IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 27 June 2023, accepted 25 July 2023, date of publication 28 July 2023, date of current version 3 August 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3299815

TOPICAL REVIEW

Grid-Connected Solar PV Power Plants Optimization: A Review

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ABSTRACT Due to photovoltaic (PV) technology advantages as a clean, secure, and pollution-free energy source, PV power plants installation have shown an essential role in the energy sector. Nevertheless, the PV power plant cost of energy must be competitive when compared to traditional energy sources. Therefore, numerous studies are continuously being conducted aiming to optimize PV power plants, including components arrangements within the installation site, the inverter topology, cables, PV modules and inverters numbers, PV module tilt angle and shading effect. For selecting the most suitable combinations for system parameters, this study seeks to systematically analyze and synthesize the design of the PV power plant optimization from the current literature. The study also examines component sizing for PV power plants, involving PV modules tilt angle, inverter, transformer, and cables. Moreover, it provides an overview of the main components employed to install the PV power plant, which includes PV modules, inverter, transformer and wiring. It examines the different inverter topologies used in PV power plants along with a comparison between these topologies.

INDEX TERMS PV power plant, photovoltaic, optimization, grid-connected, optimal design, inverter.

I. INTRODUCTION

Energy is necessary to improve living standards and advance the economies of all nations [1]. Currently, most of the power is generated using fossil and nuclear resources, which have negative environmental effects, fluctuating costs, and resource limitation. The industrial sector is responsible for more than 75% of global greenhouse gas emissions (GHG). [2]. However, the limitations of fossil fuel supplies and the huge demand for power throughout the globe have significantly reduced the dependency of these energy systems [3].

In order to minimize CO_2 emissions caused by the current climate change and meet the goal of keeping global temperatures below 1.5°C, it is essential to use more renewable energy sources (RESs) [4]. In light of this, the transition towards RESs to generate electrical power instead of using fossil fuel sources is required [5]. By the end of 2021, more than 28.3% of electricity in the world is produced by RESs, as shown in Fig. 1. RESs share has increased by 7.9 % between 2011 and 2021 [6].

RESs, which includes wind, solar, biomass, geothermal as well as hydropower, are limitless and free sources of energy production. In addition, RESs are seen as a better option than fossil fuels for boosting energy growth and dependability. Due to the penetration of photovoltaic (PV), hydropower, and wind in the electrical sector, the electricity production from RESs is gradually expanding in terms of capacity and production [6]. The available RESs are combined with traditional sources to create the hybrid electrical system. It seeks to resolve the problems associated with RESs unpredictability and intermittency, such as solar and wind relying on weather conditions. Besides, hybridization is an effective strategy to supply reliable energy [7].

The associate editor coordinating the review of this manuscript and approving it for publication was Jahangir Hossain.

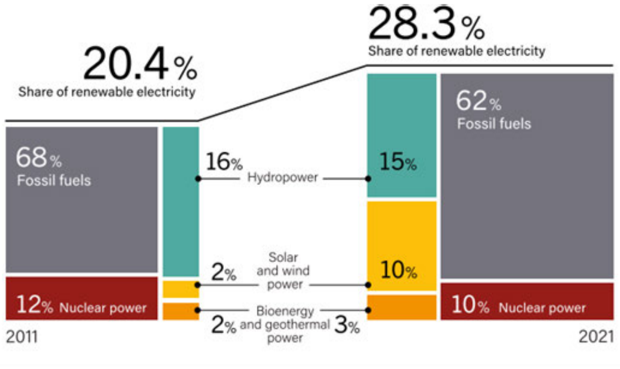

FIGURE 1. RESs share in global energy generation by the end of 2021.

Among the existing RESs technologies, PV technology demonstrates significant progress and efficiency for generating electricity. Compared to traditional power production and RESs like wind power, the highest rate of power investment is now being made in large-scale PV power plants [8]. Also, their penetration rate has increased noticeably, which includes small PV power plants [9]. Apart from that, the cost of a PV power plant is encouraging, given its significant advantages over other renewable energy sources. It requires less maintenance, has much lower service costs, reliable, silent, as well as very simple to install [10]. As opposed to that, the conversion efficiency of PV modules is continuosly increasing [11], [12]. In 2021, an additional 175 GW of capacity, PV energy increased. According to statistics, the PV market's capacity expanded from 70 GW in 2011 to 942 GW in 2021, as portrayed in Fig. 2 [6].

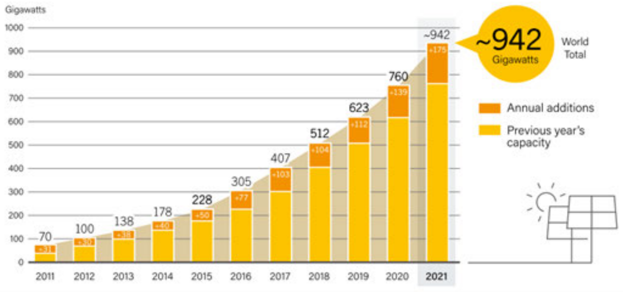

FIGURE 2. PV annual additions and global capacity, 2011-2021.

Recently, levelized cost of electricity (LCOE) for large-scale PV power plants dropped to 0.03 ($) [13] as a consequence of the decline in PV module costs of up to 86% between 2010 to 2017 [14]. Large-scale PV power plants have lower costs than other energy sources and are cost-competitive with them, according to the LCOE of various energy sources published by US investment bank Lazard. Fig. 3 demonstrates the LCOE comparison between PV power plants and the other energy sources for the year of 2021 [6].

PV technology was first implemented with a limited capacity (1 MW) in structures such as homes, companies, farms, and buildings [15]. Recent additions to the installation of PV power generating facilities include large (greater than 1 MW) and extremely large (greater than 100 MW). PV modules' technological advancement, inverters, and transformers, as well as the decline in the cost of these devices, are primarily responsible for the PV industry's explosive expansion. As a result, PV power plants' overall performance has improved greatly increased thanks to component technological advancements. Consequently, the energy cost per kW of PV power plants linked to electrical grid is consistently decreasing and is in competition with that of other clean and traditional sources of energy. In 2021, China will built hundreds of PV power plants of various sizes, leading the market for PV energy production with an annual additional capacity of approximately 54.9 GW, and the United States comes second by adding around 26.9 GW [6]. The location's solar energy potential, the system's components and topology, and the load all play major roles in how well a PV power plant linked to the main electrical network performs. The yearly electricity output of the PV plant is computed as the sum of its hourly generation during the whole year. Moreover, this hourly power generation is dependent mainly on a number of factors, which includes the PV module highest power, the solar irradiance availability, PV module efficiency and temperature, the effect of shading, the topology and capacity of the inverter, the PV modules series and parallel connections, the physical arrangement of the numerous components as well as the losses of the maximum power point tracking [16].

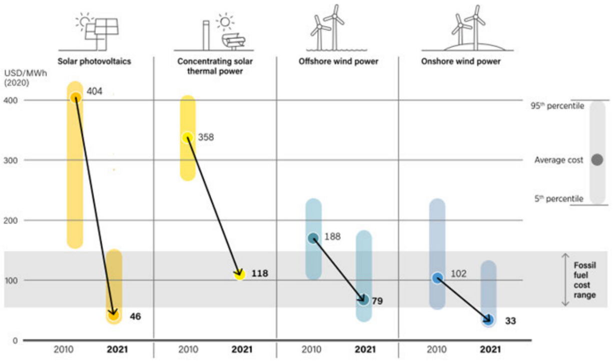

FIGURE 3. Solar PV LCOE compared to other energy sources, 2010-2021.

In the literature, a few review studies for PV system connected the main grid addressing optimization, design and complications are published. The review presented in [17] examined the application of artificial intelligence techniques to optimize PV systems. However, the authors focused more on the implementation of particular algorithms rather than focusing on the design optimization problem. Moreover, the review discussed only the optimization of standalone PV systems. Therefore, there is a lack in discussing design optimization for grid-connected PV systems. The review presented in [18], examined grid-connected PV system technical and economic characteristics. An in-depth explanation is provided considering PV modules, power analysis, potential issues, and PV converter. However, optimization models were not included in this research. In [19], the optimization techniques utilized in renewable energy are thoroughly examined. However, this approach did not sufficiently address PV systems. A few research that look at PV system optimization have been published in the past research. The work in [20], provided a review of PV systems optimization for standalone, grid-connected, and hybrid systems. However, there is lack in discussing inverter typologies, various PV power plant components optimization and sizing, and evaluation indicators for sizing PV power plants. In [21], a discussion on PV system component modelling, available PV software, PV optimization criteria, and different techniques to optimize PV systems is presented. However, the authors fail to cover the PV system's inverter topologies and other component optimization.

