Study and Filtering of Harmonics in Steel Industry

Y. DJEGHADER and H. LABAR

ABSTRACT *- In modern steel industry, Electric Arc Furnaces (EAFs) are widely used for iron and scarp melting. The operation of electric arc furnace causes many power quality problems. They generate current harmonics including low frequency and cause of flicker. It is important to build a practical model to describe the behaviour of electric arc furnace. This paper presents a DC Electric Arc Furnace, the model is based on utilization of twelve power rectifiers for the study of harmonics in electrical networks. The model has been implemented using a numerical simulation environment to facilitate later analysis. In the second part of this work we made a reduction of these harmonics, using conventional methods such as the compensation and passive filtering. Several simulations were performed to find the best combination that gives us a minimum THD below the standard "Standard IEEE Std-519."*

Keywords: Arc furnace, harmonics, flicker, power quality, filtering.

1. INTRODUCTION

The arc furnace was used industrially in the manufacture of steel in the early twentieth century. Its flexibility has simplified the production process of steel flows through the mini-mills. The arc furnace is today, in many cases, the merge tool is best suited. Today 35% of the steel in the world come from electric arc furnaces. Arc furnaces are highly developed in North America where they produce half of the steel. The use of arc furnaces is increasingly considered in the countries of Eastern Europe, by steel integrated mills, faced with high costs of maintenance of furnaces and environmental problems [1, 3].

The electric arc furnaces (Electrical arc Furnaces (EAFS)) receptors are specific electrical charge with a continuous duty cycle, characterized by the succession of mergers, with the decision to drain the liquid metal, and bake for loading. During operation, the arc furnace causes random shocks reactive power, determining the appearance of the busbars from the center of power disturbances that affect the normal functioning of other consumers connected to the same point with the oven. The arc furnace consists essentially of a tank filled with refractory material, tipping for casting and slagging, and intended to receive the metal charge is melted by means of one or more electric arcs struck between graphite electrodes and the load.

Figure 1 shows the structure of an AC arc furnace. Originally, the arc furnace was used primarily for the production of special steels, because it allows not only reach high temperatures (above 1650 ° C), but also to achieve a refined measure ensuring the choice an oxidizing atmosphere and / or reductive. Over the years, the arc furnace has experienced dramatic improvements and has become a multi-energy metal reactor [1].

The reduction in the length of refining liquid steel and the increased power density, has improved its competitiveness by increasing productivity and reducing energy consumption. Arc furnaces are now widely used and represent, in many cases, the merge tool is best suited. Thus, the range of finished products obtained in runs requiring the use of many raw materials [3, 4].

2. DC ARC FURNACE (DC EAF)

By nature, the DC arc is more stable than the AC arc, so it produces less fluctuation means fewer flickers. This is one reason that led to the development of DC arc furnaces. The difference between the DC EAF and AC EAF lies in the power supply [6].

The power of arc furnace current recovery has a AC/DC,-based power electronic circuits. It has one or more electrodes that form the sole anode, the cathode being formed by one or more graphite electrodes. The hearth electrode implanted in the bottom of the tank to close the electrical circuit [3,6]. DC characteristic of the oven, which proved to be an important advantage when passed to the industrial stage, is the behavior of the arc [8,9]. While the AC arc is directed to the oven walls with an angle of 30 to 45 degrees, the arc current goes from the electrode tip to the bathroom and turned several times a second at random because electromagnetic forces. Control of the arc deviation requires a careful study of the path of drivers. The melting of the scrap is faster and more regular, heat losses are lower. We can design a change to an electric melting process (ARP "Arc Refining Process") both automated and optimized [5,8] with bath deep and intense mixing.

