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Integrated dynamic energy management for steel production

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Abstract

The steel industry is an important consumer of electrical energy having a significant impact on the electricity network and accounting to a significant part of production costs. Thus, there is the opportunity of closer cooperation between grid operators and steel industry to improve the power consumption prediction and actively contribute to a secure network operation. This paper aims to describe an overall dynamical approach for electricity demand monitoring and timely reactions to the grid situation, to avoid non flexible equipment disconnection, financial fines when deviating from energy contingent and contributing to the grid stability. Energy management, simulation, decision support procedures and process control tools will be integrated in an agent based system able to predict and manage power consumption.

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*Keywords:*Energy Management System; Demand Side Management, Agent Technology

1. Introduction

Steel industry is an energy-intensive sector, in particular for the electrical energy consumption and its impact on the electricity network is significant. A closer cooperation between grid operators and steelworks can be a key factor for improving the power consumption prediction and management. In this cooperation, the dynamic search of the optimal conditions in multi-constraint environment, taking into account the current objectives of yield, quality, resource efficiency and sustainability, has big potential. Looking to the daily evolution of electric energy demand and consumption, steel sector can establish proactive win-win relationship among the players on the power grid optimizing power demand and proposing, for example, balancing services. The adoption of the innovative technologies in the fields of the *Smart Manufacturing* and *Smart Grid*s, are enabling factors to optimize OPEX, especially in the electric steelmaking route, which produces steel by melting scrap via the Electric Arc Furnace (EAF) and its decrease and control is a key factor for the competitiveness of the European Steel Industry.

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This paper presents the ongoing *DynergySteel* European research project aimed at the demonstration of the related benefits exploiting the potential of the integrated through-process approach for managing events coming from the power markets and the transmission network by means of increased negotiation capability supported by the new automation tools. Smart interaction with the power distribution system has been pointed out as one of the most viable solutions [1], as already done in other industrial sectors [2] Scientific and technical literature highlight the importance of the integrated approach to cooperate with the grid and describe developments of new devices for linking electrical power usage and performance with existing production automation systems [3]. Optimization techniques are considered for the bets trade off among total electricity-cost, production, process flow and storage constraints for different tariff structures [4]. Continuous-time scheduling model [5] with generic energy-awareness is presented for optimizing the electricity purchase and the load commitment problem in the melt shop of a stainless steel plant. For the same case study the impact of fluctuating energy prices on the operations scheduling and the economic benefits that are achievable through suitable management programs is discussed in [6]. In this context, the proposal newly addresses an holistic approach where the active link with the power network is coupled with energy management, simulation, decision support procedures, scheduling and process control tools in line with the commitment announced by the Steel Industry inside and outside Europe to reduce its energy demand and the related environmental footprint [7]. In fact, such capabilities are founded on the development of methods and tools to support the negotiation between steelworks and power market and new dynamic production scheduling approaches for managing network events.

2. The context and approach of the project

The steel sector is an important part of the Energy Intensive Industries (EII); it is the second world's main energy intensive manufacturing systems consuming more than 500 Mtoe (Million tons of oil equivalent) in 2012 (source: International Energy Agency - IEA) and producing in 2015 1.599.484 thousand ton of crude steel (source: World Steel Association). Energy constitutes a significant portion, around 20%, of the cost of steel production and about 35% of an integrated facility's energy input comes from electricity. In particular, the electric route needs about 1.6 GJ of electricity per ton of produced steel. Thus steel industry a large consumer of electrical energy, by significantly contributing to the power network overloads: for instance in Italy in 2014 the steel sector accounted for about 6% of total national use of electricity. This is becoming more and more important, as the network security and stability is influenced by seasonal and daily fluctuations, due to the increasing use of renewable power.

Therefore, actions are planned, under development and in the deployment stage for improving the load flexibility in steel manufacturing; the integrated approach devoted to through-process integration, electricity consumption optimization and event management in manufacturing plays an important role; it is the core of the project whose preliminary results are presented in this paper.

Energy Markets analysis

The Electricity price is the result of the supply / demand equilibrium among producers, consumers and prosumers (consumers which are also producing electricity).

Day ahead & Intra Day markets

The power price fluctuations in the day-ahead and intra-day in both Italian and German spot markets offer the opportunity to take profit from demand flexibility in purchasing energy, taking into consideration the price fluctuation during the hours of the day and between working days and holidays. The company can access directly the Day ahead & Intra Day markets. This is the most flexible option allowing to take full profit from hourly price differences and to change the consumption profile nearer to real-time. However it can be risky because it exposes to the volatility of Power Exchange prices without forward contracts that fix the price for the bulk of energy consumption requiring an internal structure affordable only by larger companies could afford. In Germany, Belgium, Austria negative prices are present both in day-ahead and balancing markets.

