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Feasibility Study of Grid Connected Photovoltaic Power Plant In the Southern of Tunisia

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Abstract— **World energy consumption is rising due to population growth and increasing industrialization. Traditional energy resources cannot meet these requirements with notice to their challenges, e.g., greenhouse gas emission and high lifecycle costs. Renewable energy resources (RES) are the appropriate alternatives for traditional resources to meet the increasing energy consumption, especially in electricity sector.**

This paper investigated the potential operation of PV plant Grid connected system in the northernmost city in Africa, city of Tozeur in the South of Tunisia, this region is characterized by High ambient temperature in the summer and high solar irradiance potential. This study presents a feasibilit0y analysis. For this we have choose to work with one of the most powerful tools for this purpose is Hybrid Optimization Model for Electric Renewable (HOMER) software that was developed by National Renewable Energy Laboratory (NREL), United States ,with the implementation of an excel application to simulate the impact of representative PV generators with and without ESS (energy storage system)functions. Homer has widely been used by many researchers around the world .The system is optimized by this software and Excel application using Tunisia global irradiation and the Tunisian load profile, the electricity tariffs and the photovoltaic system components are modeled according to the Tunisian market.

Keywords— **Grid-connected PV system, technical analysis, Homer software, excels application …**

I. INTRODUCTION:

Among the RES technologies, solar energy technologies have shown a significant advancement and maturity for power generation. Solar photovoltaic (PV) technology, which directly converts the sun irradiation into electricity, is one of the fastest growing RES technologies worldwide. Recently, the solar PV modules' prices have dropped by 80% since 2009 and are anticipated to keep falling [1] .

In the near future, the applications of solar photovoltaic systems will certainly play a contentious role in the development of countries. Solar photovoltaic systems are generally categorized into stand-alone and grid-connected systems. In stand-alone photovoltaic power systems, there is no connection to the utility grid and the systems are usually categorized into two main sub-groups: direct-coupled system without storages (batteries) and standalone system with storages. However, in some cases, other types of energy systems such as gas, steam, and wind or micro-hydro generator systems are used in the supporting of stand-alone photovoltaic systems; this configuration is called a hybrid system. On the other hand, grid connected photovoltaic power systems which are directly connected to the utility grid have recently experienced a rapid growth worldwide and have become more popular especially in developed countries.

In the context of diversifying its energy mix for power generation, improving the level of independence from fossil fuels, and enhancing the enormous potential of renewable energy resources (solar and wind) , The Tunisian Company of Electricity and Gas (STEG) has started the development of the wind energy sector since the year 2000 through the construction of the first 54 MW power station in Haouaria, then a second power station at the end of 2013 at Bizerte (Kchabta-Metline) with an overall power of 190 MW.

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STEG recently elaborated a new plan of action, within the context of the Tunisian Solar Plan (PST), which stipulates the construction of solar and wind power plants by 2020 with an Overall power of the order of 300 MW in wind energy and 67 MW in photovoltaic solar energy. STEG then began its first project for the construction of a 10 MW photovoltaic (PV) solar power plant in Tozeur. This plant will be located on a site next to the Tozeur-Nafta road near the 150/33 kV (STEG) transformer station on an area of 22 ha. The programmed power is 10MW with the possibility of extension in the future.

PST: The Tunisian Solar Plan (PST) is a long-term strategy that follows the goal of diversifying the energy mix, which is currently based on 95 percent of natural gas.

This strategy foresees the reduction of the share of natural gas to only 50% in 2030 thanks to a massive deployment of renewable energies and the entry into the production of carbon-based electricity. The PST envisages a contribution from renewable energies of about 30% of electricity production by 2030, including 15% for wind, 10% for photovoltaic (PV) solar and 5% for solar concentrating (PSC) **[2].**

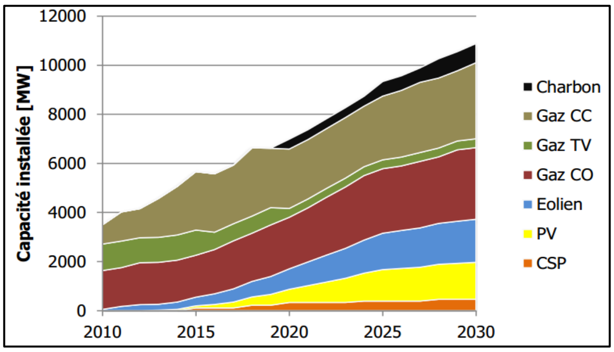

Fig.1 Evolution of installed capacity as provided in PST [1]

The third of the renewable production (2887 GWh) is made available by photovoltaics, which corresponds to 1,510 MW of capacity installed in 2030. For 2020, photovoltaic capacity reaches 540 MWp and produces 1030 GWh according to The PST. In calculations, the capacity factor is estimated to be constant at 22 percent for all the installations.

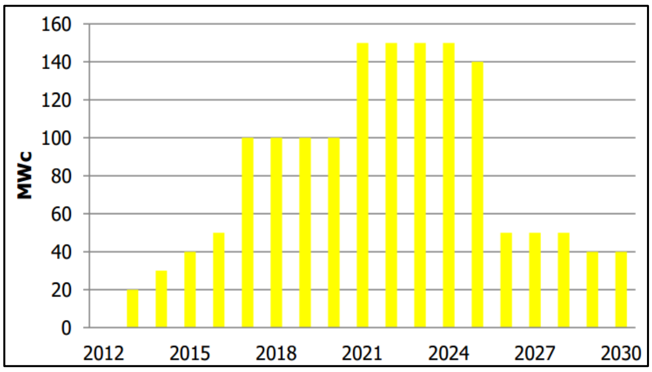

Fig.2 Evolution of the installed PV capacity as provided in PST [2]

The objective of this work is to investigate the techno-economic viability of solar PV plant- grid connected energy system in a location in the south of Tunisia. This system may not only improve access to reliable supply of electricity, but can also reduce dependency on diesel generator systems.

Many research papers studied the techno-economics of PV systems based on off-grid [3–14] or grid-connected settings [16–24]. The grid connected systems are intended to supply power generated by RES into the electric grid.

