Application of a solar photovoltaic system to artisanal fishing products freezing in Peru

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Abstract. An experimental study has been carried out to reduce the costs of freezing products from artisanal fishing in Peru using a photovoltaic solar system. The refrigeration chamber and the photovoltaic system have been equipped with electrical sensors to determine the cooling efficiency and thus calculate the savings. The results indicate that it is possible to reduce costs up to 45% using photovoltaic solar energy. The target users of this technology are artisanal fishermen in Peru. Using photovoltaic energy for freezing would allow them to add value to their products and improve their selling price. In this way, fish commercialization can be performed in better sanitary conditions and at fair prices.

1 introduction

A country's development is directly related to the availability and consumption of energy. Electricity is a key element for economic and social development: without electricity the global economy would not function. In recent years, the reduction of "energy" poverty and greater access to energy for the population have become of utmost importance in public policies [1]. This research study addresses the main problem of high electricity consumption and associated costs to freeze artisanally fished products, mainly dolphinfish, which influences the final selling price [2] [3] [4] [5]. During the dolphinfish fishing season, the price per kg is low, causing important economic losses for artisanal fishermen. During this period, in average 6 tons of dolphinfish can be fished and transported in artisanal vessels. After arriving to the port, it is necessary to quickly sell the product to prevent it from deteriorating over time. According to the National Institute of Statistics and Informatics (INEI), in 2017 the sales of frozen fish attained 149 400 tons, compared to 88 600 tons in 2014, which constitutes an increase of 68.6% [6] [7].

Likewise, this increase in sales has been followed by an increase of the installed capacity, which has increased by 12.9%, compared to 2014, currently attaining 8 964 tons per day [6] [8]. For artisanal fishermen it is not profitable to use electricity to freeze the fish and sell it later in times of scarcity due to the high electricity costs, consequently, fishermen must accept the price offered by traders at the port. Currently the price per kg ranges between 1.8 USD and 2 USD, but in fishing season it can cost as low as 1 USD per kg. In this sense, due to the lack of a freezing system, the product is dealt based on the supply at the port. In Peru, due to the studies carried out by the Peruvian Sea Institute (IMARPE), the Ministerial Resolution N° 245-2014-PRODUCE was issued establishing that the national open fishing season for dolphinfish (Coryphaena hippurus) would span from October 1st to April 30th [9]. During spring and summer this resource is fished intensively, and the exploitation decreases during autumn and winter [10]. This research study aims to demonstrate that fishermen can store the caught fish and freeze it (at -18°C to -20°C) using photovoltaic solar energy for 3 to 4 months to sell it later (during the closed season) and be able to negotiate for more reasonable selling prices [11].

The southern Peruvian city of Arequipa is a profitable option for the implementation of photovoltaic solar technology since it enjoys more than three hundred sunny days per year [12]. According to the Solar Energy Atlas of Peru, Arequipa has an annual average daily solar irradiation of 5.31 kWh/m^2, attaining peaks in February and November [12].

2 Experimental Model

The experimental model (Fig. 1) is made up of the refrigeration chamber (Fig. 2), the photovoltaic module (Fig. 3) and the measurement and parameter acquisition system.

The refrigeration chamber (Fig. 2) is made of stainless steel with a 5"-thick thermal insulation of expanded polyurethane. This prototype has a volume of 9 m^3, with a maximum capacity of 1000 kg of fish. It has a 6-kW vapor compression refrigeration system. The photovoltaic system is made up of 24 monocrystalline silicon panels of 280 W each (Fig. 3). A Fronius 10 kVA current inverter was used with two MPPT control systems. The

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photovoltaic arrangements were made so that the first MPPT had 4480 W and the second MPPT had 2240 W. K-type thermocouples were installed in the thermal load and inside the chamber. To monitor power, electrical sensors were installed (power, current and voltage.) The studied uncertainties are shown in Table 1 [13].

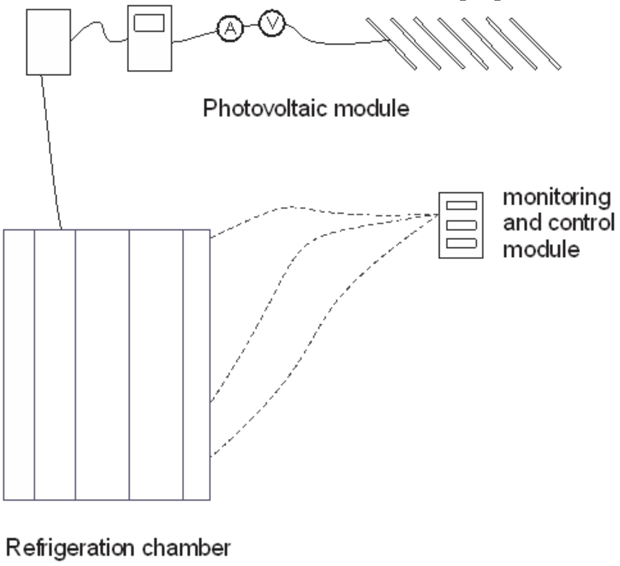

Fig. 1. Diagram of the Experimental Model.

