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DESIGN AND SIMULATION ANALYSIS OF 100MW GRID-CONNECTED SOLAR PHOTOVOLTAIC POWER SYSTEM AT TRIPOLI-LIBYA

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ABSTRACT

This paperpresents design modelling and simulation of a large scale solar PV grid-connected electricity generation system of 100MW capacity in Tripoli-Libya. It also describes, technical and economic potential, along with its annual performance. The sizing of the system is determinant based on the planned power, characteristics of the used PV module and the meteorological data of the installation site. The design is validated and simulated under Matlab/Simulink environment. Moreover, PVSYST software is used as sizing and optimization tool for determining the optimum size and specifications of PV grid connected system components, and the corresponding generated electrical power. Simulation results and analyses are provided to confirm the designed and arrangement of the designed system. Simulation results also show that the annual plant's electricity generation is 181614 MWh, which could be used to reduce the load shedding hours or powering sea water distillation plant capable of producing enough water for city of Tripoli. A simplified financial evaluation of the plant's capital, operation and maintenance costs using recent market prices show that the levelized cost of electricity (LCOE) is around $0.0321/kwh. The results of this work also should encourage the future government of Libya to make the decision of installing large PV projects to reduce load shedding and ensuring continuous supply of electricity and drinking water in Tripoli capital as well as implementation in other Libyan cities. Furthermore, oil saving and environmental benefits are outlined.

Keywords - PV-Grid Connected, PVSYST, Solar Energy, Simulink, Tripoli- Libya

I. INTRODUCTION

The demand for electrical power is increasing rapidly throughout the world. In addition, conventional energy resources emit toxic gases which are harmful to human and environment. Nowadays almost all nations build its own strategy according to the available natural resources to face increasing demand of electrical power.Solar energy has potential to meet increasing electrical power demand. Ii is considered to be the best solution for securing electric power use to address the concern of environmental impact and climate change.

Due to Libya crisis electrical power supply in the country is inadequate due to lack of production forcing the distributor to practice regular load shedding. The energy production potential of grid connected solar PV plants substantially contribute in making the national power supply system diversified, independent and ecologically sustainable. In addition todecline in solar modules and invert prices, the cost of solar electric power is competitive, compared to the conventional electric power generation. [1], [2], [3].Solar power in Libya iseasily and abundantly available renewable source of energy. If implemented it results in to comparatively low cost at large scale. The long term average sunshine data indicates that there are good prospects for solar thermal and photovoltaic application in the country. Research suggests that a 0.1 per cent Libyan land use for solar energy production would lead to energy production equivalent to 7 million barrels of oil a day, or almost five times the daily amount of energy produced from oil in 2012[4].Libya has the largest oil and natural gas reserves in Africa, and second-highest solar radiation in the world. [5], [6], [7]. Oil and natural gas exportation is the backbone of the Libyan economy. According to GECOL (General Electrical Company of Libya 2014) large amount of oil is consumed for the production of electrical energy. Libya islocated within the high solar belt, which requires not to miss this opportunity, and to take advantage of this feature lacking in some other nations.

Major significant cost in erection of such plants are panel and land costs (near load centers). Tripoli municipality owned areas is suitable for optimizing and utilizing resources properly and hence decreasing the load shedding hours. Thispaper discussesthe prospectsofsolar energy toeradicatethepowercrisisofLibya. It also presents design modelling and simulation of a large scale solar PV grid-connected electricity generation plant of size capacity 100MW in capital city of Libya. It also investigates, technical and economic potential of grid connected photo voltaic system. The design is validated and simulated under Matlab/Simulink environment. Moreover, PVSYST software is used as sizing and optimization tool for determining the optimum size and specifications of PV grid connected system components, and the corresponding generated electrical energy. A simplified financial evaluation of the plant's capital, operation and maintenance costs is carried out to demonstrate the plant's financial feasibility.

The process of designing a large PV plant is typically performed by taking into consideration not only the cost of the installation, but also the annual energy production (AEP), the performance ratio (PR), and/or the levelized cost of generated electricity (LCOE). AEP is equal to the aggregate energy injected into the electric grid during a one-year period for the PV plant servicing.PR quantifies the overall effect of losses. It is equal to the ratio of the final PV system yield divided by the reference yield [8]. LCOE is a metric used in the electricity market in order to evaluate the commercial breakeven of alternative energy technologies [9]. LCOE takes into account the electrical output of the installation over its lifetime. The designed plant is technically and financially feasible in Libya. It is large enough to supply sufficient energy to power either a large number of houses or to supply power to the sea water distillation plant needed to install it urgently.The results of this study further illustrate the possibilities to use photovoltaic generation at large-scale to reduce load shedding or for feeding sea water distillation plants.It is a very cost-effective project and could be generalized to other Libyan cities. The results of this work also should encourage the future government to make the decision of installing large PV projects to reduce load shedding. In addition it could alsohelp ensure continues water supply using electricity for sea water distillation plant needed to Tripoli city capital of Libya.

