Evaluation of Saving Energy of SOFC and Battery Combined System

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ABSTRACT

Fuel Cells have been utilized for residential use recently. Because they are very effective saving energy, generating not only electricity but also hot water. Especially SOFC (Solid Oxide Fuel Cell) has been utilized because of its higher efficiency of generating electricity than PEFC (Polymer electrolyte fuel cell).

The authors have found that it has high efficiency 42% at full capacity but it decreases on smaller scale. To overcome this shortcoming, the authors have made the system, combining SOFC and battery. This system accumulates overflowed electricity into the battery, operating SOFC on the full scale, and emits electricity from the battery when the electricity load is beyond SOFC capacity.

The authors have evaluated its efficiency of generating electricity, saved energy compared with the traditional method, which provide electricity and hot water by the Commercial power and the gas boiler, and the only SOFC on various electricity and hot water scale patterns. They have found that it is more effective by generating electricity and accumulating overflowed electricity and emitting it generally. But it is not more effective than the only SOFC when it is operated on smaller electricity scale. The proposed system loses some electricity during accumulating it into the battery, emitting it from the battery, and translating it between direct and alternate current.

It is suggested its efficiency and effectiveness could be improved by reducing this electric loss.

Keywords: *SOFC (Solid Oxide Fuel Cell), battery, saving energy*

1. INTRODUCTION

Fuel cells have been utilized for residential use to save energy. At first PEFC (polymer electrolyte fuel cell) have been used, recently SOFC (Solid Oxide Fuel Cell), which have higher efficiency, have been introduced for not only for commercial use but also for residential use.

