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The current state of solar energy and prospects of offshore solar energy in Singapore

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Abstract. Situated in an area near the equator, Singapore has a promising potential to develop solar energy. And apart from solar energy, other types of renewable resources are relatively scarce in Singapore. As a result of the continuous supply of sunlight, as well as the silent operation, low maintenance costs, and environmental friendliness, solar was the best choice for developing renewable energy resources in Singapore. However, on account of the dense population and limited land resources, photovoltaic development is also facing some problems. And the use of the surrounding sea area to develop offshore photovoltaic is a very good option. This paper mainly discusses the current state of solar energy in Singapore and puts forward some future prospects for the development of offshore PV in Singapore. In general, the photovoltaic industry in Singapore has developed rapidly in recent years, but it can still only meet a small part of the demand for electricity. In the future, it should continue to vigorously promote its development, especially in the offshore photovoltaic sector, which deserves more attention.

Keywords: Solar energy, Photovoltaic, Singapore, Offshore, Development.

1. Introduction

On account of the aggravation of environmental pollution and an increase in some extreme weather events, humans are reducing the use of fossil fuels and trying to develop renewable energy sources with effort. However, of the major renewable energy sources, only solar energy is the most suitable for Singapore. Other renewable energy sources, such as hydropower, wind and tidal power, are scarce, and the development of geothermal energy is economically problematic[1]. In recent years, Singapore's solar industry has developed very rapidly, and has made considerable progress in both solar power technology and industrial scale. But there are also some difficulties, such as the limited land resources available for solar development. As a highly urbanized and densely populated country, except for some available roofs, there is not a lot of land area available for PV development. In addition to the use of piecemeal land resources, other ways of developing photovoltaics are also being sought. And it seems that developing offshore solar energy is the best choice. As an island nation, Singapore has sufficient water area to develop offshore PV. So it is necessary to study the current state of solar energy development in Singapore and then consider further the development prospects of offshore PV. With further research, offshore PV will play an important role in improving Singapore's energy mix in the future.

2. Current energy situation in Singapore

2.1. Geographic profile of Singapore and the irradiance sources

Singapore is a very small, densely populated island city-state. The total land area of Singapore is 724.2 square kilometers and Singapore has a population of 5.45 million as of June 2021[2]. Currently, it is the third most inhabited region in the entire planet.

Singapore is located entirely between the first and second parallels, 1.5 degrees north of the equator. With no definite seasons, Singapore's climate is categorized as tropical rainforest climate. Its climate is characterized by constant temperature and pressure, high humidity, and copious amounts of rainfall as a result of its geographic location and sea exposure. As a result, it is typically warm and wet. 2,340 millimeters of rain fall on average each year.

Due to its location in the tropical sun belt, Singapore receives an average yearly solar irradiation of 1,580 kWh/m2/year. Its daily sun radiation is lower than that of several other equatorial nations due to the heavier rainfall. However, Singapore still has a great potential for photovoltaic development due to its comparatively high daily sun radiation. Figure 1 provides details on the sun radiation in Singapore.

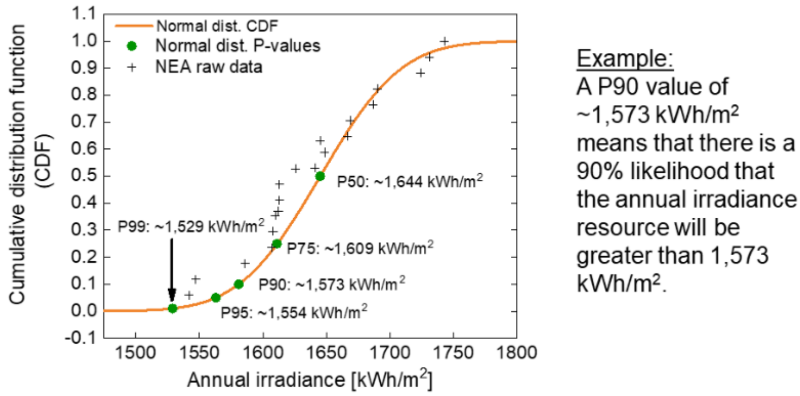

Figure 1. Irradiance resource in Singapore [3].

2.2. Energy consumption and demand

Considering a 2.2% compound yearly growth rate, Singapore's system demand climbed from around 42 TWh in 2009 to over 50 TWh in 2020. Over the same time period, the system's peak demand increased from about 6,000 MW to over 7,000 MW at a CAGR of 1.8%. In 2020, the COVID-19 measures had a negative impact on business activity, which caused a 2% decrease in the year-over-year annual system demand. The demand for electricity is anticipated to increase to about 55 TWh in 2021 (an increase of about 3% from the level in 2020). The peak demand for the 2021 system as of October 2021 was 7,667MW. Over the ensuing ten years, from 2022 to 2032, it is expected that the annual system demand and system peak demand would grow at a CAGR of between 2.8 and 3.2%. These take into account a number of variables, including as population shifts, climate changes, anticipated rates of Gross Domestic Product (GDP) development, and anticipated demand from emerging, rapidly expanding industries like data centers[4]. Energy consumption and GDP growth are always closely correlated, and Fig. 2 contains some pertinent information.

