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Design and Investigation of 10 MW On-Grid PV System Under Duhok Climate Conditions

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ABSTRACT

Solar energy is one of the most important and versatile renewable energy sources available. The importance of photovoltaic systems has increased in recent years in the majority of the world, as it is a clean, reliable, and sustainable energy source. This paper presents the designing of 10MW On-grid solar plant under Duhok weather conditions (annual solar radiation & temperature). The design of the plant consists of ten units of 1MW each, (connected in parallel) to a 33 KV, 50 Hz distribution feeder through a 2MVA step-up transformer each unit. The study contains investigation of finding the optimal solar panel tilt angle, estimation of solar irradiance in Duhok city as case study, and evaluation of an important system parameters (all types of losses, system performance, energy yield, system efficiency and environmental effect), with aid of Matlab program. It was concluded from the results obtained from the programs, that Duhok city has a good location to establish a large-scales of solar photovoltaic plants.

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1. Introduction

Nowadays, a new renewable energy had been introduced and used commonly in the systems of distribution generation. This energy is known as the Solar Photovoltaic (SPV) energy. The flourishment of the SPVs technologies and their applications in the systems of grid-connections proved their efficiency in producing a multipurpose electricity with the property of being environmentally safe (Myneni, et al., 2019). During the recent decades, the electrical power demands have been increased continuously due to several reasons like population growth. Furthermore, the electric power plants use fossil fuels which is capable of being depleted and can be polluting the environment (Ali, et al., 2019).
As a result, the technologies in this field have advanced and diversified, and this is evident through the latest methods and software releases that are involved in building and designing these projects.

The province of Duhok has witnessed an increase in demand for electrical energy due to rapid population growth in recent twenty years ago due to the migration of displaced people and the lack of sufficiency of traditional stations in producing and compensating the energy shortages. Hence the idea came to present a study regarding the city of Dohuk as case study and the possibility of establishing solar energy stations there according to its geographical location and weather conditions and the extent of the success of such a project under these conditions. From the results obtained from this study, it can be determined whether the city of Dohuk is a good environment for such a project or not, as this depends on its location and climatic conditions like rates of solar radiation and temperature variations. So, the precise aim of this study is to identify whether the 10 MW project's design is successful in Duhok or not, which is the focus of the problem of this study.

Therefore, the contribution of this paper (which is the proposed solution) is, designing a large-scale solar plant with specifications that suit the conditions of the city of Dohuk, then investigating this project and studying the extent of its success by evaluating efficiency and performance by using some traditional and common parameters and standards that are specific to this specialty.

2. Literature Review

There are many and different methods for designing large scale grid-connected solar PV systems, depending on the conditions of the region, the type of software used, the amount of energy needed to be generated, and types of devices and components used. This section presents the work reported in the literature on various types of them.

(Alnoosani, et al. 2019) presented the grid-connected design of a solar PV system of 100 MW in university of Um Al-Qura in Kingdom of Saudi Arabia. They also offered a special analysis for the economic and performance of the PV system. The design was achieved by using PVSYST Simulink program to find the optimum system size, generation capacity and the other specifications of the system.

This study was accomplished in a Ghanaian university, and it is proposed to add some improvements to the standard procedure that is depended in designing the grid-connected solar PV power plants by the use of RETScreen software in order to design 1 MW at KNUST. This idea has been put in application in the building's roofs and parking garage, (Kumi & Hammond, 2013).

(Myathari, et al., 2020) presented a design similar to the PV system, it was connected to a grid of 9 MW for providing an Indian village which was set at a geographical location of (17.25_N, 77.55_E). This required a complete generating unit combined with the SAM software package (Process Advisor Model). These runs results were contributed to the 9 MW PV process's final parameters.

The research purpose of (Hindocha & Shah, 2020) was aiming to develop a convectional procedure for designing a large-scale of (50MW) solar PV systems on a grid mode by using the software of PVSYST as well as the AutoCAD program. It is noteworthy that the output of the system was also imitated using the same software with a design of plant layout. In addition, a substation was accomplished by using the AutoCAD to transmit it to 132Kv Busbar. All of the standard measures were used.

This article represents a (10 MW) solar photovoltaic plant performance analysis, which was installed in Eastern Uganda, specifically in the City of Soroti. The data related to the energy production of this solar power plant were collected through the period of over three years between (January 2017 - December 2019), it was followed by an analysis depended on an IEC standard 61724-1. The results showed that the project's performance ratio was about (75.84%), (Oloya, et al. 2021).

(Kumar, et al., 2022) In this research under Louisiana climate, a comparison along with a performance analysis of three PV technologies were executed. In 2018, the University of Louisiana at Lafayette created a (1.1 MW) solar PV power plant in order to investigate the solar power in south of Louisiana as well as providing the university with a partial energy demand. The different technologies evaluation was depending on the ratio of performance, final yield, and on the factor of capacity for one year starting from (September 2019 to August 2020). The levelized cost of energy was used to accomplish the economic analysis for the three PV technologies.

The following research (Palm, et al., 2023) is concerned about the study of the performance's in-depth analysis of the largest Grid-Connected Solar Photovoltaic System, it was performed in Burkina Faso during two years (2019 - 2021). The paper used the measured data and simulated the plant's performance by utilizing the database of PVGIS. The final results recorded that the ratio of the system's performance was ranging between (80.73% in 2019 - 79.36% in 2021).

(Kumar & Sudhakar, 2015) This study involved two aspects related to the solar PV plant which are the design and the annual performance in which the calculations of the numerous power losses types such as internal network, temperature, power electronics and the grid connection in addition to the ratio of performance were performed. The plant presented results were also compared with the simulation values gained from both the PV syst and PV-GIS software. The plant final yield (YF) was ranged from (1.96) to (5.07) h/d, and the annual performance ratio (PR) record was 86.12%.

Connecting a PV system to the grid has an impact which are being studied by this article, (Sreedevi, et al., 2016). It depended on the simulation of the system by using the (RSCSD) software in the real time on the Real Time Digital Simulator (RTDS). The grid connected PV system's Performance Ratio (PR) was evaluated for the determination of the PV system accuracy and grid connectivity.

This paper was presented by (Bano & Rao, 2016). It was concerned about the grid connected SPV power plant of L&T construction. The capacity of the power plant was about (1 MW) and it has been in operation since March 2012. The authors have had evaluated the performance in this study and calculated the performance parameter (PR) depending on three different methods: the PVSYST, Excel sheet and the System Advisory Model (SAM).

The aim of this paper is to investigate the features of 22 PV plants in Italy and evaluate their geographical and installation typology effects on the computed PR. The study used three different PR standards formulas which are applied and compared on two different cases. In addition, the test plant performance was located at Politecnico di Milano for three years (2017 - 2020). The standard PR was raised from 70 % to 88 %, (Ogliari, et al., 2023).

