Cost-Optimal Sizing of Residential grid-tied PV and Battery System

Anthony Kimanzi
ORCID: 0000-0002-6769-9616

1 ABSTRACT

This paper explores the integration of residential grid-tied PV (Photovoltaic) and battery storage systems to understand better the sizing of grid-tied PV and BESS (Battery Energy Storage System). For this purpose simulation model is for power build based on Photovoltaic Geographical Information System to determine PV power forecast and samples of energy consumption of a normal household in Austria for a period of one year in 15 minutes intervals is considered, the current cost of energy from the grid and current cost of the feed-in tariff in €/kWh is considered. Various PV sizes and Battery sizes are considered for this simulation. The effect of varying different PV sizes and battery sizes is analyzed to determine the cost-optimal system configuration. Self sufficiency(Autarky) and self-consumption are averaged to determine the cost-optimal PV and BESS configuration for a residential home.

2 INTRODUCTION

With the growing integration of grid-tied PV and BESS installation, there is a need to do proper sizing of the PV and of BESS to have the most cost-optimal system configuration that will be able to meet customers' demands. Proper sizing of the PV and BESS helps the customer to save on cost hence improving efficiency[1] by cost saving on resources.

This paper explores optimization based on energy cost and consumption, though other researches carried out, indicate that optimization of PV and BESS heavily relies on meteorological and technical elements, Khatib et al. explore optimal sizing of PV systems based on various approach on economic, environmental and technical details[2]. And adopt an Artificial intelligence algorithm to obtain the optimal configuration. According to Notton et al. They explore optimal sizing based on analyzing various inverter sizes for various PV optimization as they establish inverter efficiency curve is crucial for sizing of PV systems, they also rely on AI method (particle swarm optimization to determine the optimal configuration [3]. In this paper we have abstracted the meteorological and technical details and focused on energy assessment criteria based on self-consumption, self-sufficiency and battery cycles and economic energy assessment criteria based on mean electricity price and internal return rates for comparisons, as it is presented by Volker, Q et al [3]Weniger et al. of berlin university on optimal sizing of PV and BESS(Battery Energy Storage system)[4], and Hartner et al. Austria case study.[5]

This paper explores the option of using averaging of self-consumption and self-sufficiency to determine the cost-optimal PV Battery system for the clients. Previously related work by Weniger et al. [4] and Hartner et al. [5] are explored in the related work section of this paper. The graphs and of different outputs are provided in the result sections and detailed discussion on each of the graphs is provided to analyze this option. From the analysis of the results, a detailed conclusion is made in the conclusion of this paper.

3 RELATED WORK

For the sizing of PV and BESS related work has been carried out though it uses a different approach. In this paper, we explore Weniger et al., approach of using Mean electricity price and Hartner et al. approach of using internal Return rates.

Before diving further into this paper, we start by first demystifying the two crucial terms self-consumption[6] and self -sufficiency[6] in this domain of PV and BESS usage. Self-consumption[6] refers to the share of self-used electricity from the energy produced from the PV. Self-sufficiency[6] also referred to as Autarkiegrad refers to the share of self-used electricity in the total energy consumption per year. The higher the degree of self-sufficiency the higher the independence[7]. The independence, in this case, refers to less over-reliance on the energy from the grid.

3.1 Energy Assessment Criteria

Self consumption(s) [6], [4]

$$s = \frac{E_{\mathrm{DU}} + E_{\mathrm{BC}}}{E_{\mathrm{PV}}} \tag{1}$$

Self sufficiency(d) [6], [4]

$$d = \frac{E_{\mathrm{DU}} + E_{\mathrm{BD}}}{E_{\mathrm{L}}} \tag{2}$$

Number of storage cycles(n_{c}) [4]

$$n_{\mathrm{c}} = \frac{E_{\mathrm{BD,DC}}}{E_{\mathrm{UB}}} \tag{3}$$

E_{DU}- direct consumption
E_{BC}- energy used for charging the battery
E_{PV}-PV production
E_{BD}-Energy discharged from the battery
E_{L}-Total energy demanded by the premise yearly

