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Large, grid-connected solar photovoltaic power plants renewable energy

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Abstract. As an essential part of renewable energy, the solar photovoltaic technic grows rapidly with two main types: off-grid and grid-connected systems. This paper focuses on grid-connected solar photovoltaic power plants and introduces the main physical principles of solar photovoltaics. Typical components of solar photovoltaic power plants are also presented, along with their functions. The extraordinary environmental impact and the relatively low and decreasing cost of grid-connected solar photovoltaics reflect its excellent development potential. Compared with other energy, grid-connected solar photovoltaics provides an alternative to conventional fossil fuel generation. With the improvement of silicon purification technology and the working efficiency of solar batteries, the scale of grid-connected solar photovoltaics power plants will be further expanded.

Keywords: solar photovoltaic power plants, grid-connected system, environment, PV system components, environmental and economic analysis.

1. Introduction

Our Sun produces an enormous amount of energy. When countless photon hit the Earth, the mass amount of heat is generated, and there are still much for us to utilize. There are several approaches to harnessing solar power: solar thermal conversion, which transfers heat from the sun. A photochemical conversion uses energy from the sun to initiate a chemical reaction and photovoltaic conversion that directly generate electricity with light. Electricity plays a pivotal role in today's society as it directly powers most of our devices. Thus, solar photovoltaic technology's capability of converting solar radiant energy directly to electricity makes it particularly valuable. With continual developments in such technology over the last few decades, the solar photovoltaic cell is one of the most prevailing renewable energies. It is not only cost-efficient and reliable but also very accessible. Our group believes that solar energy is the most promising technology, and thus it is the focus of our study here.

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2. History

1)Discoveries of photovoltaic effect

The very first discoveries of the photovoltaic effect unfolded in 1839 when Edmond Becquerel was working on metal electrodes and electrolyte solutions [1]. While experimenting, he noticed a slight voltage change when the device was exposed to light. He later confirmed that electricity could be generated when metal electrodes are exposed to various radiant energy sources, including visible and ultraviolet light. Becquerel's discovery marks human's first grasp of the photovoltaic effect and lays the foundation for future solar panel development.

2) First solar cell

1883 was the turning point for solar photovoltaic technology. Using a selenium wafer, American inventor Charles Fritts created the first functioning solar cell that converts solar energy into electricity for use [2]. By adhering to a selenium layer wafer between a metal plate and a golden coating, he produced electricity at an efficiency rate of 1%. Since that Fritts' cell does not operate effectively and has high production cost, it was not adopted (Figure 1) [2].

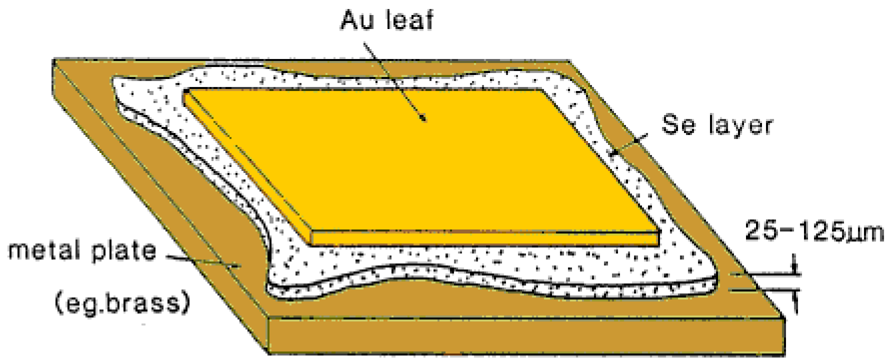

Figure 1. The solar cell constructed by charles fritts in 1883 [1].

3)Albert Einstein's proposal of the photoelectric effect

In 1905, Einstein published his theory regarding the photoelectric effect. He theorized that light is a package of energy, a photon that can be described as both wave and particle depending on the situation. This provides a solid explanation of the principle of the photovoltaic effect.

4)Silicon solar cell

A breakthrough finally came during the 1950s, as Daryl Chapin, Calvin Fuller, and Gerald Pearson brought a new generation of solar cells with drastically improved proficiency in converting energy. Daryl, like his predecessors, was trying to create a more effective solar cell based on selenium. However, selenium continues to be proven as a defective material in the solar photovoltaic conversion process. Chemists Calvin Fuller and Gerald Pearson's experiments on semi-conductor with impurity provided new insights for Chapin. By doping silicon that contains gallium into lithium, Fuller and Pearson created the first p-n junction [2], which produces current reliably when exposed to light. Collaborating with Chapin, they experimented with different doping combinations and finally adopted boron and arsenic as the impurity pair. This boosted the efficiency of the solar cell to around 6% and made the technology practical [3].

5)Further developments

More initiatives were taken in developing solar cell technology after the Bell Lab innovation. In particular, the United States' establishment of the Solar Energy Research Institute in 1977 provoked global interest in this renewable energy source. Solar photovoltaic technology is applied to our daily life and can generate considerable energy. The decreased cost of materials and manufacturing and the advancing technology that improves conversion rate made large-scale production and application possible. At the domestic or industrial level, solar photovoltaic has become the leading sustainable energy source with very high potential.

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3. Physics and technology principles

1) Photovoltaic effect

The photovoltaic effect describes the current generation by the energy given from light or solar radiation. Solar radiation increases the potential energy of electrons within the material and potentially creates a separation of charge, generating electricity.

