International Journal of Electrical and Electronics Engineers
Vol. No.8 Issue 01, January-June 2016
www.arresearchpublication.com
IJEEE
ISSN 2321 - 2055

POWER QUALITY IMPROVEMENT USING ARC FURNACE

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ABSTRACT

An Arc furnace represents one of the most intensive and disturbing loads in the electric power system. Utilities are concerned about these effects and try to take precautions to minimize them. Therefore, an accurate model of an arc furnace is needed to test and verify proposed solutions to this end. This paper, presents the results of a study, where arc furnace is modeled using both chaotic and deterministic elements. The flicker effect, which is the manifestation of voltage fluctuations, is captured using the well-studied Chua's chaotic circuit whereas a dynamic model in the form of differential equation is used for the electric arc. Simulation of developed model is done in Sim-Power-System environment of the MATLAB 7.1 versions

Keywords: *Power quality, Arc furnace, Chaos, Simulink, voltage flicker*

I .INTRODUCTION

An Electric Arc Furnace (EAF) is a very widely used device in metallurgical and processing industries It is a, nonlinear time varying load, which can cause many problems to the power system quality such as unbalance, harmonic inter-harmonic and voltage flicker. Thus study of electric arc furnaces has potential benefits for both customers and utilities. An accurate modeling of an EAF will help in dealing with the problems caused by its operation. Minimization of the undesirable impact of EAFs can improve electric efficiency and reduce power fluctuations in the system.

The description of an arc furnace load depends on the following parameters: arc voltage, arc current and arc length (which is determined by the position of the electrodes). Based on the study of above essential parameters, many models are set up for the purpose of harmonic and flicker analysis. In general, they may be classified as follows, a) time domain analysis method (Characteristic Method, Time Domain Equivalent Nonlinear Circuit Method), and b) frequency domain analysis method (Harmonic Voltage Source Model, Harmonic domain Solution of nonlinear differential equation). Each method has its own advantage and disadvantage. Comparison and commendation of different arc furnace models were presented in [1] Most of the existing models make some kinds of approximation on the characteristic of arc.

There have been two general approaches to the problem of arc furnace modeling: stochastic and chaotic. In most of the previous studies, stochastic ideas are used to capture the aperiodic, nonlinear, and time-varying behavior of arc furnaces [2]–[4]. In [2], the arc furnace load is modeled as a voltage source. The model is based on representation of the V-I characteristics using sinusoidal variations of arc resistance and band limited white noise. Here empirical formulas related to the arcing process are used.

Recent study shows that, the electrical fluctuations in the arc furnace voltage have proven to be chaotic in nature. Some chaos-based models reported in specialized literature [5]–[6] have been applied to simulate ac [7], [8] and dc [9] arc furnaces. In [7] the Lorenz chaotic model has been used to represent the highly varying behavior of currents in an ac arc furnace and a tuning procedure is applied to obtain the model parameters.

In this work instead of using single valued piece-wise linear v-I characteristics of the arc furnace load, a dynamic and multi-valued v-I characteristics are obtained by solving corresponding differential equations [10]. The output of dynamic model developed is modulated with low frequency chaos signal to produce the arc furnace model. The model developed is connected to sample power system to study the voltage fluctuation.

II. ARC FURNACE OPERATION

Electric arc furnaces are available in both alternating current (AC) and Direct current (DC) models. A transformer directly energizes furnace electrodes in a high current circuit in ac furnaces, whereas dc furnaces employ a controlled rectifier to supply dc to the furnace electrodes. Arc furnace operation may be classified into stages, depending on the status of the melt and the time lapse from the initial energization of the unit.

Consider the case of the processing of scrap steel in an ac EAF. During the melting period, pieces of steel create momentary short circuits on the secondary side of the furnace transformer. These load changes affect the arc characteristics, causing fluctuations of current. The current fluctuations cause variations in reactive power, which cause a momentary voltage drop or flicker, both at the supply bus and at nearby buses in the interconnected system. The arc: currents are more uniform during the refining period and result in less impact on the power quality of the system. Arc furnaces also create harmonic load currents and asynchronous spectral components. Harmonics represent an important power quality issue, because they may cause undesirable operating conditions such as excess losses in transformers. Figure 1 shows typical installation of EAF.

