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Impact of Solar Cell Infrastructures on Energy Efficiency in Power Grid Integration

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ABSTRACT

Photovoltaic technology harvest electrical energy by stimulating liberated electrons within the semiconductor layers using solar radiation. Photovoltaic technology produces electrical energy by collecting electrons that are liberated in a semiconductor pn-junction by solar radiation. Photovoltaic solar cells have layered semiconductor structures and this study utilised for this objective. Current researches on energy storage with solar cells, focused to optimise the utilisation of the generated energy with cell efficiency. This study offers a thorough analysis of the energy efficiency of solar cells based on their infrastructures. The study involved obtaining computational visuals and doing efficiency verification. This was done by comparing the impact of different chemical structures on energy production. The MATLAB software was used with fixed parameters and varying efficiency. The results show that the Monocrystalline N-Type IBC model exhibits the maximum efficiency in terms of PV cell structure. The MIBC structure is more efficient than polycrystalline cells and also standard monotypes with high temperatures. This allows the cell to reflect itself and passivise the cell base, resulting in a 5% or more increase in energy production. Standard monotype cell has %16.2 efficiency and Monotype IBC has %20.1 efficiency results achieved with PVsyst and Matlab softwares. The results of the calculations were applied in real time and confirmed by testing the impact of structural differences on efficiency with real climate data..

Keywords: Solar cell, Energy efficiency, Renewables integration, Power grid.

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Introduction

Solar cells and photovoltaic (PV) systems have made significant progress in recent decades. Crystalline silicon accounted for 90% of the PV systems built worldwide in 2019 [1]. Nevertheless, inorganic structure as silicon solar cells have an inherent efficiency threshold of 29.4% [2], which contemporary cell technologies are rapidly nearing. An alternative solution to surpass this limitation is presented through the use of silicon-based tandem solar cells [3]. In order to enhance the conversion efficiency to above 30%, several novel cell designs that include silicon as the bottom cell are being examined.

Photovoltaic or solar cells are devices that directly convert solar energy into direct current (DC) electricity by using semiconductors like silicon, gallium, arsenide, cadmium telluride, or copper indium diselenide when exposed to sunlight. Solar cells typically have a square, rectangular, or circular shape with an area ranging from approximately 100 to 243 cm2 with a thickness between 0.2 and 0.4 mm [1-5]. The efficiency of single-junction solar cells varies between 5% and 25%, contingent upon their construction. Nevertheless, 0.5 Volt cells thus photovoltaic systems that include panels are constructed by connecting cells in series to provide higher voltage. int current (Immp) of a 6-inch (silicon?) crystalline cell is 7.83 Amperes, while the maximum power point voltage (Vmmp) averages at 0.49 Volts under an irradiance of 1000 Watts per square meter. A 6-inch cell measures 15.6 cm x 15.6 cm, whereas a 5-inch cell measures 12.5 cm x 12.5 cm [1, 6, 7].

Solar cell efficiency is the measure of the ability of a solar cell to convert solar light energy into electricity using photovoltaic technologies. The annual energy output of a photovoltaic system is determined by the efficiency of its solar cells, as well as factors such as density of energy and climate. For instance, when a solar panel with a 20% efficiency and a surface area of 1 m2 is subjected to 2.74 hours of sunlight per day at the 1000 W/m2 standard test condition, it will produce 200 kWh/year of energy under the same test conditions. Usually, solar panels receive sunshine for an extended duration throughout the day while the intensity of the sun's radiation remains below 1000W/m2 for the majority of the day. A solar panel's energy production is maximised when the sun is at a high position in the sky, as the light reaches the panel at a more perpendicular angle. Conversely, during overcast weather or when the sun is near the horizon, the panel's energy output decreases. In winter, the sun's position in the sky is more inclined towards the horizon. Within a remarkably productive solar area, like central Colorado, where there is an annual sunlight intensity of 2000 kWh/m2 [1], a solar panel of this kind is projected to produce approximately 400 kWh of energy annually. Nevertheless, in Michigan, where the energy availability is limited to 1400kWh/m2/year, the annual energy output for the same panel will decrease to 280kWh. In contrast, the energy efficiency in the northern European suburbs is much reduced. For instance, in the South of England, it is possible to attain an annual energy efficiency of 175kWh under identical circumstances [2].

Figure 1 illustrates the temporal evolution of solar cell efficiency [3]. According to research conducted at the NREL laboratory, multijunction-type solar cells have recently achieved the greatest efficiency of 47%.

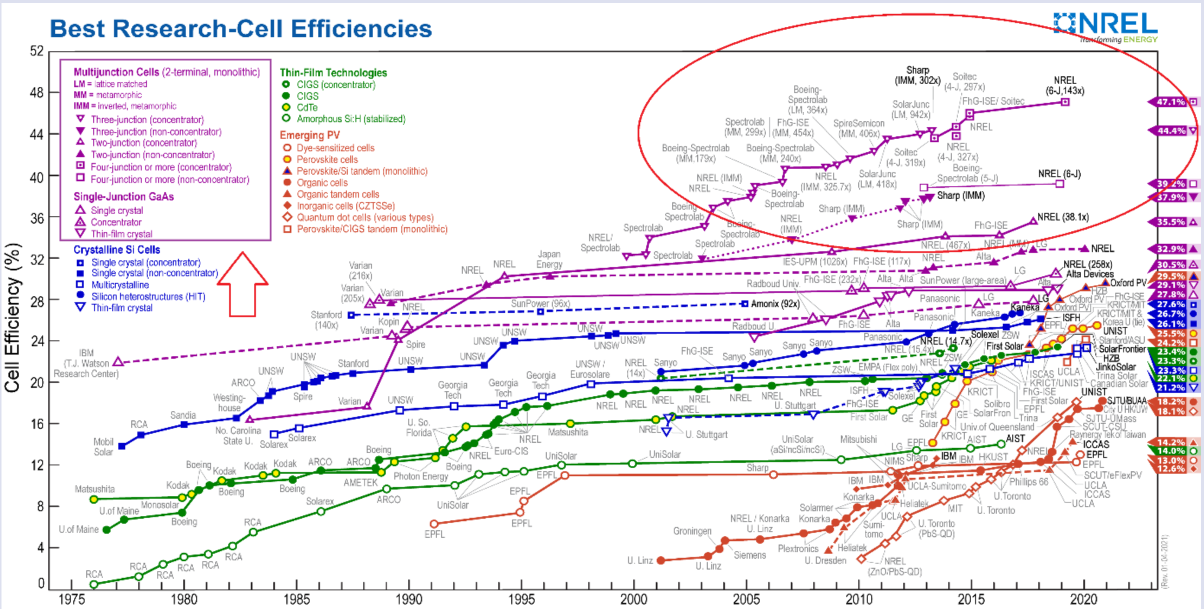

Figure 1. Temporal evolution of solar cell efficiency [3]

Currently, grid-connected systems have approved the use of 72-cell 24 Volt systems. The front side of these panels is coated with tempered glass, while the back surface is coated with a protective and water-resistant substance. Additionally, the corners and connection points are encapsulated. A panel array is formed by interconnecting panels either in parallel or in series, depending on the desired voltage or current specifications.