II. SELECTED SITE:

This plant will be located, in the southern of Tunisia, on a site next to the road Tozeur-Nafta near the transformer station 150/33 kV (STEG) on an area of 22 ha. The scheduled power is 10 MW with the possibility of extension in the future.

Latitude and longitude coordinates for Tozeur: 33.9185° N, 8.1229° E. This region is characterized by High ambient temperature in the summer and high solar irradiance potential**.**

Fig.3 Tunisia Map

III. HOMER DESCRIPTION :

HOMER (Hybrid Optimization Model for Electric Renewable) is a computer optimization model developed by the U.S. National Renewable Energy Laboratory (NREL) to assist the design of micro-power systems and to facilitate the Comparison of power generation technologies across a wide range of applications.

HOMER models a renewable energy system's behavior, its life-cycle cost and allows to choose optimal design options based on technical, economical and environmental criteria. Many resources such as WT, PV array, fuel cells, converter, batteries, and conventional generators are modeled in

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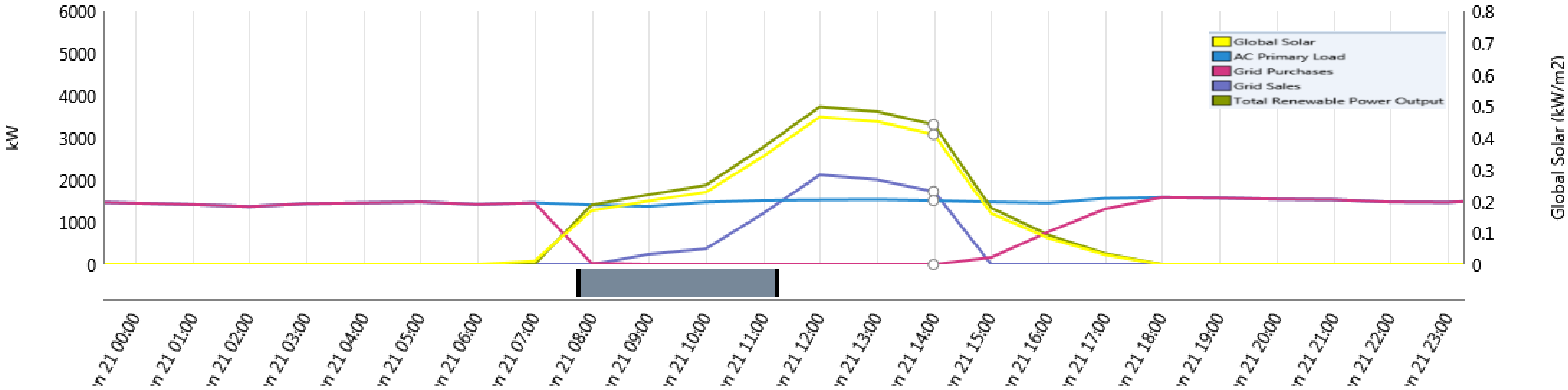

Fig.4 Homer inputs Data

HOMER also simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. Required input data for simulation with HOMER.

A. *HOMER INPUTS Data:*

To judge the feasibility of the grid connected PV system, technical and economical evaluation criteria can be applied, so HOMER requires six types of data for simulation and optimization including meteorological data, load profile, equipment characteristics, and search space, economic and technical data.

HOMER first assesses the technical feasibility of the system and whether it can meet the load demand, technical feasibility depends mainly on the load energy consumption and the available area to place the photovoltaic modules. These data are described in details in the following subsections.

B. *Economic data:*

The economical parameters are calculated. The calculation assesses all costs occurring within the project lifetime, including initial set-up costs which is the total installed cost of that component at the beginning of the project., component replacements within the project lifetime, operating and maintenance cost (O&M) and the purchasing power costs (PPC) from the grid.

1) *Annual real interest rate:*

The real discount rate is used to convert between one-time costs and annualized costs. HOMER calculates the annual real discount rate from "Nominal discount rate" and "Expected inflation rate" inputs. HOMER uses the real discount rate to calculate discount factors and to calculate annualized costs from net present costs.

The annual real interest rate is related to the nominal interest rate by the equation given below which Homer uses [25]:

$$i = \frac{i' - f}{1 + f} \qquad (1)$$

Where i the real discount rate, i'=nominal discount rate (the rate at which we could borrow money), and f the expected inflation rate.

2) *Net present Cost:*

The life cycle cost of the system is represented by the net present cost (NPC) which is the present value of all the costs that it incurs over its lifetime, minus the present value of all the revenue that it earns over its lifetime, HOMER calculates the total NPC by summing up the total discounted cash flows in each year of the project lifetime, REF HOMER HELP

It was calculated according to the following equation:[25]

$$c_{NPC} = \frac{TAC}{CRF} \qquad (2)$$

Where T_{AC} is the total annualized cost ($/year) (which is the sum of the annualized costs of each system component) and CRF is the capital recovery factor given by [25]:

$$CRF_{(i,N)} = \frac{i(1+i_{rr})^N}{(1+i_{rr})^N - 1} \qquad (3)$$

Where N is the number of years and i_{rr} is the internal rate of return (%) which is the nominal discount rate that corresponds to a net present cost of zero for projects.

3) *Levelized cost of energy:*

As techno-economical evaluation criterion. COE represents the unit cost of the energy produced by the system and can be calculated by dividing the total annualized cost by the annual produced energy as follows[25]:

$$COE = \frac{TAC}{E_{pv}} \qquad (4)$$

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Therefore, among different measures of the economic value of an investment, an appropriate economic analysis payback period, and the internal rate of return (I_{RR}) can guarantee the profitability of the investment in photovoltaic systems.

C. *Solar radiation and clearness index:*

The meteorological data for our system are solar radiation and temperature which are fed into the software in the form of monthly averages or time series data. HOMER uses these inputs data to calculate the output power of PV array.

The figure below shows the daily radiation and clearness index for every month of a year, the solar radiation data inputs on the left axis and the solar radiation's clearness index on the right axis. Solar radiation varies with time and season.

