AIMS Energy, 10(4): 858–884.
DOI: 10.3934/energy.2022039
Received: 22 April 2022
Revised: 26 June 2022
Accepted: 18 July 2022
Published: 22 July 2022

http://www.aimspress.com/journal/energy

Review

A review of PV solar energy system operations and applications in Dhofar Oman

Fadhil Khadoum Alhousni[1,]*, Firas Basim Ismail[1,]*, Paul C. Okonkwo[2,]*, Hassan Mohamed[1], Bright O. Okonkwo[3] and Omar A.Al-Shahri[1]

[1] Power Generation Unit, Institute of Power Engineering (IPE), Universiti Tenaga Nasional (UNITEN), 43000 Kajang, Selangor, Malaysia
[2] Mechanical and Mechatronics Engineering, Dhofar University, Salalah, Oman
[3] Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, Daejeon, South Korea

* **Correspondence:** Email: pokonkwo@du.edu.om, Falhousni@du.edu.om, Firas@uniten.edu.my; Tel: +96899674453.

Abstract: Energy is seen as one of the most determinant factors for a nation's economic development. The Sun is an incredible source of inexhaustible energy. The efficiency of the conversion and application of Photovoltaic (PV) systems is related to the PV module's electricity generation and the location's solar potentials. Thus, the solar parameters of a region are important for feasibility studies on the application of solar energy. Although solar energy is available everywhere in the world, countries closest to the equator receive the greatest solar radiation and have the highest potential for solar energy production and application. Dhofar in Salalah-Oman is one of the cities in Oman with high temperatures all year round. The city has been reported to exhibit a maximum solar flux of about 1360 w/m^2 and a maximum accumulative solar flux of about 12,586,630 W/m^2 in March. These interesting solar potentials motivated the call for investment in solar energy in the region as an alternative to other non-renewable energy sources such as fossil fuel-powered generators. As a consequence, several authors have reported on the application of different solar energy in the different cities in Oman, especially in remote areas and various results reported. Therefore, the present review highlighted the achievements reported on the availability of solar energy sources in different cities in Oman and the potential of solar energy as an alternative energy source in Dhofar. The paper has also reviewed different PV techniques and operating conditions with emphasis on the advanced control strategies used to enhance the efficiency and performance of the PV energy system. Applications of standalone and hybrid energy systems for in-house or remote power generation and consumption in Dhofar were discussed. It also focused on the relevance of global radiation data for the optimal application of PV systems in Dhofar. The future potential for the full application of solar systems in the region was mentioned and future work was recommended.

Keywords: solar energy; photovoltaic (PV); solar radiation; solar irradiance

1. Introduction

Solar and wind energy sources are the fastest growing (alternative) renewable energy. The most abundant of all renewable energy is solar energy [1]. For instance, about 10000 TW worth of solar energy hits the earth's surface per day on approximation, but altogether only about 17.4 TW of solar energy is reported to be consumed as of 2015 [1]. Comparing the current consumption with the amount of solar energy received hourly, the potential of solar energy in solving the present/future global energy needs can never be over-emphasized. Considering the enormous energy usage/demand on the world's scale which approaches 56% according to the US Energy Information Administration (EIA), 2013, the need to unlock the full potential of solar energy becomes inevitable. Some countries like Germany have converted their energy needs to approximately 38% to solar, intending to completely replace nuclear with solar by the year 2050. However, developing countries are yet to achieve their feet in solar technology.

There is no doubt that the intensity and availability of solar energy do vary from country to country. Some cities in Gulf regions, such as Oman, receive an average annual amount of sun hours of up 2880 hours and a peak sunny month with 336 hours of sunshine [2]. The temperature can be high (hot) and humid during the summer months. For instance, during the winter, the lowest temperature is around 15 °C, while in summer, the temperatures can rise to 48 °C in Muscat and 54 °C in the desert. Dhofar, which is located in the country's southern region, has a regular monsoon between June and October every year [3]. Such solar radiation and environmental temperature data are important for conducting feasibility studies for solar energy systems. They are also paramount for designing all kinds of solar power systems like solar collectors, PV systems, buildings, and solar dryers [4]. Several studies have been performed on solar design, and applications for this region [1,5–7]. Abdul-Wahab et al. [3] presented the best PV system for the solar conditions of some cities in Oman using the hybrid optimization model for electric renewable energy. The report further reveals that using PV systems instead of fossils would prevent the generation of a million kg/year of pollutants and could reduce the energy cost to 0.085/kWh in the regions. The report indicated that the best type of PV for the location with the best solar radiation is 1164 kVA with generic PV modules. Despite the studies performed so far on power generation using solar and wind energy in the Oman region, a review of the different energy systems for applications in Dhofar is limited in the literature. This study attempts to fill the gap.

PV modules convert solar radiation into thermal or electrical current [8]. These solar devices come in different designs for different purposes. While the flat-plate thermal collectors, compound parabolic concentrating (CPC), evacuation-tube solar thermal collectors, etc., convert solar radiation into heat, the PV modules convert solar radiation directly into electricity [9]. However, depending on the PV cell type, the solar conversion rate into electricity is still below 20% (typically 5%–20%). A larger part up to 60% of absorbed solar radiation can be lost in the form of heat. Heat generation has been reported to increase the temperature of the photovoltaic modules, which lowers conversion efficiency[10,11]. To mitigate this effect, a suitable heat exchanger can be coupled with the PV system, such as the fluid or air circulation, as reported by other authors [12]. For the design of a PV system for household application in any region, the solar radiation data of the region need to be ascertained to estimate the daily output effectively.

The PV can operate under different conditions which can affect the output efficiency of the system. Conditions such as mismatch losses, output variation, cloud enhancement, etc. have been linked with the PV power output [13]. The review also as an objective discusses different advanced control strategies that have been used to regulate the performance and efficiency of the PV energy systems.

The weather conditions in Dhofar, Oman, made solar energy a promising energy source for power generation in the region. But, due to the dependence of solar energy on weather, the power output may often not be able to meet the demanded electrical load. To mitigate this effect and ensure continuous energy supply, hybrid solar systems have been developed [14]. Hybrid systems involve the combination of PV systems with another renewable source (wind, tidal, geothermal, etc.). This combination ensures that uninterrupted and continuous electric power can be provided[15]. It can also be created by combining solar-based renewable power sources with an energy storage device such as a battery, ultracapacitor, etc. [15,16]. Hybrid systems can close the gap when there is no solar energy to meet the required load application.

Solar energy can be deployed as either passive or active [15]. A passive system is when solar power is used for heating or cooling a living space mainly, whereas, in an active system, PV modules are used to convert solar energy to electrical power for the operation of household appliances i.e., fans, lighting bulbs, TV sets, etc. [17]. Since the efficiency of PV panels depends on the solar parameters PV panel properties, etc. [18,19], the solar potentials of a region contribute to the successful application of solar power in the region [4,7,20].

Though all nations have the availability of solar energy, the Middle East has the highest solar resources/temperature on the planet Earth, with some cities in Oman (i.e., Dhofar) exhibiting one of the highest in the world. Exploiting and reviewing the potentials and applications of these energy sources in Dhofar becomes necessary. Therefore, in this review, the solar potentials in Dhofar, Oman, and their suitability for the design and development of the solar system for power in-house generation are explored. Secondly, the PV principles, modeling, andoptimizationn technologies, including the economic data requisite for improving the application of solar energy in the region and beyond presented. The review also highlighted the need to intensify research efforts in the area of solar to exploit the abundant solar resources available in Dhofar and other regions in Oman for energy generation to aid in achieving the general future projections in the Middle East.

2. PV materials and systems arrangements

Photovoltaic cells or PV cells are fabricated in different forms with different kinds of materials. Though, they are all adapted for harvesting solar energy and converting it to useful electricity. The commonest material for the manufacture of a solar panel is silicon which has semiconducting properties [21]. Several solar cells are needed to fabricate a solar panel, and many panels constitute a photovoltaic array. There are varied types of PV cells available today, including those that are still being researched in the development stage. In general terms, monocrystalline silicon, polycrystalline silicon, and thin-film dominate the world market. While, the higher efficiency PV technologies, such as gallium arsenide and multi-junction cells are less common because they are very expensive. However, they can be applied in concentrated photovoltaic systems and space applications. Other materials for PV cell application used today include cadmium telluride (CdTe) and copper indium diselenide ($CuInSe_2$). Furthermore, technologies using organic materials have been developed and are attractive in recent times because of their low cost and fast production compared with silicon-based ones. However, they have lower efficiencies (4%) and can be affected by environmental degradation [22]. Other emerging technologies include Perovskite solar cells which are fabricated from organic compounds and are named after their specific crystal structure [23]. Their production cost is relatively low and can heighten efficiencies similar to the commercially available silicon cells. However, these are presently affected by a limited lifespan. There are also emerging PV cell technologies such as Perovskite cells, organic solar cells, dye-sensitized solar cells, and quantum dots [21].

Organic solar cells are mostly made up of polymer layers and can be fabricated in high volumes at a cheap rate/cost. They can be designed as semi-transparent films, but they suffer from relatively low efficiencies [24]. Dye-sensitized solar cells can be manufactured from semiconducting titanium dioxide and a single molecule thick layer of 'sensitizer' dye. These cells can offer modest efficiencies but are affected by bright sunlight. Quantum dots utilize nanotechnology to manipulate semiconducting materials at extremely small scales [24,25]. Although theoretical efficiency values are huge, laboratory test efficiency results are still very low. Solar photovoltaic systems can be grouped into two major categories depending on the application. The PV can be designed to generate energy directly from the sun to power DC loads such as electric lamps, fans, pumps, or even recharge batteries [26]. This is effective only when there is sufficient sunshine. Another more complex PV system can also be designed to generate energy that can be stored for later use when there is no sufficient sunlight. In these systems, the generated energy can be used to power DC loads and converted to AC using a converter for ac loads application [27]. Furthermore, PV in a typical residential or business building can generate energy that can be sent to a utility grid to offset the cost of electrical energy used by the homeowner or business [27]. There are different photovoltaic technologies and systems available, which will be discussed in the subsequent section.

