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Dust Induced Shading Effects on the Performance of Photovoltaic Modules in Libya

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ABSTRACT

While, solar photovoltaic (PV) for clean electricity generation is promising, ensuring its optimum performance is crucial for sustainability. Accumulation of dust from the outdoor environment on the modules of PV system is natural, but dust becomes a major issue in the performance of PV systems in the Sahara region, like Libya, where the availability of high solar radiation. The considerable increase of installations in desert areas, it makes essential to assess the resistance of modules to sand and weather conditions in various areas of the country. This paper will investigate the effect of dust on PV module performance. The important of this study came due to the transfer of large scale PV technology to the local area characterized by hot and dusty conditions for most seasons that is represents the main barrier to PV utilization. A fundamental understanding of how dust affects PV module performance is presented. However, further investigation on induced shading and losses of electrical PV module performance due to dust accumulation is conducted. A mathematical simulation model to justify the shape of the typical behavior of the electrical characteristics in the presence of shading on the tilted module surface is considered. The simulation results will be applied to develop a dust correction model for long term energy prediction for PV modules that is able to provide better energy prediction and possible variation in the PV module performance over long period of time.

Key words: PV module, Dust Shading, Simulation

INTRODUCTION

The electricity generation around the world is mainly produced by using non-renewable energy sources especially fossil fuel. However, these resources will be gone at some time in the not-too-distant future. Over recent years the demands for clean and sustainable sources of energy have increased dramatically. Solar energy can be collected to produce electricity by a variety of methods. One of these environmentally-friendly methods is solar photovoltaic (PV) systems that can produce electrical energy from solar energy by means of direct energy conversion phenomena. Solar photovoltaic (PV) technology is a promising means of generating clean electricity, ensuring its optimum performance, is crucial for sustainability and the use of this technology is rapidly developing around the world [1].

In most arid zones of the world and in the Sahara region in particular, such as Libya, where high levels of solar radiation are available, photovoltaic solar energy applications are concerned and considerable increase of PV systems installations. However, implementations of PV systems have shown that their reliability and efficiency depend on many factors, the dominant being geographical (latitude, longitude, and solar intensity), environmental parameters and the type of PV used. Active meteorological parameters such as: humidity, sand dust, high temperature, windspeed, and low frequency of rain have significant effect on the PV performance. On the other hand, many other parameters affecting the PV modules efficiency such as: PV module degradation, the shadow and the impact of the tilt angle of the PV modules [2].

Dust is one of the natural elements present in most environments and is considered as the slighter acknowledged factor that significantly influences the performance of the PV installations and plays an important role in the determination of the PV yield. An effecting of dust on PV module surface is produce losses in the generated power and decrease an electrical energy output as it obstructing the solar radiation. The accumulation of dust on the surface of a photovoltaic module obscuring the irradiance falling on the surface of the module and altering the solar spectrum which affects PV modules as they are spectrally dependent devices. Dust not only reduces the radiation on the solar cell, but also changes the dependence on the angle of incidence of such radiation. When dust particles are deposited on PV modules, they interfere with illumination quality by both attenuating and scattering incident light. However, the dust effect can be accounted for when looking at long term energy prediction by minimizing the losses associated with dust accumulation on the surface of the PV modules. On the other hand, the random accumulation of dust on the PV module surface increases the possibility to trigger the hot spot effect for modules that are installed in a string where the operating current of a module exceeds the short circuit current of the affected cell. Hot-spots, with varyingconcentrations(shape, location and dust density) ofdustparticles, can cause permanent damage to the module and the affected cells are forced into reversed bias and thus dissipate power [3, 4].

In the Sahara region, dust accumulation is one of the major reasons for the poor performance of PV systems and it possibly damage the PV module. As well known, most of the Middle East regions including Libya are characterized by high solar irradiance, high temperatures, low frequency of rain and frequently dust storms [5]. These factors play a significant role in PV performance and they are dominant factors for solar energy applications. Unfortunately, no long term ground stations were located in Libya for dust measurement and also no predicted percentage values in PV performance losses can be measured. Therefore, explaining and modeling the effect of dust on PV modules can provide a valuable tool to quantify and minimize the impact of this problem. By doing so, the dust effect can be accounted for when looking at long term energy prediction by minimizing the losses associated with dust accumulation on the surface of the PV module. Also, knowing that dust can affect the performance and possibly damage the PV module, a way to prevent this can be investigated and different approaches can be sought to reduce the energy losses caused by the dust effect. Furthermore, knowing how dust selectively attenuates the solar spectrum can provide a better approach for technology selection under specific dusty environments.