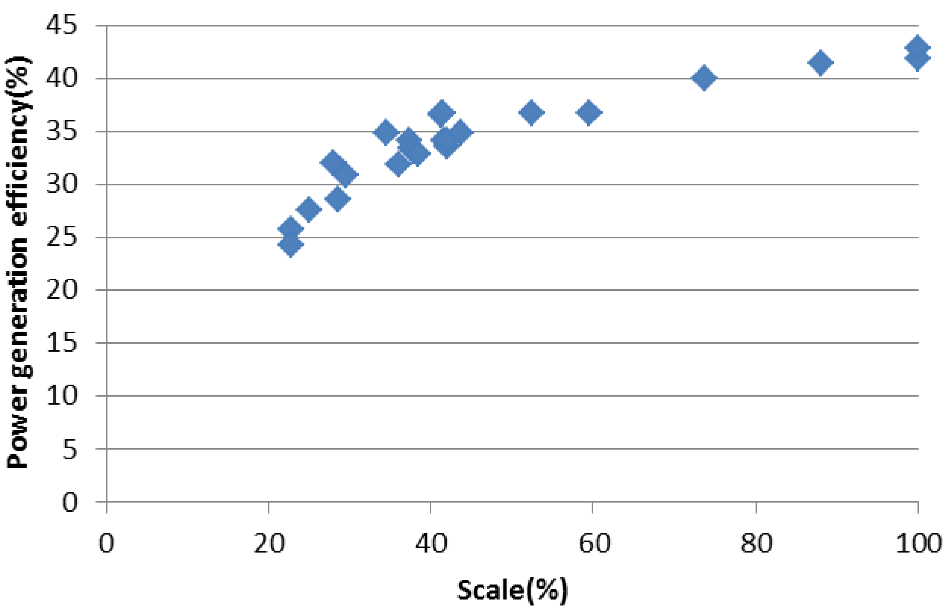

Figure 1: Power generating efficiency of SOFC

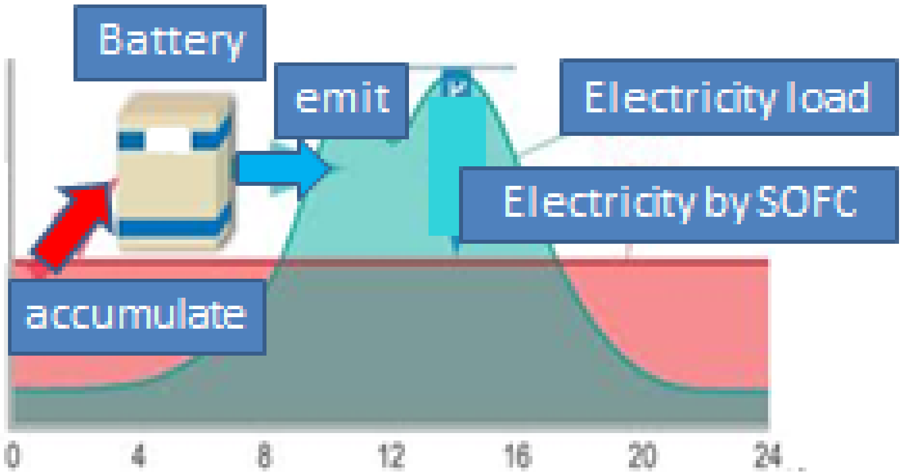

Figure 2: Operation of SOFC and battery

It is said that SOFC efficiency of generating electricity is high (about 42%) at the full scale but it decreases at small scale.

To overcome this shortcoming, the authors combined SOFC with battery. SOFC is operated at full scale if the battery is not full, accumulating overflowed electricity. On the other hand, Battery emits electricity when the electricity load is beyond SOFC capacity. The authors have examined efficiency and effectiveness of this system.

2. EVALUATING TESTS FOR EFFICIENCY System and loads for evaluating tests

Figure 3 shows the system combining SOFC (producing from 50 to 700W electricity, with hot water tank 90 Litter) and Battery (The full capacity 7.2 kWh, the Rated Voltage 2.5W) and locations of various sensors, such as electricity, gas, temperature and flow censors.

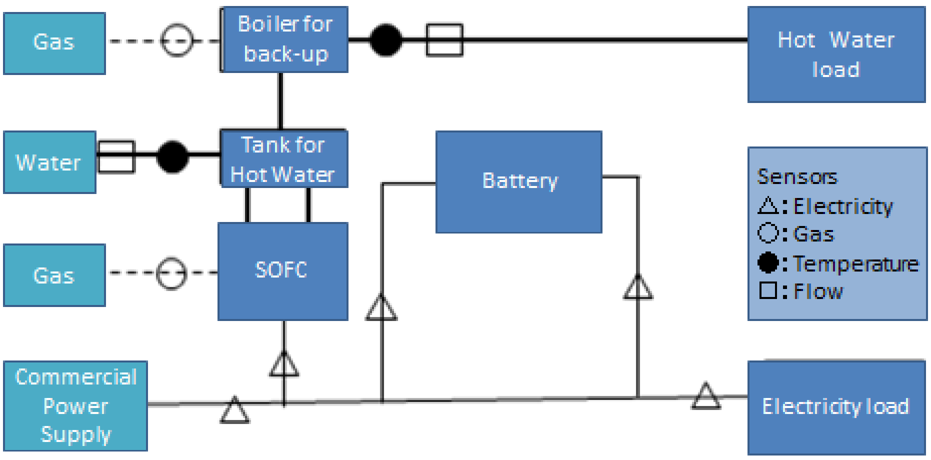

Figure 3: System of SOFC and battery

Test electricity loads are set based on the Japanese Standard Energy-Saving Building Guideline (10.96kWh/ day) and the full capacity of SOFC (16.8 kWh/ day). 4 Types of loads are set, which are large one with 2 peaks (16.27 kWh/ day), large one with gentle slope (16.27 kWh/ day), medium one (the Japanese Standard Energy-Saving Building Guideline 10.96kWh/ day) and small one (6.58 kWh/ day).

