Electrical Energy Storage Optimization based on Predictive Control

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In the framework of the European project AMBASSADOR, an online optimization aims at reducing the operational costs (i.e. global electricity bill) by taking into account all electric power generators and consumption elements of the districts and taking advantage of storage elements. The same framework can also be used to reduce the installation cost of batteries by performing an optimal sizing. To reach that goal, Model Predictive Control (MPC) is applied. MPC relies on adaptive models that predict the energetic behavior (production and/or consumption) of the various elements. Extensive simulations on experimental data were carried out under various real conditions and showed where significant savings can be achieved.

Increasing use of intermittent renewable energy sources, such as photovoltaics (PV) and wind turbines, as well as the availability of versatile storage equipment, offers the possibility of reducing costs by optimizing the energy flow between districts and electricity grid [1].

The optimization is based on a Model Predictive Control (MPC) approach where the energy flow is optimized over a horizon of 24 h and updated every 15 min. In other words, the goal is to find the battery charge/discharge profile that minimizes costs over a 24-h horizon. The optimized control variable is the amount of charge or discharge of the battery. The main input variable is the aggregated energy, defined as the sum of renewable energy minus the sum of consumed energy, estimated over a 24-h horizon. The second input variable is the tariffs for buying from and selling to the grid, called TFG and TTG respectively. These tariffs can be variable (lower at night than in the daytime) or flat. Also, TTG can be equal to or different from (lower than) TFG. Third, the present state of charge of the battery storage is used as an input variable.

The optimization minimizes the resulting cost function, shown in Figure 1, taking into account efficiency factors and constraints. An extra constraint can also be added to avoid trading, that is, to prevent charging of the battery from the grid.

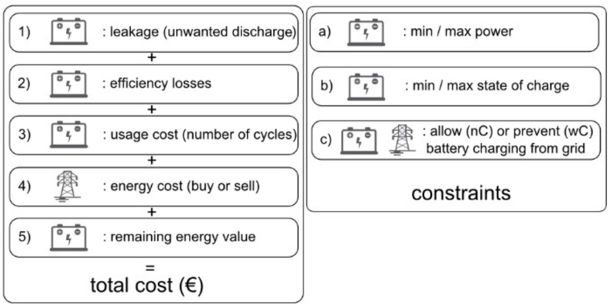

Figure 1: The different terms of the objective functions and constraints that are taken into account in the optimization problem.

Prediction models, based on Support Vector Regression (SVR) algorithms, estimate the production and consumption of the considered district elements. Prediction of renewable production, including PV and wind turbines, depends on the weather forecast (i.e. solar irradiance and wind speed) and time reference. Prediction of consumption elements, including houses, office buildings, and PMEs, depends on the weather forecast (i.e. temperature), working schedule, process planning, and time reference. Training of the SVR algorithm is done over the last 4–7 days with all available data.

This approach also makes it possible to optimize the battery size as early as the design stage, as illustrated in Figure 2.

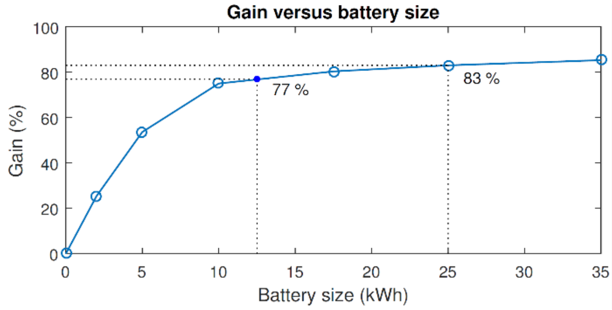

Figure 2: Optimization gain vs. battery size. When the battery size is halved from 25 to 12.5 kWh, the gain is reduced by only 6%.

In the following table, we qualitatively compare a solution without storage (NoSto) to two energy flow management strategies: simple storage (SimSto, acting as a buffer without optimization) and optimal storage based on MPC. For the latter we consider a version with no battery constraint (MPCnC), which allows trading, and a second version that prevents the battery from charging from the grid (MPCwC).

Table 1: Synthesis of various storage strategies and use cases.

	Variable Tariffs		Flat Tariffs		RoP
	Lo TTG	Hi TTG	Lo TTG	Hi TTG	
NoSto	☹	😐	☹	😐	☺
SimSto	☺	☹	☺	☹☹	☺
MPCwC	☺	☺	😐	☹☹	😐
MPCnC	☺☺	☺☺	😐	☹☹	☺

The results shown in Table 1 suggest the following conclusions:

- MPC shows significant advantages in the case of variable tariffs from and to the grid and is even better if trading is allowed.
- In the case of flat tariffs, MPC does not offer advantages compared to simple storage.
- Robustness towards Prediction errors (RoP) is average for MPCwC but rather good for MPCnC.

These conclusions were experimentally confirmed by the deployment of MPC strategies on a test site in Greece and with experimental data from the Swiss Energy Park.

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[1] Y. Stauffer, S. Arberet, M. Boegli, E, Onillon, "Centralized energy optimization at district level", EnergyCon 2016.