On the Value Proposition of Battery Energy Storage in Self-Consumption Only Scenarios: A Case-Study in Madeira Island

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Introduction

This work presents a Techno-Economic assessment of the value proposition of introducing battery energy storage in the Madeira Island electric grid, where only micro-production for self-consumption is currently allowed.

The evaluation was conducted against two local micro-producers using one year of energy consumption and solar PV production measurements.

The assessments considered three different pairs of battery capacity/inverter size, and the outputs were analyzed considering self-consumption, self-sufficiency, and energy costs.

Madeira Island Electric Grid

Madeira is an archipelago in the North Atlantic Ocean, located about 1000 km southwest of mainland Portugal. It has a population of almost 270,000. 111,000 of which live in Funchal.

Madeira is a total energy island, and all the energy is generated locally by a single DSO/TSO (Distribution / Transmission System Operator). The DSO/TSO is responsible for the activities related to transport, distribution, and commercialization of electric energy, including buying electric energy that is produced by private micro and mini-producers.

In Madeira, since 2014, the DSO/TSO does not accept new UPPs (Unit of Small Production), and UPACs (Unit Production for Self-Consumption) are not allowed to inject the excess energy to the Public Service Electric Grid (RESP).

This happens due to the isolated nature of the electric grid that is very sensitive to intermittent and uncertain nature of the energy produced by RES (Renewable Energy Sources) [1].

Research Design

This paper uses one year of data from two local UPACs. The time-series measurements for solar PV production (P_{PV}) and power consumption (P_{Loads}) were taken from the metering infrastructure of each UPAC at the maximum sampling rate allowed by the installed smart-meters and averaged at the rate of 1 sample per minute (1/60 Hz).

Table I. Installation details of the UPACs considered in this work.

ID	Contracted Power (kVA)	Installed PV (kWp)	Year Totals		
			Consumption (MWh)	Production (MWh)	Possible SS (%)
A	6.9	1.5	4.92	2.133	43.36
B		3	3.709	3.029	81.65

Metrics

The following metrics were computed from the yearly consumption and production data:

- Power from the PV that is being consumed in real-time by the loads:

$$P_{PV\_Loads}(t) = \min(P_{PV}(t), P_{Loads}(t))$$

- Surplus power from the PV that is injected in the grid in real-time. Since there is no feed-in tariff for grid injection, this is considered wasted power:

$$P_{PV\_Grid}(t) = P_{PV}(t) - P_{PV\_Loads}(t)$$

Table II. Baseline results for the one year of data available.

ID	Production (% of total)		Consumption (% of total)		SC (%)	SS (%)	Cost			Optimal SS
	PV_Loads	PV_Grid	PV_Loads	Grid_Loads			No PV	PV	Diff. to No PV	(SC = 100%)
A	67.7%	32.3%	26.8%	73.2%	67.7%	26.8%	787.74€	561.88€	225.86€ (28.67%)	44.4%
B	51.9%	48.1%	40.0%	60.0%	51.9%	40.0%	593.97€	351.64€	242.33€ (49.8%)	81.65%

Table III. Simulation results for the one year of data available (5kWh BESS only).

ID	BESS	Production (% of total)			Consumption (% of total)			SC (%)	SS (%)	Cost	
	kWh/kW	PV_Loads	PV_BESS	PV_Grid	PV_Loads	BESS_Loads	Grid_Loads			PV + BESS	Diff. to PV only
A	5/0.75	66.08%	26.45%	7.47%	28.65%	9.75%	61.6%	92.53%	38.4%	485.23€	76.65€ (13.64%)
	5/1	66.08%	26.8%	7.12%	28.65%	9.86%	61.49%	92.88%	38.51%	484.37€	77.51€ (13.79%)
	5/1.5	66.08%	26.88%	7.04%	28.65%	9.81%	61.54%	96.96%	38.46%	484.8€	77.08€ (13.72%)
B	5/1	49.94%	31.47%	18.58%	40.78%	21.92%	37.30%	82.41%	62.7%	221.55€	130.09€ (37.00%)
	5/1.5	49.94%	32.0%	18.05%	40.78%	22.18%	37.04%	81.94%	62.96%	220.01€	131.63€ (37.43%)
	5/3	49.94%	32.20%	17.86%	40.78%	21.72%	37.50%	82.14%	62.5%	222.76€	128.88€ (36.65%)

- Power from the grid that is being consumed by the loads:

$$P_{Grid\_Loads}(t) = P_{Loads}(t) - P_{PV\_Loads}(t)$$

- Self Consumption:

$$SC = \frac{\sum_{t=1}^{T} P_{PV\_Loads}(t)}{\sum_{t=1}^{T} P_{PV}(t)} \times 100$$

- Self Sufficiency:

$$SS = \frac{\sum_{t=1}^{T} P_{PV\_Loads}(t)}{\sum_{t=1}^{T} P_{Loads}(t)} \times 100$$

- Total energy cost (after one year) calculated assuming the price of 0.16 €/kWh.

Simulations

SimSES (Simulation of Stationary Energy Storage Systems), an open-source modeling framework for simulating stationary energy storage systems developed in MATLAB at the Institute for Electrical Energy Storage Technology of the Technical University of Munich [2], was used, taking as input parameters:

1. Battery (Tesla Daily Cycle PowerWall battery and aging model):
   a) Capacity: 1 kWh, 2 kWh, 5 kWh and 10 kWh.
   b) State of Charge: 20% - 80%.
2. Power electronics (3 inverters):
   a) UPAC A: 0.75 kW, 1 kW, 1.5 kW.
   b) UPAC B: 1 kW, 1.5 kW, 3 kW.
3. Battery Operation Strategy (Greedy): storing excess production or supplying the excess demand.

