Harmonics Mitigation Using the DC Power Supply Case Electric Arc Furnace

Y. DJEGHADER and H. LABAR

ABSTRACT - *Electric Arc electric (EAFs) highly reduce power quality of the network by generating disturbances such as flicker and harmonics. The harmonics created by powerful nonlinear loads and abrupt changes of such loads (EAF) can considerably worsen quality of the buses voltage feeding of such loads. In this paper we presents a new electric arc furnace model based of his parameters (R_{arc} and X_{arc}) has been proposed. This paper investigates the harmonics produced from electric arc furnace operation generated by an AC EAF. In this work we also made a change on the power supply i.e. we make to the DC EAF, shows that there is an optimisation in power quality study shows that mitigation of harmonics 5 and 7, give a small THD and so improvement of the plant power factor.*

Keywords: EAF, Electrical arc, Harmonics, Power Quality, Steelmaking.

1. INTRODUCTION

The electric arc furnace (EAF) employs high temperatures produced by the low-voltage and high-current electric arc which exists between the electrode and melting material [2]. Nowadays, EAFs are designed for very large power input ratings and due to the nature of the electric arc and the meltdown processes, these devices cause significant electric distortion such as harmonics, inter-harmonics and flickers in the supply network. Electric utilities and their customers pay much attention to mitigate such power quality (PQ) problems associated with EAF loads [3, 4].

Obtaining time response of the EAF is important for investigating the impact of the nonlinear and time-varying load on power systems. Because of the technical and economical superiority of Electric Arc Furnace (EAF) in steel-making, the application of EAFs in metallurgical industry is increasing day by day, the monomer capacity is increasing unceasingly also, and the disturbances produced by EAFs to power system are becoming more and more prominent [1,5].

From the two available technologies of this process (alternating current (AC) and direct current (DC) systems), the DC technology currently covers approximately 70 pct of the new EAF being commissioned around the world due to several advantages this technology has in comparison to the AC furnace. DC power supplies are widely used in the steel and non-ferrous industries technology while improving safety, reliability, efficiency, maintainability and performance. With increasing pressure from utility companies to their big industrial customer to be ‘clean’ (low flicker, tighter power factor requirements and no unbalanced load), DC EAF technology continues to demonstrate advantages over AC EAFs.

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As plants with EAF’s are often built close to the mine site, in a rural area far away from the next power station, the utility’s electrical grid is normally very weak for big industrial consumers (a Minimal easily consumes 400 MVA). In such cases, DC EAF becomes the ideal answer [14, 15].

2. OPERATION OF THE EAF

The typical EAF load cycle varies from 4 to 7 hours depending upon the size of the furnace and metallurgical requirement .The operation of the arc furnace is divided into melting and refining stages [7]. The random property of arc melting process contributes to lowering of power factor resulting in additional voltage drop through the power system yielding a lower system voltage on the plant buses. The arc melting process is a very complicated process. It converts the electrical energy into thermal energy.

The electric arc is used to melt the raw materials held by the furnace. The random movement of the melting material results in heavy current fluctuations during the arc melting process. During the refining period, the scrap metal is at a molten form and hence fluctuations are small. The furnace operation depends upon arc voltage, arc current and arc length, which is determined by the position of the electrodes, by examining the actual “V-I” characteristic of the arc furnace [13].

In an iron and steel plant, the loads problematic in terms of PQ are EAFs, ladle furnaces (LFs) and rolling mills (RMs). EAFs are the main sources of harmonics, inter-harmonics, flicker and varying reactive power consumption caused by the iron and steel plant; although, LFs and RMs also cause relatively less significant PQ disturbances. The power system of an EAF consists of utility grid, high voltage/medium voltage (HV/MV) power transformer, cables and/or

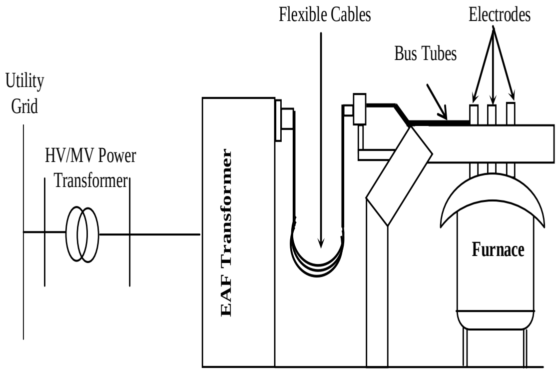


Fig. 1. Illustration of the AC EAF Power System.

O/H line segments, EAF transformer, flexible cables, bus tubes and electrodes as illustrated in Fig. 1.

