Power Losses on PV Solar Fields: Sensitivity Analysis and A Critical Review

Khaled A. Amer[1], Massuod Fakher[2], Abdallah Salem[3], Suliman M. Ahmad[4],
Mukhtar A. Irhouma[5], Salah Aldeen S. Altahbao[6], Elsadic Salim[7]

[1,2,3,4,5,6,7] Department of Mechanical & Industrial Engineering, Faculty of EngineeringScience & Technology, Sebha University,
Brack-Libya

Abstract: Much efforts are made around the world to mitigate the global pollution as well as to provide humanity with a secure and sustainable energy source. This research comes within these efforts to try to understand the causes of energy losses in the greatest inventions of the last century in the field of converting solar energy into electrical energy. advantages of PV solar technology from the rest of solar applications encourage the scientists and engineers to make further efforts in order to improve the efficiency of the PV solar panels and as a result to reduce the cost of the electricity production. The study showed that, the Thin-Film solar modules are the most suitable for Libyan climate, which is characterized by high temperatures in the summer season, and it is different from the type prevailing in the Libyan market nowadays.

Keywords: *Energy losses, Libya, PV solar panel, shadow*

I.INTRODUCTION

In September 1882 the world's first coal-fired public power plant was built in London. Since then, electricity has been considered one of the most important elements of life and development for the mankind and since then this industry moves from one stage to another and extends to all populated areas. However, its economic and environmental problems cannot be overlooked. The fluctuation of the price of fossil fuels and the approaching depletion of them and the amount of pollution caused by the traditional electric power plants that depend on burning fossil fuels, which cause global warming and climate change [1,2]. For these reason, efforts were combined at the Paris Conference to reduce greenhouse gas emissions, and most countries signed the pollution agreement. Among them is the State of Libya, which has approved several legislations for its part, including the adoption of a carbon tax policy [3]. A strategy has been adopted to the transmission from the traditional energy industry to the renewable energies that available in the country. Solar and wind energy, which exist in economic quantities making them the first candidate for exploitation during the next few years. Especially, Libya and the energy sector in particular are experiencing a large deficit in the security and continuous supply of electrical energy. The shortage in electricity reaches long hours (for example: in Brack city), it recorded for the period of 25 July to 7 September about 57.2%. We believe that the way out of these issues is the wide exploitation of the renewable energies at the domestic and commercial levels [4,5] instead of the small mobile generators which cause damage the environment and national economy [6].

According to studies specialized in the field of renewable energies, the Mediterranean basin is rich in solar energy sources, as well as wind energy sources [7]. Libya locates on the solar built zone and has a high potential of solar energy. The potential of wind energy is remarkable also, especially in some coastal and mountainous areas, such as the city of Derna in the northeast and the city of Mesllata in the northwest [8].

Looking at the distribution ratios of electrical energy represented graphically in Figure 1 [9], we find that the household sector consumes about 31% of total electricity production and is the largest sector consuming electrical energy in the country - as is the case in most developing countries - this percentage is greater than the deficit ratio. In the general generation of electricity. If 75% of the household load was covered, the country would have recovered from the electricity crisis that we have been dealing with since 2011 until now. So the solution is divided into two parts: the first part is to use solar heaters to heat water, which constitutes about 30% of the house load and equivalent to 9.3% of the total load, as well as the use of solar cooling systems, and this will cover 18.35% of the household load, equivalent to 5.7% of the total load of the network General Electricity. This part - the thermal application of solar energy - has been discussed in many local papers [10-14].

The electric power crisis and the high price of fuel pushed many companies tend to import solar systems (solar panels, storage batteries, inverter, etc.), and many residents accepted to install these systems on the roofs of homes. In fact, the Libyan market does not have experience with such systems, and therefore it must be noted that there is a difference between the operational data available with the device and the real energy that the owner will obtain. Of course, the reason for this is the difference in standard conditions (STC) with actual operating conditions. This may shock the investor and negatively affect the spread of these systems' distribution in the Libyan market. From here, the objective of the study was determined to determine the causes of energy loss in the fields of solar cells installed on the roofs of buildings, which in turn will help the merchant, the installer and the owner in understanding the reality of solar cells' work and how to avoid energy losses.
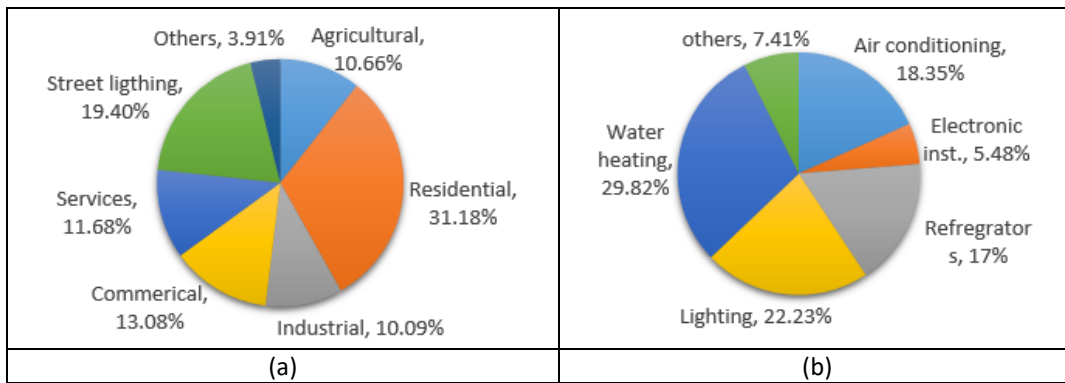
Figure 1: Pie chart distribution of the electric load rating (a), and the domestic electricity consumption (b) in Libya

