Study on Distributed MPPT System in Solar EV

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Abstract

In this study, we investigated a photovoltaic (PV) system for a solar powered Electric Vehicle (converted from a Honda Gyro Canopy). PV modules were installed on four surfaces of a rear-delivery-box (top, rear, right, and left). Each PV module had a maximum power point tracker (MPPT). To maximize total output power, two types of distributed MPPT systems using series–parallel connections were examined, and the output power was measured in outdoor experiments. The results clearly indicate that differences in the currents lead to a reduction of output power of the top and rear surfaces in a series–parallel system in which the left and right surfaces are in parallel.

Keywords: PV system, Solar EV, Converted EV, Distributed MPPT System, Through-mode

1. Introduction

One solution for environmental problems is the development of vehicles that utilizes renewable energy. The prevalence of vehicles that directly utilize solar energy is limited, particularly solar racing vehicles. Every year, emissions from automobiles are becoming increasingly regulated all over the world, especially in European countries. Since 2015, the Euro 6 standards (EU, 2012) have been adopted by products across the market, and vehicle emissions must be zero by 2040 (BBC, 2017; D. Muoio, 2017). We intend to develop a solar electric vehicle (EV) utilizing a park-and-solar-charge system for future commercial use in such vehicles as the Sion (Sono Motors, 2017) and the ehome (Dethleffs, 2018). In this study, the output power and conversion efficiency of a distributed photovoltaic (PV) system in a solar EV for personal mobility are discussed.

2. PV System

Fig. 1(a) shows the solar powered EV, which is converted from a Honda Gyro Canopy. Fig. 1(b) shows a delivery box installed on the rear of the solar EV. The power unit of the solar EV is a surface permanent magnet-type synchronous motor. Four PV modules and four pyranometers are installed on four surfaces (top, rear, left, and right) of the delivery box of the solar powered EV. The top surface contains 32 crystalline Si cells in its module and the other vertical surfaces contain 24 crystalline cells in each module. The total area of the four PV modules is 0.975 m^2.

Fig. 2 illustrates block diagram of the PV system. Each PV module has a maximum power point tracker (MPPT) set on each individual surface. The power-generating system with the distributed MPPT charges a valve-regulated 27 Ah lead-acid battery. The MPPT is a KW-MPPT Rev 3.0 (Takanori, 2014), which is able to boost the output voltage to a range of 7.5 V (minimum) to 37 V (maximum). Its DC-DC efficiency is 99% with a voltage boost ratio of 1.1. The KW-MPPT has a through-mode function, which is activated when the input drops below 7.5 V or the boost ratio drops below 1.1. In through mode, the MPPT does not operate at the peak power point or boost the voltage, but photovoltaic current still flows.

In the distributed PV system, series, parallel, and series–parallel connections can be utilized to charge the battery (Toru, 2016). An ammeter and a voltmeter are connected to each input/output of the MPPT to measure its operating performance. ML-02 pyranometers (EKO, Tokyo) are set on the surface near each PV module for a total of four surfaces of irradiance being measured and compared at the same experimental conditions.

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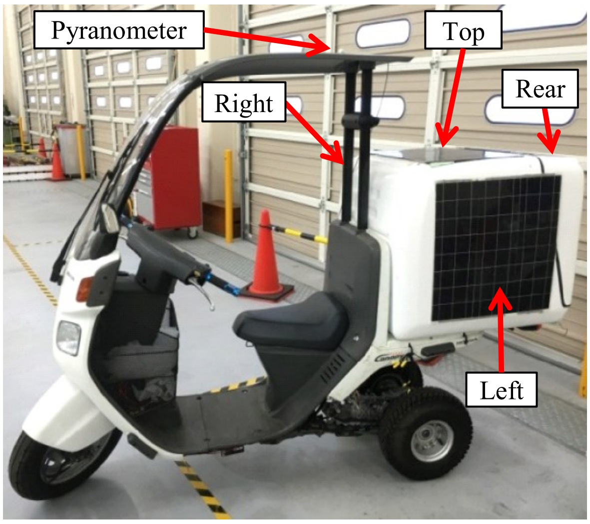
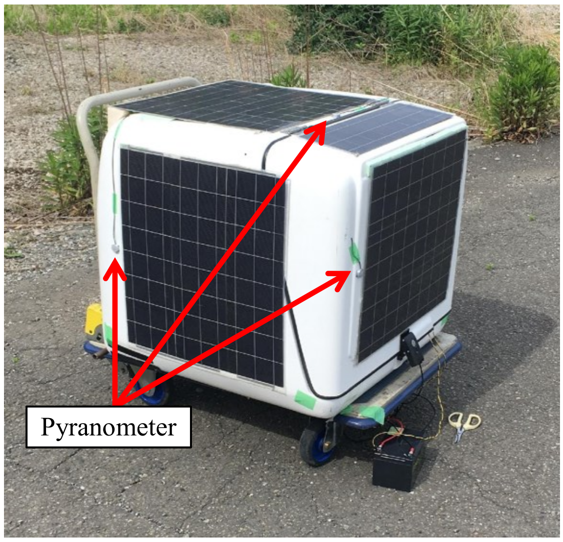