Edmund Becquerel discovered photo-electric effect in 1839, and Albert Einstein further developed it in 1905, earning him the Nobel Prize in physics that same year. He found that the voltage across electrodes submerged in electrolyte solution fluctuates in response to the intensity of light incident on the electrolyte. Adams and Day discovered a comparable occurrence on solid surfaces during their work on selenium crystallines in 1876. In subsequent years, light metres in the field of photography extensively utilised photodiodes constructed from copper oxide and selenium. In 1954, Chapin et.al. introduced Si crystalline cells and also panels with an efficiency of 6%. In subsequent years, photovoltaic technology was employed in spacecraft and is in a state of ongoing advancement at present [1–3, 8].

Enhancing the compatibility between the inverter and PV groups can augment the efficiency of the PV system. It is crucial to select an inverter that is appropriate for the nominal voltage operating range. When analysed based on the sorts of cells used, first, crystalline silicon cells were investigated. Monocrystalline solar cells and polycrystalline solar cells Polycrystalline band cells EFG, String Ribbon, Dentritic web, and Polycrystalline thin film cells are all types of solar cells manufactured by Apex. B-Thin cells made of amorphous silicon, copper-indium-diselenide (CIS), and cadmium telluride (CdTe) Microcrystalline and micromorphological cells [2, 4, 9–14].

Infrastructures of Solar Cells for panels are commonly used Crystalline and there exist two distinct categories of structures: Monocrystalline and Polycrystalline. Their mean life expectancy exceeds 20 years.

Monocrystalline Cells

The product excels in both quality and efficiency, however, its production entails significant time and technological challenges, resulting in relatively higher prices. It is a favorable choice for tasks that require a significant amount of time to complete. A monocrystalline cell is composed entirely of crystalline and possesses a uniform atomic structure, indicating homogeneity. In order to manufacture monocrystalline cells, silicon must possess a high level of purity. Consequently, their prices are exorbitant. To accomplish this, individual ingots made of single-crystalline silicon are extracted from the molten silicon. An optimal characteristic for this sort of panel is to have a module tolerance of +5% or more. Monocrystalline possess a uniform structure and commonly exhibit color shades ranging from deep blue to black. The shape of an object might vary depending on the degree of diffusion, ranging from circular to rectangular. Panels with monocrystalline cells are employed for measuring high power outputs in the megawatt range [2, 4, 9–14].

Polycrystalline Cells

The process involves pouring (casting) molten silicon into the rectangular molds to create these cells. The polycrystalline blocks, measuring 40 cm x 40 cm and 30 cm in length, are subsequently sliced into “bricks” and then into wafers. The crystalline exhibits a grain size of around 1 cm and is distinctly visible against a dark blue background. Due to the highly crystalline nature of the cell structure, the crystallines are readily visible in the light reflections. The colours of wafers are blue with an anti-reflective coating, and silver grey without any coating. Due to its poorer quality and efficiency compared to a monocrystalline cell, the cost of this type of cell is significantly lower. Polycrystalline lack a singular crystalline structure, thereby rendering them non-homogeneous. The presence of cracks within the crystalline has a detrimental impact on the level of effectiveness, however, the manufacturing of these cell types is more cost-effective. Polycrystalline panels consist of vessels with crystalline structures that share identical electrical, optical, and structural properties, with the exception of their opposite orientations. The magnitude of the veins is directly proportional of the crystalline [2, 4, 9–14].

The lack of consistency between the vessels poses a substantial obstacle, particularly in the transit of electrical load carriers. Due to the proportional reduction in electrical characteristics with the size of the container, the efficiency of polycrystalline material is lower compared to monocrystalline cells. Nevertheless, the production methods for Polycrystalline Si are characterized by lower energy consumption and reduced weight, resulting in a lower cost for manufacturing polycrystalline cells. Consequently, they are favored in regions that necessitate minimal power production, in regions with abundant sunshine, and in regions that do not prioritise efficiency [15–19].

Silicon cells with enhanced power output

These cells are derived from polycrystalline structures formed during injection. In addition, they also undergo mechanical forming procedures. Microscopic perforations are created on both the front and back surfaces of silicon plates using a high-speed rotating milling blade. The processed pieces are arranged in a rectangular shape, with minor gaps intentionally left at the cutting sites. These holes facilitate the cell's permeability. The permeability ranges from 0% to 30% and is contingent upon the magnitude of the gaps. The efficiency of the cell that passes by 10% is once again around 10%. The forms have dimensions of 10cm x 10cm and are square in shape. The colour matches that of the Polycrystalline cell [2, 4, 9–14].

Ribbon created

About 50% of the brick material is wasted during the wafer slicing process in conventional manufacturing techniques. Various strip extraction methods are implemented to mitigate this loss and enhance utilisation. These techniques generate fluids by directly melting silicon. The fibres possess the necessary plate thickness and are exclusively divided into strip pieces by laser cutting. This strategy uses less quantities of resources and energy. Moreover, it is a more economical alternative to injection casting or crystalline pulling methods. Three technologies have been developed specifically for mass production [2, 4, 9–14].

The Cells are Made of aa-Polycrystalline EFG silicon

These cells, which have an efficiency of 14% and an average thickness of 0.28 mm, are manufactured using a technique called Edge-Defined Film-Fed Growth (EPG). They are typically made in a rectangular or square shape. The colour of the object is blue [2, 4, 9–14].

Polycrystalline string ribbon silicon

The cells possess a rectangular shape, exhibiting an efficiency of 12% and an average thickness of 0.3 mm. Their structure closely resembles that of EFGs, appearing in shades of blue or silver grey [2, 4, 9–14].

Monocrystalline dendritic web silicon (cc-monocrystalline dendritic web silicon)

The cells possess a homogenous structure, similar to monocrystalline silicon cells, with an efficiency of 13% and a rectangular thickness of 0.13 mm. The structure, in fact, calls double-crystalline or Apex cells represent the initial utilisation of thin film technology in the manufacturing of crystalline silicon that is ready for use. The conductive ceramic substrate, which contains silicon, is substituted with a thick layer of silicon. This silicon layer is then coated with a thin film of Polycrystalline silicon, measuring 0.03-0.1 mm in thickness, using a sequential process. This technique yields solar cells of greater dimensions that possess polycrystalline characteristics. By employing this technique, lower temperatures prove enough for the fabrication of superior semiconductors, resulting in a decreased cost for accelerated manufacturing.

Thin manufactured solar panels

The method of coating the semiconductor material in a thin film across large surfaces has effectively addressed the reduction in materials and labour, as well as the simplification of technology and cost reduction, in the manufacturing of solar panels. These panels are multi-layered and have the ability to absorb photons across a larger range of wavelengths. This approach involves the application of photoactive semiconductors in thin layers onto a mostly glass substrate. The employed techniques encompass chemical processes such as electrolytic baths and cathode toning.

Thin film panels have the advantage of not being restricted by the size of the plate. In theory, the substrate can be precisely sliced to the desired dimensions and then covered with semiconductor material. Nevertheless, it represents the maximum achievable rectangular area with an electrically conductive region for an asymmetrical shape, as only cells of identical dimensions may be connected in a series. Regions beyond this domain lack electrical activity and cannot be discerned from an optically active domain.

