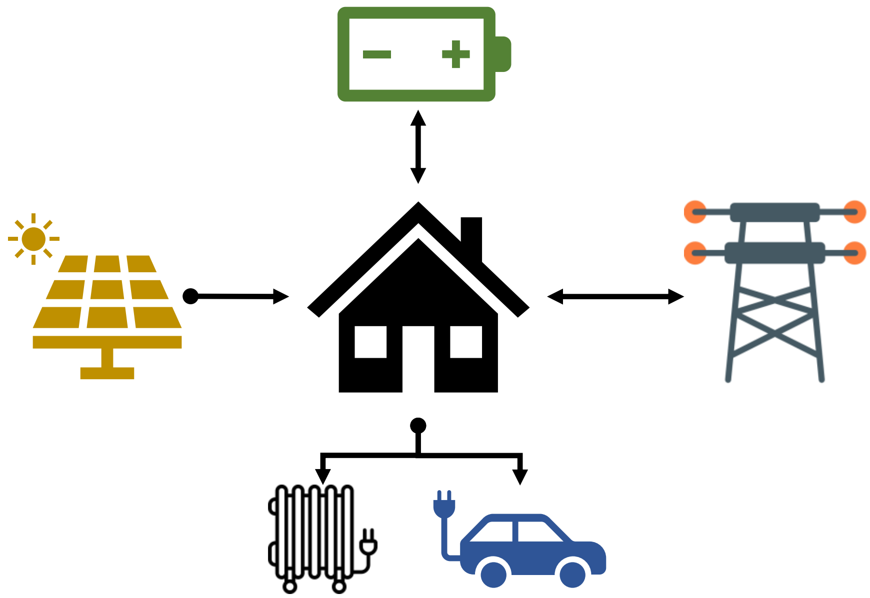
PV-BESS Tool (Analysis and Sizing tool for the small-scale PV/BESS)

Version 1.1 (01/2021)



This tool was validated and detailed in a submitted paper titled ‘A Comprehensive Robust Techno-Economic Analysis and Sizing Tool for the Small-Scale PV and BESS’, authored by Ahmed A.Raouf Mohamed, Robert J. Best, Xueqin Liu, and D. John Morrow. (publication details will be added soon)

EPIC Research Cluster
School of Electronics, Electrical Engineering and Computer Science
Queen’s University Belfast
Belfast, UK

This work is part of SPIRE 2 project (Storage Platform for the Integration of Renewable Energy), supported by the European Union’s INTERREG VA Programme, managed by the Special EU Programmes Body (SEUPB). The views and opinions expressed in this document do not necessarily reflect those of the European Commission or the SEUPB.

1. Introduction:

Small-scale battery energy storage systems (BESS) are attracting more customers due to their ability to achieve a profitable energy arbitrage in the presence of heat-pumps, electric vehicles (EV) and solar photovoltaics (PV) with time of use (ToU) tariffs in addition to maximizing the self-consumption and self-sufficiency. A comprehensive techno-economic analysis tool for the PV and BESS (PVBT) and PV/BESS sizing optimization algorithm are detailed in this document.

The repository contains two programs: 1) PVBT and 2) PVBTOptimization. The first one is for the analysis only, the second one is for the PV/BESS sizing optimization and analysis.

The PVBT tool utilizes a real-time BESS control method that aim to maximize the PV self-consumption and energy arbitrage that has been validated using real measurements in addition to integrating a rigorous ageing model to determine the loss in savings due to the capacity degradation. The PVBT outputs are:

1. The net household with and without the BESS.
2. Electricity bill with and without the BESS.
3. BESS power dispatch.
4. BESS state of charge.
5. Battery degradation and SoH.
6. PV self-consumption with and without the BESS.
7. Self-sufficiency with and without the BESS.
8. Power curtailed with and without the BESS.
9. Exported power to the grid with and without the BESS.

In addition to five cost benefit analysis (CBA) are conducted for:

1. CBA for the PV investment according to the lifetime warranty.
2. CBA for the BESS investment according to the warrantied lifetime.
3. CBA for the BESS investment according to the lifetime based on the minimum state of health (end of lifetime based on SoH).
4. CBA for the PV and the BESS according to the warrantied lifetime of the PV and the BESS.
5. CBA for the PV and the BESS according to the PV warrantied lifetime and the BESS lifetime based on the minimum state of health.