2) Band gap

Depending on the materials, each atom has discrete energy levels, and all electrons will be residing on any one of them based on their potential energy. One electron can only absorb or lose a specific amount of energy to jump to a higher energy level or goes to a lower one. The excess energy loss or gain would be exchanged as heat. In the higher energy level, there is the conduction band, where electrons possess enough energy to move around freely. On the other hand, in the lower energy level, there is the valence band where electrons remain to be bonded with the atoms. The difference between these two bands is called a band gap, the amount of energy we require to free an electron [4].

3) Semiconductor

In order to generate electricity, we must promote some electrons to the conduction band to create a potential difference. The insulator has a large band gap, making it impractical to gain energy since the energy input substantially exceeds the outcoming electricity. On the other hand, metals have a continuous energy band, which enables their electrons to move around at all times, making it hard to create separation of charges by simply inputting energy. The semiconductor's band gap can usually match the energy of solar photons in the range between 0.3eV and 4.5eV [5], making it possible to use the energy of solar radiation to produce charge separation. Therefore, the semiconductor became the ideal material for solar photovoltaics (Figure 2).

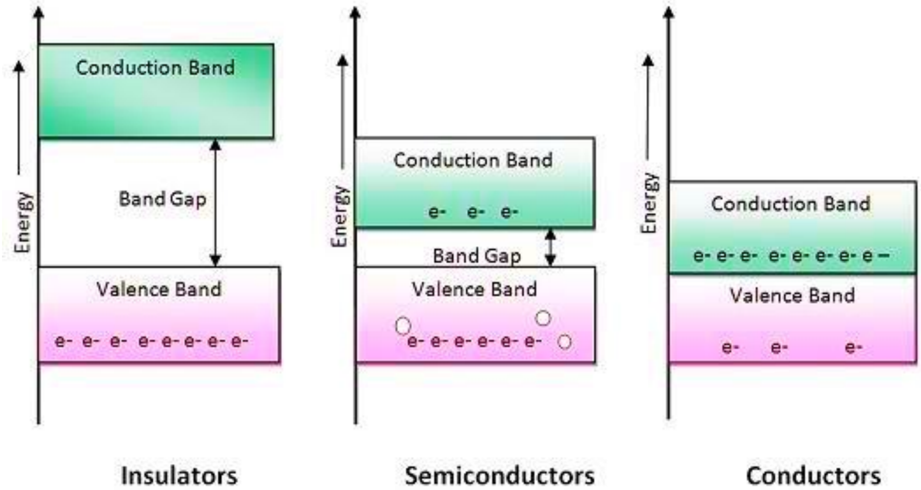

Figure 2. Band gap of insulators, semiconductors, and conductors [6].

Take the most common solar cell material, silicon, as an example. Intrinsic silicon has four valence electrons. In the crystal lattice structure, they bond with each other by sharing two electrons. With energy carried by the light that is equal to or greater than the band gap going through the structure, the electrons can be knocked out of the bond and become free to move around, leaving a vacancy at its original position – a hole [5]. Afterwards, these free electrons will move around and fill these "holes." The movement, hence, produces electricity. Nonetheless, the movements of these electrons, or the current, do not necessarily go through where we want them to be. Therefore, it can still be challenging to generate enough energy.

4) Doping

Doping is a process of adding impurities to intrinsic semiconductors. This procedure helps to enhance efficiency. The doping aims to create a p-n junction, which is made up of two distinct pieces of semiconductors (positive-type and negative-type) with a difference in the number of electrons they have. For example, the p-type silicon is often doped with phosphorous, which contains one extra electron than silicon. In contrast, the n-type is doped with boron, an element with one less valence electron than silicon (Figure 3) [4].

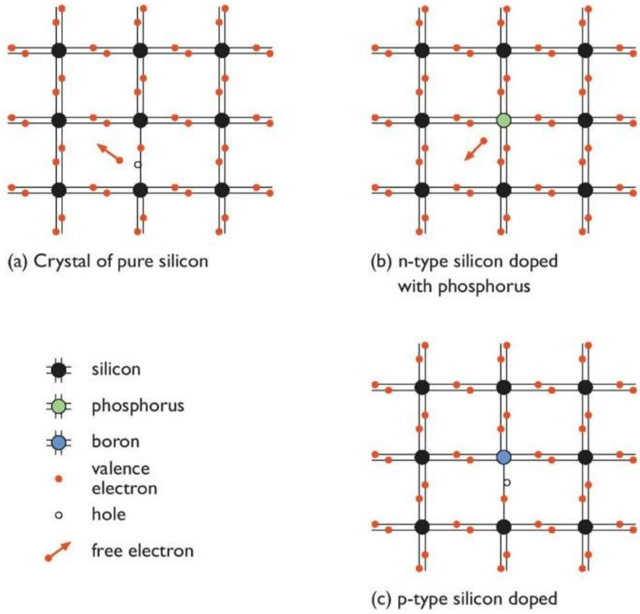

Figure 3. Doped silicon [4].

Due to this formation, the top of the layer, the negative layer, will possess more electrons than the bottom layer, the positive layer. The inherent difference in electrons creates an electric field, guiding electrons' movement within the cell. Therefore, when two layers touch, several electrons near the border flow from the N-type layer toward the P-type layer, while the "holes" in the P-type layer near the border flow in the opposite direction due to natural electron diffusion in an electric field. However, most of these electrons will remain on the border between the two layers because of the opposite force exerting their original protons. This creates the P-N junction, where the electrons and holes block or repel any further electron diffusion. Consequently, when photons strike again in the cell and create an electric field, those freed electrons will not simply move over the junction and fill the hole. Instead, they would follow the wire that we joined between junctions and thus create an electric current we can use.

