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Solar Powered Ice Maker System in Karimunjawa Island, Indonesia

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Abstract. The solar-powered ice maker was developed in Kemujan, Karimunjawa island, Indonesia. It was powered by 6.66 kWp of solar PV, 19.2 kVAh battery storage, as well as 2 kW of solar ice maker machine, and connected into the utility grid (PLN). Solar energy is applied in this system to minimize utility grid consumption, which is produced by a diesel generator. The hierarchy of the energy supply was PV, batteries, and PLN, respectively. The system is capable to produce 180 kg of ice per production cycle, with a production cycle duration of roughly 20-27 hours. On cloudy days, the renewable energy penetration is around 15-19%. The COP of the ice maker machine is 1.02 and 1.45 for production cycle with ambient brine water temperature and low brine water temperature, respectively.

Keywords. Solar, ice maker, PV, battery, renewable energy penetration, COP

1. Introduction

Solar energy, as one of non-combustible energy takes an important role in the world's energy supply from the renewable energy sector, due to the sun's unlimited source. As shown in Figure 1, solar energy is the largest non-combustible energy sector. Earth receives huge amounts of incoming solar radiation each day. Thirty percent of this sun light is reflected back into the atmosphere, and the rest is absorbed by plants, sea water, buildings, etc. Solar radiation on the earth's surface is equal to almost 1,366 W each day [1]. This energy source can easily be converted into electricity without going through a power generation cycle. It can be directly used by photovoltaic (PV) cells or converted into thermal energy by using solar thermal collector.

The solar energy has been applied for some activities, both in the form of PV cells or thermal collectors. It has been implemented for electricity generation as PV power plant, for domestic or household use as rooftop PV and solar water heaters, and for productive use as well. Solar application for productive use is the application of solar energy to enhance the social economic aspect by giving service in agricultural, commercial, and public industrial activities [3]. It has been popular since it is deemed more useful for people with limited access to the electricity.

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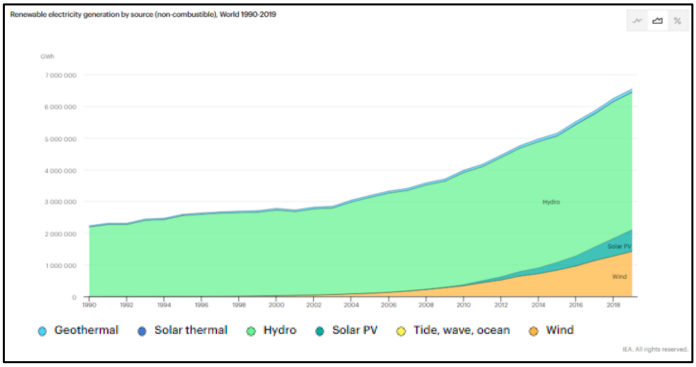

Figure 1. Total primary energy supply composition from renewable energy non-combustible process [2].

One example of the solar application for productive use is solar ice maker for fishermen in a rural area. The feasibility of utilization of solar energy as renewable energy to power the ice maker machine is questionable; therefore, the techno-economic analysis should be performed to identify the feasibility of this system implementation in Indonesia. One of solar ice makers that is being operated in Indonesia is located in Karimunjawa. Karimunjawa is the islands located in Jepara regency, Central Java Indonesia that consists by four inhabitated islands, e.g., Karimunjawa, Kemojan, Parang, and Nyamuk island. The total area of those islands reaches 71.2 km^2 with 9,514 population [4]. Most of the population works as active fishermen, while the rest are fishing periodically. The fishermen need tons of ice cubes each day for fish or seafood storage. There is a need to produce ice blocks as fish storage by ice maker machine. The ice maker machine needs high energy to operate, therefore it requires a huge electricity bill to operate the ice maker machine. Solar photovoltaic (PV) could become a solution to this challenge, since as a tropical area Karimunjawa has global horizontal irradiation of up to 1,818 kWh/m2 [5].

The solar-powered ice maker in Kemujan, Karimunjawa island, initially was developed by Ali. M, et al, [6]. The system used 5 kWp of PV and 3 kW biobased diesel engine generator as a power generator. Five kW bi-directional inverter regulated the power generator, 16 pcs of battery 100 Ah/12 V 5 kW, and the ice maker. The system produced 120 kg ice per 62.5 hours with a total energy requirement of 121.591 kWh. Indartono, et al [7] had connected the previous system with the utility grid and used a bio-based diesel generator as backup power. In this study, the system which was developed by Indartono, et al [7] is improved by increasing the PV capacity and implementing a gap between PV and roof to reduce the surface PV temperature.