Table 1. Electricity Consumption in Singapore, 2020.

Electricity Consumption in Singapore（2020）	Industrial-related	Commerce and Services-related	Households	Transport-related	Others
Electricity Consumption（TWh）	21	18.5	8.2	2.8	0.2
Proportion（%）	41.3	36.5	16.2	5.5	0.5

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Table 2. Imports & Exports of Energy Products, 2020.

Imports & Exports of Energy Products(2020)	Petroleum Products	Crude Oil	Natural Gas	Coal and Peat	Other Energy Products
Imports of energy products(ktoe)	93,778.5	47,047.3	9,901.3	433.2	70.4
Exports of energy products(ktoe)	75,513	963.9	-	0.1	-

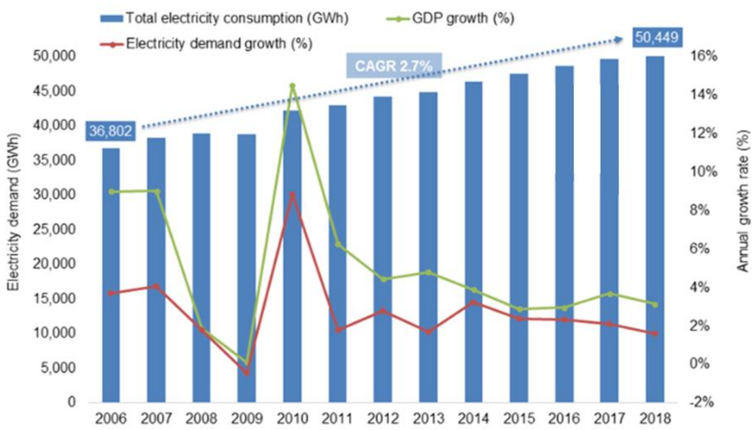

Figure 2. Demand growth compared to GDP growth.

2.3. Technical and policy support for solar energy development

The National University of Singapore (NUS) and Nanyang Technological University (NTU), two top-notch research universities in Singapore, have made significant contributions to the growth of the country's solar industry. The Solar Energy Research Institute of Singapore is also worth mentioning (SERIS). Singapore's national institute for applied solar energy research is located at the National University of Singapore (NUS), and it is known as SERIS. It started doing business in 2008. The Energy Market Authority of Singapore (EMA), the National Research Foundation (NRF), the National University of Singapore (NUS), and the Singapore Economic Development Board all sponsor SERIS (EDB). It has the standing of a research organization comparable to NUS University, and it has a lot of freedom and flexibility, including a supportive IP policy. An important component of Singapore's efforts to reduce its carbon intensity and greenhouse gas emissions is the national solar energy research institution. In order to build the local solar ecosystem and aid Singapore's solarization, SERIS conducts research and development on solar cells, modules, and systems, trains local talent, and provides technical knowledge to governmental agencies and the solar sector [5].

Singapore aims to install 1.5 GWp (or 1,500 MWp) of solar PV capacity by 2025 and at least 2 GWp (or 2,000 MWp) by 2030. Through the first quarter of 2021, the installed PV has reached 444MWp. To successfully promote the development of solar energy, Singapore now is using four main ways. The first step is to properly price energy to encourage its efficient use. Second, keep streamlining the current procedures and regulations to speed up the deployment of solar energy. Third, the Solar Nova program, spearheaded by the government, combines demand for solar PV from the public sector. Fourth, the Singaporean government collaborates with business and the research community to test-bed technologies that will help them handle the intermittent problems that renewable energy sources provide. This will enable them to preserve the stability and dependability of the system while incorporating additional renewable energy sources into our energy mix.

2.4. Solar photovoltaic adoption in Singapore

The installed photovoltaic capacity is increasing year by year, and some figures are shown in Fig.3.

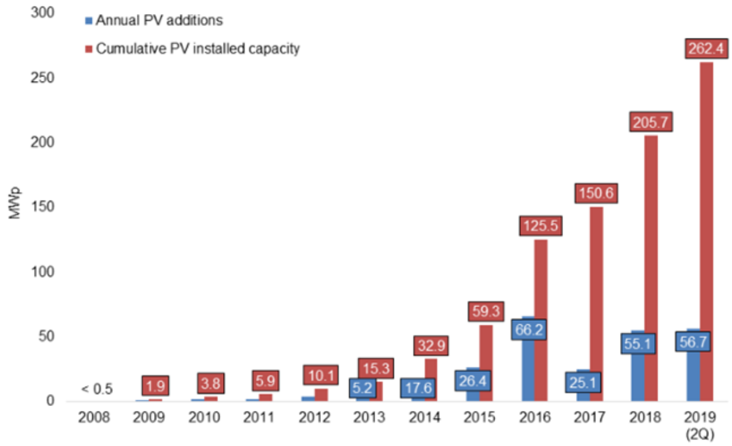

Figure 3. Installed capacity in Singapore today.

