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The Effect of Corrosion of Electrodes in the Electric Arc Furnaces Model

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Abstract— **The Electric Arc Furnaces is time varied and non linear load that up to now so many models are suggested for the analysis of its operation. This kind of unstable load can make many problems in power quality (i.e. Flicker, Sag and Swell), unstable voltage and current and harmonics for the power transmission network. In this essay, you can find a new model for making a model for the Electric Arc Furnaces by complex two methods of Casi and Mayre and choosing a complex function that can cover both two methods. In this method, Electric Arc Furnaces is considered as a load with a variable admittance and corrosion of electrodes is considered as a parameter variable by time. At the end, you ca find the result of simulation and its comparison with the other models.**

Keywords- Electric arc furnaces; modelling; simulation.

I. INTRODUCTION

The Electric Arc Furnace is one of the most popular non linear loads of modern systems that the electricity power is used for melting and purification of metals in it and each day it can be used more in developing the Steel Industry. In comparison with the Blast Furnaces, having less pollution and the ability of using of scraps instead of ironstone are the logical reasons for using of these Furnaces instead of blast Furnaces. Unfortunately, the Electric Arc Furnace is known as a load with many distortion and unsuitable power quality in its electricity network and imposes some problems according to the quality of the power to the network that should be known and compensated. Having accidental and severe changes in the Electric Arc Furnaces caused to occurring the severe changes in the voltage of the network, occurring some kinds of harmonica and severe changes in the light used by the users [1]. The undesirable effects of the Electric Arc Furnaces can be decreased by connecting it to a point with high short circuit capacity, but most of the time it is not possible, so in order to decrease its undesirable effects, compensating systems are used accompany with the Furnace. First step for doing this work knows the action of these Furnaces in the sub-transient, transient and steady states. Due to the importance of the exact modeling for the Electric Arc Furnaces, many works were done in this case both in the Industry and in the Academic groups. Due to the inherent characteristics in the function of the Electric Arc Furnaces and its complexity, show its complexity Due to the dynamic specialty of the Electric Arc Furnaces and its effect on the power system, drawing the exact and suitable model for analyzing harmonica and compensating of the flicker are necessary. As melting is an accidental and unsteady process, drawing a model with high accuracy for the load of Electric Arc Furnace is considered to be difficult. There is some factors such as raw materials used in the Furnace, electrodes statues, process of controlling the electrodes' arm, voltage and impedance of the feeding system have effect on the manner of the Electric Arc Furnace, so for describing the load of the Electric Arc, knowing the parameters of voltage, current and length of the Arc (stimulated according to the situation of the Electrodes) is necessary. Nowadays, many researches are done for manufacturing and drawing a model for the Electric Arc Furnace which consider the above parameters and pattern the equations between them. There are many described manners for modeling for the 3 phase Electric Arc Furnace that can be divided in 2 groups: analyzing manners in the time domain and analyzing manners in the frequency domain. The described models for the Electric Arc Furnace are as following: using the empirical equation to make a relation between the radial and/or the length of the Arc with the related voltage and current [2] , using the specialty nominate of the voltage and current of the Electric Arc [3], using the equal non linea-r circuit in the time domain [4,5], using the harmonica source of voltage [6], using the solve of the non linear differential equations in the frequency domain [7], using the estimated information and implementing the model of the source of the current and/or resistance variable by time [8], using the accidental and irregularity process [9] and using the intelligent systems in modeling for the Electric Arc Furnace [10] . Models based on the specialty of the voltage- current of the Electric Arc are very simple and direct and using them under the specific function of circumstances can be desirable. Having a simple and linear specialty of the voltage-current of the Electric Arc are the main factors for the accuracy of these models. Models based on the equivalent nun linear circuit on the time domain are put on the base of specialty of the curved of voltage-current Arc. In fact, these methods are based on the linear voltage-current Arc. In the models based on the harmonica sources of voltage, the study of harmonica is a specific kind of waveform of voltage of the Electric Arc that under this waveform , working of the system of the Electric Arc Furnace under the Max. Power condition is impossible. Methods based on the solving the nun linear differential equations in the frequency domain depend on the topology of the system and the circumstances of its function. Models based on accidental process and disorder generator circuits can reflect the function of the system of the Electric Arc

