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Modeling Smart Energy Systems for Model Predictive Control

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Abstract: Integrating large amounts of renewable energy sources like wind and solar power introduces large fluctuations in the power production. Either this energy must be stored or consumed right away. Storage solutions are very expensive and not applicable everywhere. So utilizing all of this green energy as it is produced requires a very flexible and controllable power consumption. Examples of controllable electric loads are heat pumps in buildings and Electric Vehicles (EVs) that are expected to play a large role in the future danish energy system. These units in a smart energy system can potentially offer flexibility on a time scale ranging from seconds to several days by moving power consumption, exploiting thermal inertia or battery storage capacity, respectively. Using advanced control algorithms these systems are able to reduce their own electricity costs by planning ahead and moving consumption to periods with green and cheap electricity. This situation occurs when there is a lot of excess wind power in the system which is reflected in the electricity price and in turn creates an incentive to absorb the energy.

In this paper a decentralized control strategy is investigated where prices indirectly influence the total power consumption of the smart energy systems connected to the power grid. Compared to a direct control strategy the complexity of the problem is reduced and decreases both the computation efforts and the need for communication. However, not only the current price, but a forecast of the expected future price should also be available in order for the individual units to plan ahead in the most feasible way. This is necessary since Economic MPCs do not respond to the absolute cost of electricity, but to variations of the price over the prediction horizon. Economic MPC is ideal for price responsive units where the model is known very well. Constraints and disturbance forecasts are straight forward to implement in the controller. MPC relies on the receding horizon principle, where a new optimal control signal is calculated at each time step for the prediction horizon. Only the optimal control signal at the current time step is implemented and consequently closed loop feedback is obtained.

A generic model of an energy component is proposed in this paper, so the same Economic MPC framework can be used to design controllers for the different units. However, different signals and forecast, e.g. weather forecasts and usage patterns, are used depending on the unit. The generic state space will be a discrete time state space model with hard input constraints and soft output constraints. For the considered energy systems there is usually a strict limit on the maximum available power, but the output, e.g. a temperature or an EV battery state of charge, can often be relaxed. The output constraints thus define a band of operation, that can be time varying, and the controller must keep the output within these limits in the cheapest possible way.

In this paper the price forecast available by all units is assumed to be known and equal to the day-ahead elspot price from the Nordic electricity exchange market NordPool. The resulting electricity cost savings compared to an MPC with no price considerations are around 30-50% for the chosen units. In future work the price could be replaced by an intrahour price that is related to the deviation between the planned and the actual consumption. In this way all units are motivated to stick to the predicted consumption plan.

Keywords: Economic Model Predictive Control, Smart Grid, Heat pump, Electric Vehicle