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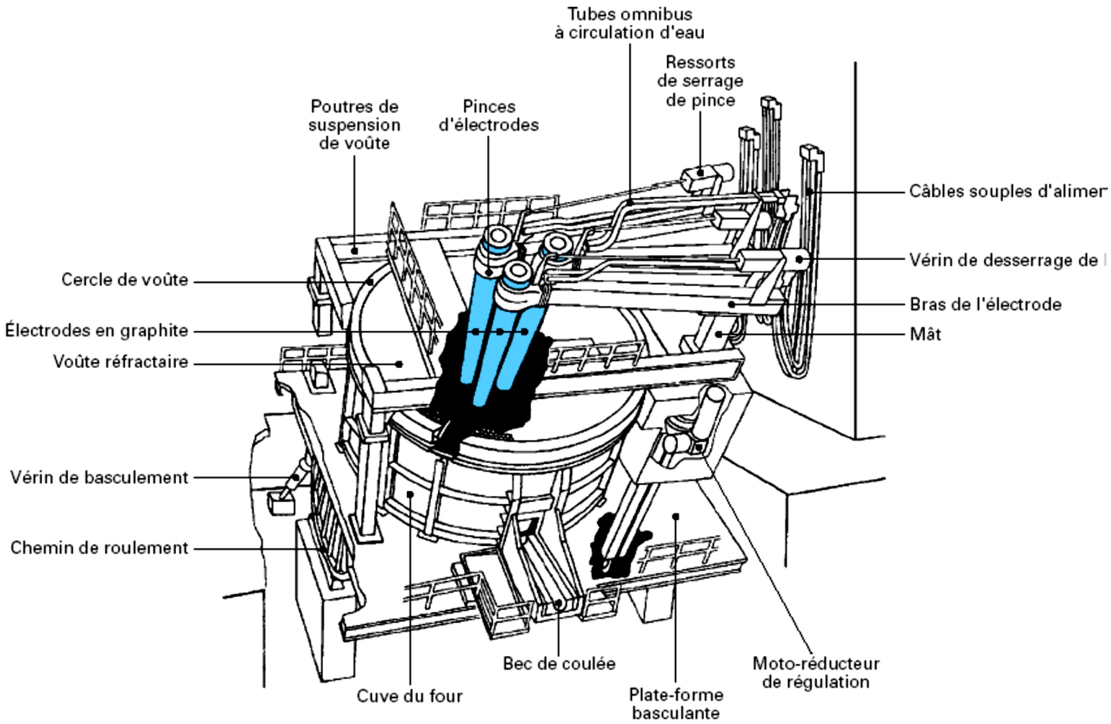

Fig. 1. Electric arc furnace.

Now, the oven can be attributed DC the following advantages over the alternative oven:

- Flicker reduction of about 50 %.
- Significant reduction of noise.
- Reduced consumption of graphite electrode (about 1.2 kg/t from 1.3 to 1.5 against the alternative oven).
- Increased productivity and energy savings (about 2%).

3. DESCRIPTION OF THE MODEL

Our model is to use a twelve pulse rectifier for feeding three-phase arc furnace [8], and our proposal is used as output rectifiers' electrodes of the furnace, as shown in Figure 2.

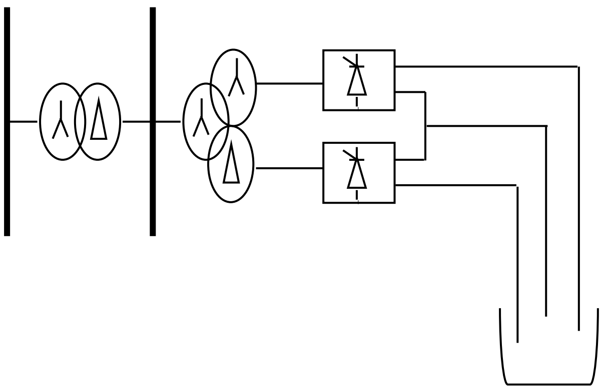

Fig. 2. Proposed model of a DC EAF.

The principle is to use a transformer with two secondary delivering voltages shifted from 30 ° to each other, each side feeding a **Graetz bridge** rectifier which carries a **six-phase** recovery. This means it includes two bridges converters. A bridge connection **star-star** (PD3) and another bridge to connect **star - delta** (S3).

Generally used the parallel two-phase thyristor bridge, connected to a double winding transformer. The rectifiers must provide identical currents so that they take on alternating current transformer secondary have the same values.