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Furnace well, but this model is just suitable for analyzing the flicker of the voltage. In none of the models up to now submitted for the Electrical Arc, the corrosion of electrodes is not considered as an independent parameter. The static models are just suitable for the harmonica studies. In some of the models, the real information of the furnace should be entered. For drawing compensators such as SVC and STATCOM, at first, the furnace should be erected. By having less distance between the electrodes and the surface, the current will be more, should this distance become more the current will become less. The Casi and Mayer Models are two models that have the most conformity with the reality.

II. CASI AND MAYER MODELS

According to the Natingham equation, the relation between the symmetrical Arc and the stable length is as following:

$$v = A - \frac{B}{i^n} \tag{1}$$

That in above equation, V is Voltage and I is Current. The power of ((n)) in this equation depends on the temperature of the Anode and the kind of available gas in the Furnace. Meanwhile, specifying it with high accuracy is not possible. A and B are the constant of the above equation.

For the density of a stable current, the radial of the Arc is in relation to the square of the current of the Arc. On the other hand, the around of the arc column and consequently, the losses of the heat is in relation to the Arc radial. Then there is a relation between the current, voltage and conductance as following:

$$G \propto vi^2 \tag{2}$$

$$V \propto \frac{1}{\sqrt{i}} \tag{3}$$

This equation shows a good relation for the weak current of the arc. But for the high current of the Arc, the equation will be as following:

$$G \propto i \tag{4}$$

In the Casi Model, the length of the Arc will be considered stable in relation to the temperature and coefficients and the place of the occurring the Arc will be considered changeable. According to the Casi Model, the density of the current of the Arc will be considered to be stable then the area will be changed directly by changes occurred in the current. In this model, the special resistance of the Arc, the size of the perunit of the saved energy and the size of the perunit of the losses of heat will be considered to be unchangeable. In this case, the equation of the Casi Model will be as following:

$$\frac{1}{R}\frac{dR}{dt} = \frac{1}{\theta}\left(1 - \frac{V^2}{E_0^2}\right) \tag{5}$$

In the above equation, E_o is the constant of voltage of the Arc, R is the resistance of the Arc and Θ is the constant of the time of the Arc that can be calculated by dividing the saved energy on to the unite of the size of the Arc. In this model the Arc should not be cut and just show the action of the Arc while its current is very much. As for the small amount of R of the simulation (convergence) some problems may occur in this model, so the G parameter will be used as a changeable factor. In this case, the Casi Model will be as following:

$$G = \frac{Vi}{E_0^2} - \theta\frac{dG}{dt} \tag{6}$$

In the model of Mayor, the place of occurring the Arc or the length of the arc column is described to be stable and the temperature and conductance during the length of arc column, is considered to be changeable. The model of the Mayer supposed that the losses of heat are just caused due to outer surface of the Arc and the conductance of the Arc will be changed with the saved energy. This equation is as following:

$$\frac{1}{R}\frac{dR}{dt} = \frac{1}{\theta}\left(1 - \frac{vi}{P_0}\right) \tag{7}$$

P_o is the stable losses of the power. In this mode, G is supposed to be a changeable parameter so the model of Mayer will be changed as following:

$$G = \frac{i^2}{p_0} - \theta\frac{dG}{dt} \tag{8}$$

As the model of the Mayer used for the low current and the model of the Casi used for the high current submitted good results, we use a combination of both of them for modeling in this assay. The parameter of Θ is common in both equations and has many effects on the temporary action of the Arc.