This review paper aims to seek the systematical analysis and summarize the PV power plant optimization design from the recent literature to choose the optimal system parameter combinations. Additionally, this review examines component sizing for PV power plants, which involves PV modules tilt angle, inverter, transformer, and cables. Moreover, it examines the different inverter topologies used in PV power plants along with a comparison between these topologies. Based on design methods identified in this review paper, more information about the recent studies has appeared that enables the researchers to find the gaps more easily for future studies. Furthermore, important evaluation indicators for sizing PV power plants are discussed in the paper including performance indicators and economic indicators to allow researchers to compare different PV power plants designs. This study also indicates recommendations for relevant research in the future and the possible barriers associated with different aspects such as artificial intelligence, data acquisition, mathematical modeling, accurate models, generic model, economic considerations.

II. COMPONENTS OVERVIEW

Large rooftops or the ground could be used to build PV power plants. Moreover, the optimal design must be carefully considered for a PV project to be successful. Large-scale PV plants need a precise high level of solar irradiance, high quality of components, and considering the economic as well as technical factors. Whatever the topology employed, all large-scale PV power plants include four essential pieces of equipment. Fig. 4 depicts the general layout of the PV power plant linked to the main network. The first element is a PV array, transforming solar energy into electricity as direct current (DC). It comprises numerous PV modules linked in both parallel and series. The second equipment deals with the PV inverter, and it aims at converting the PV array (DC) output into alternative current (AC) with an improved quality. The LCL filter component also contributes significantly to the suppression of the inverter (AC) switching harmonics for both voltage and current. Lastly, a step-up transformer is necessary and must be chosen according to the network voltage requirements to evacuate the generated power and provide galvanic isolation. Furthermore, junction boxes, DC, and AC cables are discussed in detail.

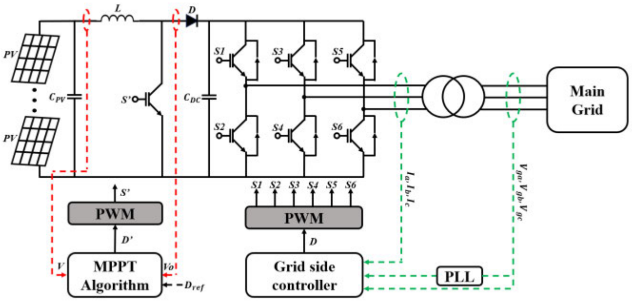

FIGURE 4. **Primary components with respect to PV power plants linked to the main network.**

A. PV MODULES

In the year 1954 at Bell Telephone Laboratories, [22] established the first silicon solar cell having a 6% efficiency, taking into account all the operating mechanisms for the energy conversion of semiconductor p-n junction silicon PV cell. However, a limited efficiency has been determined to be around 30% [23], [24]. Efficiency of PV modules is among the crucial aspects of PV systems. Due to its effectiveness, PV technology has become the first installed energy source in the last decades. Polycrystalline PV cells only achieved 21% efficiency under STC, while monocrystalline PV cells technology currently offers a greater efficiency of roughly 25%. Additionally, thin-film (CdTe) PV cells achieved an efficiency of 22% [11], [12]. The world record evolution for laboratory cell efficiencies in chronological order of technologies such as silicon and other technology families have different efficiencies, where this evolution is always being updated and compiled by the National Renewable Energy Laboratory (NREL). The PV module converts sunlight directly into usable energy. A PV module consists of many PV cells connected in series and parallel. Furthermore, the performance of the PV cell, availability and amount of irradiance, and the PV cell voltage output, affect the amount of power generation. Single-diode model with five parameters is illustrated in Fig. 5. It is among the most often used physical models to determine the single PV cell's electric properties [25]. Additionally, a two-diode model with seven parameters was explored in [26], with a view to improving the precision of the PV cell created by [27].

Most research examining the effectiveness of PV systems calls for employing the model in converting meteorological data received by the PV module surface into the equivalent maximum power. Here, the accuracy and complexity of the models reported in the literature, as seen in [28].

During the day, due to fluctuations in sun irradiation, the single diode functions as an inconstant generator of current. Moreover, the electrical properties of the PV cell are influenced by the fluctuations in solar radiation. The location

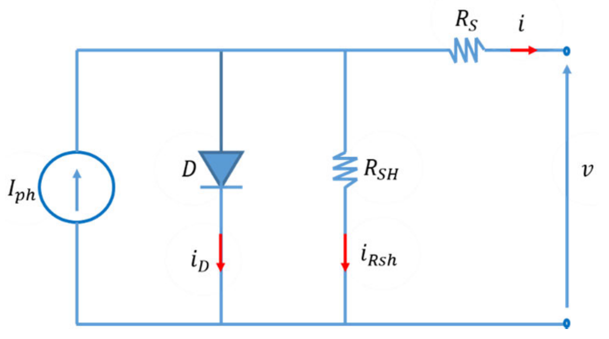

FIGURE 5. The single diode RSH PV cell model.

temperature and solar irradiance have the most effects on PV module voltage and current. As a result, the PV modules are modelled in PV systems as a dynamic source of current. Additionally, the geographic latitude of the PV plant installation site can significantly affect the optimal tilt angle of the PV module from one area to another [29]. The manufacturer determines the characteristics with respect to the PV module according to the standard test conditions (STC). Here, PV module current and voltage calculations are based on solar irradiance of 1000 (W/m^2) at a 25°C temperature. Consequently, the computations under real conditions results in real values of the voltage and current [30]. Fig. 6 and Fig. 7 illustrate the P-V as well as I-V curves characteristics in varied solar irradiance and temperature conditions. To get the maximum power output, solar irradiance rises, and the PV module voltage is at its optimum level. Despite the current increasing because of the solar radiation, the active power decreases as the ambient temperature rises.

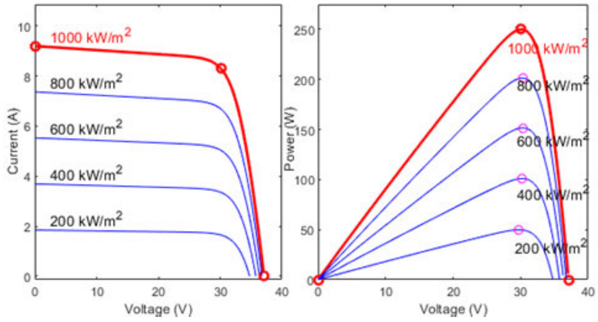

FIGURE 6. I-V and P-V curves for various solar radiations.

PV module performance parameters enable the comparison of various cell types. According to IEC standard 60904, these parameters are computed under STC. In accordance with this standard, STC is defined as a vertical radiation of 1000 (W/m^2), at 25°C with a tolerance of 2°C, and light spectrum compliant with IEC 60904-3 with an air mass of AM=1.5 [31]. The following performance criteria apply to PV modules, the maximum power point (MPP) with respect to the I-V characteristic is defined as the voltage (V_{mpp}) and current (I_{mpp}) at which the PV cell operates at its maximum power, as well as its short circuit current (I_{sc}) stands for open-circuit voltage and zero output current. As shown in equation (1), V_{oc} denotes the voltage at zero output current, and fill factor (FF) is the solar cell quality determined by dividing the MPP by the product of V_{oc} and I_{sc}. The magnitudes of the series and shunt resistances have an impact on this variable. The efficiency (η) is the final factor and is expressed in equation (2) as the proportion of power transformed from sunlight to electric power, where I_r represents the solar radiation at STC and A_c represents the surface area of the PV cell [31].

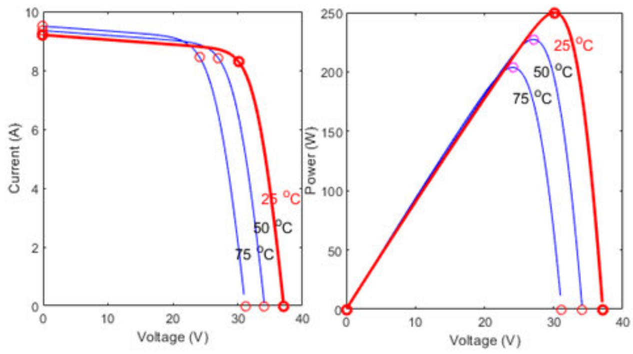

FIGURE 7. I-V and P-V curves for different ambient temperatures.

$$FF = \frac{MPP}{V_{oc} \times I_{sc}} \% \tag{1}$$

$$\eta = \frac{MPP}{I_r \times A_c} \times 100 \tag{2}$$

The type of material employed in the PV modules has a substantial impact on how well a PV plant performs. Additionally, better PV module materials help to minimize the area needed to install massive PV power plants. PV modules must be developed with a higher capacity and smaller size for PV power plants. This is mostly done to assist designers in lowering installation and occupied area costs. Research in [32] has shown that the silicon PV modules are the best choice that can be utilized for building PV power plants, since they have high efficiency and occupy less area compared to thin-film PV modules. Additionally, it is anticipated that prices will fall in the coming years, which will enable designers to improve the designs of PV power plants. Thin-film PV module technology development is still in its early stages. Though, given that it is less expensive than mono-crystalline and multi-crystalline PV modules, it is anticipated that larger PV power plants would use it more frequently. At present, mono-crystalline and multi-crystalline PV modules have dominated the market of PV systems due to many factors such as their high efficiency, less size, stability, and reliability. However, this type of technology still represents a high price due to the material quantity and manufacturing process [33], [34]. In contrast, thin-film PV modules' price is competitive. The main drawbacks of this technology are its lower stability and efficiency, as well as its larger size, which occupies more area in PV power plants [35], [36], and the material scarcity [37]. Therefore, the area utilized is one of many parameters affecting the project cost, other factors include the PV power plant's installation cost, various components transportation, system maintenance, and mounting characteristics. Several studies are currently being conducted to improve solar cell characteristics to increase efficiency, decrease in prices, and long-term stability. The significant number of PV modules placed in a large-scale PV power plant is vital to improve additional PV cell characteristics including sustainability, recycling, and CO_2 generation reduction during the course of the cell's lifetime [38].

