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Improvement of electrical arc furnace operation with an appropriate model

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ABSTRACT

Electrical arc furnaces are commonly employed in industry to produce molten steel by melting iron and scrap steel. Furnace control is a necessary operation for production optimization. The principal parameters to be controlled are: maximum productivity requirements, minimum power off time, good power quality and safety. The aim of this study is to achieve all these objectives. Hence, because of the stochastic and dynamic behaviour of the arc during the melting process, a proposed model is checked with measurements at an industrial electrical arc furnace. How electrodes position and transformer taps can affect *X* and *R* arc function are discussed in detail. This new operating strategy has been determined taking into account Flicker, melting stages and electrode positions. It is shown that optimum efficiency can be reached by the integration of the proposed model in regulation loop.

1. Introduction

Nonlinear loads are the principal cause of power quality problems [1] including voltage dips, harmonic distortion and Flicker [2–4]. An electrical arc furnace (EAF) is the worst nonlinear load type, because of the chaotic nature of arc impedance [5] as its conductivity is determined from temperature and pressure [6].

Irregularity in the voltage wave forms is caused by abrupt initiation [7] and interruption of current which provides a source of harmonic currents (Fig. 1). Thus voltage and current waves deviate considerably from a symmetrical sinusoidal form.

The increase in iron demand such as in vehicle industries encourages steel makers to invest more in metal recycling using electrical or chemical furnaces. It is known that electrical arc furnaces are used to provide high-quality steels from a raw material of steel scrap.

A typical furnace is shown in Fig 2. It consists of a refractory lined shell, a removable roof, three graphite electrodes, held in clamps at the end of a supporting arm, passing through openings in the furnace roof. Electrical power is supplied to the electrodes by an adjustable AC voltage tap transformer and the heat is generated by electric arcs between electrodes. Once a temperature of 1300 °C is reached the metal scrap starts melting (Fig. 3).

The maximum electrical power converted into heat occurs for a particular length of electric arc [8]. Any deviation from this optimum length impairs the power utilization efficiency. The steel load surface is irregular by nature of the scrap and as the melting process begins there is a change in the contours of the surface. Thus, random disturbances in the arc length occur continuously. It is the function of the position control system to respond to such disturbances by moving the electrode to maintain the arc length at its preset value [9].

1.1. Typical EAF process

First we load the furnace with metal scrap, then the electrodes can be lowered within the furnace using a specific regulator and mechanical drive for each electrode. The electrodes are connected to the furnace transformers, which may be rated from 90 to 265 volts, using 9 taps. To achieve meltdown as quickly as possible, one must follow the following stages [10,11].

Stage 1: The current is initiated by lowering the electrodes, just over the metal scrap.
Stage 2: Electrodes bore through the scrap to form a pool of liquid metal.
Stage 3: Electrical arc is lengthened by increasing the voltage to maximum power.
Stage 4: Arc length is changed so that the shorter arc will deliver a higher portion of its heat to the metal below the electrode.
Stage 5: Chemical treatments to improve steel quality are done under low power to maintain the liquid state.
Stage 6: The process is ended and the liquid metal is transferred.

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Nomenclature

P_{EAF}	total active power
P_{arc}	arc active power
Q_{EAF}	total reactive power
Q_{arc}	arc reactive power
Q^L_{EAF}	arc inductive reactive power
Q^C_{arc}	arc capacitive reactive power
X_{arc}	arc reactive impedance
X^L_{arc}	arc electromagnetic impedance
X^C_{arc}	arc electrostatic impedance
EAF	electric arc furnace
n	number of measurements
d	distance between electrodes and scrap
I_e	electrode current
U_1	electrode voltage

2. Model description

To operate the EAF considered in this study, an AC current is applied to graphite electrodes. It requires about 520 kWh/ton (Fig. 4a). All the processes of the electrical arc furnace (Appendix AAppendix A) can be summarized in Fig. 5 [12]. We have recorded 32 measurements for each parameter in 9 transformer taps (Fig. 4b). The operation of the electrical arc furnace is subjected to two main constraints, namely normal power and rated current. Fig. 5 shows the various limits of operation for each voltage tap. The control of the process by the rated current does not protect it sufficiently, since the absorbed power can largely exceed the capability of the furnace transformer. On the other hand, the control by the rating power offers a better protection for the furnace.