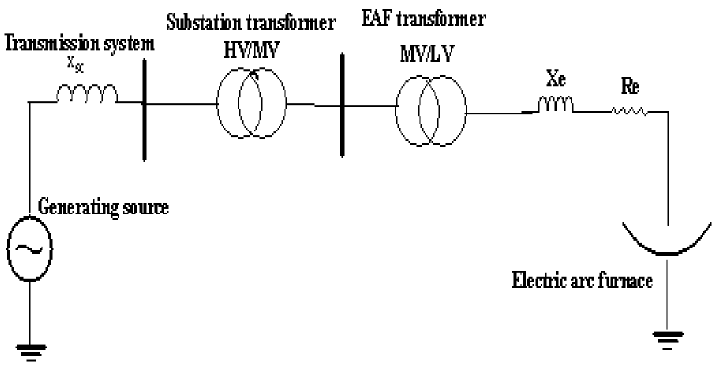

Fig. 1 Typical installation of EAF

III. CHAOTIC DYNAMICS IN ELECTRIC ARC FURNACES

Chaos, also known as the strange attractor, does not generally have an accepted precise mathematical definition. Usually, from a practical point of view, it can be defined as the bounded steady-state behavior that does not fall into the categories of the other three steady-state behaviors (i.e., equilibrium points, periodic solutions, and quasiperiodic solutions [5]. While equilibrium points are zero dimensional and periodic solutions are one dimensional, strange attractors are more complex, and their dimension

is a fraction. A chaotic system is a deterministic system that exhibits random movement, and it is a nonlinear system that exhibits extreme sensitivity in the state trajectory with respect to the initial conditions.

After recognizing the chaotic responses in EAFs, the first model based on chaotic dynamics is introduced in [7]. This model employs chaos as a key element to produce a chaotic response as close to actual data as possible. The basic feature of this first chaotic model is that it is self-tuning to adjust the model parameters in order to match the model output with the artifact readings. The time-scaled Lorenz system is used to represent the highly varying behavior of the currents in an electric arc furnace. The scaled Lorenz system is tuned to generate a time series that matches the given real data as close as possible.

In summary, at the end of the simulation, the arc current data are generated for the selected time interval, and injected to the arc furnace bus as an ideal current source. While this model can successfully duplicate the artifact data obtained from a real arc furnace, for most of the harmonic spectra, it is insensitive to changes in the network. Also, it should be noted that it is hard to get real data from each kind of arc furnace installation. Therefore, it would be desirable to develop a model that can be connected to any bus in the network as a circuit component, and requires only conventional data available for arc furnaces.

It has been shown that in order for an autonomous circuit consisting of resistors, capacitors, and inductors to exhibit chaos, it has to contain the following components [5][6]:

1) At least one locally active resistor;
2) At least one nonlinear element;
3) At least three energy-storage elements.

Chua's circuit is the simplest type of circuit that satisfies the conditions that are listed; moreover, it is the only physical system for which the presence of chaos has been proven. These two properties of this circuit motivated its use as a chaos generator in this work. More detailed information about this circuit can be found in [6],

IV. ARC FURNACE MODEL

The development of general dynamic arc model in the form of a differential equation is based on the principle of conservation of energy. The approach is fundamentally different from those methods where some empirical relation is used to represents the electrical arc. In the dynamic model such relations are implicit for steady state conditions (are not pre-defined) and will result for different conditions, depending on both frequency and current magnitude. Here arc furnace is modeled in two stages. First dynamic electric arc modeling is done then obtained arc

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ISSN 2321 - 2055

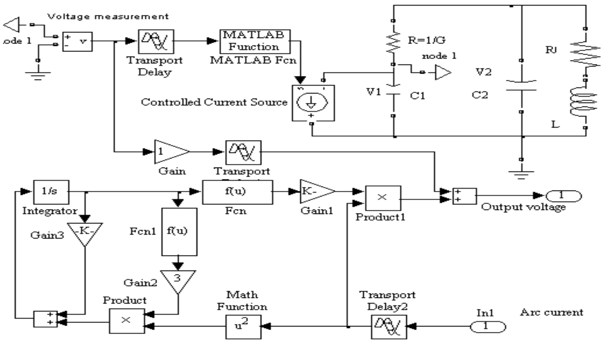

Fig.2 Mat lab implementation of EAF model

Voltage is modulated with chaotic signal to produce final arc furnace model.