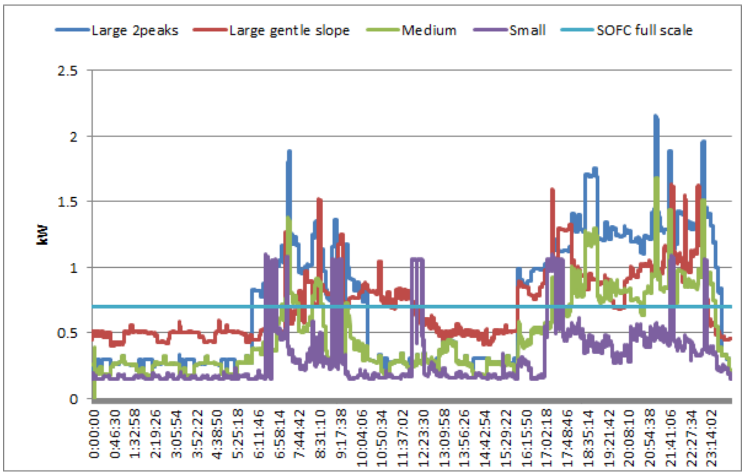

Figure 4: Test loads of electricity

Test hot water loads are set based on the Japanese Building Suppling Hot Water Guideline. Modified M-1 mode (650,550,470,380,380,240 Litter/ day) is allocated with 2 large electricity loads. Modified M-1 mode saving type (522,454,387,306,166 Litter/ day) is allocated with Medium and Small electricity loads. The Efficiency and effectiveness of this system are examined with various electricity and hot water loads in this way.

Hot water loads(L/day)	
Modified M1 mode	Modified M1 mode (Saving type)
650	522
550	454
470	387
380	324
380	306
240	166

Table 1: Test loads of hot water

2.2 Electric power supply of this system with various loads

The authors have examined efficiency and effectiveness of this system with various electricity and hot water loads mentioned on the above.

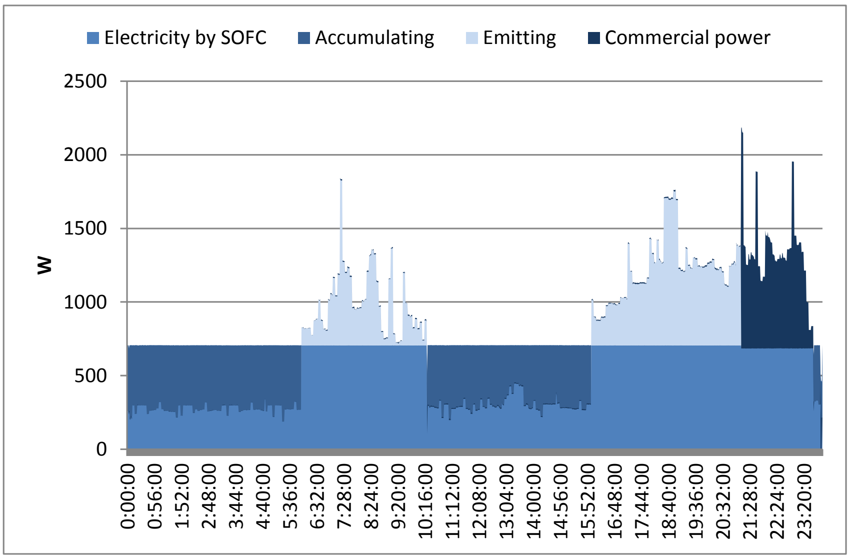

Figure 5: Supply of electric power (large 2peaks)

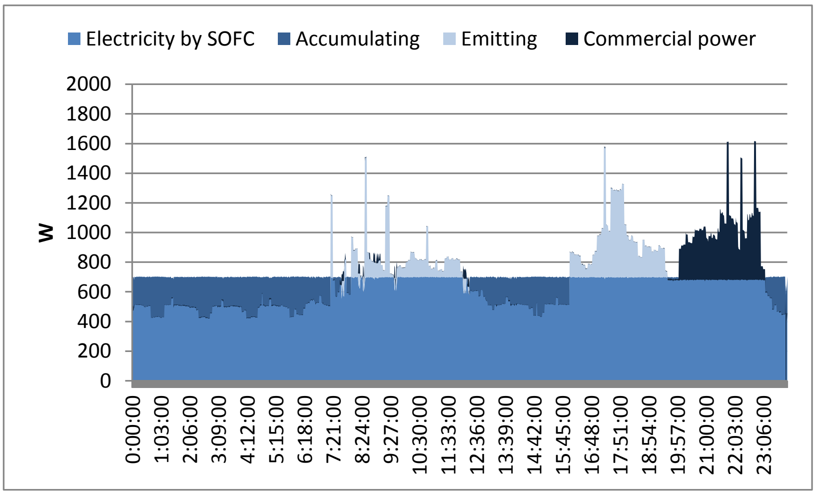

Figure 6: Supply of electric power (large gentle slope)

Figure 5 shows supply of electric power by this system with large electricity load with 2 peaks and Figure 6 shows that with large electricity load with gentle slope. In both cases, the batteries accumulate overflowed electric power while the load are low, operating SOFC on the full scale and emit electric power from the batteries while the loads are higher than the full capacity of SOFC. Also in both cases, the commercial powers are supplied after the batteries run out of accumulated electricity.