2. Ice Maker Machine in Kemujan, Karimunjawa

The ice maker machine design is shown in Figure 2. The machine used the secondary refrigeration principle since it used brine water for water cooling inside the ice container. The machine consisted of the below components:

a. The brine water tank, for brine water cooling. The ice container was being submerged in the brine water for the cooling process. The brine water is used as a secondary cooling agent, with a 20% concentration of salt.

b. The ice container tank, contained 6 containers with 30 kg in each. There was baffle in this tank to help brine water circulation. The baffle configuration was shown in Figure 3
c. Refrigeration machine: compressor, condenser, and drier.
d. Pump, with the suction from brine water near ice container tank and the discharge flow into the outside evaporator coil. The pump was occupied to circulate the brine water, in order to accelerate the heat transfer and to prevent salt deposition.
e. Evaporator coil, to circulate the refrigerant inside the coil. The refrigerant used in the machine was hydrocarbon refrigerant R-290 (Propane).

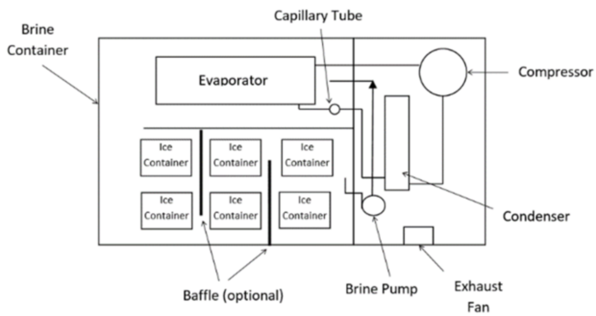

Figure 2. Ice maker machine design [7].

3. The Smart Grid System in Kemujan, Karimunjawa

The experiment in the Kemujan site was conducted to find out the system performance of smart microgrid systems and ice maker machines. The testing scheme was arranged as per Figure 3. The 4 strings monocrystalline PV (total 12 PV) 295 Wp and 3 strings polycrystalline PV 260 Wp (total 12 PV) were arranged and connected into a smart grid inverter 10 kW and battery. The national utility grid (PLN) was connected into the system in bypass connection, which means the utility grid does not take a part in battery charging in order to minimize the cycle use of the battery to lengthen the battery lifetime.

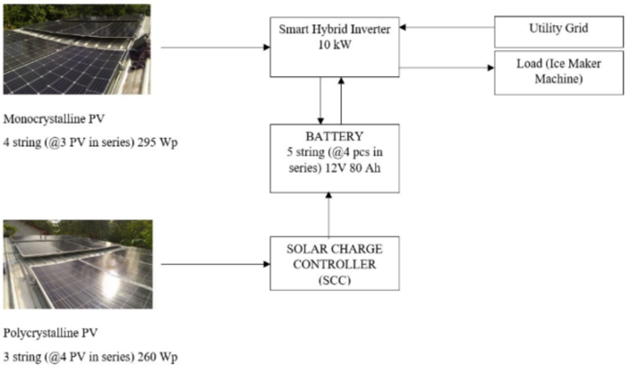

Figure 3. Real-scale testing at Kemujan site.

4. The Smart Grid System in Kemujan, Karimunjawa

4.1. Design Comparison

In this study, PV capacity was increased become 6.66 kWp (previous system was 5 kWp). Comparison between the new and the existing design is shown in Table 1.

Table 1. Design comparison of this study and the previous design.

Parameter	Previous Design [7]	This study
PV Capacity	5 kWp	6.66 kWp
Implemented Gap/PV tilt	0 cm / 10°	13.5 cm / 10°
PV Productivity	5.762 MWh/year	8.412 MWh/year
Cycle time	30 – 62.5 hours	20 – 27 hours

The PV productivity in a year was simulated by PVSyst software with considering the shading and geographical coordinate of the site. From Figure 4, the highest PV productivity is in August to September and the lowest is in December to January, since those months have a rainy season.