(a) Converted solar EV



(b) Delivery box with PV modules on four surfaces

Fig. 1: Honda Gyro Canopy and delivery box

The photovoltaic conversion efficiency is measured with PV modules placed on the delivery box, as shown in Fig. 1(b). An I-V curve tracer from Oyo Electric (Kyoto) and the aforementioned pyranometers are used to evaluate the I-V characteristic curve and peak power point. In this experiment, the rear surface is oriented to the south. The I-V curve was measured every hour for each module on each surface on 26-Aug. 2018 from 9:25 to 15:40.

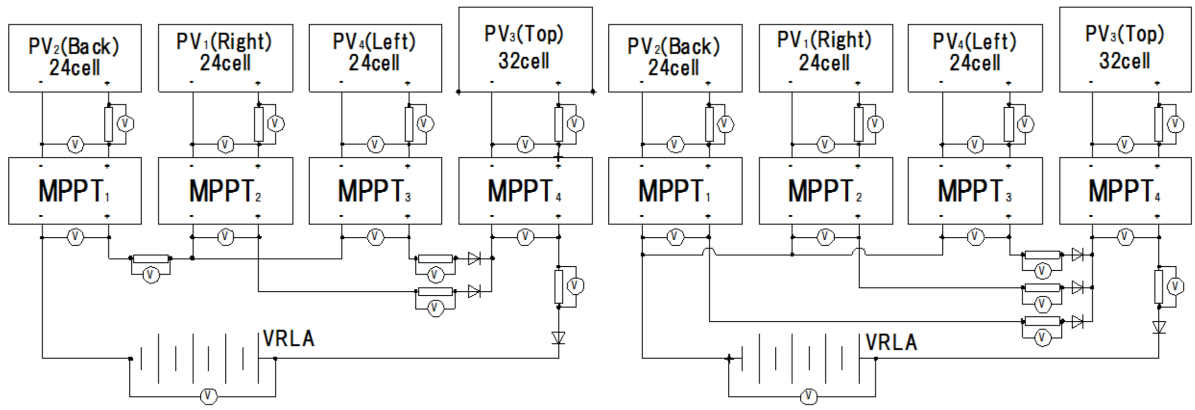
Tab. 1 shows the experimental results of irradiance and the maximum output power of the PV modules for each surface (top, rear, right, and left).

Tab. 1: Conversion efficiencies of photovoltaic modules

Time	Top Surface	Rear Surface	Right Surface	Left Surface
9:30	11.14	6.213	11.09	6.141
10:30	11.01	10.91	10.01	11.97
11:30	10.90	10.07	10.27	10.89
12:30	10.41	10.30	10.54	10.33
13:30	10.72	9.388	9.960	11.53
14:30	11.59	8.462	9.819	11.98
15:30	12.15	8.255	9.081	12.01

3. Experiments

To evaluate the distributed MPPT system, outdoor experiments were conducted. We discuss two series–parallel systems. One system consists of two parallel PV modules on the left surface and the right surface of the delivery box. The other system consists of three parallel PV modules on the left, rear, and right surfaces of the delivery box. Fig. 2 shows the block diagrams of these systems. The load is provided by a valve-regulated 48 V/27 Ah lead-acid battery. Two Graphtec midi LOGGER GL200 units are used for data logging to measure the input/output current and voltage. A GL220 data logger is used to measure the irradiances. Resistors of 0.005 Ω and 0.05 Ω are respectively applied to measure the input and output currents for the MPPT.



(a) Right and left panels in parallel **(b) Right, left, and rear panels are in parallel**

Fig. 2: Block diagrams of distributed MPPT system with series–parallel connections

3.1. Series–Parallel (Right and Left) Connection

An experiment was conducted outdoors to evaluate the series–parallel connection. In Fig. 2(a), it can be seen that the right and left surfaces are connected in parallel, since the I-V characteristic curve shows less output current for those surface—thus, they are intended to complement each output. The experiment was conducted on 1-May 2018 from 9:00 to 15:00 with the rear surface is oriented to the south. Fig. 3 shows the irradiance on each surface. Fig. 4 shows the output power for each surface. A peak irradiance of 1,121 W/m^2 (horizontal irradiance) was obtained on the top surface. Simultaneously, the incident irradiance of the other surface were 37.8%, 21.9%, and 30.7% for the rear, right, and left surfaces, respectively, normalized by the irradiance of the top surface. Since the delivery box is cube-shaped, the difference in irradiance is significant.