In this paper (Ramoliya, 2015), an evaluation of the performance and suggestion of the simulation of a grid-connected solar PV system using the computer software package PVSYST was performed. The study involved the calculation of the performance ratio and the types of power losses. The results revealed the discussion about the possibility of installing (1 MW) solar PV power plant at geographical location shapur, Gujarat.

The aim of presented article (Khan, et al., 2021), is the comparative analysis performance of (1MW) grid-connected PV power plant for the industry of silver star at Sialkot depending on the technology of fixed and seasonal tilt angles. The daily record of the solar radiation average at the plant site is (4.55 kWh/m2). While, the annual temperature average is (25.18℃). The certain PV power plant measured results were compared with those attained by simulations application at the fixed and the seasonal tilt angles by the use of PVsyst software.

This study proposed a simulated Photovoltaic System with grid-connection of (10MWp), including its performance analysis and assessment under the Mediterranean climate of Alexandria, Egypt using the simulation tool of PVsyst. The designed of Photovoltaic plant was made specifically to accomplish the highest possible performance. The system’s performance ratio recorded (84%) with the use of polycrystalline module type, while a ratio lesser than that by (1%) has been reached when using the monocrystalline ones, (Ibrahim, et al., 2022).

This research suggested an early database performance analysis for the PV system. The time series of the performance were collected within the European funded COST Action PEARL PV. The study included consistent monitoring of the database of over 8400 PV systems with associated metadata. It is noteworthy, that the PV plants representing small residential systems which are installed mainly in Europe, and the higher density is based in Belgium. This study determined and evaluated the annual ratio of the average performance, the energy yield, and the loss rate of the systems performance, (Lindig, et al., 2021).

The main objective of this research (Elshafei, et al., 2021) was offering a development for the standard procedure in order to design a floating PV energy system at the location of the Lake Nasser’s surface for the purpose of producing a solar energy. The simulation performance of the connected solar PV system was performed with the design of large-scale system using the application of PVSYST software. The same software was used for the technical performances.

It is possible to summarize the results of the literature mentioned and make a comparison to one of the most important parameters that evaluate the efficiency and performance of the system. Performance ratio (PR %) finds the extent of the project’s success, it is one of important criteria to evaluate the achievement of Large Scale Solar Photovoltaic Power Plant. Table (1) shows that.

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Table (1): Comparison of some values of performance ratio.

No.	Author Name	Published Year	Software or Method used for designing	PR %
1	Alnoosani	2019	PVSYST	78
2	Kumi	2013	RETScreen	73.4
3	Myathari	2020	SAM	75
4	Hindocha	2020	PVSYST	80.7
5	Oloya	2021	IEC standard 61724-1	75.84
6	Kumar	2022	SAM&PVSYST	79
7	Palm	2023	PVGIS-SARAH2	80.73
8	Sudhakar	2015	PVSYST	86.12
9	Sreedevi	2016	RSCAD	71.2
10	Bano & Rao	2016	SAM&PVSYST	78.8
11	Ogliari	2023	MATLAB	88
12	Ramoliya	2015	PVSYST	76.4
13	Khan	2021	PVSYST	76.5
14	Ibrahim	2022	PVSYST	84
15	Lindig	2021	COST Action PEARL PV	76.7
16	Elshafei	2021	PVSYST	72.4

3.Methodology

Design of this project depends primarily on the location and the details of its conditions, the size and capacity of the station required to be built, as well as the types and number of devices and components used. But the problem is how to select the best design fits with the location of installation and other conditions resulting to acceptable outputs. The research method was summarized in the following steps:

1- Collecting data related to the climatic conditions of the city from the meteorological directorate of Duhok.

2- Collecting data related to the national electricity network from Dohuk Electricity Directorate to determine the extent of the possibility of connecting solar stations.

3- Correspondence with international companies to learn about the latest types of devices and equipment and find out which ones are most suitable for the proposed design.

4- Finding the best tilt angle for solar panels with the help of MATLAB software.

5- Finding solar radiation rates with the help of MATLAB software.
6- Designing the station by selecting the equipment and devices that suit the situation, based on the basic and traditional mathematical equations in this field and also on the ideas and experience of previous research that dealt with this topic.
7- Calculating the various losses for the proposed station because they are included in other subsequent calculations with the help of the MATLAB software.
8- Evaluating the efficiency and performance of the system, the amount of energy produced, and the environmental impact of this station (annually and over 25 years of the project’s life) using a program in MATLAB that author designed for this purpose.

4. Calculations of Solar Radiation

Solar radiation is defined as energy emitted quantity of the sun divided by per unit area of the surface. Simply the two steps are followed:

4.1 Finding the optimal tilt angle

The calculation of the optimal tilt angle can be achieved by two parameters, geographical latitude of the location (L) (table 2) and the solar declination angle (δ), which is given by the equation (Duffie & Beckman, 2013):

$$\delta = 23.45 \sin [(360/365)(N+284)] \qquad (1)$$

where; N is the sequence of the day in the year.

The optimal tilt angle is (Zank, et al., 2016):

$$\beta_{optimal} = L - \delta \qquad (2)$$

4.2 Finding the Solar Radiation

The solar radiation meteorological stations' readings related to the horizontal plane surface placed at level of the Earth, therefore to increase the value of radiation and reduce reflection losses, the solar modules should be installed at angle called tilt or slope angle. Therefore, designers need to know the data of solar radiation that falls

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on titled surfaces. The radiation's fall illustrated in figure (1) shows for the two cases, on the horizontal and tilted surfaces.

Figure (1): The incident solar radiation on two surfaces, tilted and horizontal.

The geometric factor R_b, expresses the proportion of the incident radiation on the tilted surface divided on that of the horizontal ones, which is calculated in the following formulas:

$$R_b = \frac{G_{Bt}}{G_B} = \frac{G_{Bn}\ \cos}{G_{Bn}\cos\Phi} = \frac{\cos\theta}{\cos\Phi} \qquad \text{………………….. (3)}$$

$$G_{Bt} = R_b \times G_B \qquad \text{……………………. (4)}$$

Where; G_{Bt}: incident radiation on a tilted surface, G_B is hourly global solar radiation intensity in clear undimmed sky on a horizontal plane surface, neglecting the components of reflection, G_B (W/m2) is presented as:

$$G_B = R_a\ 0.7^{m^{0.678}} \qquad \text{…………………………….. (5)}$$

m represents air mass which the ratio of the atmosphere's mass from which the radiation beam passes through to reach the mass would pass through if the sun was at its zenith position that's to say directly overhead, it is showed as:

$$m = [1229 + (614\cos\Phi)^2]^{0.5} - 614\cos\Phi \qquad \text{……………… (6)}$$

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Where; $\boldsymbol{\Phi}$: is the angle of incident on a horizontal surface (zenith angle), which represents the angle formed between the beam and the normal on the horizon, and R_a is the extraterrestrial irradiance on a horizontal surface, obtained from:

$$R_a = R_{SC}[1 + 0.033 \cos\frac{2\pi N}{365}] \cos\Phi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where; R_{SC} is the solar constant and equals to 1.367 kJ/m^2.S, N is the day no. of the year, $\boldsymbol{\Phi}$ is the incident angle on a horizontal surface which is defined as (zenith angle), and we can calculate it from the equation:

$$\cos\Phi = \cos L \cos\delta \cos H + \sin L \sin\delta \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