II. AN APPRAISAL OF ELECTRICAL ENERGY SITUATION IN LIBYA

A review of present state of the art shows that the electricity generation in Libya depends entirely on fossil fuel for generating its electricity needs. Currently electricity is provided by gas-turbine, steam-turbine and combined cycle power generation plants which use heavy oil, light oil and natural gas respectively. Gas- turbine and combined cycle power plants have a share of 30%and 20% respectively in total installed power capacity. The

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share of steam power plants is 50% in total. Furthermore, some small diesel power plants are also used to contribute the electrical energy supply, especially in remote areas. Currently power generation capacity in Libya is estimated to be around 6,000 megawatts, with average working capacity of 4,000megawatts, to provide electricity for about 6 million people [10].Whilst power infrastructure has mostly been maintained during on-going Libya crisis in situations with a limited level of destruction. This is being quickly repaired. The nationalelectrical power grid is still seen as a target for some Militias and dissenting elements within Libyan society.Electric power demand in Libya is increasing at faster pace than energy supply rate. Libya'spowerdemandis growingrapidly in the last decade around6% to 8% annually.Daily load shedding does often exceeds 15 hours. Irony is that Libya experiences load shedding despite plenty of solar energy potential. Load shedding may continue for decade as growth is likely to increase hugely as Libyan civil war continues and Libyan people don't realize the shortage of energy problems. Proper energy mix and use of renewable energy is a possible alternative to resolve the problem in a quickest possible manner.

III. POTENTIAL OF SOLAR ENERGY IN LIBYA

Libya is located in the middle of North Africa. Its capital city Tripoli is located at 32° 54' North latitude and 13° 11' East longitude. The area of Libya is characterized by a vast plain area i.e. an ideal location for solar energy utilization. Libya is exposed to the sun's rays throughout the year with long hours during the days [10]. It has an average daily solar radiation rate of about 7.1 kilowatt hours per square meter per day (kWh/m²/day) on a flat plane on the coast and 8.1kWh/m²/day in the south desert region [11], Libya is blessed with a rich and reliable supply of solar energy with an average sunshine duration of more than 300 days per year.Figure 1 shows the solar map of Libya, employing long-term satellite based solar irradiation data.

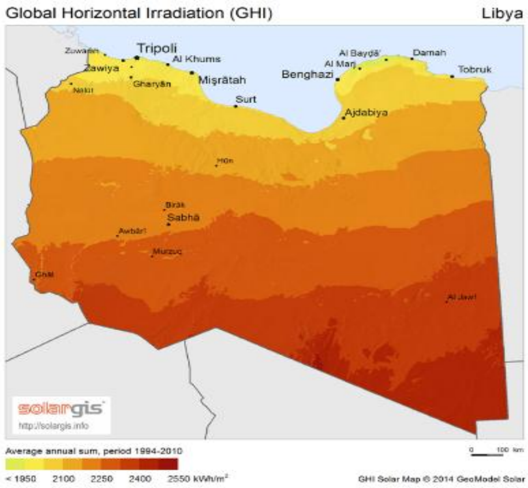

Figure 1. Solar map in Libya (Solargis, 2016)

IV. DESIGN OF THE PROPOSED SOLAR PV POWER PLANT

Utility-scale PV plants are comprised of several thousands of PV panels, each being in the range of hundreds of watts. During the design stages of a large PV plant, the designer needs to choose the values of many design parameters, for instance number, size and type of PV modules and inverters, distribution of the components in the installation area, etc. Moreover, the values of the design parameters are conflicting. Installation of many PV modulesnot only increases the PV plant energy production but also leads to high installation and lifetime maintenance cost of the PV plant. Thus, the design of a large PV plant is a big challenge for bothenergy production and cost. Designing a large scale megawatts solar PV power plant requires considerable technical knowledge and experience. There are many constraints that need to be resolved in order to achieve the optimum balance between performances. The main system design is undertaken based on the amount of generated power (100MW). The generated output power from the PV system is at 0.4 kV voltage level. It steps-up from 0.4 kV to 11 kV by 10 step-up distribution transformers.

4.1 SITE SELECTION

Solar energy study results are site specific. One of theaims of this paper to arrive at results to be applied to various Libyan cities locations, using the following selection criteria:It needs to be close to the national grid, and to load centers in an area where large parcels of low priced, vacant land are available. The design in Tripoli city with geographical coordinates havelatitude 33.9° N and longitude 13.2° E.Tripoli has an average of 3187 hours of sunlight per year with 8:43 of sunlight per day. It is sunny during 72.7% of daylight hours. The remaining 27.3% of daylight hours are likely to be cloudy or with shade, haze or low sun intensity. At midday the sun is on average 57.7° above the horizon in Tripoli.

4.2 SIZING AND SELECTION OF PV MODULES

Factors affecting the selection of a PV module for grid connected systems are the efficiency of the module and its cost. To decide whether to use poly-crystalline or mono-crystalline modules is not easy. It requires consideration regarding weighing costs against efficiencies. Since the cost has a higher importance due to the large number of modules expected to be needed, poly-crystalline modules of considerably high efficiency are needed. For this design, a large variety of PV panel options are studied in terms of type, power, cost and warranty using the Canadian solar power of 435 Wp production selected and adopted in this work. Electrical Data for Solar Panel E-20-435-COM SunPower is shown in Table 1.

Table 1. Electrical Data for Solar Panel E-20-435-COM SunPower

Nominal Power (Pnom)	435 W
Power Tolerance	+/–5%
Avg. Panel Efficiency	20.3%
Rated Voltage (Vmpp)	72.9 V
Rated Current (Impp)	5.97 A
Open-Circuit Voltage (Voc)	85.6 V
Short-Circuit Current (Isc)	6.43 A
Max. System Voltage	1000 V UL & 1000 V IEC
Maximum Series Fuse	15 A
Power Temp Coef.	–0.35% / °C
Voltage Temp Coef	. –235.5 mV / °C
Current Temp Coef.	2.6 mA / °C
dimension	L=2067mm. w=1046mm

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4.3 DESIGN CALCULATIONS

Due to inherent constraints the proposed PV plant has total capacity is 100 MW.The energy production factor is an industry estimate for sizing purposes that 1kw of solar produce approximately 1,700kwh/year. Therefore this production factor is chosen for sizing the desired plant.