Nowadays, efforts are made towards improvement in the efficiency of PV solar panels, and as a result, reduce the cost of electricity unit production. This research is located within these efforts. Knowing the causes of decline in the PV systems efficiency is necessary to prevent falling in and to try avoided them during the design and construction process.

II.   ENERGY LOSSES IN PV SOLAR PANELS

The energy losses in PV solar systems may be classified in to four types. as:

2.1. Manufacturing Losses

There are three major types of commercial solar panels on the world market today. There are [15]:

- Monocrystalline solar panels: Last the longest, high energy efficiency;
- Polycrystalline solar panels: Lower efficiency than monocrystalline
- Thin-film solar panels: this type includes (Amorphous silicon, Gallium arsenide, Copper indium gallium selenide – CIGS, and Cadmium telluride - CdTe), least expansive, shortest lifespan, lowest efficiency, and most flexible.

All these types have advantages and of course they have disadvantages also. Table 1 summarises some characteristics of the three most common solar panel types.

Table 1: Summery of the solar panels characteristics

Solar panel type	Efficiency	Cost [15]	Temperature effecting [16]	Appearance
Monocrystalline	18%-24%	1.0-1.5 $/W	-0.446%℃	Black or dark blue cells with rounded corners
Polycrystalline	15%-17%	0.9-1.0 $/W	-0.387%℃	Blue rectangular cells
Thin-Film	11%-15%	0.7-1.0 $/W	-0.172%/℃	Black or blue uniform surface

These data are very important for calculations and decision making. Therefore, the manufacturing must print the thermal-electrical characteristics and the type of solar panel on the back-side of the solar panel. The polycrystalline is the most prevailing type of solar modules in the Libyan market.

2.2. Installation Losses

Tilt angle

Tilt angle of fixed mode- PV solar panels is considered as a critical parameter. Many efforts are made in order to determine the optimum tilt angles [17,18]. Missing the optimum tilt angle leads to an attenuation of solar radiation as a result, the production of the PV panels is reduced. For Tripoli – Libya the optimum tilt angle varies from 0° to 50° during summer and winter seasons respectively [17]. While the optimum fixed tilt angle is calculated by Agha and Sbeta [19] and it found to be equal to 20°. Therefore, tracking-mode PV panels receive more incident radiation than fixed mode ones. Nassar shows that, the increasing in solar radiation can be reach to 38% in case of dual axes and about 23% by using one axes solar tracking system [20].

MS excel working sheet is prepared to study the sensitivity of the solar radiation to the tilt angle. It is well known that the global tilted solar radiation is depending mainly of the sky-diffuse and ground-reflected transposition models and the albedo [21]. Unfortunately, there are no time series readings for long periods of time for solar radiation, as well as there are no studies that determine the appropriate model for determining solar radiation on sloping surfaces, except for the city of Brack - Engineering and technology Faculty - where this study was conducted. Alsadi and Nassar indicated in an experimental study of the solar radiation in PV solar fields [22] that the Liu & Jordan model (1963) is the most accurate model that represents the solar radiation data for Brack city.

The obtained results show that, the annual global solar radiation incident on affixed tilted to 20° south facing solar collector is found as 2,485 kWh/m^2 while when moving the solar collectors once a month this will be augmented the solar radiation incident on the solar collector surface by 3.74%. According to the Liu & Jordan isotropic sky transposition model, the global tilted solar radiation (H_t) will be calculated by [10]:

$$H_t = H_b R_b + H_d R_d + (H_b + H_d)\rho_g Rg \qquad\qquad (1)$$

Where: H_b is the horizontal direct beam radiation, the horizontal sky-diffuse, R_b is a geometric factor which equal to $R_b = \frac{\cos\theta_i}{\cos\theta_z}$, θ_i and θ_z are the solar incident and zenith angles, respectively. R_d is the sky diffuse transposition model, which for Liu & Jordan model $R_d = \frac{1+\cos\beta}{2}$, β is the tilt angle of the solar collector, ρ_g is the ground reflectivity (albedo), and often taken as 0.2. R_g is the ground reflectivity transposition model, which $R_g = \frac{1-\cos\beta}{2}$.