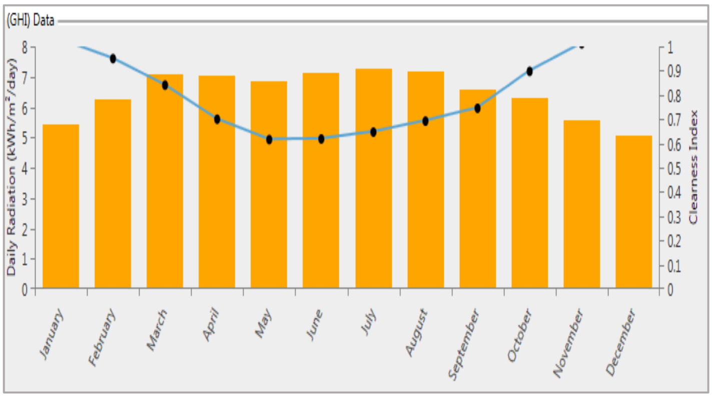

Fig.5 Global horizontal solar radiation of Tozeur

The radiation data is obtained by the PVGIS software. The figure shows that the irradiation is maximum in summer (July) and very low in winter (December). PV system designed to supply entire load considering the worst month solar radiation, which will deliver sufficient energy during rest of the year.

The global horizontal solar radiation in Tozeur ranges from 5kWh/m^2/day to 8kWh/m^2/day and the annual average of the solar radiation is estimated to be 6.47 kWh/m^2/day which make it an ideal location for photovoltaic application and enough to generate the required power for the area.

The clearness index is a dimensionless number between 0 and 1 indicating the fraction of the solar radiation striking the top of the atmosphere that makes it through the atmosphere to strike the Earth's surface.

HOMER calculates the clearness index from the global horizontal radiation (GHI). The following equation defines the monthly average clearness index [25]:

$$K_t = \frac{H_{ave}}{H_{0,ave}} \qquad (5)$$

Where:

H_{ave} is the monthly average radiation on the horizontal surface of the earth [kWh/m^2/day].

H_0.aveis the extraterrestrial horizontal radiation, meaning the radiation on a horizontal surface at the top of the earth's atmosphere [kWh/m^2/day].

D. *Load profile:*

Load profile of each region is the most important factor in the simulation and optimization. These real data are fed into HOMER as time series data. However, in some regions especially remote and rural areas that the real load consumption data are not available, the load profile should be forecasted with notice to the specification of that region. These data are fed into HOMER as daily profile and HOMER uses them in power balance constraint.

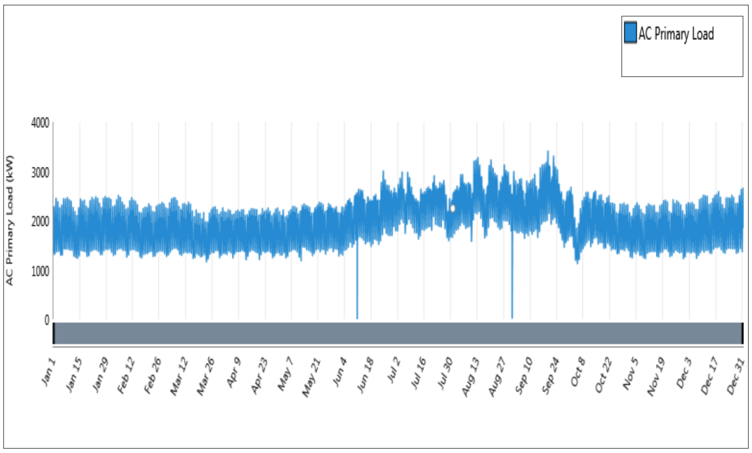

Fig.6 The annual average electrical load of Tunisian people

This figures 06 and 07 shows for each day of 2016 three values, the mean power, and the maximum and minimum load. The Tunisian power system has its peaks during summer, The Load data showed that the average daily energy consumption is 47,587.61 kWh/d and the peak demand is 3.403 kW in August. The required consumption is not the same over the year. The peak loads depends on the season since the day length changes.

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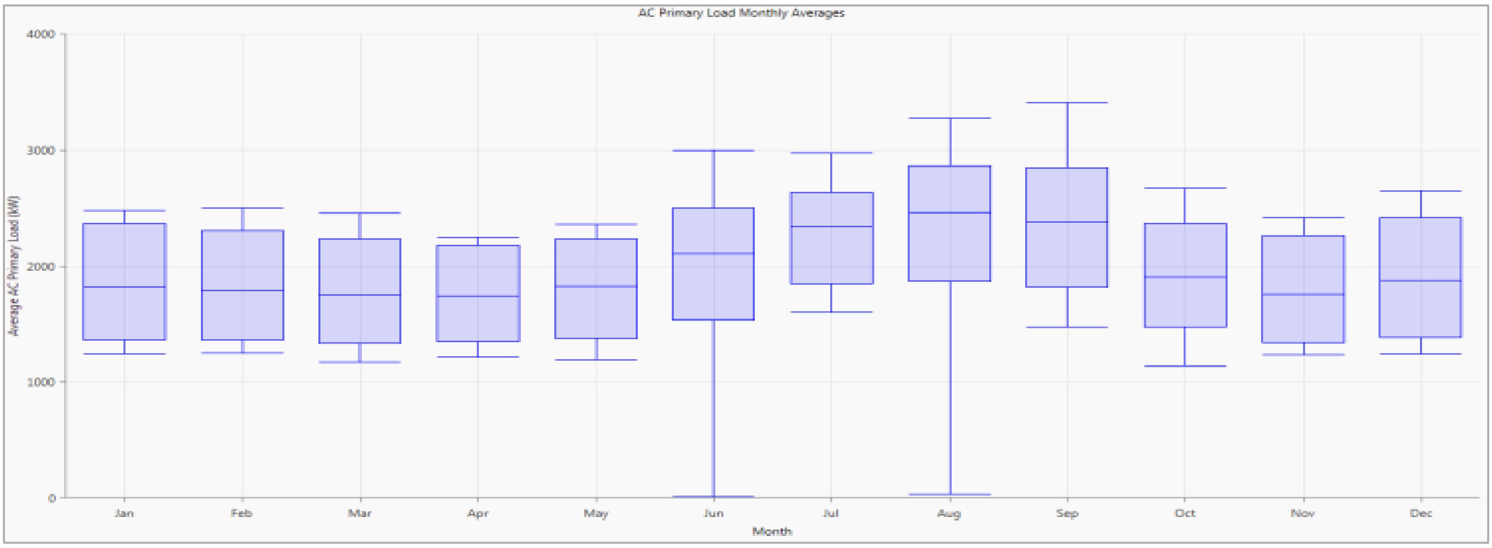