The variation of dust density on PV module performance has been investigated by several groups for different location, tilted PV module and module technology and design. Some approaches to analyze and quantify the effect of dust on photovoltaic modules have been introduced. In addition, several experimental studies have been carried out to investigate the relationship between dust deposition density glass transmittance and PV module performance. It is found that the power output performance could be significantly reduced over the whole year [6, 7]. However, it becomes important to set up a further investigation to look into minimizing the losses of PV systems due to dust accumulation. Furthermore, explaining and modelling the effect of dust on PV modules that can provide a valuable tool to quantify and minimize the impact of dust accumulation problem are not clearly quantified in Libya.

DUST-INDUCED SHADING on PHOTOVOLTAIC MODULES

The main issue with dust is the attenuation of the incident solar spectrum and reduction in transmittance due to dust accumulation. The accumulation of dust on a horizontal surface plane is determined by uniform distribution of the number of particles occupying surface area. The variation in dust accumulation can lead to different transmittance of light into the module, thus leading to small random areas on the PV module with reduced solar radiation, asillustratedinfigure 1.

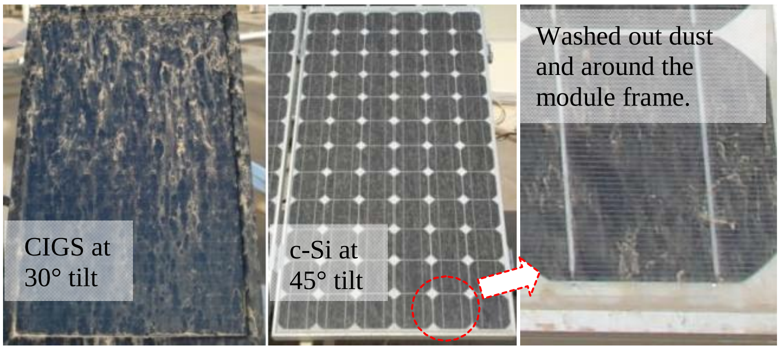

Fig. 1 Accumulated dust on different PV modules on inclined configuration

These effects can produce inhomogeneous partial shading on the surface of the cell. The effects of partial and whole shading are very interesting as the ratio of shade covering a cell determines whether the cell is operating in a current or voltage mode. As a cell becomes Partially Shaded, the un-shaded portion remains operational with virtually no change to voltage and it continues generating albeit at a reduced current. As the partial shade increases there is a threshold point at which the cell transitions to whole shading and the cell voltage collapses. The reverse characteristics of the selected shaded cell can be voltage limited where it has a high shunt, or current limited where it has a low shunt. The high shunt resistance cell will limit the reverse current flow into the cell, which will lead to the cell uniformly, and slowly heat it up until it reaches a point where it can cause damage to the cell. A low shunt resistance cell allows a large amount of reverse current to flow in a small area, causing localized, non-uniform heating. Thus under an objective shading condition, even though the output current may be extremely low or even zero, it doesn't mean the system is dormant, while the PV array may still generate high voltage [8].

Shading is further divided into either Static Shading or Dynamic Shading. Static Shading refers to shade caused by close proximity obstructions that have typically adhered to the glass, such as bird droppings, leaves or accumulated dirt on a

