A METHODOLOGY TO ASSESS THE POTENTIAL OF DEMAND RESPONSE OF INDUSTRY IN ITALY

Simone MAGGIORE
Ricerca sul Sistema Energetico – Italy
simone.maggiore@rse-web.it

Anna REALINI
Ricerca sul Sistema Energetico – Italy
anna.realini@rse-web.it

Claudio ZAGANO
Ricerca sul Sistema Energetico – Italy
claudio.zagano@rse-web.it

ABSTRACT

One of the issues addressed by the transformation of the energy system towards an increased sustainability is represented by the potential role of industrial flexible electric loads to meet the growing needs for balancing electricity demand. However, such a flexibility is subject to a variety of constraints, which imply different types of potentials for different production process.

Such a topic has already been extensively analysed in literature, showing that the most important obstacles to overcome are the risk of interrupting continuous process operations, the impact on product quality and the uncertainty on the reduction of energy costs and, consequently, on the economic convenience of the electrical flexibility.

This paper presents a methodology to evaluate the potential of demand response in industry at local level: this allows the relevant stakeholders to perform an assessment of the intervention margins for the suspension of electricity supply for the various types of industrial processes in different sectors.

INTRODUCTION

The participation of the industrial sector in Demand Response programs requires an adequate consumption flexibility which is not easily defined, due to the numerous types of production processes, technical constraints and process requirements [1][2].

Moreover, several studies in literature show that there is a certain resistance to its application [3][4].

The subject has already been extensively analysed in various scientific works, reporting different investigations performed on industrial operators. These surveys show that the most important obstacles that electricity flexibility must overcome are the risk of interrupting continuous process operations, the impact on product quality and the uncertainty on the reduction of energy costs and thus on the economic convenience of the electrical flexibility.

Moreover, on the basis of the analysis carried out in various real cases of industrial plants, it has emerged that electricity consumption profiles are irregular and depend widely on the production process, the characteristics of the finished product and the size of the factory. It is therefore not possible to consider each factory according to standard models, as occurs, for example, in the residential sector.

Only an in-depth knowledge of the industrial sector can make it possible to identify sections within production processes which, in part or under certain conditions, can be disconnected from the continuous process. The purpose of this paper is to present a methodology to analyze the processes in order to model energy processes and optimize energy consumption and production on site with automatic control of the process flexibility in order to make them more flexible in the MG contest.

THE METHODOLOGY

Industrial production processes have loads which can be reduced and/or shifted over time in cases in which at least one of the following characteristics is present:

- thermal storage (heating and cooling,…);
- physical storage (cement industry, supply of fresh water,…);
- batch process (grinding, ventilation,..).

The shift of the industrial load may be limited by technical constraints, process requirements and availability of unused machines or plants. For processes with very high energy utilization rates, such as those found in energy-intensive industries, the load curtailment cannot be counterbalanced by other actions. This is usually the case when the production process has very long and delicate start-up phases (the temperature of the components can only grow gradually and in time interval set in advance,…) and, once started, the process has to be maintained at constant load, in order not to reduce its performances in terms of energy efficiency of the process and quality of the output.

However, even in energy-intensive processes, some batch process phases can be identified. These production phases are independent from the continuous process such as, for example, the preparation of raw materials (milling of raw materials, mixing with additives,…): the flexibility of such phases depends on the storage capacity of the semi-finished material. The storage tanks of the semi-finished products play, in fact, a fundamental role in the field of electrical flexibility becoming a buffer between the batch phases and the continuous process phases.

Based on the experience gained by R.S.E. in the field of energy efficiency in the Italian industry [5] and the European industry, thanks to the EU-MERCI project [6] (of which RSE was the coordinator), we analyzed in detail the production processes and electricity consumption for each phase in several sectors, in order to derive a methodology which can be used to determine the electrical flexibility potential of production processes; such a methodology is based on three steps:

1. identification of electricity consumption for the main phases of the most energy-intensive industrial processes;
2. identification of continuous processes and batch processes;
3. identification of the reductions in electricity consumption and the maximum permissible time intervals of production processes.

The validation of the methodology has been then carried out in Italy in the steel sector, which represents one of the most energy-intensive industrial sector in Europe. The details of the methodology and the results of the validation are shown in the next paragraphs.

