Flicker Effect on Cable's and Line's Sizing in Distributed System

A .Roghani Araghi, B .Vahidi, S.H. Hosseinian and A. Doroudi

Abstract—**Nowadays by developing technology and invention of various electrical devices, voltage flicker and how to compensate it become more important for the power energy providers. One of the best ways to overcome the flicker problem is to decrease production of it by electrical devices. In this paper the effect of power line conductor and cable' size on producing voltage flicker in distribution systems is studied. For this purpose, the electric arc furnace (EAF), as one of the biggest flicker producers, is assumed as load and simulated with chaos theory, then by using various kinds of power line conductors and cables and calculating produced power, Pst, the effect of power line conductor's and cable's size on producing voltage flicker is studied. Simulation results show the importance of cable's size on production of flicker. In the past only the voltage and short circuit current limitations were parameters that effect on choosing cable's size. In this paper the effect of voltage flicker on choosing cable's size will be shown and then the advantage of using cables or conductors with bigger surfaces on decreasing flicker will be proved.**

***Index Terms*—Flicker, Distributed system, Cable, Line conductor, Chaos theory**

I. INTRODUCTION

Flicker study is important in power quality problems because of some oscillations that occurred in voltages.

Costumers of electrical energy usually expect a proper voltage source from electrical power providers. But because of some reasons voltage have flickers or harmonics that may dissatisfy them or may harm their devices. In early years after invention of electricity, electricity was used for light, so people confront to light fluctuation but it wasn't important. After a while by developing technology and innovation of various electrical devices the voltage flicker resulted in costumer dissatisfaction. So study of voltage flicker and power quality becomes more important to electrical power providers. Sudden changes in the current of some devices like arc furnace, rollers, diggers, welders and starting current of motors are voltage change producers. When various loads was entered in grid by various costumers, voltage may have some flickers but first, these changes in voltage is slow and second, these changes could be regulated by voltage regulators. In the opposite when some devices like arc furnace, rollers, diggers, welders and huge motors were entered in network, voltage would have some flickers, the reason of voltage flicker is same. Among an electrical arc furnace, as a major industry customer of a utility, consumes considerable real power and reactive power with time-varying, stochastic, and even chaotic characteristics during its melting and refining process and, therefore, generates severe flicker to the grid [1]. These voltage changes may result in light fluctuation and noise in television broadcasting and some effects on ICU and CCU systems. (These clinical systems by different voltage source amplitude made different reports). In comparison with various kinds of electrical devices, filament lamps have the most sensitivity on voltage changes. Fig. 1 shows one sample of flicker's waves [2].

Considering above, study of flicker and the ways of decreasing it is necessary. Also with the widespread use of power electronics equipment and nonlinear loads, industrial, public and household equipment/appliances, the understanding and modeling of harmonic sources have been an essential part of harmonic analysis [3].

In past only voltage drop and short circuit current were parameters that effect on choosing cables and power line conductors.

In this paper the effect of cable and conductor sizes on production of flicker has been studied. For this purpose, arc furnace as one of the major sources of producing flicker in distribution systems assumed as load. In section II and III the arc furnace has been simulated. The model was simulated with MATLAB and voltage and current waves of arc furnace

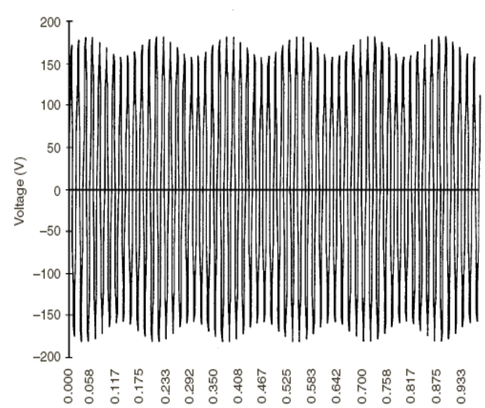

Fig. 1. One sample of flicker's waves

A. Roghani Araghi, B. Vahidi and S. H. Hosseinian are with department of Electrical Engineering, Amirkabir University of Technology, Tehran, Iran.
A. Doroudi is with department of Electrical Engineering, Shahed University, Tehran, Iran.
Corresponding author email: vahidi@aut.ac.ir

978-1-4244-2235-7/09/$25.00 ©2009 IEEE

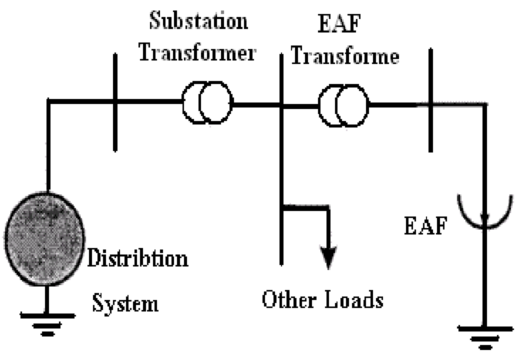

Fig. 2. Arc furnace diagram

were calculated. In section 4 cables and conductors with different dimensions have been studied. By calculating Pst in the common coupling point, the effect of cable's and conductor's sizes on production of flicker have been studied. Also by calculating of THD in common coupling point the harmonic content of them has been studied. In summary the simulation results have been compared and the optimum size in choosing the cable's and conductor's sizes have been established.