2.1. Direct photovoltaic (PV) system

In this kind of system, where there is no energy storage device, the generated energy is used directly to power loads such as many household appliances. Hence, the size and number of PV modules would be determined by the energy requirements of the load [28]. For instance, if the energy required for the operation of a submersible pump is equivalent to the output of a single PV module, the pump can be powered to supply water by the solar module's direct current (DC), as shown in Figure 1. The setback associated with this system is that energy is not stored, so the system cannot function without sufficient sunlight. Also, a reduction in the solar flux due to the cloud might decrease the module's current output, thereby decreasing the load's performance. This decrease can cause a ventilation fan or water pump to stop operating [29]. If the loads operate on AC, DC from a PV module can be converted to AC using an inverter [29].

2.2. Battery-based PV system

This system is more complex than the direct PV module system in that it involves the storing of energy for use in the absence of sunlight radiation [30]. PV modules can charge batteries that can supply energy when the PV modules are not generating electricity in a cloudy atmosphere or at nighttime. To control the amount of current going into the battery during the day charging a charge controller can be installed [31]. As the power demand of the load's appliances/installations is large, more batteries can be connected to meet the power demand. The battery design usually takes into consideration the load and the hour the system will operate without sunlight. Battery-based systems are necessary for the operation of communication systems, railroad crossing signals, street lighting, and traffic control systems, especially when located in rural areas. In battery-based PV systems, loads run on direct current (DC). However, when loads require AC, small inverters can be connected with the DC source. The limitation of the battery-based is the high initial installation cost coupled with the maintenance, load calculations, and the replacement of dead batteries [30,31]. Figure 1 shows the block diagram of the PV array connected with other components and submersible pumps.

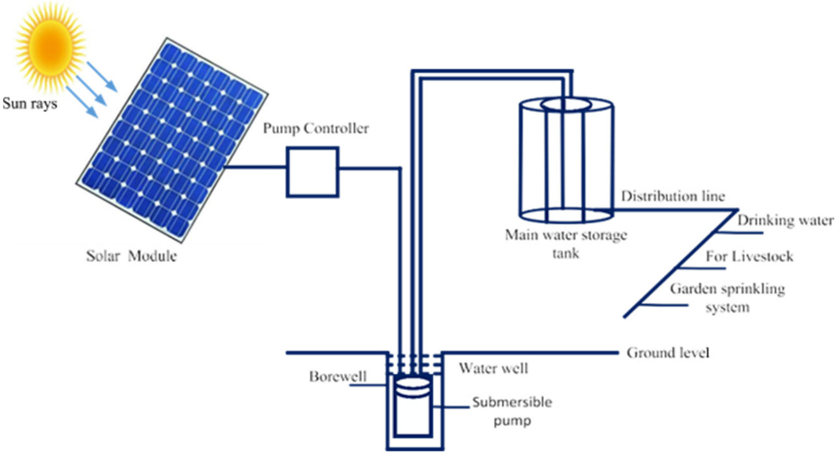

Figure 1. A simple PV direct system connected to other components [32].

2.3. Non-grid-connected and grid-connected systems

It is an off-grid system, a battery-based PV system that can be designed to power a home not connected to a local utility [33]. The size of the battery can be estimated from the load demand of the house [33,34]. Since electrical loads in homes often run on alternating current (AC), an inverter is employed to convert DC from PV modules and batteries to an AC for household appliances [35].

The grid-connected system is the PV system with the fastest growing demand. It involves connecting a PV system-powered home to the local electric utility [34]. Here, when solar power is not available, the electrical energy demand of the home can be supplied by the utility connection. However, during the day, when there is abundant solar radiation prompting maximal solar energy generation by the PV systems, excess energy can be sent to the grid. The energy generated during the day when house owners are out of the house causes lower energy demand that is sent to the grid compensates for the energy demand at night, which comes from the grid. The net sum of energy generated during the day and the energy used during the night when house owners are active (back home) reduces bills for the owner [35,36].

2.4. Grid-connect interactive system and hybrid system

In some designs, a grid-connect system may be backed-up with a battery bank or a generator to provide electrical power when there is a power outage from the utility [37,38]. The solar PV systems can simultaneously charge the battery bank and provides power to the system during the day [37]. While at night, if there is a power outage, electric power can be supplied by the battery bank. In the hybrid system, more than one energy-producing source such as integrated wind power is involved [38]. The scheme in Figure 2 demonstrates the grid-connect interactive and the hybrid system.

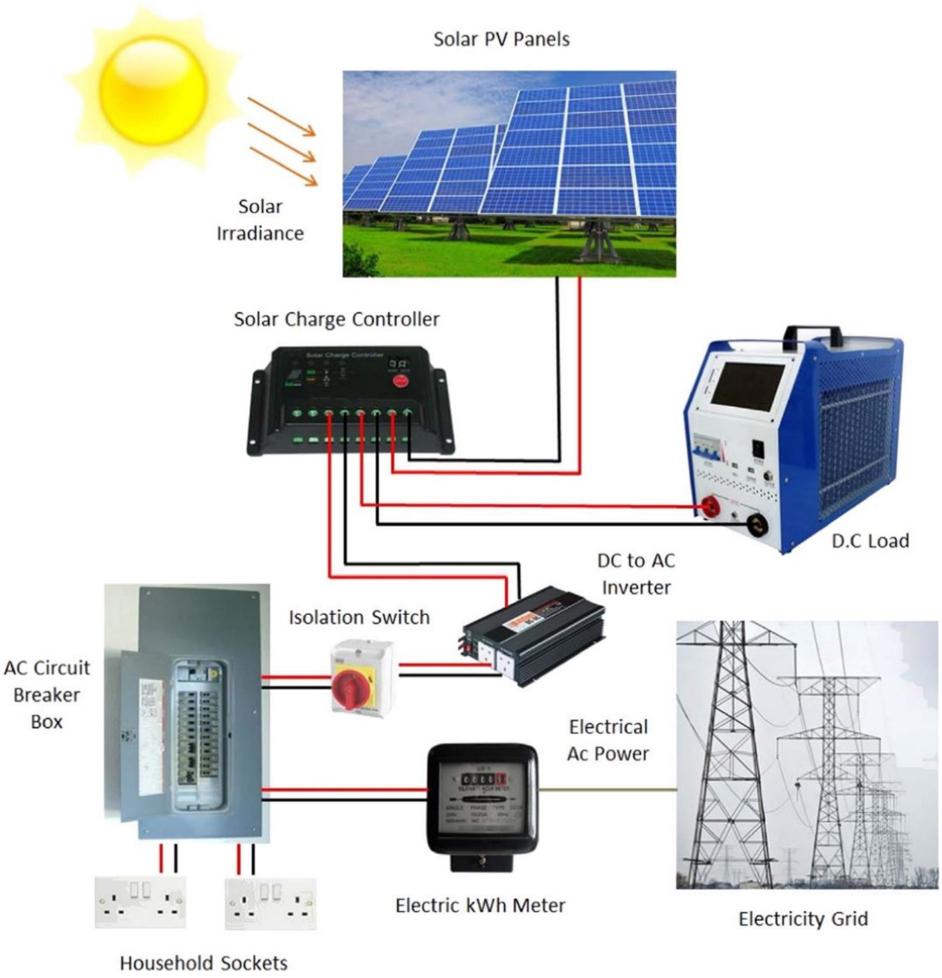

Figure 2. A block diagram showing the grid-connected PV system with battery backup [39].

2.5. Potential of solar energy in Dhofar and other cities in Oman.

The strategic geographical location of Oman makes it suitable to harness renewable energy on varied scales for economic development. Oman receives solar radiation at a tremendous level all year round and is among the highest globally due to its geographical position in the globe [40]. Thus, it is adapted for harnessing and developing solar energy resources. In 2008, the Authority for Electricity Regulation in Oman studied the potential of the application of renewable energy resources in the entire Sultanate of Oman [40], as illustrated in the map in Figure 5. The study reveals the pronounced potential sources of renewable energy in the Sultanate. Furthermore, the report finds out that Oman is among the highest in the world in terms of the level of solar energy density.

Oman receives extensive daily solar radiation ranging from 5,500–6,000 W/m^2 a day in July to 2,500–3,000 W/m^2 a day in January making it to be the part of the world with the highest solar energy densities coupled with a high ratio of "sky clearness" [41]. It is located at 17.0167° N, and 54.0929° E [4]. Previous studies have shown that apart from Marmul and Qairoon Hairiti, (which are reported to possess the greatest solar radiation parameters in Oman) the other cities in Oman have almost the same solar radiation values [41]. Dhofar, Salalah is one of the cities in Oman with abundant solar radiation properties [4]. Aref Wazwaz et al. 2013 [4] investigated the solar parameters at Dhofar University in Salalah from December to Match (Winter). The results from Dhofar University revealed that the region (AlSaadah-Salalah) is one of the regions with plenty of solar radiation sited for varied solar energy conversion applications. The maximum solar flux (1360 W/m^2) and the maximum accumulative solar flux (12,586,630 W/m^2) were recorded in March. The maximum relative humidity (88%) occurred in March as well and the minimum value was in December (29.74%). The maximum atmospheric temperature (36.4 °C) occurred in March while the minimum value (19.07 °C) made March the best for the winter season's solar energy conversion. However, in summer, the highest sunshine occurs in May and drops to the lowest in June, July, and August in Salalah [42]. The average monthly radiation on surfaces ranged from (3.4 MJ/m^2) in August and reached the highest level of (29 MJ/m^2) in May [42]. Since it is obvious that the solar radiation of this region has the potential to afford sufficient electricity to meet the demand for domestic electricity requirements, including providing for export, there is an increasing campaign to intensify the development of solar energy resources throughout Oman. Figure 4 shows the map of various cities in the Sultanate of Oman. The availability of high solar energy density in all the regions of Oman with the desert areas exhibiting the highest solar radiation density values and the coastal areas in the southern part giving the lowest density in Oman will enhance the development of solar energy in Oman.

Figure 3. Map showing the various cities in the Sultanate of Oman [43].