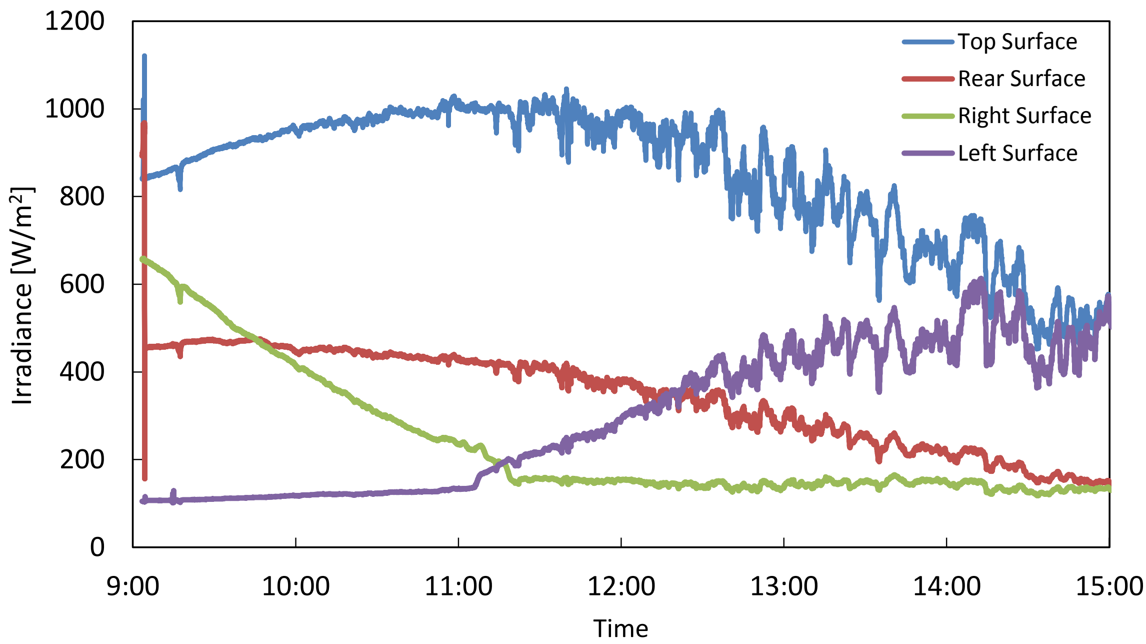


Fig. 3: Plot of the irradiance on 1-May 2018 for 4 surfaces

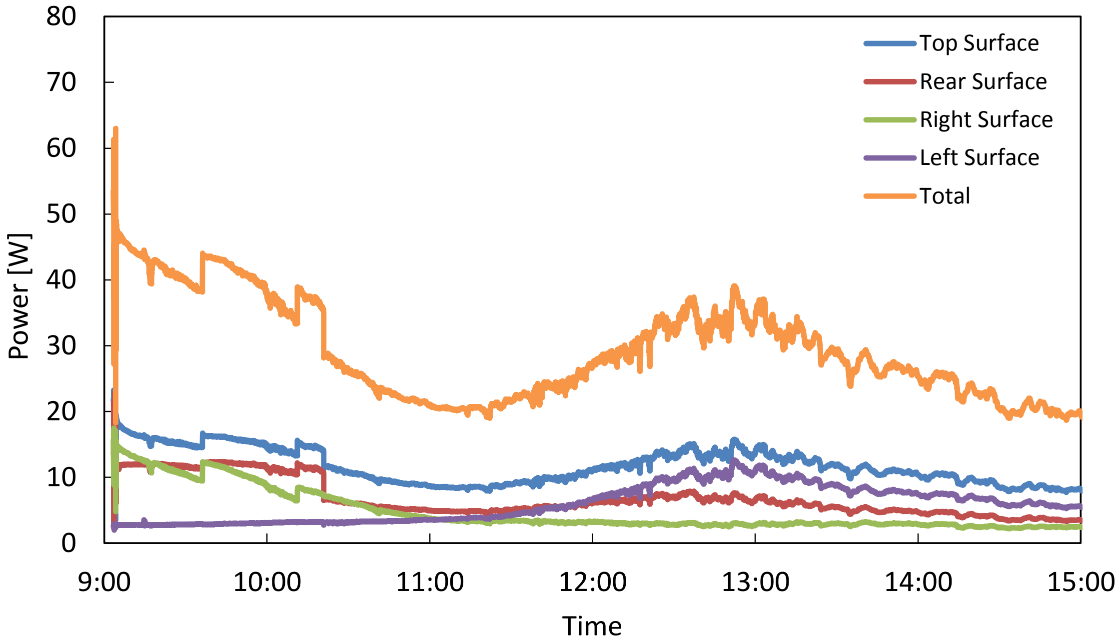


Fig. 4: Plot of the output power on 1-May 2018 for MPPT in four directions

Due to the shadow of the delivery box, the irradiance was less than 200 W/m^2 in the morning for the left surface and in the afternoon for the right surface. From the results, it is observed that the MPPT output currents in the morning (left surface) and afternoon (right surface) were insufficient, as expected. Therefore, Fig. 4, which shows the output power, demonstrates that direct sunlight yields 10 W or more but indirect sunlight yields 5 W or less. Generally, the generated output power of a PV module is directly proportional to irradiance, but the irradiance during 10:20-12:40 does not produce high output power on the top surface or rear surface. In other words, the output power of the right and left surfaces decreased proportionally with the irradiance, causing the current to decrease as well, which ultimately means that the MPPT current of the top and rear surfaces was restricted by the lower current. To reduce current restriction, the MPPTs on the left and right surfaces are placed in parallel. However, if the output current of both sides were insufficient, then the MPPT output current of the top and rear surfaces would be significantly restricted by the lack of current in a series circuit.

