Reducing the residual power supply of Singapore with solar PV in combination with energy storage

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Abstract:
Using Singapore's solar potential to produce electricity could increase its energy independence and reduce the specific CO_2 emissions of its power supply. Thereby, energy storage technologies offer the opportunity to increase the usage of electricity from solar PV during power demand peaks. This would lead to more efficient power plant use and less required residual generation capacity. In this paper we analyse the power generation capacity that can be replaced by solar PV in combination with energy storage. In our research, we use a linear programming model of Singapore's power supply that optimizes power generation and storage according to minimal total cost. To determine the power generation by solar PV we use direct measurements of solar irradiation in Singapore. Results show that generation capacity can be replaced by solar PV most efficiently with lower storage sizes and lower solar PV capacity installed. By installing 5 GW of solar PV installed and a storage capacity of 1000 MWh, up to 750 MW of generation capacity could be replaced.

Keywords: *Solar Photovoltaics; Residual Power Supply; Singapore*

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1. Introduction

Over the past decades, power generation in Singapore shifted further and further from oil- to gas-fired power plants which increased energy efficiency and reduced specific CO_2 emissions of its power supply. But Singapore itself does not possess any fossil reserves or resources and therefore, its fossil fuel supply strongly depends on imports from its neighbouring countries. However, despite its limited availability of space, the power generation potential of solar photovoltaics (PV) in Singapore is significant, amounting to 10 GW by 2050 according to the Solar PV Roadmap for Singapore (SERIS, 2014). Using Singapore's solar PV potential to generate electricity offers the opportunity for both an increase of its energy independence and further reduction of specific CO_2 emissions of electricity generation. Furthermore, the installation of solar PV could reduce the required generation capacity of the residual power supply, i.e., the power supplied by all power plants except solar PV. If solar PV could replace more residual generation capacity, less thermal power plant expansion would be required to supply Singapore's future power demand once solar PV is installed. Moreover, the residual power plants could be used more efficiently as their annual full load hours would increase.

But due to the intermittent character of solar irradiation, the electricity generated by solar PV is highly fluctuating. This especially applies for Singapore, where due to its small land area the opportunities to compensate the fluctuating solar power generation by distributing PV installations widely across the country are quite limited. To overcome the negative impact of solar intermittency on the potential of solar PV to replace residual generation capacity, energy storage technologies seem to be an appropriate option. Therefore, we modelled the power supply of Singapore and analyse in this paper the potential of solar PV in combination with energy storage to reduce the residual peak supply. Thereby we especially focus on the sizing of solar PV capacity and storage to replace residual generation capacity effectively.

The paper is organised as follows: After introducing the methodology we use in Section 2, the main results of the study are shown and discussed in Section 3. Finally, Section 4 gives a short conclusion and an outlook for further research.

2. Methodology

In our analysis, we model and optimise the power system of Singapore for the year 2013. We use the linear unit commitment model URBS (SERIS, 2014) that optimises power generation, transmission and storage according to minimal total annual cost. The power demand and supply of Singapore is dispatched in half-hourly time steps. In each time step, the power demand is covered by the power plants or energy storage (if installed) which are available and lead to minimal total cost. As the variable cost of electricity generated by solar PV is close to zero, it will be used whenever possible to supply the demand. Moreover, the energy storage can supply electricity to avoid the usage of more expensive generation capacity which would be usually used during demand peaks.

The half-hourly power demand data of Singapore is taken from EMA (EMA, 2014). The load profile of a typical day in Singapore is shown in Fig. 1 on the right. To determine the electricity that is produced by solar PV in each time step, measurements of solar irradiance of the year 2013 are used which were obtained from a measuring station owned by SERIS (SERIS, 2014). These measurements have a temporal resolution of one minute. A typical solar irradiation profile for Singapore is illustrated in Fig. 1 on the left.

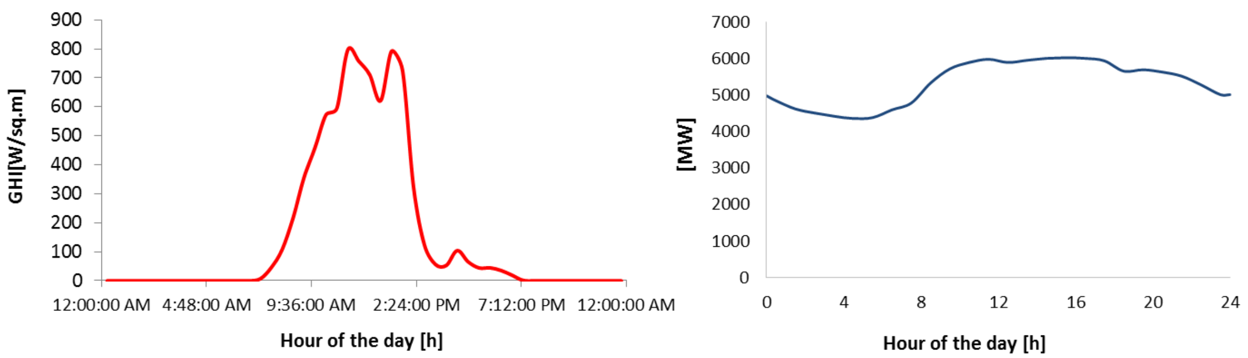

Fig. 1 Solar irradiation profile (left) and load profile (right) of a typical day in Singapore. GHI is measured in Watts per meter square (W/sq. meter) and is defined as the total amount of irradiation received by a horizontal surface on earth.

