Models to Estimate Energy Requirements for Iron and Steel Industry: Application Case for Electric Steelworks

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***Abstract*— Nowadays the price of electricity depends on many factors; the introduction of renewable energy sources has changed the basics of electricity production and the determination of energy price. Iron and steel industries have the necessity to forecast the power amount they are going to spend: today production planning is performed without taking into account that the difference in electricity price between night and day can overcome 500%. The aim of this work is to create a model able to estimate energy requirements for iron and steel industry; the model correctness is assessed, for both energy and power analysis, by comparison with real data. The provisional planning tool is employed to provide data to a computer platform able to assess, on the basis of required energy, the best market on which power can be purchased in view of a money saving for the Company.**

***Index Terms*— Decision support system. Consumption forecasting. Electric power. Energy market.**

I. Introduction

IN steelworks industry [1,2], not long time ago, the Companys'attention was mainly turned to production process itself, to its control and automation. The success of this focusing is evident, and the quality standards offered by the market, which nowadays are taken for granted, are extremely high, so as applications, which are more and more advanced.

In order not to risk the falling of the Occidental industries competitiveness com-pared to the big Asiatic Companies, it is necessary to become competitive not only on a technological and quality horizon, but also, and above all, to be able to excel in the customer satisfaction field, being able to suit in a repeatable manner, customer's requirements in terms of delivery time, building a stable process of Planning, Insertion and Management of the orders.

Such system requires firstly a production order and a definition of the status quo; after that, an optimized production planning needs to be implemented to satisfy the orders. It must be taken into account that during production problems may occur that can require an immediate production re-programming.

The introduction of a virtual planning, in all the possible problems that can require a production re-programming, allows to assess in a virtual time the plant status; the system is able to process and show the new organization of the production line. At the same time, the system is able to interact in a continuative manner with the energy market basing on plant necessities.

In this paper, the Authors propose a planning method for a complex steelworks plant. The proposed method performance is assessed by comparison with real data obtained by measurements on the plant. The analysis involved fully productive days, days with up and down power ramps, non productive days and anomalous days. To provide thorough terms of comparison, the MAPE (mean absolute percentage error), the Least Squares and the ANOVA (analysis of variance) methods were employed.

Manuscript received August 10, 2017; revised August 14, 2017.

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II. 2 Steel Manufacturing Plant

In Figure 1 is visible the flow scheme of the whole process, including the material flow rates processed by each component. The examined plant comprises two production lines; we have:

- EAF: Electrical Arc Furnace that can work 7 days a week; after that it requires maintenance (these operations take between 8 and 12 hours)
  - EAF A: processing every 75 minutes and capacity 110T/H;
  - EAF B: processing every 60 minutes and capacity 150 T/H;
- LF: Ladle Furnaces with the same capacity of the EAF of the line; they consume 20MW;
- CASTER: it's the station where casting starts. The plant has three caster:
  - NNS (Near Net Caster): capacity 100 T/H, it mainly supplies billets to Large Section Mill (LSM);
  - B CASTER: capacity between 100 and 160 T/H, it supplies billets to Medi-um Section Mill (MSM);
  - A CASTER: capacity 100 T/H, it supplies billets to Bar Section Mill (BSM).
- MILLER: three rolling mills.