Shadow

It is a fact that shadow on solar harvesters reduces their output power, especially in case of PV solar panels. For this reason, that the presence of shade on the PV solar panels must be prevented [23-25]. The Energy losses in PV systems due to the shading is approximated by 4% [26].

Shadow can occur as a result of the presence of objects around the solar field or as a result of the shadow of the previous row falling onto the next row in the solar fields. The presence of the shadow in the distance between the two rows also has an effect on the intensity of solar radiation as evidenced by experimental and theoretical researches [22, 27]. Figure 2. illustrates a side view of a horizontal solar field. The shadow calculations have been derived and presented in [25].
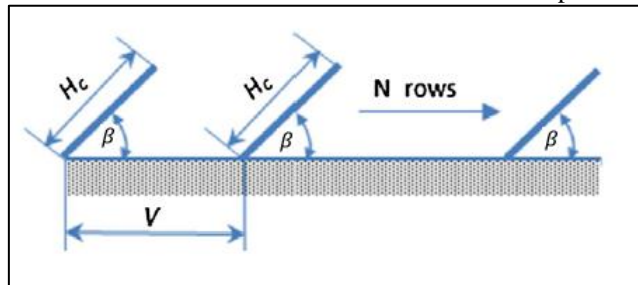

Figure 2: Side-view of deployment of solar collectors on a horizontal solar fields

It is a well-documented fact that shading of a PV solar array reduces it output power capability. However, the relative amount of such reduction in energy yield cannot be determined in a straight forward manner, as it is often not proportional to the shaded area. Many researches clarify the mechanism of partial PV shading on a number of PV cells connected in series and/or parallel with and without bypass diodes. Authors of [22] provided a simple analysis and can be useful to someone who wishes to determine the impact of some shading geometry on a PV system. The configuration considers two rows connecting in parallel and in series with diodes connecting in parallel with each row as it illustrated in Figure 3 (a) and (b), respectively. The solar radiation intensity is considered uniform on the first row and some panels are shaded in the second row. The resulting I-V characteristics of these configurations and the corresponding P-V curves for the above two cases, in addition to the case with uniform solar distribution on both rows are schematically shown in Figure 3 (a), (b).
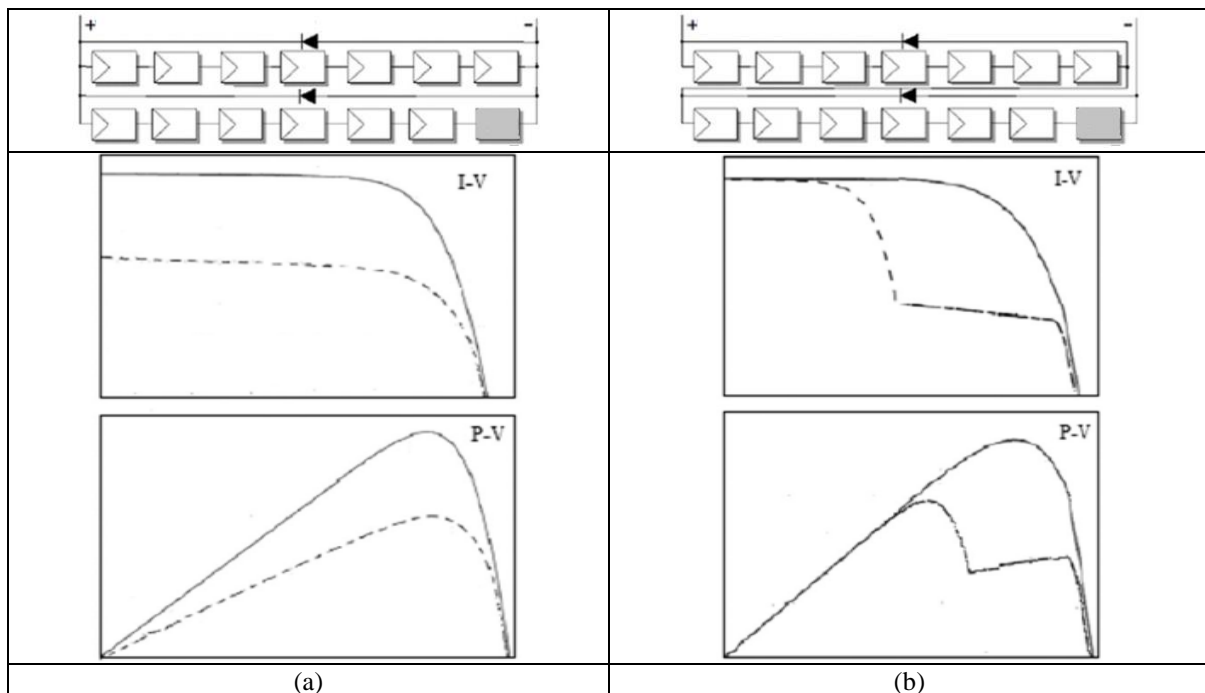

Figure 3: PV array connection scheme and I – V characteristic and P – V of two rows w/o shaded PV panels connected in parallel, and (b) connected in series.