In Tripoli city 1 kWp is estimated to produce approx.1700 kWh/year, therefore for installing 100 MW could produce 1700×10^5 kWh/year. The expected energy generated by PV plant in one year is 1700×10^5 kWh/year, and the expected energy generated by the PV plant per day is:

$$= \frac{1700\times10^5}{365} = 4.6575\times10^5\, kWh/day$$ ………………………………………………………………. (1)

The expected energy generated by PV = 0.77625×10^5 kW………………………………………………………. (2)

Since modules has efficiency factor of 0.8 i.e. it would not absorb peak sun hours, but only about 0.8 or 80% of that.

Therefore the expected generated energy by PV plant need to be multiplied with the design factor 1.288. Hence the total expected energy generated by PV plant would be equal to0.99981×10^5kW

Having chosen the (sun power 435W),therefore the total number of modules in the plant is

$$Total\ number\ of\ modules = \frac{0.99981\times10^5\, kW}{435W} = 229841.379 \approx 229824\ module$$ ……………………………. (3)

4.4 SIZING AND SELECTION CRITERIA OF INVERTER

Different solar PV module technologies and layouts would suit different inverter types. Care needs to be taken in the integration of modules and inverters to ensure optimum performance and lifetime. Inverters have to be sized such that to handle the expected power level, and be compatible with the specifications on the grid side.The calculated number of panels is 229824. These are considered to generate the desired energy of 100MW.The selected inverter size (solar max 1320KW), isshown in Table 2.

Table 2. Specifications for SolarMax 1320 TS-SV Inverter

Input values	MPP voltage range	450 V...800 V
	Maximum DC voltage	900 V
	Maximum DC current	2880A
Output values	Rated output power	1320 kW
	Maximum apparent output power	1360 kVA
	Nominal mains voltage	3 x 280 V
	Maximum AC current	2800 A
	Mains nominal frequency / range	50 Hz / 45 Hz...55 Hz
	Power factor cos(f)	Adjustable from 0.8 overexcited to 0.8 under excited
	Distortion factor at rated power	< 3 %
	Grid connection	Three-phase (without a neutral conductor)
Efficiency	Maximum efficiency	98 %
Ambient conditions	Ambient temperature range	-20 °C...+50 °C
	Ambient temperature range at rated power	-20 °C...+45 °C
	Relative humidity	0...98 % (no condensation)
	Noise emissions	< 65 dBA
	Noise emissions	< 65 dBA
Weight & dimensions	Weight	3960 kg
	Dimensions in mm (W x H x D)	1200 x 1970 x 800 mm

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Based on the selected inverter size the total number of inverters for the plant is 100MW/1320kW =75.756 ≈ 76 inverters. The calculated number of panels 229824 are divided by the number of obtained inverters i.e.76. Here the number of array for, each inverter is 3024 solar panels. Based on the inverter input values, efficiency as well as safety operation is chosen according to the specifications for both modules and inverters.
Therefore,the number of modules per string are obtained as below:

No of module/string= $\frac{(MPP\ voltage\ range)_{inverter}}{(V_{MPP})_{module}} = \frac{450+800}{=72.9} = 8.57$which isrounded to 9 modules……….... (5)

The maximum number of strings in parallel is calculated as follows:

$= \frac{(P_{inveter})/\eta_{max}}{(number\ of\ module\ /string)\times(P_{\max for\ module})}$ …………………………………………………..………………. (6)

$= \frac{1320\times1000\ /_{0.98}}{(9\times435)} = 344\ module$0r $\frac{number\ of\ arry\ /inverter}{number\ of\ modules\ per\ string} = \frac{3024}{9} = 336\ modules$ ………...…. (7)

Therefore the number of strings in parallel is 336 modules.The total number of modules for each inverter is equal 9×336 = 3024 module.

4.5 DESIGN LAYOUT OF SOLAR PV GRID-CONNECTED SYSTEM

A Solar PV Power plant is a concept of generating electrical .power from the sun and converting it to the AC electrical power used in our daily lives. PV modules are installed on fixed metallic support structures arranged in rows, with adequately space between rows and modules, and facing to the south with an appropriate tilt. PV modules are electrically connected together in series and parallel and then connected by to the centralized inverters which converts DC electrical power into AC electrical power. String Inverters are connected together, on AC side, to Medium Voltage substation, are delivered to the HV grid by means of one or more step-up transformers.For safe operation of a transformer specifications of a maximum PV inverter power is 1.5 times the transformer rated power [12].
In this designed solar PV grind connected system each inverter of size 1320 kW is connected with 336 parallel strings, and 9 modules per string in a series. And each inverter also its output is connected to step-up transformer of size 1320×1.5 =1920 rounded to 2MW as shown in Fig.2.