B. INVERTERS

The PV inverter aims at converting the PV module DC output into AC power. An automated synchronization of the PV inverter output is carried out to match the same frequency and voltage of the power network. Relying on the location, the selected inverter must control the quantity of energy to satisfy various standard requirements, for instance, EN 50106, IEEE 1547.1-2005, IEC61727, and VDE0126-1-1 [39]. Considering its electrical properties, including input voltage, and nominal power, its selection can strongly impact the optimization sizing of PV power plants. In PV farms, inverters maintain the connection between the electrical network and the PV modules [40]. The inverter can only convert from DC to AC in one stage or it may convert from DC to AC in two stages, in which case a second DC-DC converter is required [39], [41]. When using a central, string PV plant layout, one-stage conversion is employed. On the other hand, the multi-string PV plant configuration requires two phases of conversion. The DC-DC converter is the focus of countless types of active research. It may be categorized into two main groups, isolated (with transformer) as well as non-isolated (without transformer), are used in PV plants [42]. The primary cause of the difference is the galvanic separation between the sides of the PV modules and the power grid [40]. Review, analysis, and research on non-isolated as well as isolated DC-DC converters were conducted in [43], [44], and [45], respectively. Several non-isolated DC-DC converter configurations, for instance, Cuk, buck-boost, SEPIC, ultra-lift Luo converters as well as positive-output super-lift Luohave been designed to increase voltage gain [44]. Non-isolated DC-DC converter characteristics is mostly determined by its configuration, as described in [43], [46], and [47]. The main benefits of non-isolated DC-DC converters over isolated DC-DC converters are their reduced cost without any design complications. Apart from that, non-isolated DC-DC converter topologies have several drawbacks, including current ripple, voltage stress, and leakage current. Transformers with high frequency are applied to ensure isolation and their principal benefit is to protect the sensitive load [44]. Forward, push-pull, flyback, and boost-half-bridge present isolated DC-DC converter structures [48]. However, isolated topology faces some issues related to cost and efficiency [45]. Each converter configuration has its advantages and disadvantages, where the selection process should take into account the application and its requirements [48]. Therefore, isolated DC-DC converter topology is reflected as more suitable for PV power plants [32]. The selected PV inverter for PV power plants should have galvanic isolation [45], MPPT tracker [49], and meet the electrical standards that depend on the regulations of a country [40], and is applicable for PV inverters in case of one or two stages of conversion. PV inverters with one stage of conversion DC-AC are the dominant topology in integrating PV power plants into the power network. On the other hand, PV inverters with two stages of conversion could be an attractive technology for PV plants in the future [32].

C. TRANSFORMERS

To ensure the grid connection, the inverter output power needs an additional voltage step-up. The primary function of transformers utilized in PV power plants is to supply electrical power with appropriate voltage levels for transmission throughout the installation and exportation to the power network, ranging from 33 kV to 110 kV based on the network voltage level. Line frequency transformer has been employed in PV power plants to ensure the separation and step-up the inverter voltage. The transformer performance considers the assessment of the various losses that occur while converting electricity from DC to AC. The transformer price can account for one-third of the inverter price in PV plants. According to a recent study, the price of dry-type transformer in Brazil with a capacity of around of 500 kVA might approach 4.14 ¢/Watt [50].

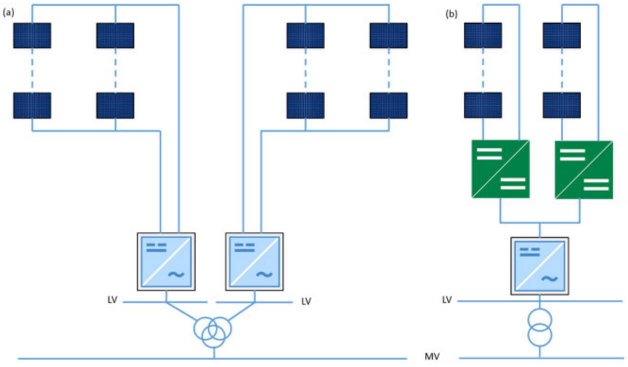

FIGURE 8. Transformer connection at medium voltage, (a) Central inverter topology is connected to three winding transformers, (b) Multi-string inverter topology connected to two winding transformers.

According to [51], the transformer occupies over a third of the surface area of the inverter station for a 1 MW PV power plant.

There are two types of transformers that may be placed in PV power plants including Tn and T-HV. (Tn) steps up the PV inverter output voltage at the level of 13.8 to 46 kV [52]. In contrast, (T-HV) functions as a voltage step-up, providing galvanic isolation from the electrical grid [53]. Transformers linked with PV inverters increase the voltage to around 0.4 kV to 30 kV. Note that the use of an additional transformer in the range of 30 kV-110 kV is mandatory. As detailed in [54], if PV inverters rated power exceeds 500 kW, three windings transformer should be installed with two low voltage (LV) windings and one medium voltage (MV) winding [55]. On the other hand, two windings transformer is used in case of PV inverters rated power is below 500 kW with one LV winding and one high voltage (HV) winding [56]. T-HV transformers type have one LV winding and one HV winding. Fig. 8 shows central and multi-string inverter topologies connected to the transformer at medium voltage.

D. WIRING

PV power plants involve both AC and DC cables. The wiring must not reduce efficiency with respect to the PV plant components. Here, PV cables must be able to stand throughout the PV power plant lifetime and should meet all minimum standard requirements for safety. Generally, voltage rating, current carrying capacity, and losses are the criteria that must be considered while sizing cables for PV power plants. Cables should be sized such that 80% of the rated ampacity (125% E) is higher than or equal to 125% of the short-circuit current (125% N), where 125% is a derating factor, E for equipment limitation, and N for normal operation. In brief, the PV cable's minimum ampacity must be equal to the rated short-circuit current multiplied by 1.56 [57], [58]. The AC cables should provide cost-effectiveness and safety while transmitting AC power from the PV inverters to the transformers. AC cables must obey relevant IEC standards, including the IEC 60502 for cables in medium voltage in the range of 1kV and 36kV, IEC 60364 for low voltage cabling, and IEC 60840 for high voltage cables ranging from 30kV and up to 150kV [59].

E. JUNCTION BOXES

The installation of several junction boxes within the installation area is required according to the selected inverter topology. When using central inverters topology, it is necessary to install junction boxes via the DC main cable before exiting the inverter. Junction boxes can present overheating and losses throughout the PV plant lifetime. In this case, it is required to utilize junction boxes with high-quality screw terminals. Junction boxes consist of both isolation and protective equipment. In PV power plants, the junction boxes should clearly separate the positive and negative sides within the box and be executed to protect class II. If mounted externally, the protection level should be at least IP 54 [31]. In the string inverters topology, strings are linked directly to the inverter, and there is no need to install junction boxes in the PV plant.

III. TOPOLOGIES FOR PV POWER PLANTS

Inverters that transform DC power generated by PV arrays into AC power in order to inject it into the power grid have drawn a lot of interest in recent years. Here, the chosen inverter topology influences both the overall cost of the PV power plant and the total energy generation. For example, the study presented in [60] examines the performance of two alternative systems implemented in Spain including central and string inverter topologies. Additionally, the PV systems have capabilities of 56 kW and 113.4 kW for distributed and central systems, accordingly, and both systems are exposed to the same weather conditions. According to the study, the distributed topology performed better than the central topology. However, due to their benefits, central inverter topologies are more commonly used in PV systems compared to the other topologies [32]. For the most effective development of PV power plants in Turkey, the central topology was recommended in [61]. However, the design, its effects on the amount of energy produced as well as the total cost with respect to the PV plant were not discussed in relation to the performance of large-scale PV power plants using the string inverter topology. The PV power plant design is strongly advised given the ongoing development of component technology. However, it is also done to increase the system's economic profitability. This implies that the goal of developing a PV plant is to decrease the cost of the energy produced. The literature reviews various topologies, standards, as well as evolutions in PV converters [39], [62], [63], [64]. Moreover, a recent study in [65], investigated the optimal inverter topology for PV power plants using both central and string configurations. According to the optimization results, the cost-effective topology for PV plants is the central topology based on the economic evaluation. PV systems with the best components, topology and operating mode will inject more power into the network and decrease their LCOE by up to 17% [66]. Six primary group topologies of PV plant can be found such as: string, multi-string, central, as well as AC modules [67]. Other suggested topologies need to demonstrate their effectiveness in actual PV plant circumstances as they are still in the experimental phase [68]. Low PV maintenance costs and the inverter's MPPT makes the central topology the most used in PV power plants with high capacities of several megawatts [69]. From the above studies, it is worth mentioning that the common topology used for large scale PV power plants is central.

