Sizing as a first step to local energy system integration

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Germany's transition to decentralized power systems has introduced new challenges in energy management. Fraunhofer IWES is exploring how to size and optimize local energy systems simultaneously, ensuring cost efficiency, system reliability, and effective integration of renewable energy and storage solutions.

Since Germany began its energy transition, the power system has increasingly shifted toward decentralization. Unlike the traditional system, which relied on large, central power plants, the modern system, with its high share of renewable energy, is built around a decentralized structure with distributed power generation. Additionally, energy storage units are playing a growing role, helping to balance the intermittent nature of renewable energy with demand.

Energy storage systems inherently introduce a bidirectional power flow, adding complexity to the operation of distributed power generation. As operation impacts system sizing, at Fraunhofer IWES, we ask: is it possible to size a local energy system while simultaneously optimizing its operation?

What are local energy systems?

The shift toward a decentralized power system with distributed generation and storage requires viewing the power system as a network of interconnected local energy systems. A local energy system is made up of distributed energy resources such as renewable sources, storage systems, and local energy loads. By functioning as a single unit, it simplifies managing and optimizing local energy use.

These systems are designed to efficiently interact with other local energy systems and support the stability of the wider electrical grid. They can operate independently, like a microgrid, when needed, providing flexibility based on system demands. Local energy systems can work across various voltage levels of low, medium, and high, and incorporate different energy types, including chemical fuels, electricity, and heat. In essence, they integrate diverse energy resources and loads to improve local energy management and contribute to overall grid stability.

What are the challenges in local energy system operation?

The challenges in operating a local energy system are varied and span time scales from milliseconds to years. On the millisecond scale, issues mainly concern power electronic devices and their control. In systems with a high share of converter-connected resources, maintaining power system stability is a key challenge, which is being addressed through research on grid forming controller design.

On a timescale of seconds to hours, optimizing the operation, or dispatch, of the local energy system is essential. Current approaches for this, such as model predictive control, rely on model based controllers. Over longer periods, from hours to years, component degradation, like the health of a battery, becomes significant.

This longer time frame also involves the initial question of sizing the system components, based on either known or reasonably estimated power demand within the local energy system.

How can local energy systems be sized?

Sizing a local energy system requires creating a model of the system. A general model is beneficial for adaptability to various configurations. The model being considered includes generation, consumption, and storage units, with several key components. Wind turbines (WT) generate electricity from wind energy, while photovoltaic arrays (PV) convert solar energy into electricity. A battery energy storage system (BESS) stores excess energy to ensure reliability and stability.

Additionally, a hydrogen energy storage system (HESS) features an electrolyzer (Ely) that converts surplus electricity into hydrogen, storage tanks for the hydrogen (HST), and a fuel cell (FC) that converts the stored hydrogen back into electricity when needed. This system is designed to supply both electrical and hydrogen loads. This is shown in Figure 1.

The model operates in two main modes. In surplus power mode (SPM), when energy generation exceeds demand and all storage units are fully charged, excess power is curtailed using a dump load. Conversely, in deficit power mode (DPM), when energy generation and storage are insufficient to meet demand, load shedding is implemented to balance the system. In a grid connected