5) Other components.

Besides the semiconductor layer, other components comprise a functioning solar cell.

Glass:

Glass is a common component placed on top of solar cells. Though it does not help generate electricity, it acts as a protective layer that prevents external forces from damaging the inner cell while not interfering with the transmission of photon energy from outside due to its high transparency.

Metal grid and metal plate:

There are two sections of metallic structure within a solar cell, one above the semiconductor junctions and one beneath. They are connected to the wire as the conducting transport for electricity. The section beneath is a plate, while the top is a grid, covering only a part of the panel. It is designed so that the maximum amount of sunlight can reach the semi-conductor panel without too much obstruction. At the same time, the electrons can still travel toward the electric wire efficiently.

Anti-Reflection Coat:

Both metallic grid and semi-conductor are shiny materials. In other words, they have a high reflection rate. Therefore, an anti-reflection coating is deployed to reduce energy loss and power rating. Furthermore, by controlling the thickness of layers, light reflected at the bottom of the coating can be cancelled out with other incoming light.

Multi-Junction:

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The band gap of a specific material is minimal. Thus, not all parts of the incoming light can be absorbed and used for photovoltaic conversion. Any energy that either exceeds or is less than the band gap will be dissipated as waste heat. The multi-junction solar cell uses this energy by stacking various semiconductors back-to-back. Since each material has a distinct band gap, the wavelength of light it takes in is also different.

$$E = hf = \frac{hc}{\lambda}$$

Therefore, the spectrum of light filtered out by one layer can be absorbed by another, increasing the overall light being converted and improving the solar cell's power rating (Figure 4).

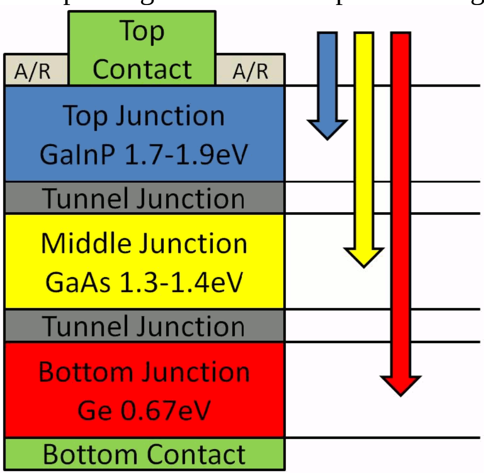

Figure 4. Multi-Junction solar cell structure example [7].

4. System description

Due to the support of national policies and the cost reduction of critical components, photovoltaic power generation has developed rapidly. In China, the installed capacity of photovoltaic power generation exceeded 300million kW in 2021[8]. The global installed capacity PV in 2021 exceeded 175GW, and the cumulative installed capacity exceeded 942GW [9]. With renewable energy gradually replacing traditional energy, photovoltaic power generation will continue to grow for a long time.

In the context of large-scale development of photovoltaic power generation, photovoltaic grid connection is a significant development direction. A typical grid-connected photovoltaic power plant system consists of a PV array, DC-DC converter, inverter, filter, and primary distribution panel [10], shown in Figure 5

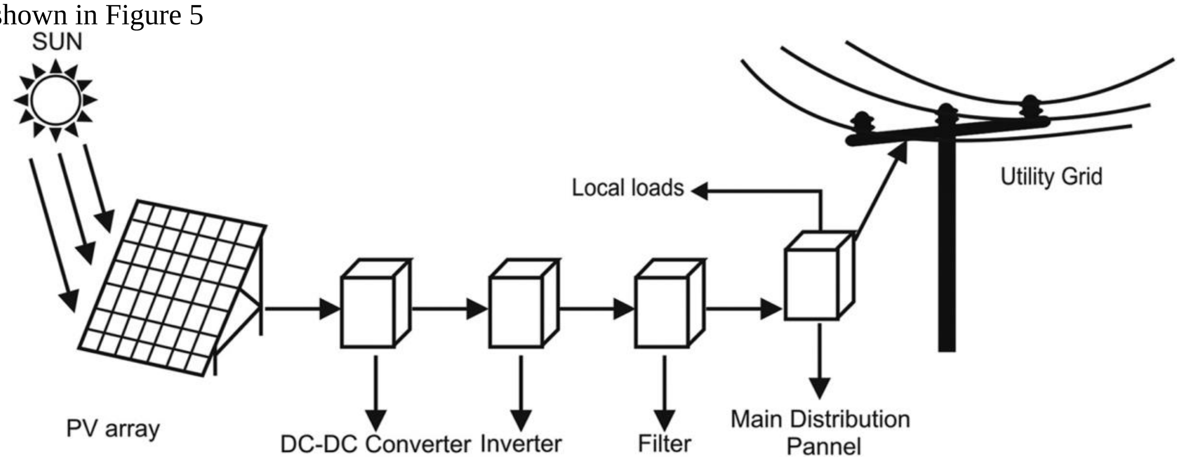

Figure 5. Typical grid-connected photovoltaic power plant system [10].