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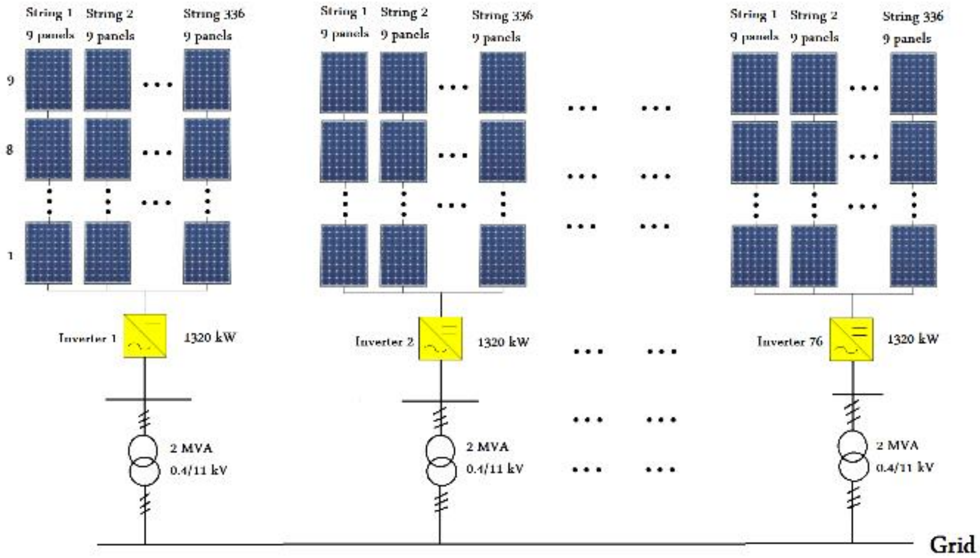

Figure 2.Layout of solar PV grid connected system.

4.6 ENERGY GENERATED FROM DESIGNED PV GRID CONNECTED SYSTEM

By assuming that the solar energy is available for about 7 hours during the normal day, the average solar insulation in Tripoli City onto a horizontal surfaceis 5.48 KWh/m^2/day.

Therefore, 5.48 KWh/m^2/day = 5.48 x1000/ 7 = 783 W/m^2/day ……………………………...……..……….. (8)

The energy supplied by the solar PV system in a year is found by the following formula.

Total energy supply = Maximum Power at defined irradiance of a solar panel × Average bright sunshine hour ×365 days × total no. of solar panels.

Total energy supplied = 435 ×783× 365 × 229824 = 28571909.285 MWh/year ……………...….…………. (9)

Considering 80% of panel's output efficiency the total energy supply = 2285752742.78 MWh/year …...… (10)

4.7 CALCULATION OF REQUIRED AREA

As solar modules are not energy-dense, they require a substantial amount of space in order to work. The 435W solar module selected above as shown in table.2 has a length of2067mm (2.067 m) and a width of 1046 mm (1.046m). This means each panel has an area of 2.067 x 1.046 = 2.162 m^2.Therefore, the total modules area for the designed plant =total modules ×modules area=229824×2.162=496879.5m^2 about 50 hectare.Although the panels have a total area of 496879.5square meters, the space between the panels need to be accounted for (as these panels require stands) and the total space required is estimated by dividing the total area by 0.7 which yields to:496879.5m^2/ 0.7 = 709827.8m^2 Therefore, around70 hectare actual area is required. Summary of proposed design is given in table below in Table 3.

Table 3.Summary of proposed design calculations

System Overview	
peak power	100MW
number of modules	229824
number of groups	76
Number of modules per group	3024
No of strings	336
Number of modules per string	9
inverter	Central inverter MPPT TL /3 phase
Total no of inverter	76
Strings per inverter	336
No of modules per string	3064
Output voltage of each string	72.9×9=656.1V VDC
Output current of each string	5.97A DC
Output voltage of each group	583.1V VDC
Output current of each group	5.97×336=2005.92A DC
Output power of each string	656.1×5.97= 3.916KW
Output power of each group	3.916×336=1316.1KW
Output power of 75 groups	1316.1×76=100000KW=100MW.
Overall efficiency of power plant (as a capacity factor)	Actual capacity/desired capacity
Area required	70 hectare

V. MATLAB/SIMULINK OUTPUT OF DESIGNED PV PANEL

The mathematical model of the photovoltaic (PV) generator based on the one diode equivalent circuit was developed in [13].A general block diagram of the PV model using Simulink also was developed in [13] and is shown in Fig. 4. The block in Fig. 3 contains the sub models connected to build the array for each inverter. Variable temperature (T), and variable solar irradiation level (G) are the inputs to the PV model. The equation of the PV output current I is expressed as a function of the array voltage V as given by (1).

$$I = I_{ph} - I_D = I_{ph} - I_{sat}\left[e^{\frac{q(V+IR_s)}{nkT}} - 1\right] \quad (11)$$

Where:

I_{ph} the light current [A], I_{sat} the diode reverse saturation current [A], R_s, the series resistance [Ω], V the operation voltage [V], and I the operation current [A].

q = charge of one electron$(1.602 \times 10^{-19} C)$.

$n =$ Diode idealizing factor, and $k =$ Boltzman's constant $(1.38 \times 10^{-23} J/K)$. T=Junction temperature in Kelvin.

The modeling detailsof the PV array for Matlab/Simulink environment is discussed in [13], [14].