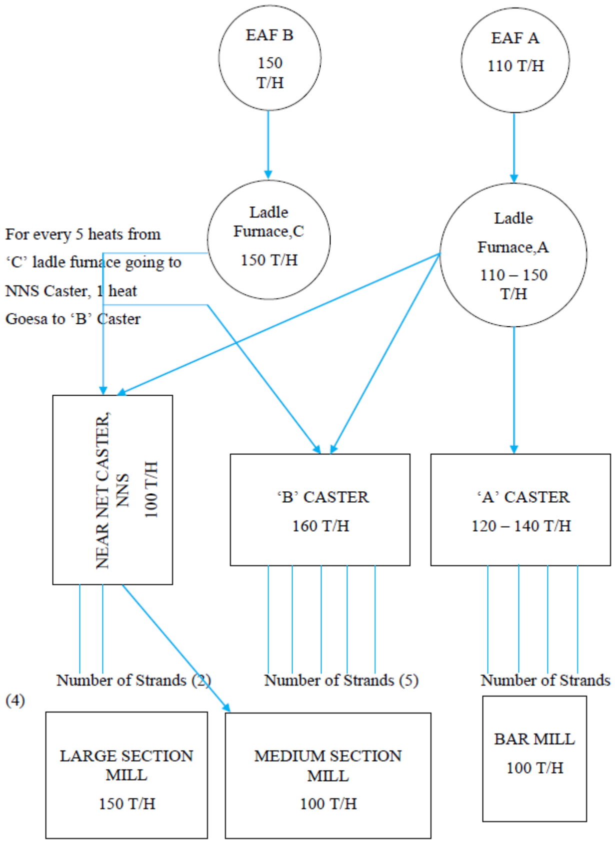

Fig. 1. Process flow diagram.

III. Consumption Data

The steelworks consumptions have been monitored and collected in a data-base for a period between 1/1/2010 and 30/9/2015, excluding the year 2012 for which it was not possible to obtain an exhaustive documentation.

Each day has been divided into 3 shifts (from 9 p.m. of the day before to 4.00 a.m. of the current day, from 5.00 a.m. to 12.00 a.m. of the current day, from 1.00 p.m. to 8.00 p.m. of the current day). The average of hourly required power has been calculated, such as the average of all day. Based on this, can be identified:

— Days of production: if the average of the absorbed power is 21 MW at least;

— Days of ramp down production if: (i)The second half of the first shift, the second shift and the first half of the third are productive; (ii)The day hasn't been classified as productive; (iii)The first half of the third shift, the second half of itself and the first half of the first shift (the one related to the day after) have to be characterized by a ramp down.

— We have a ramp down if:

1. The second half of the previous shift is productive;
2. The first half of the next shift is no-productive;
3. The average of the half concerned is higher than the average of the next half;
4. The first value of the half under exam is higher than the value associated last hour of the half itself.
5. The next half is no-productive.

— Days of ramp up production if (i)the second half of the first round, the first half of the second or the second half of the same must be characterized by a rising ramp; (ii) the second half of the second shift have to be productive just like all the third shift and the first half of the first shift (the one connected to the next day); (iii) the day must not have already been classified as fully productive.

— We have a ramp up if:

1. the second half of the previous shift is non-productive;
2. the first half of the next shift is productive;
3. the average of the half in question is less than average of the later half;
4. the first value of the half under examination, corresponds to the first hour of the same, is less than the value associated with the last hour of the same half;
5. the half later is productive.

— Days of no-production if: (i) the first half and the second half of the first shift are not productive; (ii) the second and the third shift are not productive; (iii) the day hasn't been categorized as productive with one of the two ramps.

— Abnormal days: any day does not fit into any of the classes above described.

Each of the 1732 days analyzed has been assigned to the category with the following result:

- 336 whole days production;
- 523 no-productive days;
- 81 productive days characterized by ramp down;
- 88 productive days characterized by ramp ;
- 704 abnormal days.

IV. Construction of Production Profiles Based on Planning

In this section will be described the steps moved to create a simplified ideal produc-tion profile basing on which to organize and manage the purchase of electric energy, avoiding to buy useless power in those days in which the plant will be stopped or partially operative.

An optimized production plan, based on times that each machine uses for doing its task, was implemented. In particular, in the following are described the processing times for a complete production process.

EAF: 60 minutes; Transport between EAF and LF: 5 minutes; LF: 40 minutes; Transport between LF and CCO/VD: 5 minutes; Degassing (DEG): 20 minutes; Con-tinuous casting (CCO): 40 minutes.

The last two processes were considered as one for simplicity, creating a unique process CCO/VD lasting 60 minutes.