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1) Solar cell & photovoltaic array:

Solar cells can be divided into monocrystalline silicon solar cells, polycrystalline silicon solar cells, and amorphous silicon solar cells. The photoelectric conversion efficiency is listed in Table 1, showing that the efficiency of monocrystalline silicon, polycrystalline silicon and amorphous silicon solar cells decreases in turn. However, monocrystalline silicon solar cells adopt the Siemens process to improve the Czochralski method, leading to a high cost. Polycrystalline silicon solar cells are produced by the casting method. The silicon material is directly poured into a pot to melt and mould, making it cheaper than monocrystalline solar cells. Amorphous silicon solar cells' manufacturing process is greatly simplified, the consumption of silicon materials is small, and the power consumption is lower. Generating electricity under weak light conditions is its main advantage.

Table 1. Solar cell photoelectric conversion efficiency comparison.

Solar cell type	Photoelectric conversion efficiency
Monocrystalline silicon solar cell	18%-24%
Polycrystalline silicon solar cells	14%-18%
Amorphous silicon solar cells	5%-10%

In order to generate the desired current-voltage characteristics, solar cells are grouped and combined to form the PV array.

2) DC-DC converter:

The DC-DC converter is a circuit that can convert the current from the initial voltage to the required voltage level. Four types of DC-DC converter are used for solar photovoltaic: buck converter, boost converter, buck-boost converter and cuck converter. The buck converter's output voltage is always lower than the input voltage. So, it is widely used for front-end step-down applications, battery charging, and maximum power point tracker [11]. The boost converter can increase the voltage level. It is used to integrate the low voltage generated by PV arrays and connect it to the power grid and in the maximum power point tracker. Both buck-boost converter and cuck converter can step up or down input voltage. The main difference is that the cuck converter has an extra capacitor and an inductor. These two converters are used to improve the performance of the photovoltaic power plant and meet special requirements such as improving reliability and reducing the size and total cost (Figure 6).

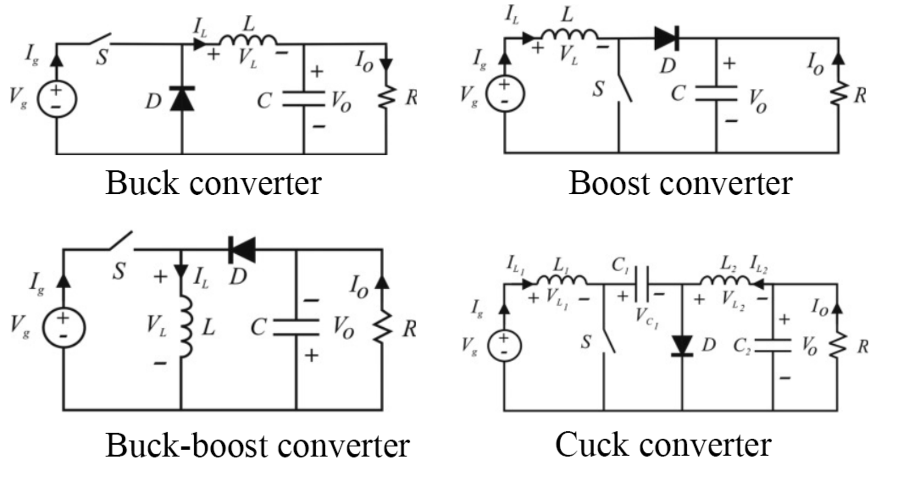

Figure 6. Basic circuit diagram of typical converters [10].

3) Inverter:

An inverter converts the DC power from solar PV array output into 50 or 60 Hz AC power. The inverter is the key to ensuring reliable and safe grid-connected photovoltaic system operation. There are four possible structures of the inverters: central inverter, string inverter, multi-string inverter, and module inverter. The central inverter has high total power and few components. String inverter has the minimum losses to enhance system reliability, but the power is low. The multi-string inverter is the upgrade of the string inverter. It inherits the reliability of the former and improves the power, but it becomes complex. Finally, the module inverter can easily adjust the scale of the system but also has a higher installation cost.

4) Filter:

A filter is a circuit consisting of an inductor and capacitor. It is used between the inverter and the grid to reduce higher-order harmonics introduced by the DC/AC converter [12].

5) Main distribution panels:

Main distribution panels are responsible for managing the facility's network, generator, ups, and compensation systems. Therefore, main distribution panels' equipment must be designed according to to shortcircuit, heating, and selectivity risks.

5. System integration into the energy grid

Compared with off-grid photovoltaic power generation, grid-connected photovoltaic power plant costs less and has high efficiency. Besides, Grid-connected operations can also expand the scope and flexibility of solar energy use. After high-frequency DC conversion, the grid-connected power plant system converts the received solar radiation energy into high-voltage DC through photovoltaic panels. Then, the sinusoidal inverter AC with the same frequency and phase as the grid. After that, the filter processes the sinusoidal AC to improve the quality. Finally, through the distribution of main distribution panels, connected to the power grid or stored in the energy storage system.