module's bottom edge. This type of shade is dependent on the initial random positioning of the shade barrier only and does not change during the course of the solar day. Static Shading is fixed and unaffected by the angle of the sun. Dynamic Shading is typically caused by buildings, trees, narrow spaced array tilt frames and other such objects that create a shadow based on sun angle. Dynamic Shading is subject to the angle of the sun and therefore changes dynamically during the course of the solar day. There is simply too much ambiguity when trying to use the term partial shade in reference to a solar module, string or PV array. To maintain consistent language, whole shading and Partial shading should only refer to cell shading ratio. whole shading and partial shading references the threshold point below which there is insufficient irradiance to generate cell voltage (whole shading) and above which there is sufficient irradiance to generate cell current (partial shading). Whole or partial shading of a cell will lead to different effects on module voltage or current or both. When connected cells are partially shadowed or have lower power rating due to manufacturing defects, for example, at series connection, Kirchhoff's voltage law requires all series connected cells to generate the same current for the cell voltages to be added. When one cell generates less or no current due to manufacturing defect or shading (weak cell) the other connected cells will start to dump current into the shaded cell. This leads to power dissipation in the weaker cell equal to the module current multiplied by the reverse voltage developed across the weaker cell. This can lead to a drop in the PV module power, but a more dangerous situation develops when the reverse voltage across the weaker cell is equal to the voltage generated across the remaining other cells (module operating at short circuit).
The effect of shading on PV system depends upon the following factors:

- number of shaded modules;
- cell and bypass diode interconnection;
- degree of shading;
- spatial distribution and the course of shading over time;
- Interconnection of the modules.

However, with the series modules connection, both power maxima for the shaded characteristic curve are clearly pronounced; when fewer modules are shaded, the voltages are within the tracking range of the inverter. For this reason, both operating points must be taken into account in the following comparison. With parallel connection, the power loss only depends upon the number of shaded strings. With shading in two strings, despite the increase from two shaded modules to eight, power loss remains almost constant.It would only be possible to track to the left maximum if there is severe shading in many strings. In this case, there would be a somewhat lower power loss than in the right maximum. For comparison purposes, both designs were implemented on the same PV system by switching between the two [9].
In order to fully understand Subjective Shading effects, it is necessary to introduce the module's built in protection device, the "Bypass Diode". Ideally the highest tolerance to shading can be achieved if a bypass diode is connected across every cell in the module, but due to manufacturing reasons it is connected only to a group of cells. Therefore the number of bypass diodes is dependent on the number of cells in the module where for example a c-Si module consists of 72 cells will have 3 bypass diodes. The bypass diodes are not limited only to PV cells as they are used for modules connected in arrays, as they fall under the same principle of mismatch when they are connected together. However, it is common to find bypass diodes connected across PV modules terminals to allow protection of the whole PV array when connected together in addition to PV cells bypass diode for module protection. In general, by using bypass diodes in PV crystalline silicon technology modules, the current in the module is allowed to flow through the bypass shaded cells which will sacrifice the PV module power but protect the module from permanent damage. The system speaks in terms of Active Bypass Diodes. For example a shaded module that has one active bypass diode is referred to as 1BP, two active bypass diodes is described as 2BP, and three as 3BP[10]. To scale the shade classification up to a string of modules, the number of bypass diodes in the string is tallied and becomes a dividend in the description.

SIMULATION OF DUST INDUCED SHADING EFFECT ON PV MODULES

As mentioned before, the variation in dust accumulation on PV module can lead to small random areas on the PV module with partial shading from incident solar radiation. The shading loss evaluations become more and more important. In order to assess the shading resulting from the location, a shading analysis is performed. For this, the shadow outline of the surroundings is recorded for one point in the system: usually the center point of the PV module.

Shading Analysis Using 3D Near Shadings Construction

The outcome of the shading analysis is the silhouette of shading caused by the surroundings in the sun path diagram. Several shade analysis tools that use software are available. These enable accurate shade analysis and are less prone to error than manual methods. The PVsyst electronic simulation programme was used to determine the PV array characteristic *I-V* curves and the expected power losses with different shading situations. The electrical operation behavior of the PV modules and PV system modeled, including shading analysis, is based on the model presented in PVsyst design and simulation program. The softwareenable a three-dimensional shading analysis that also takes inhomogeneous shadow outlines into account. On the other hand, the PVsyst deals with pumping, stand alone and grid-connected PV systems, and includes extensive meteo and PV systems components, databases, as well as general solar energy tools. This software is geared to the needs of architects, engineers, researchers and it is also very helpful for educational training [11].