A. CENTRAL TOPOLOGY

In a centralized configuration, as displayed in Fig. 9, a huge number of PV modules have been linked in series in order to form a string [70]. All strings are linked in parallel to inverters. The transformer is then used to feed AC power directly into the electrical grid. When compared to other existing structures, this configuration offers the lowest cost and easiest maintenance over the course of its operation [71]. Additionally, all the arrays in this configuration operating with a single MPPT exhibit significant losses and lower performance [72], for instance, PV module surfaces that have the lowest yield to changes in solar radiation, ambient temperature as well as shade [39].

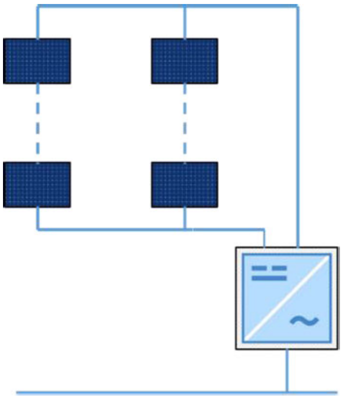

FIGURE 9. Central topology.

B. PRIMARY-SECONDARY TOPOLOGY

This topology's primary goal is to enhance the reliability with respect to the central inverter topology, as illustrated in Fig. 10. For this topology, the PV power plant inverters are connected in parallel, hence they can deliver the entire amount of PV power even if one fails. However, some of the inverters are shut down in case of low irradiance level. Due to the design of inverters to operate according to the irradiance level, its advantage is to extend overall operating efficiency and inverters lifetime. Moreover, the mismatch between the partial shading and modules gives a substantial power loss. It is still a problem with this topology and its high cost compared to centralized topology [73].

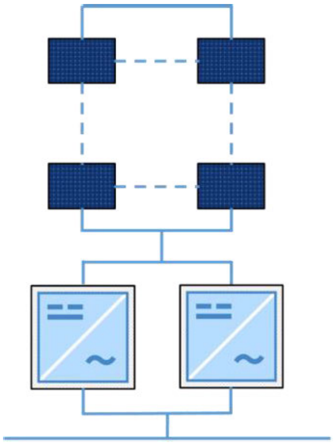

FIGURE 10. Primary-secondary topology.

C. STRING TOPOLOGY

PV power plant which utilizes string mode is shown in Fig. 11.

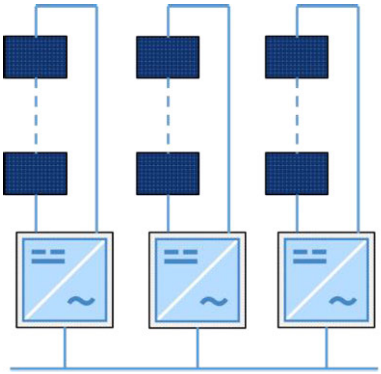

FIGURE 11. String topology.

Here, each inverter is connected to a single string with no parallel connections. This mode lowers power losses when working under partial shading conditions and when PV modules are not matched since each string functions independently at its maximum power [74]. Strings of PV modules of various sizes and types can be utilized in this design. Furthermore, it is simple to raise the PV system's power rating and add a new string, which increases the flexibility of PV plant design. Additionally, string mode guarantees service continuation in the event of an inverter fault. However, this topology calls for several inverters, which raises the installation cost significantly.

D. TEAM CONCEPT TOPOLOGY

This topology is based on the combination of the primary-secondary concept with string technology. In a large-scale PV power plant, each string has its own MPP tracking controller and runs independently. In this configuration, only at levels with low irradiance is the PV array completely connected to one inverter, as seen in Fig. 12. The PV array is split up into string units which are smaller as the irradiance level rises, however, until each string inverter is operating close to its rated power [75].

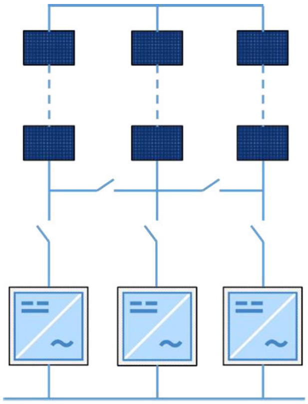

FIGURE 12. Team concept topology.

E. AC-MODULE TOPOLOGY

The AC-module topology is displayed in Fig. 13. Only low-power applications with high cost-effectiveness are intended for this design [74]. An inverter is built with each PV module. The array design flexibility, enhanced monitoring for PV

TABLE 1. Optimal results for each location.

Topology	Advantages	Disadvantages	Range Power
Centralized	1- Easily monitored 2- Easily maintained 3- Low cost due to central inverter. 4- Can be used for large-scale PV installation. 5- Configuration is very simple and easier to control.	1- More power is lost as a result of centralized MPPT, string diodes, and PV module mismatch losses. 2- Low reliability 3- No flexible design in large production PV plants 4-High voltage DC cables and DC losses in high voltage DC cables connecting the PV modules to the inverter. 5- Large DC cabling is required, so the cost is high. 6-. Different V-I characteristics for different PV module in the system makes MPPT inefficient and less robust. 7- Installation cost is more. 8- Damage of one PV cell makes that string defective in power generation.	up to several megawatts
Master-Slave	1- Greater reliability in comparison to centralized topology. 2- Enhanced efficiency for the inverters that are in use. 3- Inverters' lifetime are extended.	1- High voltage DC cables. Results in DC loss. 2- Power loss caused by centralized MPPT, string diodes as well as mismatch in PV modules. 3- Multiple inverters causes high cost. 4- The design is not flexible.	up to several megawatts
String	1- Reduction in the energy loss caused by partial shading. 2- String diodes eliminate all losses, therefore there are no losses at all. 3- Good reliability 4- Design flexiblity 5-To prevent voltage amplification, the input voltage might be high enough. 6- The price decrease brought on by mass production. 7-MPPT tracking is much efficient than central topology. 8-Robustness improves.	1- Cost still quite high in comparison to centralized. 2- Employed for low power ratings. 3- Long DC cabling is required, so high cable loss is present. 4- The system becomes bulky due to the presence of an inverter in each string.	3-5 kW /string
Team Concept	1- Greater efficiency because of individual MPPT and a boost in the inverter's efficiency. 2- Greater reliability in comparison to centralized topology	1- Losses resulting from PV module mismatch. 2- High cost due to the need of numerous inverters.	up to several megawatts
Multi-String	1- Less energy is lost as a result of partial shading. 2- String diodes are free of losses. 3- Current control and MPPT are separate. 4- The DC-DC converter can produce voltage amplification. 5-Simple configuration makes the system more robust.	1- A single inverter is attached to all strings. As a result, the system's reliability declines. 2- Inside the DC/DC converter, there are additional losses. 3- In comparison to the centralized topology, the cost is higher. 4- The process of DC-DC boost converter increases system cost. 5- Bulky system.	5 kW
AC modules	1- No losses caused by partial shading. 2- No mismatch losses between PV modules. 3- Easy in the detection of the PV module failure. 4- Expandable and flexible in design. 5- Increase the possibility of large integration. 6- Simple configuration. 7- Robustness and system modularity.	1- The system is much costly. 2- It is difficult to replace the inverter in the event of a fault. 3- Extra thermal stress results in power electronic components having a shorter lifespan. 4- Bulky system.	up to 500 W

module failure, as well as improved performance with lower losses under partial shade situations are all benefits of this topology. Additionally, installing inverters with PV modules outside reduces their lifespan mostly because of the increased thermal stress [70].

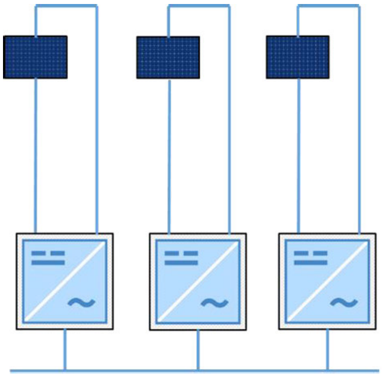

FIGURE 13. **AC-module topology.**

F. MULTI-STRING TOPOLOGY

The multi-string inverter mode is shown in Fig. 14. Every string in the PV plant is connected to a single DC-DC converter for voltage amplification and tracking the highest power point. Additionally, a DC bus connects all of the DC-DC converters to only one inverter [74]. The other losses from the PV plant's string structure and converters are included into the system's increased reliability. In contrast to the disadvantages of having two conversion stages, this mode combines the benefits of centralized and string topologies for increased system power output [70].

