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A novel tool for the evaluation and assessment of demand response activities in the industrial sector

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ABSTRACT

This paper introduces a novel tool for industrial customers to perform a cost-benefit analysis regarding the implementation of Demand Response (DR) strategies in their facilities with the final goal of softening the impact of RES intermittency in the grid. The dynamic simulation tool focuses on assessing the participation of industries in reserve energy markets in the same conditions as generators offering capacity reserve, energy reserve or both of them and taking into account all the technical restrictions of production processes as well as possible extra costs due to the implementation of DR (additional labour cost, productivity losses, etc.) Main innovations of the methodology are the DR assessment carried out per process and the introduction of the “margin of decision” as a decision making strategy for the energy consumer.

Along the paper, the methodology behind this tool is introduced step by step in order to show how the technical, economic and environmental analyses are performed. At the end, it is included the application of the methodology to a real paper factory in Germany. Results of the dynamic simulation tool are provided and discussed, showing the potential of the paper manufacturing in DR programmes as well as the benefits associated to it.

1. Introduction

Horizon 2020 context is promoting the reduction of CO_2 emissions, which is related to the increasing integration of Renewable Energy Sources (RES) in the electricity generation mix as it appears in the European Directive (2009/28/EC). However, higher penetration of fluctuating energy sources, such as solar and wind, makes difficult the task of maintaining a predictable and reliable system operation at all voltage levels [1]. Therefore, the implementation of mechanism allowing a specific regional transmission system operator (TSO) to interact directly with demand response resources could be beneficial from different points of view: a) environmental, reducing the required capacity reserve of thermal power generation and avoiding curtailments of RES in periods of excess generation; b) for customers, enhancing their opportunities by means of providing ancillary services to the grid; and c) for TSOs, increasing the number and quality of fast resources for balancing the grid which allows cheaper and more reliable operation [2].

According to this, demand response (DR) can be a significant resource to integrate RES where customers will shape their normal consumption patterns in response to the variations in the electricity price over time or to incentive revenues designed to induce lower electricity usage at times with high wholesale market prices or when system reliability is jeopardized [3]. Traditionally, industrial customers have had a passive role in European power systems, where only large consumers (i.e. melting furnaces or electrolytic cells) have provided (if any) some kind of interruptibility services to the grid. However, it is a fact demonstrated in different research and applications [4–6] that many medium industrial customers may be also able to offer DR services to the TSO if they were allowed, directly or through an aggregator. For this reason, it is important to provide them with new tools and mechanisms so as to enable them for estimating the DR potential that could remain hidden in their production processes [7,8].

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Nomenclature

B_{NE}	expected benefit for the customer (€)
B_R	real benefit (€)
C_0	initial investment (€)
CE_k	CO_2 emission balance in the period k (tonCO_2/kWh)
CF	annual cash flow (€)
C_{VAR}	variable cost (€)
E_1	energy reduced during a DR event (kWh)
E_2	additional energy consumed before a DR event (kWh)
E_3	additional energy consumed after a DR event (kWh)
EB_{Total}	*total* energy balance involved in a DR process and month (kWh)
f_k	CO_2 emission factor in the period k (tonCO_2/MWh)
M_D	margin of decision (€)
p_k	price of the electricity in the time period k (€/kWh)
P_M	revenues from the DR program operator (€)
ΔP_{R1}	average power reduced or interrupted during a DR event (kW)
ΔP_{R2}	average power increased before a DR event (kW)
ΔP_{R3}	average power increased after a DR event (kW)
P_{RES}	residual power during a DR event (kW)
S_{ij}	availability of the process *i* in the quarter-hour *j*
S_{MA}	economic savings in a DR action due to extending the useful lifetime of machines (€)
S_S	economic balance in the implementation of a DR action (€)
r	discount rate (%)
T_{av}	availability time (h)
T_D	duration of a DR event (h)
T_{IA}	notification time in advance (h)
T_{MIN}	minimum time between two DR events (h)
T_{PR}	duration of the preparation period (h)
T_{RC}	recovery period (h)

Currently, some tools for the estimation of the DR potential of customers in the primary and tertiary sectors (agricultural sector and commercial buildings) are available in different sources [9–12]. However, such tools are just focused on buildings [13] (like the Demand Response Quick Assessment Tool –DRQAT- described in Ref. [14]), existing a significant gap regarding industrial applications. Existing models are focused on very specific processes (for example, air conditioning or lighting), which have been traditionally used for DR applications. However, more specific processes of industrial consumers have not traditionally been involved in DR issues due to misgivings about potential risks in the degradation of the production processes. This is especially true when DR actions are applied to sensitive processes directly related to the quality of the final product, which tend to make customers wary of changing any element or parameter of those processes. The tool here presented permits the modelling of industrial and non-industrial processes so as to evaluate the impact of specific DR actions and providing a detailed economic, technical and environmental evaluation every 15 min. In addition, the tool provides a holistic approach, linking the impact of DR actions on a process with each other, so that the application of any specific action is constrained to what happened with the rest of processes. Moreover, the tool provides a detailed analysis about when and how the different types of DR actions may be implemented in order to maximize the economic benefit for both the consumer and the power system.

On the other hand, existing tools deal with economic models using Time-of-use or similar fix price schemas [15] but neither research studies nor tools have been found so as to evaluate the economic benefit of the participation of industrial customers in reserve energy markets (offering capacity reserve, energy reserve or both of them). Conversely, this tool provides the simulation of customers participation in ancillary services based on a dynamic prices scheme with the possibility to consider a set of different prices for different services (capacity reserves, balancing services, interruptibility, etc.) every 15 min.

In this paper, a dynamic simulation tool based on previous works of the authors (described in Ref. [16]) is presented so as to fill this gap. This tool does not consider industrial customers as a black box, but they are evaluated as a sum of parts (manufacturing processes) which can be modified individually while the effect in the total electricity pattern of consumption for the whole facility is analysed. In this regard, the results of the economic evaluation are obtained for each DR process enabling customers to select the most cost-effective options. Moreover, the simulation tool includes an environmental evaluation that calculates the reduction of CO_2 emitted by the replaced thermal power generators to the atmosphere.

The tool was developed in the framework of the project "Demand Response in Industrial Production (DRIP)" [17], co-funded by the Environment LIFE Program of the European Commission[2], and it was empirically validated in the four factories involved in that project, which belong to some of the most suitable segments for DR implementation [18]: a paper factory in Germany, two meat factories in the Netherlands and Spain (respectively) and a logistics warehouse for food products in Spain.

The paper is organized as follows: Section 2 describes the calculation methodology of the new simulation tool. In Section 3 the methodology is applied to a paper factory. Finally, some conclusions are drawn in Section 4.

2. Calculation methodology

2.1. General description

In order to assess the potential benefit of the participation of an industrial customer in a particular reserve energy market, a set of information is required:

- On one hand, information related to the customer, such as the load curves of the processes, the definition of DR actions of the processes according to standardized parameters (see Section 2.2) and electricity contract.
- On the other hand, the reserve energy market prices where the participation of the consumer would be simulated and CO_2 emission factors, which depend on the country where the consumer is located.

Based on this information, the simulation tool performs the technical, economic and environmental evaluation of the DR potential in the customer facility considering all the complex relationships among all the variables in a mathematical model that takes into account the chronological order of events. Fig. 1 shows an overview of the required information (inputs) and the main results of the simulation tool (outputs).

[2] Detailed reports and more information about DRIP can be found in the website www.drip-project.eu [17].