The design of a photovoltaic system is considered as a starting point for investigating the shading analysis for PV modules. In general, the design of a photovoltaic system is addressed to the best matching conditions between the energy supplied to the system by the sun and the energy required at the load to be fed by the system. For designers and planners of PV systems, it is of course important to have an idea about which parameters are critical for system performance and safety, and which may be relaxed on without significant consequences. Number of important parameters can be identified as the most important for a successful PV system design such as: location, inclination, orientation, environmental conditions, nominal power, system voltage, the electrical characteristics and specifications of the PV system components.

The system design and simulation sequence starts by inserting the site's name, region and location and it automatically displays the Monthly meteorological window and all the data will be saved in the software database. PV system components can be chosen by clicking the system buttons, such as PV module, DC-AC Inverter etc., which are used in the system design and analysis. From a number of sites presented for evaluation, Surman site (N27°13'08", E14°41'22") is one of suitable sites for solar power project. One of the main reasons for selecting this site is that the solar radiation is suitable for investigation and that this site is easily accessible by road transport, ease of site access and proximity to the distributed sub-station and transmission network and has sufficient large area suitable for large-scale solar power development. Using designing program PVsyst V5.4 for 15 KW PV power plant located at Surman, PV system components can be chosen by clicking the system buttons, such as PV module, DC-AC Inverter etc., which are used in the system design and analysis. Then the specifications of these components will be appeared in figure 2.

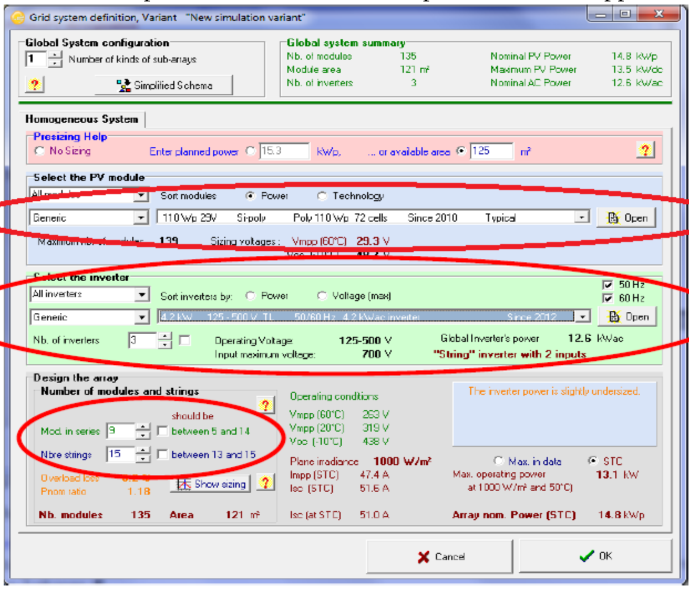

Fig. 2 Show Program PVSyst for design PV power system

The simulation results, such as nominal system power, system production, daily input/output diagram etc., can be obtained in report form.

Shading losses effects are not intuitive. They have to be quantified using simulation software working in hourly or sub-hourly steps, along the whole year. We distinguish two kinds of shadings on a PV plane: the “far shadings”, which are supposed to act globally on the PV plane; and the “near shadings”, which produce partial shades on the PV installation. In our case, we treated with the near shading situation. The construction of the near shadings are a part of PVsyst that requires some time and exercise to be fully mastered and take advantage of all available options and features. The procedure for the 3D near shadings construction analysis can also allow the construction of the iso-shadings graph, which gives a synthetic view of the times of the day and seasons where the shadings are particularly problematic. The final loss diagram on the report, there will be a specific loss for the "Near shadings". This loss reflects the fact that a fraction of the sensitive area will be shaded at certain times of the day and year [11].