In the fourth and fifth CBAs, the total number of BESS replacement is determined based on the BESS lifetime and the year of the installation. Each of these CBA contains five metrics that are calculated in order to evaluate the investment viability: the total savings (TS), the investment net present value (NPV), annual return on investment (AROI), discounted payback period, and any required subsidy.

Two plots are developed after the program converges: 1) the net demand with the battery state of charge; 2) the battery degradation. The main results are printed in the command window and can be saved in excel file.

2. PVBT Guide:

The PVBT tool has two MATLAB files and two excel/CSV file, described as:

PVBT.m	Used to enter the tool inputs and run the PVBT.
MAINCODE.p	Main code file.
Inputs.csv	CSV file to enter the power profiles.
Results.xls	Excel template for the results. Results are saved in this file.

In order to run the code, the required inputs are detailed as follows:

- The power profiles should be entered in any data resolution in the file (Inputs.csv) in the following format:

Demand (kW) (first column)	PV (kW) (second column)	EV (kW) (third column)

  - One-year power profiles are required, and all values should be positive.
  - To add measurements of a heat pump, please add their values to the demand (sum) in first column or to the EV in third column. If there is no EV, just replace the EV column by zeros.

- Use PVBT.m, to run the code. The inputs for the (PVBT.m) are described as followings:

Main Inputs	
`SaveR`	To save the data in excel sheet: 1 will save in Results.xls, other values will not
`DataRes`	Data resolution in minutes: 10 for 10 minutes, 30 for 30 minutes, 60 for 1 hour
`Tariff`	Tariff structure, inside the tool three tariffs are given, choose one of them (FT for flat tariff), (DT for double ToU tariff), and (TT for three level ToU tariff) – tariffs can be adjusted using the **utility inputs**.
BESS Inputs	
`BESS`	Actual Battery Capacity [kWh]
`DOD`	Maximum depth of discharge in fraction (0 to 1)
`SOCMAX`	Maximum state of charge (0 to 1)
`BESSP`	Maximum rating of the BESS [kW]
`RE`	BESS System efficiency = BESS Efficiency ($\sqrt{roundtrip\ efficency}$) $\times$ Inverter/Charger Efficiency
`SOCI`	Initial value of SOC that the simulations will start with, default=minimum SOC
`SOHM`	Minimum BESS state of health (end of lifetime)
`FB` *(V 1.1)*	Fixed part of the BESS price that does not decline with years [£/kWh] (not affected by the `Dr`)
`BP`	BESS price [£/kWh] (affected by the `Dr`)
`LTY`	Warrantied lifetime [Years]
PV Inputs	
`PVSize`	PV rating [kWp]
`PVCost`	PV price [£/kWp]
`InvCost`	Inverter cost [£/kW]
`InvSize`	Inverter size [kW]
`PVdeg`	PV annual degradation rate [% p.a.]
`PVOM`	PV annual O&M cost as a percentage of the capital cost [% of CAPEX]
Utility Inputs	
`EXP`	Export power limit [kW]
`EX`	Export tariff rate in [p/kWh]
`SC`	Standing charge [p/day]
`SR`	Flat tariff value [p/kWh]
`HR`	High/peak rate value [p/kWh]
`MR`	Shoulder rate value [p/kWh] (for the three-level time of use tariff)
`LR`	Low-rate value [p/kWh]
`TLS`	Start hour of low-rate tariff
`TLE`	End hour of low-rate tariff
`TPR`	Tariff daily profile, please insert the values of high rate (HR) and low rate (LR) at each hour according to your preference.
Cost Benefit Analysis Inputs	
`YearI`	Year of installation

IR	Interest rate [%]
er	Electricity price annual growth rate [% p.a.]
Dr	Annual declining rate in BESS prices [% p.a.]
BESS Control Method Inputs: Threshold Rule-based Inputs	
PTHD	Upper threshold for discharging [kW]
PTHC	Lower threshold for charging [kW]
PCNS	A percentage of the BESS capacity to be charged during each season using low tariff rate to maximize the energy arbitrage. Set all values to zero if you don't want to use this feature

- The electricity and export tariffs are entered in British pence / kWh. However, it can be changed to different currency according to the country regulations and tariff structures. The export power, assumptions, parameters, and tariff profiles can be adjusted also according to specific preference.
- The main code content is obscured in the file (MAINCODE.p). This code will be revealed as an open source soon.