Fig.7 the Monthly average Load profile of Tunisian people

E. Energy purchase and sellback price:

Tunisian power grid is managed by the Tunisian Company of Electricity and Gas (STEG) .The load considered in the area is domestic in nature. The tariff of electricity for domestic consumers in Tunisia which is a fixed rate is about 0.167d /kWh which is equal to 0.07£/kWh and to US dollar of \$0.08/kWh. The "feed-in-tariff" or sellback price for renewable energy less than 20 MW in Tunisia has multiple rates which are set by Decision of the Minister of Industry, Energy and Mines in 2 June 2014 are mentioned in the table below:

TABLE I

FEED-IN-TARIFF" FOR RENEWABLE ENERGY IN TUNISIA

Period	Price of the kilowatt/hour(d/kwh) (STEG to renewable exceedance)	MT (uniform)	MT uniform incl TVA	MT (poste horaire)	MT poste horaire inc TVA
Day	0.115	0.167	0.202	0.152	0.184
Morning Peak summer	0.182	0.167	0.202	0.238	0.286
Peak evening	0.168	0.167	0.202	0.218	0.262
evening	0.87	0.167	0.202	0.115	0.141

IV. SYSTEM COMPONENTS:

The design of the grid-connected PV system was modeled using HOMER. Which it consists of a PV array and an inverter Typically, PV panels are mounted at fixed orientation. However they can be made to "track" the sun in order to maximize the incident solar radiation and HOMER has the feature to include PV tracking. The function of the PV array is to extract solar energy from the sun and convert it to DC voltage. The generated voltage is converted to AC by the inverter. The surplus photovoltaic electricity is sold to the grid, and in case of insufficiency of photovoltaic energy, the country uses the grid to meet the lack of power. This system will be studied with and without storage bank, The Battery bank is only charged by the excess electricity from PV array after fully supplying the load. This is called "load following strategy".

A. PV ARRAY:

The photovoltaic modules used in the feasibility study are the STP 230-20 Wd by SUNTECH Company. The Optimum Operating Voltage of each module (Vmp) is 29.8 V and the optimum operating current I_m pis 7.72A (from Datasheet), the lifetime of the photovoltaic modules are estimated to 25 years. The peak power to be installed is given by the following formula:

$$P_c = \frac{B_i}{\eta_{inv} * E_i} \quad (6)$$

Where :P_c: The peak power(Kw) ,B_i: The daily needs for electricity (kWh) ,n_{inv} :The Inverter efficiency(%) , E_i: The irradiation (kWh/m²) .
The provisional number of modules is therefore calculated as follows:

$$N_{panels} = \frac{P_c}{P_{(c,unit)}} \quad (7)$$

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The designed PV is rated to 10MW (10000 kW) and this is the base electricity supply for the system. It has 43470 modules with each proposed module rated at 230 W.The total area that can be occupied by all the modules of the array is 71800m².

The cost for a 1kW PV module was assumed to be 2600dt/kw equal to $1170/kW. The replacement cost for a 1kW PV module was assumed to be $0 because system's lifetime is assumed to be 25 years so panels will not be replaced. The Operating and Maintenance cost was assumed to be 52dt/year equal to $233/year .HOMER calculates the power output of the

PV array using the equation from Homer files [25]:

$$P_{pv} = f_{pv} y_{pv} \frac{H_t}{H_s} \tag{8}$$

Where, f_{PV} is the PV derating factor,Y_{PV} the rated capacity of the PV array (kW),H_T the global solar radiation (beam plus diffuse) incident on the surface of the PV array (kW/m^2), and H_S is 1 kW/m^2, which is the standard amount of radiation used to rate the capacity of the PV array.

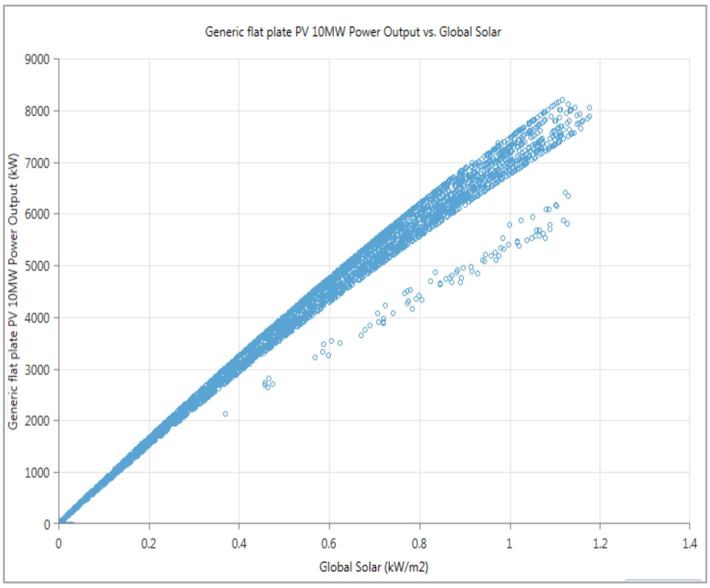

Fig.8 yearly PV productions (10MW) (Homer output*)*

According to fig 08 from Homer software, it was observed that the production of total PV output power is in the range of 6000–8000 kW at the local solar irradiation varies between 0 and 1.2KW/m².