III. THE SUGGESTED MODEL BY CONSIDERING THE CORROSION OF ELECTRODES

One of the methods for the complex of the equations (5) and (7) and changing it to a equation is describing the current of the transmission ((I_o)) in a way that the conductive of the Arc can be as following:

$$\begin{cases} G = \frac{vi}{E_0^2} - \theta \frac{dG}{dt} & i > I_0 \\ G = \frac{i^2}{p_0} - \theta \frac{dG}{dt} & i < I_0 \end{cases} \quad (9)$$

But this description cause to some problems in Io boundary for the derivatives. For having more smooth transfer between two equations (5) and (7), we described a transition factor S_i which is a function of the current of the Arc, and then we have the (9).

$$G = (1 - S(i))G_C + S(i)G_M \quad (10)$$

G_m and G_c are conductance shown on the (5) and (7). One of the suitable way for calculating S_i is through (10), that I_o is the transition current of the stable mode.

$$S(i) = e^{-\frac{i^2}{I_0^2}} \quad (11)$$

In the small current, the amount of the S_i is converged to one and in the (8), it is equal to the Mayor model. In the high current, the amount of the S_i converged to zero and in the (8), it will be equal to the Casi Model. There should be the min. amount for the conductance even when the current of the conductance between two electrodes become very small. This conductance shown with G_{min} depends on the distance between two electrodes, kind and temperature of the electrodes. Then the complete model will be describing with the (11) and (12).

$$G = G_{min} + (1 - e^{-\frac{i^2}{I_0^2}})\frac{vi}{E_o^2} + (e^{-\frac{i^2}{I_0^2}})\frac{i^2}{P_0} - \theta \frac{dG}{dt} \quad (12)$$

$$i = G * v \quad (13)$$

In the general form, Θ should be the function of the current of the Arc. So we will have:

$$\theta = \theta_0 + \theta_1 e^{-\alpha|i|} \qquad \alpha \rangle 0 ,\ \theta_1 \rangle \theta_0 \quad (14)$$

Fig. 1 shows the equivalent three-phase circuit for the suggested the complex model. In this model, voltages of the phase e_a, e_b, e_c, resistance and inductance of the power supplies of R_s, L_s, resistance and inductance of the second side of transformer R_k, L_k will be for K=1,2,3. They will be the voltage of the balance phase as following:

$$\begin{cases} e_a = E\sin(\omega t) \\ e_b = E\sin(\omega t - 120°) \\ e_b = E\sin(\omega t - 240°) \end{cases} \quad (15)$$

In the above equations, E will be the balance peak voltage of the power supplies and ω will be the angular frequency. The conductance of the Arc, in 3 phase of $g_k(t)$ will be for K=1,2,3 that will be calculated through the bellow equation-s:

$$\begin{cases} g_1 = g_{min1} + (1 - e^{-\frac{i_{f1}^2}{I_o^2}})\frac{i_{f1}^2}{g_1 E_1^2} + (e^{-\frac{i_{f1}^2}{I_o^2}})\frac{i_{f1}^2}{P_0} - \theta_a \frac{dg_1}{dt} \\ g_2 = g_{min2} + (1 - e^{-\frac{i_{f2}^2}{I_o^2}})\frac{i_{f2}^2}{g_2 E_2^2} + (e^{-\frac{i_{f2}^2}{I_o^2}})\frac{i_{f2}^2}{P_0} - \theta_b \frac{dg_2}{dt} \\ g_3 = g_{min3} + (1 - e^{-\frac{i_{f3}^2}{I_o^2}})\frac{i_{f3}^2}{g_3 E_3^2} + (e^{-\frac{i_{f3}^2}{I_o^2}})\frac{i_{f3}^2}{P_0} - \theta_c \frac{dg_3}{dt} \end{cases} \quad (16)$$

$$\begin{cases} \theta_a = \theta_0 + \theta_1 e^{-\alpha|i_{f1}|} \\ \theta_b = \theta_0 + \theta_1 e^{-\alpha|i_{f2}|} \\ \theta_c = \theta_0 + \theta_1 e^{-\alpha|i_{f3}|} \end{cases} \quad (17)$$