It constitutes nearly 75% of the total impedance as viewed from the low voltage (LV) terminals of the EAF transformer and varies in time during the operation of the EAF. Furthermore, the non-linear arc resistance is changing dynamically depending not only on the state of the scrap and the molten material within the crucible but also on the settings and capability of the electrode control system. Active power delivered to EAF is controlled by the operator either manually or in a pre-programmed manner by changing the taps of the EAF transformer several times from one tap to another. Therefore, the EAF is a highly inductive non-linear, unbalanced and rapidly changing load on the utility grid.

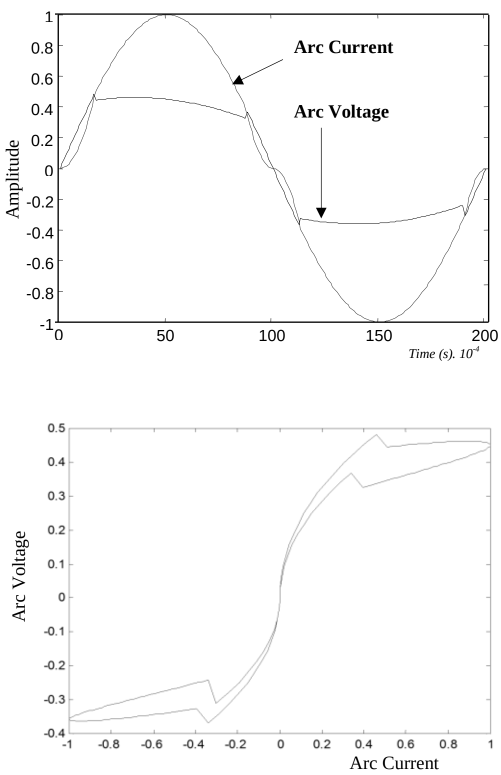
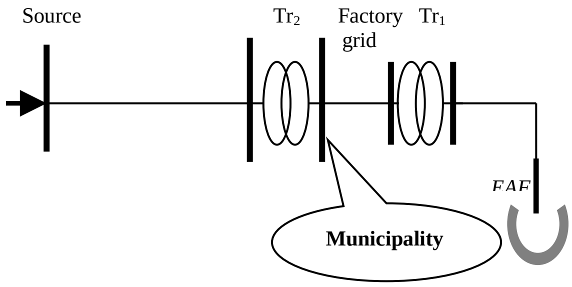


Fig. 2. Characteristic [IV] of the arc furnace.

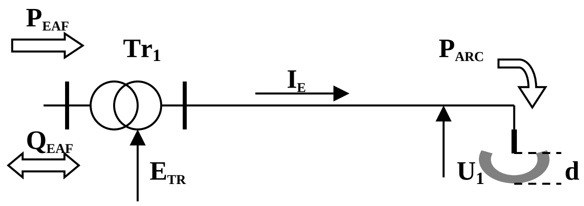
3. AC ELECTRIC ARC FURNACE

3.1. Model description

Our EAF melt steel, by applying an AC current to a steel scrap charge by means of graphite electrodes. It requires about 520 Kwh /ton, and produce 700t/year approximately, these characteristic in Annex 01.



a. EAF supply



b. Measured parameters

Fig. 3. Studied model.

3.2. Treatment of measured

The EAF is modelled together with the neighbouring network [13] .The circuit equation of the furnace transformer to the end of electrodes can be written as follow.

$$E_{tr} = \sqrt{3} Z_1 I_e + U_1 \tag{1}$$

Where U_1, I_e and Z_1 are respectively electrode voltage, current and impedance of EAF transformer with flexible cable [11, 12].

Then,

$$Z_1 = \frac{[E_{tr} - U_1]}{\sqrt{3} I_e} = \frac{\Delta U_1}{\sqrt{3} I_e} \tag{2}$$

$$Z_1 = \sqrt{R_1^2 (I_2, T) + X_1^2 (T)} \tag{3}$$

$$R_1 = \frac{P_{EAF} - P_{arc}}{3 I_e^2} \tag{4}$$

Where:

P_{EAF} : is total active power of EAF.

P_{arc} : is the active power of arc.

So, from equations (1, 2, and 3) we can deduct.

$$X_1 = \frac{1}{\sqrt{3} I_e} \sqrt{\Delta U_1^2 - \frac{[P_{EAF} - P_{arc}]^2}{3 I_e^2}} \tag{5}$$

$$R_{arc} = \frac{P_{arc}}{3I_e^2} \quad (6)$$

$$Q_{EAF} = Q_{arc} + \Delta Q \quad (7)$$

$$Q_{arc} = Q_{EAF} - 3I_e^2 X_1 \quad (8)$$

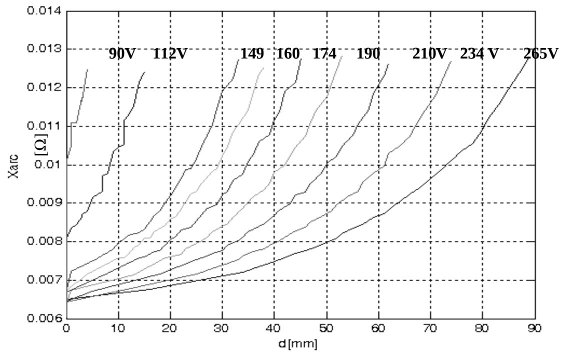
Where:

Q_{EAF} : is total reactive power of EAF.