2.3. Operation Losses

Load mismatch

Figure 4 illustrated a typical hourly PV energy generation and the energy consumption by the load [28]. As it depicted in the Figure 4, there are three zones A, B and C. The energy generated by the PV system (A+B) and the energy consumed by the load (C+B). To reduce the load mismatch, the area A must keeping at the minimum level. Even in case of existence of storage system (batteries), it is better to consume energy immediately and in the place of generation without needing to transport or conversion, because this will reduce the overall efficiency of the PV system.
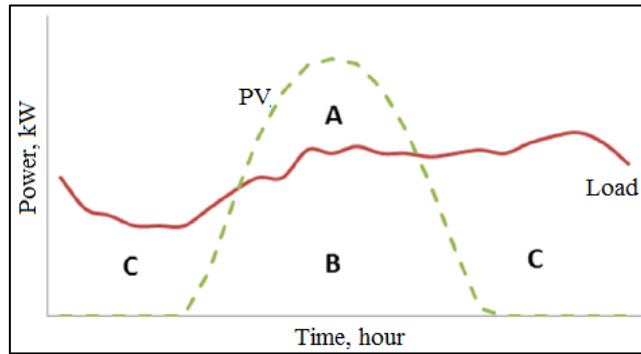

Figure 4: Typical hourly PV generation and load curves

Maximum power point (MPP)

MPPT is an algorithm embedded along with power electronic converter and load. It forces the PV module to operate at MPP in any given solar irradiance [29]. The feature that allows an inverter to remain on the ever-moving maximum power point (MPP) of a PV array is called maximum power point tracking (MPPT). The IV characteristic curve of PV modules includes the short-circuit current value (Isc) at 0 Vdc, the open-circuit voltage (Voc) value at 0 A and a "knee", the point where maximum power point (MPP) is found on the curve, this is the location on the IV curve where the voltage multiplied by the current yields the highest value of power. Figure 5 shows the MPP for a module at full sun at various temperature conditions. As cell temperature increases, voltage decreases and module conversion efficiency suffers. Other than temperature, module performance is also affected by sun irradiance. When sun is full i.e. at irradiance of $1000W/m^2$, module current is highest and when there is less sunlight, module current decreases and so is conversion efficiency. Since sunlight intensity and module or cell temperature vary substantially throughout the day and the year, array MPP (current and voltage) also varies accordingly. The ability of an inverter to accommodate these environmental variations and optimize its performance to meet grid criteria and other regulatory standards (NEC, IEEE and UL etc) at all the time of operation is achieved largely due to effective maximum power point tracking feature [30].
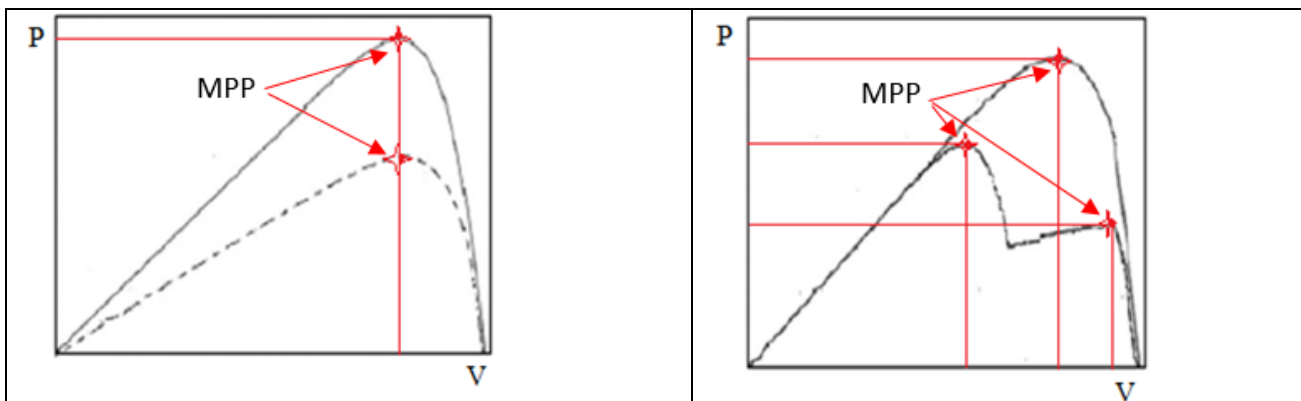