In a 4-hour outdoor experiment that took place from 11:00 to 15:00, the total charging energy was 105.6 Wh and the average value was 26.4 Wh per hour. Fig. 5 shows the ideal power calculated from the measured photovoltaic conversion efficiency and irradiance, as in Fig. 3. In the Fig. 5, the accumulated total output power was 187 Wh with an average value of 46.8 Wh per hour. An ideal output of 76% greater than the measured output is obtained. From calculations of the ideal case, the output capability is estimated to be 187 Wh at the same conditions of irradiance.

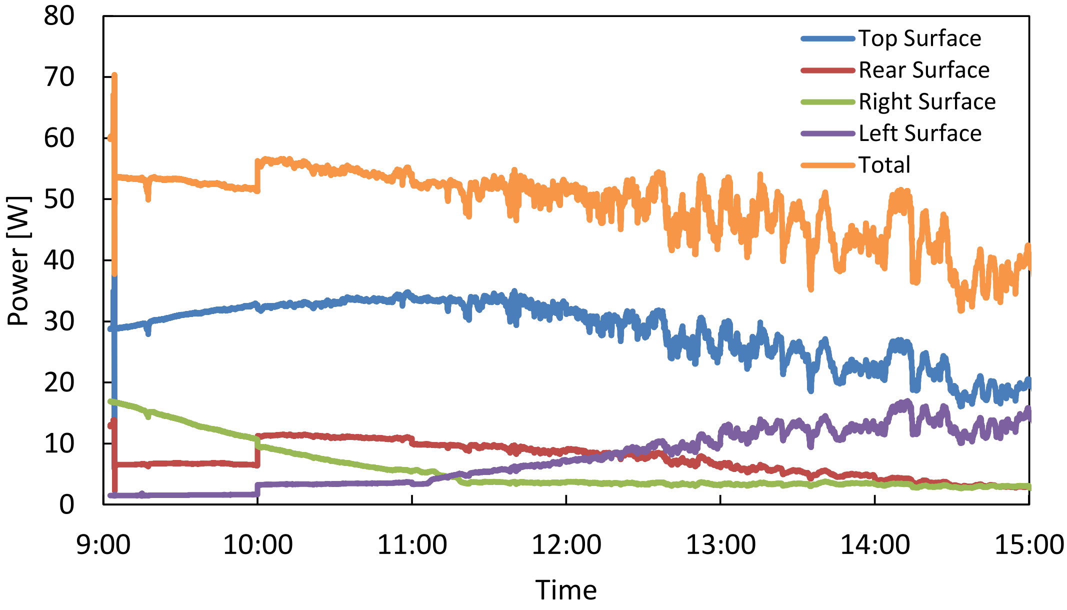


Fig. 5: Ideal power calculated by measured photovoltaic conversion efficiency and irradiance

Tab. 2: Accumulated horizontal irradiance and output power

Period	Horizontal Irradiance [Wh/m^2]	Output energy [Wh]
11:00 – 15:00 (4.0 hours)	3,215	105.6

3.2. Series–Parallel (Right, Left, and Rear) Connection

The connections of the three vertical surfaces of the MPPTs were changed such that the right, left, and rear were placed in parallel, after which an outdoor experiment was conducted. Fig. 2(b) illustrates the block diagram of the distributed series–parallel MPPT system.