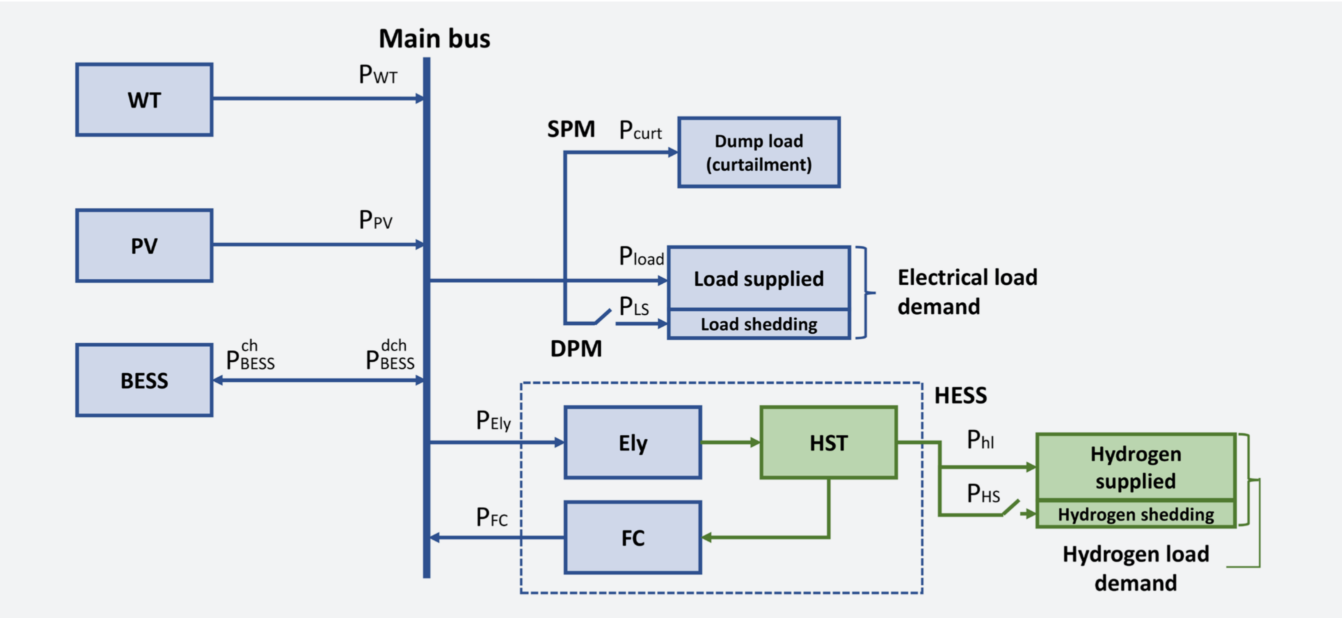

Figure 1

scenario, curtailment can be adapted as energy export to the grid, while load shedding corresponds to energy import from the grid.

To keep the model linear, certain assumptions are made: the efficiency of all energy devices remains constant across different operating conditions, and the energy and power capacities of these devices stay the same throughout the system's life cycle. The model's dynamics are reflected in the battery charge state and the hydrogen level in the storage tank.

To maintain energy balance at the main electrical bus, the model ensures that total load demand equals total generation and storage output. Operational constraints are applied to keep the state of charge and hydrogen levels within set limits, and ensure that power inputs and outputs adhere to maximum and minimum operational thresholds.

The key sizes to determine in this system include the rated power of the wind turbine, which represents its maximum possible power output, and the rated power of the photovoltaic system, indicating the peak output of the solar arrays. Additionally, the rated capacity of the battery energy storage system must be defined, representing the total energy the batteries can store.

Other important factors are the rated power of the electrolyzer, which indicates the maximum power it can absorb, and the rated power of the fuel cell, reflecting its maximum output capacity. Lastly, the rated capacity of the hydrogen storage tanks needs to be determined, which refers to the total energy they can store in the form of hydrogen.

Defining design constraints is essential for the optimal sizing of stand-alone local energy systems. Aiming for complete reliability can cause oversized and costly systems, so several indexes are used to establish practical constraints for the optimization process.

The Loss of Power Supply Probability (LPSP) measures the likelihood of failing to meet electrical load demand, calculated as the ratio of lost power to the total demand. Similarly, the Loss of Hydrogen Supply Probability (LHSP) gauges the probability of not meeting hydrogen demand, based on the ratio of hydrogen supply losses to total hydrogen demand.

These indexes help define a reliability index, which serves as an indicator of overall system performance and consumer satisfaction. The reliability index is the average of the LPSP and LHSP, offering a comprehensive assessment of the system's dependability.

This reliability index is balanced against the relative excess power generated, which represents the proportion of power curtailed compared to the load demand. By considering this metric, it is possible to prevent oversizing, ensuring that the system remains cost-effective while maintaining adequate reliability.

How can the operation and size of a local energy system be optimized at the same time?

The abstraction level, constraints, and objective function of the model are designed to enable a linear programming (LP) approach, allowing the problem to be solved with an LP solver. This requires transforming the problem into a matrix formulation, where the goal is to minimize a function subject to equality and inequality constraints, and bounds on the decision variables.

The decision variable vector includes both operational and sizing variables. The operational variables consist of battery charging and discharging, power of the electrolyzer, power of the fuel cell, load shedding, excess power, and hydrogen shedding. Each operational variable is assigned a value at every sampling interval, typically every 15 minutes over the course of a year. By discretizing the derivatives using the Euler forward method, recursive equations for system states can be developed, simplifying the formulation of state equations for each discrete time interval.

Inequality constraints are incorporated to ensure that all system states remain within their specified limits. This results in multiple constraints, such as those relating to the state of charge and power inputs. Two key design constraints are introduced: the first ensures the reliability index exceeds a minimum threshold to guarantee performance, while the second limits relative excess power to prevent surplus energy from exceeding set bounds. These constraints are applied at every time step, forming the necessary matrices for the LP formulation. Additionally, lower and upper bounds are set to limit the sizing variables based on user-defined preferences.

The objective function is the life cycle cost of the system. This approach allows for the simultaneous optimization of system sizing and operational variables, since the operation impacts the sizing decisions. At Fraunhofer IWES, we are developing a tool that can efficiently size local energy systems and optimize their operation in a single step, using advanced solvers to minimize life cycle costs while maintaining required reliability and controlling excess power.

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