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Optimization of PV Battery Systems Using Genetic Algorithms

Dirk Magnor[a,b,c]*, Dirk Uwe Sauer[a,b,c]

[a]*Electrochemical Energy Conversion and Storage Systems Group, Institute for Power Electronic and Electrical Drives, RWTH Aachen University, Aachen, Germany*
[b]*Jülich Aachen Research Alliance, JARA Energy, Jülich/Aachen, Germany*
[c]*Institute for Power Generation and Storage Systems, E.ON ERC, RWTH Aachen University, Aachen, Germany*

Abstract

A modular simulation model of a PV battery system has been developed and integrated into a genetic algorithm framework in order to evaluate optimal sizing of such systems under various boundary conditions. The presented paper describes the simulation assumptions and presents optimization results for a PV battery system having a DC topology, comparing current economic scenarios with and without KfW funding. Sensitivity analyses provide information on critical boundaries to reach economic operation. The fitness of a system is evaluated based on the levelized cost of electricity (LCOE) defining the average cost – including all investment and operation cost over the system lifetime – per kWh supplied to the load.

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Keywords: PV, battery system, grid-connected, optimization, genetic algorithm, levelized cost of electricity

1. Introduction

PV battery systems gain increasing interest due to rising electricity cost and decreasing feed-in tariffs. Nevertheless, at the moment an economic operation of such systems is not possible when relying on self-consumption. Due to significantly decreasing installation cost, an optimally sized system can come close to economic operation when considering funding by the German market incentive program.

* Corresponding author. Tel.: +49-241-80-49312; fax: +49-241-806-49312.
E-mail address: batteries@isea.rwth-aachen.de

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Nomenclature

β	Tilt angle of the PV generator (Degree)
Δ_{Az}	Azimuth angle of the PV generator (Degree; zero towards south, pos. values towards west)
η	Efficiency (%)
A	Annuity (€)
c_{Bat}	Initial specific battery cost (€/kWh)
c_{el}	Initial electricity price (€/kWh)
c_{fi}	Feed-in tariff (€/kWh)
c_{PV}	Initial specific PV generator cost (€/kW)
Cap_{cell}	Battery capacity per cell (Ah)
d_{Bat}	Price degression of battery (%/a)
$E_{k,\mathrm{el}}$	Electric energy purchased from the grid in year k (kWh)
$E_{k,\mathrm{fi}}$	Energy fed to the grid in year k (kWh)
E_{load}	Annual energy demand of the household (kWh)
i	Interest rate (%/a)
i_{el}	Increase of electricity price (%/a)
I_{out}	Converter output current (A)
j	Index referring to a respective number of replacement of a component
k	Index referring to a respective year under consideration
l_{Bat}	Lifetime of battery (a)
l_{PE}	Lifetime of power electronics (a)
l_{PV}	Lifetime of PV generator (a)
$LCOE$	Levelized cost of electricity (€/kWh)
NPV	Net present value (€)
p	Proportionality factor for maintenance cost; same for all components (%)
$P_{\mathrm{bat\ conv}}$	Nominal power of the battery converter (kW)
P_{in}	Converter input power (kW)
P_{Inverter}	Nominal power of the inverter (kW)
P_{loss}	Converter power losses
P_{MPP}	Nominal power of the MPP tracker (kW)
P_{out}	Converter output power (kW)
P_{PV}	Nominal power of the PV generator (kW)
R_{loss}	Ohmic term of converter power losses (Ω)
T_X	Residual value of component X
SoC_{Min}	Minimum state of charge of the battery (%)
SoC_{Max}	Maximum state of charge of the battery (%)
t_{ref}	Reference time frame for cost calculation (a)
V_{loss}	Voltage term of converter power losses (V)
X	Index referring to a respective component of the system

The economic balance of system operation is strongly dependent on the given load profile and an appropriately matched system design with respect to battery and converter sizes, PV generator size and orientation but also the operation strategy of the system. On the other hand, for an appropriate system design the economic boundary conditions like capital cost, electricity price and feed-in tariff, investment cost for the system components but also funding schemes like the German market incentive program initiated by the German federal government and the KfW banking group, play a major role. An additional degree of freedom to influence the economics of PV battery systems is the operation strategy with respect to the battery, offering the potential to prolong battery lifetime.