STEP1: identification of electricity consumption for the main phases

Steel production plants have various types of production lines [5][6][7]; in particular, there are two main production cycles, which differ in the raw materials used in input:

- "integral cycle" (28% of the total production): in most cases, raw materials are used in input as found in nature (minerals, fossils) and, only for some cycles and small quantities, even steel scrap;
- "scrap cycle" (72% of the total production): the raw material used in input consists of only steel scrap.

The "integral cycle" makes it possible to produce all types of steel, but it requires a complex process of preparation and treatment of raw materials, which constitutes the preliminary phase before the blast furnace. The "scrap cycle", instead, makes it possible to produce medium-low quality steels, but it is more compact and less energy demanding than the "integral cycle", as steel scrap is the only raw material used in input. For these processes, the main production phases (which are the most representative of the supply chain) have been identified. For the energy analysis of the Italian steel industry, a sample of 68 plants was used, representing, from the point of view of energy consumption, about 90% of the national plants. Figure 1 shows the flows of electric energy both in percentage terms (on the left of the graph) and as average specific consumption (right) for the different phases of steel production.

STEP2: identification of continuous processes and batch processes in the steel sector

The analysis of steel production process has allowed to identify three distinct sections which can work separately:

- Preparation of raw materials (batch process);
- Production of cast iron and steel (continuous process);
- Cold working of steel (batch process).

In the first phase (raw materials preparation), coke and agglomerate constitute the input material of the blast furnace and can be produced in quantities and times that can be independent of the operation of the blast furnace, provided that a storage with an adequate capacity is available. The milling, mixing and sintering plant is the main consumer of electric energy. This system supports sudden and repetitive interruptions.

The second phase (production of cast iron and steel) is the core of the process: it is characterized by a high thermal inertia, due to the size of the blast furnace, the temperatures reached and the minimum load under which a proper operation is not possible. The process is continuous from the fusion of raw materials to the production of billets and cannot be stopped instantly: it is possible to act only on the gradual reduction of production and, therefore, of the absorbed energy.

The third phase (cold working of steel) is of batch type: the input material are batches of billets and the energy consumption depends on the dimensions of the heating furnace, the zinc coating, the galvanizing tanks and the coating tunnel. This section is responsible for most of the electricity consumption. These different phases can be interrupted at regular intervals and independently of one another.

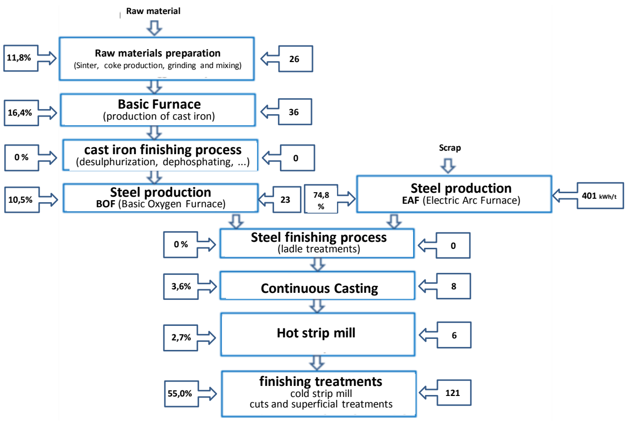

Figure 1: average specific consumption (kWhe/ton) e percentage consumption (%) of electric energy for the main phases of steel production.

STEP3: identification of the reductions in electric energy consumption

The analysis of the electric energy absorption curves of various steel plants showed distinct load trends, despite the factories belong to the same industrial sector and use the same type of production process. Figure 2 shows the daily electric energy consumption of four different steel production plants with a 15 minutes sampling for working days and Saturdays and Sundays.

For Foundry n°1, the load is almost constant during working days, as well as during weekends but at a lower level (about 1/5), probably due to the base consumption of auxiliary systems and/or to maintenance work.