Self-consumption rate decreases and the degree of self-sufficiency rises with an increasing PV system size. But with larger sized PV systems the degree of self-sufficiency tends to saturate since more PV surpluses occur that cannot be used simultaneously. Both assessment criteria are usually raised by increasing battery size.Quaschning [7]

3.2 Economic Assessment Criteria

3.2.1 Mean electricity price.

To carry out an economic assessment the Weniger et al.[4] use the annuity method to determine to mean electricity price, and the system with the lowest mean electricity price corresponds to the cost-optimal system. The annuity describes the annual payments of investment including interest charges and repayments for amortization of the investment within a defined period.

Annuity factor (a)

$$a = \frac{r}{1 - (1 + r)^{-n}} \tag{4}$$

r-rate n-Period of investment

PV investment(C_{PV})

$$C_{\mathrm{PV}} = I_{\mathrm{PV}} \cdot P_{\mathrm{PV}} \cdot (a_{\mathrm{PV}} + o_{\mathrm{PV}}) \tag{5}$$

I_{PV}-cost of PV
P_{PV}-size of the PV

Battery investment(C_{B})

$$C_{\mathrm{B}} = I_{\mathrm{B}} \cdot E_{\mathrm{BU}} \cdot (a_{\mathrm{B}} + o_{\mathrm{B}}) \tag{6}$$

I_{B}-cost of battery
E_{BU}-size of battery

Cost of energy from the grid(C_{GP})

$$C_{\mathrm{PV}} = I_{\mathrm{PV}} \cdot P_{\mathrm{PV}} \cdot (a_{\mathrm{PV}} + o_{\mathrm{PV}}) \tag{7}$$

p_{GP}-price of energy from the grid ($\frac{e}{kWh}$)

Returns of PV and BESS(R_{PV})

$$R_{\mathrm{PV}} = p_{\mathrm{PV}} \cdot E_{\mathrm{PV}} \cdot (1 - s) \tag{8}$$

Mean electricity price(p_{EL})

$$p_{\mathrm{EL}} = \frac{C_{\mathrm{PV}} + C_{\mathrm{B}} + C_{\mathrm{GP}} - R_{\mathrm{PV}}}{E_{\mathrm{L}}} \tag{9}$$

3.2.2 Internal Return Rates(IRR).

To determine the most configuration optimal configuration Hartner et al. [5] uses the internal rate returns and the system configurations with maximum internal rate of returns is the most optimal system.

$$\max_{x} IRR(x)0 = \sum_{t=0}^{T} \frac{R(x)_t - C(x)_t}{(1+IRR)^t} \tag{10}$$

x - PV system size [kW]
IRR - Internal rate of return [%]
R - Revenues and savings compared to a no investment case [€]
C - Costs compared to a no investment case [€]
t - Index for time period [–]
T - Total lifetime of the PV system [a]

$$\begin{gathered}\max_x IRR(x)0 = \\ -\left(c_{fix} + c_{va}x\right) + \sum_{t=1}^{T} \\ \frac{E(x)_t\theta(x)_t p_r + E(x)_t(1-\theta(x)_t)p_f - Opex_t \cdot x}{(1+IRR)^t} \\ s.t.: 0 < x < x_{\max}\end{gathered} \tag{11}$$

4 APPROACH

In this paper, we took the average of self-consumption (1) and self-sufficiency (2) of each system configuration and above the trend of how this average was changing with change with system configuration. This average we referred to it as the Optimality.

$$= \frac{selfconsumption(s)(1) + selfsufficiency(d)(2)}{2} \tag{12}$$

5 EVALUATION

In this paper we have used the following system configurations.