Al-Badi et al. [43] 2011 reviewed the economic perspective of PV electricity in 25 locations in Oman utilizing the average daily solar radiation and sunshine duration. Comparing the average global solar radiation and duration (global solar radiation varies between slightly greater than 4 kWh/m^2/day at Sur to about 6 kWh/m^2/day at Marmul) with the values for 25 locations in Oman (which is more than 5 kWh/m^2/day), the great promise of PV system application in these cities was revealed. Likewise, the renewable energy produced each year from the PV power plant varies on the global scale ranging between 9000 MWh at Marmul and 6200 MWh at Sur; whereas the mean value for all the 25 locations is 7700 MWh. Advancing solar energy technology in the Sultanate of Oman could specifically provide the requisite energy power in the Sultanate considering the abundance of unused land and solar resources in the area. Progressing solar energy applications in these regions could compensate for the growing need for energy and economic diversifications.

Due to the excellent solar radiation parameters associated with the different regions in Oman, many researchers have reported the tendency of adopting solar energy for application in the different cities in Oman.

3. Stand-alone energy systems for in-house power generation

Usually, domestic apartments have a roof or a backyard which can serve as a substratum for the installation of PV system modules (solar panels) to produce electricity. When exposed to direct sunlight a typical home PV system or solar panel produces about 300 watts in one hour which indicates up to 3 kWh of energy can be generated per day during summer [44]. With substantial PV panel arrays, the produced energy could be sufficient to power the various home appliances such the AC power to operate lighting systems, gadgets, appliances, and equipment such as computers, refrigerators, mixers, fans, air conditioners, TVs, and music systems, etc. A simple stand-alone PV system automatically produces current to charge banks of batteries when there is sunlight in the daytime which can be used even at night when there is no availability of sunlight. A standalone PV system is composed of batteries that can be recharged for storing the generated electrical energy from PV panels or arrays, electrical components, conductors, and one or more loads [44,45]. This kind of PV system is perfect for homes in isolated areas where there is an unavailability of other power sources. It is more cost-effective to apply PV stand-alone in remote domestic homes than to pay the running cost of extending the local power source to your location. The scheme in Figure 4 reveals the major components of a stand-alone PV system for rural/remote domestic applications.

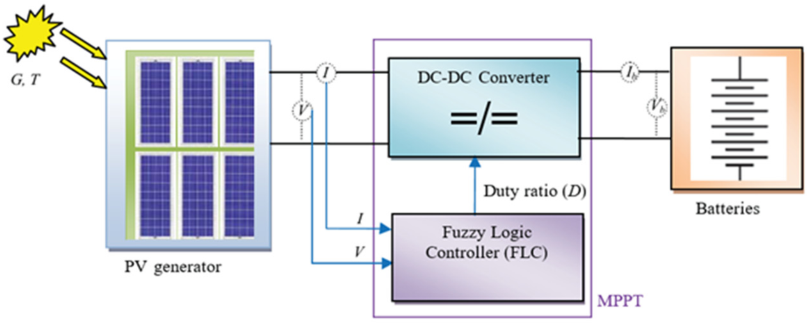

Figure 4. Simplified stand-alone PV system [46].

The function of the major component of a stand-alone PV system include:

- Batteries—Batteries are adopted to reserve excess electric power for use in times when there is no solar (at night) or power outage in the day time (emergency scenario). Depending upon the solar array configuration, battery banks can be of 12 V, 24 V, or 48 V and many hundreds of amperes in total [47].
- Charge Controller—A charge controller is adopted to regulate /control the electric current output from the solar array to avoid overcharging of the batteries which are paramount to the life span of the battery. Although a PV system can function without this device, it is a good idea to have one for safety reasons [48].

- Fuses and Isolation Switches—These protect the PV system if short-circuiting occurs and permit the turning off when continuous charging is not needed thereby saving energy and persevering and/or enhancing the battery life [49].
- Inverter—Inverters are used to convert the direct current (DC) power from the solar array and batteries into an alternating current (AC) electricity for operating home AC appliances such as TVs, washing machines, freezers, etc. [50,51].
- Wiring—This is another important component of a PV system. They are rated following the voltage and power requirements of the system [52].

Standalone systems are more suited for certain operations, such as operating well pumps to lift water from the ground to the storage tanks which can now be used even when the system is not generating energy at night. Other aspects of operation where it finds application include solar-powered fans, irrigation systems, water walls or fountains for livestock, etc. [48].

3.1. Hybrid energy system application in Dhofar

Hybrid solar panel systems are synonymous with grid solar system in that they store energy batteries for later use because, during a power outage or blackout, the stored energy in hybrid systems supply energy similar to an Uninterrupted Power Supply (UPS) [53,54]. Generally, hybrid solar systems rely on two or more energy-generating sources such as complementing wind and solar, and they can be better described as integrated systems [55] as shown in Figure 6. The integration of a hybrid PV system with wind power offers several benefits compared with a single system. Interestingly, wind speeds are minimal during summer when the intensity of sunlight is high, brightest, and longest; but strong during the winter when there is less sunlight. Hybrid systems would more likely provide power when needed since wind and solar systems' operating peaks occur at different times of the day and year. In most cases, hybrid systems are stand-alone systems (not connected to an external grid system). Thus, in the absence or insufficient presence of wind or the solar system power can be supplied from batteries and/or an engine-generator powered by conventional fuels, such as diesel. When the batteries run out of energy, they can be recharged by a conventional engine generator. These make the system complex but can be made to operate automatically with modern electronic controllers. The battery capacity should be large to the extent to be able to supply the required electrical energy needs during non-charging periods. The size of battery banks is typically enough to supply the electric load for one to three days.

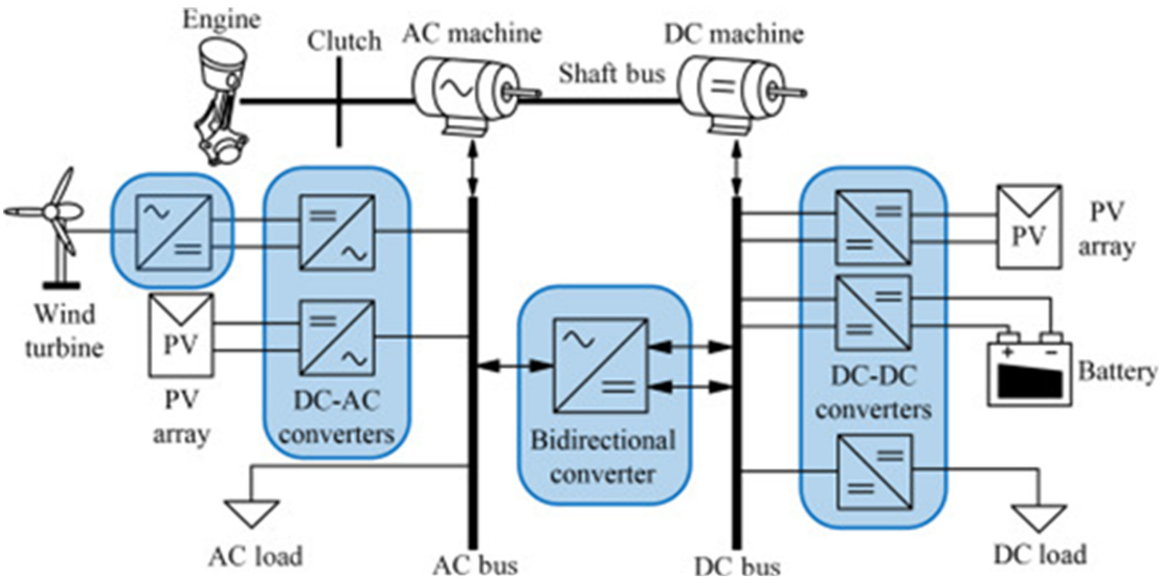

Figure 5. Hybrid power system-combined multiple sources for non-intermittent power supply [56].

Hybrid systems conglomerate different components in a single system, thereby enhancing the overall advantage of benefits when compared to single-sourced dependent systems. Previously, they are designed to incorporate non-renewable generation (e.g., diesel generators) with battery energy storage systems (BESSs). But in recent times, it has been expanded to incorporate systems that are 100% based on renewable energy (e.g., solar photovoltaic and wind) or a combination of distinct energy storage systems [56]. Hybrid systems have played a vital role in domestic and agricultural applications in the various cities in Oman. The integration of a PV system and hydropower plant has been employed to power a smart irrigation system in Oman. Wesam H. Beitelmal et al., 2020 [57] reported the availability of hybrid energy systems for applications in a factory in Oman. The HOMER software was employed to investigate and compare the application and performance limits of two renewable hybrid energy systems: the photovoltaic/battery (PV/B) hybrid energy system and the photovoltaic/wind turbine/battery (PV) system/WT/B). The PV/WT/B and PV/B systems show better electricity production (higher) and low cost of energy (COE) and net present cost (NPC) values making the system the most economically viable. Hussein A. Kazem et al., 2016 [58] investigated the optimum design and evaluation of a hybrid solar/wind/diesel power system for Masirah Island, Oman. They investigated the possibility of combining renewable energy sources with a diesel power plant. Here HOMER software coupled with other simulation analyses were employed to propose the energy generation from different hybrid power sources or systems including diesel generators only, wind/diesel/battery, PV/diesel/battery, and PV/wind/diesel/battery. The results vividly maintained that up to 75 % reduction in total energy cost could be achieved with a PV/wind/diesel hybrid power system and up to 25% reduction in greenhouse emissions [58]. Yuzheng Lu et al., 2016 [59] reviewed the hybrid power generation system of solar energy and fuel cells. The paper highlights the integration of solar energy and low-temperature solid oxide fuel cells. They proposed a novel integrated solar cell and fuel cell device with the capacity to simultaneously convert solar energy and chemical energy of the fuel to electric energy within the same device. M. J. Mbunwe et al., [60] developed a local hybrid solar/Wind/Diesel power integrated system that harnesses the sun and winds renewable energies to generate electricity. A. H. Al-Badi et al., 2013 [61] studied the optimum size of PV systems capable of providing the energy requirements of local sites located in Hajer Bani (HB) Hameed in the North of Oman. Employing HOMER software, the feasible systems, according to the net present cost was presented. The revenue for electric power generated from renewable energy resources was compared in the studied locations, including the duration required for the payback of the renewable energy components.

