Validation of an Electric Arc Model in the Two Technological Phases of an Electric Arc Furnace Process

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Abstract: - It is well known that the electric arc is a nonlinear element. Thus, this paper presents a model used to analyze the electric arc behavior of a three phase electric arc furnace. This model is based on the voltage-current characteristic of the electric arc. The influence of the voltage on the secondary side of the furnace transformer on the model parameter waveforms was analyzed. Model parameters are the real technological installation parameters. Also, the accuracy of the model was tested by simulating the electric arc behavior in the two technological phases of the electric arc furnace process. The two stages are meltdown and refining stage of the charging material. Results obtained by simulation were compared with measured data.

Key-Words: - modeling, simulation, electric arc, nonlinear systems, meltdown stage, refining stage

1 Introduction

Electric arc furnace is a massive generator that causes disturbances in the electric power system. The three types of disturbances that appear in the electrical power system are: generation of the three phased harmonic currents, of an important reactive power and unbalanced high power three-phase load. So, it is necessary to find some solutions in order to improve the electric power qualitative indicators: the power factor and the three-phase electric charge [1].

Despite these major problems, these kinds of furnaces are used in the whole world in the iron and steel industry [2] because of the short time in the elaborating charge, good thermal efficiency, great real dissipated power, etc.

Normal operation of an electric arc can be divided into two stages: the meltdown stage and the refining stage. In the first stage the metal loaded in the furnace tank has different forms. In this stage the electric arc burning is unstable and the electric arc furnace absorbs as much active power as possible from the supply system [3]. In the refining stage, the charging material is melted, so the arc is becoming stable.

In Romania exists a three phase AC electric arc furnace which is used for the production of steel, so at this equipment, measurements were made. Measured data were acquired using a data acquisition board, ADA3100. This process is presented in [4]. Measured parameters are: the three-phase currents of the electric arc, the voltage at the point of common coupling, and the acquisition time. Measurements were made during an entire elaboration time of a charging material.

In the reference literature many models of the electric arc have been presented: models based on the non-linear and time-variable resistances [4]; models based on the approximation of voltage-current characteristic of the electric arc [5]; models where the voltage and the current are related by hyperbolic functions [6]; advanced models which use the artificial neural networks [7].

2 Modeling of the Electric Arc

This paper uses a model of the electric arc which is based on the voltage-current characteristic of the electric arc. One of the major requests that a model needs to fulfill is that it must allow modifying some parameters value that can be supervised in the real plant.

Electric arc models are influenced by the voltage on the secondary side of the furnace transformer, by the arc length and also by the phase in which the technologic process is: meltdown or refining stages.

Parameters that can be supervised and modified in the real plant are the distance between the

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graphite electrodes and the metallic bath and the tap of the furnace transformer. The distance between the electrodes and metallic bath can be modified in simulation by modifying the ignition and the extinction voltage of the electric arc. The tap of the transformer can be also modified in simulation by changing the voltage at the secondary side of the transformer that feeds the electric arc. In the real plant the charging material is loaded in the furnace tank and during melting process the tap of the transformer will be changed.

Next, will be presented a model of the electric arc that exists in the reference literature and will be tested the accuracy of it using Matlab/Simulink software. This model was proposed by the author of this paper in [8].

Waveforms of the arc voltage, arc current and voltage at the point of common coupling will be presented for that model. Also, the voltage-current characteristic of the electric arc will be presented.

Model of the electric arc was implemented in Simulink and using a Matlab program were obtained the voltage-current characteristic and the parameters waveforms.

Relation (1) presents the mathematical model that is used to simulate the electric arc behavior. This model is described in [8].

$$u = \begin{cases} i \cdot R_1, & i < i_1 \; and \; di \geq 0 \; or \\ & i > -i_1 \; and \; di < 0 \\ sign(i) \cdot \left| u_{ex} + \dfrac{C}{D + |i|} \right|, & otherwise \end{cases} \tag{1}$$

where,

R_1=0.048 Ω; u_{ex}=200 V; Ca=190000; Cb=39000; D=5000.