For each of the three equipments, a power-time chart was built, containing the ab-sorbed MW (y axis) in function of time (x axis). if we carry all three in the same chart, we can achieve the graph in the next figure; the equipment consumptions are estimated in 50 MW for EAF, 20 MW for LF and 1MW per both degassing and CCO.

Planning begins from "zero-day" and the first process of each equipment doesn't consider the time interval needed to reach the processing temperature.

To optimize working time, in both the lines of the plant the second casting starts when the first semi-finished piece is exiting from the ladle furnace (LF) (gap time of 5 minutes) in order to avoid delays which would turn into costs for missed production.

The treatment in ladle furnaces LCF-A and LF-B lasts for

ISBN: 978-988-14048-4-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

40 minutes, after which billets are transported, in a 5 minutes time, to degassing machine. This treatment lasts 20 minutes, downstream of which there is the continuous casting plant which termi-nates its work after 40 minutes.

Reporting on a single diagram the power required by all the three components (EAF, LF and CCO/VD) in order to complete a production phase, in the ideal case of considering instantaneous the temperature ramps (zero startup time), to transform a whole steel batch into finished product, and overlapping of three of these optimized power diagrams, opportunely shifted in time one each other, the diagram in Figure 2 is obtained.

Summing in function of time the power values and considering a base-load power for auxiliaries equal to 5 MW, the diagram of the total absorbed power is obtained, as visible in Figure3.

From this diagram it is possible to estimate the energy amount required for each hour of plant operation, as visible in Figure 4.

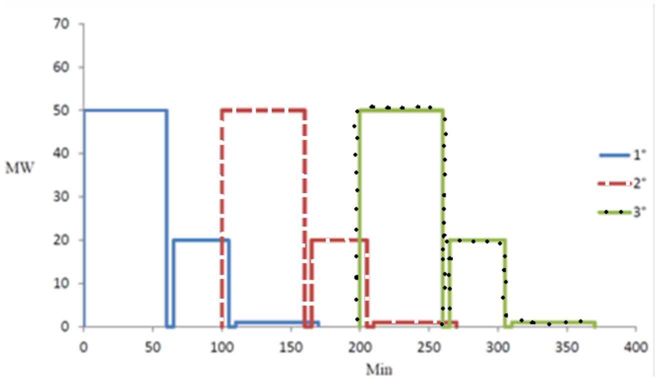

Fig. 2. Three cycles in series.

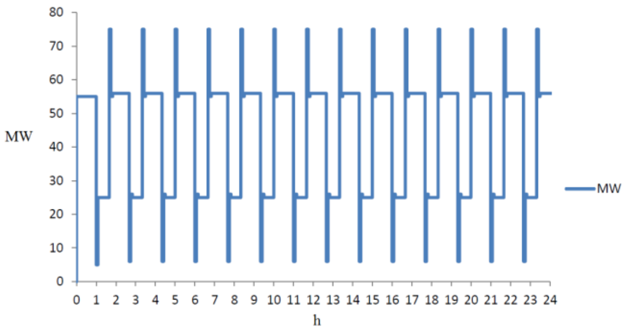

Fig. 3. Total absorbed power.

V. Comparison between Planning and Real Data

In this section energy and power analysis [2-8] is conducted, for each day typology as described in paragraph 3. The planned power and energy data were compared to the plant real data, by employing the MAPE (Mean Absolute Percentage Error), the Least Squares and the ANOVA variance methods.

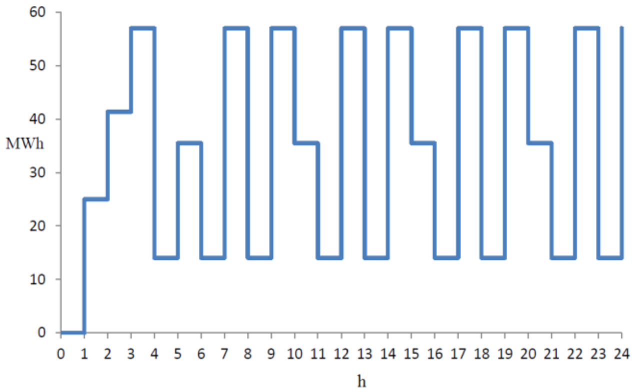

Fig. 4. Energy consumed in each hour of plant operation.