From Eq. (3), θ is the incident angle on a tilted surface which is taken from (Duffie & Beckman, 2013):

$$\cos\theta = \sin\delta \sin L \cos\beta - \sin\delta cosL\ sin\,\beta \cos\gamma + \cos\delta \cos L \cos\beta \cos H + \cos\delta \sin L \sin\beta \cos\gamma \cos H + \cos\delta \sin\beta \sin\gamma \sin H \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where; γ is the azimuth angle and H is the hour angle obtained from:

H = 15 (12 - LT) ………………………………………….. (10)

LT is the daily local solar time which obtained from the equation:

$$LT = LST + \frac{ET}{60} + \frac{4(L_S - L_L)}{60} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where; LST is local standard time, L_S: standard meridian for the local time zone, L_L: longitude of the region, and ET is the time equation calculated by:

$$ET = 9.87 \sin 2D - 7.53 \cos D - 1.5 \sin D \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Where; D = 360 (N – 81) / 365 ……………………………………………. (13)

Two codes in Matlab software have been improved to evaluate first the optimum tilt angle, then the solar irradiance on a sloped modules under climate conditions of Duhok city. The flowcharts of the two codes are shown in figure (2) & figure (3)

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respectively, with required data shown in table (2). The results of the first program (δ & $\beta_{Optimum}$) will be input data for the second one.

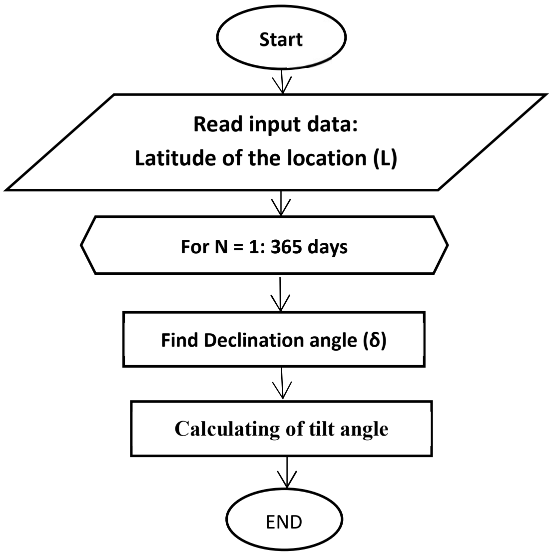

Figure (2): Evaluation of declination and optimum tilt angles.

Table (2): Meteorological data of the Meteorological Directorate of Duhok city.

Latitude of Duhok (L)	36.5°
Longitude of Duhok (L_L)	43°
Standard meridian (L_S)	45°
Local standard time (LST)	1 to 24 hours
Azimuth angle (γ)	zero
Tilt setting type	Fixed

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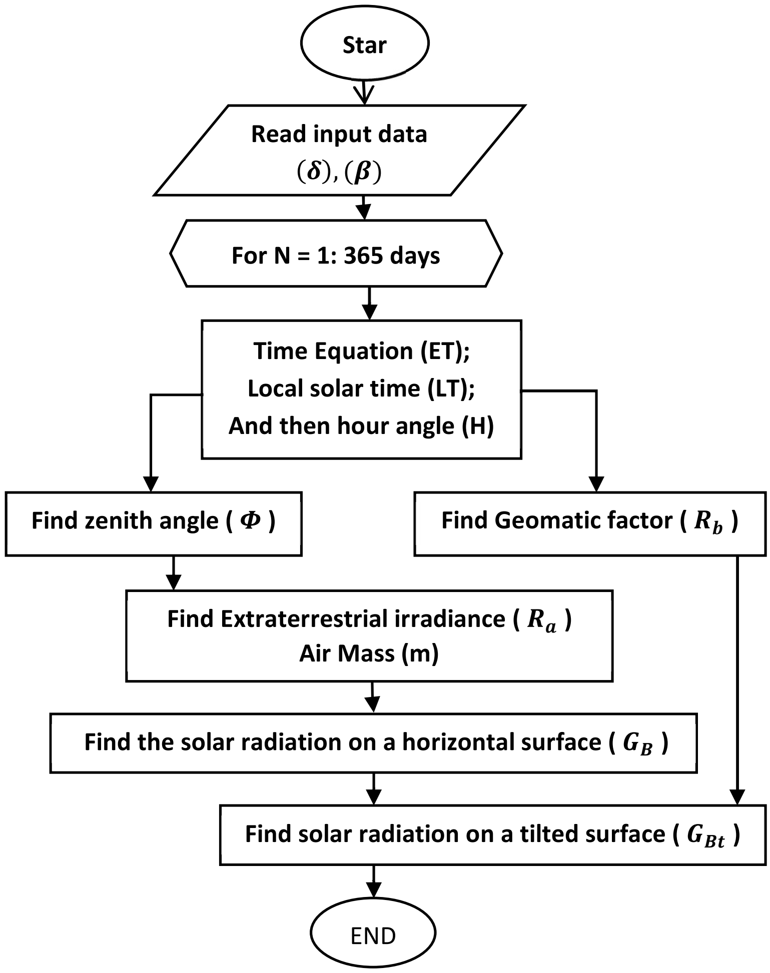

Figure (3): Estimation solar irradiance at any location in each month in year.

5. Choosing of the Main PV System Parts

Selection of the solar plant's main parts carefully, which constitute the largest costs, is very important in the evaluation calculations required to establish such a project, they are solar panels and inverters.

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5.1 Solar PV Panels

Several aspects that effect on the selection of the type of panel such as mechanical and electrical specifications, climate conditions of the location, capital cost and the area that will be used to such project. Based on the foregoing, the panel that was chosen to be used in the completion of the station is to get the best efficiency at high temperatures at the lowest possible cost (Stapleton & Neill, 2012). (AMA technology LP182*182-M-72-NH N-Type 585 Wp, German brand) module has been selected in this study, which is commonly used in the middle east countries as shown in table (3):

Table (3): Module Features and Characteristics.