4. Performance model for PV system applications

Modeling of PV systems is necessary for optimizing the design of the PV system and predicting the performance of the PV system [62]. The percentage of solar radiation reaching (incident) a PV panel strongly depends on some variables or local parameters such: as the PV installation angle, tilt of the PV panel, hour angle, the PV system location based on latitudes, PV azimuth angle, hourly solar radiation, and the diffusion fraction of the solar irradiation [62–64]. Hence, the performance of a typical PV system can be estimated by estimating the hourly incident radiation on a horizontal or tilted PV surface [62–64]. The successes recorded in the design, installation, and estimating of the performance and efficiency of PV systems in Oman and beyond using modeling and experimental methods. Yousif JH,et al. [65] designed and implement a machine learning technique called Support Vector Machine (SVM) for the management of energy generation based on experimental using Modelling & Experimental approaches. The proposed model achieved less Mean Square Error (MSE) in comparison with other related work. Bin Omar AM et al. [66] developed of inverter simulation model in Grid-Connected Photovoltaic System (GCPV)in Matlab/Simulink software using modeling techniques. Results showed that the inverter output power from the simulation model was at an acceptable level (with minimal deviation) from the actual data. Chakraborty S et al. [67] create a trustworthy mathematical model to predict the potentials of several commercially available grid-connected solar energy plant technologies in various Indian regions using modeling methods. It was possible to predict the PV type with the best performance in the given. Shukla AK et al. [68] design a standalone rooftop solar PV system that can supply steady power for a hostel building making use of modeling approaches. Demonstrated the effect of operating parameters on the design and cost of energy generation. Kumar R, et al. [69] design and install a standalone solar PV System by utilizing modeling methods. The results reveal months with the best, least an average performance

4.1. Advanced control strategies of PV system

Solar photovoltaic (PV) energy conversion system has shown an increase at a moderate annual rate of 60% in the last five years [70]. The total amount of incident solar energy on the Earth is much greater than the current and anticipated energy needs of the world [71]. With a standalone system, the remote area is supplied by DC or AC power with converters and energy storage devices [72]. On the other hand, in grid-connected, generated power supply to the utility services without any energy storage types of equipment that have made added advantage of 99% benefit than a stand-alone system. The control of solar photovoltaic (PV) systems has recently attracted a lot of attention [73]. Over the past few years, many control objectives and controllers have been reported in the literature.

Two main objectives can be identified. The first is to obtain the maximum available PV power with maximum power point tracking (MPPT) control and the second objective is the PV power utilization[74]. Power can be obtained from the PV panels and then transformed to supply the load demand or be injected into the electrical power network. According to the application, PV systems can be classified into two categories: (i) islanded systems, and (ii) grid-connected systems [75]. The islanded system concept refers to systems that operate independent of the electrical grid. In islanded systems, ac or dc loads are directly supplied by the PV energy source. The majority of loads are AC, although the number of DC loads has dramatically grown as a result of the use of renewable energy sources to provide DC power. Servers, data centers, lighting systems, electric motors for ventilation and air conditioning systems, electric cars, and desktop computers are a few examples of possible DC loads [75]. Any load or customer linked to the grid can consume the electricity produced by grid-connected systems, which inject it into the electrical network. The center bricks carry out the energy conversion. This function is performed by power converters and electronic circuits based on power switching devices. Some possible system topologies for islanded and grid-connected systems Power converters are essential parts of PV systems because they provide control functions. Systems that are linked to the grid and those that are isolated and have different control requirements. Both situations call for current/voltage controllers and MPPT algorithms. It is feasible to integrate extra energy management controllers for energy storage systems (ESS) and filters in island systems to enhance the caliber of power delivered to loads [76]. Power inverters convert the DC voltage PV output for grid-connected systems into AC waveforms for the electrical power grid. At the point of common coupling (PCC), the AC waveform must meet the amplitude and frequency specifications [77]. Phase locked loop (PLL) methods or synchronization algorithms are needed to synchronize the inverter outputs with the grid voltages to secure the connection. Controlling the harmonic content that is injected at the PCC as a result of the inverter's semiconductors being switched is also essential [77]. In addition to a synchronization algorithm and power quality management, notions of quality, continuity, and dependability also call for additional functions including anti-islanded protection, energy storage regulation, active power control, and grid support.

Table 1. Controllers in PV systems.

Level	Control objective	Strategy	References
1	Current/voltage	PI controllers Predictive control Passivity-based control sliding Droop control Intelligent controllers actively reject disturbances	[78]
	MPPT	modernized classical intelligent algorithms	[78,79]
2	Power quality	Active filters—Hybrid filters	[80,81]
	Grid support	Frequency voltage	[82]
3	PV monitoring	Neural network-Genetic algorithms-Machine learning	[83]
	Energy storage	Power control	[84]

Comparatively speaking to islanded systems, the operation of grid-connected PV systems is complicated. The higher standards of rules implemented as a result make control actions more complicated. Island-based and grid-connected systems' control needs [77]. In general, there are three tiers of controllers: fundamental control loops for photovoltaic systems; (ii) controls required for legal requirements; and (iii) sophisticated controllers. The table provides a broad summary of the utilized controllers.

4.1.1. Distributed event-triggered hierarchical control of PV inverters to provide multi-time scale frequency response for AC microgrid

The frequency stability of power networks has recently been challenged by the decline in system inertia brought about by the increased penetration inverter-interfaced renewable energy [85]. Due to its advantages of being clean, quiet, and simple to harvest, solar photovoltaic (PV) power generation is one of the most promising and widely used renewable energy-based power-generating technologies [86]. Since there is no capacity set aside to offer frequency response, PV systems typically operate at their maximum power point (MPP). However, the capacity for frequency control of traditional synchronous generators is deteriorating as more and more of them are being replaced with PV power generation. Although constructing more and more energy storage systems can also provide frequency regulating service (ESS). The ESS, however, often has higher costs and a shorter lifespan than PV systems [87]. Additionally, adding ESS will raise the power system's investment and maintenance costs. As a result, frequency response auxiliary service offered by PV systems will unavoidably exist, which is also the primary driving force behind this study. The hierarchical control approach is used in conventional power systems to regulate a power system's frequency [88]. Governors of distributed generators (DGs) typically follow proportional droop control in primary frequency response. By effectively allocating the AGC instructions among the many power plants that take part in frequency regulation, the AGC control center typically seeks to remove the steady inaccuracy brought on by primary control in secondary frequency response. A PV plant often has many PV inverters, which should be mentioned. However, conventional secondary frequency control is created from the viewpoint of the system operators without taking into account how to distribute the reference instruction given by a high-level AGC control center among many PV inverters in a PV plant. Zhongwen Li et al. [89] has suggested a unique distributed event-triggered hierarchical control (DEHC) of PV inverters, which enables PV systems to offer multi-time scale frequency response for AC microgrids. Some PV inverters work in frequency regulation (FR) mode for the main frequency response (PFR) by automated reloading, and their neighboring DC/AC converters can acquire the available MPP reference while they are in MPPT mode. As a result, it demonstrates the benefit of not requiring irradiance sensors and MPP estimators.

4.1.2. Adaptive power point tracking control of PV system for primary frequency regulation of AC microgrid with high PV integration

Recent years have seen a rise in interest in power generation based on renewable and sustainable energy as a result of rising energy needs and environmental protection regulations [80]. There has been a noticeable increase in the power penetration from PV systems in the worldwide electrical sector over the past ten years due to photovoltaic (PV) panels' efficiency, lack of noise, and ease of energy harvesting. Several nations have established various long-term goals for expanding electricity generation from PVs [90]. As a result, both the electric power grid and microgrid systems will continue to use more electricity generated by PV systems. The maximum power point tracking (MPPT) option is typically used by PV systems to gather the most energy possible. However, due to the intermittent and stochastic nature of PVs, maintaining the stability of a microgrid's frequency will be a difficult task as PV penetration into microgrids increases [91]. There are typically three approaches that may be used to control the frequency of an AC microgrid with a high PV penetration: the energy storage system (ESS) based approach, the dump load based approach, and the PV curtailment approach. In terms of the ESS-based approach, PV systems typically run in MPPT mode, and frequency variation is controlled by setting up and using an energy storage system [92]. The lifespan of present storage technologies, however, is often shorter than that of PV system components, and storage technologies are far more expensive than PV. Additionally, the investment and maintenance expenses would rise with these frequency control techniques based on energy storage. Regarding the dump load-based technique, the dump load will use energy to balance the power consumption and generation in a microgrid when there is excess power, such as when the PVs create more energy than the load demand. Therefore, this approach can only control frequency rise when power is in excess; it cannot control frequency decline when power is insufficient. Additionally, the dump load's nonlinear properties will cause harmonics to be injected into the microgrid, which will negatively impact the power quality [93]. When it comes to the PV curtailment approach, the PV systems often run below the maximum power point (MPP) to conserve some power for ancillary functions like frequency regulation. Although running the PVs below MPP will result in opportunity cost, producing a power reserve, the reserved power can be compensated in the energy reserve market [94]. Additionally, the PVs are connected to power electronic converters that have a quick frequency reaction time and have lower maintenance costs than storage systems. Several researchers studied the PV curtailment-based frequency regulation method. Zhongwen et al. [94] have studied, a unique MPPT based on sliding mode control (SMC) is initially introduced. It analyzes the power-voltage and the power-voltage derivative dPpv/dVpv characteristics of a PV array. Then, an SMC-based adaptive power point tracking (APPT) control strategy is also put forth to provide the bi-directional primary frequency regulation (BPFR) of an AC microgrid. APPT can adaptively regulate the sliding mode surface based on the measured frequency of the microgrid to provide adaptive power reserves. By releasing the stored energy or boosting the PV systems' reserves, the term "BPFR" refers to the ability to regulate the AC microgrid's frequency both up and down.

4.2. Operation of PV systems under actual operating conditions

The photovoltaic solar cell operates in different conditions and is influenced by several factors. Some of the operating conditions will be discussed in the subsequent section of this review paper.