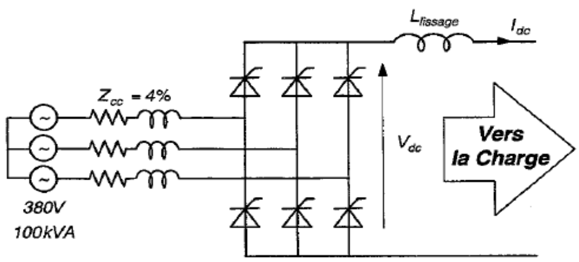

Fig. 3. Graetz bridge rectifier.

Under these conditions, there is a recombination of the harmonic currents generated by each of the rectifier transformer primary and the calculation shows that the harmonics **6.k ± 1** with k odd are eliminated [8.10].

4. SIMULATIONS RESULTS

The following figure shows the shape of current at the output of parallel double three-phase rectifier (PD3) for the three phases.

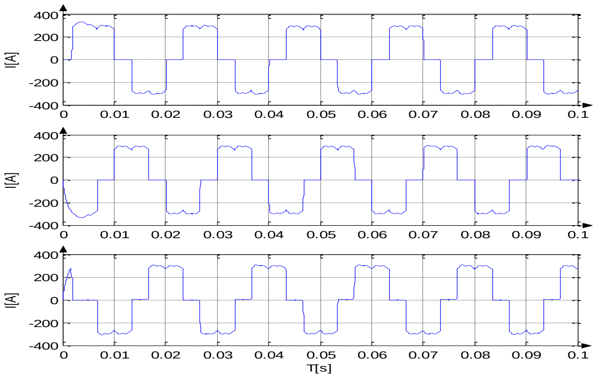

Fig. 4. Current at the star of transformer rectifier.

In Figure 5 we show the shape of current at the output of three-phase rectifier series (S3) star-delta connection for the three phases.

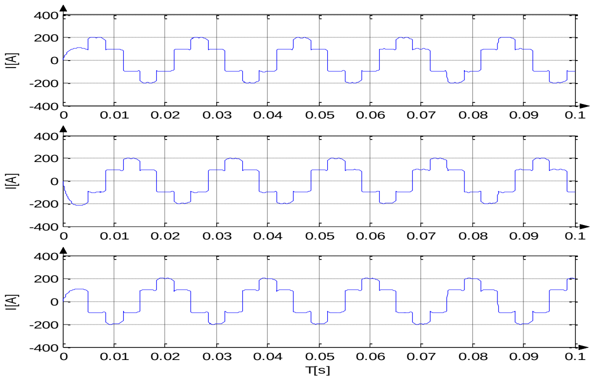

Fig. 5. Current at the triangle of transformer rectifier.

We have made the parallel to both the rectifier PD3 and S3 reason to increase the current; we obtain a twelve pulse rectifier (P12). The following figure shows the forms of three-phase current.

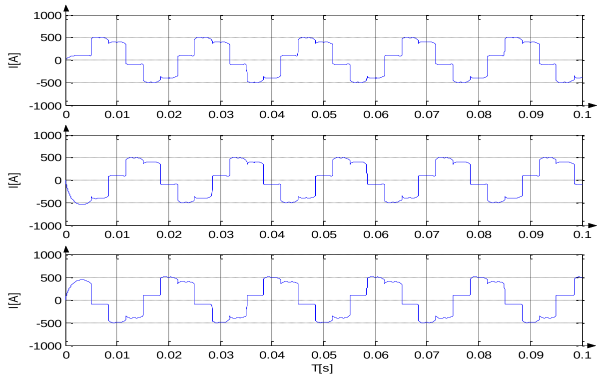

Fig. 6. Current of twelve pulse rectifier.

