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Utilizing PV-battery systems with varying electricity prices

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Abstract

Solar water heating systems and photo voltaics are able to provide cheap heat and electricity. Unfortunately the time at which they do this is not decided by needs, but by the weather. For this reason people have started to equip solar panels with hot water tanks and batteries, in order to store the energy produced for when it is needed. We present the methodology for doing this in the case of varying electricity prices using Economic Model Predictive Control (E-MPC).

Objective

Consider a system consisting of a photovoltaic (PV) and a battery, which is also connected to the electrical grid. Utilizing the PV, battery and grid we are interested in fulfilling the demand for electricity in a household in the cheapest possible way. The prices for buying from the electrical grid varies with time as a consequence of varying costs of producing electricity and possibly to help grid operators stabilize the grid. One would like to operate the battery in a way such as to minimize the money spent on buying electricity. If this problem is considered for a time horizon of N then it can be formulated in the following way

$$\text{Minimize} \quad \sum_{k=1}^{N} \lambda_k g_k^- \tag{1a}$$

$$\text{s.t} \quad d_k = p_k + b_k^- - b_k^+ + g_k^-, \tag{1b}$$

$$b_k = b_{k-1} + c_B b_k^+ - b_k^-, \tag{1c}$$

$$0 \leq b_k \leq b_{\max}, \tag{1d}$$

$$0 \leq b_k^+ \leq b_{\max}^+, \tag{1e}$$

$$0 \leq b_k^- \leq b_{\max}^-, \tag{1f}$$

$$g_k^- \geq 0, \tag{1g}$$

where k is a time index. Equation 1a gives the total cost of fulfilling the demand for the next N time steps, since λ_k is the price of electricity while g_k^- is the amount of bought electricity from the grid at time k. Equation 1b expresses how the demand, d_k, has to be fulfilled by a combination of PV production, p_k, battery charge and discharge, b_k^+ and b_k^-, and the grid. Equations 1c to 1f describes the physical constraints of the battery. b_k is the amount of electricity stored in the battery, which according to 1d can be at most $b_{\max}$, in particular b_0 is the amount of electricity in the beginning of the time horizon. c_B is the coefficient of efficiency of the battery. It is limited how fast the battery can be charged and discharged with a maximum of $b_{\max}^+$ and $b_{\max}^-$ respectively as described by 1e and 1f respectively.

Solution

This is a standard optimization problem that can easily be solved for some time horizon, N, to yield a schedule for how much to charge/discharge the battery and how much electricity to buy for all the coming time steps untill time N. Of course one can only forecast the production of the PV and the demand for electricity, and so the plan should be updated as time goes on. This is done by using only the first part of the schedule, and then recalculating the schedule for each time step.
Figure 1 shows the demand and production together with the battery state of charge for 3 consecutive days. It is clear that when the production exceeds the demand then the battery is charged. Any controller, no matter how simple, should have this behavior. But we also see periods where the battery is charged even though the demand is higher than the production. This is explained by Figure 2 that shows the battery state of charge for the same three days, but this time compared to the electricity price. It is clear that the battery is charged when the price is low relative to the future prices. This is where E-MPC offers more than simple rule-based control.

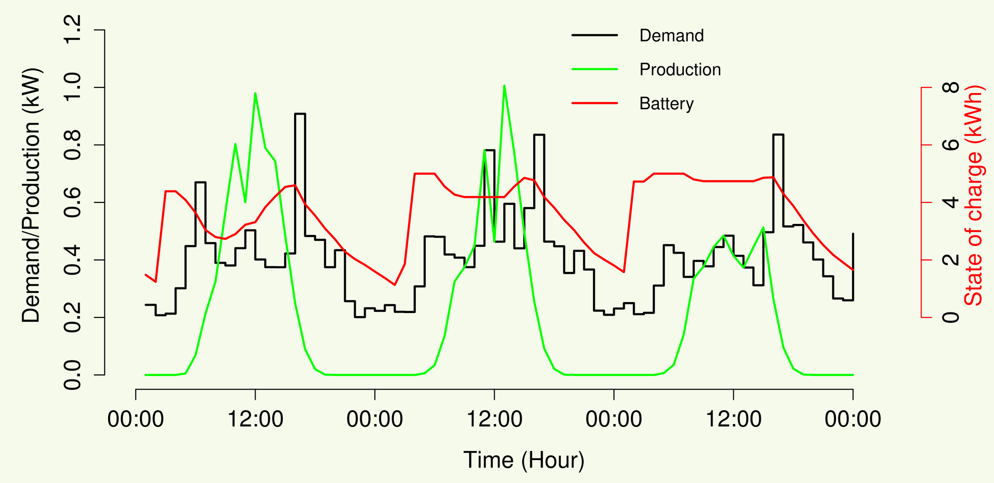

Figure 1: Demand and own-production with the corresponding state of charge of a battery.

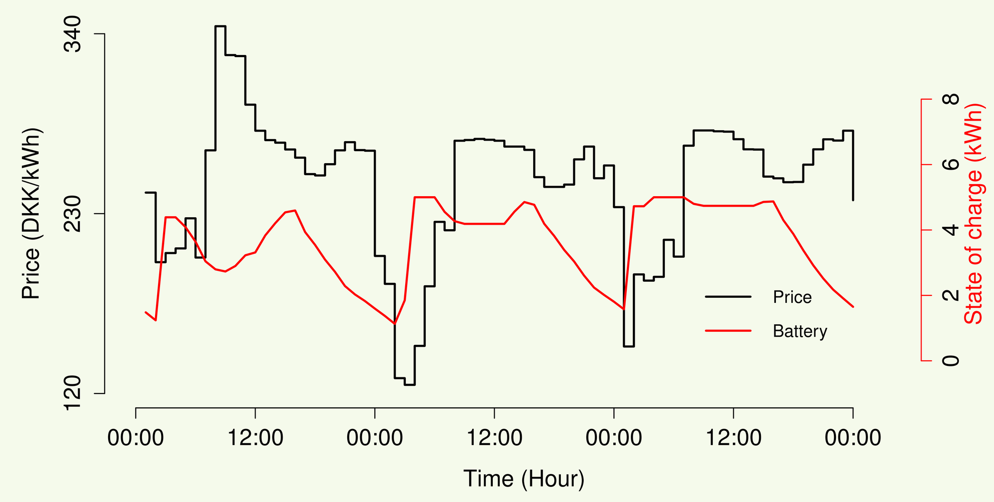

Figure 2: Electricity price and the corresponding state of charge of a battery.

Conclusions

Simulations have shown that the performance of a typical PV-battery system increases by more than 50% when using E-MPC compared to simple rule-based control. Thus a good controller with reliable forecasts is mandatory for acceptable performance.

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