Fig. 2. Picture of the refrigeration chamber.

Fig. 3. Picture of the photovoltaic system.

Table 1. Measurement uncertainties.

Parameters	Uncertainties, %	Reference
Electric current	0.5	Instrument
Voltage	0.1	Instrument
Temperature	2.5	Instrument
Electric power	0.5	$\left[\left(\frac{\delta I}{I}\right)^2 + \left(\frac{\delta V}{V}\right)^2\right]^{0.5}$

3 Results and analysis

The experiment was carried out in the refrigeration chamber with a thermal load of 200 kg. The experiment lasted 18 h, a period during which the thermal load was frozen to -18 °C.

Figure 4 shows the variation of the electric current over time, it can be seen that the DC electric current is a function of the photovoltaic power installed in each string. In the AC part, there are 3 currents which are very similar to each other.

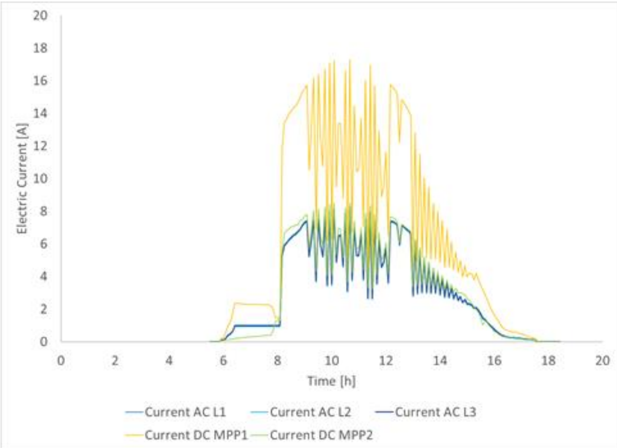

Fig. 4. Electric current.

Figure 5 shows the variation of the voltage as a function of time. It can be seen that in DC the voltage is defined according to the photovoltaic solar power. These values oscillate between 0 V and 280 V. In AC, the voltage remains constant at a value of 220 V. It can be seen that the inverter has the capacity to maintain a very stable output to guarantee the correct operation of electrical loads.

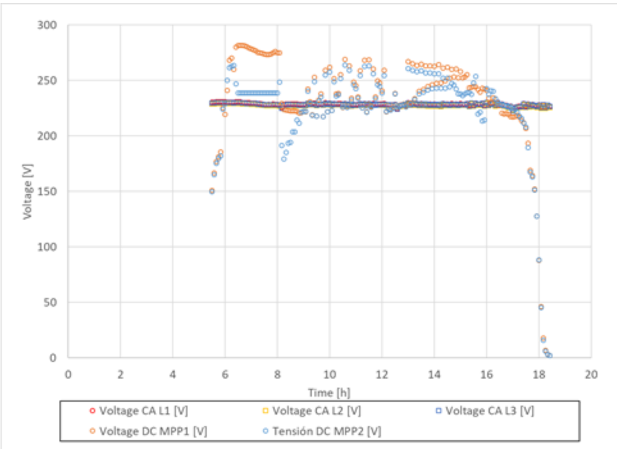

Fig. 5. Voltage.

Figure 6 shows the variation of energy and power factor as a function of time. In DC, it is observed that the energy produced by the photovoltaic system varies depending on the solar radiation. The energy in AC varies mainly depending on the electrical load. The power factor is kept at a constant value equal to 1 W/V A.

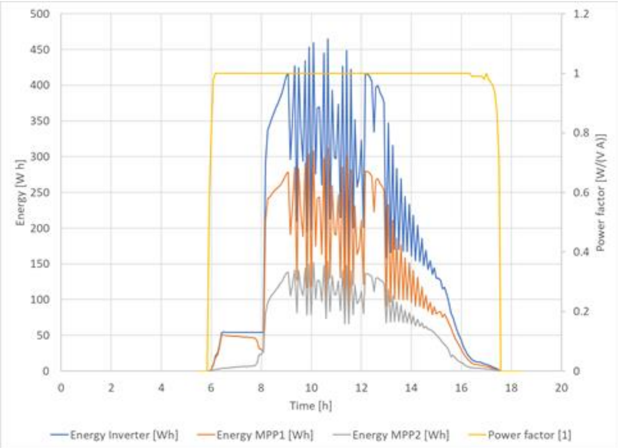

Fig. 6. Electric energy and power factor.

Figure 7 shows the variation of power and specific yield over time. The apparent power is very similar to the solar power produced because the reactive power is almost zero, which indicates the high quality of produced energy. The specific performance varies between 0 kW·h/kWp and 0.07 kW·h/kWp. This value indicates that the energy produced varies greatly depending on the maximum power, mainly due to the variation of the electrical load's consumption.