With more and more photovoltaic power plants being built and on the grid, modern grid codes put forward new requirements for photovoltaic power plants [13]. Since it is no longer a suitable way to be disconnected from the grid during disturbances. Grid codes require the photovoltaic power plants to withstand grid voltage dip for a specific duration. It is called low-voltage ride-through requirements [14]. However, sunlight exposure conditions cannot be controlled, and critical situations can also be caused by overvoltage. Thus, modern grid codes require that photovoltaic power plants stay connected to the system and withstand it when overvoltage occurs. These are the high-voltage ride-through capability requirements [15]. In some countries, the grid code requires these power plants to contribute the grid voltage to normal levels during grid faults. This requirement needs photovoltaic power plants can play a role in overcoming the grid voltage deviation by using reactive support to the grid like the traditional power plants [16]. For large-scale photovoltaic power plant systems, the grid requires the power plant to keep the voltage and frequency stable (change within the specified boundary) under different situations [17]. Besides, the active power supplied by the power plant should be identical to the load demand. Otherwise, the frequency will deviate from its nominal value. A traditional power plant can overcome it by using a governor control. Recently, photovoltaic power plants have been replacing these conventional generators gradually. Thus, photovoltaic power plants should also be able to keep the balance to maintain frequency stability [18].

In order to meet the needs of the modern power grid, photovoltaic power generation systems usually use a particular controller. For example, in [19], the controller can enhance the output waveform quality and overcome the dc-link voltage fluctuation by setting a variable dc-link voltage. Another study mentions applying a proportional-resonant current controller to suppress the overcurrent and guarantee a sinusoidal output current waveform [20]. Currently, maximum power point tracking (MPPT) is a superior control technology. MPPT controller can extract the maximum power from the PV module.

Moreover, working with a battery, an MPPT controller can enable the system to charge the battery with the maximum power output, output more electricity, and improve the charging efficiency. Besides, the grid voltage is proportional to the reactive power. Therefore, controlling the reactive current using a supercapacitor energy storage system during grid faults is another method to maintain stability [21].

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6. Environmental impact

The environmental impact of solar photovoltaic cells is presumably the most subtle among various available renewable or non-renewable electricity-generating modules. PV systems emit no gaseous or liquid pollutants or radioactive substances in the generating process. Moreover, it is worth mentioning that the PV cells can be appropriately recycled for the high purity silicon (6 kg or more in PV array), which means that the PV electricity systems can be disposed of easily and thus be more environmentally friendly compared to others.

However, there are some downsides to the environmental influence of PV systems on the surroundings. Firstly, the PV arrays usually require large amounts of land, sometimes covering several square kilometres. This problem raises objections to PV construction on agricultural and industrial locations that could be utilized for crop cultivation and product manufacture. Besides, even though the primary material from which most PV cells are made, silicon, is not intrinsically detrimental, the production of silicon may harm the environment. The chemicals used in silicon production must be treated with special care, such as the silane gas (SiH_4) from which pure silicon is produced inflammable and waste silicon tetrachloride ($SiCl_4$), which is highly toxic, can also be made [22].

The energy saving of solar photovoltaic power generation is mainly to replace the amount of traditional energy. Therefore, the amount of conventional energy can be obtained by calculating the amount of solar photovoltaic power generation. On this basis, the emission reduction of carbon dioxide, sulfur dioxide and dust in the environment is calculated and analyzed.

1)The replacement amount of CO_2

The reduction emission amount of carbon dioxide Q_{rco2} should be calculated as the following formula:

$$Q_{rco2} = Q_{tr} \times V_{co2}$$

In the formula, Q_{rco2} is the reduction emission amount of carbon dioxide, whose unit is kg; Q_{tr}· is the replacement amount of traditional energy source by solar PV electricity systems, whose unit is also kg; V_{co2} is the CO_2emission factor of the standard coal, which is 2.47 kg/kgce.

2)The replacement amount of SO_2

The reduction emission amount of sulfur dioxide Q_{rso2} should be calculated as the following formula:

$$Q_{rso2} = Q_{tr} \times V_{so2}$$

In the formula, Q_{rso2} is the reduction emission amount of sulfur dioxide, whose unit is kg; Q_{tr} is the replacement amount of traditional energy source by solar PV electricity systems, whose unit is also kg; V_{so2} is the SO_2 emission factor of the standard coal, which is 0.02 kg/kg.

3)The replacement amount of dust

The reduction emission amount of dust Q_{rfc} should be calculated as the following formula:

$$Q_{rfc} = Q_{tr} \times V_{fc}$$

In the formula, Q_{rfc} is the reduction emission amount of duct, whose unit is kg; Q_{tr} is the replacement amount of traditional energy source by solar PV electricity systems, whose unit is also kg; V_{fc} is the dust emission factor of the standard coal, which is 0.01 kg/kg.

With these formulas and data, we can obtain the number of reduced pollutants by utilising solar photovoltaic systems.

7. System economics

“The cost per kwh of power from PV cells consists essentially of a combination of the costs of repaying the initial capital cost and the running cost.” [22]

The capital cost of a PV system is usually proportional to its power output. It contains the cost of the PV modules themselves and the 'balance of system'(BOS) costs. These include "the costs of the interconnection of modules to form arrays, the array support structure, the costs of cabling, switching, metering and inverters, and, if the array is not building-mounted, the land and foundations" (Figure 7).[22]

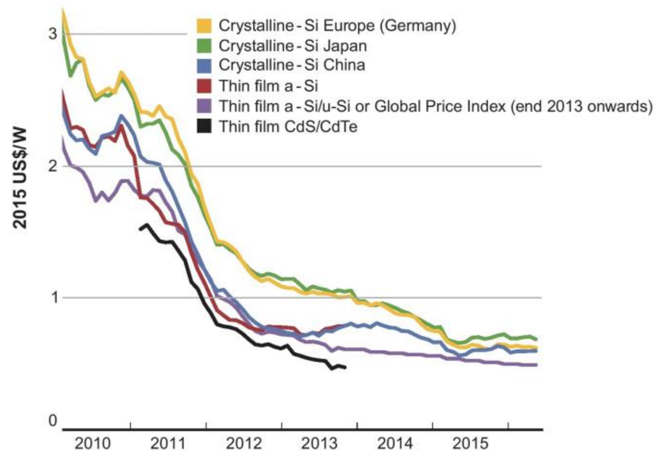

Figure 7. Average quarterly solar PV module prices by technology and manufacturing country sold in Europe, 2010-2016(Source: IRENA,2016).