Crystalline cells rely on external means for intercellular communication, whereas thin film cells are interconnected in a monolithic structure. During the forming steps of the production process, the cells are electrically isolated from one other. Consequently, sticky folds are formed between these cells. In order to enhance energy efficiency, these waves are minimised to the greatest extent feasible and are imperceptible to the unaided human eye [15].

Although thin film cells have a rather low efficiency, it is certainly worth considering energy recovery under some circumstances. They exhibit superior performance compared to other cells in both low-light and high-temperature situations. They persist in manufacturing during overcast and indoor conditions. Their cell morphologies, which are thin and elongated strips, make them more resistant to shade.

Their electrical connections are established through the application of an opaque metal coating on the back surface. The technique is carried out on the front surface, which is exposed to light, using a highly polished and conductive coating called the TCO (Syddam or Transparent conductive oxide layer). Zinc oxide (ZnO), tin oxide (SnO2), and indium tin oxide (ITO) are the most often utilised metal oxides [7, 16, 17, 20, 21].

Solar cells serve as the primary components for manufacturing solar modules/panels, which produce electrical energy by harvesting sunlight. A solar panel harvests solar radiation to generate renewable energy. Research findings indicate that a wide range of semiconductor materials can be applied as a coating on various substrates, including glass, metal, or plastic foil. Thin-film photovoltaic (PV) products typically possess a polycrystalline structure and contain vascular defects that vary in density from one in a thousand to one in a million per millimeter. The semiconductor material exhibits favourable electrical, optical, and structural characteristics for photovoltaic (PV) applications in various devices. However, the presence of structural imperfections at the microscopic scale, such as intervascular borders, poses significant challenges in polycrystalline materials [21–25].

Based on its optical qualities, a certain semiconductor has the ability to effectively dissipate nearly all of the sun's radiation within a thickness of 0.001 millimeters. Transitioning from this point, there are limited applications for cells composed of thick silicon in thin film photovoltaic material. Simultaneously, thin film semiconductor material can be applied on expansive surfaces on virtually any type of material, whereas silicon batteries are constrained by increased crystalline sizes [15, 24, 25].

An impressive characteristic of the NREL's 18.8% efficient cell was orientation of the CIGS films. Typically, chalcopyrite CIGS films have a random orientation. Currently, absorbers with orientation are widely used in high-efficiency devices [15]. Figure 2 describes the imagination of standard structure of solar cells [2].

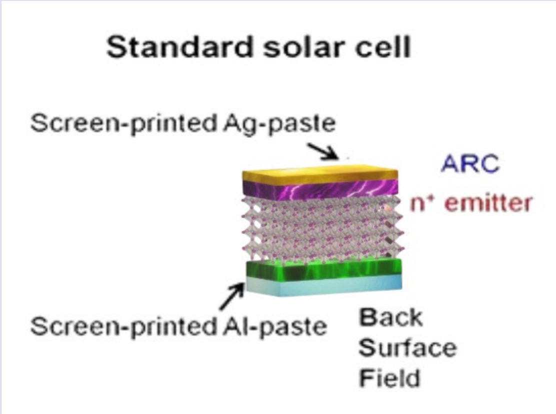

Figure 2. Standard solar cell structure in PV.

The cellular modules are equipped with windows, glass enclosures, and various surfaces, including side fronts. These shade devices, known as "Shadow-Voltaic", offer protection from the sun's disruptive effects while also generating electricity for users, resulting in a rapid return on investment. Control systems can be optionally integrated with shading systems, allowing for both horizontal and vertical use in sunbeds, and storefronts. The integrated modules and designs, in the form of glass that is incorporated, can also be used without frames. These structures are referred to as synergy fronts and roofs. There are two available applications: one that is integrated into the roof structure and another that is separate and installed on the rooftop. The laboratory efficiency of these panels is approximately 18%, but, their long-term durability does not meet the acceptable standard [14, 16].

Amorphous silicon, cadmium, cadmium telluride (CdTe), and copper-indium-diselenide (CulnSe2) are notable compound semiconductors used in thin film panels [15–18].

Amorphic Silicon Thin Film Cells possess a notable cooling coefficient and may be uniformly applied to expansive surfaces at a temperature of 250 degrees. The key characteristic that sets the material apart from crystalline silicon is the random arrangement of silicon atoms, which are positioned beyond the surrounding atoms in close proximity. Amorphous silicon, instead of adopting a normal crystalline structure, produces an irregular network. Consequently, unoccupied bonds have the capacity to retain hydrogen. The hydrogen silicon is synthesised in a plasma reactor using the chemical vapour deposition of gaseous silicon (SiH4). The addition is performed by combining the gases that contain the pertinent components [14, 18, 26]. Despite the negative impact of a haphazard arrangement of structural stones on the efficiency of amorphous-silicon electricity, the inclusion of hydrogen in the semiconductor can enhance its electrical characteristics by 5-10%, making it suitable for the PV circuit. Despite the challenges they pose, Amorphous Silicon cells are widely utilised as power sources in applications that demand small-scale power. Due to advancements in addressing issues of inconsistent performance, these solar cells have also been implemented in extensive projects.

The primary drawback of amorphous cells is their suboptimal efficiency. Stacked cells have been developed as a means of preventing this. Every segment of these cells is specifically designed to maximise efficiency for a particular colour wavelength, hence enhancing the total effectiveness. Additionally, it mitigates the impact of light-induced fatigue by decreasing light sensitivity. The cell shapes can be customised according to preference. The efficiency of the modules varies between 5% and 8% depending on their static state. The standard dimensions of a module are 0.77 m × 2.44 m, while individual modules measuring 2m x 3m can also be produced. The substrate has a thickness ranging from 1 to 3 mm, and it is coated with a layer of amorphous silicon that is roughly 0.001 mm thick. Their composition is uniform, however their colour ranges from crimson to ebony [2, 8, 27]. Amorphous-silicon PV panels have the benefit of being highly responsive to wavelengths in the transmission spectrum, resulting in a greater energy generation capability. It generates a reduced amount of raw materials and consumes a lower amount of energy. An exemplary illustration of hybrid panels is provided by Kaneka, comprising a total of 53 interconnected cells. Every individual cell produces an electrical voltage of 1.02 V. The current generated by the panel under 1000W/m^2 radiation is 2.04 Amperes, while the voltage is calculated as 1.02 multiplied by 53, resulting in 54.0 Volts. The power output (Wp) is determined by multiplying the voltage (54 Volts) by the current (2.4 Amperes), resulting in 100 Wp [8].

Cadmium telluride thin film solar cells

Cadmium telluride (CdTe) cells are manufactured using a glass substrate coated with a solid conductive layer, often indium mould oxide (ITO). The front connector is coated with a very thin coating of n-type CDS. Subsequently, the p-type CdTe coolant layer is introduced. Common production techniques such as serigraphy, galvanization, or spray pyrolysis are employed.