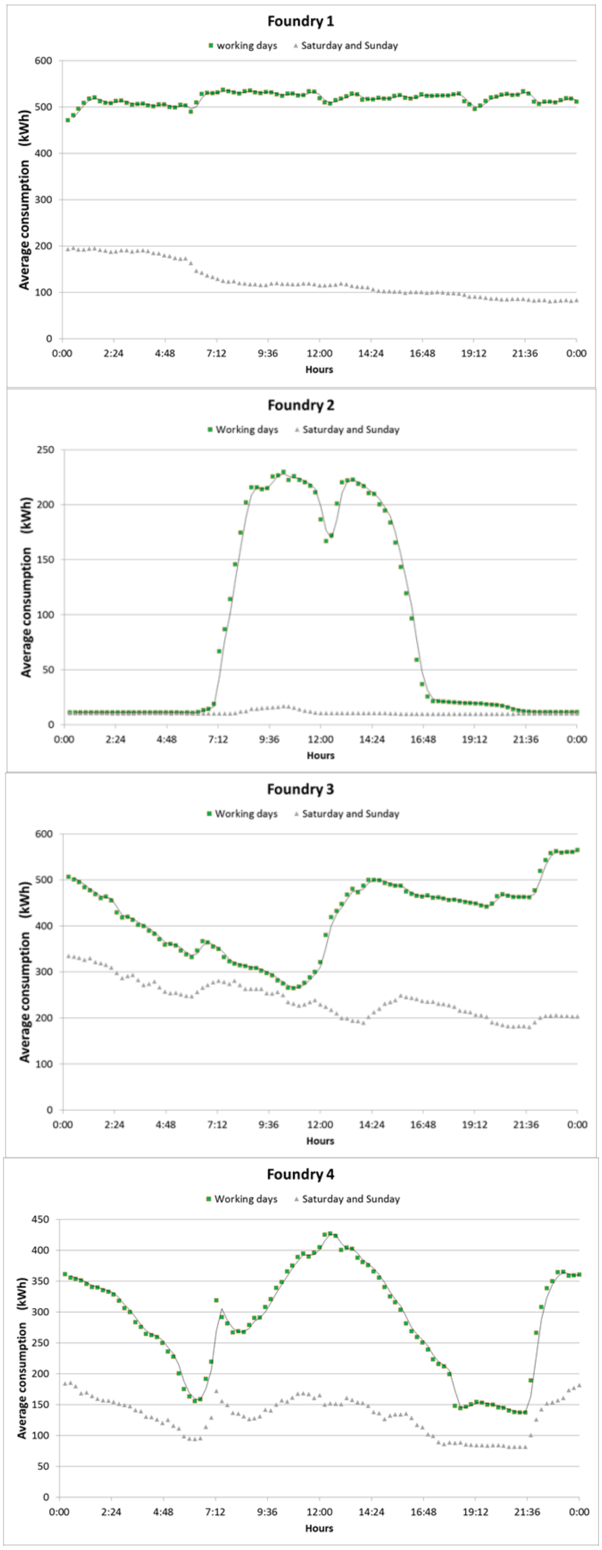

Figure 2: electric energy absorption curves of 4 different steel plants.

For Foundry n°2 the load is concentrated in the typical daytime working hours (from 8 am to 5 pm), with almost no consumption during weekends (likely due to the closure of the plant). Foundries n°3 and n°4 show different trends and are very diverse from the first two ones. The production process is probably not linked to a particular phase of processing but to several phases (tempering, galvanizing,...) which take place at different times and with overlaps. During the weekend there is no closure of the plant but only a moderate reduction of the load, that appears smoother than during the weekdays. It was thus possible to identify three classes of factories:

- Large factories producing only steel without special cold working (e.g. Foundry n°1);
- Small factories with production concentrated in the typical working hours 08:00 - 17:00 (e.g. Foundry n°2);
- Medium-sized factories with mixed production processes and hot and cold working (e.g. Foundries n°3 and n°4).

For large and small factories, it is possible to define two standard intervention plans to act on the flexibility of the electric energy demand. For all other medium-sized plants, it is necessary to define a customized action plan.

Having to deal with systems with different plant configurations and with consumption that vary among one another from one to three orders of magnitude, it is convenient to consider a production base with a value of 100 (e.g. 100 tons/hour) as the reference value. As it is not known in advance what could be the acceptable time interval for each plant, one hour as a unit interval is assumed as a reference. On this basis, we have derived the "normalized" scenario reported in Table 1, which allows the evaluation of the electrical flexibility for all types of factories.

Table 1: Estimation of the maximum electric energy consumption reductions with a steel production base of 100 tons/hour and a unit time interval of 1 h.