Parameters significance is the following:
- u - voltage of the electric arc (V);
- i - current of the electric arc obtained during simulation (A);
- u_{ex} - extinction voltage of the electric arc (V);
- C and D - constants that determines the difference between the characteristic zones in which the value of the current increases of decreases;
- R_1 - line slope of the linear zone from the electric arc voltage-current characteristic (Ω).

In the meltdown stage was set the voltage at the secondary side of furnace transformer at 500 V and in the refining stage at 600 V.

3 The Influence of the Voltage on the Secondary Side of the Furnace Transformer on the Model Parameters Waveforms

Voltage on the secondary side of the transformer will be modified with next five values: 350 V, 380 V, 420 V, 480 V and 600 V. The extinction voltage will be maintained constantly, so the arc length should be constant as well. Parameter waveforms from fig. 1, 2 and 3 are obtained by simulating the electric arc model in Simulink in the meltdown stage of the technological process.

In fig. 1 are presented current waveforms of the electric arc obtained with the five values previously mentioned for the voltage on the secondary side of the furnace transformer.

It can be noticed that the current of the electric arc increases as the voltage on the secondary side of the furnace transformer increases too. Also, it can be observed that the current of the electric arc has approximately sinusoidal shape.

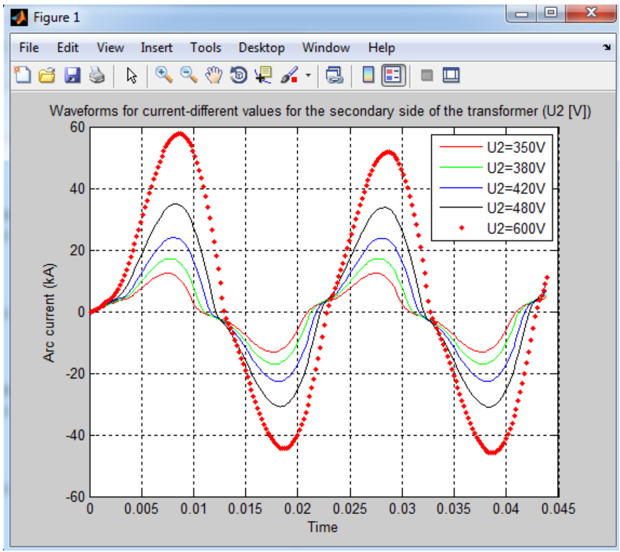

Figure 1. Different current waveforms of the electric arc.

In fig. 2 are illustrated voltage waveforms of the electric arc for different voltages on the secondary side of the furnace transformer.

It can be noticed that the voltage of the electric arc has approximately the same values for different supply voltages. Also, it can be observed that the

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voltage of the electric arc has approximately rectangular shape.

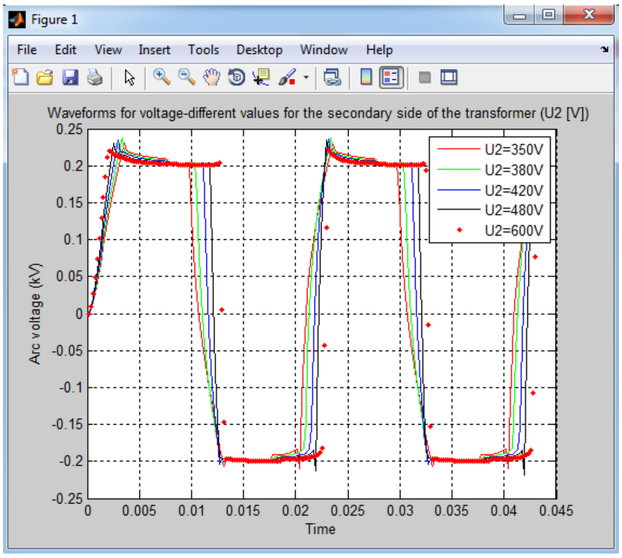

Figure 2. Different voltage waveforms of the electric arc.