The issue with this technology lies in Cadmium contamination, which has the potential to impact the level of adoption in the market. Cadmium telluride (CdTe) is a chemically stable molecule that does not emit pollutants. Health-risk circumstances only develop in the gas phase, namely under closed production conditions. The module's efficiency varies between 6% and 9%. The cells can be moulded according to one's preference. The cells possess a covering with a thickness of 0.008 mm, in addition to a substrate that is 3 mm thick. The maximum dimensions are 1.20 millimeters in length and 0.60 square meters in area. Their structures exhibit uniformity, but their colours range from lustrous dark green to black [1, 3, 28]. The forbidden energy range of CdTe at ambient temperature is Eg = 1.5 eV, which is in close proximity to the threshold needed for optimal conversion of solar energy into electricity from the solar spectrum [14, 19, 29]. Furthermore, the CdTe compound semiconductor has gained prominence in the manufacturing of large-scale solar cells due to its high cooling coefficient and the ease of production offered by various thin film enlargement technologies.

Solar cells made of copper indium diselenide

This compound semiconductor exhibits high cooling ratios and allows for precise adjustment of the energy gaps to optimally align with the sun spectrum. The group known as CIS is commonly referred to as solar cells, and CdTe is the most formidable competitor to solar cells. Today, the incorporation of the Ga element in these cells has led to a higher yield. Nevertheless, the production method becomes increasingly intricate as the number of components comprising the semiconductor increases. During the production of cells, a glass substrate is initially covered with a thin coating of molybdenum to provide a back surface connection. The P-type CIS cooling layer is formed through the reverse evaporation of copper, indium, and selenium at a temperature of 500 degrees within a vacuum chamber. CIS cells do not experience light-induced reduction in efficiency, unlike Amorphous cells.

In addition, stability issues develop in environments characterised by high temperatures and humidity. Hence, it is crucial to prioritise insulation in humid settings. The current most efficient thin film technology available today is CIS cells [14, 17, 19, 29]. Mass production yields significantly lower production costs in comparison to crystalline silicon cells. An inherent drawback is the necessity for further investigation to eliminate the use of cadmium in the CdS buffer layer. Selenium is considered safe due to its low overall toxicity [14, 18]. The shapes can be customised according to one's preferences. The dimensions of the cells do not exceed 1.20 mm x 0.60 mm^2 and they are coated with a layer that is 0.003 mm thick. The cells are mounted on a 3 mm substrate made of warmed glass [7, 15–17]. They exhibit a uniform structure and possess a dark coloration. Silicon (Si) cells exhibit greater productivity in hot climes and offer a more affordable pricing compared to Si. batteries.

However, the coverage area of the cells is significantly greater than that of the Si. cells. Photovoltaic cells generate a greater amount of energy from light compared to other types of cells. Additional cell types are positioned at an average incline of 30 degrees, whilst thin film panels are affixed to external facades with a 90-degree inclination relative to the floor [17, 18].

Bifacial solar panels

Bifacial cells, which are panels composed of various cell combinations such as monocrystalline and amorphous silicon, have the ability to generate electricity on both their front and rear surfaces. This is achieved by harnessing solar radiation from direct sunlight as well as utilising solar rays. This product is not derived from a homogeneous cell population. N-PERT technology refers to the production of panels using p-PERC+ and Heterojunction cell types [2, 5, 30, 31]. The panel's transparent rear covering and entrance window allow for angular positioning, which enhances the reflection of light from the ground

PERC standards for passive emitter rear cell

PERC solar cells, or solar panels including these cells, have a higher efficiency in converting sunlight into electricity. Perc solar panels, equipped with solar cells, have demonstrated superior performance compared to conventional panels under conditions of low light and high temperature [8]. The incorporation of a thin film layer created using SiO2 or Al2O3 chemicals in the PERC structure enhances the efficiency of the conventional solar cell, resulting in numerous advantages for the cell's efficiency. This design enables the reflection of some photons within the cell, enhancing energy production. Additionally, the cell base is passivised to reduce energy production losses at high temperatures. The Multi Bus Bar is a system that allows for the simultaneous stripping and connecting of many wires using a single bar. This is a cellular technology designed to increase the number of tin alloy wire strips used in standard (typical) cell types while reducing the amount of silver paste required in the metallization process, hence lowering costs. It is feasible to apply to a wide range of cell types. 12-busbar technology has gained significant popularity in recent times.Furthermore, transitioning to PERC production necessitates minimal alteration to current cell production procedures. Manufacturers can easily transition to producing more efficient PERC cells at a reduced cost. These structures are referred to as PERC or Aluminium cells.

Half-Cut — Refers to cells that have been physically divided into two halves

A panel refers to a specific form of panel that is achieved through the process of laser cutting Mono and Poly structured cells. The purpose of this cutting is to maximise power output within a limited area by combining the cells on the surface, effectively doubling the number of cells. This advancement has enabled the production of solar panels with a power output of 400 Watts peak (Wp) or more [9, 10].

Also it used for Dual Glass refers to a type of glass that consists of two layers, commonly known as Double Glass. Double-glass panels without frames. The level of efficiency is contingent upon the specific type of cell employed.

Biosol Panels

These foldable thin film solar panels are particularly effective when utilised for roof applications. If mounting the PV system proves challenging, it is possible to install it on the roof without causing any harm to the roof insulation. Furthermore, this installation might serve as an extra layer of protection for the rooftop [27, 31]. The Biosol panels are offered in different options, including crystalline and thin film cells. The Biosol panels are composed of thin film cells, which are also referred to as the Thin Film Tandem. It possesses great adaptability and can be utilised in uppercase format. It does not require an additional structure. Thin-film panels have a weight that is 70% lighter than crystalline panels. The multi-layer (tandem) solar cells have a theoretical yield of 40%.

Nanocrystalline cells

These cells serve as a substitute for silicon technology. The fundamental constituent of this cell is titanium dioxide (TiO2), which functions as a semiconductor [9, 32]. This semiconductor utilises the absorption of solar light by chlorophyll during plant photosynthesis to convert sunlight into a cooler organic form, rather than relying on the p-n connection concept. Upon exposure to light, the cell undergoes activation, causing the transmission of an electron through Titanium Dioxide in the paint. The electron travels to the higher electrode from inside the particles. An electron is conveyed via a platinum catalyst to an electrolyte solution.

The electrolyte facilitates the transfer of electrons back to the paint, thereby closing the circuit. This technique is entirely devoid of any harmful properties. Their production is cost-effective and straightforward. However, addressing the issue of long-term commitment is vital. The cell yield in laboratory conditions is approximately 12%. It exhibits high tolerance for shadows and suboptimal angles of incidence. Conversely, crystalline cells exhibit enhanced productivity in elevated temperatures, making them particularly well-suited for compact devices and building-integrated systems designed for indoor applications [21, 29].

Tandem or multijunction cells

These cells utilise layers of different materials with differing bandgaps to catch a wider range of sunlight wavelengths, hence enhancing the overall effectiveness of the cells.

Micro-crystalline and micromorphic solar cells

Silicon is an abundant chemical that is absolutely non-toxic. It is spontaneously created by cells in the form of a thin film derived from crystalline silicon. This technology capitalises on the benefits of silicon as a material, as well as the ease of thin film technology. The production method utilised in the aforementioned Apex cells is pioneering. In this process, a superior silicon coating is applied over a low-cost substrate using high temperatures, resulting in the formation of huge granular formations similar to those found in polycrystalline cells.