Steel production reference (100 ton/hours)	**Electric energy consumption reduction** [kWh]	**Time interval** [h]	**Maximum degree of reduction of the energy load**
Preparation of raw materials (batch process)	2,600	1	100%
Production of cast iron and steel in Basic Oxygen Furnace) (continuous process)	1,500	1	66%
Production of cast iron and steel in Electric Arc Furnace (continuous process)	26,700	1	66%
Cold working of steel (batch process)	12,100	1	100%
Entire process	42,900	1	75%

The continuous processes in Table 1 cannot be interrupted but can be gradually adjusted towards a minimum admissible value which, for large plants, is commonly around 1/3 of the nominal value. Scientific literature does not provide detailed split of real consumption by type and size of plant. However, it is possible to find several analyses offering models of energy flexibility. For example, a German study [8] showed the average flexibility of the steel production industry in Germany with an electric oven based process (EAF), which can be summarized in:

- the number of days with a possible interruption of electric energy consumption in one year (40);
- the maximum duration of the electric energy consumption interruption (4 hours).

These numbers show that for the steel production sector, the main obstacles to electricity flexibility are the risk of interrupting continuous process operations, the impact on product quality and uncertainty on energy savings and costs which make a true flexibility not feasible in practice, but allow only a "programmed flexibility".

Therefore, it is essential to carry out an in-depth analysis of the involved processes, the operability of the plant and the different needed levels of electrical power. Based on the sample analyzed in the Italian case [5] and according to the figures provided by the literature [9], we estimated the maximum reduction value of the electricity consumption obtainable in Italian steel sector. Such results are shown in Table 2.

Table 2: estimation of the maximum reduction value of the electricity consumption obtainable in the steel industry in Italy.

	Electric energy daily consumption [kWh]	Maximum hourly reduction [kWh]	Maximum daily reduction of electric energy consumption [MWh]	Maximum annual reduction of electric energy consumption [MWh]
First quartile (25° percentile)	41,800	18,101	72	2,896
Median value (50° percentile)	210,700	91,240	365	14,598
Third quartile (75° percentile)	1,129,200	488,979	1,956	78,237
Fourth quartile (100° percentile)	6,493,200	2,811,758	11,247	449,881
Total	7,874,900	3,410,078	13,640	545,612

CONCLUSIONS

In a context of microgrids (MG), it is clear that the black-box modelling approach (a generic nonlinear dynamic equivalent model based on recurrent Artificial Neural Networks) has little chance of working in the presence of large industrial users. The grey box modelling based on a physical model structure which tries to understand the physical behaviour of the different components of the MG has more chances of success, provided that it is supported by a detailed knowledge of the characteristic response to the demand of the particular productive processes of industrial users.

This paper has presented a methodology based on three steps which can be used to determine the electrical flexibility potential of production processes in industry: this makes it possible to identify the production phases that are batch-type or that can be stressed to become batch-type even with the introduction of tanks or deposits, between two production steps, with a storage function for the semi-finished products. In fact, in many studies in literature, where questionnaires were issued to industrial stakeholders, a source of flexibility was often found in a process which was not indicated upfront as flexible in the questionnaire. This confirms the need for an appropriate approach both to identify the presence of flexibility in industry and to identify possible changes in the process to improve flexibility while reducing business risks.

REFERENCES

[1] Shoreh et al., 2016, "A survey of industrial applications of Demand Response", *Electric Power Systems Research*, vol. 141, 31-49.

[2] Yamashita, K. et al., 2012, "Modelling and aggregation of loads in flexible power networks", *IFAC Proceedings Volumes*, vol. 45, issue 21, 405-410.

[3] "Flexible Industrial Demand Assessment Case Studies Summary", available at http://www.industre.eu/downloads/category/project-results.

[4] "Business models and market barriers", available at http://www.industre.eu/downloads/category/project-results.

[5] Borgarello, M. et al., 2017, "L'efficienza energetica nell'industria: potenzialità di risparmio energetico e impatto sulle performance economiche e sulla competitività delle imprese", *R.S.E. report n°17001209*.

[6] The EU-MERCI (*EU coordinated MEthods and procedures based on Real Cases for the effective implementation of policies and measures supporting energy efficiency in the Industry*) project, (http://www.eumerci.eu/).

[7] Janjua, R., 2014, "Energy use in the steel industry", available at https://www.worldsteel.org/en/dam/jcr:f07b864c-908e-4229-9f92-669f1c3abf4c/fact_energy_2016.pdf.

[8] Olsthoorn, M. et al., 2015, "Barriers to electricity load shift in companies: A survey-based exploration of the end-user perspective", *Energy Policy*, vol. 76, 32-42.

[9] Trianni, A. et al., 2013, "Innovation and adoption of energy efficient technologies: An exploratory analysis of Italian primary metal manufacturing SMEs", *Energy Policy*, vol. 61, 430-440.