A. MAPE

The MAPE (Mean Absolute Percentage Error) is defined as:

(Expected Value- Real Value)/Real Value.

Such value was calculated for all the days typologies above described, both for en-ergy and for power values, obtaining the following results:

— - production days: 27,2% (energy) and 32% (power);

— - no-production days: 76,7% (energy) and 84% (power);

— - production days with ramp up: 12,7% (energy) and 13% (power);

— - production days with ramp down: 80,4% (energy) and 81% (power);

— - anomalous days: 38% (energy) and 76% (power).

B. Least squares

It is an optimization technique that allows to determine the linear function that mini-mizes the sum of squares of distances between data. The general formula of the straight line is: y= mx +q where y in this case is the actual plant data, the x is the planning data. Also in this case the analysis is carried out for all the five day typolo-gies.

It was first calculated the hourly average of relative power errors for the days from which were determined:

— Average Error: the average of the power errors;

— Error^2: square of all the related errors;

— Average Error^2: the average of the values just above;

— Average Hours: the average of the twenty four hours per day;

— AverageHours^2. the average of the squares of hours;

— Error*Hour: the product of the errors and their hours;

— Average (Err*Hour): the average of the 24 values calculated above.

The coefficient m is given by:

$$m = \frac{(x \,.\, y)^{*} - x^{*} . y^{*}}{(x^{2})^{*} - (x^{*})\text{^}2} \quad (1)$$

where:

— (x . y)* : it is the average of the product of the actual data for the ideal ones ;

— x* : it is the average oh the ideal data ;

— y*: the average of real data;

— (x^2)*:it is the average of the square of the ideal data;

ISBN: 978-988-14048-4-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

— (x*)^2 :it is the square of the average of the real data

The known term, q, is given by:
q = y – m x

The calculation of the correlation coefficient (CP), also called Pearson coefficient, gives us an indication on the goodness of our approximation: its range is [-1;+1], more its value tends to 1, better was the approximation.

$$CP = \frac{(x\,.\,y\,)^{*} - x^{*}y^{*}}{sqr\,\{[(x^{2})^{*} - (x^{*})^{2}] - [(y^{2})^{*} - (y^{*})^{2}]\}} \quad (2)$$

As for the power analysis:

- For productive days CP is 0,1167
- For no-productive days CP = 0,066
- For abnormal days CP = 0,7670
- For productive days with ramp CP is 0,739
- For productive days with ramp down CP = 0,33

As regards the energy analysis is obtained:

- For productive days CP = -4,5E-02
- For no-productive days CP = 6,9E-02
- For abnormal days CP = 7E-02
- For productive days with ramp CP = 1E-02
- For productive days with ramp down CP = 3E-02

C. *Analysis of variance (ANOVA)*

Analysis of Variance (ANOVA) is a collection of statistical models used to analyze the differences among group means and their associated procedures. It is based on the test null hypothesis: H0 = the average of different populations are the same; indicating with µ1, µ2, µ3 the average dimensions of populations, the null hypothesis can be written as H0: µ1 = µ2 = µ3 = … = µk. Once we have gathered data, the solidity of the null hypothesis can be gauged. The variability measured between k average (on groups) are compared to variability on each population (in groups). The comparison between variance on groups and variance in groups gives F-value: low F-value means that H0 is true, high F-value means that H0 is false. In this context, the P-value is defined as the probability that the observed data come from the null hypothesis or from the alternative hypothesis. In particular, high P-values favour the null hypothesis, while low P-values are against the null hypothesis. The P-values calculated for the different day typologies are presented in the following:

- For productive days: 6,85 E-73
- For no-productive days: 1,05E-50
- For abnormal days: 1,24E-271
- For productive days with ramp: 1,55E-06
- For productive days with ramp down: 1,91E-34

Such small values are an evidence against the null hypothesis, but relative errors are not classifiable, thus it is not possible to establish their nature by means of this analysis [10].

