

ABSTRACT

The objective of this doctoral dissertation was to develop and validate a proprietary control algorithm for energy storage integrated with renewable energy sources, forming a Hybrid Energy System (HES). The task of the developed algorithm, based on the proposed objective function, was to optimize the utilization of energy stored in the storage system for self-consumption or for exchange with the power grid, in order to achieve the highest electricity sales price. Both meteorological data and information on energy price volatility were used as input data.

For the optimization of the energy storage operation, a hybrid approach was proposed utilizing Long Short-Term Memory (LSTM) artificial neural networks and a Genetic Algorithm (GA) with a modified population initialization procedure. As initial conditions, the Genetic Algorithm uses the results obtained from a deterministic Rule-Based (RB) algorithm solution. The results demonstrate that this approach allows for the faster development of an optimal energy storage operation schedule within a Day-Ahead time horizon by eliminating the risk associated with the initial randomness of solutions.

To achieve the aim of the study, a mathematical model of a hybrid energy system composed of a photovoltaic installation, a wind turbine, an energy storage system, and a local load was developed. In the first stage, the effectiveness of the developed algorithm (GA) was compared with classic Rule-Based (RB) control. Real-world meteorological data and price dynamics with a 15-minute resolution for one full calendar year were used to conduct the simulations. Analysis of the obtained results showed that the application of the proposed genetic algorithm allows for achieving greater economic benefits compared to the RB method, even after accounting for storage degradation costs. Distinct benefits resulting from the increase in the number of storage charging and discharging cycles, caused by intelligent price arbitrage, were also demonstrated. This strategy is economically justified and significantly outperforms strategies based solely on maximizing self-consumption. The conducted sensitivity analysis showed that, in addition to meteorological data and energy price dynamics, the storage capacity and its State of Charge (SoC) at the end of the day are also key parameters that should be taken into account.

In the subsequent stage, a validation of the proposed control algorithm's operation was conducted using data collected from a real-world facility. In this case as well, the obtained results clearly indicate that the proposed proprietary scheduling algorithm leads to a significant increase in economic profits thanks to the possibility of implementing dynamic price arbitrage, which classic rule-based algorithms are unable to provide.

In this thesis, an electrical energy storage system was used to verify the operation of the developed scheduling algorithm. This serves as one example of the algorithm's potential applications, as the obtained research results unequivocally indicate that it is a universal tool that can be utilized to operate with any type of energy storage system.

