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Energy management in storage-augmented, grid-connected prosumer buildings and neighborhoods using a modified simulated annealing optimization

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A R T I C L E I N F O

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A B S T R A C T

This article introduces a modified simulated annealing optimization approach for automatically determining optimal energy management strategies in grid-connected, storage-augmented, photovoltaics-supplied prosumer buildings and neighborhoods based on user-specific goals. For evaluating the modified simulated annealing optimizer, a number of test scenarios in the field of energy self-consumption maximization are defined and results are compared to a gradient descent and a total state space search approach. The benchmarking against these two reference methods demonstrates that the modified simulated annealing approach is able to find significantly better solutions than the gradient descent algorithm – being equal or very close to the global optimum – with significantly less computational effort and processing time than the total state space search approach.

1. Introduction

OUR ELECTRICITY production and supply system, having in the last 50 years heavily built on electricity generated by centralized fossil fuel and nuclear power plants, is about to be transformed into a distributed electricity generation system consisting of smaller-scale renewable energy producers like buildings equipped with photovoltaics (and optionally also storage) systems [1,2]. This massive structural change, accompanied by novel regulatory policies, brings along new challenges in terms of sustainable energy use [3–5]. In this context, the term "sustainable" can have different meanings depending on the concrete objective of the involved stakeholders. Examples for currently envisioned objectives are the maximization of the consumption of locally produced renewable energy, the achievement of energy autonomy, grid stability support, or a maximization of financial benefits [25–27]. Combinations of objectives are of course also possible. Each of these (sets of) objectives requires a particular "energy management strategy". Finding the optimal energy management strategy for each situation is however a task far from trivial and can massively benefit from computational assistance [6–8]. Optimization algorithms are an effective tool for identifying optimal strategies within complex energy management systems [9,10].

In the context of building and microgrid energy management, several computational optimization approaches have already been proposed in literature for different applications. [11] presents an optimization approach for the effective energy management of a HVAC system using a metaheuristic simulation-evolutionary programming coupling method. [12] proposes a particle swarm optimization approach to optimize a control system having the task to improve user comfort and save energy. [13] aims to match load consumption from heating, ventilation, and air conditioning (HVAC) with available energy from a hybrid-renewable energy generation and energy storage system. A genetic-algorithm-based optimization approach together with a two-point estimate method is used to minimize the size of the photovoltaics and wind generation installation as well as the storage capacity to supply the HVAC load. [14] describes a dual evolutionary programming approach for a power system in which software agents co-evolve optimal operational behaviors for a simple microgrid configuration consisting of photovoltaics and conventional energy production sources, a battery storage, and partly controllable loads. [15] uses a genetic algorithm for optimizing the control of a stand-alone hybrid electrical system to achieve cost minimization over system lifetime. The electrical system can include renewable resources (e.g., wind, photovoltaics, hydro), batteries, a fuel cell, an AC generator and an electrolyzer.

In this article, we propose a modified simulated annealing approach for finding optimal control strategies for energy management in grid-connected, PV-supplied, storage augmented

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prosumer buildings and neighborhoods in dependence of the objectives and goals of the involved stakeholders. To evaluate the performance of this approach, comparisons to a total state space search and a gradient descent method are provided for a range of different test scenarios aiming at an optimization of the local consumption of locally produced photovoltaics energy.

2. Materials and methods

2.1. System setup and challenge definition

Fig. 1 gives an overview about the topology of the system for which an optimal energy management strategy shall be found. It illustrates a neighborhood of six single-family houses in which each house consists of the following components: (1) a PV system, (2) a battery storage system, (3) household loads, (4) an interface to the neighbor buildings, (5) a grid connection.

The arrows between the building blocks indicate the principally possible directions of energy exchange within the system (in the further article referred to as possible "actions"), which are additionally summarized in Table 1. Table 1 furthermore lists the pre-conditions for the execution of each action. In Section 2.4, different test scenarios will be specified and it will be indicated which of the energy exchange options will be supported in each scenario. The task of the energy optimizer developed in this article will be to prioritize/rank this list of supported actions based on the specified objectives of the energy management system (see Section 2.5.1). Optimization will be carried out in a distributed fashion, meaning that for each building, a separate instance of the optimizer is implemented.