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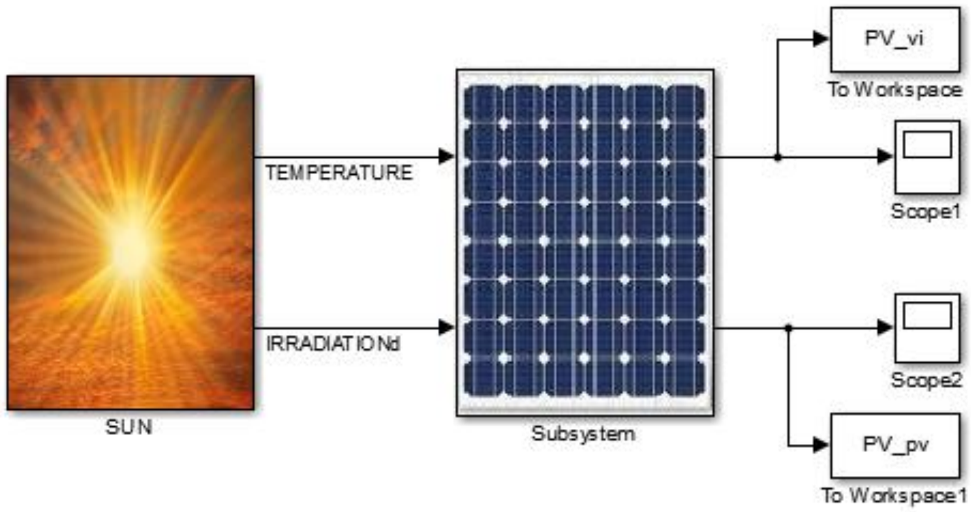

Figure3. Simulink model of PV module

The Simulink model shown in Figure3is used to simulate solar PV plant using the designed calculated data and manufacturer's modules data sheet specifications shown in Table 1. The simulation results for the plantoutput characteristics, with varying irradiation at constant temperature are shown in Figures 4, 5,I-V and P-V respectively. Plantoutput characteristics, with varying temperature at constant irradiation are shown in Figures.6, 7. From figures.4, 5, it is clear that increasing the irradiation increases, the output current and voltage. This results in net increase in power output. From Figures. 6, 7,increasing temperature at constant irradiation,outputcurrent increases marginally but the output voltage decreases drastically. This results in net reduction in output power. These results are verified and found matching with the manufacturer's data sheet output curves.

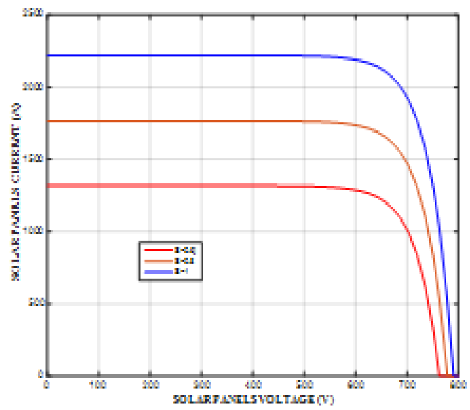

Figure. 4.I-V Characteristic curves at different insolation levels (S= 1.0 S, =0.8, S= 0.6), for 336 panel per inverter.

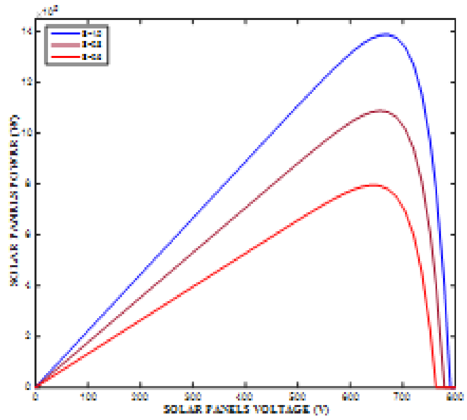

Figure 5.P-V Characteristic curves at different Insolation levels (S=1.0, S= 0.8, S=0.6), for 336 panel per inverter.

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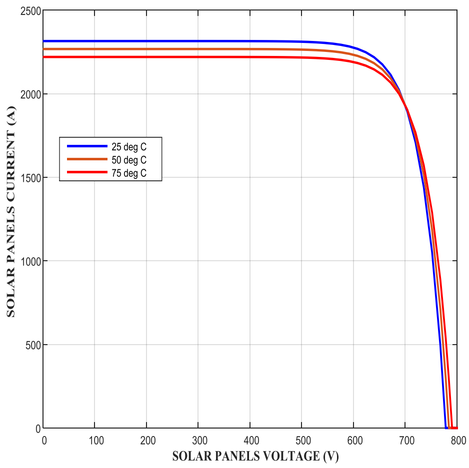

Figure. 6. I-V Characteristic curves at different cells working temperature (Tc =25^{o}C, 50^{o}C, 75^{o}C), for 336 panel per inverter.

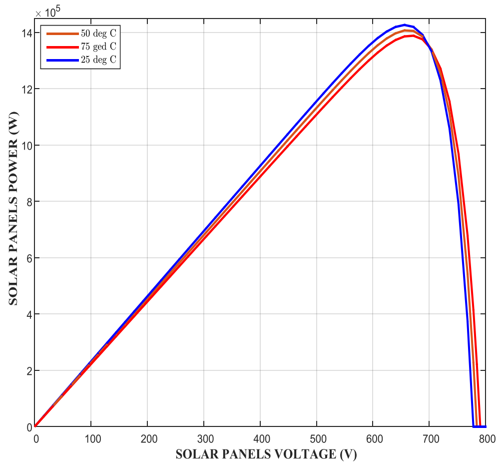

Figure.7.P-V Characteristic curves at different cells working temperature (Tc=25^{o}C, Tc=50^{o}C, Tc=75^{o}C), for336 panel per inverter.