The second category involves procedures conducted at reduced temperatures. Due of the low temperatures, inexpensive substrates made of glass, metal, or plastic can be utilised. The silicon films generated through this procedure exhibit micro-crystalline characteristics and are manufactured using methodologies akin to Amorphous Silicon Technology. The maximum efficiency reached in these cells is 8.5%, and superior outcomes are obtained by utilising Tandem cells composed of micro-crystallines and employing amorphous silicon in combination. The term "micromorphic" refers to these tandem cells, which are a fusion of the words "microcrystalline" and "amorphous". The cells exhibit a remarkable steady efficiency of 12% and were initially manufactured by the Japanese business company named Kaneka [8].

Hybrid (HIT) cells

HIT solar cells consist of a hybrid structure that combines traditional crystalline and thin film solar cell technologies. The name HIT (Hetero-Junction with Intrinsic Thin layer) refers to the specific construction of these solar cells. The HITs structure comprises crystalline and amorphous silicon, along with an extra non-contributing thin film layer. Similar to thin film cells, the effectiveness of the cells does not diminish based on the intensity of light. HIT cells exhibit higher efficiency than crystalline cells in high temperature conditions. Production procedures are more cost-effective. Due to the specified processing temperature of 200 degrees, the plates are not subjected to excessive heat conditions, allowing for a reduction in their thickness to 0.2 mm. The cell dimensions are 104 mm × 104 mm, forming square forms. The cellular composition is uniform, with cells exhibiting a mostly dark blue to black coloration [5, 26].

Thin-Film Solar Cells consist of Cadmium Telluride (CdTe)

This type of material with a high absorption coefficient and lower production expenses. This combination allows for good efficiency and cost-effectiveness. Copper Indium Gallium Selenide (CIGS) is capable of attaining high levels of efficiency and can be applied onto flexible substrates.

Materials and Methods

A thorough comprehension of certain principles is necessary for optimising solar panel efficiency. The effectiveness of a solar cell is intricately linked to its inner structure, specifically the elements employed and their organisation. Different simulation programs were used to compare the efficiency of PV panels with different structures. In order to change the internal structure of the panels, the results obtained in the Matlab program were tested on another simulation program, PVsyst, and the results were compared. In practice, real climate data was used when testing the production of panels, ensuring real panel production results were achieved. Details of study explain below of how the compositions impacts the efficiency of solar cells.

Choosing the Optimal Semiconductor Material

Energy efficiency is related with the bandgap of a semiconductor material dictates the specific wavelengths of light that it is capable of absorbing. An optimal efficiency can be achieved by utilising a material having a bandgap that closely aligns with the photons in the sun spectrum. The efficiency of a substance is influenced by its absorption coefficient, which measures its capacity to absorb light. Materials possessing high absorption coefficients have the capacity to collect a greater number of photons, resulting in enhanced efficiency Carrier mobility refers to the ease with which charge carriers, such as electrons or holes, can travel within a material. Enhanced mobility leads to a decrease in carrier recombination and enhances efficiency. The previous section also discussed the many types of solar cells. Monocrystalline solar panels have superior efficiency as a result of their consistent crystalline structure, however they are more expensive to manufacture. On the other hand, Polycrystalline solar panels have lower efficiency but are more cost-effective due to their less complex production method.

Furthermore, Perovskite materials have garnered significant interest because to their remarkable capacity for high efficiency and their cost-effective manufacturing methods. Manipulating the chemical composition enables the enhancement of bandgap and carrier transport capabilities, which are vital for increasing efficiency. The term "chemical enhancements" refers to the process of doping, which involves injecting impurities into a semiconductor to modify its electrical characteristics, hence improving conductivity and increasing carrier mobility. Surface passivation refers to the application of surface treatments or coatings to decrease the presence of defects or states that capture charge carriers on the surface of a semiconductor. This process aims to reduce recombination and enhance carrier efficiency.

The effectiveness of a system is significantly influenced by nanostructures and morphology. Nanowires or nanotubes can augment light absorption and charge carrier collection by offering a larger surface area and diminishing carrier travel distances. Furthermore, meticulous management of material morphology, such as nanostructuring and surface texturing, can enhance light trapping and minimise losses caused by reflection. Comprehending and controlling the chemical composition of materials used in solar cells is essential for advancing efficiency limits, cutting down expenses, and broadening the range of potential applications for solar technology.

The general structure of grid connected real time working principles of PV could be seen in Figure 3. The material differences used in the PV cell inner structure provide the opportunity to control nominal power and gain changes within the VSC together with the cell parameters.

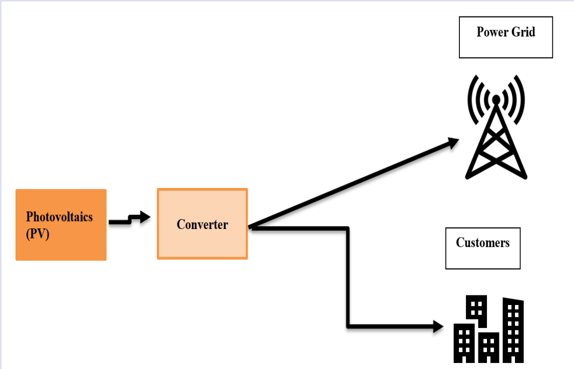

Figure 3. Grid Connected Solar Panel Infrastructure.

The efficiency of a solar panel is determined by comparing the power consumed by the panel to the power it generates when exposed to a light source that closely resembles sunshine in laboratory settings. Typically, solar cells that are used on land are evaluated at AM0 and AM1.5 circumstances, while maintaining a consistent temperature of 25°C and incident light power is same for each panel. Figure 4 shows Matlab software application for the efficiency formula for the actual designs of the photovoltaic (PV) panels, and using ideal parameters for calculation with SunPower SPR-315E, as follows within the Matlab software. This calculation is conducted under appropriate conditions and the efficiency of solar panels and solar cells can be quantified using different equations that correspond to their performance.

Equations for Solar Cell Efficiency

The Shockley-Queisser Limit refers to the maximum theoretical efficiency of a single-junction solar cell. The Shockley-Queisser limit represents the highest possible efficiency that a solar cell can achieve, based on the bandgap of the material it is made of. Equation 1 used voltage, current and power values in Matlab calculations.

$$\eta_{SQ} = \frac{V_{OC} \times I_{SC}}{P_{in}} \quad (1)$$

V_{oc}= Open Circuit Voltage

I_{sc}= Short Circuit Current

P_{in} = Incident Light Power

The efficiency of a solar panel can be calculated using the following equation :

$$Solar\ Panel\ Efficiency = \frac{Power\ Output}{Solar\ Energy\ Input} \times 100\% \quad (2)$$

Power Output: The tangible electrical power generated by the solar panel, commonly quantified in watts (W).

Solar Energy Input: The quantity of solar energy that reaches the panel, typically measured in watts per square metre (W/m^2) or kilowatt-hours per square metre per day ($kWh/m^2/day$).

Equation 2 measures the efficacy of the solar panel in converting incoming sunlight into practical electrical energy. When assessing the efficiency of solar panels in real-world scenarios, it is crucial to consider variables such as temperature, angle of incidence, shading, and climatic conditions. Meteonorm and Weatherspark database used for climate parameters.