5. MODELING OF A DC EAF

We use an empirical mathematical model arc furnace modeled after their resistance and reactance arc [11] :

$$R_{arc}=A_R(u)e^{\alpha(u)d} \quad (1)$$

$$A_R=\frac{\left[0.7.(U\text{-}210)^2+1.7\right]}{50^2}.10^{-3} \quad (2)$$

$$\alpha=0.097e^{0.011(90-U)}-\frac{1.7}{(U\text{-}112)^2+80}+\frac{100}{(U\text{-}360)^2+50} \quad (3)$$

$$X_{arc}=A_X(u)d^2+B_X(u) \quad (4)$$

$$A_X=1{,}05.10^{-3}e^{0.075(90-U)} \quad (5)$$

$$B_X=\frac{3{,}14.U}{153}-3.10^{-3}.e^{0.075(90-U)} \quad (6)$$

with:

R_{arc} & X_{arc}: The resistance and reactance of arc.

A_R, α, A_X et B_X : Are constants that depend on the experimental output voltage and the distance between the electrodes.

Using this model in our work gives the results presented in the following figure.

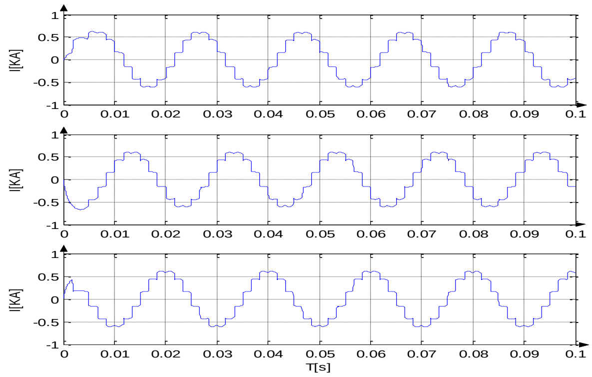

Fig. 7. Current of a DC EAF.

Figure 8 shows the harmonic current spectrum of an DC arc furnace powered through a twelve-bridge rectifier, the presence of the latter explains the high harmonics of ranks 11 and 13.

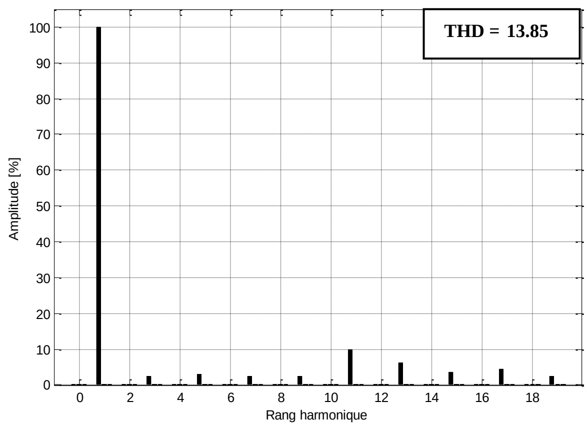

Fig. 8. Harmonic spectrum of the furnace.

6. HARMONIC FILTERING

6.1. Passive filtering

A passive filter has two functions: first, it must compensate the reactive power on the other hand, it must reduce the troublesome harmonics. The design of the filters is very complex because on the one hand, the impedance of the network is variable in nature and on the other hand, the harmonic currents generated by the arc furnace are poorly understood and taken into account requires a measurement campaign. Filters are always connected in parallel across the network [1.13]. The single phase equivalent circuit of a resonant filter unamortized connected to the network is represented in Figure 9.

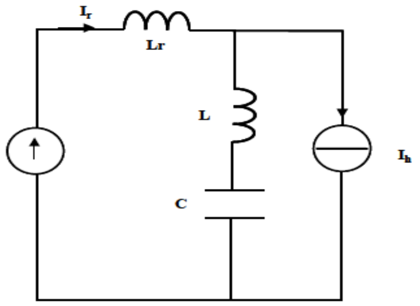

Fig. 9. Single-phase equivalent circuit diagram of a filter connected in parallel on the network harmonic of the furnace.

With:

Lr : The inductance of the network

E : Voltage of the line.

I_h : Harmonics currents equivalent to the « arc furnace ».

L & C: Parameters of passive filter

The equivalent transfer function is given by Equation 7:

$$\frac{I_r}{I_h} = \frac{(1+p^2LC)}{(1+p^2C(L_r+L))} \quad (7)$$

The transfer function thus shows a parallel resonance (or anti-resonance) in addition to the natural resonance of the filter.