B. converter:

A grid connected inverter is required for PV system to maintain the flow of energy between DC photovoltaic generation and AC load and power grid. The inverter plays a vital role in the operation of the grid connected PV system. Inverters have special features adapted for use with the grid connected PV systems that make the system more robust such as MPPT [27], automatic synchronization with the grid, anti-islanding protection, and high conversion efficiency.

The grid connected inverter efficiency is defined as the ratio of output AC power to input DC power and can be expressed as the following equation:

$$\eta_{inv} = \frac{E_{AC}}{E_{DC}} = \frac{\int P_{AC}.dt}{\int P_{DC}.dt} \tag{9}$$

Where E_{AC} is the AC output electrical energy, E_{DC} is the DC input electrical energy, P_{AC} is the AC output power, and P_{DC} is the DC input power. The converter used in this system is SUNNYCENTRAL 1000MV by SMA Company, it is assumed that the inverters have a maximum efficiency between of 98% and 98.2%, and 10 years lifetime, it is rated at 1000 kVA AC output power based on 1100 kVA DC input power from PV array. The maximal input current of the inverters 2500A.

The output grid voltage of the inverter is rated to 3-phase 20 kV/ 50 Hz.

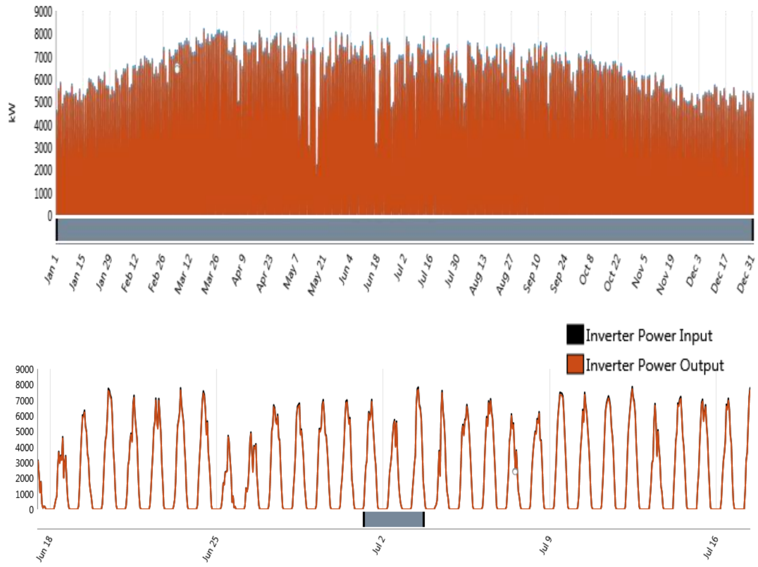

Fig.9 inverter power input and output (zoom)

The capital cost of an inverter was assumed to be 150dt/kW equal to $67.21/kW. The operating and maintenance cost was assumed to be zero. The inverters must be replaced twice during the project period and the replacement cost is supposed 50% of the initial cost which equal to $33.6/kW .In the studied system, 10 converters will be used.

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C. Battery Bank:

The battery bank is a collection of one or more individual batteries. A battery was modeled as a device capable of storing a certain amount of DC electricity at fixed round-trip energy efficiency, with limits as to how quickly it can be charged or discharged, how deeply it can be discharged without causing damage, and how much energy can cycle through it before it needs replacement.

HOMER assumes that the properties of the batteries remain constant throughout its lifetime and are not affected by external factors such as temperature.

Battery Parameters are:

1) Battery Capacity

The battery capacity is the amount of energy that could be extracted from the battery bank from the fully charged state to the zero charge state; it is measured in Ampere hours (Ah). The battery capacity changes depending on factors such as age, rate of discharge or temperature. High ambient temperatures cause internal reactions. Therefore, many batteries loose capacity quicker in hotter climates. On the other hand, extremely cold climates may stop the discharge of the storage by freezing the electrolyte.

2) State of Charge (SOC)

The state of charge is the percentage amount of energy stored in the battery with respect to the nominal battery capacity. The latter parameter is mainly used to reveal the current amount of power stored and to evaluate the performance of the battery.

3) Charging and Discharging rate

The amount of power extracted/added from/to the battery per unit time; it is measured in Amperes.

4) Battery Efficiency

The battery efficiency is described in two ways: the Columbic and voltage efficiency. The columbic efficiency is the ratio of the amount of power that enters the battery when its charges versus the amount of power that can be extracted from the battery when it discharges. The voltage efficiency is the discharged voltage average versus the charged voltage average. More generally, the roundtrip efficiency is the energy extracted from the battery versus the energy sent into the device.

In order to study the behavior of PV power plants from techno-economical points of view, the feasible sites in Tunisia to install is a 10 MWp PV-grid connected power plant are selected. The main geographical and meteorological data are tabulated in the supplementary part of the study as mentioned before.

V. ANALYSIS OF A 10 MW PV GRID-CONNECTED FOR JANUARY AND JULY

A. Analysis of a 10 MW PV grid-connected without energy storage (Results with HOMER) for January and July:

Data recorded collected during January and July 2016 for weather and total radiation will be presented (Homer).

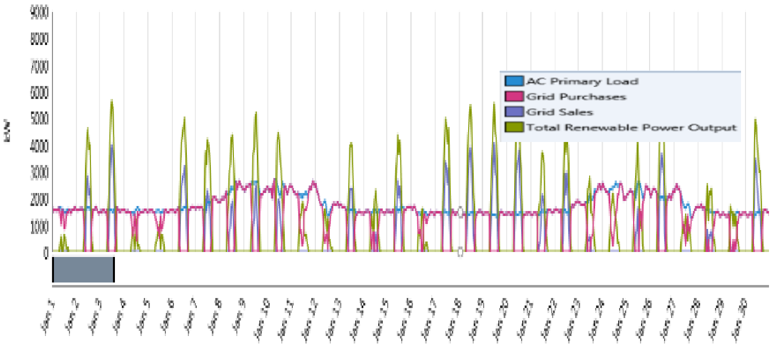

Fig.10 data recorded during january2016

An average hourly variation of local solar irradiation to the production of PV output power during 7:00–18.00 for January 2016. From previous Figs it was found that the production of total PV output power is in the range of 1500–4000 kW at the local solar irradiation varies between 0 and 600 W/m².