RESULTS and DISCUSSION

System Performance Simulation and Yield Assessment

PV system performance is evaluated by means of the total energy output (energy yield) measured in a given time period. It is also widely used as a comparison parameter between different technologies, installation methods, orientations, balance of systems, etc. Energy yield is also considered to be an economic indicator that defines how much the PV modules have produced over a period of time. The performance of the grid connected small scale PV system at Surman city has been estimated and the PV power plant indicators such as the energy yield, yield factor (YF), capacity factor (CF) and performance ratio (PR) has been computed. Energy yield and yield factor are the most important parameters for PV system analysis for grid connected PV plants. The energy yield is defined as the annual, monthly or daily net AC energy output of the PV array, while the yield factor (YF) is defined as the annual energy yield output of the PV array divided by the peak power of the installed PV system [12]. In this work, the energy yield analysis was carried out using **polycrystalline** silicon technology at two conditions with and without partial shading categories. Performance ratio can be considered as one of the most important performance indices to analyze and visualize the performance characteristics of grid-connected PV system as a function of time. This dimensionless parameter is characterizing the ratio between the final yield [in kWh/kWp] and the average incoming global irradiation [in kWh/m²] incident on the plane of the array surface under Standard Test Conditions (STC). The Performance Ratio (PR) is a good indicator of overall plant quality and operating conditions and represents the overall effect of losses in the system output due to the array temperature and thus by the ambient temperature of the system's site, incomplete utilization of the irradiation, and system component inefficiencies or failures (cabling, MPP deviation, inverter, transformer) [12].

The first year monthly system output for the selected site plant as obtained from the PVsyst output report at no shading and with linear shading PV modules is depicted in Figures 3 and 4. As can be seen, there is a significant difference in the PV electricity production through the whole year since the energy production at winter season is less than the other seasons which is expected due to a low level of solar irradiance. On the other hand, regarding to the performance ratio, it can be seen that the PV system is a temperature dependent factor that it changes with ambient temperature. For no shading condition, the PR is much depends on the ambient temperature than with linear shading condition. This may attributed to the cooling of the PV modules in the presence of shading.

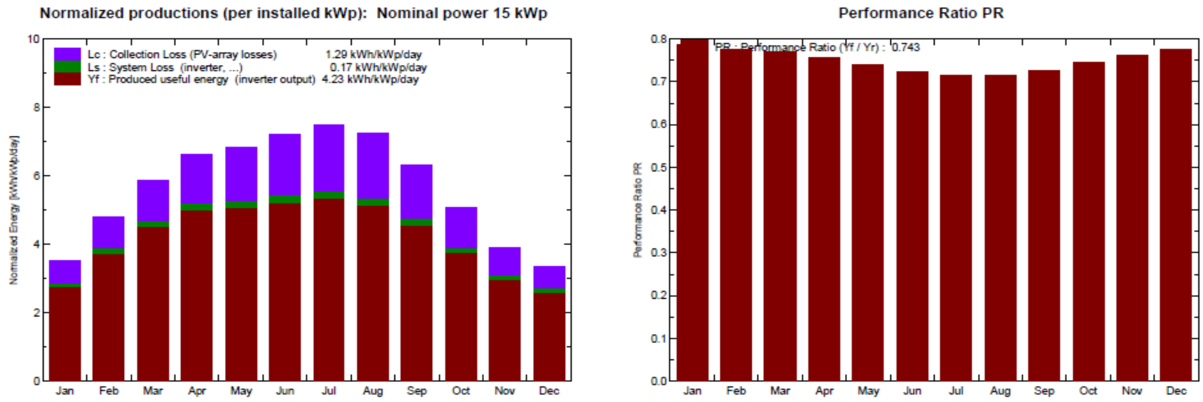

Fig. 3 Monthly output of the PV system and the performance ratio of the plant at no shading PV modules