A battery-charging experiment was conducted on 25-May 2018 from 11:00 to 15:00 with the rear surface oriented to the south. Because the current produced by connecting a pair of the opposite-vertical-surfaces (the left and right) in parallel was relatively low, based on the results of the previous experiment, the rear MPPT current was added to complement that of the left and right. Fig. 6 shows the irradiance of each surface, and Fig. 7 shows the output power of each PV module.

Irradiance characteristics are affected by clouds. Thus, the output power from the MPPTs varies widely. At noon, a horizontal irradiance over 1000 W/m^2 was obtained, though the output power of the top surface was not proportional to the irradiance. On the other hand, the output power measurements from the left, right, and rear surfaces were not restricted by the top surface at noon and around 14:00 compared to the left and right surfaces of the parallel system, as shown in Fig. 4. The output of the left surface was proportional to the irradiance of the left surface. The output energy from the series–parallel MPPT system over the four hours (11:00 to 15:00) was 167 Wh, or an average of 41.8 Wh per hour, as listed in Tab. 2. Fig. 8 represents the ideal output power of each surface based on the conversion efficiency from the I-V curves, listed in Tab. 1. The accumulated output energy was assumed to be 176 Wh over the four hours, or 44.0 Wh per hour.

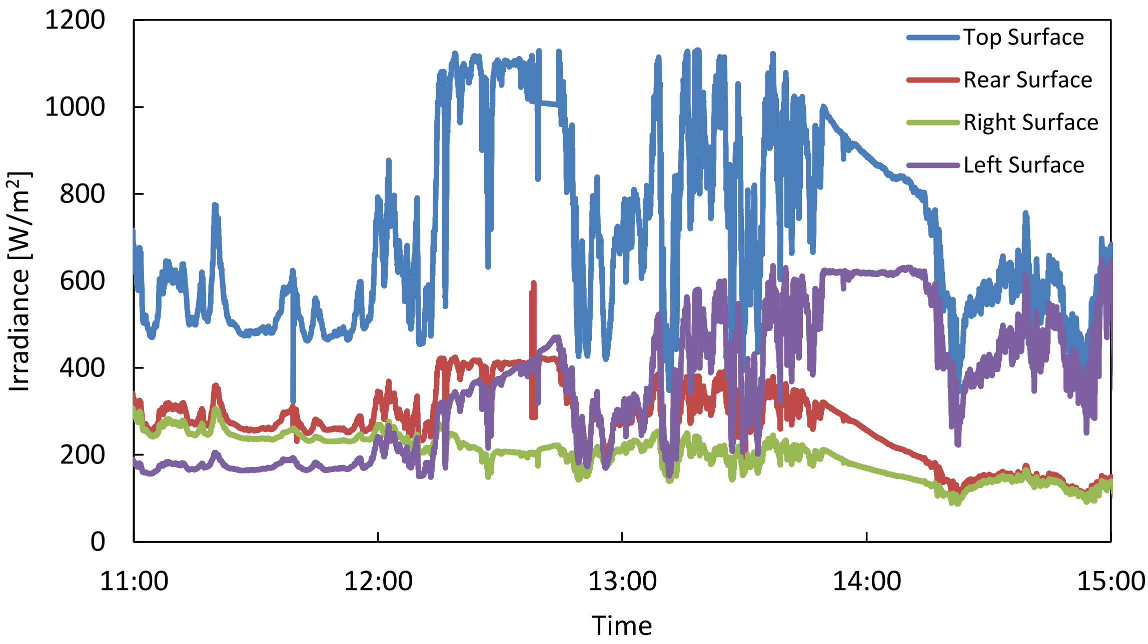


Fig. 6: Plot of the irradiance of the four surfaces on 25-May 2018

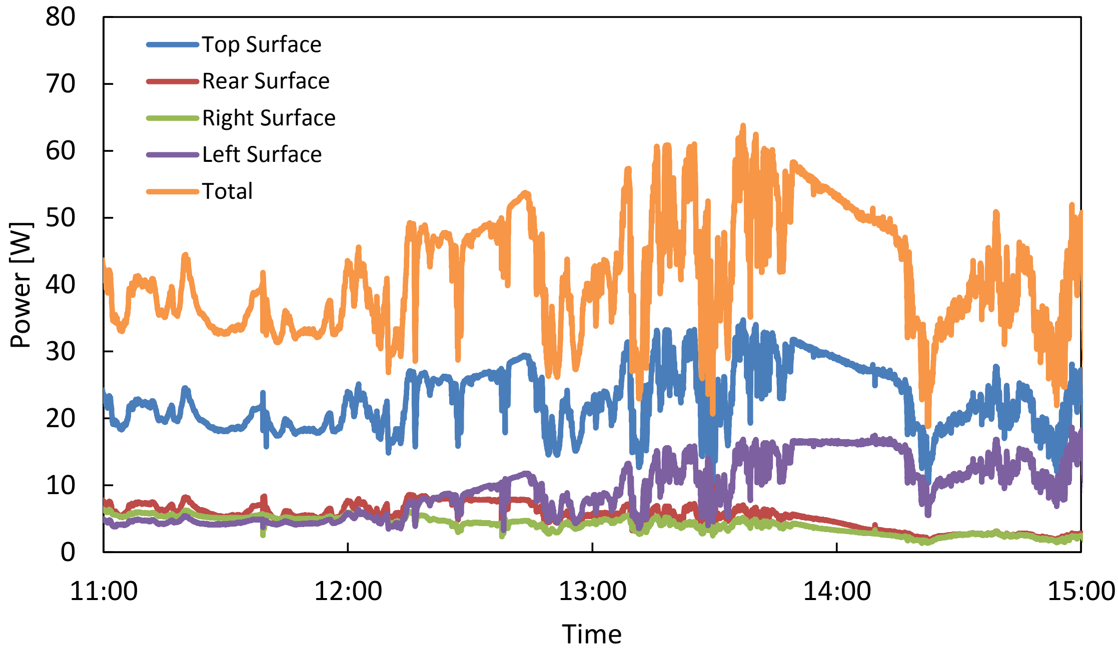


Fig. 7: Plot of the output power on 25-May 2018 for the four MPPTs

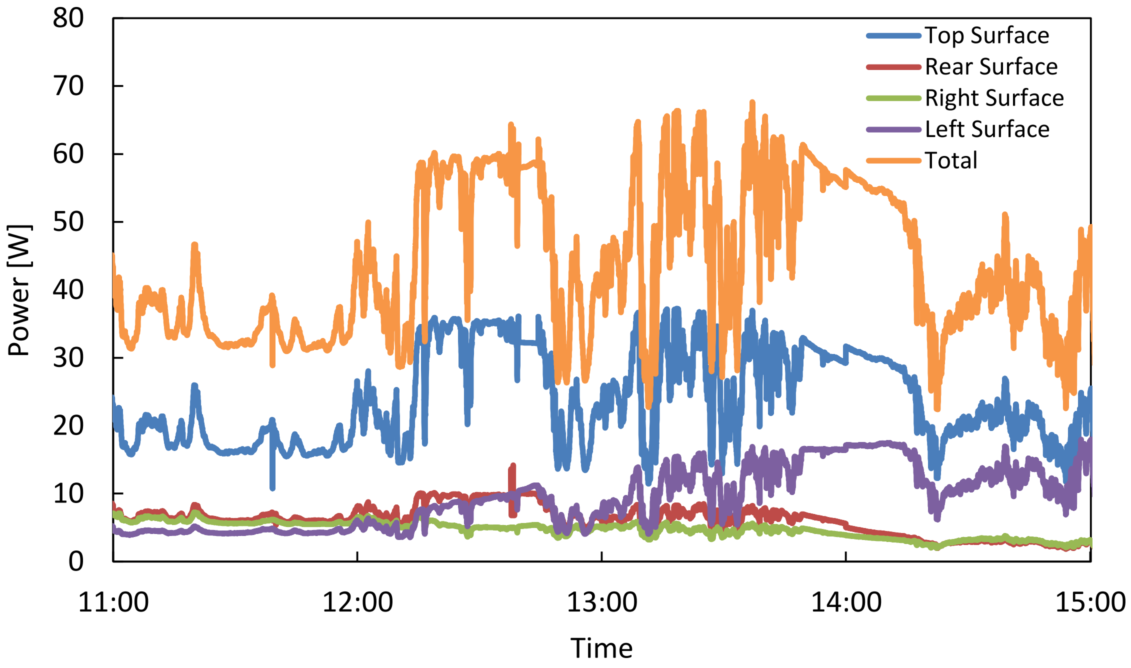


Fig. 8: Ideal output power on 25-May 2018 of the four MPPTs from the irradiance, I-V characteristic curves, and conversion efficiency.

Tab. 3: Accumulated horizontal irradiance and output power

Period	Horizontal Irradiance [Wh/m^2]	Output energy [Wh]
11:00 – 15:00 (4.0 hours)	2,763	167.2

3.3. Power Generation Efficiency

We now discuss the power-generating efficiency of the distributed MPPT system. If the MPPT is operated at the peak power point the entire time, the power-generating efficiency can be described by the irradiance, photovoltaic efficiency of the PV module, and DC-DC boost efficiency. Thus, the power-generating efficiency of the distributed MPPT system is defined by eq. 1.

$$\eta = \frac{P_{mppt\_out}}{AE} \qquad \text{(eq. 1)}$$

where η is the power-generating efficiency, P_{mppt_out} is the output power of the MPPT, A is the surface area of the PV module, and E is the irradiance on the surface of the delivery box. Fig. 9 shows the power-generating efficiency on 1-May 2018. Fig. 10 shows the power-generating efficiency on 25-May 2018.