4.2.1. Partial shading and Electrical characteristics of a PV module on partial shading short circuit failure of bypass diodes

In PV (Photovoltaic) systems, the PV array is made up of parallel strings of PV modules, each of which is made up of modules connected in series. The significant reasons for jumble in PV arrays are cases that which one is a bypass diode worked by shading condition, and the other is a short circuit failure of the bypass diode. The number of shaded modules and shading factor are primary factors that determined the partial shading operating condition. The partial shading working condition is portrayed by the concealing variable and number of unshaded modules. Partial shading occasion examination began when the contrast between the estimation value of irradiance sensors at the closures of the string surpassed 50 W/m^2 and finished when the irradiance distinction presently not surpassed 50 W/m^2 [95]. Investigated the issues with PV arrays under partial shadowing and a bypass diode short circuit failure using simulation to simulate the mathematical equation. The same model was also used to simulate the electrical and thermal properties of an outdoor module that was constructed assuming a real PV array.

The simulation model demonstrates that the mismatch current resulting from a bypass diode failure is proportional to the quantity of parallel PV array threads and fault diodes. According to the findings of a field trial, whether the system was operating or not, a reverse current did not flow into the mismatching string under partial shading, although the temperature of the bypass diode was 15–23 °C higher in the system operation scenario.

The study also established that a PV system's mismatch loss is caused by the bypass diode's short circuit failure and that a PV array's electric-thermal issues are brought on by the reverse current.

The past examination has shown that reverse current doesn't stream in a mismatch circumstance because of shading [95]. In any case, it streams in bypass diode issue condition. At the point when one bypass diode is led by fractional overshadowing, the yield voltage (¼Maximum Voltage) of the PV module diminishes by 1/3 (Commercial PV module with 6 sun-based cell strings, one bypass diode associated 2 solar cell strings). Be that as it may open circuit voltage diminishes however much the working voltage of bypass diode contrasted with the ordinary state. This is because solar cell is a free current source and produce power when there is light. As displayed in Figure 6, regardless of whether the bypass diode works, the open circuit voltage of the module doesn't diminish essentially, so there will be no voltage mismatch between PV strings.

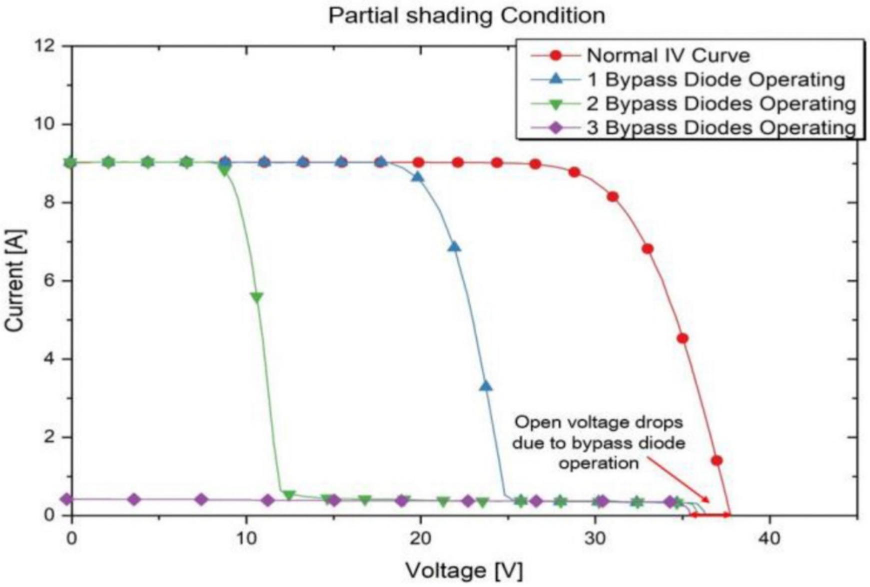

Figure 6. I–V curves of a PV module due to the number of bypass diodes operating by partial shading [95].

Bypass diodes are introduced inside the intersection box of the PV module working in shading conditions, which forestalls the resulting loss of module and problem spot damage of solar cells.

Be that as it may, assuming there are short circuits of bypass diodes in the PV module, the short out current is equivalent to the ordinary state, yet the open circuit voltage and maximum power are fundamentally diminished. The disappointment of bypass diode loses the qualities of the diode and turns into a miniature obstruction. Thus, solar cells inside PV modules that are associated with faulty bypass diodes comprise a short circuit, which can communicate as a comparable circuit, as displayed in Figure 7.

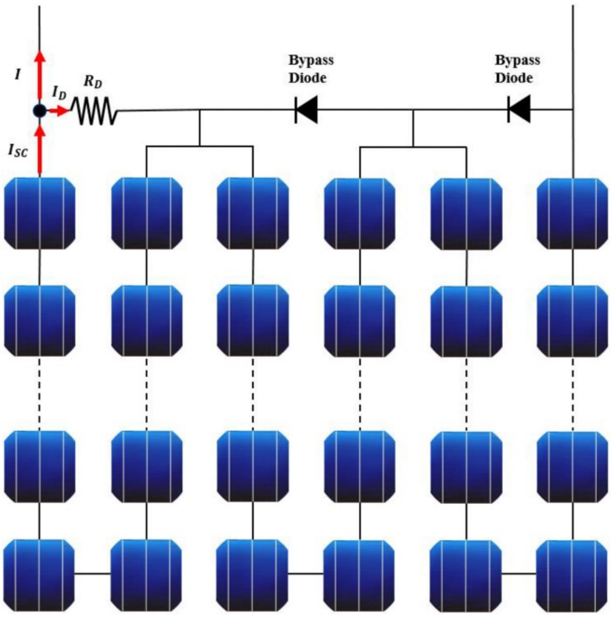

Figure 7. Schematic diagram of a PV module with a fault bypass diode [95].

Right now, regardless of whether there is no overshadowing, the ongoing current flows through the faulty bypass diode as shown in Figure 7. Failure of the bypass diode and partial shadowing are the most frequent causes of mismatch loss in PV systems. Different PV strings linked in parallel to the PV array function differently as a result of these mismatch variables. The shadows cast by obstructions at moments and swiftly moving clouds are the principal causes of partial shade. Studies that estimate and analyze the reverse current caused by partial shadowing and a shorted string in a PV system have also been published [95]. This study found that as the number of shaded PV modules increased, a little amount of reverse current flowed, but a reverse current significantly increased as the number of short-circuited PV modules increased.

4.2.2. Maximum power point characteristics

The Electrical properties of solar generators can have several maximum power points (MPP) under non-uniform operating conditions, such as partial shadowing. Lappalainen et al. [96] investigated the behavior of maximum power point characteristics of partially shaded PV stings. It was revealed that the voltage of the global MPP can fluctuate across a wide voltage range under such conditions. The authors recommended that it would be preferable to keep the inverter operation point constantly at voltages close to the nominal MPP voltage because the highly variable global MPP voltage makes MPP tracking difficult

Yang, et al. [97] conducted an in-depth review and analysis of the most advanced maximum power point tracking (MPPT) techniques for photovoltaic (PV) systems under partial shadowing conditions (PSC). To ensure that PV systems can harvest the greatest amount of power, the study exploit and analyzed various MPPT control mechanisms. It was recommended that readers can choose the best options based on application requirements and system characteristics.

4.2.3. Mismatch losses in PV

In photovoltaic (PV) systems, mismatch losses are a significant problem that is primarily brought on by partial shade. More so, the worst mismatch losses are brought on by sharp shadows. However, for rooftop and residential installations, these shadows are a common issue often experienced. In large-scale PV plants, moving clouds, which induce gradual irradiance transitions and often only result in small irradiance variations between neighboring PV modules, are mostly responsible for partial shade. The impacts of current mismatch and shading on the power result of single photovoltaic (PV) modules are very much dissected, however just a couple of examinations address mismatch losses at a PV system level that likewise limit the yearly energy yield. The straightforward inquiry, of what occurs in PV strings with various quantities of modules associated in parallel has not yet been examined exhaustively. In the event of strings with inconsistent module count, the system developer should choose whether to utilize inverters with various multiple power point (MPP) trackers, and module-power enhancers, or to abbreviate all strings for adjusting the system. The mathematical demonstration of PV frameworks with strings of various lengths lined up with a few others which have an equivalent module count renders mismatch losses below 1% for most system designs. For arrangements where one string is one module more limited than the others, the mismatch losses fall below 0.5%. In this way strings with inconsistent length may well interface with a financially savvy single-MPP inverter without causing critical energy yield losses. Also, ordinary thin film PV modules are less delicate to muddle than crystalline silicon-based ones. Lappalainen et al. [98] performed an analysis of the mismatch losses of PV arrays with various design and electrical setups using a MATLAB/Simulink model. Over about 27,000 irradiance transitions found in measured irradiance data are presented in this research. It also investigated how moving clouds' mismatch losses affect PV plants' total ability to produce energy. The result showed that shifting cloud-related mismatch losses are not a significant issue for large-scale PV systems. The fact that the mismatch losses speed up power variations relative to irradiance fluctuations is an intriguing observation from a practical standpoint.

4.2.4. Factors that affect mismatch losses

The system output loss on the PV system is caused by these mismatch variables changing the Maximum Power Point (MPP) of PV modules or strings. Sharp shadows and partial shade both contribute significantly to mismatch losses in photovoltaic (PV) systems, with partial shading accounting for most mismatch losses. However, in large-scale PV plants, moving clouds, which generate gradual irradiance transitions and often only slight irradiance variations between neighboring PV modules, are the primary cause of shading events. Even the largest PV power plants are significantly impacted by the irradiance transitions brought on by cloud shadow edges, which have an average length of over 150 m. These irradiance changes can result in maximum power point tracking failures and large swings in the output power of PV systems, in addition to mismatch losses

The impact of PV array form, electrical configuration, and orientation on mismatch losses induced by moving clouds was examined by Lappalainen et al. The study was based on apparent velocity and other observed variables. The findings of this investigation supported an earlier finding that the mismatch losses reduce with shorter PV strings. Additionally, it was discovered that the array orientation significantly influences the mismatch losses of the examined array architectures. When the shadow edges moved predominantly in a direction perpendicular to the PV strings, the mismatch losses were at their lowest. The mismatch losses between the various electrical array topologies under investigation varied very little. According to the findings, moving clouds' mismatch losses have a negligible impact on the overall effectiveness of PV arrays. To reduce the output mismatch of PV systems by computer simulation or tests, numerous studies have been published. Applying DC-DC converters, according to earlier studies, enhanced the performance of PV systems and recovered mismatch losses brought on by shade [99]. To enhance maximum power from mismatch losses on a non-uniform PV array by aging PV modules, a current collector optimizer (CCO) scheme has been recommended [100]. Additionally, a recent experimental investigation found that the improved PV module connectivity at the string or array level has enhanced the maximum power production in partial shade situations [101].