From Figure 4, the PV productivity in December is 0.489 MWh/month. In a day, the theoretical PV power output should achieve 15.77 kWh/day. The design simulation result would be utilized as a basic comparison with the real-scale experiment which explained in the next section.

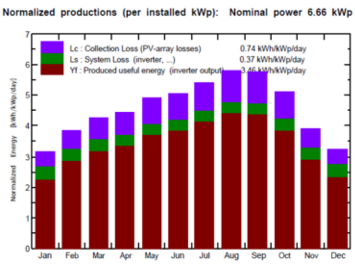

Figure 4. PV productivity prediction in a year of Kemujan site.

4.2. Supply Power Analysis of Smart-Grid System

During operation, several inverter operation modes occurred depending on the solar irradiance supply and battery power discharge rate. Since the operation used the SBU (Solar-Battery-Utility) set-up, the inverter will prioritize solar energy from PV. The second hierarchy is the battery supply. If solar energy is not sufficient, the battery will help to supply the loads at the same time. Utility grid (PLN) will supply the system if only if the battery and solar power are not adequate to supply the load. In addition, the charging mode tested during the operation was OSO (Only Solar) means that the battery was charged using solar energy only. It was chosen to minimize the battery cycle, in order to lengthen the battery shelf life. The following explanation describe the analysis of each operational mode.

a. PV Charge and Bypass
   This mode allowed PV simultaneously with the utility grid to power the load since the solar energy itself was not adequate to supply the load and the battery voltage lower than 56 V. This operation mode occurred when the weather was

cloudy with severe rains. The irradiance and PV power during this time was shown by Figure 5. The trend showed by PV power was following the solar irradiance entering the PV surface. During this operational mode, the battery voltage was floating in the value of 52-53 V shown in Figure 6.

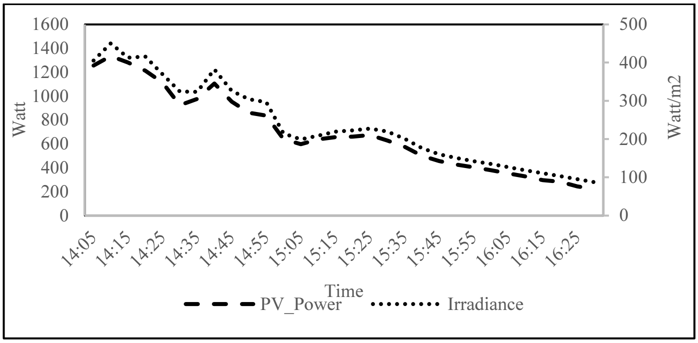

Figure 5. PV Power and Irradiance during the cloudy day (PV charge and Bypass operational mode).

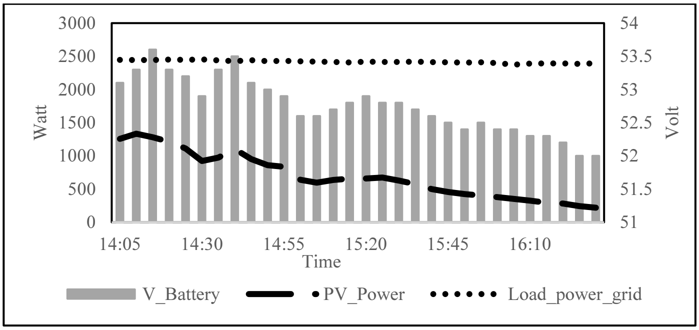

Figure 6. Supply power for the load during PV Charge and Bypass operational mode.

b. PV Charge and Discharge

This condition occurred when solar energy and battery simultaneously power the ice maker machine. The set-up for battery discharging voltage was 44.8 – 56 Volt. The battery started to discharge when the battery voltage was equal to 55.4, which is close to 56 V as voltage discharge set-up. From Figure 7, it could be seen that the PV power was higher than the ice maker load at some points. In this condition, the battery pause discharging and the load was fully supported by solar energy. The battery stopped discharging when its voltage was equal to 44.9 Volt, which is near to 44.8 as set-up discharge voltage.

