 V		
I mpp	22606 A		

Champ #2 - Champ Extension

Module PV		Onduleur	
Fabricant	Jinkosolar	Fabricant	Sungrow
Modèle	JKM400M-72-V	Modèle	SG1250
(Base de données PVsyst originale)		(Base de données PVsyst originale)	
Puissance unitaire	400 Wc	Puissance unitaire	1260 kWac
Nombre de modules PV	22536 unités	Nombre d'onduleurs	7 unités
Nominale (STC)	9014 kWc	Puissance totale	8820 kWac
Modules	1252 Chaînes x 18 En série	Tension de fonctionnement	520-850 V
Aux cond. de fonct. (50°C)		Rapport Pnom (DC:AC)	1.02
Pmpp	8205 kWc		
U mpp	666 V		
I mpp	12320 A		

Puissance PV totale		Puissance totale onduleur	
Nominale (STC)	24029 kWc	Puissance totale	23820 kWac
Total	82596 modules	Nbre d'onduleurs	22 unités
Surface modules	142201 m²	Rapport Pnom	1.01
Surface cellule	128078 m²		

Fig. 5: First page of the report

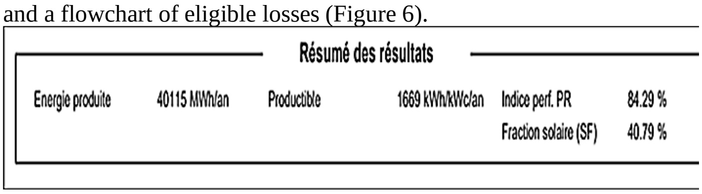
- Key Results

For our system: three relevant quantities are now defined:

➢ The energy produced: The basic result of our simulation.

➢ Producible: The energy produced divided by the nominal power of the installation (Pnom to STC). It is an indicator of the potential of the system, given the irradiation conditions (orientation, site location, weather conditions).

➢ Withe a good PR 84% Performance Index: This is an indicator of the quality of the system itself, regardless of the incoming irradiance, and a flowchart of eligible losses (Figure 6).



Résumé des résultats

Energie produite	40115 MWh/an	Productible	1669 kWh/kWc/an	Indice perf. PR	84.29 %
				Fraction solaire (SF)	40.79 %

Fig. 6: Summary of results

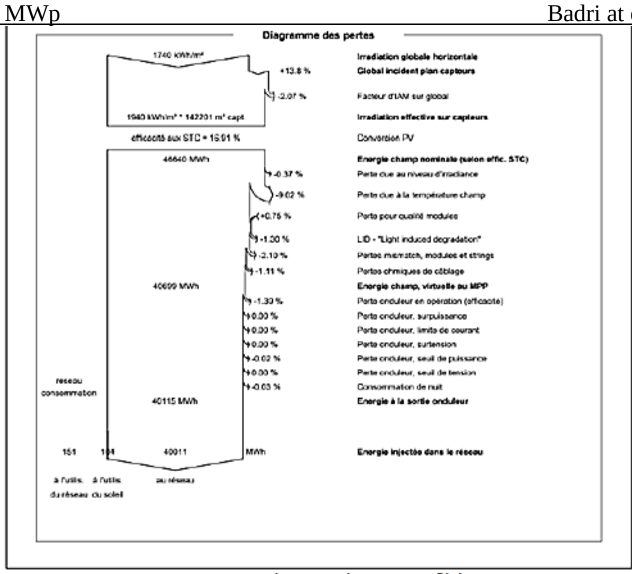


Fig. 7: Loss Diagram by Arrow

The "daily input/output diagram" displays, for each simulated day, the energy injected into the network as a function of the overall incident irradiation in the collector plane. For a well-dimensioned grid-connected system, this straight line saturates slightly for large irradiation values. This slight curvature is an effect of the temperature. If some points (days) deviate at high irradiations, this indicates overload conditions.

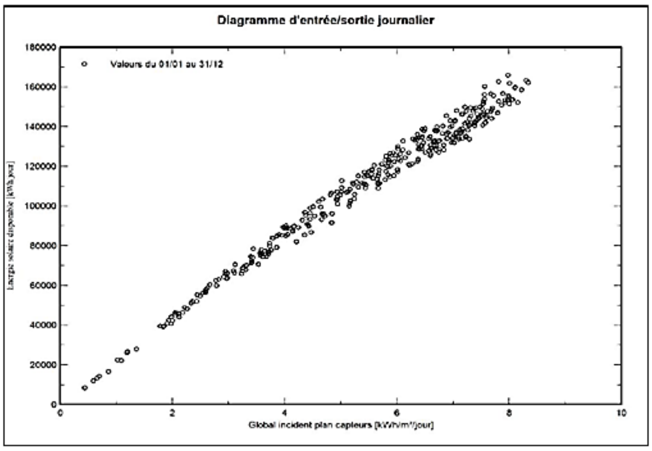


Fig. 8 Daily Input/output Diagram

This figure represents the "daily input/output diagram" which displays the energy injected into the network as a function of the overall incident irradiation per day in the collector plane. This is a line closer to a straight line that saturates slightly for large irradiation values for the new variant, which confirms that our grid-connected system under this variant is right-sized.