In fig. 3 are presented the voltage waveforms at the point of common coupling for different voltages on the secondary side of the transformer. It can be noticed that, as this voltage increases, the voltage at the point of common coupling increases too.

In fig. 4 are illustrated the voltage-current characteristics of the electric arc obtained for different voltages on the secondary side of the furnace transformer.

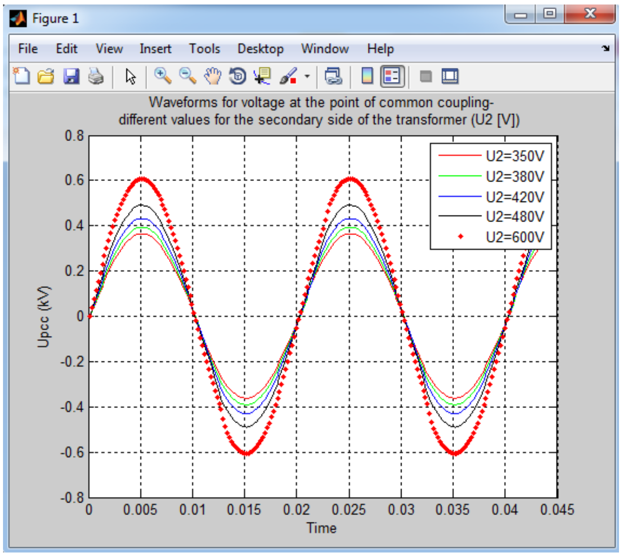

Figure 3. Different voltage waveforms at the point of common coupling.

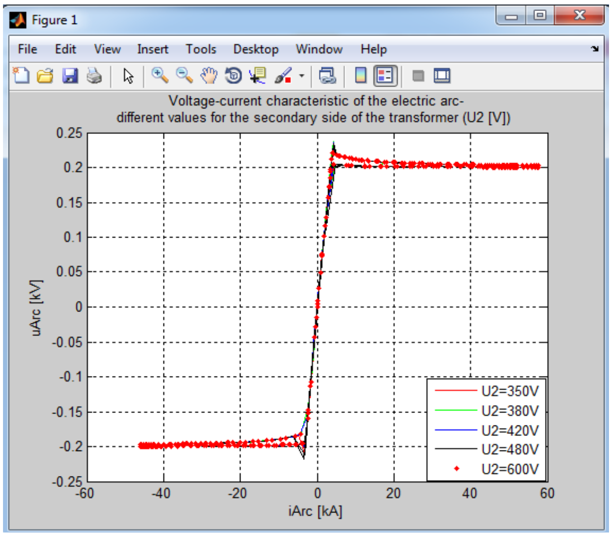

Figure 4. Different voltage-current characteristic of the electric arc.

3 Comparison Between the Simulated and Measured Data

In order to validate the model used in this paper it will be tested the accuracy of it by making comparisons of measured and simulated data. For both, meltdown and refining stages will be presented comparisons.

2.1 Meltdown Stage

Next, will be compared the voltage at the point of common coupling and the current of the electric arc when the voltage on the secondary side of the transformer has value 500 V.

In fig. 5 are presented both simulated and measured voltage at the point of common coupling. It can be observed that values are approximately the same, but in real plant exists more disturbances than in simulation.

In fig. 6 are presented current waveforms of the electric arc obtained by both simulation and measurement. Simulation data were obtained with the model used in this paper in the meltdown stage. It can be noticed that the two values are approximately the same.

Fig. 7 presents a comparison between the voltage-current characteristic obtained with the values purchased by simulation or acquired by measurement. It can be noticed that the model accuracy represent the voltage-current characteristic of the electric arc.