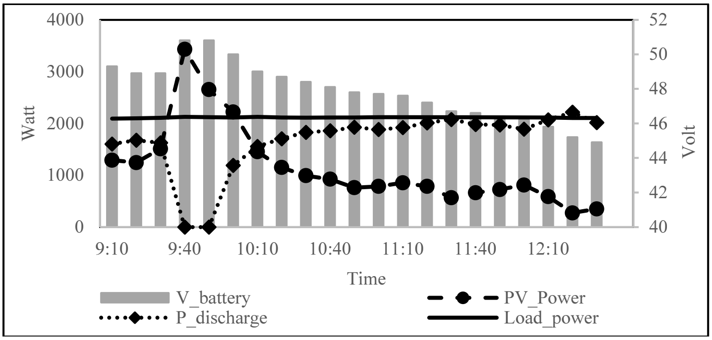

Figure 7. The supply power on PV Charge and Discharge operational mode.

c. Discharge
   The discharge operational mode occurred when there was no solar energy and the battery was fully charged, therefore it did not utilize the utilization grid electricity. This condition usually happens during the night operation. From Fig 8, it can be determined that the battery voltage was decreasing along with the ice maker machine operation. The actual battery voltage discharge range was 45.1 - 55.7 V.

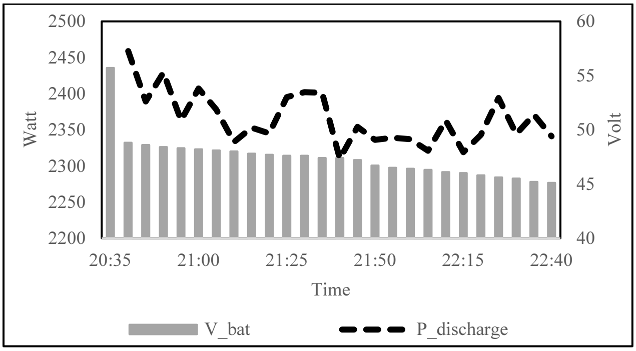

Figure 8. Battery analysis during discharge operational mode.

In the overall process, the interaction among PV, grid (PLN), and the battery are shown in Figure 9. The mode changed along the fluctuate of the battery voltage since the battery voltage indicates the battery state of charge.

The inverter efficiency evaluation shows that it varies with the operation mode. The values of each mode are shown in Table 2 below. Inverter efficiency has a higher value on the AC charge mode than during battery or PV charging. It is due to the power supply from the grid (PLN) does not need the conversion process, unlike what happens during battery charging or PV supply.

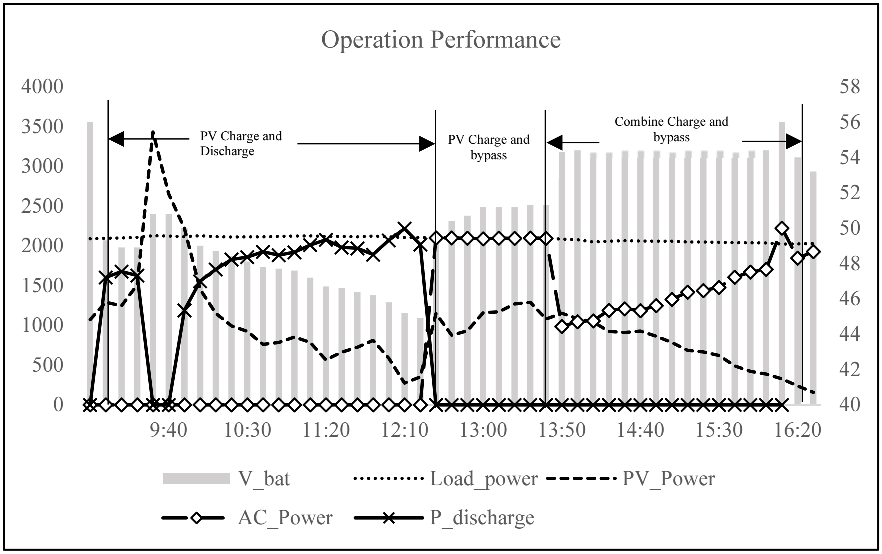

Figure 9. The interaction among PV, grid (AC Power), and Battery.

Table 2. Inverter efficiency based on operational mode.

Operation Time	Operation Mode	Inverter Efficiency
Morning-afternoon	PV Charge and Bypass	76.5 %
	PV Charge and Discharge	77.65 %
Evening	AC bypass + Battery discharge	91.28%

4.3. Energy Analysis of Smart-Grid System

The energy analysis of both ambient temperature and low temperature of brine water is shown by below table.