Electrical Parameters at STC	
Maximum power (P_{max})	585 W
Open Circuit Voltage (V_{OC})	51.67 V
Short Circuit Current (I_{SC})	14.16 A
Maximum power voltage (V_{mp})	43.08 V
Maximum power current (I_{mp})	13.58 A
Module Efficiency	22.10 %
Temperature Characteristics	
Nominal Module Operating Temperature	41 ± 3℃
Temp. Coefficient of (I_{SC})	+0.046% / ℃
Temp. Coefficient of (V_{OC})	-0.25% / ℃
Temp. Coefficient of (P_{max})	-0.30% / ℃
Maximum Rating	
Maximum System Voltage	1500 V
Output Tolerance	$0 \sim +5$ W
Operating Temperature	-40℃ $\sim +$ 85℃
Wind Load / Snow Load	2400 pa / 5400 pa
Fuse Current	25 A

5.2 Inverters Used

Multi-string inverter has many features compared with central type, so it was selected in this work although of its high cost (Mahela & Shaik, 2017). For this study the best and the most popular inverter (SUNNY TRIPOWER CORE2 STP 110-60, SMA German Company) has been selected, table (4):

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Table (4): multi-String inverter technical data.

Input (DC)	
Max. PV array power	165000 Wp STC
Max. input voltage	1100 V
MPP voltage range	500 V to 800 V
Max. input current per MPP tracker / Max. short-circuit current per MPP tracker	26 A(22A<600V) / 40 A
Number of independent MPP trackers / Strings per MPP tracker	12 / 2
Output (AC)	
Rated power (at 400 V, 50Hz)	110000 W
Rated / Max. apparent power	110000 VA / 110000 VA
Rated voltage	400 V
Voltage range	320 V to 460 V
Rated / Max. output current	159 A / 159 A
Harmonic (THD)	< 3%
Efficiency	
Max. efficiency / European efficiency	98.6% / 98.4%

6. Design of the System

It has become clear from the latest research published in this field and from the experiences of the best companies implementing such kind of projects that the best design that fit 10 MW is the following: the project is divided into ten units of 1 MW each, and each unit consists of nine PV arrays, each array connected to one inverter, so there are 9 inverters connected in parallel for each unit, and 90 inverters for all the PV plant. The basic unit of the project is designed according to the equations below:

6.1 Number of Panels per string

The number of panels in each string depends on the value of the maximum DC input voltage of the inverter. The variation of the ambient temperature in the project location leads to the voltages of different values according to the equation (Hammad, et al., 2015):

$$V_{(T)} = V_{(25°C)} \times (1 + \alpha_{V_{oc}} \Delta T) \text{ .... (14)}$$

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Where; $V_{(T)}$: panel temperature, $\alpha_{V_{oc}}$: open circuit voltage temperature coefficient and ΔT is the difference in (℃) between cell and STC temperatures. The range of temperature for panels in this region is selected to be in the worst-case climate conditions from (-10℃) to (75℃). The voltages at this range were obtained, and it is found that:

$V_{oc(-10℃)} = 56.19\ volt,\ V_{oc(75℃)} = 45.21\ volt,\ V_{mp(-10℃)} = 46.85\ volt,$
$V_{mp(75℃)} = 37.69\ volt.$

It should be noted that both values of voltages are maximum at (-10℃). According to the maximum values of voltages, number of modules per string is calculated:

$$Min. Number\ of\ modules/string = V_{(mp)inverter}/V_{mp(-10℃)} \quad \text{………… (15)}$$

= 800 / 46.85 = 17.075

$$Max. Number\ of\ modules/string = V_{(input\ max.)inverter}/V_{oc(-10℃)} \quad \text{……. (16)}$$

= 1100 / 56.19 = 19.57

The range in safety case is between 17 to 19 and let choosing (19 module) per string.

6.2 Number of Strings per inverter

The maximum number of strings in parallel can be found based on output power of the inverter used (Hammad, et al., 2015):

$$No. of\ strings\ per\ inverter = \frac{P_{(output)inverter}/\eta_{(\max)\text{inverter}}}{[No. of\ modules\ per\ string] \times P_{(\max)module}} \quad \text{……………. (17)}$$

$$= \frac{110000/0.986}{19 \times 585} \cong 10\ strings\ in\ parallel\ connected\ to\ one\ inverter.$$

Therefore, the no. of modules for each inverter is (19*10=190 module), so we need to know the total no. of inverters required and we can do that by dividing the total power to the total no. of panels and power of each panel:

$$No. of\ total\ inverters\ used = \frac{10{,}003{,}500}{190 \times 585} = 90$$

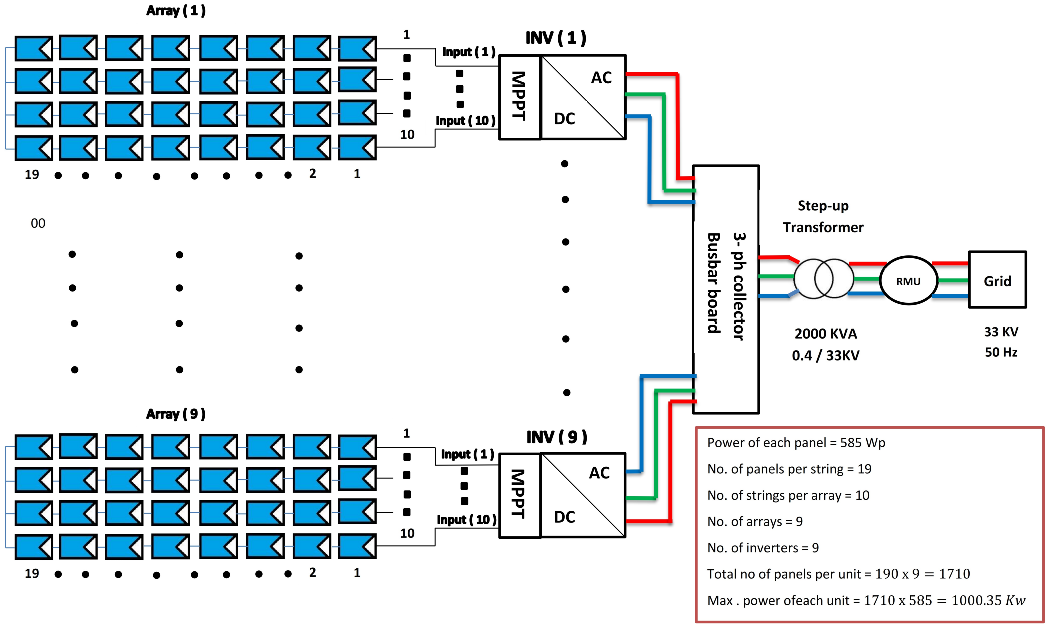

Figure (4): Single line diagram of one unit of (10MW) of solar PV plant.

7. Types of PV Plant Losses (PV Plant Losses Estimation)

There are many factors that affect the output of a PV systems and prevent from working at maximum efficiency and reaching their rated output, these factors are quantified as losses. These are: thermal, AC & DC ohmic wiring and connection, dust and dirt, array mismatch, transformer, shading, and DC to AC inversion losses (losses of the inverter).