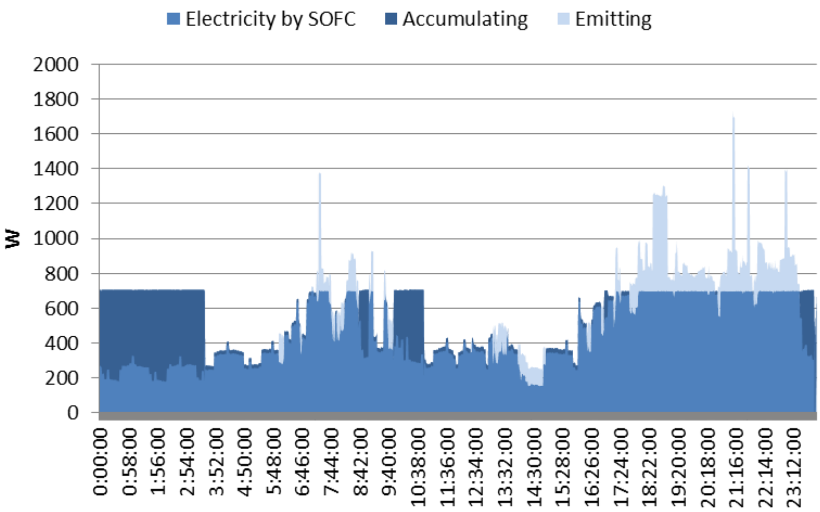

Figure 7: Supply of electric power (medium load)

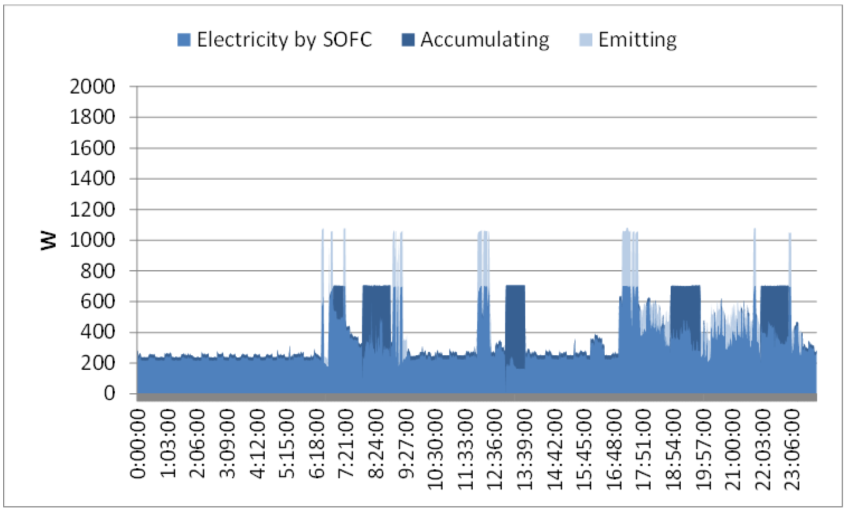

Figure 8: Supply of electric power (small load)

Figure 7 shows supply of electric power by this system with medium electric load and Figure 8 shows that with small electric load. As shown in Figure 5 and Figure 6, the battery accumulates overflowed electricity while the load is low and emits electricity from the battery while the load is higher than the full capacity of SOFC.

On the other hand, in Figure 7 and Figure 8, the batteries accumulate electricity until they get full. In both cases, the SOFCs operate according with the electric load after they get full, not on the full scale.

So the authors have seen different patterns of electric power supply between large electric loads and medium, small load.

2.3 Evaluation of energy saving of this system with various loads

The authors have evaluated the rate of energy saving of this system as below. The total load is provided as below.

Et = Ee + Ew
Et: Total load (kWh)
Ee: Electric load (kWh)
Ew: Hot water load (kWh)

The supplied energy to this system to provide the above load Et, is described as below.