6. Conclusion

Today, photovoltaic energy has gradually become an energy source in its own right. It is increasingly being used to produce electrical energy. It is first because this photovoltaic solar energy is a clean, silent, available and free energy; but also because the demand for electrical energy continues to increase.

The study of the extension of the Oued El Kebrit (OKP) photovoltaic power plant to 24 MWp shows the effectiveness of the use of PVSyst as a simulation tool and the validity of the proposed solution, as well as the contribution to the PNEREE with a relatively lower cost compared to the creation of a new plant.

Our proposal to increase the power of the OKP power plant to 24 MWp was been welcomed by SONELGAZ (**National Electricity and Gas Company of Algeria**).

Officials (SKTM executives) pointing out that the efficiency and feasibility of the idea is subordinated to the rehabilitation and upgrading of the 30 KV stage of El Aouinet substation which will be taken into account in the next investment programs according to the Eastern regional directorate of the Algerian electricity and gas distribution company (RDE/SADEG SONELGAZ).

Finally, it can been said that a project to extend a photovoltaic power plant can play a very important role in providing a truly economical solution to cover energy needs compared to the construction of a new power plant with the same power delivered.

7. References

[1]- T. Pavlovic, The sun and Photovoltaic Technologies, Suisse: Springer, 2020.

[2]- v. Ion, D. Anca , M. Macedon , B. Bogdan et N. Mircea , Solar Energy Conversion Systems in the Built Environment, Suisse: Springer, 2020.

[3]- ESMAP, «Global Solar Atlas 2.0 Technical Report,» World Banc, Washington, DC, 2019.

[4]- IRENA, «Renewble Capacity Statistics 2021 International Renewable Energy Agency (IRENA),» Abu Dhabi, 2021.

[5]- CEREFE, «Transition Energétique en algérie : Leçons, Etat des Lieux et Perspectives pour un Développement Accéléré des Energies Renouvelables,» Alger, 2020.www.atm.com

[6]- A. Reinders, P. Verlinden, W. van Sark et A. Freundlich, Photovoltaic Solar Energy : FROM FUNDAMENTALS TO APPLICATIONS, United Kingdom: Wiley, 2017.

[7]- A. H. A. Al-Waeli, H. A. Kazem, S. Kamaruzzaman et M. T. Chaichan, Photovoltaic/Thermal (PV/T) Systems : Principles, Design, and Applications, Suisse: Springer, 2019.

[8]- H. Yatimi et M. Louzazni, «ResearchGate,» 16 02 2020. [En ligne]...

[9]- A. Shah, Solar Cells and Modules, suisse: Springer, 2020.Theses:

[10]- Taleb.A et Haouchine.L, Dimensionnement et simulation de l'augmentation de puissance d'une centrale pv raccordee au reseau., PFE-ESTI, 2021.

[11]- S. K. Sharma et Khuram Ali, Solar Cells : From Materials to Device Technology, Suisse: Springer, 2020.

[12]- D. Wilson, Wearable Solar Cell Systems, USA: CRC Press, 2020.

[13]- D. Rekioua et E. Matagne, optimization of Photovoltaic Power Systems, London: Springer, 2012.

[14]- A. A. El Baset, M. A. Saad Awad, H. Anwer Ibrahim, et M. Abdelmowgoud Elsayed Eid, Performance Analysis of Photovoltaic Systems with Energy Storage Systems, Suisse: Springer, 2019.

[15]- H. Tyagi, A. K. Agarwal, P. R. Chakraborty et S. Powar, Advances in Solar Energy Research, Suisse: Springer, 2019.

[16]- C. BRUYANT-ROZOY, «MÉMOIRE par l'UNIVERSITÉ DU QUÉBEC,» 12 Aout 2019. [En ligne]

[17]- F. Amir, « Etude du fonctionnement des centres de production dans un système de marché libre de l'énergie électrique », magister, Université de Batna 2, 2012.. [En ligne]. Disponible sur: http://eprints.univ-batna2.dz/1301/

[18]- « Global Solar Atlas ». https://globalsolaratlas.info/global-pv-potential-study.

[19]- « Sonelgaz : Appel d'offres pour 15 centrales solaires d'une capacité totale de 2000 MW ».Stage pratique