It can be concluded that the production of PV output power is a function of solar irradiation and module working temperature. It increased with increasing solar irradiation and decreased with increasing module working temperature as explained in previous work [28]. These mean that solar irradiance and module working temperature play important factors in order to estimate energy production and degradation of the PV system. We can observe that the hourly global parameters performance of PV plant is more significant between 10.00 and 15.00 h. The PV power production takes the maximum value at 12.00 and equal to zero at night so that local consumers have to buy electricity from grid to feed their needs, which illustrate the effect of weather conditions on the efficiency of PV panels and the relations between the radiation and the output power of PV panel [28]. The surplus photovoltaic electricity is sold to the grid, and in case of insufficiency of photovoltaic energy, the country uses the grid to meet the lack of power.

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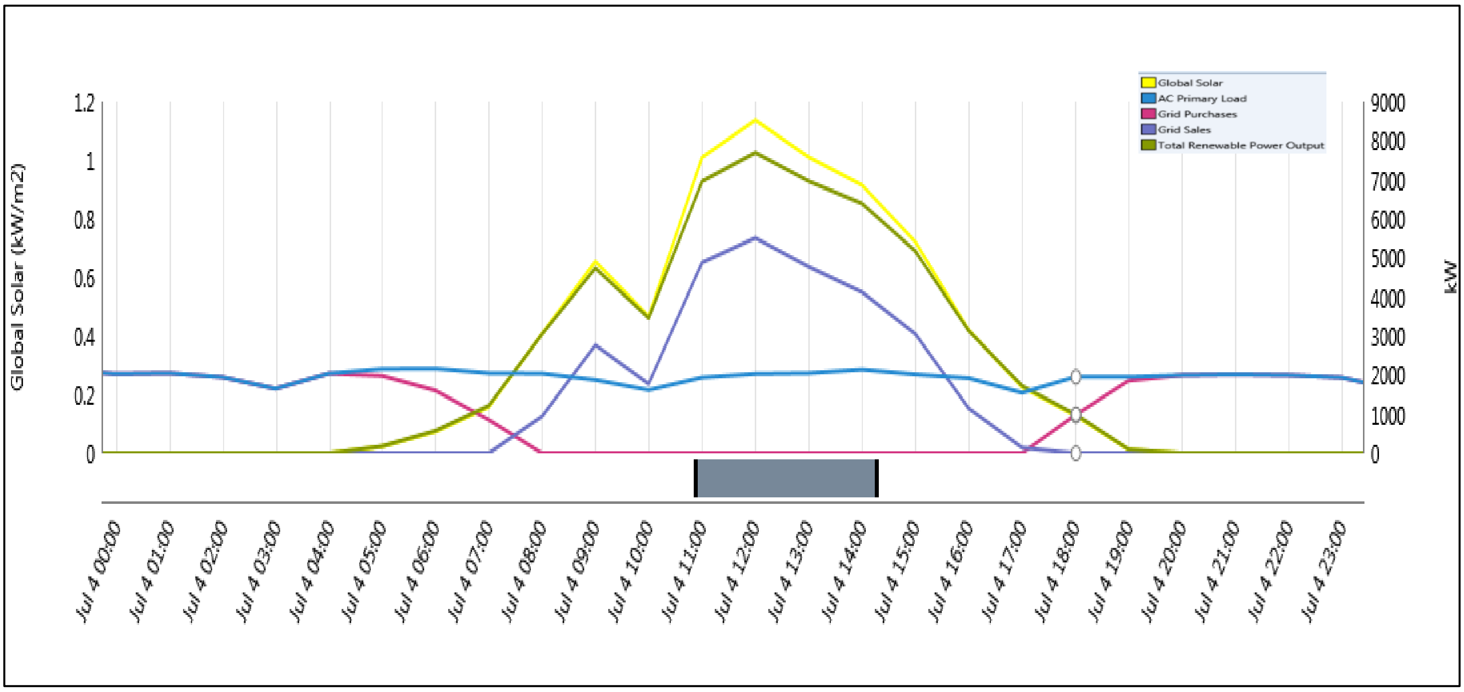

Fig.11 Data recorded during July 2016

Same during July ,only the production of total PV output power change in the range of 6000–8000 kW at the local solar irradiation varies between 0 and 1000 W/m².We can observe also that the hourly global parameters performance of PV plant are more significant between 10.00 and 16.00 h. The PV power production takes the maximum value at 12.00 and equal to zero at night from 19h.Compared with the configuration of grid only in previous work, this configuration has higher initial capital and total NPC.This is because the total NPC includes the initial capital and replacement cost of inverter, initial capital of PV and operation and maintenance (O&M) cost.

The tables below gives Balance over PV plant lifetime project for 25 years taking into account the variable tariffs for electricity bying from grid, Annual Electricity Generation & Consumption statics are shown in Table II.

In this particular study, the overall net present cost (NPC) is achieved as $2900.The payback duration for proposed power system is achieved as 20.2 years which provide almost 21 long years of exclusive income for a period of 25 years. For this case PV productibility reduction due to PV aging was assumed to 0.9% per year.