As shown in the Fig.7, the costs of PV systems have been decreasing, and it is likely that in the future, this falling trend can continue (Figure 8).

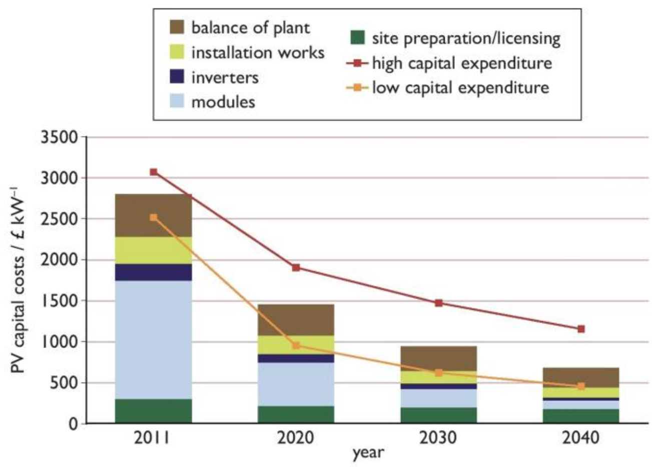

Figure 8. Capital cost breakdown for a 10 MWp ground-mounted PV system in 2011 and projected costs for 2020,2030 and 2040(Source: CCC,2011).

As shown in the Fig.8, PV capital prices are expected to reduce continuously, which is beneficial to compress the costs further. In addition, the running costs of PV modules are usually low because of no fuel costs and low maintenance and insurance costs per year. In order to make an accurate approach to costing electricity from power plants, we need to calculate the Levelized Cost of Electricity (LCOE). Moreover, here are some key cost elements to consider (Figure 9):

- Fuel costs (zero in the case of PV)
- Operation and maintenance (O&M) costs (low for PV)
- Initial capital costs (high in the case of PV)
- Final decommissioning costs (likely to be very low in PV modules)

$$\text{cost per kwh} = \frac{(\text{annual capital repayment} + \text{averageannual running cost})}{\text{average annual energy output}}$$

BOX 6.1 Example [22]: *Comparing the cost and benefit of generating electricity by a particular solar PV module*

Let us consider a 10 MW_p (10000 kW_p) scheme situated in the south-west of the UK with:

·A capital cost of £800 per kW_p

·An operating and maintenance (O&M) cost of ₤10 per kW_p per year

·A project lifetime of 25 years financed with a loan over that amount of time at a real interest rate of 8%.

It can be calculated that:

Total annual cost (annual cost of repaying + O&M cost + running cost) = ₤852000

Fih.7.4 suggests that for a PV system in the south-west UK, we can assume that each kW_p of capacity produces 1000 kWh of electricity each year:

Total annual electricity production = 10000000 kWh

Then based on the formula above, we can acquire that:

$$LCOE = 8.52\ p\ kWh^{-1}$$

This is well below the domestic consumer price and slightly lower than the UK industrial electricity price.