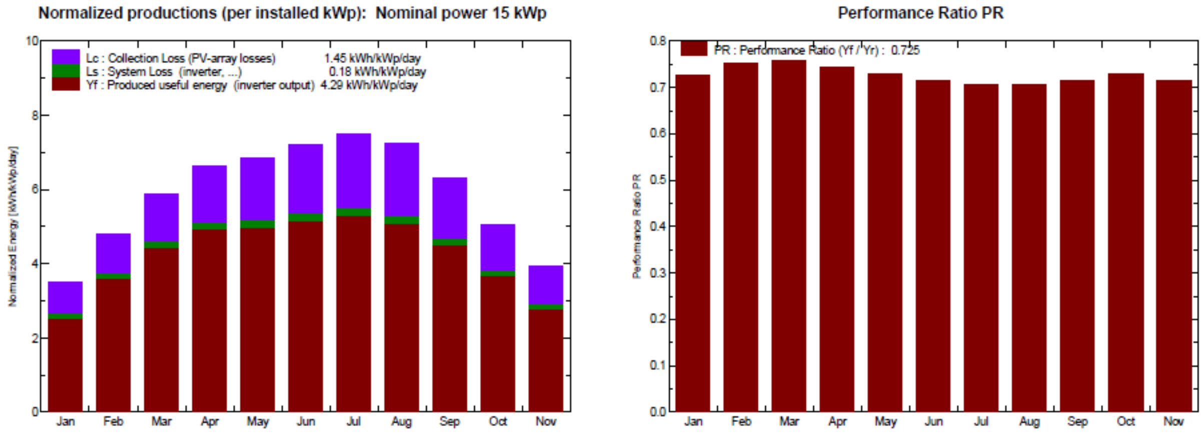

Fig. 4 Monthly output of the PV system and the performance ratio of the plant with linear shading PV modules

Since PV system performance is strongly dependent on loss factors, therefore, there is a necessity for investigating these loss factors to disseminate high quality and reliable PV system. PV system is characterized by the losses due to panel degradation, temperature, soiling, shading, internal network, inverter, transformer and system availability and grid connection network. Shading losses can cause two effects: an irradiation loss and system loss. In the latter case the energy loss is considered as a mismatch loss, because the modules receive non-uniform irradiance. The single most important factor is PV loss due to irradiance level. It is typical for many PV modules that their efficiency decreases with decreasing irradiance. Mismatch losses are attributed to inhomogeneous irradiance at the array plane, because of shading resulting from surrounding objects, or because of differences in the orientation of parts of the array.

To give good indication on the effect of linear shading on the performance of PV module and hence the PV system, a comparison between the simulation results of PV system at no-shading and under shading conditions has been performed. In addition, the effect of shading on the power loss has been also conducted. The performance characteristics and the simulation parameters of the PV systems according to the optimal installation angle with and without shading are summarized in comparison Table 1:

Table -1 Main PV system design and performance characteristic results with and without shading for Surman place

Site: Surman		**Without shading**	**With shading**
Output			
Peak power	[kWp]	15	15
Average Horizontal Global Irradiation	[kWh/m²]	1943.2	1869.4
Average Global incident in collector plane		2078.5	1974.3
First Year Performance at transformer output			
Energy Yield	[MWh/year]	22.94	21.26
Overall YF	[kWh/kWp]	1545	1432
Overall PR	[%]	74.3	72.5

It is clear from the table that the results for PV system performance at no shading is higher than with shading causing reduction in power extract from the PV modules, and a significant variation in the PV electricity production. As can be seen, the PV modules can give higher annual energy yield and yield factor under no shading condition, which can be attributed in our case, as one effect, to the accumulation dust on the PV modules (Linear shading). However, the high values of energy yield under both conditions in all year seasons demonstrate how well the conditions of irradiation in the site.

When it comes to systems losses, it is clear that system continues to have loss. In this direction, we try to demonstrate how linear shading or dust accumulation can significantly affect the PV module characteristics. The overall losses diagram for both categories is shown in figures 5 and 6 while the Table 2 summarizes the compared results.