$S_1 = G_1 + G_{1b} + E_1$
S_1: Total supplying energy to this system (kWh)
G_1: Gas usage by SOFC (kWh) (Gas calorific value 45MJ/ m^3)
G_{1b}: Gas usage by the back-up boiler (kWh) (assumed 85%)
E_1: Commercial power usage (kWh) (with The Japanese Guideline. Transferred as 9760kJ/ KWh)

The supplied energy to the traditional energy providing system, which is by the commercial power and the gas boiler, is described as below.

$S_2 = G_{2b} + E_2$
S2: Total supplying energy to the traditional system, which is by the commercial power and the gas boiler (kWh)
G2b: Gas usage by the traditional gas boiler (kWh) (assumed 85%)
E2: Commercial power usage (kWh) (with The Japanese Guideline. Transferred as 9760kJ/ KWh)

Energy saving rate is evaluated, comparing total supplying energy S1 with this system and S2 with the traditional energy providing system, which is by the commercial power and the gas boiler.

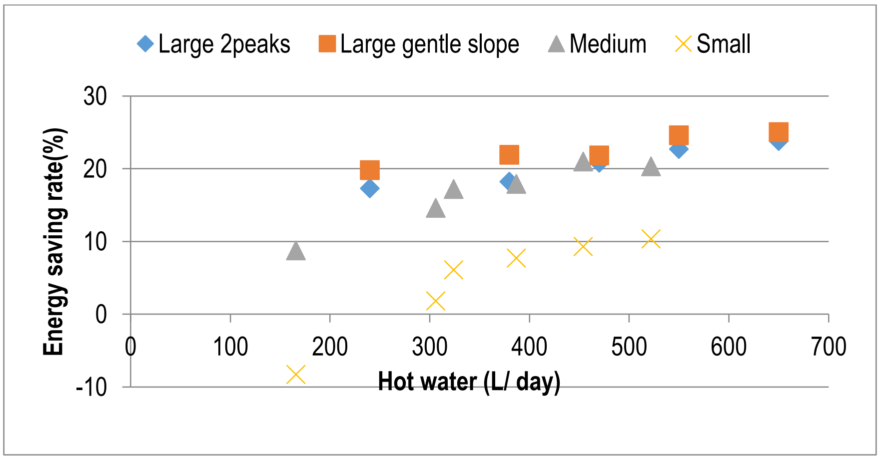

Figure 9: Energy-saving rates with various loads

Figure 9 shows energy saving rates with various loads. In all loads, energy saving rates are higher in larger hot water loads. It is typical with fuel cells. In general energy saving rates with large 2 peaks, large gentle slope and medium loads are beyond 15%, with small load are below 10%. So this system has advantage with more than medium electricity load.

2.4 Evaluation of energy saving of this system with only SOFC

The authors combined SOFC with battery to overcome the shortcoming that SOFC efficiency of generating electricity is high (about 42%) at the full scale but it decreases at small scale.

So the authors have evaluated energy saving of this system with not only the traditional providing system, which is by the commercial power and the gas boiler, but also with only SOFC.

The authors have known the general trend of energy saving of this system on 2.3. So the authors have compared energy saving of this system with only SOFC with not every type of load but only large electricity load with 2 peaks and medium load.

The supplied energy to only SOFC to provide the above load Et, is described as below.

S3= G3 + G3b + E3
S3: Total supplying energy to only SOFC(kWh)
G3: Gas usage by SOFC (kWh) (Gas calorific value 45MJ/ m3)
G3b: Gas usage by the back-up boiler (kWh) (assumed 85%)
E3: Commercial power usage (kWh) (with The Japanese Guideline. Transferred as 9760kJ/ KWh)

Energy saving rates are evaluated compared with the traditional energy providing system, which is by the commercial power and the gas boiler, both for SOFC with the battery and only SOFC.