- Household consumption of 4000kWh per year
- PV RANGE- 1 to 15kWp
- Energy cost – 26 €/kWh
- Feeding Tariff – 9 €/kWh
- Hybrid Inverter
- Battery capacity – 9kWh to 40kWh
- Source of the data

We observe the following outputs and make comparisons

- Mean Electrity Price
- Optimality
- Amortization Period[8]
- PV Return on investments in Euros(€) for a period of 25 years
- PV and BESS investment in Euro (€)

6 RESULTS

6.0.1 Discussion.

By observing Fig. 1 we notice the values are not robust and no meaningful conclusion can be drawn from this mean electricity price. As the PV size keeps increasing the mean electricity price keeps decreasing, hence not robust enough to be used to size the PV AND BESS.

We notice an interesting trend in the optimality chart Fig. 2. The value of optimality starts from a lower value and as the value of PV size increases the value increases until it hits an optimal value where it starts decreasing with increase in PV size.Combining the observation in optimality chart Fig.3 which we observed that the amortization period doesn't show any significant change after the optimality value starts decreasing.The optimal point in this setup was PV of 4kWp and we notice after 4kWp there is no significant change in amortization period.

From Fig.5 we observe that the bigger the PV and BESS the bigger the investment.Hence it is unnecessary to have a big PV and BESS that u r not exploiting fully during these times of very low feed in rates. Fig.6 shows the effect of increasing the BESS without increasing the PV size.Increasing the BESS increases the invest cost and also a bigger BESS might not be fully exploited hence resulting to negative returns. Since after the highest optimality there no significant drop in amortization period, and from Fig.5 the higher the size of PV the

Anthony Kimanzi
ORCID: 0000-0002-6769-9616

MEAN ELECTRICITY PRICE

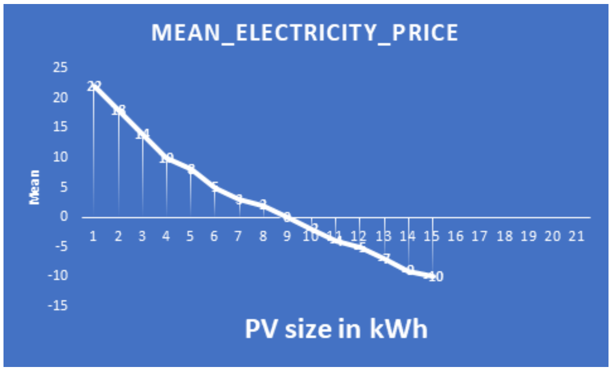

Figure 1: Mean Electricity Price

OPTIMALITY

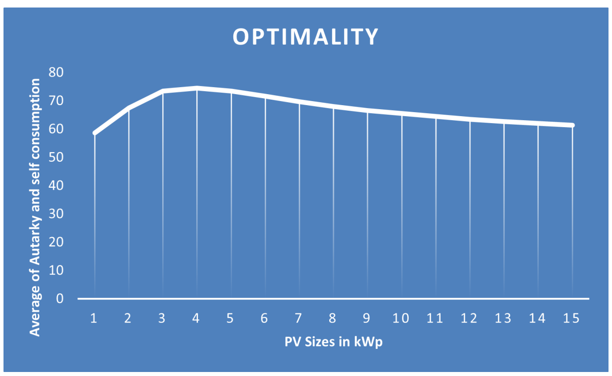

Figure 2: Plot of optimality against PV size in kWp

higher the investment hence around the highest optimality lies the cost optimal system configuration.

Figures.

