Solar power based heating systems with electrical storage as alternative to fossil based systems for small residential buildings

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Abstract. Renewable energy is expected to replace thermal power by fossil fuel for reduction of green gas emission, air pollution and energy-security. Especially solar power generation is expected because it is got anywhere and its cost has reduced recently. But it is got only in the daytime on sunny days. Furthermore the amount, the time period it can get depends on seasons, weathers. Storage battery is essential for accumulating overpowered electricity and emitting it after sunset. The peak electricity demand is important factor to design electricity power plants. There are large electricity demands in summer and winter by air-conditioning. It is important to replace them by solar power with storage battery. Building Research Institute in Japan has a demonstration house, which has solar power generator and storage battery combined system. The authors have measured how this system worked with air-conditioning electricity demand in summer and winter. And the authors applied these results to the actual electricity demand in Tokyo Metropolitan area. If solar power generator is combined with storage battery, it could cover air-conditioning cooling demand completely. In winter, peak electricity is high in morning and evening. So solar power could not mitigate electricity supplying demand in winter directly. But it is expected to supply electricity for a whole day, combined with storage battery.

1. Introduction

Solar power is very useful renewable energy, got anywhere. But it got only in the daytime on sunny days. The yearly electric supply on a day in each month of Tokyo Electric Power Company Holdings, which supplies electricity in the Tokyo metropolitan area, is shown in Figure 1. It looks the solar power generation is very little, and there lots of room to expand the amount of the solar power generation.

Figure 1. The yearly electricity supply (TEPCO) (2017/4/1 – 2018/3/31)
The hourly electric supply from 11:00 to 12:00, in which solar power generates the largest amount on a day, on the same period, is shown in Figure 2. Solar power provides more than 1/3 of all supplied electric power on some period.

The composition of electricity supply, such as nuclear, hydro, thermal, and pumped-storage hydro power on 2019/5/4, is shown in Figure 3. It is a national holiday in Japan and the electric demand is small on this day. It shows overflowed solar power is pumped by pumped-storage hydro in daytime and utilized after sunset. So it is suggested we should install storage battery to accumulate overflowed solar power and utilize after sunset to expand the amount of the solar power generation.

But there is some loss during accumulating, emitting and transferring process. Each loss should be measured to evaluate energy saving efficiency of whole this system precisely.

So the authors have set up solar power generator (full generating capacity 4.0kW) combined with storage battery (full capacity 11.2kWh) combined system in a demonstration house in Building Research Institute in Japan, described in Figure 4 and Table 1.

![Figure 2. The hourly electricity supply 11:00 to 12:00 (2017/4/1 -2018/3/31(TEPCO))](image)

![Figure 3. Electricity supply (2017/5/4 TEPCO)](image)

![Figure 4. Solar power generation with storage battery](image)

### Table 1. Specimen of the units

| Solar power generator | Max output:4kW |
|-----------------------|-----------------|
| Storage battery       | Capacity : 11.2kWh |
We have measured generated solar power, accumulated, emitted electricity for a year. Overflowed solar power is accumulated into the storage battery, after it is full, overpower is delivered to the commercial grid in reverse. After sunset, accumulated electricity is emitted from the storage battery, shown in Figure 5. Solar power is available only in daytime. But combined it with storage battery, accumulating overpowered electricity, and emitting it after sunset, it is available not only in daytime but also after sunset. It is very effective for saving energy, utilizing lots of solar power.

Generally solar power provides 20 – 40 % of the total electric load. Combined it with storage battery, it provides 60 – 80%, shown in Figure 6. It is very effective for saving energy, utilizing lots of solar power. On the other hand, the authors have got important information on the solar power generation and the storage battery.

- Solar power is generated from April to June, in large amount. It decreases from the summer solstice. And it is generated from October to December, in small amount. It increases from the winter solstice. Maximum generation is as 1.5 times larger as the minimum, shown in Figure 7.

- Generally efficiency of accumulating and emitting electricity is 80 - 100%, multiplied by transferring direct current to alternate one, it is 60 - 80%.

- Not only efficiency of accumulating into and emitting from storage battery, but also transferring from direct current to alternate, from alternate to direct, should be taken into consideration, shown in Figure 8.

It is suggested that we can improve efficiency and effectiveness of the solar power generator and storage battery combined system furthermore, taking the traits of solar power generator and storage battery into consideration.
2. Supply of electricity in peak seasons (summer and winter)

The peak electricity demand is one of important factors to design electricity power plants. Fig. 1, 2 suggest there are large electricity demand in summer and winter. It is important for solar power generation to provide large electricity in these peak seasons, summer and winter. But there are lots of differences with electricity demand by air-conditioning between summer and winter. Furthermore, daytime, when it produces solar power, is longer in summer than winter. So the authors have examined how solar power generator and storage battery combined system work in summer and winter respectively.

2.1 Supply of Electricity in Summer

Solar power generation is expected to supply electricity in summer daytime, when air-conditioning cooling demand is high. So it could mitigate electricity supplying demand in summer daytime.