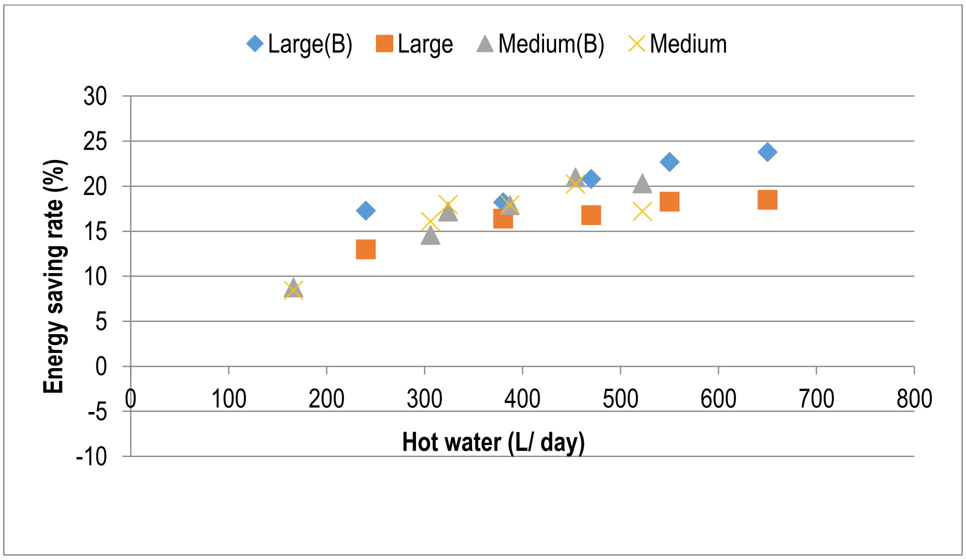

Figure 10: Energy-saving rates (SOFC + battery vs SOFC)

Figure 10 shows the results of this evaluation. This system, combining SOFC and the batter, has higher energy saving rate than only SOFC with large 2peaks electricity load, especially with heavier hot water loads. But it has no higher energy saving rate than only SOFC with medium electricity load.

2.5 Battery's traits

If this system, combining SOFC and the battery, could accumulate, emit electricity and translate it between direct and alternate current perfectly with no electricity lost, it could always have higher energy saving rates than only SOFC. But in reality, it always has some electrical loss during accumulating, emitting and translating electricity. So it is important to know the battery's traits and evaluate these losses to make this system more energy saving.

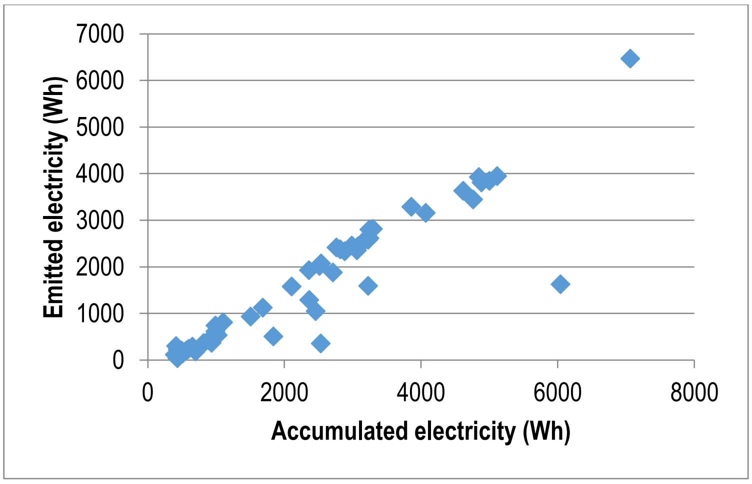

Figure 11: Battery's trait (emission vs accumulation)

Figure 11 shows correlation between accumulated electricity into the battery and emitted electricity from it. It is suggested they are proportional in general. But there are some exceptions, which are lower than proportional dots. Moreover, the direct line to connect dots does not pass the Zero point, crossing X line with positive. It suggests effective efficiency is low, where accumulated electricity is small.