Balancing Markets

The analysed markets are IL (Interruptible Load) only upward, SCR (Secondary Control Reserve) and TCR (Tertiary Control Reserve). Presently in Italy SCR and TCR markets are not available for demand (only to energy producer) but the authority is working in order to open the markets to demand in the near future.

The companies can participate solitarily or as part in a pool both downward-negative (cut-in of aggregates, increase electricity use) and upward-positive (shutdown of aggregates, decrease electricity use) ways. The bidding processes are both for capacity and energy and are payed as bid.

These short term markets, i.e. balancing markets, where it is more difficult to implement reaction policies and tools, are mostly interesting both for electricity producers and consumers. In effect, the EAF route holds some elements of flexibility in process scheduling which could allow acting on the energy markets in a positive and profitable way for all the actors.

Table 1 Italian- German balancing markets characteristics comparison

	Italy	Germany
Reaction time		
IL	< 200 ms Instantaneous	< 1 s Immediately
	< 5 s Emergency	< 15 min Quickly
SCR	< 200 s	< 300 min
TCR	< 15 min	< 15 min
Load / generation alteration		
IL	1MW	50-200 MW
SCR	± 10 MW	±5MW
TCR	± 10 MW	±5MW
Holding period		
IL	No limits	1-2-4 h
SCR	> 2 h	< 15 min
TCR	No limits	< 4 h

The fundamental characteristic to be taken into consideration in order to identify how the steel companies can participate in those markets are reaction time, load/generation alteration and holding period. In Table 1 the comparisons between these factors in Italy and Germany are shown.

Identification of services to be provided by steelworks

The identification of services that the system/process can potentially provide to the network is also based on the characteristics of the processes themselves. The processes that are nearly always on or off or bivalent on/off are very good to use, heating and cooling are good to use while process with high fluctuation needs to be modified to provide services to the network.

A preliminary result shows how the steelworks can participate with quite high electrical aggregate (50-60 MW each) for relatively short periods (less than 15 minutes) or with lower, some MWs, for longer period. In principle the EAFs load is adjustable. Nevertheless a reduction of the voltage will also reduce the output of the steel melting shop. This might be possible for a short time if the EAF capacity is still high enough to satisfy the overall need of the downwards processes without the risk of a shortfall of the production chain. Therefore the priority and possible sequence of the production chain has to be evaluated case by case with respect to changing situations of the quality management of the heats and possible process stops because of unplanned maintenance. Oxygen is used in the steel production as additive gas for burners and it can be stored. This way the status of the oxygen-storage devices can be used for energy management purpose acting like a storage of electrical energy improving the flexibility.

3. Tools under development to allow interaction between steel industry and electricity market

Integrated system for energy management based on Agent system technology

In order to exploit the benefits and to face the challenges of dynamic energy market, a flexible adaptation of the production processes is needed. Generally, when acting on energy markets two problems must be adequately handled by the production systems: firstly, the deviation in the prediction of energy price has direct impact on the production costs. Higher prices lead to increased production costs compared to the planned ones; lower prices offer the potential to decrease costs or to extend margins for manoeuvring. The production system must react to the current situation by enabling or disabling non-critical processes, by increasing or decreasing the energy consumption. Secondly, the request to modify the energy consumption can also originate from the energy network itself. Due to the increasing utilisation of renewable energy sources, such as solar or wind generation systems, the energy network becomes ever more volatile with alternate energy excesses and undersupplies. EIIs need to react according to the situation of the global energy network load. Due to the generally higher proportion of requested energy, in this case the reaction may affect critical production processes. The production systems must adapt their strategy according to the situation both focusing on global cost optimisation and considering process stability. In both cases, a flexible solution is required in order to achieve the multi-objective optimisation. Within the project multi-agent systems [8], [9] will be applied in combination with auction mechanism to calculate the optimal combination of enabled/disabled peripheral systems and or processes according to the load demand. Autonomous software agents that "know" their current relevance for the production process and their energy demand function represent the different plants and machines. Based on this information each agent calculates its own impact. Such impact is submitted as a bid to the auction system that decides whether and eventually which agents are selected for the execution of energy consumption-related actions.

To reach the above goal is fundamental to be able to evaluate both the internal and external costs when deviating from the planned energy profile. Specifically the internal costs/benefits of process modifications due to e.g. change in order due date, increase in energy demand and external costs/revenue offered by the electricity markets or due to not alignment with the forecasted electricity profile should be evaluated.

Energy price forecasting

An investigation was developed on the possibility to forecast the cost of an eventual variation of actual energy needs compared to the booked one. If the actual consumption deviates from what agreed with the supplier or from the Power Exchange purchases, then the imbalance energy is settled at specific imbalance prices. Considering that such imbalance contributes or counteracts the overall imbalance of the macro zone where the company is located, the purchase/selling prices are penalizing or profitable for the company itself. Thus, forecasting such price can be useful for the company for evaluating costs of mismatching between actual and planned consumptions due to unpredictable events and eventually cut-in or shutdown one or more aggregates.