Data source: EMA(SP PowerGrid Ltd)

3. Current status of offshore PV development and prospects in Singapore

Nowadays there are two main types of mainstream offshore solar photovoltaic, Pontoon based floating photovoltaic systems and flexible thin film floating photovoltaic systems. Generally speaking, the pontoon type is suitable for installation in shallow water, while the floating type is suitable for installation in deep water.

As early as 15 years ago, research institutions and companies in a number of countries started research on offshore PV. An earlier example is the collaboration of SPG Solar of Novato and Thompson Technologies Industries. They launch a 175 kWp project in 2007 at Far Niente Winery in Napa Valley, California. The offshore array was developed to satisfy the winery's sustainability principles without displacing any commercial land needed for their grape harvest[6]. It is situated on pontoons on the winery's irrigation pond. All of the facilities in the examples were first constructed on rigid structures or pontoons on lakes or reservoirs. Moreover, in the ocean, there is more available area to develop offshore solar energy. But there are also further problems caused by the salt water and big waves or even heavy storms. In recent years, with the progress of science and technology, people have gradually overcome these difficulties. On July 15, 2021, Oceans of Energy announced that its floating offshore photovoltaic (PV) has been operating smoothly for a year and a half off the coast of the Netherlands during the past 18 months, experiencing various intense storms without any problems. This example demonstrates the possibility of deploying photovoltaics over the ocean.

Last year, some research institutes launched a solar farm project at the Tengeh Reservoir. The 60 megawatt-peak (MWp) floating solar photovoltaic (PV) system, reportedly has over 100,000 solar panels extending over 45 hectares. The five local water treatment facilities in Singapore will be able to run on the electricity produced by the 60 MWp solar farm, which will offset around 7% of PUB's yearly energy requirements and lower the organization's carbon footprint. And this year, Keppel signed a Technology License Agreement with Ocean Sun for the 1.5MWp floating PV project to be deployed near Jurong Island. According to Keppel, the membrane-based PV system was developed using Ocean Sun's technology to dependably capture solar energy in a maritime environment near shore where there are larger waves and harsher seas. In contrast, Singapore uses traditional floating PV installations in its calmer waterways. In order to do this, solar panels are directly mounted onto sizable circular reinforced membranes that are protected by a framework constructed of high-density polyethylene pipes. This creates a solid and safe platform. The three circular platforms that make up the prototype PV system will have a combined installed capacity of 1.5 MWp when they are submerged in the saltwater off Jurong island.

In the near future, the Singapore government is expected to increase support for the offshore PV industry. In previous years, offshore solar PVS were usually located in reservoirs, but with the development of technology, the sea near the coast is also becoming an area where solar PV can be deployed. In recent years, some companies like Ocean Sun and Oceans of Energy have successfully developed some PV systems which are able to survive intense storms without any problems. It is necessary for the Singapore’s government to increase cooperation with these companies, offering some policy or financial support. Some universities and research institutions in Singapore should also increase cooperation with some advanced technology companies to better develop offshore photovoltaic technology. Over the next few years, the waters around some islands off the southern tip of Singapore will be further developed and more floating pv will be deployed. With further research and development, photovoltaics that are more suitable for offshore use will be developed and their power generation efficiency will be further improved. With the continued development of the PV industry, Singapore's energy mix will be further improved.

4. Conclusion

As a country located near the equator, Singapore's potential for photovoltaic development is very large. And Singapore's huge domestic energy consumption and its long history of energy imports have encouraged it to develop its domestic energy sector. Through the above analysis, we can see that the proportion of solar energy is still relatively small, but it has a good development trend. At present, the photovoltaic development of Singapore is also faced with problems such as limited land resources, and the development of offshore photovoltaics is a good solution. With the progress of technology, the development of offshore PV will become a better and better method of PV development. Moreover, the continued development of offshore PV in the next few years will not be possible without the strong support of the government, and the full cooperation of universities, institutions and research and development companies. It is hoped that the PV industry chain can be quickly improved in the future, so as to make the PV industry a healthy and sustainable development. In conclusion, it is appropriate and meaningful to deploy more floating pv in Singapore. This paper lacks some research on the specific contents and details of offshore photovoltaic technology, such as the floating system of offshore photovoltaic, specific materials for seawater corrosion resistance, etc. It is expected that that will be more studies on offshore photovoltaic technology in the future.

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