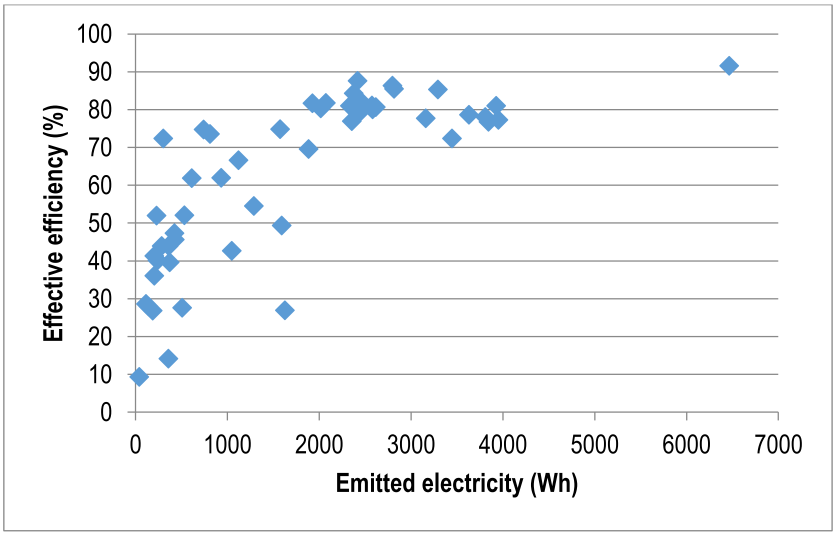

Figure 12: Battery's trait (effective efficiency vs emission)

Figure 12 shows correlation between emitted electricity from the battery and effective efficiency. The effective efficiency is stable, around 80%, where emitted electricity is over 2000. But dots are scattered and below 80% where is emitted electricity below 2000.

This means at least 20% electricity is lost during accumulating and emitting process. And it is suggested that more than 20% electricity is lost, where emitted electricity is below 2000. Moreover, it is suggested it is difficult how much electricity is lost in this part because dots are scattered vastly.

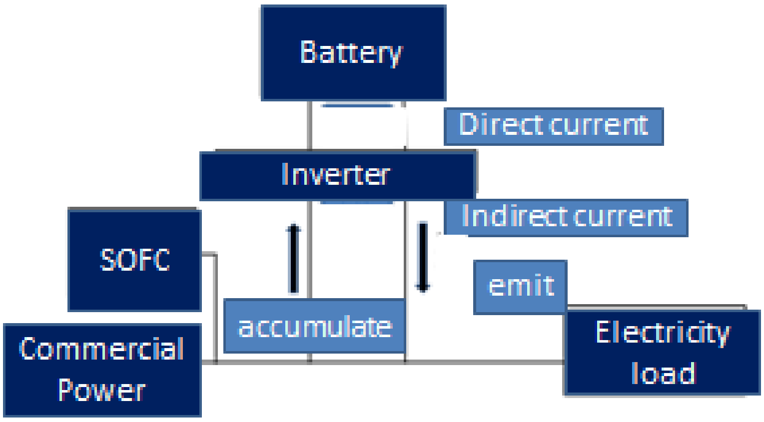

Figure 13: Mechanism of SOFC + battery system

Figure 13 shows the mechanism of this system, combining SOFC and the battery. This shows the flow of electricity from SOFC, the commercial power to the battery and it from the battery to the electricity load.

The electricity from SOFC, the commercial power is indirect current and it is converted to direct one in the inverter and accumulated into the battery as direct one. On the other hand, the electricity from the battery is direct current and it is converted to indirect one in the inverter and delivered to the electricity load.

It is suggested some electricity is lost during this converting process. This loss is included in Figure 9 and 10.

3. CONCLUSION

The authors have evaluated its efficiency of generating electricity, saved energy compared with the traditional method, which provide electricity and hot water by the Commercial power and the gas boiler, and the only SOFC on various electricity and hot water scale patterns. They have found that it is more effective by generating electricity and accumulating overflowed electricity and emitting it on larger electricity scale. But it is not more effective than the only SOFC when it is operated on smaller electricity scale.

The proposed system loses more than 20% electricity during accumulating it into the battery, emitting it from the battery, and translating it between direct and alternate current. Especially more than 20% electricity is lost, where emitted electricity is small. Moreover, it is suggested it is difficult how much electricity is lost in this part because dots are scattered vastly.

It is suggested its efficiency and effectiveness could be improved by reducing this electric loss.

REFERENCES

[1] Yasunori Akashi, 2013, Energy Saving Effects of Solid Oxide Fuel Cell Co-Generation System : Part 3 Examination of the Optimal Specification for Collective Housing according to Energy Demand, Building National Conference, Sapporo, 8/ 30 – 9/ 1