Figure 5: The position of MPP for various PV solar modules behaviours

2.4. Environment Losses

The performance of PV systems is generally affected by the real weather conditions. In the desert climate, dust accumulation is one of the main concerns that may cause a significant deterioration of PV efficiency. The analysis indicates that in a temperature climate, during days with high humidity intervals similar to the ones discussed in the paper, crystalline silicon modules have the lowest efficiency losses, followed by CdTe, CIGS, and CIS modules. The results can be useful for PV system designers, installers, and end-users of PV systems for a better system design and for a more accurate prediction of the daily energy production [31]

2.5. Estimation losses

Engineers and scientists predict the yield of a PV solar field using the methodologies described in many researches and commercial softwares. The input of these softwares are the manufacturing and weather data, including time series historical temperature and solar radiation information. Therefore, the accuracy and reliability of the obtained results – which the decision makers will be considered to make their decisions – very sensitive to the accuracy of these informations and the conveniently of these programs for use in a specific site. Nassar et al. [21] tabulated some wide-use commercial programs and the models used and tabulated in Table 2.

Table 2: Performance evaluation software of solar and transposition model

No	Software	Country	Transposition model
1	HOMER	USA	HDKR (1990)
2	INSEL	Germany	Liu & Jordan (1963), Temps & Coulson (1977), Bugler (1977), Klucher (1978), Hay (1979), Willmott (1982), Skartveit & Olseth (1986), Perez (1990) and HDKR (1990)
3	MATLab (Simulink)	USA	Perez (1990)
4	PVGIS	Slovakia	Muneer (1990)
5	PVSyst	Switzland	Hay (1979) and Perez (1990)
6	PVWatts	USA	Perez (1990)
7	SAM	USA	Liu & Jordan (1963), Hay & Davies (1980), Perez (1988) and HDKR (1990)
8	TRNSYS	USA	HDKR (1990)

Also, miscues in estimation may be accrued during PV panel characteristics correction form STC (Standard Test Conditions) to the real conditions (solar radiation and cell temperature). In fact, there is a lock of information about estimation the temperature of PV cells temperature, where it depends on many factors. The cell temperature is often determined experimentally for specific location [26]. An experiment has been carried out in order to measure the following parameters: output power, surface temperature, solar radiation, ambient temperature and wind speed. An experimental model has been designed and built up in the Solar Energy Laboratory at the Department of Mechanical Engineering, in Brack City (27.6°N, 14.2°E). According to the results of the experiment, the maximum cell's surface temperature reached up to 100°C. The solar radiation was around 896 W/m2. The percent of the failure of the power was found to be 69% of the nominal power at STC [32]. The reduction in the output power was depicted graphically in Figure 6.
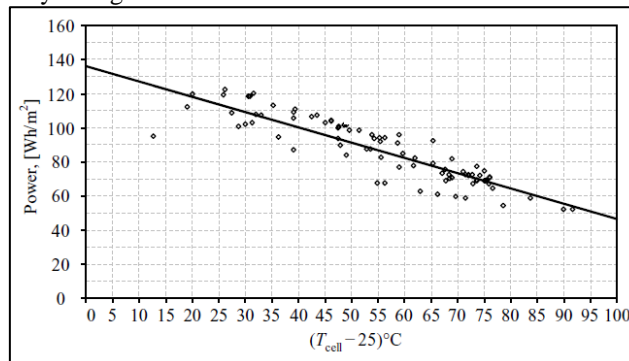

Figure 6: Power behaviour related to the change of the cell's temperature

The best curve fitting is obtained by curve fitting toolbox of Mat Lab software and found as:

$$T_{cell} = T_\infty + 0.078H_t \qquad (2)$$

Where T_{cell} and T_∞ are the surface cell and the ambient temperatures [°C], respectively, and H_t is the global solar radiation incident on the PV panel [W/m²].

The general equation for correction the electrical characteristics is presented in [33]:

$$X_{real} = X_{STC} + \beta_X(T_{cell} - T_{STC}) \qquad (3)$$

Where: X presents any electrical characteristic, it could be (Short-circuit current, open-circuit voltage, power or either efficiency) and β is the temperature coefficient of the character. Table 3 presents the electrical characteristics of a PV solar panel type SX 150.

Table 3: Electrical characteristics of a PV panel type SX 150

No	Item	Value
1	Maximum Power (Pmax)	150W
2	Voltage at Pmax (Vmp)	34.5V
3	Current at Pmax (Imp)	4.35A
4	Short-circuit current (Isc)	4.75A
5	Open-circuit voltage (Voc)	43.5V
6	Temperature coefficient of Isc	(0.065±0.015)%/°C
7	Temperature coefficient of Voc	-(160±20)mV/°C
8	Temperature coefficient of power	-(0.5±0.05%/°C
9	NOCT	47±2°C

Published by :

http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 09, September-2020

For this reason, many researchers suggested cooling down the solar cells by passing a current of air over them [34-37]. Adopting this technique will rise rate electricity production and benefits of thermal energy extracted from the solar cells in this approach rise system efficiency [38].