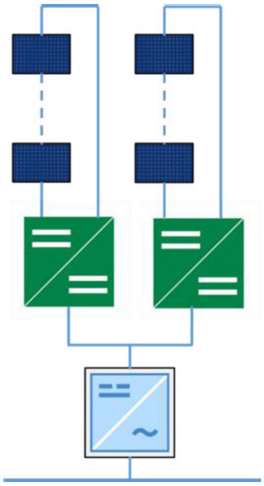

FIGURE 14. **Multi-string topology.**

G. COMPARISON BETWEEN PV PLANT TOPOLOGIES

The topology in every large-scale PV power plant that has been installed worldwide is very important for its performance. Central topology is commonly used by most large-scale PV power plants due to installation simplicity including the lesser components number in the field. A Comparison between these topologies can be seen in Table 1 [32], [40]. By comparing these six topologies, it is evident that the efficiency with respect to these inverters has this relationship: AC modules > string inverter > multi-string inverters > central inverter.

IV. EVALUATION INDICATORS FOR SIZING PV POWER PLANTS

In this section, site selection, performance indicators and economic indicators have been discussed.

A. SITE SELECTION

Due to its vital significance in the design process, selecting the place of construction is an essential step in large-scale PV power plant projects. Numerous aspects have to be taken into account to increase the performance of PV plants. In order to satisfy the increasing need for electricity without impacting the urban expansion and development of cities, the PV power plant should be built close to urban areas. From the perspective of profitability, having close proximity to the load decreases the loss of electricity and decreases the cost of the transmission line. Additionally, the electrical output of the PV plant has to be equivalent to the transmission line capacity. In order to lower the cost of building the PV power plant and the transportation costs of a significant amount of components, it is also vital that the chosen location be close to major highways and rail infrastructure. Easy access to the area is necessary for future maintenance as well as to prevent the expense of building the road. It is highly suggested that the PV plant be adjacent to substations in order to receive the power produced by the PV plant due to the expensive nature of creating new substations. In order to optimize the performance of the PV arrays, the site for the power plant must also have enough water supplies to facilitate cleaning the modules at least twice a month.

B. PERFORMANCE INDICATORS

Different factors were examined to assess the grid-connected PV power plant's performance, including the LCOE ($/kWh), output power, size ratio (R_S), ground cover ratio (GCR), performance ratio (PR), and energy losses. Regarding the fluctuation of several factors impacting the optimum sizing and efficiency of the PV plant, these parameters were utilized to carry out the electrical analysis of the system.

1) ENERGY OUTPUT

It is possible to calculate the total amount of electricity generated by the PV power plant throughout its operational period using equation (3). Also, the total quantity of energy that is produced by the PV power plant during a particular period of time may be calculated, for example, if $n_s = 1$, the total energy produced over a year can be determined.

$$E_{tot} = P_{plant}(t)\, n_s EAF \tag{3}$$

where P_{plant} denotes the total output power and EAF is the energy reliability factor.

2) SIZING RATIO

PV arrays sizing ratio (R_s) is often defined as PV arrays rated power $P_{PV(rated)}$ over the inverter rated power $P_{i(rated)}$ at STC. The equation below can be utilized to get the sizing ratio:

$$R_s = \frac{P_{PV(rated)}}{P_{i(rated)}} \tag{4}$$

Equation (5) can be used to determine the PV array's rated nominal power, $P_{PV(rated)}$.

$$P_{PV(rated)} = P_{mpp,stc}.N_s.N_p \tag{5}$$

where $P_{mpp,stc}$refers to the nominal maximum power with respect to PV module at standard test conditions, N_s and N_p denote the number PV modules linked in series and parallel, respectively.

3) PERFORMANCE RATIO

For grid-connected PV power plants, the performance ratio refers to the quality factor and efficiency index that compares the final energy yield (Y_f) to the nominal yield (Y_r). PV power plants can be compared using performance ratio regardless of nominal capacity, tilt angle, location, or orientation [76]. The performance ratio may be computed by [77]:

$$PR = \frac{Y_f}{Y_r} \tag{6}$$

Here, Y_f denotes the ratio between PV plants final power generation as well as its nominal DC power.

$$Y_f = \frac{\text{Final energy output in kWh}}{\text{Nominal DC power in kW}} \tag{7}$$

On the other hand, Y_r may be expressed as the reference irradiance to the entire in-plane irradiance ratio with respect to STC.

$$Y_r = \frac{\text{Total in plane irradiance in kW/m}^2}{\text{PV reference irradiance in kW/m}^2\text{at STC}} \tag{8}$$

Reference yield is clearly geographically location-dependent, as shown by equation (8).

4) GROUND COVER RATIO

The ground cover ratio (GCR) differs amongst PV power plants as a result of the variations in PV module tilt angles. Calculating the GCR ratio is as follows [78]:

$$GCR = \frac{A_{PV}}{A_{PV} + L} \tag{9}$$

where total PV area excluding land is denoted by (A_{PV}) and (A_{pv+L}) refers to the total PV area including land. In addition, A_{pv} can be expressed as:

$$A_{PV} = A_c.NI \tag{10}$$

in which NI refers the total number of PV modules, and A_c denotes the PV module area (m^2).

5) ENERGY LOSSES

The difference that exists between the energy generated by PV modules (P_{PV}) as well as the total output power (P_{plant}) before it is injected into the grid is considered as the total amount of PV power plant energy losses over its operational lifetime (25 years), and includes shading losses, component losses, DC as well as AC cable losses. The equation given below may be used to determine the energy losses in PV power plants:

$$\sum P_{losses} = \sum P_{PV} - \sum P_{plant} \tag{11}$$

C. ECONOMIC INDICATORS

1) LEVELIZED COST OF ENERGY

The lifetime cost of operation (LCOE) of a plant is determined by dividing the total cost of installation, maintenance, and operation of the plant by the total amount of energy it produces. By considering the proper cost structures, the LCOE approach is typically used to compare power plants whose energy producing sources are different. The ideal LCOE for power plants, however, combines a low investment cost with a high yearly energy output [79].

$$LCOE = \frac{C_C(X) + C_M(X)}{E_{tot}(X)} \tag{12}$$

2) NET PRESENT VALUE

The NPV essentially depicts the project's overall cash flow, with a positive number indicating a profitable project and a negative value indicating a loss of financial profit [80].

$$NPV = M_{net} - C_{capital,sys} \tag{13}$$

where $C_{capital,sys}$denotes the project's actual capital cost and $M_{net}$the project's net income in its entirety at the present time.

3) INVESTMENT PAYBACK TIME

PBT measures the period of time it will take an investor to return their initial investment [81]:

$$PBT = \frac{\text{Initial investment}}{\text{Annual cash inflows}} \tag{14}$$

V. OPTIMAL DESIGN OF PV POWER PLANTS

Fig. 15 portrays the process used in solving the PV power plant design and establishes its optimal size and configuration. The measured meteorological data with respect to the PV modules, inverter specifications, location, area coordinates, as well as cost units were all taken into consideration while calculating the design parameters with respect to the PV plant in the methodology that follows.

The research in [82] established a computer application to optimize the grid-connected PV power plant, together with a few Spanish parameters. Moreover, the annual energy production has been calculated using shading analysis to prevent any shadow effects on the PV module surface, wire losses, PV array losses, PV module tilt angle, inverter size, as well as orientation. Additionally, the sold energy, annual

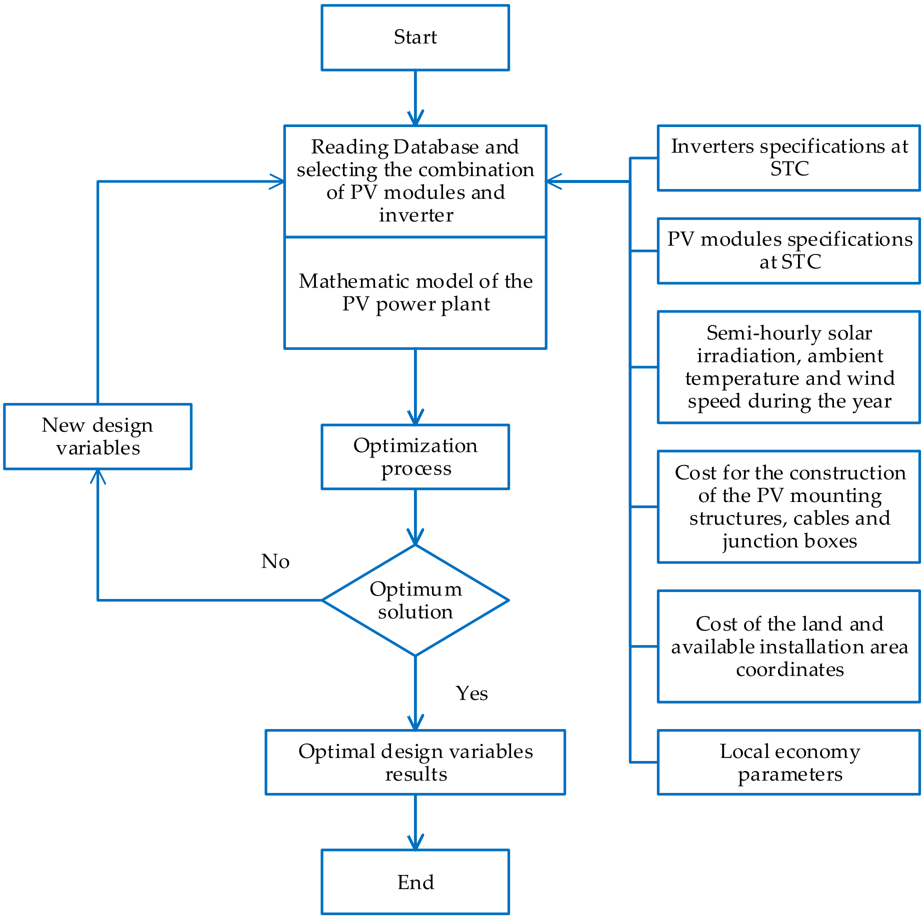

FIGURE 15. The general flowchart concerning the PV power plant's design methodology.