3. Instruments and error analysis

Currents, tensions and power measurements are done with standard precision instruments "model Goerz AE 111 S" connected to the secondary EAF transformer:

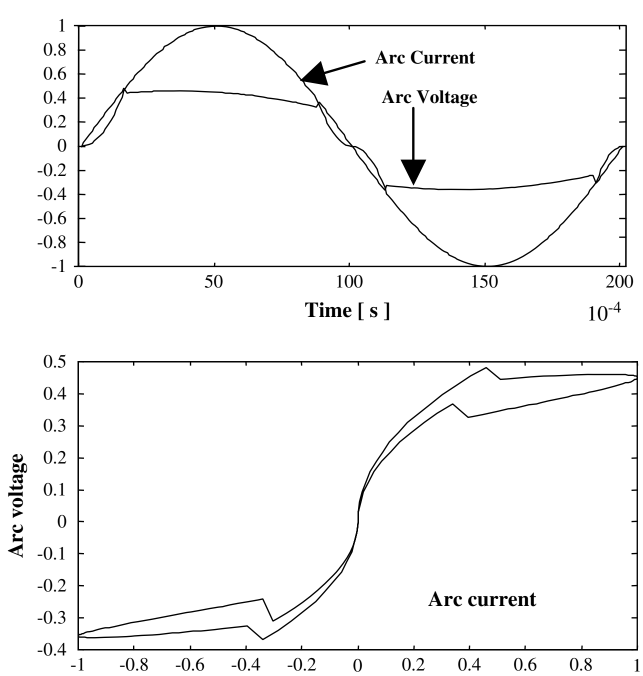

Fig. 1. Temporal and [IV] representation of electric arc current and voltage.

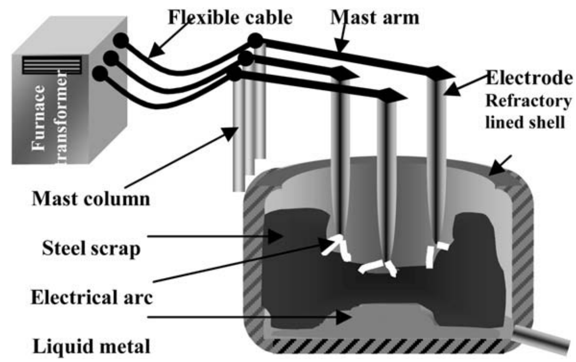

Fig. 2. Typical electrical arc furnace.

- Ampere-meter: 0–6 A, class 0.5
- Voltmeter: 90–265 V, class 0.5
- Wattmeter: 5 A, 130 V, class 0.5
- Transformer of current: 5–10–25–50/5 A, class 0.2

If one tests the instruments in the case of normal operation, under the effect of the electric arc, they can be distorted by the chaotic nature of the arc. For this reason, the tests are made in short-circuit mode, when immersing electrodes directly in the liquid steel (Table 1). For each case, phase current, lines to ground voltage and phase power are recorded (Table 2).

The maximum deviation of the impedance, resistance and inductance calculated for each test (Table 3) are respectively 2.89%, 3.73% and 2.98%. However, the melting process is supplied in three-phase current (with electrodes a, b and c) and the maximum errors are respectively 2.15%, 2.90% and 2.21%. Although these values are reached under extreme conditions, in the case of the EAF, they are of a very good precision because of the nonlinear and chaotic characteristics of the electric arcs. In normal operating mode, large deviations occur.

4. Measured parameters analysis

There are several working models of the electric arc furnace from the thermal point of view [13]. Our proposal is based on a modelling of the electrical parameters. The EAF is modelled together with the neighbouring network [14].The circuit equation of the furnace transformer up to the end of electrodes can be written as follows:

$$E_{tr} = \sqrt{3}Z_1 I_e + U_1 \quad (1)$$

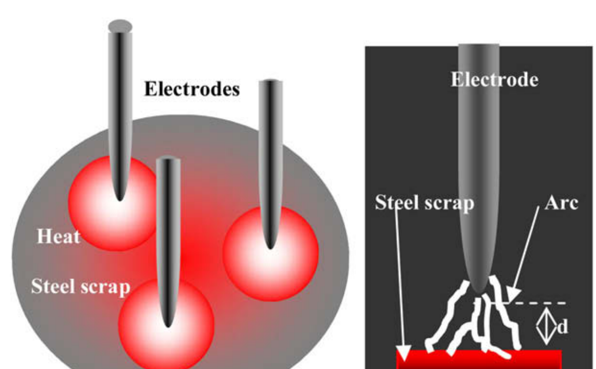

Fig. 3. Heat conversion by electric arc.