III.RESULTS AND DISCUSSION

Without any scientific basis, the importers decided to import the polycrystalline PV modules from China and Korea. Table 4 shows a comparison between the energy productivity of these three types under conditions (100 W/m^2, 100ºC) other than STC.

Table 4: Energy production Wp/m^2 comparison under 1000 W/m^2 and 100ºC

solar module type	average energy at STC	Min. energy	Max. energy	Real average energy	Real cost	Temperature Coefficient
Monocrystalline	210	99.72	132.96	116.34	1.5-1.8 $/W	-0.446%ºC
Polycrystalline	160	91.95	104.21	98.08	1,5-1.7 $/W	-0.387%ºC
Thin-Film	130	91.08	124.2	107.64	1.0-1.4 $/W	-0.172%/ºC

It is clear from Table 4 that; the cheapest price of energy production is the Thin-Film solar modules. This is due to the hot climate that Libya belongs to. Consequently, the decision of business-men to import the polycrystalline solar modules is considered an economic mistake and causes great commercial losses to the customers.

Figure 7, shows a comparison between solar radiations incident on a fixed and monthly adjusted tilt angle and the monthly optimum tilt angles.
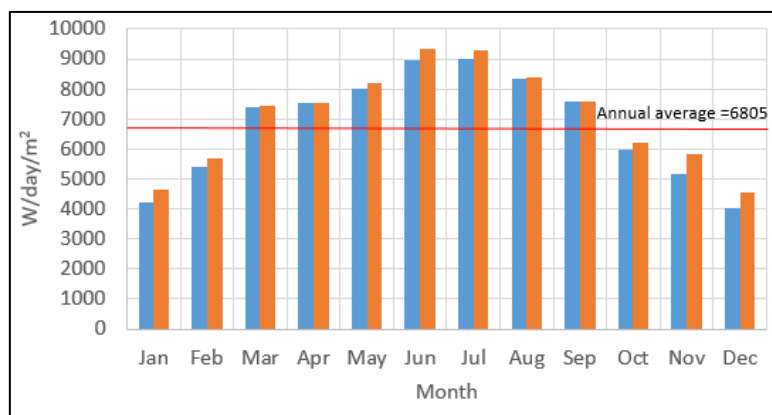

Figure 7: Comparison of several total daily global tilted solar radiation incident on fixed and monthly adjustable surfaces

Figure 8, illustrates hourly shaded area percentage for the 21st day of each month of a solar field locates in Tripoli (32.815º N, 13.439ºE) with rows height of 6m, 20º tilt angle to the south, the space separating the rows is 6m.
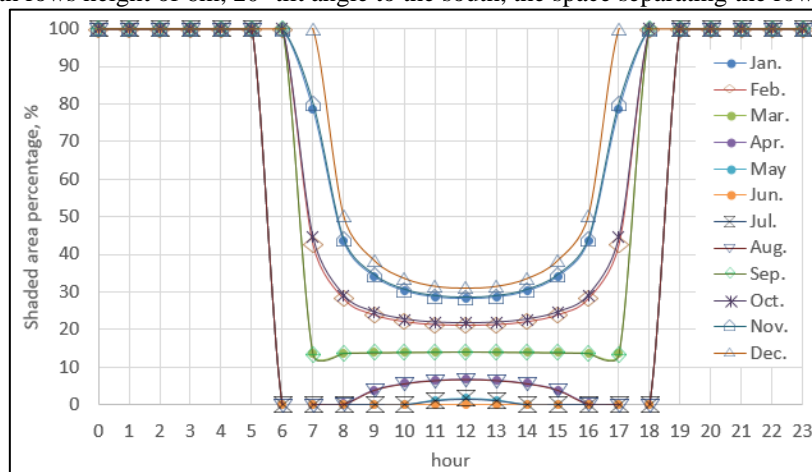

Figure 8: Hourly shaded area percentage for the day 21st for every month of a solar field locates in Tripoli (32.815º N, 13.439ºE) with rows height of 6m, 20º tilt angle to the south, the space separating the rows is 6m.