4.2.5. Identification of cloud enhancement events

A cloud enhancement (CE) occasion is frequently characterized by contrasting estimated irradiance with anticipated clear sky irradiance [102]. In like that, a CE occasion begins when the irradiance surpasses the clear sky irradiance and closes when the irradiance diminishes underneath the reasonable sky irradiance. In any case, according to the PV system activity perspective, a more reasonable way is to involve a static irradiance value as a source of perspective rather than the clear sky irradiance that is location explicit. Then again, the utilization of a static irradiance value as the constraint of CE occasions has the disadvantage that contingent upon the location, non-CE occasions with enormous clear sky irradiance might be incorporated, or circumstances with real CE during little clear sky irradiance that don't arrive at the static edge might be prohibited from the review. A normal static worth used to characterize CE occasions is the solar constant [103]. Be that as it may, the utilization of solar steady isn't legitimate from the PV power activity perspective.

The irradiance incident on photovoltaic (PV) generators can be significantly greater than the anticipated irradiance from a clear sky. The maximum output of the PV generator may surpass the rated power of the inverter linking the generator to the grid as a result of this occurrence, known as cloud enhancement (CE). Based on measured irradiances and cloud edge velocities, CE event features and the effects of CE on the electrical functioning of PV generators were explored. The maximum peak irradiance during eleven months in San Diego, California, was 1466 W/m^2. Furthermore, the maximum simulated average irradiances for generators up to 1 MW exceeded 1400 W/m^2 [13]. The longest CE events longer than 1000 W/m^2 were measured at distances of many kilometers. These findings suggest that CE events can have a considerable impact on even sizable utility-scale PV power installations. A thorough spatiotemporal model was also used to mimic the functioning of three PV plants over roughly 2400 observed CE events [13]. Additionally, the effects of inverter sizing on plant operation were investigated. It was discovered that the negative effects of CE on PV system operation grew worse with higher DC/AC ratios. The energy lost as a result of power interruptions during the CE events ranged from 5% to 50% of the total energy production [104]. Even though CE has an impact on how PV plants operate, these effects were minimal in terms of total energy because CE occurrences that have the greatest impacts on PV system performance are extremely infrequent, which means that CE does not significantly hinder how PV systems operate.

5. Conclusions and future remarks

The sun is the sole source of solar energy, inexhaustible, and can therefore be regarded as an endless source of energy. PV systems can convert the sun's energy into electric power/energy and heat respectively. Since the source of solar energy is the sun, the solar radiation data of a location is vital for the planning and designing of the PV system. The solar radiation potentials are greatest for countries located close to the equator, which means they receive the highest sunlight. Although, PV has been applied in all the regions in the world, countries or cities receiving the highest solar radiation have the greatest potential for solar energy exploitation and application.

Generally, Oman's economy is mostly dependent on oil and gas. Thus, the power sector derives most of its energy from natural gas: 97.5% and Diesel: 2.5% [41]. Hence, renewable energies such as solar or wind have a negligible contribution to the energy sector. This is not friendly to the environment and ecosystem in the long run. The insufficient reservoirs of natural resources cannot guarantee the continued practice of the current trend. Therefore, the current review juxtaposed the solar properties of this region with the performance of PV systems. It is intended to contribute to sensitizing the inclusion of solar energy in the power sector of the cities of Oman. Dhofar in Salalah of Oman for example is one of the many cities in Oman with the greatest solar radiation data as shown in Figure 8.

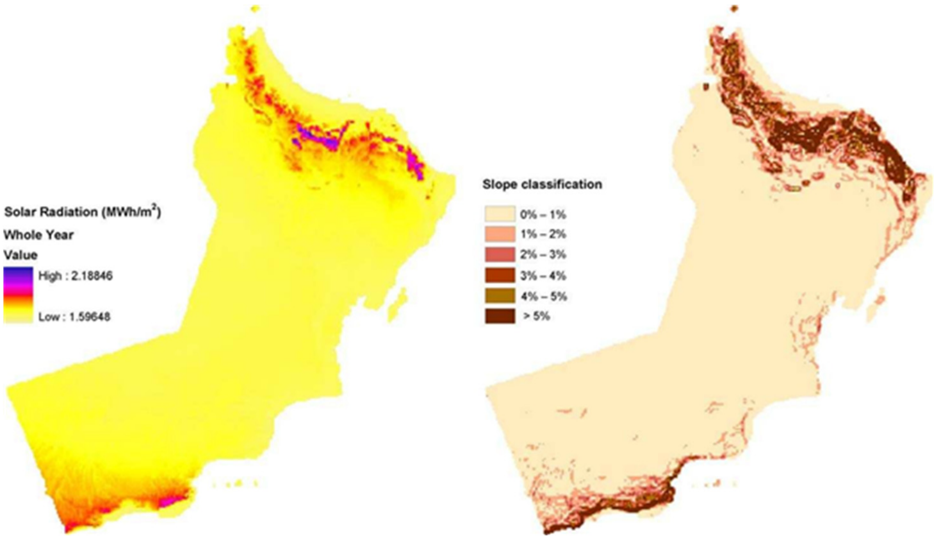

Figure 8. Yearly solar radiation density and slopes classification over the land of Oman: (a) yearly solar radiation in Wh/m2, (b) classification of slopes in percent [105].

Here we reviewed the solar potentials of this region and highlighted the reports reiterating the potential of adopting solar energy to replace the traditional non-renewable energy sources presently being used in the country/cities. The reports reiterated that the solar potential of Dhofar is suitable for solar energy application and can be beneficial mostly in remote areas and farmlands where it is difficult to assess the national grid. This report also reviewed different advanced control strategies considering the operation of the PV systems under actual operating conditions. It is obvious from this report that, the abundant solar resources in Dhofar, Salalah-Oman can enhance the installation, production, and applications of solar technology in Salalah. Hence more work is required to improve the research on renewable energy (mostly solar energy, and wind) which could contribute to reducing global emission, and help the growth of the energy sector, and the country's economy in general.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

Fadhil Khadoum Alhousni and Firas Basim Ismail conceived the review idea and developed the research theory, methodology, and draft manuscript preparation.

Fadhil Khadoum Alhousni drafted the manuscript and Paul C. Okonkwo and Hassan Mohamed performed study conception and reviewed the manuscript.

Fadhil Khadoum Alhousni, Bright O. Okonkwo, and Omar A.Al-Shahri designed the proof outline and contributed to the implementation of the research.

In summary, all authors have participated in the conception and design, analysis and interpretation of the data, and approval of the final version.

References

1. Khamisani AA (2019) Design methodology of off-grid PV solar powered system (A case study of solar powered bus shelter). Goolincoln Avenue Charleston, IL: Eastern Illinois University. Available from: https://castle.eiu.edu/energy/Design%20Methodology%20of%20Off-Grid%20PV%20Solar%20Powered%20System_5_1_2018.pdf.
2. Barhoumi EM, Farhani S, Okonkwo PC, et al. (2021) Techno-economic sizing of renewable energy power system case study Dhofar Region-Oman. *Int J Green Energy* 18: 856–865. https://doi.org/10.1080/15435075.2021.1881899
3. Jha SK (2013) Application of solar photovoltaic system in Oman—Overview of technology, opportunities and challenges. *Int J Renewable Energy Research* (IJRER) 3: 331–340. Available from: https://dergipark.org.tr/en/pub/ijrer/issue/16079/168241.
4. Wazwaz A, AlHabshi H, Gharbia Y (2013) Investigations of the measured solar radiation, relative humidity and atmospheric temperature and their relations at Dhofar University. Available from: http://www.i-asem.org/publication_conf/anbre13/M4D.6.ER654_526F.pdf.
5. Kazem H, Chaichan M (2016) Design and analysis of standalone solar cells in the desert of Oman. *J Sci Eng Research* 3: 62–72.
6. Abdul-Wahab S, Charabi Y, Al-Mahruqi AM, et al. (2019) Selection of the best solar photovoltaic (PV) for Oman. *Sol Energy* 188: 1156–1168. https://doi.org/10.1016/j.solener.2019.07.018
7. Kazem HA, Khatib T, Alwaeli AA (2013) Optimization of photovoltaic modules tilt angle for Oman, 703–707. http:/doi.org/ 10.1109/PEOCO.2013.6564637
8. Delyannis E, Belessiotis V (2013) Solar water desalination. *Ref Module Earth Syst Environ Sci,* https://doi.org/10.1016/B978-0-12-409548-9.01492-5
9. Tripanagnostopoulos Y (2012) Photovoltaic/thermal solar collectors. *Comprehensive Renewable Energy* 3: 255–300. https://doi.org/10.1016/B978-0-12-819727-1.00051-0