In order to convert the solar irradiation into power generation by solar PV, the dependency of the solar cell efficiency on the module temperature is considered according to Eq. (1), wherein η_{PV} is the efficiency of the solar PV modules and T_{PV} is the surface temperature of the solar cells. The solar cell efficiency η_{PV} is assumed to be 0.16 at a cell surface temperature T_{PV} of 25°C and decrease (increase) by 0.005 per $°C$ of cell temperature increase (decrease).

$$\eta_{PV} = 0.16 \cdot \left(1 - (T_{PV} - 25°C) \cdot 0.005\ °C^{-1}\right) \qquad (1)$$

A half-hourly time series of solar power generation is developed by averaging thirty consecutive values of solar power generation in temporal resolution of one minute.

3. Results and discussion

The reduction of the residual peak supply for different sizes of storage and generation capacities of solar PV is shown in Fig. 2. Even without storage being installed, solar PV can reduce the residual peak supply by about 50 MW because the peak demand in Singapore normally occurs during daytime when solar PV generates at least a small amount of electricity. However, due to the intermittency of solar irradiation, the reduction of residual peak supply without any storage capacity is rather low, regardless of how much solar PV capacity is installed. If the storage size is increased to 250 and 500 MWh, the peaks of the power demand can be supplied quite effectively by solar PV which leads to higher reductions of the residual peak. With a storage size of 250 MWh (respectively, 500 MWh), between 250 MW and 395 MW (332 MW and 637 MW) of residual generation capacity can be replaced, depending on the capacity of solar PV installed. In order to reduce the residual peak supply further, more and more storage capacity per MW of peak reduction is needed. Therefore, the marginal increase of peak supply reduction diminishes with higher storage sizes. Fig. 2 shows less additional reduction of residual peak supply when the storage size is further increased. Doubling the storage size from 500 MWh to 1000 MWh increases the reduction of residual peak only by 18% with 5 GW of installed solar PV capacity, respectively by 37% if the solar PV capacity amounts to 1 GW.

Generally, higher capacities of solar PV increase the reduction of the residual peak. But once the installed solar PV capacity fully charges the energy storage units, the storage size becomes the predominant parameter in order to supply the power demand peaks. Therefore, as illustrated in Fig. 2, installing more than 3 GW of solar PV capacity hardly reduces the residual peak supply further. That means, a solar PV capacity above 3 GW cannot replace other generation capacity significantly, given a maximum storage size of 1000 MWh.

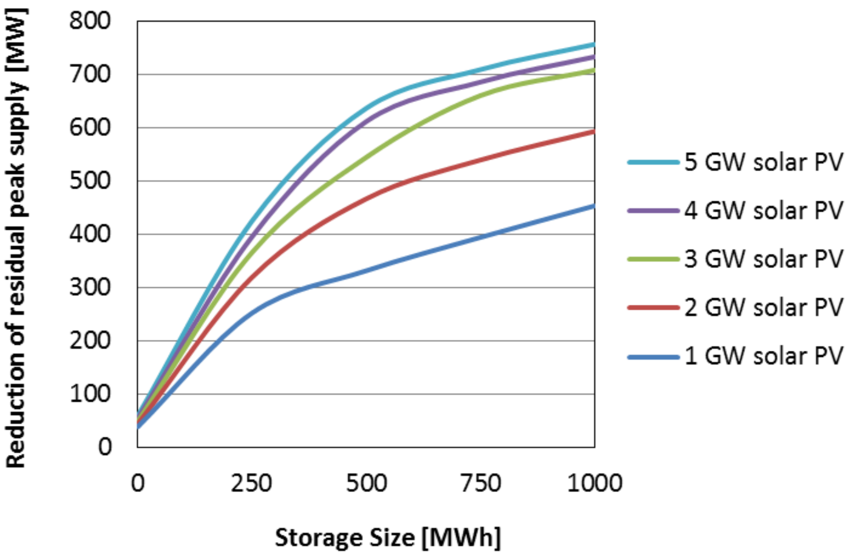

Fig. 2 Reduction of residual peak supply with different storage sizes and installed solar PV capacities

4. Conclusion

In this paper, we presented a method to analyse the potential of solar PV in combination with energy storage to replace residual generation capacity. Higher storage capacity increases the reduction of residual peak for a given capacity of solar PV. But the effect of residual reduction mitigates with increased storage sizes on the one hand and with higher installed capacities of solar PV on the other hand. Here, a right balance between storage and solar PV capacity has to be found, which depends on the power plants installed and on the costs of the respective storage technology.

In our future work, we will focus on the increased flexibility requirements for the residual power supply when high shares of solar PV capacity are installed. Moreover, further research on the integration of solar PV into the power supply of Singapore has to be carried out in higher temporal resolution.

5. Acknowledgement

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