In Fig. 9, there are points at which the power-generating efficiency changes rapidly. These rapid changes appeared when the voltage changed, which means that the operating voltage of the MPPT and DC-DC converter changes due to current limitations in the series circuit. On the top, rear, and right surfaces, the power-generating efficiency also decreases. The power reduction on the top surface is especially significant while irradiance is strong, and which the power-generating efficiency is lower than 5%. From this, a power-weighted average value does not exceed 10%. The low power-generating efficiency of the series–parallel MPPT system is assumed to be the result of power limitations of the top and rear surfaces.

In Fig. 10, large changes in power-generating efficiency occur less frequently, and no rapid breakdowns occur. The power generation efficiency is not lower than 5% on the top surface and the power-weighted average is stable around 10%. However, decreases in the power-generating efficiency arose in the top surface around 12:30. This is because the parallel connection of the MPPT for the right, left, and rear surfaces causes current summation, but this effect was insufficient due to the MPPT output current of the top surface. A decrease in the power-generating efficiency was partially avoided by adding current from the MPPT to the entirety of the vertical surfaces. Therefore, reducing the current difference in a series MPPT is required to increase the output power of a series–parallel distributed MPPT system. This can be achieved effectively by adding a parallel MPPT connection. Moreover, for a low-irradiance surface and a low-power-generating MPPT, it is possible to decrease the upper voltage limit of the boost ratio in a DC-DC converter to avoid decreased current in a series circuit. Another method by which to obtain commensurate output current from the MPPTs for each series connection is to equalize the solar energy and current such that the series MPPT system behaves like a voltage adder.

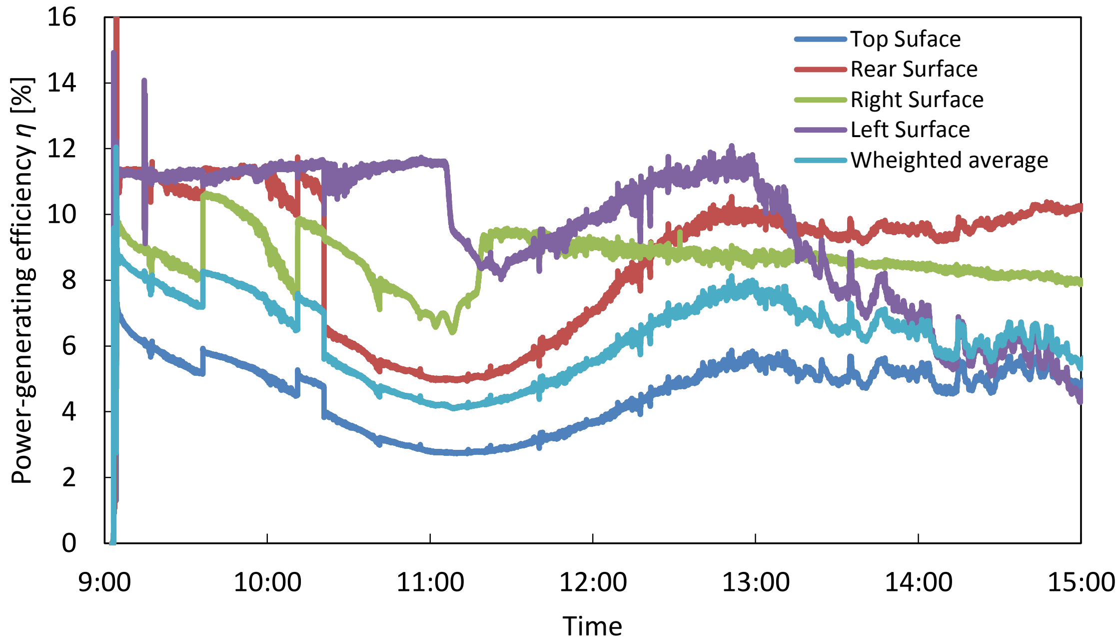


Fig. 9: Power-generating efficiency of the distributed MPPT system (left and right surfaces in parallel) on 1-May 2018