A comprehensive understanding of certain principles is necessary for optimising solar panel efficiency. The principles can be summarised as follows: the output forces are measured by comparing them with the monocrystalline values obtained from the NREL, as stated in the Efficiencies section. Figure 1. Distinct panel values were inputted for the polycrystalline configuration, and distinct computations were performed for the monocrystalline. The temperature and irradiance values were consistent, however the efficiency values varied among the 400kW solar panels. The National Renewable Energy Laboratory provides the average efficiency numbers for solar panel structures as follows [3].

The polycrystalline has a composition ranging from 15% to 18%. The Standard Monocrystalline has a purity level ranging from 16.5% to 19%. The Monocrystalline PERC (Mono PERC) solar panel has an efficiency range of 17.5% to 20%. The Monocrystalline solar cells have an N-type doping concentration (Mono N-Type) ranging from 19.5% to 20.5%. The Monocrystalline N-type HJC (Mono HJC) has an efficiency of 19 to 21%. The Monocrystalline N-Type IBC (Mono IBC) has a power output efficiency of 20 to 22%. The values are manually inputted into the parameters in the equations, and the output voltage and output forces are generated by utilising derived graphs.

Results and Discussion

The objectives of the solar panel efficiency notification, depicted in Figure 4, is to ascertain the impact of varying efficiency values on output power. The result charts clearly indicate that comparing polycrystalline and monocrystalline cells in places inside the borders of Sivas, Turkey with average Irradiation values of 25 degrees. Polycrystalline cells are suitable for regions experiencing extreme regional temperatures and limited power generation. The Matlab Application was used to conduct a comprehensive analysis of monocrystalline solar panels. The measurement results were acquired by inputting specific parameters into the 400kW networked photovoltaic cell construction. The resulting data is displayed in the graphs in Figure 5 and Figure 6. The Energy Generation results were evaluated using the 400kW PV panel model displayed in the MATLAB application. The model data includes four photovoltaic arrays, each with a maximum power production of 100 kW when exposed to sun irradiation of 1000 W/m2.

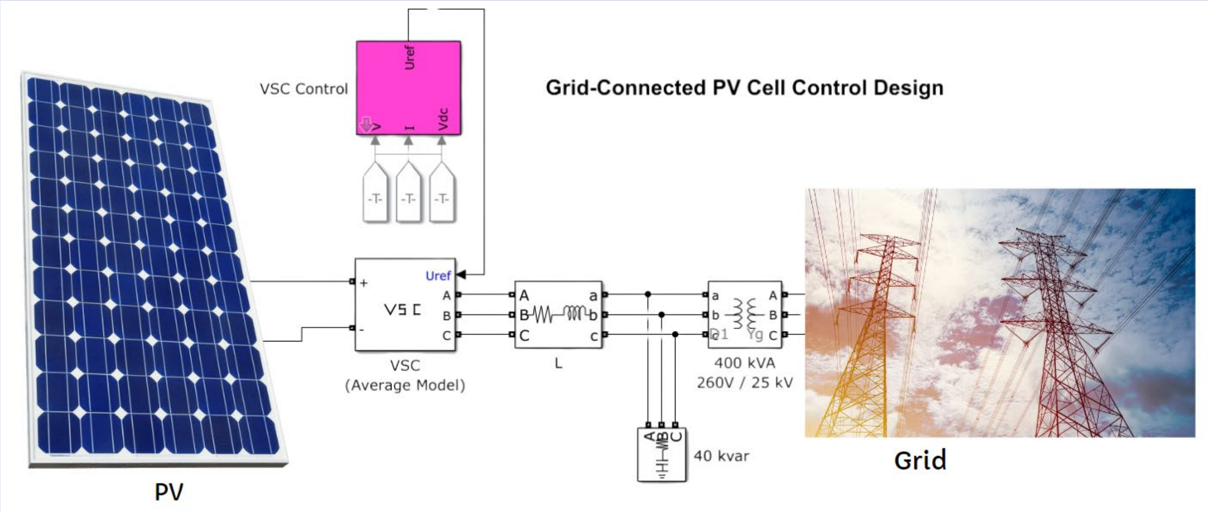

Figure 4. Grid Connected Solar Panel Efficiency Application in Matlab.

The PV array block is composed of 64 parallel threads, it is designed with based on Figure 4 Matlab PV array block diagram, then it is developed and improved with different parameters, where each thread is made up of a series connection of 5 different location same power in simulation as SunPower SPR-315E modules. Every solar array is linked to a direct current to direct current converter, specifically employing an simulation model. The outputs of the boost converters are linked to a shared DC bus operating at a voltage of 500 V. Every boost is regulated by separate Maximum Power Point Trackers (MPPT). MPPTs employ the "Perturb and Observe" method to control the voltage across the terminals of the PV array in order to attain the highest attainable power. The three-phase Voltage Source Converter (VSC) transforms the 500 V DC input into a 260 V AC output, maintaining a power factor of unity. A 400kVA three-phase coupling transformer is utilised to link the converter to the grid. The transformer possesses a primary voltage rating of 260 volts and a secondary voltage rating of 25 kilovolts. The grid model has standard 25 kV distribution feeders and a 120 kV transmission system that faithfully reproduces actual transmission networks.

The model parameters depict in Figure 4 and the boost and VSC converters as voltage sources that produce the mean AC voltage across a single cycle of the switching frequency. While this model may not accurately depict harmonics, it does effectively maintain the dynamics that arise from the interplay between the control system and the power system. This model enables the usage of significantly longer time periods (50 microseconds), leading to a significantly faster simulation. When the efficiencies of the panels remain constant, the power output chart of identical solar panels, with irradiance as a linear output, follows the same pattern, while maintaining a consistent efficiency.

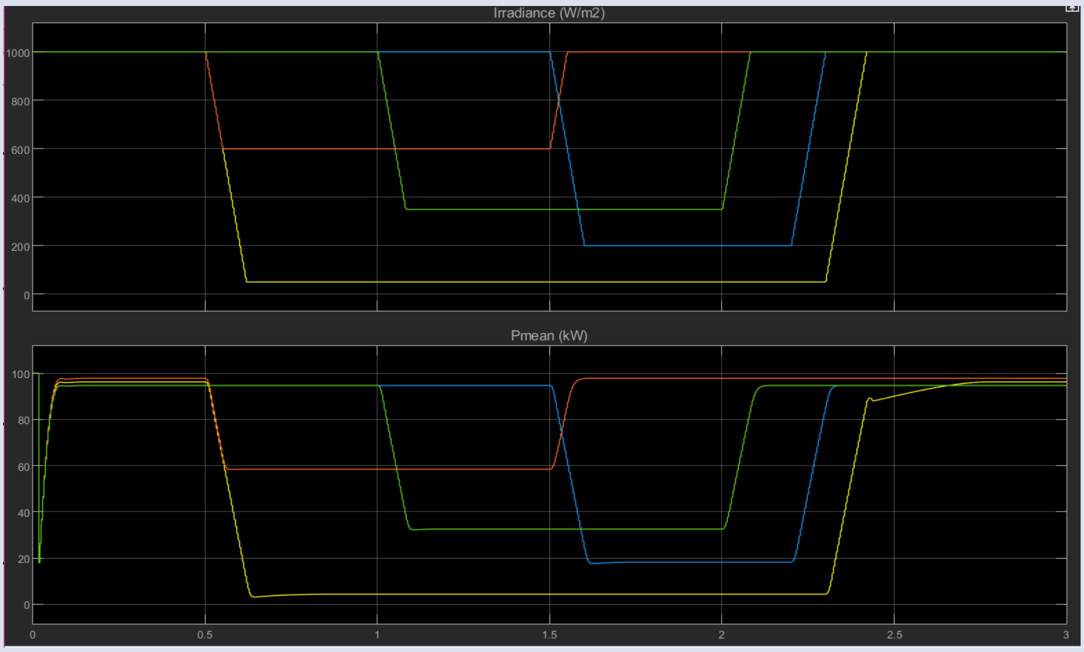

Figure 5. Irradiance and Power Output Correction Graphs.