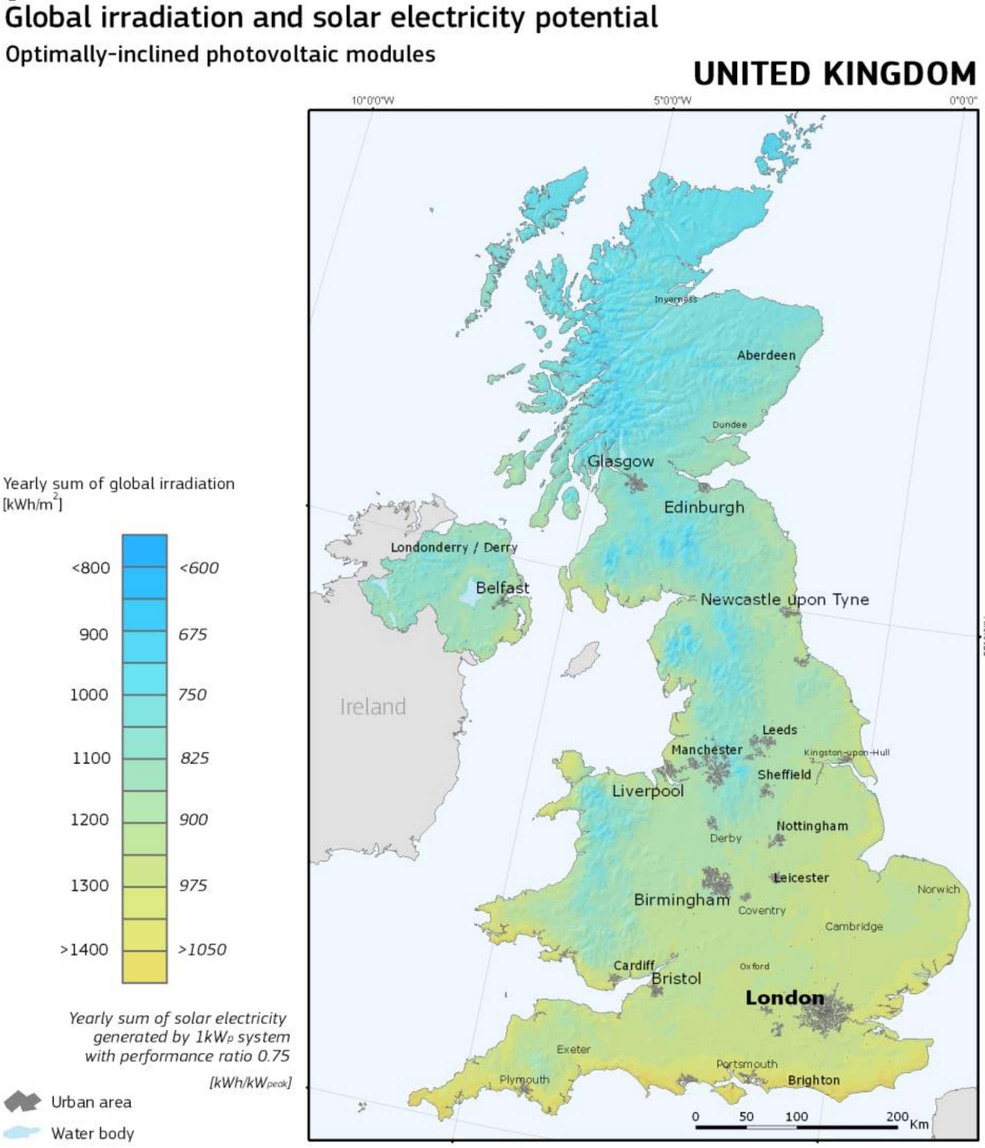

Figure 9. Solar radiation map of the United Kingdom, 'Performance Ratio' is the actual ratio to the theoretical maximum PV array output.[23].

The calculation shows the superior economic benefits of grid-connected solar photovoltaic power plants.

In many modern integrated building systems, PV modules are widely utilized and facilitate tremendous economic advantage. For instance, photovoltaic power generation modules of Daxing Airport parking buildings in Beijing consist of several sub-systems, each connected to a 380V line. In September 2018, Daxing Airport and "Yi Parking" started investing in and constructing a photovoltaic power generation project. Located on the roofs of two parking buildings P1 and P2, the project has a total installed capacity of 2.8 MW. The project is expected to save 1080 tons of standard coal and 3,040 tons of carbon dioxide per year and generate more than 3 million KWh of electricity per year, accounting for 17% of the annual electricity consumption of the parking building and saving about 2 million yuan per year (Figure 9).[24]

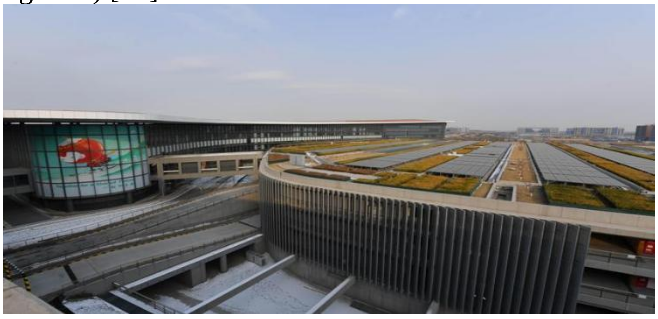

Figure 10. The roof-top PV systems in Daxing Airport.

With the continuously reduced initial costs and improved prices and profits, we can believe that the future success of PV systems will undoubtedly come.

8. Future developments

For the development of the photovoltaic industry, two main strategies are focused on most: improving silicon purification technology and the working efficiency of solar batteries.

1)Improving silicon purification technology

The high-purity silicon materials required to produce polysilicon depend on imported technology. Many research institutions or researchers have proposed corresponding metallurgical purification processes. [25] The technical routes of metallurgical preparation of solar-grade polysilicon proposed by the University of Tokyo in Japan are shown in Fig.12. In this route, industrial silicon first removes metal elements such as Ti and Fe by pickling treatment, then removes B and C by oxidative refining, and then removes P, Ca, Al, and other elements by vacuum refining, and finally solidify to obtain polysilicon ingots. Kunming University of Science and Technology uses the following process to prepare polycrystalline silicon ingots, the purity of which can reach more than 99.999%, and the resistivity exceeds 0.4Ω/M (Figure 11, Figure 12):

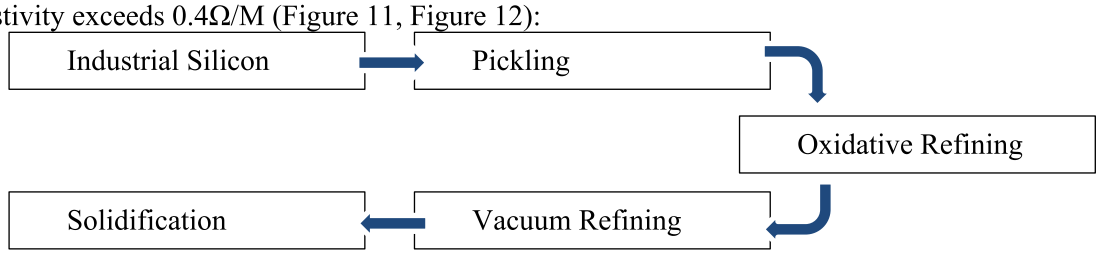

Figure 11. Technology route proposed by tokyo university.