TABLE II SIMULATION RESULTS OVER 1 YEAR

Load consumption				
Energy produced by PV plant	MWh/year	17369		
Energy from PV consumed by load in real time	MWh/year	14025		
Energy from PV to grid	MWh/year	7 982	57 %	46%
Energy from PV to battery	MWh/year	6 043	43 %	35%
Energy from battery to Load	MWh/year	0	0 %	0%
Total Energy from PV to load (incl. battery)	MWh/year	0	0 %	0%
Battery cycle	MWh/year	7 982	57 %	46%
Revenue on avoided electricity from grid	cycle/year	0		
Revenue on exceeding PV production to grid	Md/year	1,59	1, 61	
	Md/year	0,75	0, 75	

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TABLE III
BALANCE OVER PV PLANT LIFETIME (25 YEARS) - CASE A: VARIABLE TARIFF FOR ELECTRICITY BUYING FROM GRID

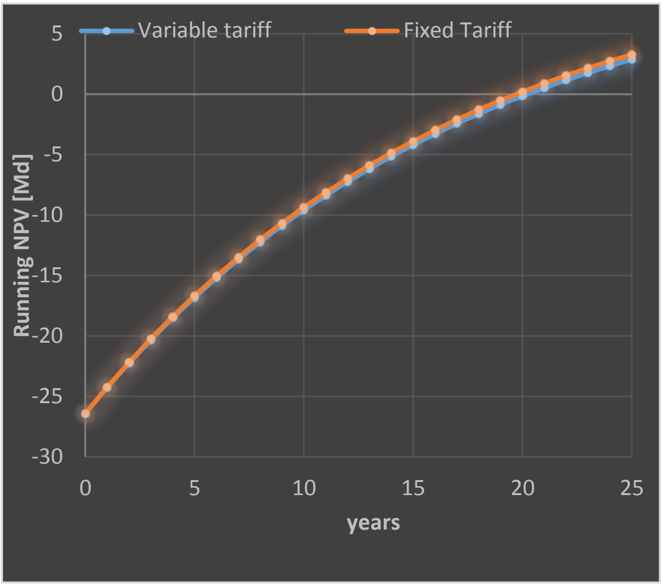
year	0	1	5	10	15	20	21	23	25
Load consumption MWh/year		17 369	17 369	17 369	17 369	17 369	17 369	17 369	17 369
Energy produced by PV plant(MWh/year)		17 424	16 805	16 062	15 352	14 674	14 542	14 281	14 025
Energy from PV consumed by load in real time(MWh/year)		8 243	8 203	8 152	8 098	8 042	8 030	8 007	7 982
Energy from PV to grid (MWh/year)		9 181	8 602	7 911	7 254	6 632	6 512	6 275	6 043
Energy from PV to battery(MWh/year)		0	0	0	0	0	0	0	0
Energy from battery to Load (MWh/year)		0	0	0	0	0	0	0	0
Total Energy from PV to load (incl. battery) (MWh/year)		8 243	8 203	8 152	8 098	8 042	8 030	8 007	7 982
Battery cycle (cycle/year)		0	0	0	0	0	0	0	0
Battery cumulated cycle (cycle)		0	0	0	0	0	0	0	0
PV CAPEX (Md)	-26,44								
Battery CAPEX (Md)	0,00								
Revenue on avoided electricity from grid (Md/year)		1,64	1,63	1,62	1,61	1,60	1,60	1,59	1,59
Revenue on exceeding PV production to grid (Md/year)		1,15	1,07	0,99	0,91	0,83	0,81	0,78	0,75
PV O&M (Md/year)		-0,52	-0,52	-0,52	-0,52	-0,52	-0,52	-0,52	-0,52
Battery O&M (Md/year)		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Net Cash Flow (Md)	-26,44	2,26	2,18	2,09	1,99	1,91	1,89	1,85	1,82
Discounted Net Cash Flow (Md)	-26,44	2,15	1,71	1,28	0,96	0,72	0,68	0,60	0,54
Cumulated Discounted Net Cash Flow(Md)	-26,44	-24,28	-16,81	-9,60	-4,20	-0,15	0,53	1,77	2,88
DPT calculation [year]							**20,22**		
NPV (MD)	2,9								
DPBT (years)	20,2								

B. Analysis of a 10 MW PV grid-connected with energy storage (Results with excel) for January and July

This section investigates the potential of using battery energy storage systems in the public distribution grid, to defer upgrades a needed to increase the penetration of photovoltaic's (PV).The potential of battery energy is to support the operation of public distribution grids gains rage systems (BESS) wide interest [26], [27]. This study performed a techno-economic assessment of grid-connected PV system . The system is considered interactive with the grid and with battery storage. A presentation of weather data analysis was provided and dfferent configurations of this system were considered, i.e. battery removed from the system.

The study concluded with cost of electricity appearing to be higher per Kw/h for the GCPV system more than utility electricity. The author attributes such results to high taxes and governmental subsidies on electricity

.



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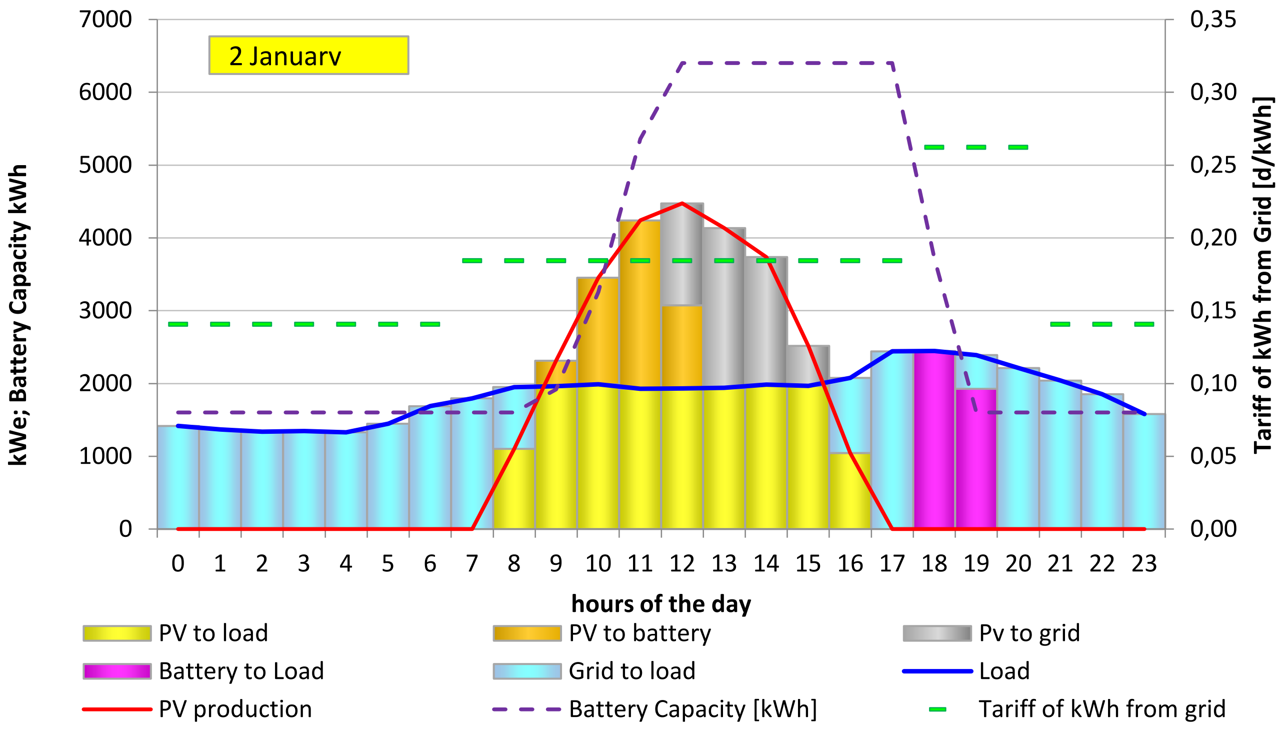