The power balance equation for the arc is $p_1 + p_2 = p_3$ (1)

Where, $\boldsymbol{p_1}$ represents the power transmitted in the form of heat to the external environment, p_2 represents the power, which increases the internal energy in the arc, and which therefore affects its radius, and $p_3$represents the total power developed in the arc and converted into heat. The above equation can be represented in the form of differential equation [10] of the arc:

$$k_1 r^n + k_2 r \frac{dr}{dt} = \frac{k_3}{r^{m+2}} i^2 \quad (2)$$

Here 'r" stands for the arc radius. Which is chosen as a state variable instead of taking arc resistance or conductance? The arc voltage is then given by $v = \frac{i}{g}$ (3)

Where g is defined as arc conductance and given by the equation $g = \frac{r^{m+2}}{k_3}$ (4)

It is possible to represent the different stages of the arcing process by simply modifying the parameters of m and n in (2). The complete set of combination of these parameters for different stages of electric arc can be found in [7]. Here, these parameters are chosen as m=0 and n=2, which represent the refining stage of the electric Figure 3 shows the dynamic V-I characteristics of 250-V, 70-kA A.C. electric arc obtained by solving (2) and (3) in time domain.

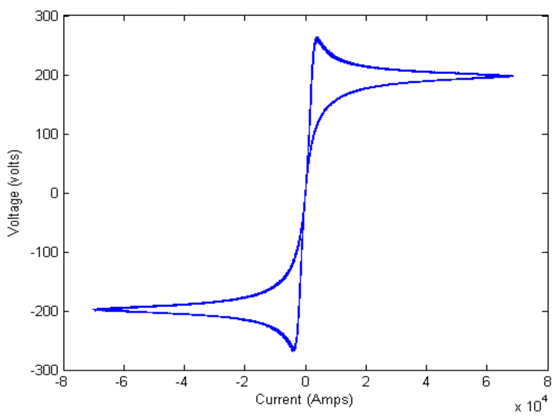

Fig.3 V-I characteristics of electric arc.

International Journal of Electrical and Electronics Engineers
Vol. No.8 Issue 01, January-June 2016
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The simulated V-I characteristics of electric arc match well with the measured characteristics [10]. The Square form of the arc voltage shown in Figure.4 is typical for wave shapes associated with electric arcs. The variation arc conductance is shown in figure 5.The MATLAB implementation EAF model that includes dynamic arc model and chaotic circuit is shown in Figure 2.

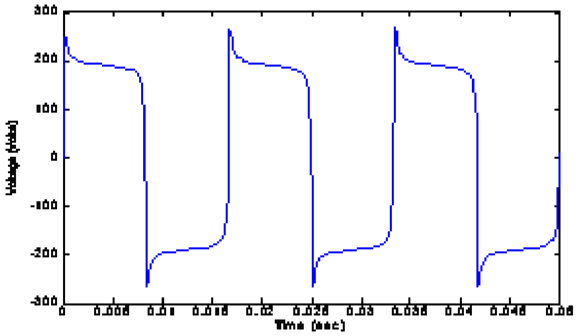

Fig.4.Voltage waveform of electric arc.