From the simulator outputs $P_{Loads}(t)$, $P_{PV}(t)$, $Grid(t)$ and $BESS(t)$, new metrics were computed beyond the baseline metrics: $PV\_BESS(t)$, power from PV going to the BESS over time and $BESS\_Loads(t)$, power from the BESS going to the Loads over time.

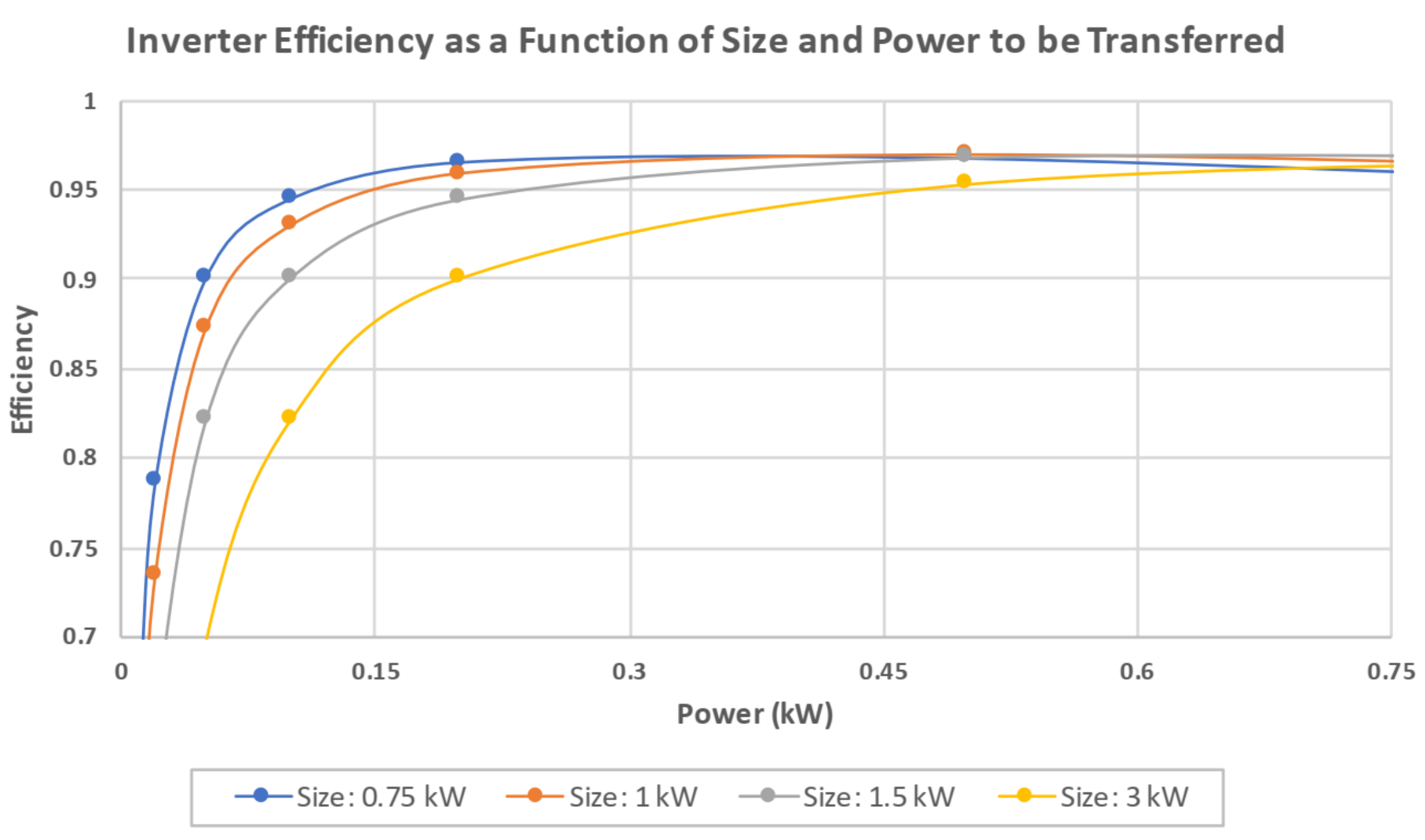

Figure 1. Inverter efficiency as a function of its size and the amount of power to be transferred.

Results and Discussion

In UPAC A there is only a difference of less than 3% in savings between the 5 kWh and the 10 kWh batteries, which represents less than 9€ after one year.

As for house B, the difference is higher, 9% to 13%, which represents about 40€ and 55€ in savings after one year, respectively.

Considering the differences to the smaller batteries, a 10kWh battery is overkill in both cases.

It is evident from the simulations that bigger inverters penalize the SS, despite an increase in SC (from 1 kW to 1.5 kW in UPAC A and from 1.5 kW to 3 kW in UPAC B). This suggests that inefficiencies affect discharge more than charge operations, where the amount of power to transfer is lower.

Conclusions and Future Work

In the current scenario of no grid-injection, BESS can help to improve the value of solar PV installations by increasing SC and SS.

It is evident that with the current prices of energy storage devices the payback times are far from acceptable. For example, even in the most optimistic forecasts that set the price of lithium-ion batteries at around 175 €/kWh by 2020 [3] it would still take between 11 years (UPAC A) and 6 (UPAC B) years to pay the initial investment of a 5 kWh battery.

Against this background it is safe to say that without additional value propositions, it is unlikely that the market will see wide adoption of BESS by the domestic sector in the near future. Consequently, more ambitious battery control strategies must be devised.

One limitation of this work is that it considers only the single-rate tariff, even though it is possible to choose from two additional Time-of-Use (ToU) tariffs. Thus, future work should also explore battery control strategies that take into consideration other billing models like ToU or even dynamic pricing.

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