inflation, discount rate, costs, as well as taxation are taken into consideration when performing the financial analysis. Additionally, computational pollution has been suggested in relation to environmental analysis. In this strategy, the PV array size was ignored during the optimization process, but the inverter size was chosen by very intuitive consideration. The ideal PV inverter sizing ratios were found using the TRNSYS software as introduced in [83]. The maximum total output of the PV system has been calculated using the simulation utilizing three different types of inverters having low, medium and high efficiency. In addition, the grid-connected PV inverter size ratio was examined for 8 European locations. According to Mondol et al., establishing a PV system having a high-efficiency inverter allows for more flexibility with regards to PV and inverter sizing in comparison to a low-efficiency inverter. Grid-connected PV power plant optimization has been described in [84]. The authors used actual meteorological data to determine the best type of PV modules and inverters, optimal PV module tilt angle, optimal PV module layout within the area of PV plant installation, and ideal PV module distribution among the inverters. By using an iterative simulation relying on the genetic algorithm (GA) method, the optimization procedure maximized the system's overall net profit. The grid-connected PV power plant was also optimized using artificial intelligence (AI) techniques, as shown in [85]. Based on the overall net economic benefit, the PV plant global solution is instead solved using the particle swarm optimization (PSO) method. The GA technique utilized in this study performed worse than the PSO algorithm. An approach for grid-connected PV power plant design that takes economic analysis into account was introduced in [86]. To develop the PV power plant, the optimal solution was examined utilizing the PSO approach relying on a multi-objective optimization problem. In order to maximize the economic as well as environmental benefits during the lifetime of the PV plant, our study sought to organize the components in the best possible way. The ideal PV module location within the installation field, their distribution among the inverters, the ideal tilt angle, the ideal number of inverters, and the ideal PV module number were the design variables. The grid-connected PV system's optimization design has been introduced in [87]. The type of PV modules, inverter as well as tilt angle are the variables for the suggested methodology. The research backs up the mathematical simulations of the PV array, inverter as well as solar radiation on the surface of tilted PV modules. The optimization process considered three different inverter types, four different PV module types, seven tilt angle values, the hourly solar irradiation, as well as the surrounding temperature. The system's optimal design was chosen in order to maximize efficiency. Work done in [88] represents an approach employing the GA technique was put out to identify the optimum design for household grid-connected systems taking into account the excess factor (EF) of an objective function. The economic analysis was absent, and this methodology only took the instance of string inverters into account. The best system performance in this design is not optimal to match. In addition, meteorological information was not considered when calculating the PV system's daily energy output.

Solar irradiance, ambient temperature, and system costs were used as input parameters in Kerekes et al's practical optimization methodology for designing large-scale PV power plants utilizing GA. The ideal PV module placement, the separation between rows, the ideal tilt angle including the optimum number of PV rows made up the design factors. The LCOE was regarded as the optimal solution. The proposed approach supported the inverter topology, including multi-string inverter, central inverter as well as mini-central inverter. However, only fixed tilting PV modules installed on equator-facing ground are suitable for this strategy [89]. In 2012, [80] evolutionary programming (EP) sizing algorithm was developed as a sizing methodology. The optimization process covers all viable PV module and inverter combinations, considering various PV module and inverter types. The highest yield factor as well as the net present value with respect to the PV system were determined using this method, which also considers the technical as well as economic factors. Large-scale PV power facilities can be optimized using a novel methodology that Kerekes et al. developed in 2013 [79]. The same design factors used in his prior research were used in this, which was carried out using the GA algorithm [89]. However, the LCOE analysis was added to improve the performance of both the new method and the internal return rate, payback period, net present value, and economic analysis. Moreover, [90] developed an iterative method for determining the best inverter size for PV systems having the greatest savings in 9 USA locations. Here, the gainful inverter size for each position was determined by the optimization procedure. Additionally, due to the intrinsic inverter parameters, economic factors as well as weather considerations, an optimum inverter size that is lower than or equal to the PV array's rated size may be placed.

Perez-Gallardo and his colleagues developed an optimal grid-connected PV power plant architecture in 2014 utilizing the GA approach while taking into account economic, technical, and environmental factors [91]. This project's goal was to raise energy production. Additionally, the work in [92] Introduced a method for sizing a grid-connected PV power plant with a high time resolution using 1 minute average values of the input data for solar irradiance and ambient temperature. The primary-secondary algorithm and dynamic demes algorithm techniques were used to investigate the optimal option. The study attempted to examine the PV plant's maximum economic gain during the PV module lifetime. Apart from that, [93] recommended an optimization method based on the inverter's requirements for the cost-effective design of large-scale PV power plants. The purpose of the study was to increase LCOE, which considered the idea of a large-scale PV power plant's availability throughout its life cycle. Moreover, this research found that the standard LCOE index identified a central topology to reduce the cost of produced energy, and that an enhanced algorithm is offered relying on the actual levelized cost of energy (ELCOE). Despite having a greater initial cost, a multi-string architecture ends up being the most profitable one, and the authors recommended inverter sizes for 0.1-100 MW PV power plants ranging from 8 to 100 kW. Another methodology has been suggested in [94] in designing a PV plant for the university campus that will function as a self-consumption mechanism with various capacities between 450 and 1,250 kWp. The simulation was run on the PV*SOL software. Moreover, a methodology was proposed by [95] was carried out to enhance the economic analysis research and PV power plant design. There are two steps to optimum design. The design procedure, which uses various optimization techniques, is in the initial stage. The second step, meanwhile, is based on a Monte-Carlo simulation-based economic analysis of the PV power plant. Furthermore, [96] examined the PV system's inverter and module configuration selection, and saving options. Using this technique, the purchasing expenses could be decreased by 16.45% of 10 kW. However, this evaluation model can only be used to produce power at the lowest cost; it cannot be used to produce power at the best efficiency. In [97], a list of commercially available components, including PV modules and inverters, as well as the solar radiation, ambient temperature, and other input data were considered during the design procedure. The PV plant was sized with three distinct targeted functions includes: maximize annual energy generation, maximize economic benefits, and minimize payback period. A mathematical procedure has been presented in [98] by taking into consideration the impact of shade on the PV module output power, to the optimal number of rows as well as a PV module tilt angle for maximizing the profit during the lifetime of a PV plant.

Size optimization for large PV power plants were suggested in [61] based on GA. Environmental data as well as commercially available components, for instance, PV modules and inverters, were taken into account during the design process. The primary goal of the suggested methodology was to reduce the LCOE of the PV project. The number of PV modules that were connected in series and parallel, the tilt angle of the modules, the distance coefficient between two adjacent rows, and the number of PV module lines per row are the decision variables. A study in [99] examined the design of grid-connected PV systems while considering of the rate of PV module degradation in order to choose the optimum inverter size for increased energy and decreased

TABLE 2. Summary of design methods with respect to the PV plants.

Year	Method	Target	Country	Reference
2005	Numerical	Maximum energy	USA	[109]
2006	Evolutionary Programming	NPV	Spain	[82]
2009	GA	NPV	Greece	[84]
2010	PSO	NPV	Greece	[85]
2010	Multi-Objective PSO	NPV	Greece	[86]
2011	GA	Excess factor (EF)	Malaysia	[88]
2011	GA	LCOE	Greece	[89]
2012	Evolutionary Programming	NPV	Malaysia	[80]
2013	GA	LCOE	Denmark	[79]
2014	GA	Maximum energy	France	[91]
2014	Master-Slave and Dynamic Demes	LCOE	Greece	[92]
2016	PVSOL software	NPV	Cyprus	[94]
2016	GA	LCOE	India	[95]
2017	Tabu Search (TS)	1) Payback time 2) Maximum energy 3) Maximum benefits	Canada	[97]
2017	Mathematical model	NPV	Croatia	[98]
2017	GA	LCOE	Turkey	[61]
2018	Multi-objective GA	1)Output energy 2)Investment payback time 3)Energy payback time	France	[81]
2019	Binary linear programming	NPV	USA	[100]
2019	Grey wolf optimizer PSO	LCOE	Algeria	[110]
2020	GA	Internal rate of return (IRR)	Hungary	[111]
2020	Hybrid GWO-SCA	1) LCOE 2) Maximum energy	Algeria	[112]
2021	Hybrid CS-GWO PSO	1) LCOE 2) Maximum energy 3) Minimum cost	Malaysia	[16]
2021	PSO GA	1) NPV 2) LPSP	Tunisia	[113]