The thermal effect can be evaluated by using the temperature coefficient from the module datasheet and the following equations (Hammad, et al., 2015):

$$T_m = 20.4 + [1.2 \times T_{(max)_{avg}}] \quad \ldots\ldots\ldots\ldots\ldots\ldots (18)$$

$$T_x = 1 + \alpha_{P_{mpp}}[T_m - T_r] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

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Where; T_x: temperature derating factor, $\alpha_{P_{mpp}}$: power temperature coefficient for a module (-0.30% /°C), T_m: module temperature (°C), T_r: reference temperature (25°C), $T_{(\max)_{avg}}$: the average daytime maximum temperature (°C). The data used is obtained from Duhok Meteorological Stations, as shown in table (5):

Table (5): Duhok city Avg. Daytime Max. Temp. (°C) (2022)

Mon.	**Ja.**	**Fe.**	**Mar.**	**Ap.**	**May**	**Jun.**	**Jul.**	**Au.**	**Se.**	**Oc.**	**No.**	**De.**
Temp.	6.45	11.2	14.4	20.65	23.1	31.65	33.85	34.1	30.3	24.7	16.05	10.85

For example, derating factor in August 2022 in Duhok city can be illustrated:

$$T_m = 20.4 + [1.2 \times 34.1] = 61.32\text{°C}$$

$$T_x = 1 + (-0.003)[61.32 - 25] = 0.891$$

The second term of equation (19) is thermal losses. Similarly, derating factors for all months of the year can be calculated as shown in table (6), and can be noted that the average temperature losses for all months in year is (6.24 %) of total power generated. Also, the other system losses can be estimated; from the datasheet of the inverter used, the value of the European efficiency which is the minimum value (98.4 %), therefore, the inverter losses of the device (1.6 %). Similarly, the total losses of step-up transformer equal to (0.96 %) at full-load operation.

Table (6): Thermal losses and derating factor values for all months of the year 2022

Month	**Thermal Losses (%)**	**Temp. Derating Factor**
January	0.0094	0.9906
February	0.0265	0.9735
March	0.0236	0.9764
April	0.0605	0.9395
May	0.0693	0.9307
June	0.1001	0.8999
July	0.1080	0.8920
August	0.1089	0.8911
September	0.0953	0.9047

October	0.0751	0.9249
November	0.0439	0.9561
December	0.0288	0.9712
Average	0.0624 = 6.24 %	0.9376

According to international standards for large-scale grid connected photovoltaic systems (Hammad, et al., 2015), the other losses of this solar plant (10MW) are; AC & DC voltage drop losses (wiring losses) of (1 %), mismatch losses (1 %), dust and dirt losses of (2 %). Shading losses depends on the project's location and panels tilt angle, it is supposed that the solar modules are arranged in a way that the losses have negligible value in proposed project. Table (7) illustrates all details of plant losses in percentage of total power generated.

Table (7) Several types of PV System losses

Item	Thermal	Inverter	Voltage Drop	Mismatch	Transformer	Dust & Dirt
Losses (%)	0.0624	0.016	0.01	0.01	0.0096	0.02
Derating Factor	0.9376	0.984	0.99	0.99	0.9904	0.98

Therefore, the total average losses of the project in one year are 12.8 % (Hashemi, et al., 2021) & (Solas, et al., 2022).

8. System Performance Parameters

The International Energy Agency (IEA) worked to develop these parameters in order to analyze the performance of the solar PV grid interconnected system (Bano & Rao, 2016). The use of suitable performance parameters is important as it would simplifies the comparison of grid-connected photovoltaic (PV) systems which may be vary in terms of the designs, technologies, or geographic locations. There are four performance parameters used for the purpose of the definition which are: (Palm, et al., 2023).

8.1 Final Yield (Y_F)

Is the net energy output E divided by the nameplate DC power P_o of the installed PV array at STC conditions.

$$Y_F = \frac{E}{P_o} \quad [h/day] \quad \text{..................... (20)}$$

8.2 Reference Yield (Y_R)

Is the total in-plane irradiance H divided by the PV's reference irradiance G. It represents an equivalent number of hours at the reference irradiance.

$$Y_R = \frac{H}{G} \quad [h/day] \quad \text{........................ (21)}$$

8.3 Performance Ratio (PR)

By normalizing with respect to irradiance, it quantifies the overall effect of losses on the rated output due to: inverter inefficiency, and wiring, mismatch, and other losses when converting from DC to AC power; PV module temperature; incomplete use of irradiance by reflection from the module front surface; soiling or snow; system down-time; and component failures, it is the ratio of Y_F to Y_R :

$$PR = \frac{Y_F}{Y_R} \times 100\,\% \quad [unitless] \quad \text{.................... (22)}$$

PR values are typically reported on a monthly or yearly basis. Values calculated for smaller intervals, such as weekly or daily, may be useful for identifying occurrences of component failures. Because of losses due to PV module temperature, PR values are greater in the winter than in the summer and normally fall within the range of 0.6 to 0.8. If PV module soiling is seasonal, it may also impact differences in PR from summer to winter. Decreasing yearly values may indicate a permanent loss in performance.

8.4 Capacity Factor (CF)

The capacity factor (CF) is defined as the ratio of actual annual energy generated by the panels of the PV plant installed (E_{AC_a}) to the amount of PV system energy generate if it operates at full rated power ($P_{PV,rated}$) for 24 hour per day for year and is given as:

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$$CF = \left[\frac{E_{AC}\,(kwh)}{P_{PV,rated}\,(kw)\times 8760(h)}\right] \times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots (23)$$

The above performance parameters provide the overall system performance with respect to energy production, solar resource, and overall effect of system losses.

9. Energy Yield Evaluation

Taking in the consideration the derating factors for all losses, overall PV system efficiency can be evaluated. Because of the unstable climate conditions through the year, and taking the effect of the not sunshiny days, and from the metrological stations, it is considered that 15 days in year are cloudy in Duhok province as maximum**.** The energy produced in (kWh) for one month can be evaluated by the equation:

$$E_{gen.\,(m)}\ (kwh) = Full\ nameplate\ capacity_{\ (m)} \times\ CF_{\ (m)} \quad \ldots\ldots\ldots\ldots\ldots (24)$$

The full nameplate capacity for one month is:

$$Full\ nameplate\ capacity\ (kwh)_{\ (m)} = modules\ capacity\ (kw) \times 24\ \left(\frac{h}{day}\right) \times no.of\ days\ in\ that\ month\ (day) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (25)$$

10. Environmental Effect of Photovoltaic Technology

Solar energy is in high demand due to its environmental benefits and economic potential. One of the main advantages of PV systems is the reduced environmental impact compared to conventional fossil fuels and some other renewable technologies, and it is not a cause of global warming. However, it is important to quantify and then minimize the impact (Zarzavilla, et al., 2022). During solar PV plants working, there are negligible of carbon dioxide emissions gas. Saving amount of CO2 emission can be evaluated using the equation (Hassan & Elbaset, 2015):

$$CO_{2_{(E)}} = F_E \times System\ Annual\ Energy\ Generated \times N \quad \ldots\ldots\ldots\ldots\ldots\ldots (26)$$

Where; F_E: Emission factor, it is set to be 0. 699 kg CO_2-eq/kwh, N: Number of years of system lifetime.