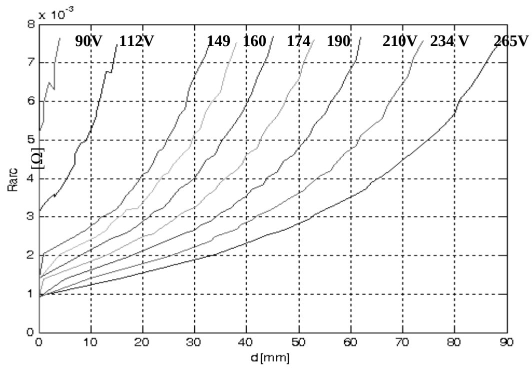
Q_{arc} : is the reactive power of arc.

$$X_{arc} = \frac{Q_{arc}}{3I_e^2} \quad (9)$$

According to the results of convenient measure we can draw the variation of the resistance and the reactance of the arc according to the distance between the electrodes and scrap as shown on the following figures [10].



a. Variation of X_{arc}



b. Variation of R_{arc}

Fig. 4. Variation of electric arc impedance.

Following to the treatment an empirical model is proposed [10, 11, and 12]:

$$R_{arc} = A_R(u)e^{\alpha(u)d} \quad (10)$$

Where:

$$A_R = \frac{\left[0,7.(U-210)^2 + 1,7\right]}{50^2}.10^{-3} \quad (11)$$

$$\alpha = 0,097e^{0,011(90-U)} - \frac{1,7}{(U-112)^2+80} + \frac{100}{(U-360)^2+50} \quad (12)$$

Where:

$$A_X = 1,05.10^{-3}e^{0,075(90-U)} \quad (13)$$

$$B_X = \frac{3,14}{153} - 3.10^{-3}e^{0,075(90-U)} \quad (14)$$

d : The distance between electrode and scrap.

3.3. Harmonics generated by AC EAF

The use of loads with non linear voltage-current characteristics, such as the arc furnace, result in the generation of voltage and current harmonics distortion. The arc at the electrode tips in an operating arc furnace acts as a voltage clamp with a trapezoidal waveform. Typical arc furnace voltage and current waveforms are shown in figure.2.The square or flat topped voltage waveform is rich in low-order odd harmonics such as 3^{rd}, 5^{th} and 7^{th} [6].

Due to the waveform variation of the arc voltage from half cycle to the other (unbalanced electrode arcing), there may be significant amounts of third harmonic and its multiples as well as even harmonics. In the following figure we represents the real harmonic spectre of an AC EAF to study, while using a special device to measure harmonics, but unfortunately, this device does not measure the inter-harmonics and harmonics above at fifteen.

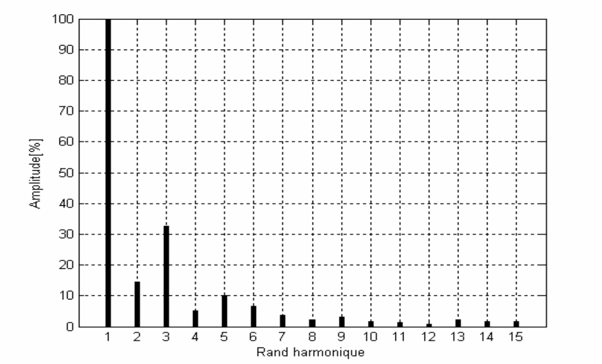


Fig. 5. Spectre harmonic of an AC EAF.

4. DC ELECTRIC ARC FURNACE

Many earlier papers have addressed the numerous advantages of the DC EAF. In summary, the following development was observed over the last 10 to 15 years: In the early/mid 90s, there were huge expectations for the newly promoted DC arc technology, based on thyristor rectifiers as power supply, promising better efficiency, better arc control, lower electrode consumption and lower flicker, while at the same time long life for the furnace bottom anodes and the furnace refractory was expected. As soon as the first success stories echoed, new ideas for DC power conversion were promoted, such as the chopper technology (converter based on IGBT) Modern high-power D.C. electric arc furnace (DC EAF) are considerable sources of power quality impacts in the electric supply systems. The total melting period of a DC EAF (tap to tap) is characterised by different operational points which are adjusted in dependency of the steel producing technique, each of it representing special load conditions within a melting cycle [16].