cost. Practical inverters with high efficiency provide a larger variety of size options than inverters that have low efficiency, which increases energy production. Study published in [81] stated that an eco-design for grid-connected PV systems was proposed. It was based on combining multi-objective optimization and other software. Simultaneous optimization was done for the techno-economic as well as environmental criteria. When compared to crystalline silicon ones, thin-film PV module installation in PV systems is advantageous. The research published in [100] suggested a method for converting the PV power plant's design to binary linear programming in order to accomplish an economic design. Here, the only design variable considered was the number of inverters and PV modules connected in parallel and series. A co-design technique has been suggested in [101] which looked into the optimum PV array structure and selection to fit the inverter layout for the highest optimal annual energy production of the PV plant utilizing PSO algorithm. Compared to constructing PV arrays and inverters independently, the authors claim that the established co-design optimization technique can provide more electricity from the PV system. To suggest a suitable design and choose the best option that take the PV system's technical, economic, and environmental factors into account, multiple methods have been used and published by academicians in this area [102], [103], [104], [105], [106], [107], [108]. Table 2 lists many approaches for designing PV power plants in the best optimal way that make use of optimization techniques or software that is available commercially. These techniques typically made use of meteorological information, economic parameters, PV module components, and inverter components. The PV plant sizing also included technological, environmental, and economic goals.

VI. OPTIMIZATION TECHNIQUES FOR DESIGNING PV POWER PLANTS

An optimization strategy may work well and produce excellent results when dealing with one optimization problem, but the same optimization technique may not work well when dealing with another problem. For instance, PSO and GA are widely applied to solve the optimal design of PV power plants as discussed in the previous section. However, recent proposed metaheuristics algorithms such as GWO have been used in a recent study and shows its effectiveness in solving the PV plant design problem compared to PSO [110].

There are two types of design optimization approaches known as conventional and modern techniques. Differential calculus is employed in conventional methods to identify the best solution. However, newly introduced algorithms utilize artificial and hybrid approaches. These strategies solve the problem accurately and with more efficiency as well as high convergence. The design of PV power plants becomes more complicated, due to fluctuations in the climate conditions, PV plant nonlinear operation, component limitations, and location selection. Therefore, researchers have shown great interest in applying modern approaches based on metaheuristics algorithms.

Both single and multi-objective optimization functions can be used to solve the design optimization of PV power plants. In modern algorithms, individual objective optimization can determine the minimum or the maximum value of the targeted function as reported in many studies such as in [111], whereas multi-objective optimization combines at least two objectives as reported in [81] using multi-objective GA and [86] using multi-objective PSO.

Single and hybrid algorithms can be used for solving optimization problems with single and multi-objective functions. Single optimization methods can be easily implemented, simple and offer quick convergence and efficiency in determining the optimal solution. But since the number of PV power plants connected to the electrical grid continues to grow quickly, it is more crucial than ever to develop the most efficient algorithms to make the optimization design more accurate and economically profitable. In order to attain superior results in addressing a particular issue, hybrid algorithms have been developed. At least two single algorithms are combined in the hybrid algorithm. The main aim of such a combination is to address complicated design challenges by utilizing the complementing qualities of the techniques. The work reported in [112] shows that the optimum design results using hybrid grey wolf optimiser-sine cosine algorithm is more efficient than PSO. Considering this, designers can increase system profit while employing the same components by utilizing novel, powerful optimization techniques.

VII. COMPONENTS OPTIMIZATION

In this section, various PV power plant components optimization and sizing are investigated including inverter, PV module tilt angle, transformer and wiring.

A. INVERTER SIZE OPTIMIZATION

In large-scale PV power plants, an optimal inverter size depends on many factors. A previous study [114] showed that utilizing a high-efficiency inverter improved the performance of PV systems for size ratios between 0.7 and 1.3. The rated capacity of a PV array must be perfectly matched with the rated capacity of the installed inverter to get the most power out of a PV system. Additionally, when the inverter's rated power is less than the PV array's rated power, the PV array's efficiency is subsequently impacted. The optimum size of a PV inverter is signified by the output power of the module, the cost/performance ratio, and the inverter itself. Low solar radiation levels cause the PV module's output power to be less than its rated capacity, which lowers the inverter's efficiency since some of the input power must be used to maintain various functions [115]. When an inverter is overloaded, the excess power that PV modules generate over the inverter's rated power is lost. Additionally, inverter oversizing or under sizing raises the cost of energy. However, to considerably improve the effectiveness and viability of PV systems, it is crucial to optimize the sizing of the inverter [116]. The optimum PV array to inverter sizing ratio was examined in [83] for PV energy locations located in Europe. The TRNSYS software tool was used to run the simulation. The ratio of the total PV module capacity to the inverter rating capacity is known as the size ratio. According to this research, the optimum sizing ratio for a high-efficiency inverter PV system must fall between 1.1 and 1.2 as well as 1.3 and 1.4 for locations with high and low solar irradiation, accordingly. Conversely, for low-efficiency inverter PV systems, the optimum size ratio for locations with high and low solar irradiation must be between 1.2 and 1.3 as well as 1.4 and 1.5, accordingly. Research in [107] gave an analytical method to determine the optimum inverter size, inverter efficiency as well as energy yield for grid-connected PV power plants in various locations. Here, the grid-connected PV power plant aspects that play essential roles led to the inverter being identified using a straightforward suitable method. Comparing the simulation outputs to the data that has been measured served to validate the analytical model that had been constructed. Another method in [117] used the PV system's optimum size ratio to increase the energy output of grid-connected PV power plants. To examine the impact of the location as well as inverter efficiency on the annual generated energy and the sizing ratio, simulations were run for 27 sites in Europe. It implies that at low latitudes, the sizing ratio should be greater, while at high latitudes, the opposite should be true. The size ratio was raised using high-efficiency inverters and locations with high irradiance levels. The iterative method is described in [118] and take into account the low, medium as well as high loads to optimize PV inverter sizing in various Malaysian locations. Here, the size ratio was improved utilizing models of commercial inverters that were readily available. Relying on hourly solar radiation as well as ambient temperature measurements, a Matlab model for PV modules and an inverter is created. The created model's primary objective was to calculate the inverter's efficiency in terms of PV module output capacity as well as inverter rated capacity. Here, the optimum size ratio values must be modified between 1.21 and 1.43.

Results proposed in [90] investigated the numerous elements that affect how an inverter is sized in a grid-connected PV system. Moreover, environmental factors, like solar radiation and air temperature, economic factors, like energy prices, and inverter specifications, overload protection plans and efficiency curves, are a few examples of these factors. As a result, the ideal inverter size varies depending on the geographic location. In Barcelona, Spain, a novel flexible solar array method was unveiled alongside information on solar radiation. To increase the PV power plant's energy yield, this experimental study assesses the optimum PV array-inverter sizing ratio [106]. Apart from that, DC input voltage's involvement in grid-connected DC-AC conversion efficiency for PV power plants is highlighted in [119]. Commercial c-Si and CdTe PV modules, as well as two PV inverters, were all characterized. The sizing ratio was determined to be dependent on PV module technology. Hence, regardless of the PV inverter chosen in Mexico, the suggested PV array-inverter sizing ratio for CdTe and c-Si was 0.95 and 1.05, respectively. Recently, an iterative method was suggested in [120] to utilize hourly radiation and temperature data to improve an inverter in grid-connected PV power facilities. A system having an optimized inverter size as well as a PV system with a standard size were compared. The PV array's rated capacity is the same as the inverter capacity. Here, it was found that the annual energy generation for the system with the optimum sizing is greater than the PV system with the typical sizing. Performance is improved in a PV system with an optimized PV inverter. Work referred to in [121] intended to examine how the performance with respect to PV power plants is impacted by inverter capacity. Moreover, the inverter capacity impact on the PV plant performance has been thoroughly assessed using data from active PV power plants and simulated by employing the PVsyst analysis tool. As a result, the central inverter topology generated a large amount of energy with very little energy loss, the string inverter topology produced a medium amount of energy with moderate energy losses, and the micro inverter topology produced the smallest amount of energy with significant energy loss. As a result, the PV power plant's performance is increased using high-capacity inverters which refers to central inverter topology. Latest research in [122] and [123] studied how the size of PV arrays affected the dependability and lifecycle of PV inverters. Since PV arrays rating power is more than the inverter rating power, PV array oversizing may have a negative influence on the PV inverter's lifetime as well as dependability. Additionally, the size ratio R_s is typically lower than 1 and ranges in values typically between 1 and 1.5, depending on the field of installation. Optimizing the grid-connected PV system design is impacted by inverter technology and PV module degradation factor [99]. They concluded that a wider range of size factors is available for high-efficiency current inverters to generate maximum energy.

B. PV MODULE OPTIMAL TILT ANGLE

The tilt angle is considered a vital factor in the PV power plant for maximizing the amount of solar radiation that reaches the PV modules, as demonstrated in Fig. 16.