10. Amelia A, Irwan Y, Leow W, et al. (2016) Investigation of the effect temperature on photovoltaic (PV) panel output performance. *Int J Adv Sci Eng Inf Technol* 6: 682–688.
11. Hirst L (2012) Principles of solar energy conversion. *Compr Renewable Energy* https://doi.org/10.1016/B978-0-08-087872-0.00115-3
12. Hachchadi O, Bououd M, Mechaqrane A (2021) Performance analysis of photovoltaic-thermal air collectors combined with a water to air heat exchanger for renewed air conditioning in building. *Environ Sci Pollution Res* 28: 18953–18962. https://doi.org/10.1007/s11356-020-08052-4
13. Lappalainen K, Kleissl J (2020) Analysis of the cloud enhancement phenomenon and its effects on photovoltaic generators based on cloud speed sensor measurements. *J Renewable Sustainable Energy* 12: 043502. https://doi.org/10.1063/5.0007550
14. Aktaş A, Kirçiçek Y (2021) Examples of solar hybrid system layouts, design guidelines, energy performance, economic concern, and life cycle analyses. *Sol Hybrid Syst: Design Appl,* 331–349.
15. Aktas A, Kirçiçek Y (2021) Solar hybrid systems: Design and application.
16. Bini M, Capsoni D, Ferrari S, et al. (2015) Rechargeable lithium batteries: key scientific and technological challenges, 1–17. https://doi.org/10.1016/B978-1-78242-090-3.00001-8
17. Phadke AA, Jacobson A, Park WY, et al. (2017) Powering a home with just 25 watts of solar PV: super-efficient appliances can enable expanded off-grid energy service using small solar power systems. Available from: https://escholarship.org/uc/item/3vv7m0x7.
18. Huld T (2011) Estimating solar radiation and photovoltaic system performance, the PVGIS approach, 1–84.
19. Ibrahim K, Gyuk P, Aliyu S (2019) The effect of solar irradiation on solar cells. *Sci World J* 14: 20–22. Available from: https://www.ajol.info/index.php/swj/article/view/208351.
20. Narayan S (2015) Effects of various parameters on piston secondary motion. SAE Technical Paper. Available from: https://www.academia.edu/download/57982967/2015-01-0079.pdf.
21. Almosni S, Delamarre A, Jehl Z, et al. (2018) Material challenges for solar cells in the twenty-first century: Directions in emerging technologies. *Sci Technol Adv Mater* 19: 336–369.
22. Luceño-Sánchez JA, Díez-Pascual AM, Peña Capilla R (2019) Materials for photovoltaics: State of art and recent developments. *Int J Molecular Sci* 20: 976. https://doi.org/10.3390/ijms20040976
23. Zhou D, Zhou T, Tian Y, et al. (2017) Perovskite-based solar cells: Materials, methods, and future perspectives. *J Nanomater* 2018: 1–15. https://doi.org/10.1155/2018/8148072
24. Meroni SM, Worsley C, Raptis D, et al. (2021) Triple-Mesoscopic carbon perovskite solar cells: Materials, Processing and Applications. *Energies* 14: 386. https://doi.org/10.3390/en14020386
25. Duan L, Hu L, Guan X, et al. (2021) Quantum dots for photovoltaics: A tale of two materials. *Adv Energy Mater* 11: 2100354. https://doi.org/10.1002/aenm.202100354
26. Li Z, Boyle F, Reynolds A (2011) Domestic application of solar PV systems in Ireland: The reality of their economic viability. *Energy* 36: 5865–5876. https://doi.org/10.1016/j.energy.2011.08.036
27. Jones GJ (1980) Photovoltaic systems and applications perspective. Available from: https://www.osti.gov/servlets/purl/5496939.
28. Clarke R, Giddey S, Ciacchi F, et al. (2009) Direct coupling of an electrolyser to a solar PV system for generating hydrogen. *Int J Hydrogen Energy* 34: 2531–2542. https://doi.org/10.1016/j.ijhydene.2009.01.053

29. El Chaar L (2011) Photovoltaic system conversion. *Alternative Energy Power Electron*, 155–175. https://doi.org/10.1016/B978-0-12-416714-8.00003-2
30. Yi Z, Dong W, Etemadi AH (2017) A unified control and power management scheme for PV-battery-based hybrid microgrids for both grid-connected and islanded modes. *IEEE Trans Smart Grid* 9: 5975–5985. https/doi.org/10.1109/TSG.2017.2700332
31. Tudu B, Mandal K, Chakraborty N (2019) Optimal design and development of PV-wind-battery based nano-grid system: A field-on-laboratory demonstration. *Front Energy* 13: 269–283. https://doi.org/10.1007/s11708-018-0573-z
32. Poompavai T, Kowsalya M (2019) Control and energy management strategies applied for solar photovoltaic and wind energy fed water pumping system: A review. *Renewable Sustainable Energy Rev* 107: 108–122. https://doi.org/10.1016/j.rser.2019.02.023
33. Lage-Rivera S, Ares-Pernas A, Abad M-J (2022) Last developments in polymers for wearable energy storage devices. *Int J Energy Res*. https://doi.org/10.1002/er.7934
34. Kumar RR, Gupta AK, Ranjan R, et al. (2017) Off-grid and On-grid connected power generation: A review. *Int J Comput Applications,* 164.
35. Chang W (2013) The state of charge estimating methods for battery: A review. *ISRN Appl Math.* http://dx.doi.org/10.1155/2013/953792
36. Zhou W, Zheng Y, Pan Z, et al. (2021) Review on the battery model and SOC estimation method. *Processes* 9: 1685. https://doi.org/10.3390/pr9091685
37. Adefarati T, Bansal RC (2019) Energizing renewable energy systems and distribution generation. *Pathways Smarter Power Syst,* 29–65. https://doi.org/10.1016/B978-0-08-102592-5.00002-8
38. Aghaei M, Kumar NM, Eskandari A, et al. (2020) Solar PV systems design and monitoring. Photovoltaic. *Sol Energy Convers*, 117–145. https://doi.org/10.1016/B978-0-12-819610-6.00005-3
39. Rehman S, Ahmed M, Mohamed MH, et al. (2017) Feasibility study of the grid connected 10 MW installed capacity PV power plants in Saudi Arabia. *Renewable Sustainable Energy Rev* 80: 319–329. https://doi.org/10.1016/j.rser.2017.05.218
40. Al-Badi A, Malik A, Gastli A (2009) Assessment of renewable energy resources potential in Oman and identification of barrier to their significant utilization. *Renewable Sustainable Energy Rev* 13: 2734–2739. https://doi.org/10.1016/j.rser.2009.06.010
41. Azam MH, Abushammala M (2017) Assessing the effectiveness of solar and wind energy in sultanate of Oman. *J Stud Res*. https://doi.org/10.47611/jsr.vi.539
42. Tabook M, Khan SA (2021) The future of the renewable energy in Oman: Case study of Salalah City. *Int J Energy Econ Policy* 11: 517. https://doi.org/10.32479/ijeep.11855
43. Al-Badi A, Albadi M, Al-Lawati A, et al. (2011) Economic perspective of PV electricity in Oman. *Energy* 36: 226–232. https://doi.org/10.1016/j.energy.2010.10.047
44. Chung MH (2020) Estimating solar insolation and power generation of photovoltaic systems using previous day weather data. *Adv Civil Eng.* https://doi.org/10.1155/2020/8701368
45. Jerez S, Tobin I, Vautard R, et al. (2015). The impact of climate change on photovoltaic power generation in Europe. *Nat Commun* 6: 10014. https://doi.org/10.1038/ncomms10014
46. Bendib B, Krim F, Belmili H, et al. (2014) Advanced Fuzzy MPPT controller for a stand-alone PV system. *Energy Procedia* 50: 383–392. https://doi.org/10.1016/j.egypro.2014.06.046
47. Kumar A, Bhat AH (2022) Role of dual active bridge isolated bidirectional DC-DC converter in a DC microgrid. *Microgrids*,141–155. https://doi.org/10.1016/B978-0-323-85463-4.00006-X

48. Salas V (2017) Stand-alone photovoltaic systems. *Perform Photovoltaic (PV) Syst,* 251–296. https://doi.org/10.1016/B978-1-78242-336-2.00009-4
49. Liao C, Tan Y, Li Y, et al. (2022) Optimal operation for hybrid AC and DC systems considering branch switching and VSC control. *IEEE Syst J.* https://doi.org/10.1109/JSYST.2022.3151342
50. Bughneda A, Salem M, Richelli A, et al. (2021) Review of multilevel inverters for PV energy system applications. *Energies* 14: 1585. https://doi.org/10.3390/en14061585
51. Kolantla D, Mikkili S, Pendem SR, et al. (2020) Critical review on various inverter topologies for PV system architectures. *IET Renewable Power Gener.* https://doi.org/10.1049/iet-rpg.2020.0317
52. Roos CJ (2009) Solar electric system design, operation and installation: An overview for builders in the US Pacific Northwest. Available from: https://rex.libraries.wsu.edu.
53. Al-Ktranee M, Bencs P (2020) Overview of the hybrid solar system. *Rev Faculty Eng Analecta Technica Szegedinensia*, 100–108. Available from: http://real.mtak.hu/111309/1/20200709_MA_BP_Hybrid_solar_system.pdf.
54. Badwawi RA, Abusara M, Mallick T (2015) A review of hybrid solar PV and wind energy system. *Smart Sci* 3: 127–138. https://doi.org/10.1080/23080477.2015.11665647
55. Li K, Liu C, Jiang S, et al. (2020) Review on hybrid geothermal and solar power systems. *J Cleaner Prod* 250: 119481. https://doi.org/10.1016/j.jclepro.2019.119481
56. Konstantinou G, Hredzak B (2021) Power electronics for hybrid energy systems. *Hybrid Renewable Energy Syst Microgrids*, 215–234. https://doi.org/10.1016/B978-0-12-821724-5.00008-8
57. Beitelmal WH, Okonkwo PC, Al Housni F, et al. (2020) Accessibility and sustainability of hybrid energy systems for a cement factory in Oman. *Sustainability* 13: 93. https://doi.org/10.3390/su13010093
58. Kazem HA, Al-Badi HA, Al Busaidi AS, et al. (2017) Optimum design and evaluation of hybrid solar/wind/diesel power system for Masirah Island. *Environ Develop Sustainability* 19: 1761–1778. https://doi.org/10.1007/s10668-016-9828-1
59. Sarkar J, Bhattacharyya S (2012) Application of graphene and graphene-based materials in clean energy-related devices Minghui. *Arch Thermodyn* 33: 23–40. https://doi.org/10.1002/er.1598
60. Mbunwe MJ, Ogbuefi U, Nwankwo C (2017) Solar hybrid for power generation in a rural area: its technology and application. *Proc World Congress Eng Comput Sci.* Available from: https://www.researchgate.net/publication/321171586.
61. Al-Badi A, Al-Toobi M, Al-Harthy S, et al. (2012) Hybrid systems for decentralized power generation in Oman. *Int J Sustainable Energy* 31: 411–421. https://doi.org/10.1080/14786451.2011.590898
62. Mustafa RJ, Gomaa MR, Al-Dhaifallah M, et al. (2020) Environmental impacts on the performance of solar photovoltaic systems. *Sustainability* 12: 608. https://doi.org/10.3390/su12020608
63. Chikate BV, Sadawarte Y, Sewagram B (2015) The factors affecting the performance of solar cell. *Int J Comput Appl* 1: 0975–8887. Available from: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.742.1259&rep=rep1&type=pdf.
64. Vidyanandan K (2017) An overview of factors affecting the performance of solar PV systems. *Energy Scan* 27: 216. Available from: https://www.researchgate.net/publication/319165448.