VI. Electric market

A. *Market structure*

Since 2005, the spot energy market has been divided into Day-ahead market (MGP), intraday market (MI), adjustment market (MA) and the market for ancillary services (MSD).

1. The day-ahead market presents an auction system where both bidders and buyers take part; bids are characterized by quantity and unit price for energy, the purpose of this market is to point out the possibility to sell and/or to buy energy not at a lower price than the one that has been proposed. GME (Electric Market Manager) arranges bids and purchase offers and it draws two graphs: (i) The sale curve: bids are ordered by descending price. (ii) The purchase curve: purchases offers are ordered by descending price.

The intersection of the two curves (point P*) defines how much energy can be ex-changed, the reached price, the approved offers and injection and withdrawal pro-grams. The selling price of the accepted offers is not higher than P* and the pur-chase price is not lower than P*.

2. The intraday markets (MI). Also these markets are managed by GME. The price calculation and the method of acceptance are the same as MGP. MI is divided into 4 submarkets (MI 1 to MI 4) according to the opening hour.

3. Adjustment market (MA). It opens at 10.30 after communication of the re-sults of MGP, it have to allow operators to modify programs that have been deter-mined after results of MGP; they can make new bids and it closes at 14.00.

4. The market for ancillary services (MSD). It opens at 14.30 after results of MA and it closes at 16.00.

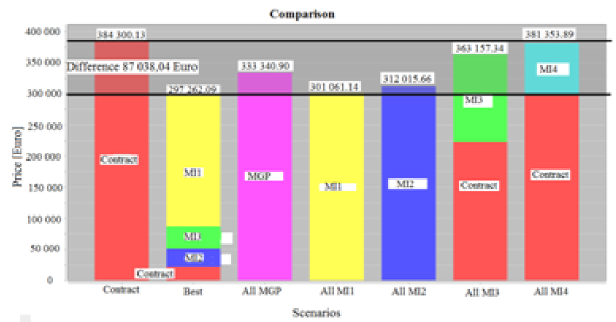

Fig. 5. Comparison diagram for energy purchase decision making.

B. *Software tool for energy purchase on the market*

To complete the optimization tool for steelworks, a software able to forecast energy price in the market based on energy price historical data was implemented. In Figure 5 is visible the graphical interface that helps the user to make decisions about the possible power buying options, this model was implemented using Systems Dynamics formalism based approach tested by Authors in many applications [9] .

Each bar of the diagram shows the total price of energy if we act on markets in different way;

referring to the graph in Figure 5:

— Bar 1: all the energy is purchased at the contract price.

— Bar 2: the amount of energy required for production is purchased in a mix of dif-ferent markets according to a cost

ISBN: 978-988-14048-4-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

minimization calculation made by the platform.

─ Bar 3 to 5: all the energy is bought in the outlined market.

─ Bar 6: part of the energy is bought in the MI 3 market price, and the remaining part at the contract price.

─ Bar 7: part of the energy is bought in the MI 4 market price, and the remaining part at the contract price.

VII. CONCLUSION

This paper presented a planning methodology for a steelworks production. The meth-odology efficacy was tested by comparison with real power and energy data collected from an operative plant in a long observation time. The comparison between real data and planning was carried out by three mathematical methods, whose main results are summarized in the following.

1. For the MAPE method is:

- Acceptable for productive day and productive days with ramp up (for both ener-getic and power analysis)
- Not acceptable for no-productive days and productive days with ramp down both for energetic and power analysis.

2. For least squares:

- Acceptable for productive days with ramp and abnormal days for power analysis
- Non acceptable for no-productive days for power analysis and for all 5 types for energetic analysis

3. Analysis of Variance:

- Errors are determined by events, so it is not possible to classify with this analysis.

Finally using the proposed methodology with a market analysis tool is was possible to obtain significant savings on energy purchase.

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ISBN: 978-988-14048-4-8
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