Figure 9 presented a pie chart illustrated the breakdown the energy losses in PV solar systems which must be taken in account during any study regarding the PV solar evaluation.
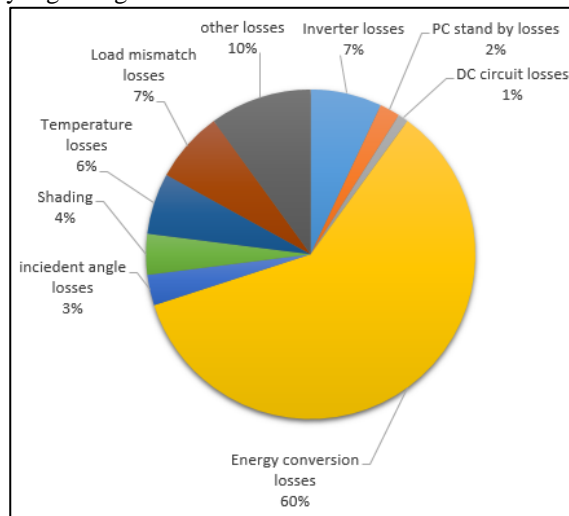

Figure 9: Break down the energy losses in PV solar systems

IV. CONCLUSIONS

The present paper discussed the losses that occurred during the operation of PV soar modules. The results can be useful for PV system designers, installers, and customers of PV systems for a better system design and for a more accurate prediction of the daily energy production. The study showed that, the Thin-Film solar modules are the most suitable for Libyan climate, which is characterized by high temperatures in the summer season, and it is different from the type prevailing in the Libyan market nowadays.

REFERENCES

[1].   Yousif, S., Salem, A., Nassar, Y., Bader, I. (2006). Investigation of pollutants dispersion from power stations, International journal of energy research 30:15, 1352-1362.

[2].   Nassar, Y., Aissa, K., Alsadi, S. (2017). Air Pollution Sources in Libya. Research & Reviews: Journal of Ecology and Environmental Sciences, 5, 63-79.

[3].   Nassar, Y., Aissa, K., Alsadi, S. (2017). Estimation of Environmental Damage Costs from CO_2e Emissions in Libya and the Revenue from Carbon Tax Implementation. Low Carbon Economy, 8, 118-132.

[4].   Nassar, Y., Alsadi, S. (2016). Economical and environmental feasibility of the renewable energy as a sustainable solution for the electricity crisis in the Gaza Strip, International Journal of Engineering Research and Development, Volume 12, Issue 3, PP.35-44.

[5].   Nassar, Y., Alsadi, S. (2019). Assessment of solar energy potential in Gaza Strip-Palestine, Sustainable Energy Technologies and Assessments 31, 318-328.

[6].   Nassar, Y., Amer, K., Irhouma, M., Ahmad, S. (2015). Economical and environmental assessment of electrical generators: A case study of southern region of Libya, International Journal of Energy Policy and Management 1(4): 64-71

[7].   Nassar, Y., Alsadi, S. (2018). Wind energy potential in Gaza Strip-Palestine state, Solar Energy and Sustainable Development, Volume (7), No (2), pp. 41-57, http://www.jsesd.csers.ly/images/pdf/vol-007-02/vol-007-02-04.pdf

[8].   El-Osta, W., Kalifa, Y. (2003). Prospects of wind power plants in Libya: a case study, Renewable Energy 28:3, 363-371. https://doi.org/10.1016/S0960-1481(02)00051-4

[9].   Amer, K., Fakher, M., Ahmad, S., Irhouma, M., Altahbao, S., Salem, E. (2020). Performance of domestic solar heating system with thermal storage using phase change materials. International Journal of Engineering Research and Development, vol. 16(9), 2020, pp 01-11. http://www.ijerd.com/current%20issue.html

[10].   Nassar, Y. Solar energy engineering active applications, Sabha University, Libya, 2006.

[11].   Belal. E., Abdunnabi, M., Rohuma I., Endya, E. (2018). Review on solar water heating in Libya, Journal of Solar Energy and Sustainable Development, 7: 1-28.

[12].   Abdunnabi, M., Idweib, A., Ramadan, A. (2015). Solar energy potential for hot water in the hotel sector in Libya, IREC2015 The Sixth International Renewable Energy Congress-IEEE,

[13].   MJR Abdunnabi, M Al-Ahjal, Ibrahim O Rahoma, (2017). Optimum Sizing of Residential Active Solar Water Heating Systems for Libyan Families, Journal of Solar Energy and Sustainable Development 6:1, 18-26.

[14].   Nassar, Y. (2015). Thermodynamics analysis and optimization procedure for domestic solar water heating system, **AASCIT**, American Journal of Energy and Power Engineering, 2(6), 92-99.   http://ww.aascit.org/journal/ajepe

[15].   https://www.homeadvisor.com/cost/heating -and-cooling/solar-panel-prices/

[16].   Dash, P., Gupta, N. (2015). Effect of temperature on power output from different commercially available photovoltaic modules, Journal of Engineering Research and Applications,5:1

[17].   Alsadi, S., Nassar, N. (2016). General polynomial for optimizing the tilt angle of flat solar energy harvesters based on ASHRAE clear-sky model in mid and high latitudes, Energy and Power, Vol. 6, No. 2, http://www.sapub.org/journal/currentissue.aspx?journalid=1018.