65. Yousif JH, Kazem HA (2016) Modeling of daily solar energy system prediction using soft computing methods for Oman. *Res J Appl Sci Eng Technol* 13: 237–244. https://doi.org/10.19026/rjaset.13.2936
66. Bin Omar AM, Binti Zainuddin H (2014) Modeling and simulation of grid inverter in grid-connected photovoltaic system. *Int J Renewable Energy Res (IJRER)* 4: 949–957. Available from: https://dergipark.org.tr/en/pub/ijrer/issue/16073/168033.
67. Chakraborty S, Kumar R, Haldkar AK, et al. (2017) Mathematical method to find best suited PV technology for different climatic zones of India. *Int J Energy Environ Eng* 8: 153–166. https://doi.org/10.1007/s40095-016-0227-z
68. Shukla AK, Sudhakar K, Baredar P (2016) Design, simulation and economic analysis of standalone roof top solar PV system in India. *Sol Energy* 136: 437–449. https://doi.org/10.1016/j.solener.2016.07.009
69. Kumar R, Rajoria C, Sharma A, et al. (2021) Design and simulation of standalone solar PV system using PVsyst Software: A case study. *Mater Today: Proc* 46: 5322–5328. https://doi.org/10.1016/j.matpr.2020.08.785
70. Arulkumar K, Palanisamy K, Vijayakumar D (2016) Recent advances and control techniques in grid connected PV system—A review. *Int J Renewable Energy Res* 6: 1037–1049.
71. Gorjian S, Sharon H, Ebadi H, et al. (2021) Recent technical advancements, economics and environmental impacts of floating photovoltaic solar energy conversion systems. *J Cleaner Prod* 278: 124285. https://doi.org/10.1016/j.jclepro.2020.124285
72. Jing W, Lai CH, Wong WS, et al. (2018) A comprehensive study of battery-supercapacitor hybrid energy storage system for standalone PV power system in rural electrification. *Appl Energy* 224: 340–356. https://doi.org/10.1016/j.apenergy.2018.04.106
73. Das P, Das BK, Mustafi NN, et al. (2021) A review on pump-hydro storage for renewable and hybrid energy systems applications. *Energy Storage* 3: e223.https://doi.org/10.1002/est2.223
74. Liu L, Meng X, Liu C (2016) A review of maximum power point tracking methods of PV power system at uniform and partial shading. *Renewable Sustainable Energy Rev* 53: 1500–1507. https://doi.org/10.1016/j.rser.2015.09.065
75. Murillo-Yarce D, Alarcón-Alarcón J, Rivera M, et al. (2020) A review of control techniques in photovoltaic systems. *Sustainability* 12: 10598. https://doi.org/10.3390/su122410598
76. Worighi I, Maach A, Hafid A, et al. (2019) Integrating renewable energy in smart grid system: Architecture, virtualization and analysis. *Sustainable Energy Grids Networks* 18: 100226. https://doi.org/10.1016/j.segan.2019.100226
77. Metri JI, Vahedi H, Kanaan HY, et al. (2016) Real-time implementation of model-predictive control on seven-level packed U-cell inverter. *IEEE Trans Indust Electron* 63: 4180–4186. https://doi.org/10.1109/TIE.2016.2542133
78. Hasanien HM (2018) Performance improvement of photovoltaic power systems using an optimal control strategy based on whale optimization algorithm. *Electric Power Syst Res* 157: 168–176. https://doi.org/10.1016/j.epsr.2017.12.019
79. Zhang W, Zhou G, Ni H, et al. (2019) A modified hybrid maximum power point tracking method for photovoltaic arrays under partially shading condition. *IEEE Access* 7: 160091–160100. https://doi.org/10.1109/ACCESS.2019.2950375

80. Agrawal S, Vaishnav SK, Somani R (2020) Active power filter for harmonic mitigation of power quality issues in grid integrated photovoltaic generation system. *IEEE,* 317–321. https://doi.org/10.1109/SPIN48934.2020.9070979
81. Smadi AA, Lei H, Johnson BK (2019.) Distribution system harmonic mitigation using a pv system with hybrid active filter features. *IEEE*, 1–6. https://doi.org/10.1109/NAPS46351.2019.9000238
82. Nanou SI, Papakonstantinou AG, Papathanassiou SA (2015) A generic model of two-stage grid-connected PV systems with primary frequency response and inertia emulation. *Electric Power Syst Res* 127: 186–196. https://doi.org/10.1016/j.epsr.2015.06.011
83. Khan MA, Haque A, Kurukuru VB, et al. (2020) Advanced control strategy with voltage sag classification for single-phase grid-connected photovoltaic system. *IEEE J Emerging Selected Topics Indust Electron.* https://doi.org/10.1109/JESTIE.2020.3041704
84. Shan Y, Hu J, Guerrero JM (2019) A model predictive power control method for PV and energy storage systems with voltage support capability. *IEEE Trans on Smart Grid* 11: 1018–1029. https://doi.org/10.1109/TSG.2019.2929751
85. Kerdphol T, Rahman FS, Mitani Y (2018) Virtual inertia control application to enhance frequency stability of interconnected power systems with high renewable energy penetration. *Energies* 11: 981. https://doi.org/10.3390/en11040981
86. Chakraborty A (2011) Advancements in power electronics and drives in interface with growing renewable energy resources. *Renewable Sustainable Energy Rev* 15: 1816–1827. https://doi.org/10.1016/j.rser.2010.12.005
87. Rajan R, Fernandez FM, Yang Y (2021) Primary frequency control techniques for large-scale PV-integrated power systems: A review. *Renewable Sustainable Energy Rev* 144: 110998. https://doi.org/10.1016/j.rser.2021.110998
88. Jabir HJ, Teh J, Ishak D, et al. (2018) Impacts of demand-side management on electrical power systems: A review. *Energies* 11: 1050. https://doi.org/10.3390/en11051050
89. Li Z, Cheng Z, Si J, et al. (2022) Distributed Event-triggered Hierarchical Control of PV inverters to provide multi-time scale frequency response for AC microgrid. *IEEE Trans Power Syst*. https://doi.org/10.1109/TPWRS.2022.3177593
90. Lee H, Song HJ (2021) Current status and perspective of colored photovoltaic modules. *Wiley Interdisciplinary Rev: Energy Environ* 10: e403. https://doi.org/10.1002/wene.403
91. Shivashankar S, Mekhilef S, Mokhlis H, et al. (2016) Mitigating methods of power fluctuation of photovoltaic (PV) sources—A review. *Renewable Sustainable Energy Rev* 59: 1170–1184. https://doi.org/10.1016/j.rser.2016.01.059
92. Rodriguez RnL (2021) Energy management optimization of a wind-storage based hybrid power plant connected to an island power grid. Available from: https://tel.archives-ouvertes.fr/tel-03338743.
93. Elkadeem M, Wang S, Sharshir SW, et al. (2019) Feasibility analysis and techno-economic design of grid-isolated hybrid renewable energy system for electrification of agriculture and irrigation area: A case study in Dongola, Sudan. *Energy Convers Manage* 196: 1453–1478. https://doi.org/10.1016/j.enconman.2019.06.085
94. Li Z, Cheng Z, Si J, et al. (2021) Adaptive power point tracking control of PV system for primary frequency regulation of AC microgrid with high PV integration. *IEEE Trans Power Syst* 36: 3129–3141. https://doi.org/10.1109/TPWRS.2021.3049616

95. Lee CG, Shin WG, Lim JR, et al. (2021) Analysis of electrical and thermal characteristics of PV array under mismatching conditions caused by partial shading and short circuit failure of bypass diodes. *Energy* 218: 119480. https://doi.org/10.1016/j.energy.2020.119480
96. Lappalainen K, Valkealahti S (2021) Experimental study of the maximum power point characteristics of partially shaded photovoltaic strings. *Appl Energy* 301: 117436. https://doi.org/10.1016/j.apenergy.2021.117436
97. Yang B, Zhu T, Wang J, et al. (2020) Comprehensive overview of maximum power point tracking algorithms of PV systems under partial shading condition. *J Cleaner Prod* 268: 121983.
98. Lappalainen K, Valkealahti S (2017) Photovoltaic mismatch losses caused by moving clouds. *Sol Energy* 158: 455–461. https://doi.org/10.1016/j.solener.2017.10.001
99. Lappalainen K, Valkealahti S (2017) Effects of PV array layout, electrical configuration and geographic orientation on mismatch losses caused by moving clouds. *Sol Energy* 144: 548–555. https://doi.org/10.1016/j.solener.2017.01.066
100. Refaat A, Elgamal M, Korovkin NV (2019) A novel photovoltaic current collector optimizer to extract maximum power during partial shading or mismatch conditions. *IEEE*, 407–412. https://doi.org/10.1109/EIConRus.2019.8657173
101. Bana S, Saini R (2017) Experimental investigation on power output of different photovoltaic array configurations under uniform and partial shading scenarios. *Energy* 127: 438–453. https://doi.org/10.1016/j.energy.2017.03.139
102. Martins G, Mantelli S, Rüther R (2022) Evaluating the performance of radiometers for solar overirradiance events. *Sol Energy* 231: 47–56. https://doi.org/10.1016/j.solener.2021.11.050
103. Neale RE, Barnes PW, Robson TM, et al. (2021) Environmental effects of stratospheric ozone depletion, UV radiation, and interactions with climate change: UNEP environmental effects assessment panel, update 2020. *Photochem Photobiol Sci* 20: 1–67. https://doi.org/10.1007/s43630-020-00001-x
104. Petrone G, Spagnuolo G, Teodorescu R, et al. (2008) Reliability issues in photovoltaic power processing systems. *IEEE Trans Indust Electron* 55: 2569–2580. https://doi.org/10.1109/TIE.2008.924016
105. Gastli A, Charabi Y (2010) Solar electricity prospects in Oman using GIS-based solar radiation maps. *Renewable Sustainable Energy Rev* 14: 790–797. https://doi.org/10.1016/j.rser.2009.08.018