VI. RESULTS USING PVSYST SIMULATION OUTPUT OF DESIGNED PV PLANT

The final system design is performed using the PVsyst V6.39 simulation software. PVSYST software is a PC package for analyzing the potential of a photovoltaic system at a known location. It consists of both meteorological data and the possibility to select system components from various manufacturers. This PC software package is used for the study, sizing and data analysis of complete PV systems. PVSYST has two options for the dimensioning of the PV system; to either size by planned power, or available area.

The simulation results of designed PV grid-connected system are displayed comprehensively through the created report by PVSYST. The report includes the optimum PV array and inverter sizes for the designed grid as shown in Fig.8. Fig. 9 shows a number of elements depicting the total potential energy that could be harvested for each month of the year totaling a potential of 187154MWh/year. The Energy injected into the grid per year also shown in this figure and is found to be about 181614MWh. Fig. 9 also depicts the effective energy at the output of the array, percentage efficiency of the array and percentage efficiency of the system, which is found to be 178154MWh, 16.69% and 16.19% respectively.The detailed losses also have been explained as shown in Fig.10.

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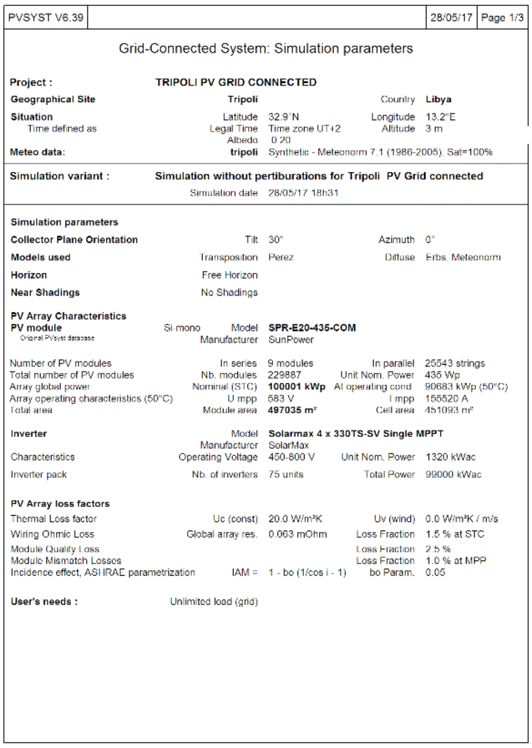

PVSYST V6.39 | 28/05/17 | Page 1/3

Grid-Connected System: Simulation parameters

Project : **TRIPOLI PV GRID CONNECTED**
Geographical Site **Tripoli** Country **Libya**
Situation Latitude 32.9°N Longitude 13.2°E
Time defined as Legal Time Time zone UT+2 Altitude 3 m
Albedo 0.20
Meteo data: **tripoli** Synthetic - Meteonorm 7.1 (1986-2005), Sat=100%

Simulation variant : **Simulation without pertiburations for Tripoli PV Grid connected**
Simulation date 28/05/17 18h31

Simulation parameters
Collector Plane Orientation Tilt 30° Azimuth 0°
Models used Transposition Perez Diffuse Erbs, Meteonorm
Horizon Free Horizon
Near Shadings No Shadings

PV Array Characteristics
PV module Si-mono Model **SPR-E20-435-COM**
Original PVsyst database Manufacturer SunPower

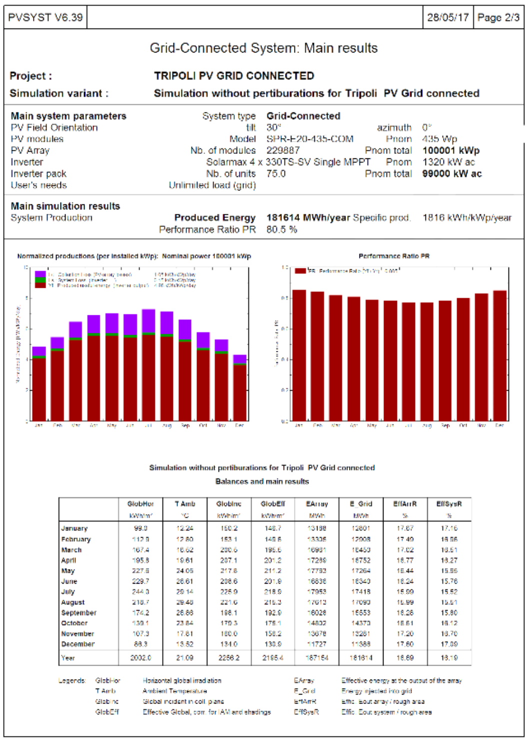
Number of PV modules In series 9 modules In parallel 25543 strings
Total number of PV modules Nb. modules 229887 Unit Nom. Power 435 Wp
Array global power Nominal (STC) **100001 kWp** At operating cond. 90683 kWp (50°C)
Array operating characteristics (50°C) U mpp 583 V I mpp 155520 A
Total area Module area **497035 m²** Cell area 451093 m²

Inverter Model **Solarmax 4 x 330TS-SV Single MPPT**
Manufacturer SolarMax
Characteristics Operating Voltage 450-800 V Unit Nom. Power 1320 kWac
Inverter pack Nb. of inverters 75 units Total Power 99000 kWac