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11. Discussion of the Results

The results obtained from MATLAB programs based on previous mathematical equations are discussed to get the most accurate analysis.

11.1 Tilt angle and Solar Irradiance

The 1st & the 2nd m-file programs were used to estimate the average value of annually solar irradiance (AASI) in Duhok city, and the results obtained were the three-slope angle setting types: fixed, monthly and semi-annual values, with their particular radiation, shown in table (8).

Table (8): Slope angle setting types & their respective annual average solar Irradiance (AASI) for Duhok city.

Month / Set type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AASI $\frac{kWh}{m^2.day}$
Fixed	37	37	37	37	37	37	37	37	37	37	37	37	5.9258
Semi-annual	51	51	51	22	22	22	22	22	22	51	51	51	6.2832
Monthly	57	50	39	27	18	13	15	23	35	46	56	60	6.3709

The value of the slope angle for months from April to September (semi-annual) was calculated by taking the average value of these six months, and the same with the other six months. However, the fixed type angle value is the average of all months of the year. Also, it is found that the solar radiation with monthly slope angle setting gives the best value (6.371 $kwh/m^2.day$) compared with the other settings. Despite of the fixed type gives the less value of (5.926 $kwh/m^2.day$), it was selected in this work to reduce the costs related to investment (mounting structures of solar panels) and operation & maintenance costs. Also, there is no significant

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difference between the two values. Fig. (5) shows monthly distribution of solar radiation in case of fixed tilt angle in Duhok city in (2022). It is evident from the curve that the city of Dohuk has a very good irradiance rate throughout the months of the year.

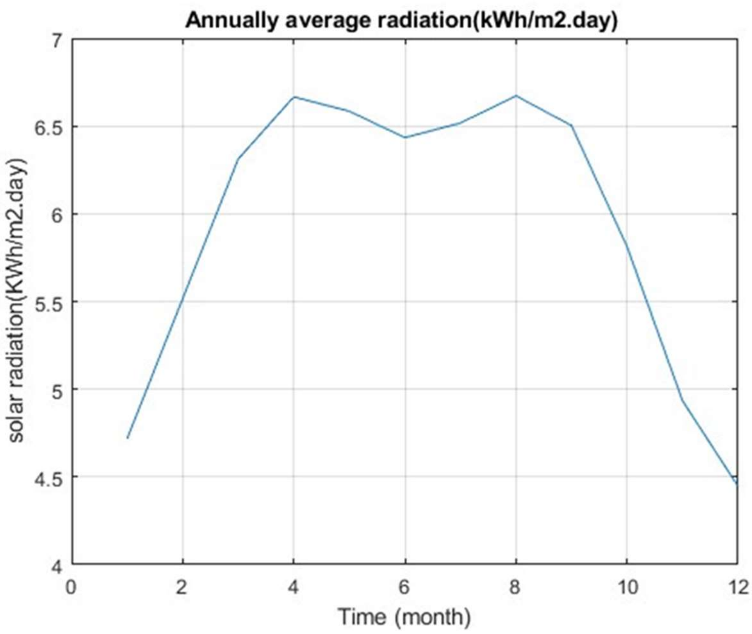

Fig. (5) AASI of tilt angle fixed type of Duhok city for (2022).

11.2 Energy Generated

The most effective matter for all solar photovoltaic projects is the amount of power generated. The result show that in the first year of operation, the total energy produced is about (1.7679e+07 kWh) distributed among the months of the first operation year as shown in figure (6), which is the very good level of generation.

11.3 Plant Performance

The average value of performance ratio for the first year is 82.02 %, it is a very good ratio compared with the other large scale solar PV plants, figure (7) shows performance of this plant in each month. The average value of the capacity factor for the first year is 20.17 %, It is also considered a very good annual percentage rate compared to other similar projects in the countries of the Middle East. Figure (8) explains the graphical representation of capacity factor parameter for (10MW) solar PV plant under Duhok climate conditions.

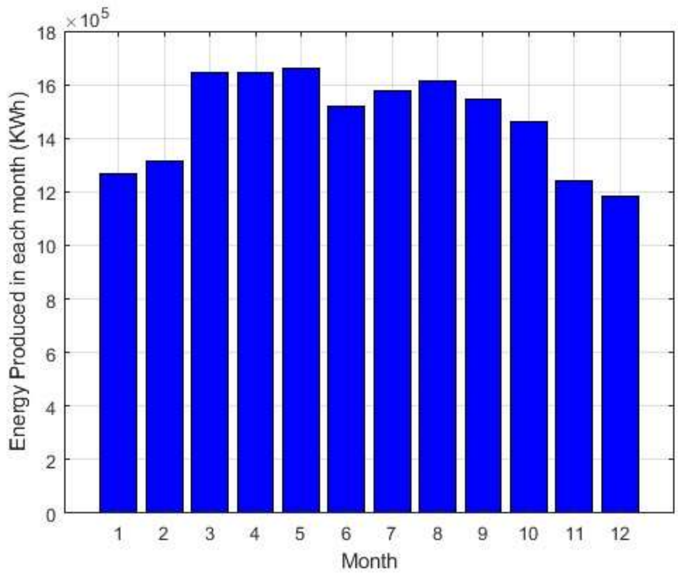

Figure (6): Energy generated in the first year in each month.

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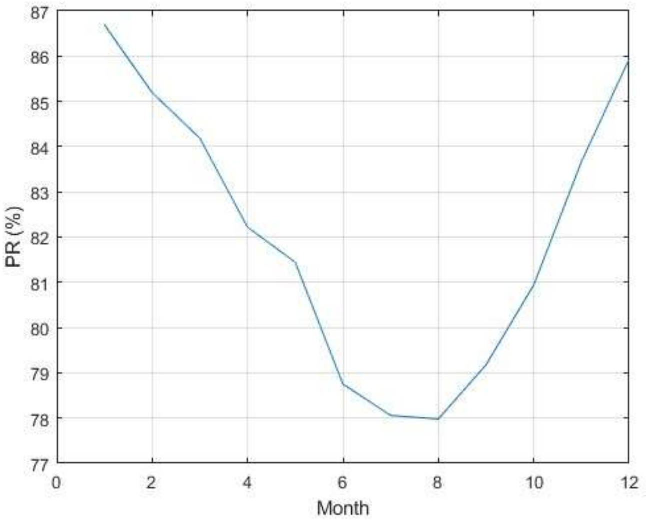

Figure (7): System Performance Ratio in each month.