Resonant filter is given by the equation (8):

$$\omega_a = 2\pi f_a = \frac{1}{\sqrt{LC}} \quad (8)$$

Anti-resonance is given by the following formula:

$$\omega_{ar} = 2\pi f_{ar} = \frac{1}{\sqrt{(Lr+L)C}} \quad (9)$$

The frequency of anti-resonance filters shunt is particularly troublesome. This frequency does not correspond to a harmonic characteristic. Damped low loss filters are often used to circumvent this problem. A structure of this type is shown in “Figure 8”.

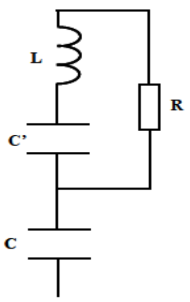

Fig10. Damped low loss filter.

C’ : is calculated to obtain:

$$\omega_1 = 2\pi f_a = \frac{1}{\sqrt{LC'}} \quad (10)$$

ω_1 : is theω angular frequency of the mains voltage supply. Thus, the fundamental current will not flow through the resistor.

Reactive power compensation is defined by this equation .

$$Q_{COMP} = \frac{U^2.C.\omega_1}{1-\omega_1 LC} \Rightarrow Q_{COMP} \succ Q_C$$

Reactive power compensation of a capacitor filter is arranged higher than that provided by a capacitor bank alone. The arc furnace current is fed by thyristor rectifier bridges. And harmonics are generated by static converters. For thyristor rectifiers, the ranks h harmonic currents dominate, known characteristics, expressed by the following equation: h = kp± 1.

With: k = 1 ... n; and p: index pulse converter (our case p = 12). However, in practice non-characteristic harmonics appear consecutively inaccuracies angles to delay the initiation of thyristors, the imbalances of supply voltages.

7. SIMULATION RESULTS

7.1. Resonant Filter only

7.1.1. Resonant filter to the rank 11

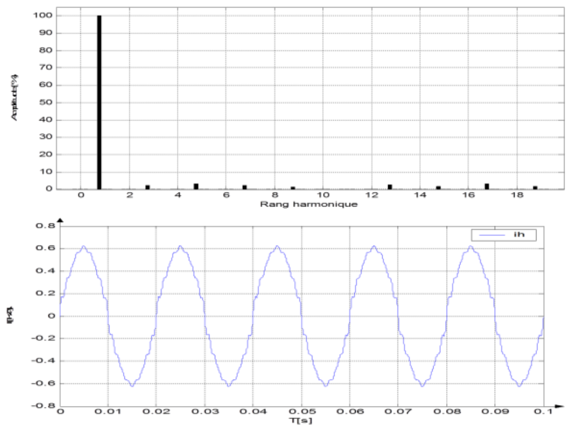

Fig. 11. Spectrum and current waveform (case A.1).

7.1.2. Resonant filter to the rank 13

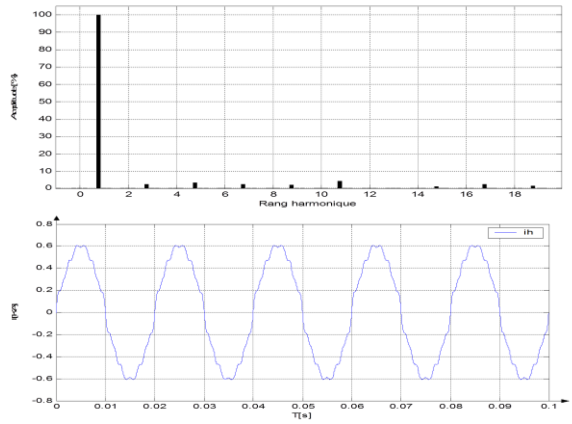

Fig 12 .Spectrum and current waveform (case A.2).