In this section, we suggest to show the corrosion of the electrodes with the changes occurred in the g_{min} related to the 3 electrodes. According to this hypothesis the effect of the corrosion of the electrodes can be calculated with the following equations:

$$\begin{cases} g_{min1} = g_{1min} - t\frac{dg_{1min}}{dt} = g_{1min} - t\frac{dg_{1min}}{dL_1} \cdot \frac{dL_1}{dt} \\ g_{min2} = g_{2min} - t\frac{dg_{2min}}{dt} = g_{2min} - t\frac{dg_{2min}}{dL_2} \cdot \frac{dL_2}{dt} \\ g_{min3} = g_{3min} - t\frac{dg_{3min}}{dt} = g_{3min} - t\frac{dg_{3min}}{dL_3} \cdot \frac{dL_3}{dt} \end{cases} \quad (18)$$

In the above equation, L_1, L_2 and L_3 will be the length of the electrodes. If there is no corrosion in the electrodes and all the three electrodes were in the symmetric mode, the following relation will be among them: $g_{1min}=g_{2min}=g_{3min.}$

IV. SIMULATION RESULTS AND DISCUSSIONS

In this section, we verify the validity of the proposed method. All simulation is executed by Matlab. The simulati-on of the Electric Arc was done with the equivalent circuit of Fig. 1 and considering the changeable admittance caused with the corrosion of the electrodes and also by considering the E_o= 200V, $\alpha = 0.0005$ and $\theta_1 = 100$. The amount of the voltage of the source will be 220 phase voltage. In the simulation, due to the circuit's parameters, cross inductance, there are losses of the voltage. The waveforms of voltage, current, the total harmonica and also v-i specialty are calculated. In the Fig. 2 we can see the waveform of voltage of the phase (a) and its spectrum. The effect of the variable admittance is shown in the maximum points of the curved of the Fig. 2. According to the waveform of the voltage, you can see that it is not in the sine-like. This voltage is similar to a rectangular form.

The Fig. 3, regularly show the waveform of the current of phase (a) of the Arc furnace and the spectrum. In this figure can see the effect of the variable admittance on the beginning of the maximum point. The Fig. 4 shows the specialty of the voltage–current for the dramatized Arc Furnace. The effect of the variable admittance is shown as a small hysteresis in the middle of the curved. Fig. 5 shows the specialty of the voltage–current without considering the effect of the corrosion of the electrodes. Fig. 6, shows the voltage of the phase a without considering the effect of the corrosion of the electrodes**.**

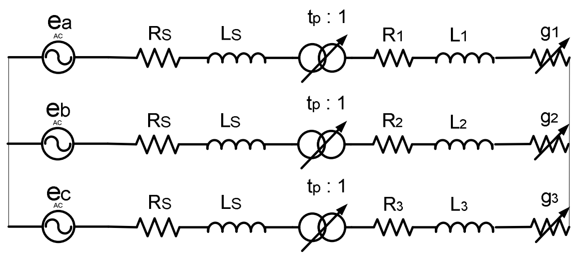
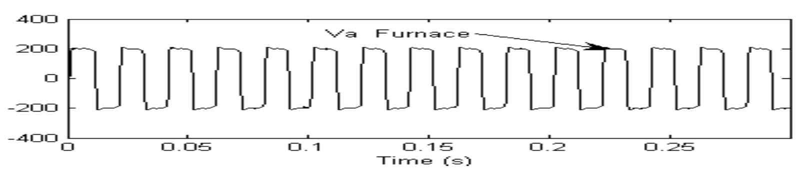
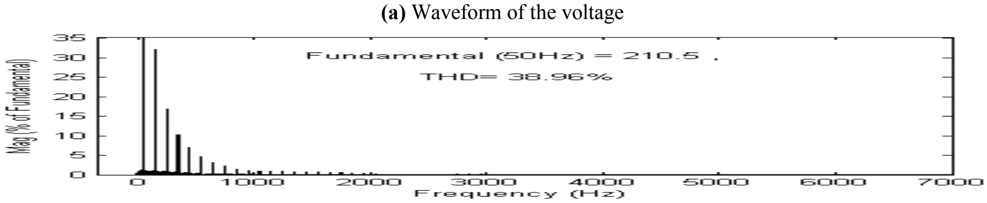