PV Array loss factors
Thermal Loss factor Uc (const) 20.0 W/m²K Uv (wind) 0.0 W/m²K / m/s
Wiring Ohmic Loss Global array res. 0.063 mOhm Loss Fraction 1.5 % at STC
Module Quality Loss Loss Fraction 2.5 %
Module Mismatch Losses Loss Fraction 1.0 % at MPP
Incidence effect, ASHRAE parametrization IAM = 1 - bo (1/cos i - 1) bo Param. 0.05

User's needs : Unlimited load (grid)

Figure8. PVSYST technical simulation results.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Grid-Connected System: Main results

Project : **TRIPOLI PV GRID CONNECTED**
Simulation variant : **Simulation without pertiburations for Tripoli PV Grid connected**

Main system parameters System type **Grid-Connected**
PV Field Orientation tilt 30° azimuth 0°
PV modules Model SPR-E20-435-COM Pnom 435 Wp
PV Array Nb. of modules 229887 Pnom total **100001 kWp**
Inverter Solarmax 4 x 330TS-SV Single MPPT Pnom 1320 kW ac
Inverter pack Nb. of units 75.0 Pnom total **99000 kW ac**
User's needs Unlimited load (grid)

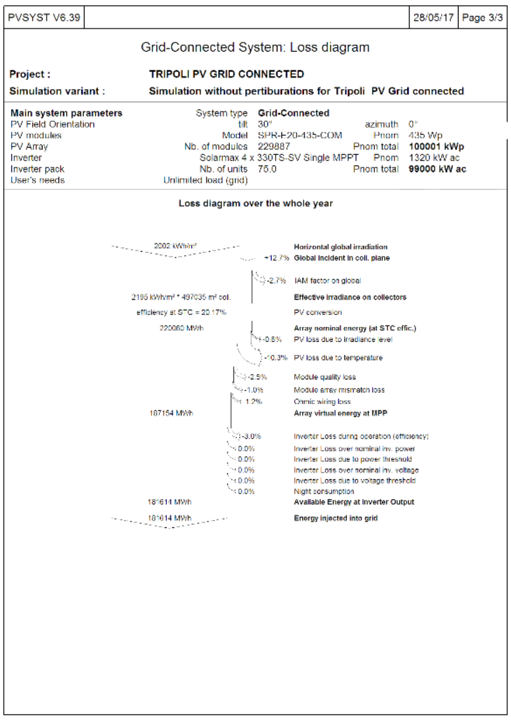
Main simulation results
System Production **Produced Energy** **181614 MWh/year** Specific prod. 1816 kWh/kWp/year
Performance Ratio PR 80.5 %

Simulation without pertiburations for Tripoli PV Grid connected
Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	99.8	12.24	150.2	146.7	13188	12801	17.67	17.16
February	112.9	12.80	153.1	145.6	13305	12908	17.49	16.96
March	167.4	16.62	200.5	195.5	16981	16450	17.02	16.51
April	195.8	19.61	207.1	201.2	17289	16752	16.77	16.27
May	227.6	24.05	217.8	211.2	17793	17264	16.44	15.95
June	229.7	26.61	208.6	201.9	16838	16340	16.24	15.76
July	244.0	29.14	225.9	218.9	17953	17418	15.99	15.52
August	218.7	29.48	221.6	215.3	17612	17090	15.99	15.51
September	174.2	26.86	198.1	192.9	16028	15553	16.28	15.80
October	139.1	23.84	179.3	175.1	14802	14370	16.61	16.12
November	107.3	17.81	160.0	156.2	13678	13281	17.20	16.70
December	88.3	13.52	134.0	130.9	11727	11388	17.60	17.09
Year	2002.0	21.09	2256.2	2185.4	187154	181614	16.69	16.19

Legends: GlobHor Horizontal global irradiation; T Amb Ambient Temperature; GlobInc Global incident in coll. plane; GlobEff Effective Global, corr. for IAM and shadings; EArray Effective energy at the output of the array; E_Grid Energy injected into grid; EffArrR Effic. Eout array / rough area; EffSysR Effic. Eout system / rough area

Figure 9. PVSYST technical simulation results


PVSYST V6.39 | 28/05/17 | Page 3/3

Grid-Connected System: Loss diagram

Project : **TRIPOLI PV GRID CONNECTED**
Simulation variant : **Simulation without pertiburations for Tripoli PV Grid connected**

Main system parameters System type **Grid-Connected**
PV Field Orientation tilt 30° azimuth 0°
PV modules Model SPR-E20-435-COM Pnom 435 Wp
PV Array Nb. of modules 229887 Pnom total **100001 kWp**
Inverter Solarmax 4 x 330TS-SV Single MPPT Pnom 1320 kW ac
Inverter pack Nb. of units 75.0 Pnom total **99000 kW ac**
User's needs Unlimited load (grid)

Loss diagram over the whole year

Figure 10. PVSYST technical simulation results

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VII. ECONOMIC ANALYSIS

Review shows that capital cost of PV grid connected systems is reported to be decreasing significantly over the past years; PV module prices are reported to decline by around 80% between the end of 2009 and the end of 2015 [15]. This means with increased global PV deployment, inverters follow a strong cost reduction path. The global average cost for inverters dropped from above 1 USD/W in 1990 to USD 0.14-0.18/Win 2015, lower costs have also beenreported.

The capital cost of a utility-scale photovoltaic plant in the year 2016 is 1.42$/kW according to the International Energy Agency NREL [16], as shown in Fig.11.