3. PVBT Sizing Optimization Guide:

The aim of the optimization formulation is to find the optimal sizes of PV only with or without BESS, BESS only in presence of PV, and PV with BESS sequentially. The optimization objective is to maximize the profitability through maximizing the net present value.

The PVBT sizing optimization tool has four MATLAB files and one CSV file, described as:

PVBTO.m	Used to enter the sizing tool inputs and run the PVBT sizing optimization.
BCM.p, MAINCODE0.p, MAINCODE.p	Main code files.
Inputs.csv	CSV file to enter the power profiles.

The power profiles should be entered in any data resolution in the file (Inputs.csv) as explained in the PVBT guide. Yet, for the PV generation profile, please insert a PV generation profile of a 1 kWp system for your location. (e.g. for a 4 kWp PV system, scale the data to 1kWp by dividing all the time-points by the system size (4kWp))

The PVBT sizing optimization require the additional following inputs:

OPTTY	Optimization type| **BPV**: find the BESS and PV sizes, **B**: Optimize the BESS size only, **PV**: Optimize the PV size only.
For the PV only (OPTTY:PV)	
LPV	PV Lower limit of the search space
UPV	PV Upper limit of the search space
BESS and BESSP	BESS capacity and power rating if there is a BESS, if there is no BESS, please leave these values as small as possible but not zero.
For the BESS only (OPTTY:B)	
PVSize	PV rating [kWp]
LPS	BESS Lower limit of the search space
UPS	BESS Upper limit of the search space
For the PV and BESS (OPTTY:BPV)	
Insert the values of LPV, UPV, LPS, and UPS	

- All the other inputs are similar to the PVBT inputs.
- The proposed sizing optimization adopts the NOMAD solver from the OPTI Toolbox. Please download and install the OPTI Toolbox from here (https://inverseproblem.co.nz/OPTI/index.php/DL/DownloadOPTI).

- The PVBT sizing optimization outputs are printed in the command window, then can be saved later as a pdf report. After determining the PV/BESS sizes, you can use these values in the PVBT and save the results in the excel template.
- The main code is obscured in the files (BCM.p, MAINCODE0.p, MAINCODE.p). This code will be revealed as an open source soon.
- More details on the work implemented in this code will be available soon through a published paper (see citation [1]).

4. Download and licensing:

The PVBT is available for free download from (https://github.com/ARa2of/PV-BESS-Analysis-Tool) This open-source simulation tool is published under the MIT-License.

5. Citations:

- If you will use this tool in work for a publication, please cite the following papers:

  A. If you used any part of this code, please cite this paper:

  [1]. A. A. R. Mohamed, R. J. Best, X. Liu, and D. J. Morrow, ‘ A Comprehensive Robust Techno-Economic Analysis and Sizing Tool for the Small-Scale PV and BESS ’, **(Publication details will be added soon)**

  B. If you used the PVBT sizing optimization, please cite the following papers in addition to paper number [1]:

  [2]. Currie, J., Wilson, D.I., Sahinidis, N. and Pinto, J., 2012. OPTI: Lowering the barrier between open source optimizers and the industrial MATLAB user. Foundations of computer-aided process operations, 24, p.32.

  [3]. S. Le Digabel, "Algorithm 909: NOMAD: Nonlinear Optimization with the MADS Algorithm," ACM Transactions on Mathematical Software 37(4), pp. 44:1 - 44:15, 2011

This PVBT utilizes the BESS degradation model described in this paper:

[4]. B. Xu, A. Oudalov, A. Ulbig, G. Andersson and D. S. Kirschen, "Modeling of Lithium-Ion Battery Degradation for Cell Life Assessment," in IEEE Transactions on Smart Grid, vol. 9, no. 2, pp. 1131-1140, March 2018, doi: 10.1109/TSG.2016.2578950

6. Contact Details:

For any inquiry or bug/issue reporting, please use the following emails: AARaoufM@gmail.com / amohamed06@qub.ac.uk