The colour codes employed in obtaining the findings are based on values associated with the chemical structure of efficiency, which are altered by adjusting the parameters inside the panels' internal structure. The output forces for each panel are also displayed in Figure 5 to verify if the outputs corresponding to these colour codes exhibit a linear relationship with constant irradiance levels.

The outcome graphs were analysed in depth, using data from the Panel efficiency account. The data was focused on the ideal values of the matching cells in the solar cell parameters, which solely consider efficiency. The temperature was set at 25 degrees. Figure 6 displays the computed results for current in Matlab, voltage, and power outputs utilising efficiency equations.

It is apparent that the maximum efficiency value belongs to the Mono N Type IBC cells, while the polycrystalline cells do not demonstrate sufficient performance even in modest power production. Different mono types also simulated with 1MW power capacity and results are compared with Matlab and PVsyst simulation. In the Matlab model data includes four photovoltaic arrays, each with a maximum power production of 100 kW when exposed to sun irradiation of 1000 W/m2.

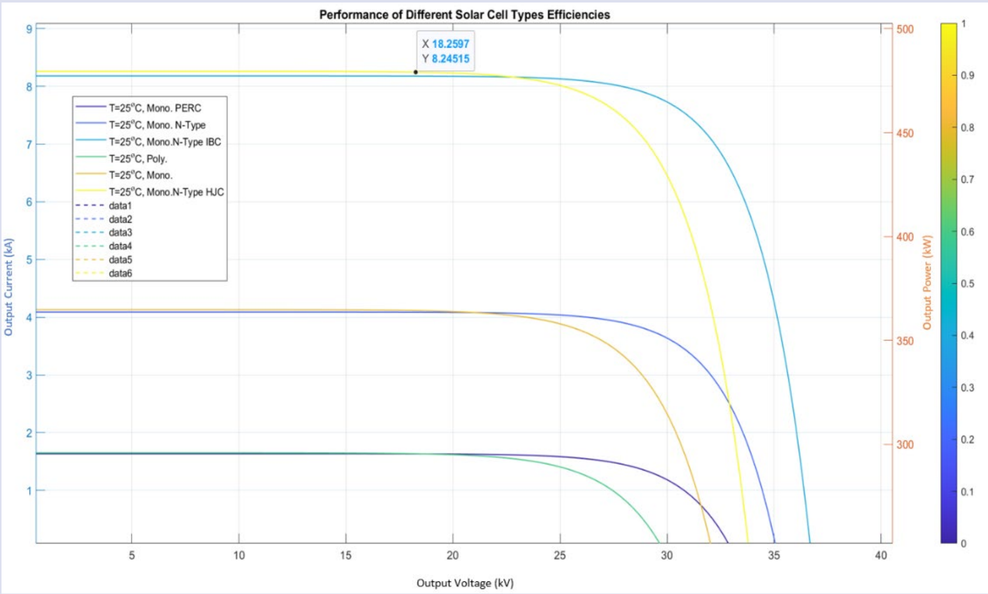

Figure 6. Solar Cell Efficiency Performance results.

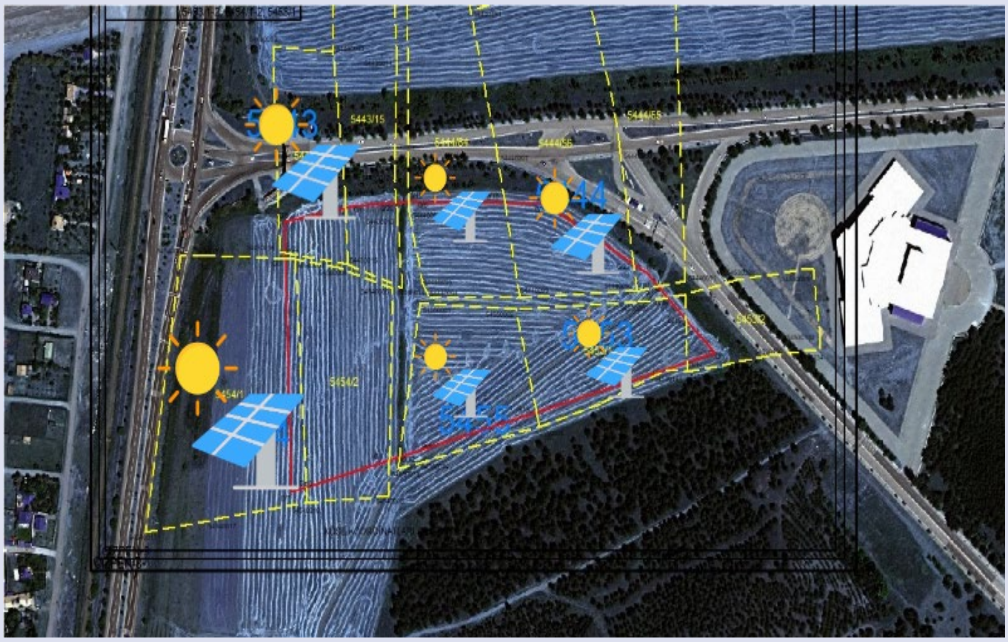

Figure 7. Suitable Areas for PV Application in Sivas Cumhuriyet University.

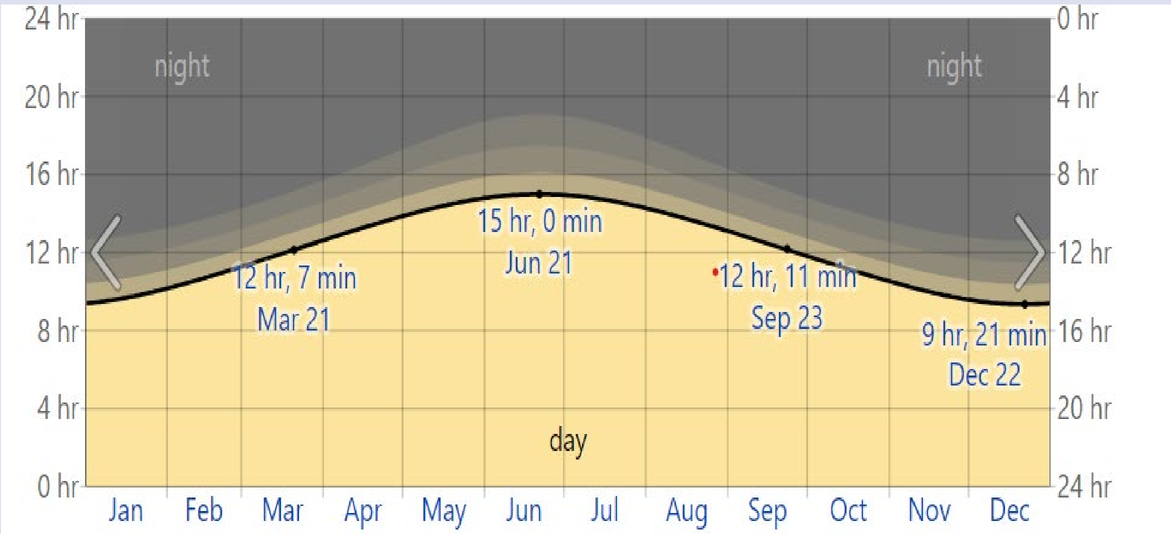

Figure 8. Sivas city daylight and Twilight values from Weatherspark database, the number of hours during which the Sun is visible (black line). From bottom (most yellow) to top (most gray), the color bands indicate: full daylight, twilight (civil, nautical, and astronomical), and full night.