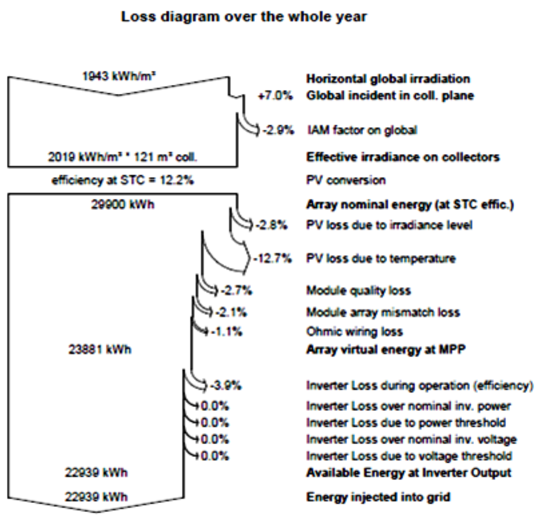

Fig. 5 Loss diagram for non-shadings PV system

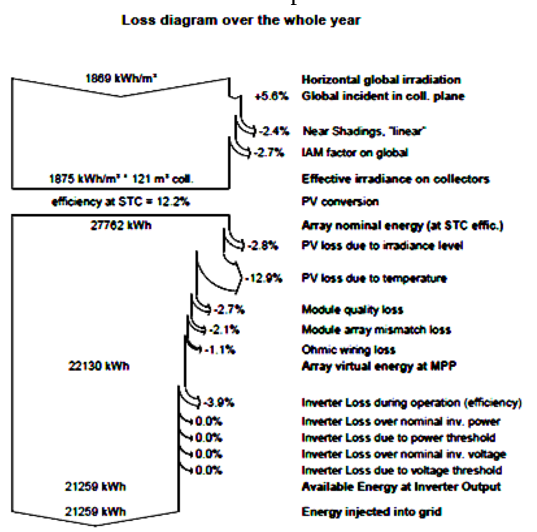

Fig. 6 Loss diagram for linear shadings PV system

Table -2 System losses over the whole year for shaded and non-shaded PV systems

Item	**No shading**	**With shading**
Effective irradiance on collectors	2019 kWh/m^2	1875 kWh/m^2
Global incident radiation on coll. plan	+7.0 %	+5.6 %
Incidence Angle Modifier (IAM)	-2.9 %	-2.7 %
Array nominal energy (at STC effic.)	29900 kWh	27762 kWh
Near shading "Linear"	0	-2.4 %
PV loss due to irradiance level	-2.8 %	-2.8 %
PV loss due to temperature	-12.7 %	-12.9 %
Module array mismatch loss	-2.1 %	-2.1%
Ohmic wiring loss	-1.1 %	-1.1%
Module quality loss	-2.7 %	-2.7 %
Array virtual energy at MPP	23881 kWh	22130 kWh
Inverter loss during operation (efficiency)	-3.9 %	-3.9 %
Energy injected to the grid	22939 kWh	21259 kWh

As can be seen, as expected, the non-shading PV system has lower power loss due to irradiance level and temperature which are mainly as a result of shading phenomena. The reduced transmission of irradiance is due to the contaminated surface of PV modules (shading loss), while DC-cable losses are defined as the ohmic losses in the wiring, on the assumption that parts of the PV array are uncoupled and that maximum power-point tracking is ideal. The overall loss in the PV system performance due to partial shading is about 18 %, while for the non-shading one is about 15.6 %. The effect of shading on irradiance incident on PV module is to decrease solar radiation of 3.8 %, and also effect to decrease electrical energy output from 23881 kWh to 22130 kWh. On the other hand, the temperature effect covers both the energy gain and the energy loss due to module temperatures being lower than or exceeding the STC temperature of 25^{o}C. This indicates that rather high temperature losses can be Dust loss and DC-cable losses are other factors that may affect the energy loss. The results can be used to find the mathematical relationship between the accumulative dust on photovoltaic module and electrical energy output of PV module and also used to predict the energy output and benefit of PV power plant.

CONCLUSION

The worldwide promotion and development of renewable energies has recently become an important priority. In Libya, where high levels of solar radiation are available, the PV systems offer an attractive platform for the future to achieve long-term energy independence, while reducing environmental impact and sustaining a strong economy and society for future generations. On the other hand, other environmental conditions such as: humidity, sand dust, high temperature, wind speed, and low frequency of rain have significant effect on the PV performance. In this work, the effect of dust accumulation on the PV modules performance, as one of the important parameters in Sahara region which should be considered, is investigated and an approach used involves modeling and simulation of dust induced shading and its effect on the performance of photovoltaic modules using a powerful PV system designing program. In this direction, grid-connected photovoltaic power plant in Surman site, as a case study, with total capacity of about 15 kWp is suggested. However, a comprehensive study including the plant design and its performance analysis and behavior is performed to observe the overall effect of climatic conditions on their operation characteristics for monitoring period. The first year analysis performance at transformer output at shaded and non-shaded PV module is investigated and the final yield, performance ratio are calculated and compared. Quantifying and analyzing the losses caused by the dust induced shading for PV modules is conducted.It is found that the losses in the power output performance could be significantly reduced over the whole year. The incident irradiance losses caused by shading are the main cause of performance ratio reduction, where significant part of the solar irradiance does not reach the PV modules surface.As a conclusion, the results from this work will help in demonstrating the benefits and challenges associated with facilitate increasing the penetration levels of PV systems in the electric network in Libya.

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