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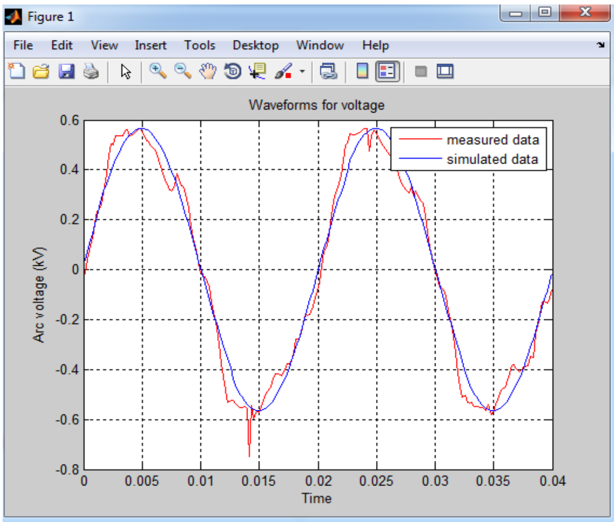

Figure 5. Comparison between measured and simulated voltage at the point of common coupling in the meltdown stage.

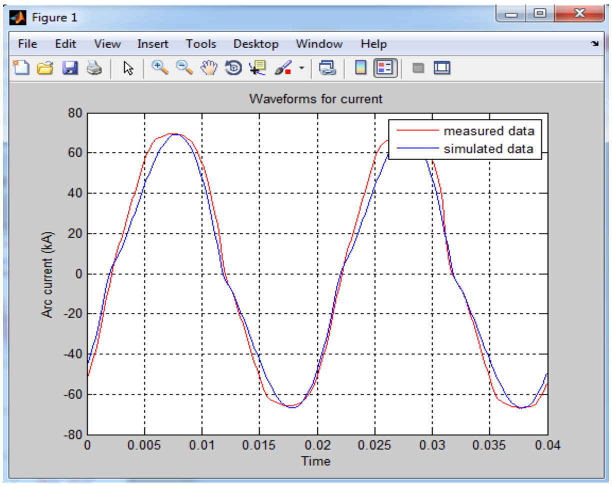

Figure 6. Comparison between measured and simulated current of the electric arc in the meltdown stage.

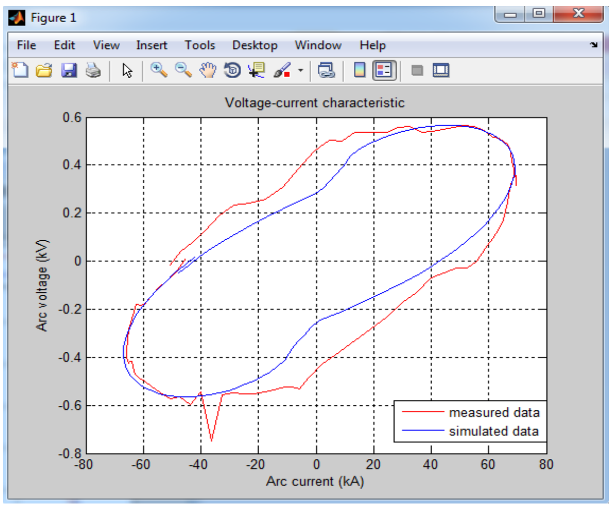

Figure 7. Comparison between measured and simulated data to obtain voltage-current characteristic of the electric arc in the meltdown stage.

2.2 Refining Stage

In fig. 8 are presented both simulated and measured voltage at the point of common coupling. It can be observed that values are approximately the same.