Table 3. Energy supply summary of ice production cycle.

Parameter	Ambient brine water temperature	Low brine water temperature
Grid electricity used	52.94 kWh (IDR 76,476)	42.4 kWh (IDR 61,261)
Load total	60. 39 kWh	43.97 kWh
PV productivity total	12.19 kWh (19% of total energy)	7.4 kWh (15% of total energy)
Production time	27 hours 10 minutes	20 hours 45 minutes
Total inverter efficiency of system	94 %	88%

From the table above, it can be concluded that the PV can contribute 15-19% of the load electricity needed. The PV productivity in Table 1, mainly for ambient brine water temperature, was close with simulation results by using PVSyst. The selling price of ice production was IDR 120,000. Therefore, the net profit from one production cycle is approximately IDR 40,000 – IDR 60,000.

4.4. Performance of Ice Maker Machine

The experiment in Kemujan site was conducted in 2 different initial brine water temperature. The first production cycle utilized ambient brine water temperature, while the second cycle is using the lower temperature of brine water since it was already cooling down from the first cycle. The latent phase of these 2 production cycles was taking approximately 18-19 hours. The total duration of the ambient brine water production cycle was taking 27 hours 10 minutes, while the low brine water production cycle had a 20 hours 45 minutes duration. Figure 10 shows the ice block product. Overall, the ice block product has a good quality and is acceptable for fishery grade.

Figure 10. The ice block production (total 6 ice blocks).

Ice maker machine in Kemujan site has 2 kW compressor power. The performance calculation is stated as COP (Coefficient of Performance) or the ratio between refrigeration capacity and the compressor power. The refrigeration capacity is calculated from heat transfer absorbed by the evaporator from the brine, while the compressor work was measured using kWh meter. The COP of the cycle with ambient brine water temperature was 1.02, while the second cycle (low brine water temperature) produced a lower COP of about 1.45.

5. Conclusion

The existing solar-powered ice maker from previous research was improved by increasing the PV capacity. During the cloudy situation, solar energy could provide around 15-17% of total energy. Some different operation modes were applied during the experiment. The PV, utility grid, and battery were working simultaneously to supply the load. The system could produce 180 kg of ice block for 27.16 hours when the water is started from the ambient water temperature. The shorter duration of ice production occurred in the low brine water temperature, which only needed 20.75 hours of production time. The COP of ice maker machine is 1.02 and 1.45 for ambient brine water temperature and low brine water temperature, respectively.

Author Contributions

Indartono, Y.S. design the system & experiment and finalize the manuscript. Mustikaningtyas, A. did experiment on smart grid and ice maker performance, and also prepare the manuscript.

References

[1] Mohd RSS, Santosh BW, Suvarna SL, Pooja VF, Anil T. A review paper on electricity generation from solar energy. International Journal for Research in Applied Science & Engineering Technology. 2017 Sep; 5 (IX):1884-9.

[2] Renewable Energy Generation from the Source (Non-combustible), get the data from IEA Data & Statistics is accessed via https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20supply&indicator=RenewGenBySource on 07 Nov 2020.

[3] Photovoltaic for Productive Use Application, implemented by GIZ. Downloaded via https://energypedia.info/images/archive/9/98/20160610130718%21GIZ_%282016%29_Catalogue_PV_Appliances_for_Micro_Enterprises.pdf on 07 Nov 2020

[4] BPS Kabupaten Jepara (2018): Kecamatan Karimunjawa dalam Angka 2018. BPS Kabupaten Jepara ISSN 2614-9036.

[5] https://globalsolaratlas.info/map?c=-5.879626,110.432907,11&s=-5.879626,110.432907&m=site accessed on 01 Feb 2020

[6] Ali, M. (2018): Design and development of smart micro grid system based on renewable energy for fishermen's ice maker machine, Master's Thesis, Institut Teknologi Bandung.

[7] Yuli Setyo Indartono, Musfirin, Aldrin (2021): Development of smart micro grid to operate ice maker in remote island in Indonesia, Conference Proceedings ASEAN Energy Transition with Resiliency in the Post-Pandemic Climate Change Era, the 1st ASEAN International Conference on Energy and Environemt, 15 September 2021 – Virtual Conference.