Fig.13 Data recorded during january2016 (with storage Bank) using excel application

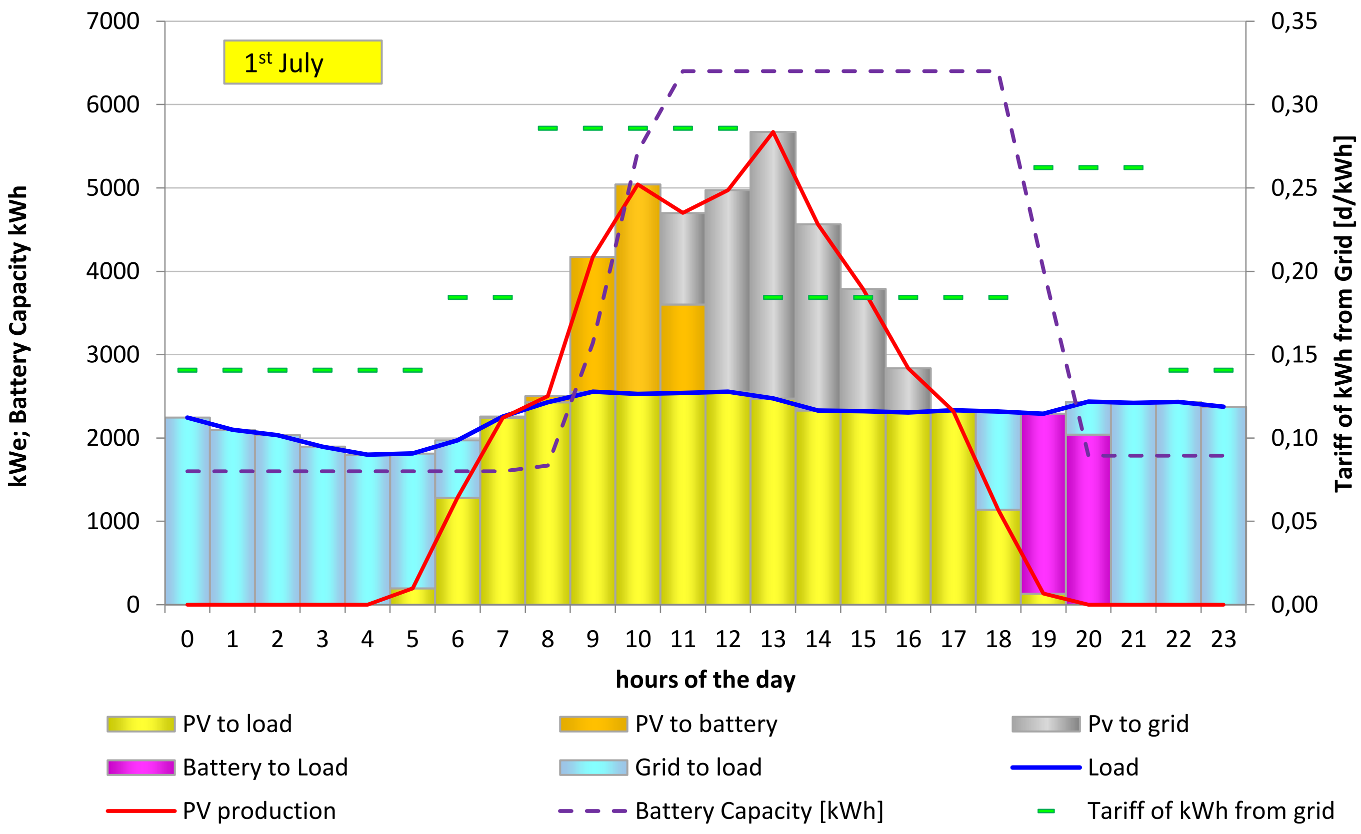

Fig.14 Data recorded during July 2016 (with storage Bank) using excel application

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VI. CONCLUSIONS

This study performed a design and techno-economic evaluation of a Grid-connected PV system in Tozeur city, with a size of 10 MW. The numerical simulation was made using Homer Software and an excel application. The optimum array size is 230 W p with around 43470 modules to satisfy the 10 MW.. The system has a payback period of 21 years and a CoE of 0,81USD/kW h. The system is feasible and shows great promise for the city of Tozeur.

To conclude, this study further enriches the body of knowledge about the feasibility, technical performance, and economic aspects of grid-connected solar PV with different time adjustments. Nevertheless, several possible limitations need to be considered. Moreover, the effect of different models of solar PV with different temperature coefficients and their effect on power generation, NPC, and LCOE are investigated. In the future research, a comparative performance analysis of off-grid and grid-connected designs for various locations with different metrological conditions will be investigated. Moreover, hybrid systems such as solar-wind-biomass could be integrated to examine the optimal design.

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