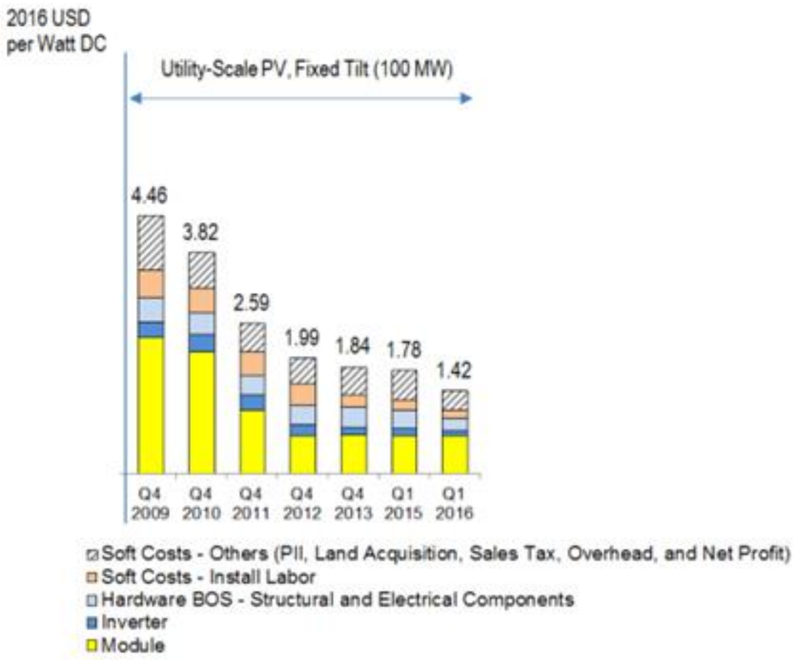

Figure 11.PV utility scale system cost (source: NREL 2016)

Capacity Factor for grid-connected PV systems is defined as hours per day of peak sun (psh) divided by 24 hours per day

Therefore$capacity\ factor = \frac{h/day\ "peak\,sun"}{24h/day}$

$\therefore\ \ for\ tripoli\ city\qquad c.p = \frac{7}{24} = 0.292$ ……………………………...……………………...…………….

(12)

VIII. LEVELIZED COST OF ELECTRICITY (LCOE) FOR THE DESIGNED PV PLANT

In recent years there are vast range of electrical power technologies available, for conventional and solar energy, which varies with respect to its physical principles and operation. (LCOE) is used to define the cost of electricity generation in ($/MWh) over the complete life of a power plant, [17]. Solar energy PV plant is completely different from a conventional energy plant. Hence the leveled cost of electricity, (LCOE) provides a common ground to compare the electricity cost across a broad range of electricity technologies.In general LCOE = Total cost of divided by System production over its lifetime kWh.For solar PV grid connected generation plant which had been sized above the LOCE is calculated as follows:

- Project capacity = 100 MW
- Initial investment = $\$142\times10^6$
- Maintenance costs = $\$142\times10^4$/year (1% of initial investment)
- Estimated yearly production = 168251 MWh/year kWh
- Project life = 25 years

Over its lifetime, the total kWh production of this PV system will be:
Lifetime output = 161614×10^3kWh/year x 25 years = 4540350×10^3 kWh.
The total cost of ownership, considering the initial investment and maintenance costs, will be:
Total Cost of Ownership = $\$142\times10^6$+ \$1420000/year x 25 years = \$145550000
Therefore, this project will have the following LCOE:
LCOE = \$145550000 / 4540350×10^3 kWh= \$0.0321 / kWh.

IX. ENVIRONMENTAL ANALYSIS

The amount of CO_2, saved by the designed PV grid-connected systems, is found to depend on the existing energy mix for powergeneration similar to the one reported in various countries. It is found that PV installations saves, on, 0.62 kg of CO_2 per kilowatt-hour generated. This takes into accountemissions during the life-cycle of the PV system of25. The overall CO_2reduction in the life-cycle of PVsystem is = 4540350×10^3 kWh×0.62=2815017 tonsof CO_2. Therefore, it is obvious that PV system as a future candidate is an effective tool to replace the conventional power generation and capable to combat climate change.

X. CONCLUSION

This paper presents design modelling and simulation as well as technical and economic potential of a large scale solar PV grid-connected electricity generation plant of size capacity 100MW in Tripoli-Libya. Simulations of the designed system is performed with PVsyst software. It is used to obtain information on energy production, efficiency of system and energy loss by PV grid connected system. The simulation clearly shows that the efficiency of photovoltaic panels decreases in summer season. This is explained by the fact that the solar cells lose energy through heat. In fact, that part of energy of solar cells is lost i.e.consumed bycells instead of producing energy. Matlab/Simulink and PVsyst shows that the PV module operates at the same parameters as that specified in the technical data. The PV grid connected system operates, and demonstrates that how much energy is produced and what are the losses, as a way forward to indicate the profitability of the system.

Finally the study demonstrates that the plant's annual performance is 80.2%. The simulation results shows that annual electricity generation of the proposed solar PV plant is 181614 MWh of useful AC electricity. This is sufficient energy to reduce load shedding or to power sea water distillation plant capable of producing drinking water for Tripoli inhabitants. In addition, the overall annual CO_2reduction in the life-cycle of PVsystem is 112600.68 tones. It is obvious that PV system as a future candidate is an effective tool to replace the conventional power generation and capable to combat climate change.

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