Effective usage of solar power generation and storage battery combined system

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Abstract. Solar power is very useful renewable energy, got anywhere. But it is got only in the daytime on sunny days. On the other hand, sometime the grid cannot receive overflowed solar power when electric demand is small. Recently storage battery is utilized in the grid, in the household, combined with solar power generator for accumulating overpowered electricity and emitting it after sunset. It is very useful to utilize solar power effectively and efficiently. It is also useful on the power failure. But we have very little information of technical traits of storage battery, such as energy loss with accumulating and emitting electricity. Building Research Institute in Japan has a demonstration house, which has solar power generator and storage battery combined system. The authors have measured generated solar power, accumulated and emitted overpowered electricity of solar power generation and storage battery combined system for a year. Lots of traits of solar power and storage battery combined system are got. The authors have made modeling and formulation solar power and storage battery combined system, incorporating these traits. In this way, efficiency and effectiveness of solar power generator and storage battery combined system with any generation, storage capacity, can be evaluated with this formulation.

1. Introduction

Renewable energy, such as solar power has been utilized for residential use recently. In such cases, solar power generator is combined with storage batteries. It generates power in the daytime and overflowed power is accumulated into the storage battery. After sunset, storage battery emits accumulated power. So we can utilize solar power effectively.

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.

Table 1. Specimen of the units

| Solar power generator | Max output: 4kW |
|-----------------------|-----------------|
| Storage battery       | Capacity: 11.2kWh |

Figure 1. Solar power generation with storage battery
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 1 and Table 1.

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 2. 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 3. 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 4.
- 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 5.

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. Various usage of storage battery
We have examined the traits of solar power generator and storage battery, accumulating overflowed solar power into the storage battery, emitting after sunset.

But we have other usage of storage battery. For example, we stockpile some amount of electricity for backup in case of power failure. When we charge electric appliances, such as vehicles, we usually accumulate electricity the maximum pace. We examine the traits of storage battery in the cases.

2.1 Effect of the ratio of storage battery composition for backup and accumulating, emitting
As above, we stockpile some amount of electricity for backup in case of power failure. So we examine the traits of storage battery, changing the ratios of storage battery composition for backup and accumulating, emitting, shown in Table 2.

| Accumulating and emitting | Backup |
|---------------------------|--------|
| 90% 10.08(kWh)            | 10% 1.12(kWh) |
| 80% 8.96(kWh)             | 20% 2.24(kWh) |
| 60% 6.72(kWh)             | 40% 4.48(kWh) |

Efficiency of accumulating, emitting and transferring electricity of each case are shown in Figure 7. There are no differences among each ratio of storage battery composition for backup and accumulating, emitting.

2.2 Effect of the pace of accumulating electricity
When we charge electric appliances, such as vehicles, we usually accumulate electricity the maximum pace. We examine the traits of storage battery when we accumulate electricity the maximum pace shown in Figure 8.
In this case, electricity is brought from the commercial grid. This electricity is transferred from alternate to direct in the inverter. Direct electricity is accumulated into the storage battery. When we use electricity, storage battery emits direct electricity. Direct electricity is transferred from direct to alternate. And we use this transferred alternate electricity.

Efficiency of transferring electricity from alternate to direct, accumulating into the storage battery and emitting from the storage battery, transferring electricity from direct to alternate, and total process, are shown in Figure 9.

Efficiency of accumulating into the storage battery and emitting from the storage battery, maximum accumulating and accumulating overflow, are shown in Figure 10. There are no differences between maximum accumulating and accumulating overflow. This efficiency is almost 0.9-1.0.

Each efficiency of transferring electricity from alternate to direct, transferring electricity from direct to alternate are shown in Figure 11 and 12. They depend on the amount of electricity. They are small in the small scale and large in the large scale. Each efficiency of transferring electricity from alternate to direct, transferring electricity from direct to alternate are shown in Figure 9 are average ones during transferring process.