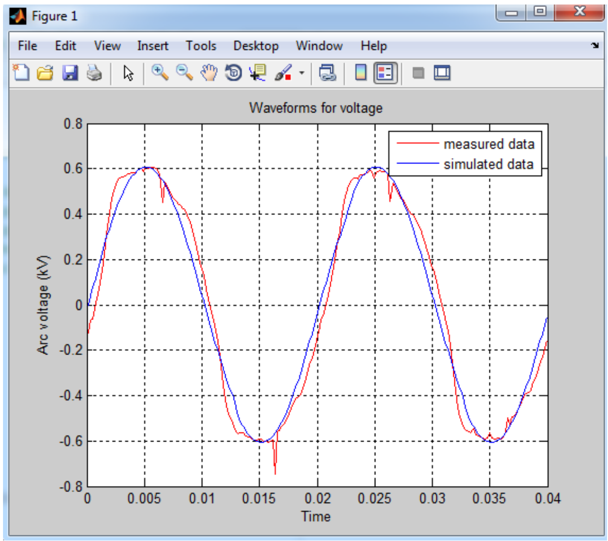

Figure 8. Comparison between measured and simulated voltage at the point of common coupling in the refining stage.

In fig. 9 are presented current waveforms of the electric arc obtained by both simulation and measurement. Simulation data were obtained with the model used in this paper in the refining stage. It can be noticed that the two values are approximately the same.

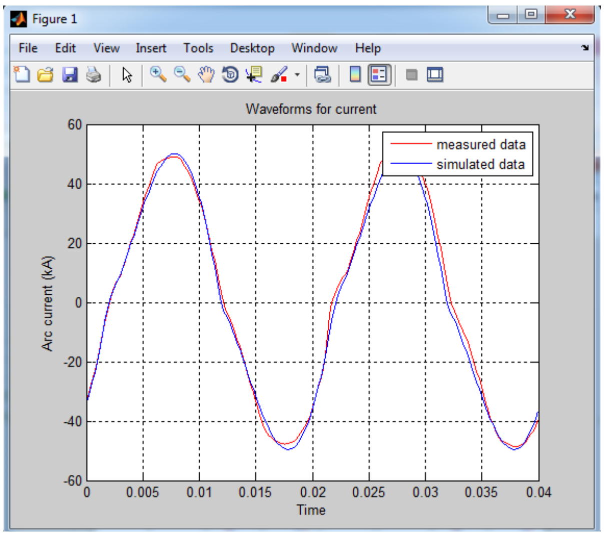

Figure 9. Comparison between measured and simulated current o in the refining stage.

Fig. 10 presents a comparison between the voltage-current characteristic obtained with the values purchase by simulation or acquired by measurement. It can be noticed that the model accuracy represent the voltage-current characteristic of the electric arc.

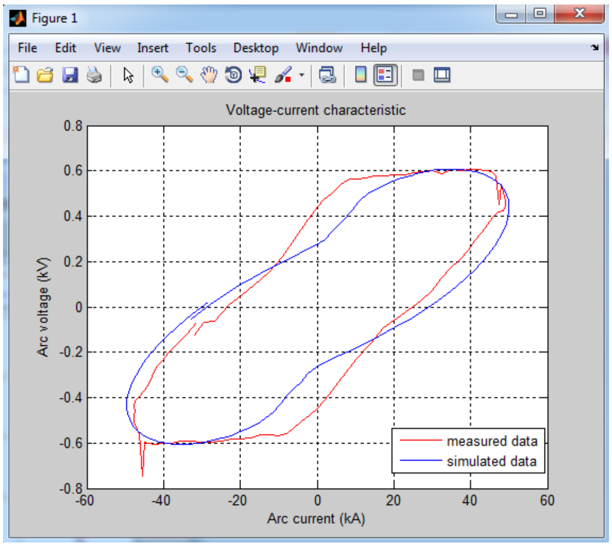

Figure 10. Comparison between measured and simulated data to obtain voltage-current characteristic of the electric arc in the refining stage.

4 Conclusion

It can be noticed that the model used in this paper illustrates well the electric arc furnace behavior in both meltdown and refining stages.

Using presented model, power conditioning devises can be designed. As well, the installations of reactive power compensation, current harmonics filtering and load balancing can be dimensioned.

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