The study in [124] outlined a technique for figuring out the best tilt angle and module orientation for PV modules to increase solar irradiance on the PV array. Such tilt angle optimization lowers the cost of large-scale PV power facilities while increasing energy production. The research described in [29] has shown that each site's optimum tilt angle for PV systems must be precisely calculated for energy gain. Additionally, yearly gain for optimum tilt angle is discussed, where a comparison between different mounted PV module systems was provided. The advantages of a dual-axis tracking system over a conventional fixed system are examined, and the gains reach 30% and 44%, respectively on the days of the winter and summer solstices. However, in large-scale PV power plants, tracking systems such as dual-axis and single-axis tracking systems are not largely used due to the complicated installation, high cost, land occupied, monitoring, and maintenance. In large-scale PV power facilities that have been constructed all over the world, the fixed system is typically used. Although some are discussed, it is not commonly noticed that large-scale PV power facilities employ any mechanical tracking systems [125]. Recent research presented in [126] suggested installing fixed PV modules in a grid-connected PV power plant, the installation angles are frequently taken into account at the initial stages of PV power plant design. The annual optimum tilt as well as azimuth angles employed in the installation of PV power plants are known as the "optimum angles," and they are designed to maximize the power output of the PV modules already in place throughout the year. Because they take up less space than traditional equator-oriented PV plants, East-West oriented PV modules are utilized to improve the installed capacity of the PV power plants [127]. Besides, the East-West orientation aids in the elimination of the spaces in between the two adjacent rows that are shaded. As opposed to that, a method proposed in [128] has shown that the general methods among designers were that PV modules must face South in the North hemisphere as well as North in the South hemisphere when facing the equator, and the tilt angle around the location latitude. However, it was difficult to calculate tilt and azimuth angles when utilizing this method, where PV modules must be fitted with a tilt angle that deviates from the optimum. A study in [129] has shown that for more energy generation, installing PV modules in different orientations in the PV power plant may be a solution to producing more energy. The research presented in [130] aimed to investigate how tilt angles affected PV power plant performance. However, many past studies have elaborated on predicting the optimum tilt angle for a more effective PV power plant design employing a variety of techniques and accounting for solar radiation and various techniques of optimum tilt angle calculations.

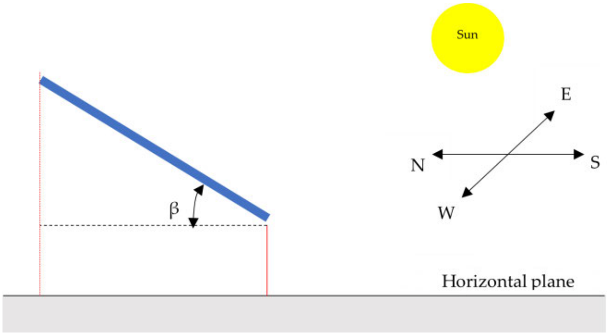

FIGURE 16. Tilt angle (β) for PV module facing equator.

Recent research in [131] recommended the optimum tilt angle for various PV module technologies in Turkey.

The cell temperature as well as wind speed, which might affect the PV module's output power, were considered while calculating the optimum tilt angle for the PV modules. The best tilt angles were discovered to be dependent on the PV module technology. Here, using the same tilt angle to various PV module technologies will yield varying results. A study presented in [132] aims to review the various approaches and procedures for figuring out the optimum PV module tilt angle at any location to increase the solar irradiance incident on the PV modules. A study in [133] aimed to discuss the relation between the solar power output and the best tilt angle for three optimum Iraqi geographical locations. The findings showed that all of these had an optimum yearly tilt angle with geographical locations similar and equal to 31° due to the same latitude. Conversely, the optimum monthly tilt angle is significantly affected by changes in the declination angle as well as the maximum solar intensity. Researchers looked into its impact on the efficiency of PV power plants in [134] using three different tools. A comparison between the results of simulation and measured data from PV power plant was presented. The proposed mathematical model was found to be more reliable than simulation.

C. TRANSFORMER OPTIMAL SIZING

The transformer should be installed in large-scale PV power plants and optimally selected, to avoid any loss of energy. The transformer could become a bottleneck if it is undersized. In contrast, an oversized transformer can cause some instabilities [52], [55]. Researches in [52], [135], and [136] proposed a design technique to select the optimal transformer for PV power plants based on power, efficiency, cost, and operation. 2% PV power plant efficiency improvement using medium frequency transformers is achieved [137]. A work presented in [138] proposed a method for choosing and sizing the transformer for PV power plants. This is to successfully detect the single-phase loss while ensuring minimum nuisance tripping of the PV power plant to achieve its safe and dependable operation. MATLAB/Simulink simulations and actual grid-connected 30 kW and 200 kW PV power plant testing were used to validate the methodology. As a result, nuisance tripping was reduced, and single-phase loss was determined. Based on the topology and rated power of the PV inverters, the transformer is chosen for solar power plants in the best way possible. Central PV inverters technology is increasing fast, and transformers should be improved in terms of power quality, maintenance, cost, operational lifetime, and size. Three windings transformers offer the possibility of connecting two central PV inverters, each with separate controls. Additionally, three winding transformers are used in the multi-string inverters topology [32].

D. WIRING OPTIMAL SIZING

A calculation methodology proposed in [139] studies the impact of wiring on the voltage and output power with a respect to the PV power plant's component operating conditions. The PV module estimated voltage, current, power output, total inverter power, as well as cable lengths and thicknesses were used. The outcomes showed that the suggested approach is appropriate for assessing the performance and energy output of large-scale PV power plants. Here, the maximum allowable voltage drop in PV power plant grid-connected is 5% [140].

VIII. CONCLUSION

Many studies and developments on the optimization of PV power plants have been performed in current years. The intermittent nature of solar energy, PV cell materials, system configuration and sizing, and complicated computation of optimization issues have all raised concerns about the investment in PV power plants. Therefore, this comprehensive analysis provides a thorough breakdown of the many components of the system, the inverter topologies used in PV power plants and the indicator parameters for sizing the system. In the one hand, it examines PV power plants optimal design considering all aspects. Apart from that, it discusses the PV system's many components being optimized individually such as, inverter, tilt angle, transformer and wiring. The following are some conclusions from this review:

1) **Artificial intelligence:** The use of conventional techniques to improve optimization design is continuously decreasing. When compared to conventional techniques, artificial intelligence methods have clear advantages in accuracy and computing time. However, as PV power plants get more complicated, AI techniques are more likely to avoid local optima due to their great flexibility and optimization effectiveness. Hybrid approaches that incorporate the benefits of various techniques have received increased attention due to their great flexibility and effectiveness in optimization. It highly recommended to continuously apply new proposed approaches to enhance the optimal design of the PV power plants.
2) **Data acquisition:** Peak solar irradiation and wind speed characteristics have an impact on PV power plants' design, even though the step time of the meteorological data used in the current optimization procedure is hourly, daily, and monthly. Consequently, the computation time step should be significantly decreased, such as to semi-hourly, 15 minutes, 1 minute, etc., to increase the level of results accuracy and the PV plant's reliability. The gathering of this data, however, is among the main obstacles in optimizing PV power plants because it is challenging to obtain complete meteorological data at such a small-time step of 1 minute. Thus, 1 minute step time is preferred in the design process for the accuracy of the results.
3) **Mathematical modelling:** Consists of three main elements such as: objective functions, design variables and constraints, which should be carefully considered during the PV power plant optimization process. Most current papers emphasize economic and performance

indicators. However, additional objectives and/or new assessment indicators may be employed for optimization to give more useful options. The multi-objective function should be a good alternative when designing a reliable optimization method for PV power plant. However, it is not simple to formulate a multi-objective function under numerous parameters and constraints. The goal of PV power plant optimization is typically identifying the best options with regards to price, size, efficiency as well as power output. Thus, multi-objective functions are recommended for more efficient design.

4) **Accurate models:** For increasing the PV power plant performance, it is essential to generate accurate models. These models must account for all the factors influencing energy production, including climatic factors, location and orientation, PV cell material, inverter topology as well as the limitations influencing energy conversion, such as the effectiveness of power electronic equipment, dust, and cables.
5) **Generic models:** PV power plant optimization is a procedure that is location reliant. The optimization results that were acquired based on a given site must thus be generalized to surrounding locations. More specifically, the optimization process should be efficient and appropriate to apply to any location in the globe by making a few adjustments to the input data parameters, such as the local economic characteristics, weather data, and geographic coordinates of the target site. In addition, the soiling effect should be adjusted to the local environmental factors, such as desert climates.
6) **Economic considerations:** One major concern about the PV power plant design is the rapid increase in components technology such as PV cells, DC-AC converters, and their associated costs. In the previous decade, PV module efficiencies were less than 16%. In contrast, recent commercially available PV modules have an efficiency of around 22%. This evolution should be considered to investigate the actual LCOE of the PV power plant. Thus, the analysis should be performed using recent data rather than that of the previous decade.

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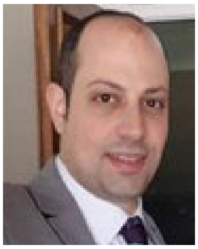

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