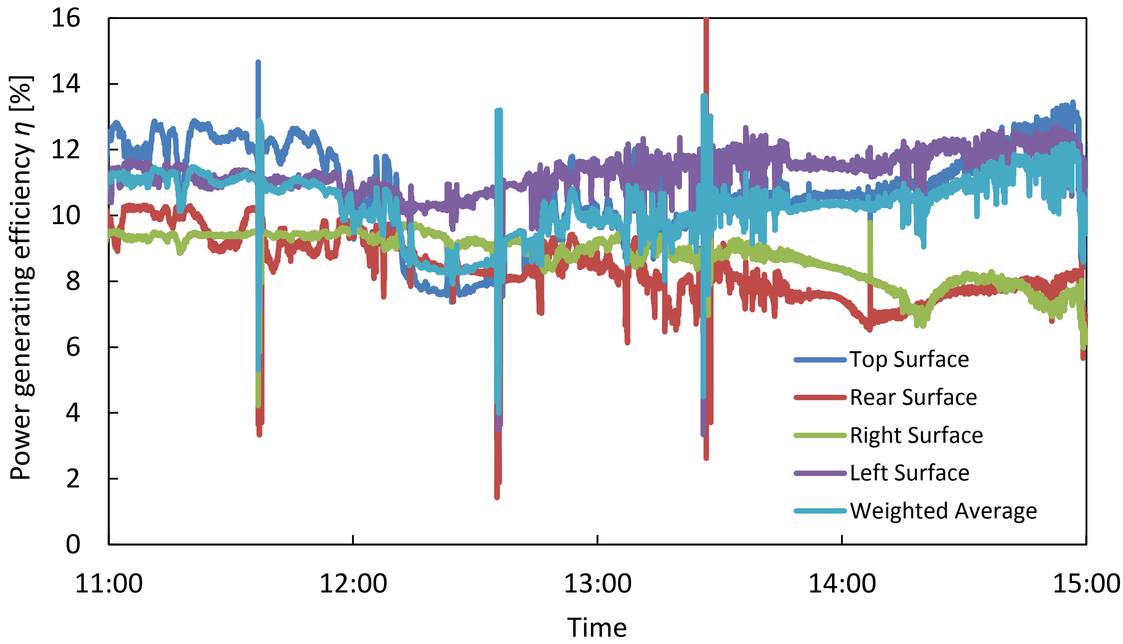


Fig. 10: Power-generating efficiency of the distributed MPPT system (left, right, and rear surfaces in parallel) on 25-May 2018

4. Conclusions

In this study, we discussed a distributed MPPT system for four surfaces on a cube-shaped delivery box of a solar EV. The results clearly indicate that differences in the currents lead to a reduction of output power of the top and rear surfaces in a series–parallel system in which the left and right surfaces are in parallel. As a result, solution methods for the problem can be proposed as follows,

- Adding photovoltaic current to equalize the output current for a series circuit.
- Optimizing the output voltage settings to level the output currents for a series circuit.
- In order to obtain more generated power, increase or decrease the area of photovoltaic module on each surface for adjusting input powers and output currents of the MPPT.
- Considering the change in transmittance and reflectivity of the PV modules with greater incident angle of the irradiance (Akihiko, 2015).
- Using by-pass diode against the partial shadow or uneven irradiance on the PV module.

5. References

Akihiko ITAGAKI, 2015. Revised Edition New Solar Energy Utilization Handbook, JSES, 3-39.

Takanori MATSUYAMA, et al., 2014. Experimental Introduction of Distributed Maximum Power Point Tracking Systems for PV Systems and Effect Applied to Solar Car, J. JSES., vol.40, 51-60.

Toru FUJISAWA, Takashi KAWAGUCHI, 2016. Performance Evaluation and Trial Making of Compact Solar EV, EuroSun 2016, Palma de Mallorca. DOI: 10.18086/eurosun.2016.08.05

BBC News, 6-July-2017, https://www.bbc.com/news/world-europe-40518293. Accessed 3-Sept.-2018.

Daniell Muoio, “These countries are banning gas-powered vehicles by 2040”, BUSINESS INSIDER, Oct. 23, 2017. https://www.businessinsider.com/countries-banning-gas-cars-2017-10/#norway-will-only-sell-electric-and-hybrid-vehicles-starting-in-2030-1. Accessed 3-Sept.-2018.

Dethleffs, 2018. e.home, https://www.dethleffs.de/pressebereich/bilder-reisemobile-2018/ehome/. Accessed 3-Sept.-2018.

EU, 2012. "Commission Regulation (EU) No 459/2012 of 29 May 2012 amending Regulation (EC) No 715/2007 of the European Parliament and of the Council and Commission Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)". Eur-lex.europa.eu. Retrieved 2012-06-01.

SONO MOTORS, 2017. Sion, https://sonomotors.com/sion.html/. Accessed 3-Sept.-2018.