The setup and verification of a suitable model based on the above considerations, was carried out using data of Italian electricity prices. Specifically, the considered input variables are the hourly average selling and purchase prices of the balancing market (in €/MWh) for each macro zone. Price data refer to the period between November 2014 and September 2015. A pre-processing phase was applied in order to have a complete time series for both selling and purchase prices, since the value of the average price, for a given hour, can be undefined. This happens when the Transmission System Operator solved the unbalance of the National Transmission Network with a redistribution of energy among the zones, without needing to resort to the balancing market for balancing purposes. Since the percentage of undefined price values is lower than 13% for both prices in each macro zone, the undefined hourly values were filled up through linear interpolation on each price time series. A model based on Non linear Auto-Regressive (NAR) Neural Networks (NNs) [10] is exploited, where the forecasted value of the series depends only from *d* past values of that series, i.e. $y(t)=f\,[y(t-1), \ldots, y(t-d)]$. Here the NAR NN forecasts the price for the following 10 hours (multi-step-ahead prediction). The time series data samples are split into two continuous blocks, made up of 75% and 25% of data and named respectively training and validation set. The validation set is sub-divided in time intervals of 10 consecutive hours. The model forecasts the energy price in the following 10 hours, from the price values of previous hours, according to the NAR model with $d=6$. The prediction error is quantified for all the predicted values in the same hour through two indexes. They are the absolute error and the so-called Normalized Root Mean Squared Error (NRMSE) [11]. The NRMSE takes into account the standard deviation of the measured values and should be as low as possible: if NRMSE>1, the deviation of predicted values is greater than σ. The results for the first three hours are shown in Table 2(a) and (b) respectively for selling and purchase prices in the North and South macro zones.

Table 2. Selling (a) and Purchase (b) prices – Multi step ahead prediction performance results with NAR

	NORTH		SOUTH	
Hour	NRMSE	Abs Err	NRMSE	Abs Err
1	0.6731	0.0303	0.6680	0.0348
2	0.8389	0.0400	0.8441	0.0471
3	0.9254	0.0444	0.9365	0.0533

(a)

	NORTH		SOUTH	
Hour	NRMSE	Abs Err	NRMSE	Abs Err
1	0.7767	0.0828	0.7388	0.0726
2	0.9202	0.1029	0.8927	0.0931
3	0.9685	0.1099	0.9952	0.1050

(b)

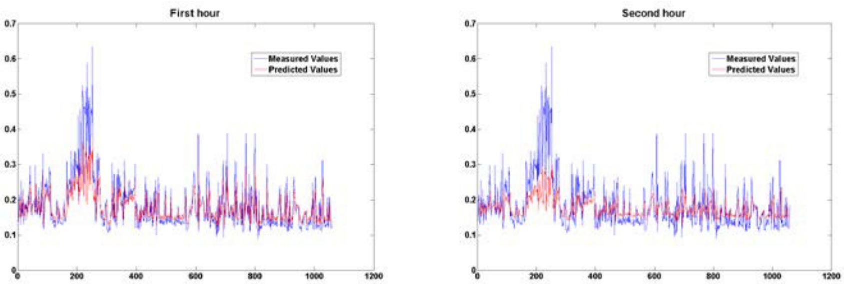

Fig. 1 North Selling Price – Measured (blue) and predicted (red) values for the first (left) and second hour (right)

The performance results show that price predictions are quite good for the first hour, while progressively decrease with increasing value of the time, becoming less meaningful when the NRMSE is close to the unity, as, in practice, the predicted values tend towards the overall average value. Even when the absolute error appears acceptable, the NRMSE points out the inaccuracy of prediction. Figure 1 allows to graphically compare measured and predicted selling price values, for the first and the second next hour in the North macro zone. Similar trends are obtained for the other macro zone and for the purchase price.

4. Conclusions and future work

The paper presents the work developed within an ongoing research project aiming at improving the interaction between electric steelworks, electricity distribution system and energy market. The following advantages and impacts, compared to the current situation are expected from this project: enhanced load flexibility in responding to unplanned power events and market opportunities; improved control of electric power engagement in order to optimize the through-process power load distribution along the time axis.; better coordination with the network load distribution in order to actively contribute to a secure network operation and establish regional agreements for the power market access; opportunities to achieve better tariffs and increase profitability, decreasing the electricity consumption costs due to an enhanced flexibility of the production process; decreased environmental impact according to the diffusion of the renewable energy sources; IT improvements in energy control and optimization easy deployed in the through-process supervision and control systems; increased production continuity by avoiding disconnections of plants due to power cut-offs also deriving from the regional grid load stabilization.

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Biography

Graduated cum laude with a master degree in Mechanical Engineer from Rome “La Sapienza” University. She is as a Senior Researcher in the Industry 4.0 competence area. She is CSM representative in the RFCS Project I2MSteel (agent technology) and EnergyDB (product related Energy DB) and coordinator of DYNERGYSteel Project.