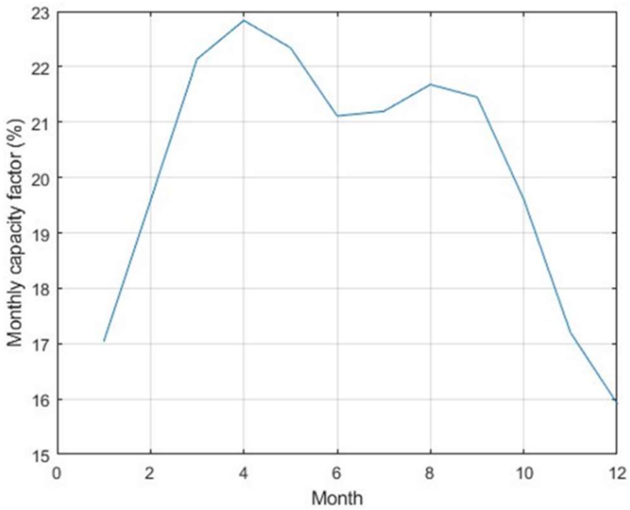

Figure (8): System capacity factor in each month.

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System efficiency is illustrated in Fig. (9), its value ranging between 93% in January and 83% in August with average annual value of 88% which is acceptable value for large-scale solar PV plants.

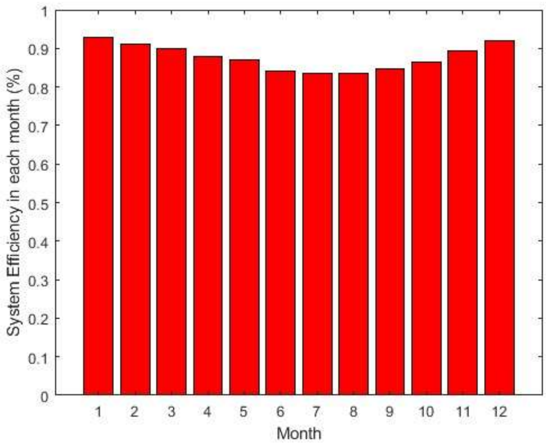

Figure (9): System Efficiency in each month of first year.

11.4 System Environmental Effect

The total saving value resulting from the emission of carbon dioxide by installing a photovoltaic station with a capacity of 10 megawatts for 25 years is about (2.7953e+08 kg), fig. (10) shows linear relation of Co2 emission reduction during solar PV plant lifetime.

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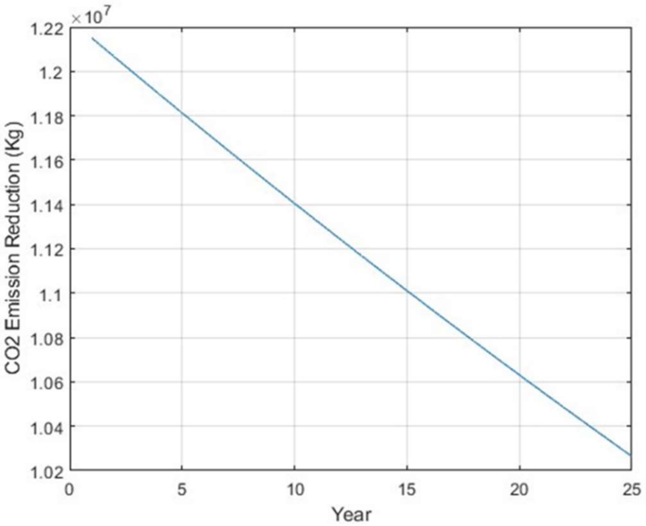

Figure (10): Saving of Co2 Emissions for 25 years of operation.

12. Conclusion

In this article, the traditional basic equations were adopted in designing a solar photovoltaic power plant with a capacity of 10 MW under climate conditions of Duhok city using some MATLAB programs that were designed and improved by the authors, and then the results obtained from MATLAB were investigated by comparing them with the results of recent related works, which were accomplished using different methods and software.

It is clear from the distinctive results obtained from Matlab software, that Duhok is characterized by a high level of solar radiation over the year, that helps in building solar photovoltaic stations connected to the distribution network or the power system. Achieving this is of great benefit to the city in terms of eliminating or reducing emissions that negatively affect the environment.

Performance ratio (PR) is one of the most important variables for evaluating the efficiency of a PV plant connected to the grid. The performance ratio is the ratio of the actual and theoretically possible energy outputs. It is largely independent of the orientation of a PV plant and the incident solar irradiation on the PV plant. Hence, the performance ratio can be used to compare PV plants at different locations all over the world and different capacities. Performance ratio of this work is about 82 % which is a good value compared with the other recent acceptable results.

References

2. *Myneni, H., Kumar, G. S., Member, S., & IEEE. (2019). Energy Management and Control of Single-Stage Grid Connected Solar PV and BES System. IEEE, 1949-3029.*

3. *Ali, A., Shah, F., Khan, M., & Mehmood, F. (2019). Design & Analysis of Solar PV System for Sarhad University Peshawar. IEEE, 2409-2983.*

4. *Alnoosani, A., Oreijah, M., Alhazmi, M., Samkari, Y., & Faqeha, H. (2019). Design of 100MW Solar PV on-Grid Connected Power Plant Using (PVsyst) in Umm Al-Qura University. IJSR, 8 (11), 356-363.*
5. *Kumi, E. N. & Hammond, A. B. (2013). Design and Analysis of a 1MW Grid-Connected Solar PV System in Ghana. ATPS Research Paper No. 27.*
6. *Myathari, V., Siddiki, S., & Siddiki, M. (2020). Design and Economic analysis of a Grid-tied PV system to power a small village. IEEE, 1658-1664.*
7. *Hindocha, K., & Shah, S. (2020). Design of 50 MW Grid Connected Solar Power Plant. IJERT, Vol. 9 Issue 04.*
8. *Oloya, I. T., Gutu, T. JL. & Adaramola, M. S. (2021). Techno-economic assessment of 10 MW centralised grid-tied solar Photovoltaic system in Uganda. CSITE 100928.*
9. *Kumar, D. J. V., Deville, L., Ritter, K. A., Raush, J. R., Ferdowsi, F., Gottumukkala, R., & Chambers, T. L. (2022). Performance Evaluation of 1.1 MW Grid-Connected Solar Photovoltaic Power Plant in Louisiana. MDPI.*
10. *Palm, S. F., Youssef, L., Waita, S., Nyangonda, T. N., Radouane, K. & Chebak, A. (2023). Performance Evaluation of Burkina Faso's 33 MW Largest Grid-Connected PV Power Plant.*
11. *Kumar, S. & Sudhakar, K. (2015). Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. Elsevier, Amsterdam, Vol. 1, pp. 184-192.*
12. *Sreedevi, J., Ashwin, N. & Raju, M. (2016). A Study on Grid Connected PV system. IEEE, 978-1-4799-5141.*
13. *Bano, T. & Rao, K. (2016). Performance analysis of 1MW grid connected photovoltaic power plant in Jaipur, India. IEEE, 978-1-4673-9925.*
14. *Ogliari, E., Leva, S., Polenghi, M. & Ciechi, L. (2023). Comparative Performance analysis of different PV plants in Italy. IEEE, 979-8-3503-4743.*