Solar power could be accumulated into the storage battery in direct without conversion. But power from the commercial grid is transferred alternate from direct when it is accumulated into the storage battery. There is some loss of electricity during this transferring process.
3. Modeling and formulation of solar power generator and storage battery combined system

Lots of traits of solar power and storage battery combined system are got so far. The authors make modeling and formulation solar power and storage battery combined system.

Electricity accumulated in storage battery Accum(\(t\)), emitted from storage battery Emit(\(t\)) are described as below.

\[
\text{Accum}(t) = (W_{\text{Sun}}(t) - (1/\eta_{d\rightarrow a}(W))*W_{\text{Load}}(t))
\]

when \(W_{\text{Sun}}(t) \geq W_{\text{Sun}}(t) - (1/\eta_{d\rightarrow a}(W))*W_{\text{Load}}(t)\)

\[
\Sigma \text{Accum}(t) \leq \text{Storage}
\]

\[
\eta_{a\rightarrow d}(W) * \text{Emit}(t) + \eta_{d\rightarrow a}(W) * W_{\text{Sun}}(t) = W_{\text{Load}}(t)
\]

\[
\Sigma \text{Emit}(t) \leq \eta_{\text{storage}} \times \text{Storage}
\]

\(W_{\text{Sun}}(t)\): solar power generation (W) (direct)
\(W_{\text{Load}}(t)\): electricity power demand (W) (alternate)
\(W_{\text{CM}}(t)\): Commercial power (W) (alternate)

\(\eta_{d\rightarrow a}(W)\): Efficiency of electricity, transferring direct to alternate
\(\eta_{a\rightarrow d}(W)\): Efficiency of electricity, transferring alternate to direct
\(\eta_{\text{storage}}\): Efficiency of accumulating into the storage battery and emitting from the storage battery

We can evaluate efficiency and effectiveness of solar power generator and storage battery combined system with any generation, storage capacity, given \(W_{\text{Load}}(t)\), \(\eta_{d\rightarrow a}(W)\), \(\eta_{a\rightarrow d}(W)\) and \(\eta_{\text{storage}}\) with simple calculating program, such as excel etc., with this formulation. \(\eta_{d\rightarrow a}(W)\), \(\eta_{a\rightarrow d}(W)\) and \(\eta_{\text{storage}}\) are described in Figure 5,7,9,10,11,12) We can show some simulated examples, utilizing this formulation.

Electric power supply with this solar power generator and storage battery, combined system, supplied electricity with this system on 7/23-24 in 2018, is shown Figure 14. 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. And accumulated electricity runs out around 23:00.

Figure 13. Model of solar power generator and storage battery combined system

Figure 14. Electric power supply and supplied power (observed on 2018/7/23)
So we simulate this case, expanding solar power generator, 4kW to 6kW. Estimated Electric power supply and supplied power are shown in Figure 15. In this case, the solar power supply is enough to provide air-conditioning cooling demand and accumulate overflowed electricity into the storage battery until it is full. And accumulated electricity is enough to cover electricity demand after sunset.

In this way, we can evaluate efficiency and effectiveness of solar power generator and storage battery combined system with any generation, storage capacity, with this formulation.

4. Conclusion
The authors have examined the traits of solar power generator and storage battery, accumulating overflowed solar power into the storage battery, emitting after sunset.

Storage battery is also utilized for other usage, backup for power failures, electric appliances, such as vehicles, usually charged with maximum pace. The authors have examined the traits of storage battery is these usages and found that there are no differences with efficiency of accumulating and emitting electricity. But power from the commercial grid is transferred alternate from direct when it is accumulated into the storage battery. There is some loss of electricity during this transferring process.

The authors also have made modeling and formulation solar power and storage battery combined system. In this way, efficiency and effectiveness of solar power generator and storage battery combined system with any generation, storage capacity, can be evaluated with this formulation.

Solar power will be incorporated to building, houses further, combined with storage battery. These information, knowledge, model and formulation will be very useful and effective.

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6. Reference
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