



Characterizing the energy flexibility of buildings and districts

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Introduction

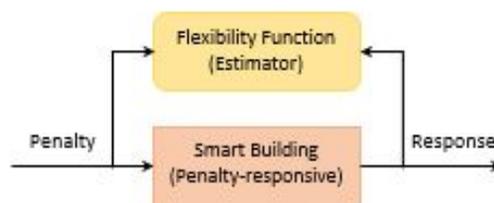
The sustainable transition to a fossil-free energy system with a high penetration of energy conversion technologies based on fluctuating renewable energy resources, like wind and solar, calls for a paradigm shift in power systems. Traditionally, the systems have been designed with centrally-situated large power generation operated to meet the demand. However, to support the transition to a renewable energy system a change is suggested, where demand is adjusted to the available generated power. Moreover, this modification moves towards a bi-directional decentralized system with smaller units and multiple prosumers.

The use of model predictive control in buildings is seen as a strong opportunity to minimize costs, while still meeting the comfort requirements. This control can either be centralized or decentralized by each building owner, which is the focus of this paper.

Method

The proposed method is to characterize the energy flexibility as a dynamic function, titled the Flexibility Function (FF), that enables the description of energy flexibility transients. In addition, FF does not need any calculation of a baseline load, as well as it can be determined either by simulation or by analysing time series data. Based on the FF, a method for calculating a Flexibility Index (FI), which measures the reaction of a building or cluster of buildings to penalty signals like CO₂ intensity or control signals imposed by the grid, is also proposed.

This paper considers the building level. However, the methodologies can be applied to any energy-consuming system. Actually, it would be more optimal to consider a group of buildings, a smart district or a smart city. A smart building is an energy-flexible building, which is equipped with penalty-aware controllers responding to external penalty or control signals. Three penalty signals are considered.



1. Real time CO₂ emission

A smart building will minimize the total carbon emission related to the power consumption. Hence, the building will be emission efficient.

2. Real time price

A smart building will minimize the total cost related to the power consumption. Hence, the building will be cost efficient.

3. Constant

A smart building will simply minimize the total energy consumption. Hence, the building will be energy efficient.

Case study

The case study analyses how different FFs enable the utilization of flexibility toward integrating various types of renewable energies. A set of three buildings, where Building 1 is able to move the largest amount of energy, while Building 3 is able to move the least. On the other hand, Building 3 is able to respond faster than the other two. Building 2 is somewhat in the middle. The combination of the buildings is also considered, which is easily as the average of the FFs.

The analysis considers how well each building performs in environments dominated by different kinds of renewable energy, namely wind, solar, and hydro power. For wind and solar power, data of the production of 2017 in Denmark is used to make penalty signals inversely proportional to the amount of produced wind or solar power. Hydro power can be controlled and thus, it does not experience the same kind of problems as wind and solar, however, large ramps in demand during the morning and afternoon hours are experienced. Therefore, a penalty signal based on these ramps has been constructed from the 2017 data obtained from the Norwegian power grid. A general representation of the penalty signals can be made based on that data, where wind is dominated by low frequency variation, solar by 24-h variation, and ramp by few sudden spikes.

Results

. **Expected Flexibility Savings Index** for each of the buildings based on wind, solar and ramp penalty signals. Building 1 is able to make the most of the wind penalty, since it is the only building that is able to sustain a demand response on a time scale similar to that which the wind penalty changes on. However, its response is so slow that usually it is not able to react to the changes in penalty when based on solar or ramp. The solar penalty is slower than the ramp penalty making it better suited for building 2 that can sustain its response for a while, while the very fast variations in the ramp penalty can only be captured by the fast response of Building 3.

. **Flexibility Index** is gotten by the use of deterministic reference scenarios that represent the issues related to ramps and integration of wind and solar power. The wind penalty is constant for 36 h, alternating between 0 and 1. The sun penalty is equal to 0 for 8 consequent hours each day and 1 otherwise, while the ramp penalty is equal to 0 all the time except for two periods of two hours each, every day, where it is equal to 1. The trend is similar to EFSI, but the numbers are 3 to 4 times larger. This means that these simple reference penalty signals are sufficient for testing the energy flexibility

	Wind (%)	Solar (%)	Ramp (%)
Building 1	11.8	4.4	6.0
Building 2	3.6	14.5	10.0
Building 3	1.0	5.0	18.4
Combination	5.4	8.0	11.5

	Wind (%)	Solar (%)	Ramp (%)
Building 1	35.1	7.2	18.9
Building 2	10.3	24.0	37.5
Building 3	4.9	11.1	71.0
Combination	16.8	14.1	42.5

Discussion

In addition to the technical and operational applicability of the presented methodology, it can contribute to or supplement the development of the smart readiness indicator, which is currently being investigated as an amendment to the European Energy Performance of Buildings Directive to assess the level of smartness of buildings.

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