15. *Ramoliya, J. & Gardi, B. (2015). Performance Evaluation of Grid-connected Solar Photovoltaic plant using PVSYST Software. Volume 2, Issue 2, JETIR (ISSN-2349-5162).*
16. *Khan, A., Aslam, A. & Imran, K. (2021). Effect of fixed and seasonal tilt angles on the performance of an ON-Grid PV plant. IEEE, 978-1.*
17. *Ibrahim, I., Shehata, A. & Abbassya, M. (2022). Performance analysis of 10MWp grid- connected photovoltaic system in the Mediterranean climate using PVsyst software.*
18. *Lindig, S., Moser, D. &Reinders, A. (2021). Performance Analysis and Degradation of a Large Fleet of PV Systems. IEEE, JOURNAL OF PHOTOVOLTAICS, VOL. 11, NO. 5.*
19. *Elshafei, M., Abdelrazik, S. & Elshenawy, A. (2021). Photovoltaic System Floating over Lake Nasser by using PVSYST Software. IRJET, Volume: 08 Issue: 04.*
20. *Shiva Kumar, B.; & Sudhakar, K. (2015). Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. Elsevier, Amsterdam, Vol. 1, pp. 184-192.*
21. *Duffie, J. A., & Beckman, W. A. (2013). Solar engineering of thermal processes. New York.*
22. *Zang, H., Guo, M., Wei, Z., & Sun, G. (2016). Determination of the Optimal Tilt Angle of Solar Collectors for Different Climates of China. MDPI, Sustainability 2016, 8, 654.*
23. *Mahela, O. P., & Shaik, A. G. (2017). Comprehensive overview of grid interfaced solar photovoltaic systems. Elsevier 68, 316-332.*
24. *Hashemi, B., Taheri, S., Cretu, A. M., & Pouresmaeil, E. (2021). Systematic photovoltaic system power losses calculation and modeling using computational intelligence techniques. Elsevier.*
25. *Solas, A. F., Romero, J. M., & Micheli, L. (2022). Estimation of soiling losses in photovoltaic modules of different technologies through analytical methods. Elsevier.*
26. *Bano, T., & Rao, K. (2016). Performance analysis of 1MW grid connected photovoltaic power plant in Jaipur, India. IEEE 978, 165-170.*
27. *Palm, S., Waita, S., Nyangonda, T., & Radouane, K. (2023). Performance Evaluation of Burkina Faso's 33 MW Largest Grid-Connected PV Power Plant. Energies 2023, 16, 6177.*
28. *Hassan, M. S., & Elbaset, A. A. (2015). A Comparative Study for Optimum Design of Grid Connected PV System based on Actual System Specifications. IJCA, volume 116 – no. 3.*
29. *Zarzavilla, M., Quintero, A., & Abellan, M. A. (2022). Comparison of Environmental Impact Assessment Methods in the Assembly and Operation of Photovoltaic Power Plants: A Systematic Review in the Castilla—La Mancha Region. MDPI.*

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پوختە

وزەی خۆر یەکێکە لە گرنگترین و بەهێزترین سەرچاوەکانی وزەی نوێبووەوە. گرنگی سیستەمی فۆتۆڤۆلتایک (PV) لەم ساڵانەی دواییدا لە زۆربەی جیهاندا زیادی کردووە، چونکە سەرچاوەیەکی پاک و باوەڕپێکراو و بەردەوامە. ئەم توێژینەوەیە دیزاینی وێستگەی 10 مێگاواتی لەسەر تۆڕی PV پێشکەش دەکات لەژێر بارودۆخی کەشوهەوای دهۆک (تیشکی خۆر و پلەی گەرمی ساڵانە). دیزاینی ڕووەکەکە لە دە یەکە پێکهاتووە لە هەر یەکەیەکی MW1،)بەستراوەتەوە بە هاوتەریب) لەگەڵ 33 KVو 50 هێرتز لە ڕێگەی گۆڕینی هەنگاوی MVA 2بۆ هەر یەکەیەک. لێکۆڵینەوەکە لێکۆڵینەوەی دۆزینەوەی گۆشەی لاری پانێڵی خۆر لەخۆ دەگرێت، خەملاندنی تیشکی خۆر لە شاری دهۆک وەک لێکۆڵینەوەی حاڵەت و هەڵسەنگاندنی پارامیتەرێکی گرنگی سیستەم (هەموو جۆرەکانی لەدەستدان، کارایی سیستەم، بەرهەمی وزە، چوستی سیستەم و کاریگەری ژینگەیی)، لە ڕێگەی باشترکردنی بەرنامەکان لە نەرمەکاڵای ماتلاب. لە ئەنجامی ئەو بەرنامانەوە گەیشتنە ئەو ئەنجامەی کە شاری دهۆک شوێنێکی باشی هەیە بۆ دامەزراندنی وێستگەیەکی گەورەی وزەی خۆر.

الملخص

الطاقة الشمسية هي واحدة من أهم مصادر الطاقة المتجددة المتاحة وأكثرها تنوعا. تزايدت أهمية الأنظمة الكهروضوئية في السنوات الأخيرة في غالبية دول العالم، باعتبارها مصدرًا نظيفًا وموثوقًا ومستدامًا للطاقة. يعرض هذا البحث تصميم محطة كهروضوئية على الشبكة بقدرة 10 ميجاوات في ظل الظروف الجوية في دهوك (الإشعاع الشمسي السنوي ودرجة الحرارة). يتكون تصميم المحطة من عشر وحدات قدرة كل منها 1 ميجاوات، (متصلة على التوازي) بمغذي توزيع جهد 33 كيلو فولت، 50 هرتز من خلال محول تصاعدي قدرة 2 ميجا فولت أمبير لكل وحدة. تحتوي الدراسة على البحث في إيجاد زاوية ميل الألواح الشمسية المثالية، وتقدير الإشعاع الشمسي في مدينة دهوك كدراسة حالة، وتقييم معلمات النظام المهمة (جميع أنواع الخسائر، أداء النظام، إنتاجية الطاقة، كفاءة النظام والتأثير البيئي). بمساعدة برنامج الماتلاب . تم الاستنتاج من النتائج التي تم الحصول عليها من البرامج، أن مدينة دهوك تتمتع بموقع جيد لإنشاء محطات الطاقة الشمسية الكهروضوئية على نطاق واسع.