The action with the ID 1 "Do No More Activity" means that all further actions ranked after this one will be ignored and thus not executed. This can be useful if the execution of certain principally supported actions worsens the optimization result. The actions with the IDs 2, 3, 4, 5, 6, 13, and 14 concern energy flows within a building and from the building to the grid and vice versa. The actions with the IDs 7, 8, 9, 10, 11, and 12 concern energy exchanges between always two specific buildings within the neighborhood. To allow for such an energy exchange, the two corresponding buildings (the one that provides the energy and the one that consumes it) first have to negotiate and agree on this energy exchange (see also execution pre-conditions specified in Table 1). The communication necessary for this negotiation takes place via specific communication channels between the buildings.

For our experiments, it was defined that for each action carried out, always the maximal possible amount of energy transfer is foreseen before the next action is considered. For the action "Own PV Energy to Own Loads", for instance, this would mean the following: If there is more own PV energy available than needed for the own loads, as much own PV energy is directed to the loads as necessary to cover their supply. Otherwise, if less own PV energy is available than needed for the own load supply, all available own PV energy is directed to the own loads. In analogy, for the action "Own PV Energy to Own Storage", this

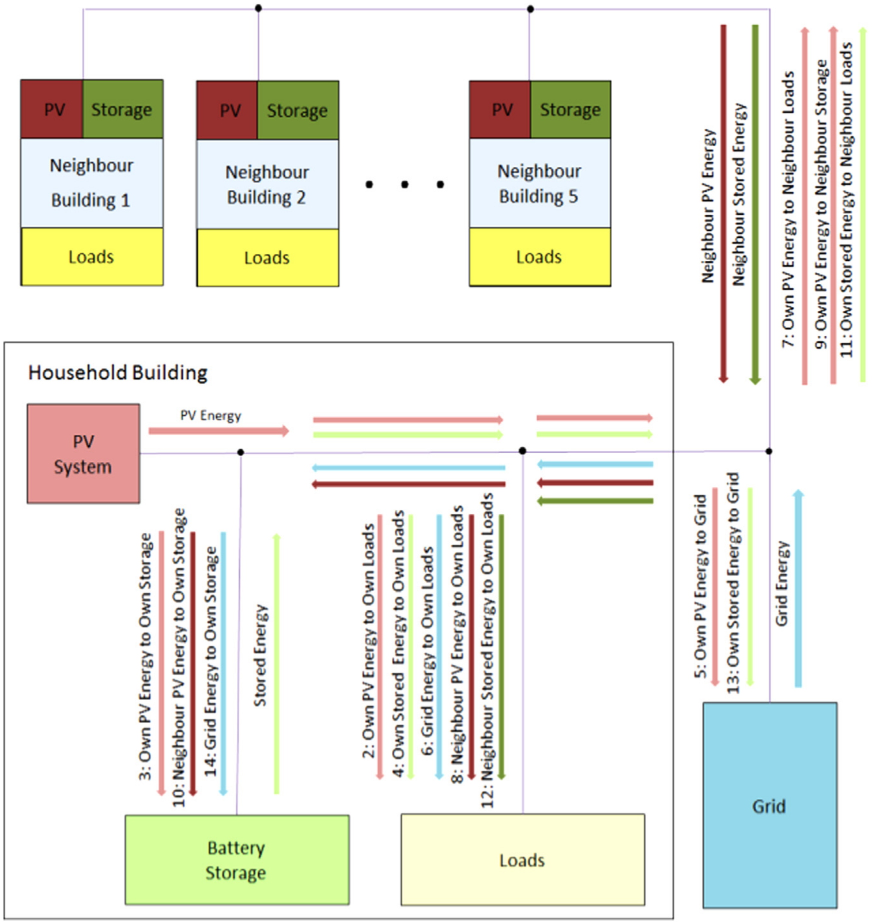

Fig. 1. Schematic overview of system topology of test setup including main building blocks and possible directions of energy exchange.