Figure 1. The Equivalent three-phase circuit considered for the electric arc furnace

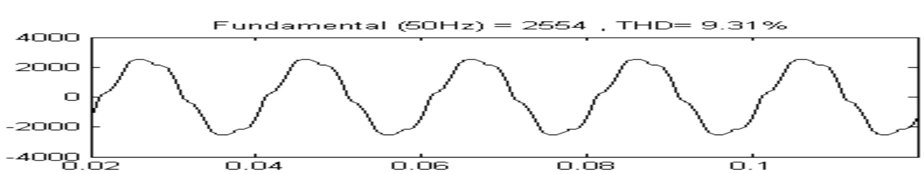


(a) Waveform of the voltage

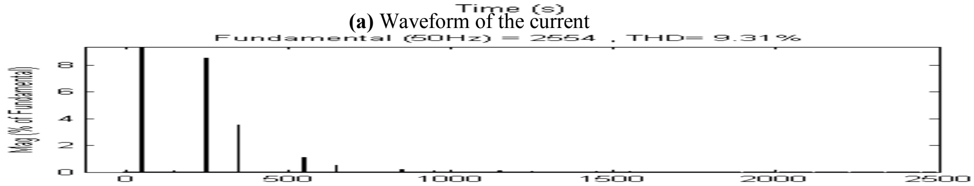


(b) Spectrum

Figure 2. The Waveform of the voltage of phase a bus connected to the Electric Arc Furnace and spectrum



(a) Waveform of the current



(b) Spectrum

Figure 3. The waveform of the current of the phase a bus connected to the Electric Arc Furnace and spectrum

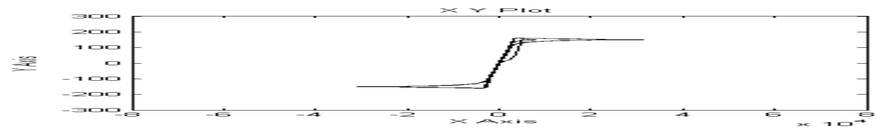


Figure 4. The specialty curved of the voltage – current of the Electric Arc Furnace with the suggested model.

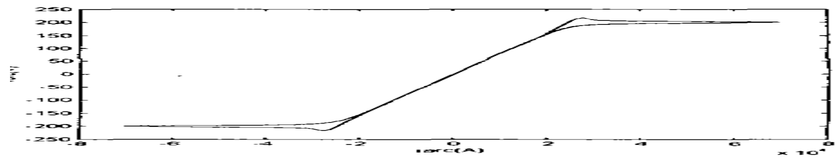


Figure 5. The specialty curved of voltage –current of the Electric Arc Furnace without considering the effect of the corrosion of the electrodes

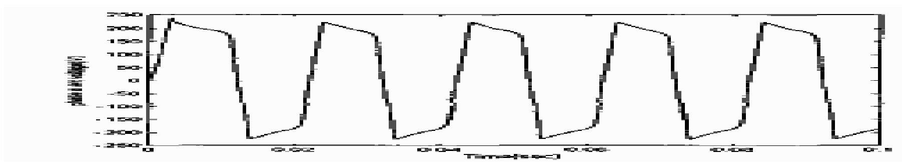


Figure 6. Voltage of the phase a bus connected to the Electric Arc Furnace without considering the effect of corrosion of the electrodes

V. CONCLUSION

By considering the effects of the corrosion of the electrodes accompany by the complex model of Casi and Mayer caused to reach a exact model by which the action of the transient mode of the Electric Arc Furnace will be predictable. This model could help to design compensator with appropriate amount of compensating for the Electric Arc Furnace. As the hypotheses described for this model are in the reality, so this model can be very near to the reality. And as this is a general model, it can be used in the Arc Furnace with both very high and very low capacity.

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