[18].   Alsadi, S., Nassar, Y. (2017). Energy demand based procedure for tilt angle optimization of solar collectors in developing countries, Journal of Fundamentals of Renewable Energy and Applications,7 : 225. DOI: 10.4172/2090-4541.1000225

[19].   Agha K, and Sbeta M. (2000). On the sizing parameters of stand-alone solar energy systems. Applied Energy; 65:73-84.

[20].   Nassar, Y. (2005). Simulation of solar tracking systems, Energy & Life Journal 21, 81-90.

[21].   Nassar, Y., Hafez, A., Alsadi, S. (2020). Multi-factorial comparison for 24 distinct transposition models for inclined surface solar irradiance computation in the state of Palestine: a case study. Front. Energy Res. 7:163. doi: 10.3389/fenrg.2019.00163

[22].   Alsadi, S., Nassar, Y. (2017). Estimation of solar irradiance on solar fields: an analytical approach and experimental results. IEEE 1601–1608.

[23]. Nassar, Y., Hadi, H., Salem, A. (2008). Time Tracking of the Shadow in the Solar Fields, J. Sebha Univ., 7(2), pp. 59–73.

[24]. Hadi, H. (2006). Tracking of shadow path and studying its effect on PV solar fields, M.Sc. thesis. Om-Durman Islamic University, Sudan.

[25]. Alsadi, S., Nassar, Y. (2019). A general expression for the shadow geometry for fixed mode horizontal, step-like structure and inclined solar fields, Solar Energy 181, pp. 53–69

[26]. Hafez, A., Nassar, Y., Hammdan, M., Alsadi, S. (2019). Technical and Economic Feasibility of Utility-Scale Solar Energy Conversion Systems in Saudi Arabia, Iranian Journal of Science and Technology, Transactions of Electrical Engineering, Transactions of Electrical Engineering https://doi.org/10.1007/s40998-019-00233-3

[27]. Nassar, Y., Alsadi, S. (2016). View factors of flat solar collectors array in flat, inclined, and step-like solar fields. J. Solar Energy Eng. ASME Trans. 138, 1–8.

[28]. Senol, M., Abbasoglu, S., Kukrer, O., Babatunde, A. (2016). A guide in installing large-scale PV power plant for self consumption mechanism, Solar Energy 132, 518–537, http://dx.doi.org/10.1016/j.solener.2016.03.035

[29]. Kamarzaman, N., Tan, C. (2014). A comprehensive review of maximum power point tracking algorithms for photovoltaic systems. Renew. Sustain. Energy Rev. 37, 585–598.

[30]. Aribisala, A. (2013). Improving the efficiency of solar photovoltaic power system. Open Access Master's Theses. Paper 161. http://digitalcommons.uri.edu/theses/161

[31]. Burduhos, B., Visa, I., Duta, A., Neagoe, M. (2018). Analysis of the Conversion Efficiency of Five Types of Photovoltaic Modules During High Relative Humidity Time Periods, IEEE journal of photovoltaics.

[32]. Nassar, Y., Salem, A. (2007). The reliability of the photovoltaic utilization in southern cities of Libya, Desalination 209, 86–90. doi:10.1016/j.desal.2007.04.013.

[33]. Nassar, N. Solar energy engineering, Sabha University, Libya, 2006.

[34]. Nassar, Y., Salem, A., Sergievsky, E. (2001). A creation of mathematical model for photovoltaic/thermal (PV/T) solar flat-plate collector, International conference on renewable energy for regional development CIGA, Bogor – Indonesia, 28–31.

[35]. Nassar, Y., Sergievsky, D. (2000). Heat transfer in flat-plate solar air heating collector, Heat Transfer 2000 "the sixth international conference on advanced computational methods in heat transfer", held from 26-28 June 2000 in Madrid, Spain, pp. 575-584. http://www.witpress.com

[36]. Nassar, Y., Sharif, M. (2014). Economic and Energetic analysis for optimizing the length of flat-plate solar air heating collectors, Applied Mechanics and Materials, vols. 446-447, pp 810-816. doi:10.4028/www.scientific.net/AMM.446-447.810

[37]. Salem, A., Nassar, Y., Yousif, S. (2004). The Choice of Solar Energy in the Field of Electrical Generation-Photovoltaic or Solar Thermal - For Arabic Region, World Renewable Energy Congress VIII (WREC 2004).

[38]. Nassar, Y., Alsadi, S., Amer, K., Yousef, A., Fakher, M. (2019). Numerical Analysis and Optimization of Area Contribution of The PV Cells in the PV/T Flat-Plate Solar Air Heating Collector, Solar Energy Research Update 6, 43-50.