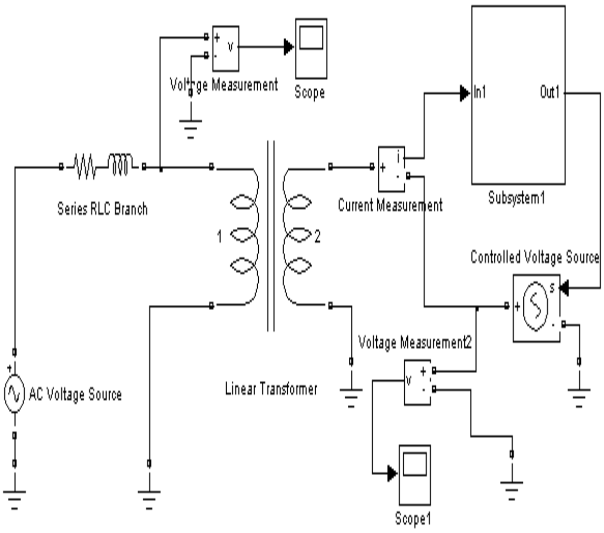

Fig: 5 connections to power system

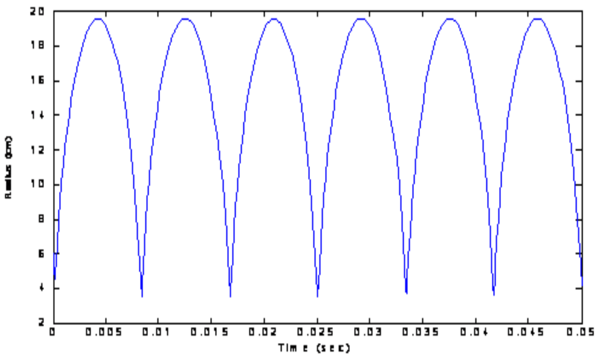

Fig.6 simulink model

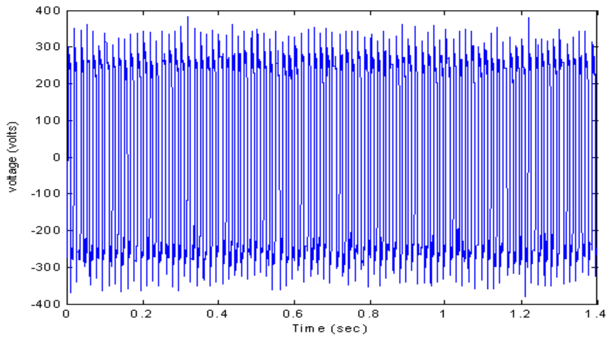

Fig. 7 Voltage at the secondary of transformer

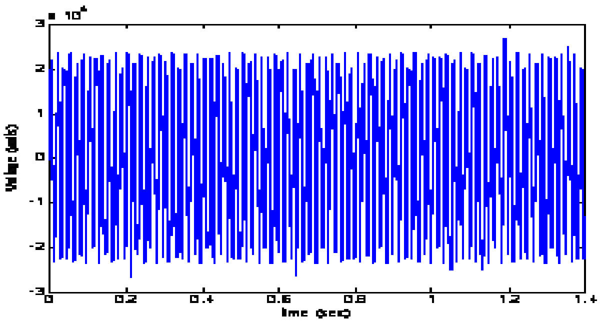

Fig. 8 Voltage at the primary of transformer

The developed EAFs model is tested using sample power system whose Simulink model is shown in Figure 6. Arc furnace transformer is connected to a the venin equivalent circuit representing the power system behind. The point of common coupling (PCC) corresponds to the primary of the arc furnace transformer. The current absorbed from the power system bus is injected as the input to the EAFs model. The model behaves as a controlled source, namely it takes the system current as an input and assigns the terminal voltage value at each time step. System data for this configuration is given in the appendix. The voltage waveforms at the secondary and primary of the arc furnace transformer, is shown in figure 7 and 8. Rapid fluctuation in the voltage, which leads flicker, can be seen in the figure 7 and this waveform can be further processed for determining flicker factor and other power quality indices Figure 9. Show the simulated furnace current waveform

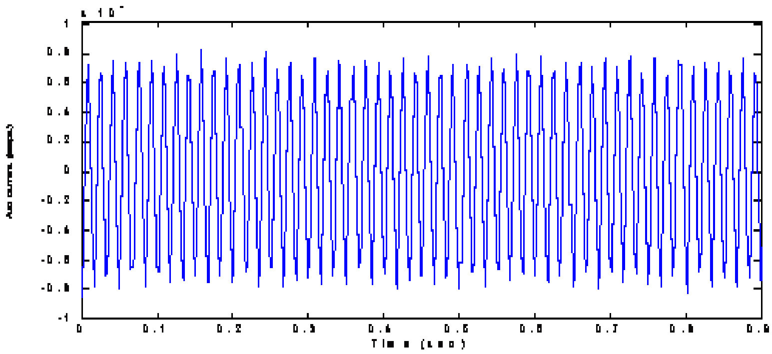

Fig. 9 Arc current

V. CONCLUSION

A new model to represent the arc furnace operation has been developed. In order to represent the flicker effect, a low frequency chaotic signal is modulated with the arc voltage. The symmetry of the arc characteristics is therefore destroyed, resulting in even harmonics as well as odd ones. The model is built in the time domain and can be readily connected at a specified bus as a circuit component, which takes the system current as input and assigns the terminal voltage value at each time step. The developed arc furnace model is used in sample power system to steady the effect of arc furnace operation and can be used for power quality studies.

APPENDIX

Parameters of EAF model and sample power system are as follows,

Source: Ideal sinusoidal ac voltage source with amplitude=50.6 kV and zero phase shift.

Zthevenin: Resistance=0.346Ω and inductance, L=9.8mH.

Transformer: Three windings linear single-phase transformer.

Nominal power: Pn=60 MVA.

Winding 1 parameters: V_1 (Vrms) =46kV,

R_1 (pu)=0.002, L_1 (pu)=0.55,

Wading 2 paramètres: V_2 (Vrms)=770 V,

R_2 (pu)=0.002, L_2 (pu)=0.55,

Magnetization resistance and reactance: R_m (pu) =500 L_m (pu) =500.

Arc Furnace: (Parameters for corresponding differential equation) k1=3000.0, k2=1.0, k3=12.5 m=0, n=2.

(Chua's circuit) C1=200nF, C2=0.2μ F, L=3.6m H with a series resistor Ro=12.5Ω, G=5.442E-4 mho.

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