AMORTIZATION PERIOD

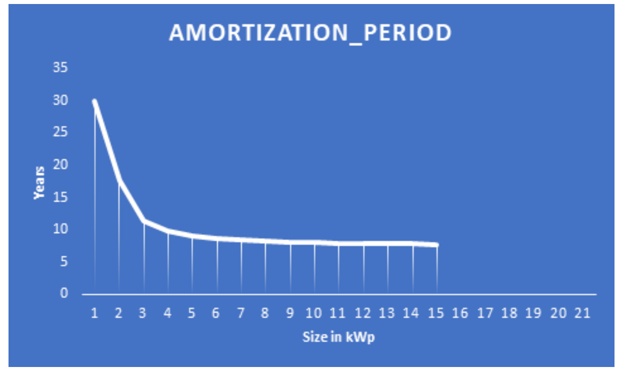

Figure 3: Amortization period in years

BATTERY OPTIMALITY

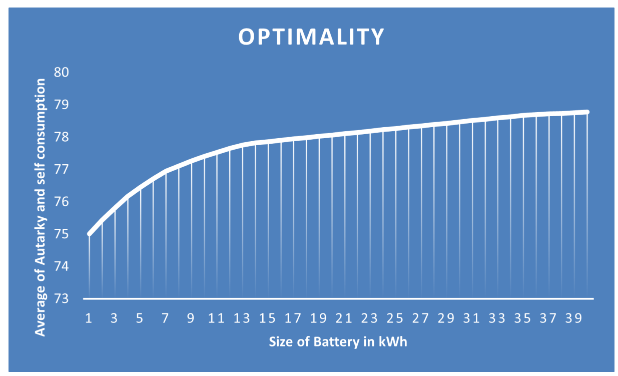

Figure 4: Plot of optimality against Battery size in kWh

TOTAL PV AND STORAGE INVESTMENT

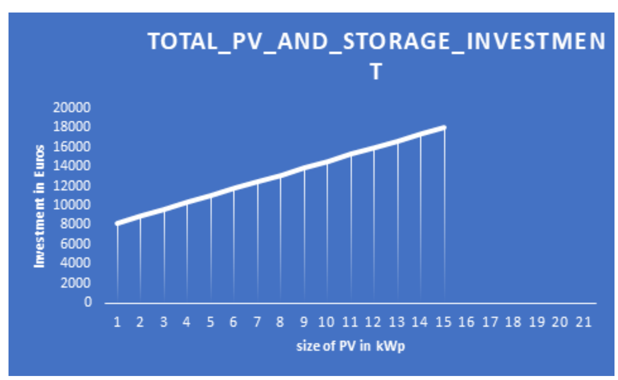

Figure 5: Total investment

BATTERY SIZING

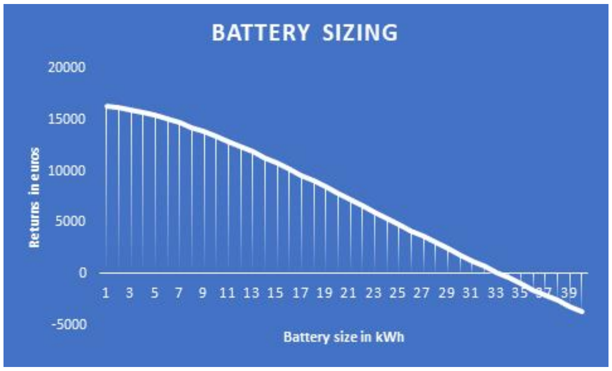

Figure 6: Varrying battery sizes

7 CONCLUSION

From our research, we establish that the cost-optimal is not the most profitable system. by getting the average of self-consumption and self-sufficiency we obtain the cost-optimal system configuration that ensures the customer fully exploits the system to avoid oversizing or under-sizing of the system. This also helps to ensure efficiency by saving the cost of resources[1].Factors like customers' budgets and roof size available also affect which system is best for the customer.

8 FUTURE WORK

This approach of combining the self-consumption and self-sufficiency to form optimality more robust when choosing a cost-optimal price for PV sizing. It less robust when the PV is coupled with the BESS as we have seen in the results; there is a weak correlation between the optimally value and the cost. For future work a more robust approach is required, that establishes a strong correlation when a PV is coupled with BESS and cost. More parameters can be considered to improve current work.

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