The peak hourly electricity demand in summer 2018 in TEPCO, with the highest and mean temperature are shown in Figure 9. The peak electricity consumption seems to have a strong co-relation with the highest temperature.

The hourly electricity consumption and solar power generation on 7/23 in 2018 are shown in Figure 10. The maximum peak hourly electricity consumption has been held on this day. In peak consumption hours, about 1/6 of electricity consumption is supplied by solar power generation. So solar power generation is effective to mitigate the electrical supply capacity in summer. But there is some time lag between the peak of electricity consumption 13:00 -15:00 and it of solar power generation 11:00-12:00.

Building Research Institute has a demonstration house, which has solar power generator and storage battery combined system, air-conditioning so on, located in Tsukuba city, which is in the center of Japan. The authors have measured generated solar power, accumulated and emitted overpowered electricity of solar power generation and storage battery combined system, air-conditioning cooling demand in this demonstration house in summer. Air-conditioning cooling, targeting 27℃, has been switched on, for a whole day. Solar power,
accumulated, emitted, reverse flow and highest temperature are shown in Figure 11.

Composition of electric supply, solar power, storage battery, commercial line and highest temperature are shown in Figure 12. The electricity consumption seems to have a strong co-relation with the highest temperature. It means that air-conditioning cooling demand is a major part of the electricity consumption.

Electric power supply with solar power generator with storage battery combined system on 7/23 in 2018, is shown in Figure 13. It shows that solar power supply surpasses air-conditioning cooling demand, accumulating overflowed electricity into the storage battery until around 15:00. After 15:00, the solar power supply is not enough to provide air-conditioning cooling demand. So the storage battery emits electricity to cover the demand.

Composition and ratio of electric supply power are shown in Figure 14. Generally solar power provides 40 – 50 % of the total electric load. Combined it with storage battery, it provides around 80%. So It is very effective for incorporating lots of solar power.

2.2 Supply of Electricity in Winter

In winter, peak electricity is high in morning and evening. So solar power generation could not mitigate electricity supplying demand in winter directly. But it is expected to supply electricity for a whole day. Dairy electricity supply, solar power generation in TEPCO in winter 2018 and the highest, mean and lowest temperature are shown in Figure 15. Dairy electricity consumption has strong co-relation with the highest temperature inversely.
Solar power, accumulated, emitted, reverse flow in demonstration house and highest, mean, and lowest temperature are shown in Figure 16. (Data from late January to early February have not got.) The solar power seems to have some correlation with the highest temperature.

Air-conditioning heating in demonstration house, targeting 20°C, has been switched on from 6:00 to 24:00. Composition of electric supply, solar power, storage battery, commercial line and highest temperature are shown in Figure 17. The electricity consumption seems to have a strong correlation with the highest temperature inversely. It means that air-conditioning heating demand is a major part of the electricity consumption.

Electric power supply with solar power generator with storage battery combined system on 2/24 in 2018, which is sunny day, is shown in Figure 18.

Composition and ratio of electric supply power are shown in Fig. 19. Generally solar power provides 20 – 30% of the total electric load. Combined it with storage battery, it provides 60 – 80%.
On the other hand, electric power supply with this solar power generator and storage battery combined system, on 2/2 in 2018, which is snowy day, is shown in Figure 20.

Solar power generator and storage battery combined system is very effective for incorporating lots of solar power also in winter generally. But it has little effect on rainy and snowy days. It is difficult for solar power and storage battery combined system to replace thermal power completely.

It is suggested that electric line should be connected with hydrogen piping, and hydrogen is made from water, utilizing overflowed solar power, and electricity is made by fuel cell when electricity is short, such as rainy and snowy days, to utilize solar power fully and to replace thermal power. This networks of electric line, hydrogen and natural gas piping were shown in Figure 21.

3. Conclusion

The authors have examined performance of solar power generator and storage battery combined system in summer and winter to replace thermal power by fossil fuel. In summer peak consumption hours, about 1/6 of electricity consumption is supplied by solar power generation. So solar power generation is effective to mitigate the electrical supply capacity. But there is some time lag between the peak of electricity consumption 13:00-15:00 and it of solar power generation 11:00-12:00. So it is difficult for solar power generation to cover air-conditioning cooling demand in summer completely. If solar power generator is combined with storage battery, it could cover air-conditioning cooling demand completely. So solar power generation is more effective to mitigate electricity supplying capacity in summer, combined with storage battery.

In winter, peak electricity is high in morning and evening. So solar power generation could not mitigate electricity supplying demand in winter directly. But it is expected to supply electricity for a whole day. Generally solar power provides 60 – 80 % of the total electric load, combined it with storage battery. So solar power generation, combined with storage battery, is effective to supply electricity for whole a day in winter.

On the other hand, solar power generator and storage battery combined system provides only 20% of the total electric load, on rainy or snowy days. It is suggested to utilize solar power fully and to replace thermal power completely, electric line should be connected with hydrogen piping, and hydrogen is made from water, utilizing overflowed solar power, and electricity is made by fuel cell when electricity is short.
4. Acknowledgment

This study has been conducted on the LCCM (Life Cycle Carbon Minus) Demonstration House in Building Research Institute in Japan.

5. Reference

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