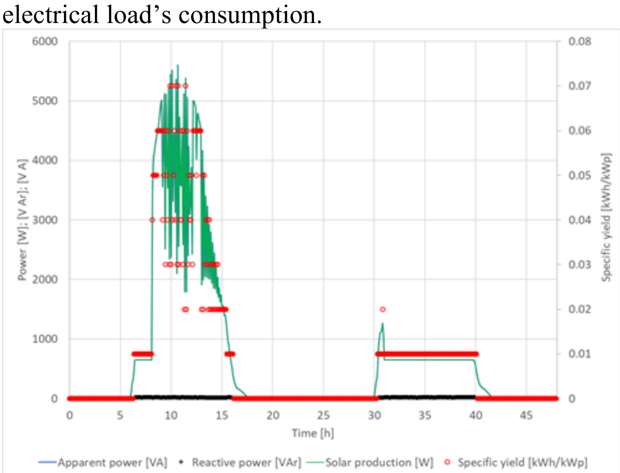

Fig. 7. Power and specific yield.

Figure 8 shows the variation of power as a function of time. Direct consumption occurs between 8 h and 16 h. In this period, there is also an energy input from the network. After 16 h there is no longer any photovoltaic solar generation, so the electrical load is supplied directly by the grid.

Figure 9 shows the energy that was directly consumed, the energy supplied by the network, the total consumption and the solar photovoltaic production. These values correspond to only one day. We can see that direct consumption is equivalent to 50 % of the total consumption, which would be as well a 50 % - costs saving for the operation of the refrigeration chamber. Solar photovoltaic production is slightly higher than the solar photovoltaic energy used in the chamber. This energy represents energy, the difference represents the unused solar energy.

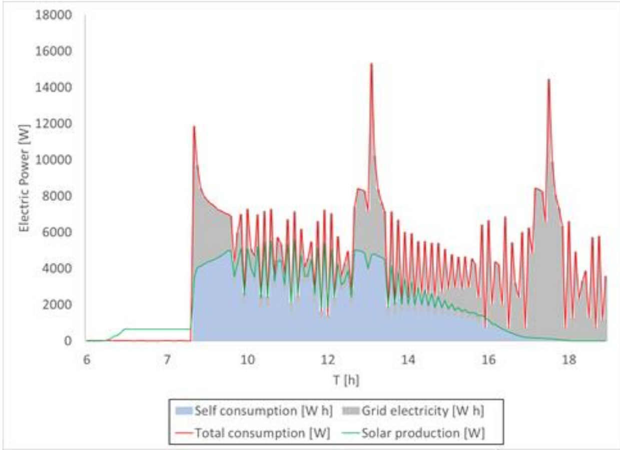

Fig. 8. Power and energy.

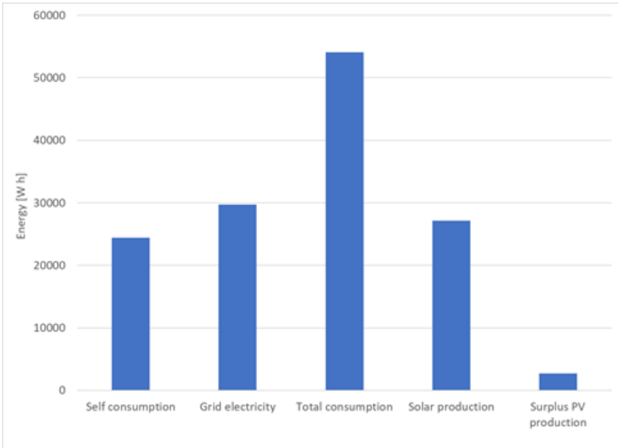

Fig. 9. Energy components.

Figure 9 shows that there is solar energy that has not been used that represents 5% of the production. Adapting the design for the freezing process could allow the use of the total photovoltaic solar energy to supply the electrical load and decrease the percentage of supply from the network. Another strategy would be to increase the photovoltaic solar power; however, this would lengthen the recovery time of the investment.

Artisanal fishermen in Peru suffer from a technological debt: the fishing processes and equipment they use date back to decades. It is necessary for them to start using new technologies that allow the reduction of costs, the improvement of the quality of the product they fish, which would be finally reflected in the increase of the selling price. Today, it is difficult to convince artisanal fishermen of the need to adopt new technologies since they prefer maintaining traditional techniques inherited from generation to generation.

4 Conclusions

An experimental study was carried out to evaluate the performance of a refrigeration system fed with solar photovoltaic solar energy. This technology could be used in artisanal fishing, allowing the product to be kept at low temperatures, giving it added value and guaranteeing its quality. Today, artisanal fishermen extract dolphinfish and sell it immediately at the selling price of the day. In certain cases, the selling price does not cover the fishing costs. The freezing process would allow the fish to be stored and kept in good conditions until the selling price is adequate and profit is ensured. This process could also allow the product to be exported to different countries, increasing profits significantly.

One of the most important conclusions is that the advantage of using this technology would only be proven if the freezing process is performed in sunlight hours to guarantee that costs are considerably reduced. If the freezing takes place at night, the refrigeration chamber would become a conventional chamber that uses all the energy from the electrical network.

It is important to highlight that the idiosyncrasy of fishermen does not allow yet the adaptation of new technologies to the fishing processes. This is change management that the Government must perform, which could set the base for sustainable and attractive artisanal fishing for future generations of fishermen.

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