In order to verify the results on a real system, areas where solar panels could be applied were identified within Sivas Cumhuriyet University and real-time application was made. According to the analysis, areas must have some characteristics in order to apply the pv system [3].

In this context, the PV application areas marked in yellow and shown in Figure 7. PV application details could be find in our previous study [33] for determined and selected areas characterisation where panels can be applied.

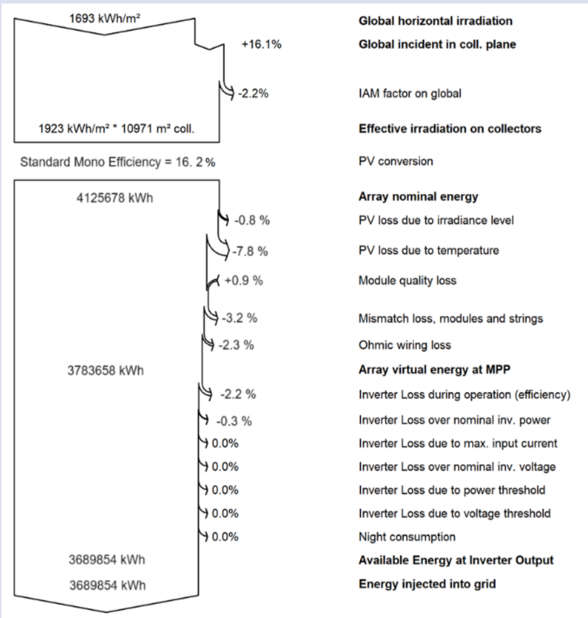

Figure 9. Standard Mono Cell losses and efficiency results.

According to the simulation results along with the climate data of the region shown in Figure 8 taken in real time, the cells giving the highest and lowest efficiency results were tested with the PVsyst simulation for different PV characteristics and efficiency results were obtained. The efficiency results of MONO IBC and standard Mono cells are shown in Figure 9 ,10 and 11.

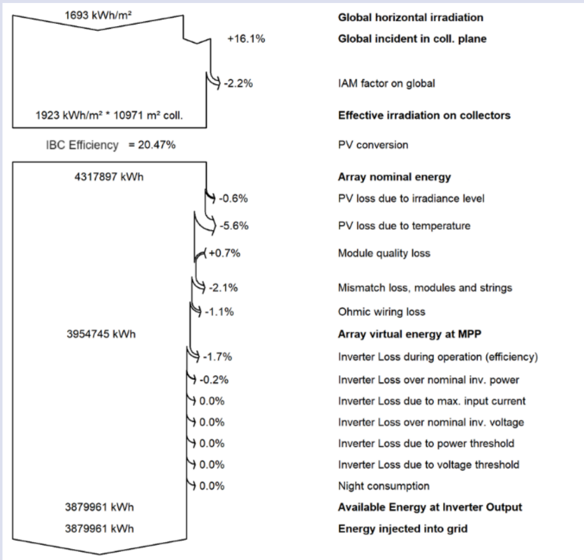

Figure 10. Mono IBC Cell losses and efficiency results.

The reason for choosing a capacity of 1 MW is to compare the efficiency of energy production in the region. Since 100 kW PV cells were selected both Matlab and PVsyst application. In addition, simulation results which made with the PVsyst, used Meteonorm 8.2 climate database and show real-time production values of PV cells.

New simulation variant

Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	ratio
January	62.7	29.78	-3.81	99.6	97.7	218117	215084	0.963
February	85.3	34.80	-2.13	122.0	119.9	261789	257980	0.943
March	124.8	49.64	3.42	156.3	153.2	323811	318809	0.910
April	159.8	61.45	8.42	173.3	169.4	348922	343215	0.883
May	196.2	71.65	13.04	193.6	188.5	383160	376599	0.867
June	219.3	65.31	16.77	206.5	200.9	400965	393696	0.850
July	219.9	61.55	20.52	210.8	205.2	401156	393560	0.833
August	207.9	56.69	21.10	219.3	214.3	417924	409984	0.834
September	165.5	43.23	16.34	198.9	195.0	384516	377458	0.846
October	115.2	42.57	10.84	158.6	155.7	320985	315755	0.887
November	75.5	29.02	4.40	120.9	118.9	254221	250453	0.923
December	60.8	25.80	-1.30	106.2	104.1	230550	227367	0.955
Year	1693.0	571.50	9.03	1965.9	1922.6	3946115	3879961	0.880

Figure 11. PVsyst simulation Pv Cell loss calculation and efficiency results.

Conclusion

The analyses conducted on the Solar Panel cell and the matlab model indicate that the Monocrystalline N-Type IBC model exhibits the maximum efficiency in terms of pv cell structure. Both polycrystalline cells and cells in the Mono structure have demonstrated inadequate power efficiency in power generation, even when considering solar panels with a capacity as low as 400kW. The Mono IBC structure is more efficient than polycrystalline cells and all monocrystalline at high temperatures. This allows the cell to reflect itself and passivise the cell base, resulting in a 5% or more increase in energy production. However, the Mono Perc cell type is less efficient in generating energy at high temperatures, leading to a lower yield compared to other mono and polycrystalline cells. Although the data obtained under constant temperatures did not provide a reason for the decrease in yields at higher temperatures, future investigations could potentially draw conclusions by comparing the efficiency at various temperature levels. The graphs exhibit findings that align with the calculated results and the different infrastructures of the solar cell.

The design of the system with an installed power of 1 MW was carried out separately in Matlab and PVsyst simulation programs, using poly panels with the lowest efficiency. 14% of the global radiation, which is 1,693 kWh/m2 annually, falls on the collector, and 2.5% turns into losses as the angle conversion factor. The efficiency obtained when standard mono panel cells were used was 16.1%. The efficiency rate in MIBC has increased up to 20%. PV loss depending on radiation level, PV loss depending on temperature, module quality loss, cabling losses, etc. When included, the annual energy given to the grid is 1,693 MWh. Figure 9 shows the annual generated energy and losses diagram obtained from the PVsyst software for the power plant built using standard monocrystalline panels. According to the results obtained with the climate data added in Figure 8, it is shown in Figure 10 that the most efficient among mono cells is the MIBC model, since the inefficiency of poly cells is clearly known in literature.

Conflict of Interest

The Author has no conflict of interests.

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