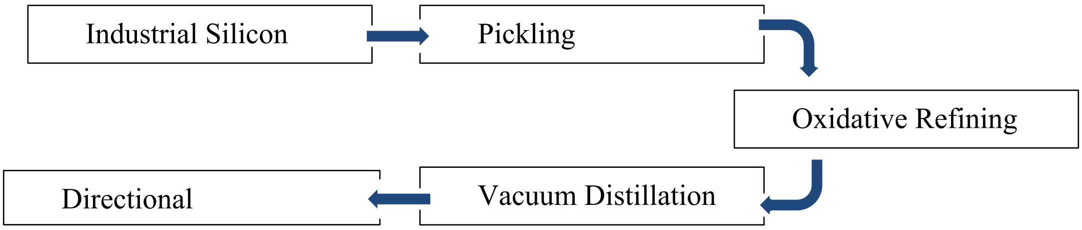

Figure 12. Technology route proposed by kunming university of science and technology.

The metallurgical method will also occupy the most crucial position in the field of crystalline silicon preparation due to its non-polluting, low energy consumption and high efficiency.

2)Improving the working efficiency of solar battery

A preferred method to improve the working efficiency of the solar cell is using composite cathode material. It is formed by superimposing different interface materials, which usually contain ZnO, SnO2 and PEIE [26]. The Fig.14 can show the performance improvement caused by the application of different composite cathode materials. The theory of optimized performance by using this material is that the interface between the donor and the acceptor forms excitons and the excitons dissociate and diffuse. In order to make the electrons and holes flow to the electrode better and reduce the recombination, an interface modification layer with those efficient materials is added between the active layer and the electrode. It can be a carrier, and the migration of the active layer provides better transport channels, improves charge selectivity, determines the polarity of the electrode, adjusts the electrode work function, forms a better ohmic contact between the active layer and the electrode, and can further improve the morphology of the active layer so that the performance of the solar generation device is more optimized (Figure 13) [27].

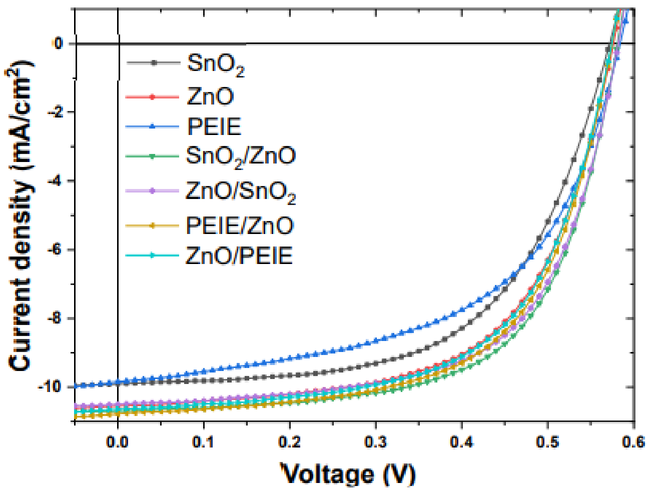

Figure 13. The J-V characteristic curves of devices with a different cathode-modified layer.

9. Comparison and conclusion

In terms of exhaust waste emission, solar photovoltaics reflects its unique advantages. Solar photovoltaic power generation directly converts sunlight into electrical energy through the photovoltaic effect [28]. As a typical renewable power source, solar energy can reduce the consumption of fossil fuels and the emission of greenhouse gases such as CO2, SO2 and nitrogen oxides. A photovoltaic power generation system can save 0.53kg of CO2 emissions per kilowatt-hour. Lower nitrogen oxide and SO2 emissions significantly reduce human disease [29].

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The comparison of power generation efficiency is shown in Table 2[30]. Although the highest solar photovoltaic efficiency can reach 25%, it is still lower than the traditional energy form, which is the main disadvantage of solar photovoltaic [31].

Table 2. Efficiency of different energy power.

Energy type	Solar energy	Coal	Natural gas	Hydropower
Efficiency	10%-25%	36%-44%	33%-50%	>90%

The cost of different energy forms is shown in Table 3[32]. Due to government subsidies and technological development, the cost of photovoltaic power generation in China is low and has market competitive advantages. This also reflects the promising trend of global photovoltaic power plants in terms of economic benefits.

Table 3. Cost comparison of various power generation modes in China in 2021.

Energy form	Installation cost (RMB/W)	KWh cost (RMB/KWh)
Fossil fuel	5~8	0.25~0.35
Hydropower	10~12	0.1~0.3
Nuclear	8~12	0.25~0.35
Wind power	6~7.5	0.15~0.3
Solar PV	4~4.5	0.15~0.3

Although the efficiency of PV power is currently lower than other traditional energies, PV energy also has various advantages like endless economic benefits, eco-friendly, sustainable development, economic benefit prospect, etc. [33]. In summary, With the development of related technologies such as energy storage technology and photovoltaic materials, photovoltaic power generation will become the main force of renewable energy, with excellent development prospects.

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