On base of the theoretical and experimental studies described before, a simulation model of the electric DC arc of an EAF was provided in form of a non linear passive network element. The result is a current-depending non-linear resistance .This element characterises the converter DC circuit of the EAF .The opportunities of a DC EAF simulator is mainly based on the release of twelve pulse rectifier. A typical DC arc furnace plant, is modelled as it is shown in Fig. 7. [10].

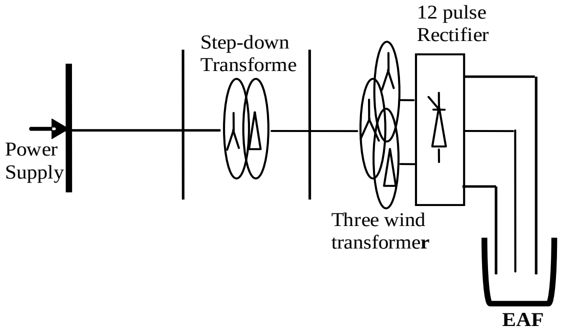


Fig. 6. Modelled DC EAF plant.

Advantages claimed for DC furnaces over AC furnaces include [14, 15]:

- 50% reduction in electrode consumption.
- 5 to 10% reduction in power consumption.
- Reduced refractory consumption.
- Uniform melting.
- 50% reduction in flicker.

4.1. Harmonics generated by DC EAF

We know that with the use of twelve pulse rectifiers the existing harmonics are characterised by following relationship $12k \pm 1$ [9]. The arc is supplied via a rectifier and is more stable than the arc in AC furnaces. The current drawn can be broken down into a spectrum similar to that of a rectifier is shown in figure.8 .But experience and analysis of the results also highlight a number of non-harmonic characteristics, amplitude non-negligible, especially in the area of low frequencies (harmonics ranges 5 and 7) [13].

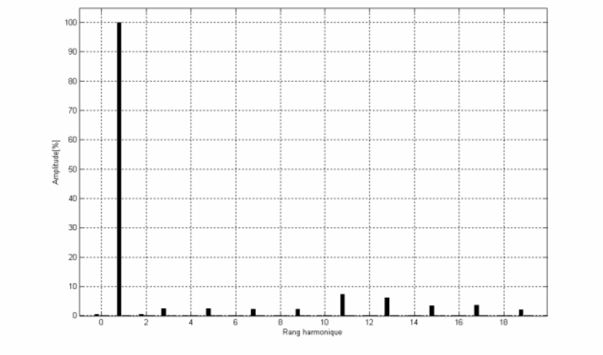


Fig. 7. Spectre harmonic of a DC EAF.

5. ANALYSIS OF HARMONICS

For the oven in AC EAF, we note that all harmonic quoted are superior to the norm "Table 01", on the other hand for the DC EAF, we notice that the harmonic of order 11 and 13 that are superior to the norm, on the other hand the harmonic others are lower as 5 and 7.

We take account that the total harmonic distortion "THD" of AC EAF is equal 34,38 % that are not acceptable; on the other hand the THD of the DC EAF that equals 12,03% is acceptable and give a better power factor and improvement of power quality.

The results of simulations and comparison with the norm are presented in the table 01.

TABLE I
IEC-CEI 61000-3-6 1996

HARMONICS	H_5 (%)	H_7 (%)	H_{11} (%)	H_{13} (%)
AC EAF	10,04	3,59	1,34	2,28
DC EAF	1,92	2,66	5,55	4,44
IEC-CEI 61000-3-6 1996	**3,5**	**3**	**2,2**	**1,2**

6. CONCLUSION

This paper presents a new Electric Arc Furnace model which implanted under numerical environment. This model is also valid for the DC EAF since it depends of parameters of the furnace. In this paper we make an improvement of power quality, that mitigation of harmonics especially use the DC EAF or have the elimination of the harmonic 5 and 7 that is the most major, as we have a small THD in relation to the AC furnace.

Therefore we can propose to put resonant passive filters to attenuate the harmonic biggest as 3, 5 and 7, and at the same time we compensate the deficit of the reactive energy. According to some survey the use of the compensation is sufficient, or while especially using the two; the compensations and the passive filters. Finally, our work falls within the overall framework of improving the quality of electrical energy level seats industrialists such a steelmaking.

ANNEX A: EAF CHARACTERISTICS

Transformer rating:	12, 5 [MVA]
Short circuit reactance:	2, 9 [mΩ]
Maximum electrode current	30, 84 [kA]
Number of voltage taps:	9
Voltage range:	[90 V ÷ 265 V]
Primary voltage:	63 [kV]
Weight capacity:	80 t
Temperature gradient:	3 ÷ 4 °C/mn
Furnace diameter:	2, 47 [m]
Electrode diameter:	0, 35 [m]
Distance electrode to wall:	0, 7 [m]

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