7.1.3. Resonant filters to the ranks 11 and 13

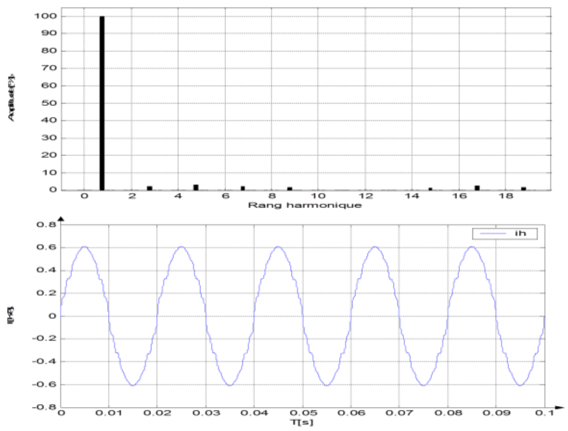

Fig 13 .Spectrum and current waveform (case A.3).

7.2. Mixed filtering " Resonant & Damped"

We used two resonants filters to the ranks 11 and 13 with a damped filter.

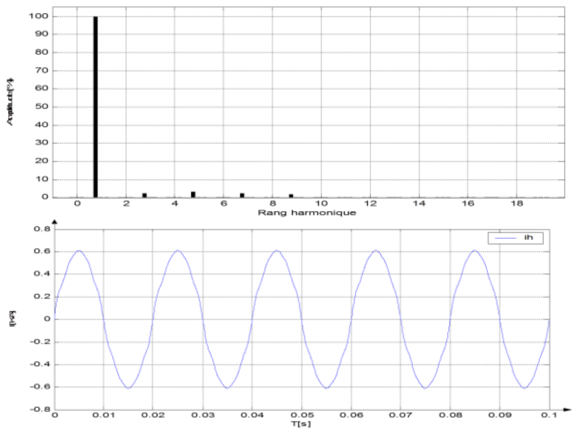

Fig 14 .Spectrum and current waveform (case B).

7.3. Compensation with filtering

We used a battery of compensation with two resonants filters for ranks 11 and 13 ,and a damped filter.

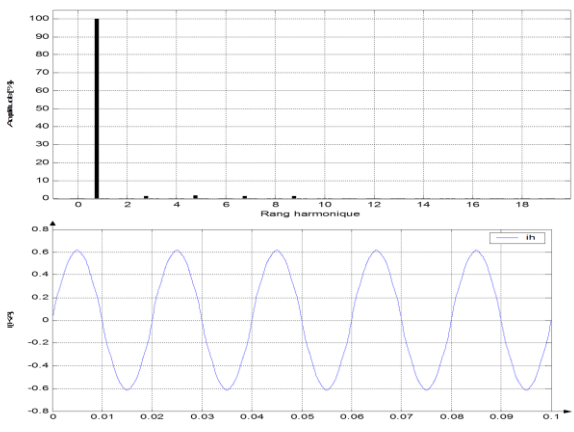

Fig. 15. Spectrum and current waveform (case C).

Table 1. Resultats of differents cases of simulations.

Device	THD [%]	Harmonics [%] H_5	H_7	H_{11}	H_{13}
DC EAF	13.85	3.10	2.60	9.84	6.08
DC EAF with RFH_{11}	6.9	3.18	2.33	**0**	2.56
DC EAF with RFH_{13}	7.19	3.20	2.43	4.19	**0**
DC EAF with RFH_{11+13}	6.04	3.20	2.38	**0**	**0**
DC EAF with (RFH_{11+13}+DF)	**4.98**	3.20	2.38	**0**	**0**
DC EAF with (RFH_{11+13}+DF+Comp)	**2.82**	1.66	1.35	**0**	**0**
IEEE 512-1992	**5**	**4**	**4**	**4**	**2**

8. CONCLUSION

The simulations results show the effectiveness of the method presented. The application of the proposed procedure hearts the uses of passive filters to reduce harmonics, and the offsetting deficit of reactive power.

At the end of this work we have mounted that the use of resonants filters corsponants to the harmonics 11 and 13, and a damped filter with and without compensation (cases B and C) gives us values of the harmonics and THD below the standard used **« IEEE 512-1992 ».**

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