II. THE ARC FURNACE MODELLING

Recently study of arc furnaces becomes more attractive. For example steel industry is developing rapidly, and at the other side arc furnaces have one of the most important roles in this industry. By placing ragged steel between arc furnace electrodes, short circuit is happened and thereupon high short circuit current and voltage drop are produced too. The voltage drop is one of the most important quantities in the characterization of transmission and distribution electric power systems. In fact it represents in a certain way the indicator of the effectiveness of the connection between the loads and the generation centers [4]. The high short circuit current would make arc and severe heat. Because of this huge current, severe current would flow in transformer secondary windings. Welding action has two major states: The long arc state and then slow welding and infiltration. The time-varying nature of electric arc furnace gives rise to voltage fluctuations, which produce the effect known as flicker [5].

Fig. 2 shows a simplified system of an arc furnace and its connection to power grid. With connection of these kinds of furnaces to power grid the study of them becomes more important. For these purposes having a proper and complete model is necessary. Although a lot of studies have been made, but a proper and complete model that can explain the exact behavior of these kinds of loads has not found yet.

One of the recent methods of modeling nonlinear phenomena is chaos theory. This is the fundamental definition of chaos theory: "Chaos in a dynamic system in transient is not predictive but in long time is predictive". The nature of chaotic systems is nonlinear. Chaotic behavior and nonlinearity have been confirmed in some problems of power systems [6], [7].

In this paper the modeling of arc furnace is done by chaos theory. The advantage of this method is that chaotic behavior of arc furnace is in spot.

III. PROPOSED MODEL

In order to estimate the adverse effects caused by arc furnace accurately, a novel chaotic model of AC electric arc furnace is presented, which is useful for power quality studies. The proposal of the appropriate model of arc furnace is made in two steps: First the dynamic V-I characteristics of arc are obtained then chaotic signal of Chua's circuit is modulated by the first step wave and the final wave is obtained.

1- Dynamic behavior of arc furnace

In this step the model of arc furnace is obtained from the balance of energy equation. The waveform of arc radius is obtained from the waveform of current and based on the energy balance equations, dynamic model of arc is calculated. The following equations show the derivation of model [8]:

$$k_1 r^n + k_2 r \frac{dr}{dt} = \frac{k_3}{r^{m+2}} i^2 \qquad (1)$$

Here "r" which stands for the arc radius, is chosen as the state variable instead of the arc resistance or the conductance. In fact in the various stages of arc creation and melting of materials are obtained by giving different values to m and n. k_1, k_2, k_3 are practical coefficients. The arc voltage is given by:

$$v = \frac{i}{g} \qquad (2)$$

Where g is defined as the arc conductance and given by the following equation:

$$g = \frac{r^{m+2}}{k_3} \qquad (3)$$

Here the refining stage of arc is simulated. The appropriate values of the parameter at this stage are m=0 and n=2 [9].

2- Derivatoin of chaotic signal

As mentioned above, for adding the time variation of dynamic V-I characteristics of arc, the chaotic signal is used. This signal can be derived from usual electrical circuits.

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 [10], [11]:

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

The Chua's circuit is one of the simplest circuits that have these conditions. On the other hand this circuit is the only physical system that the chaotic behavior is approved for it. The Chua's circuit that made the flicker is shown in Fig. 3. As it can be seen in the figure, the circuit has three major parts. The first can be an usual oscillator circuit that has the R, C1, C2, L components. The second is an op-amp that produces the –R1 resistor. In fact and finally the third is a diode with R2 that creates nonlinearity in the circuit [12].

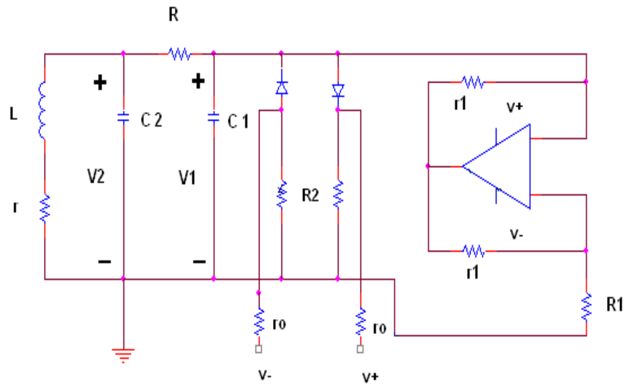

Fig. 3. The chua's circuit

3- Signal modulation

To derive output voltage, the voltage that is derived by solving (1) is modulated with chaotic signal of Chua's circuit, by amplitude modulation.

The output voltage is used in the secondary windings of transformer as a controlled voltage source and controls the system response. Simulated model and its connection to the network are shown in Fig. 4. In Fig. 5 the voltage of furnace after modulation is shown. As it is seen, after the modulation the voltage has a 10 Hz flicker that is comparable with the real condition. In Fig. 6, the voltage at point of common coupling (PCC) is shown. For better clarity some part of this waveform is zoomed. As it is expected these waveforms have major chaos.

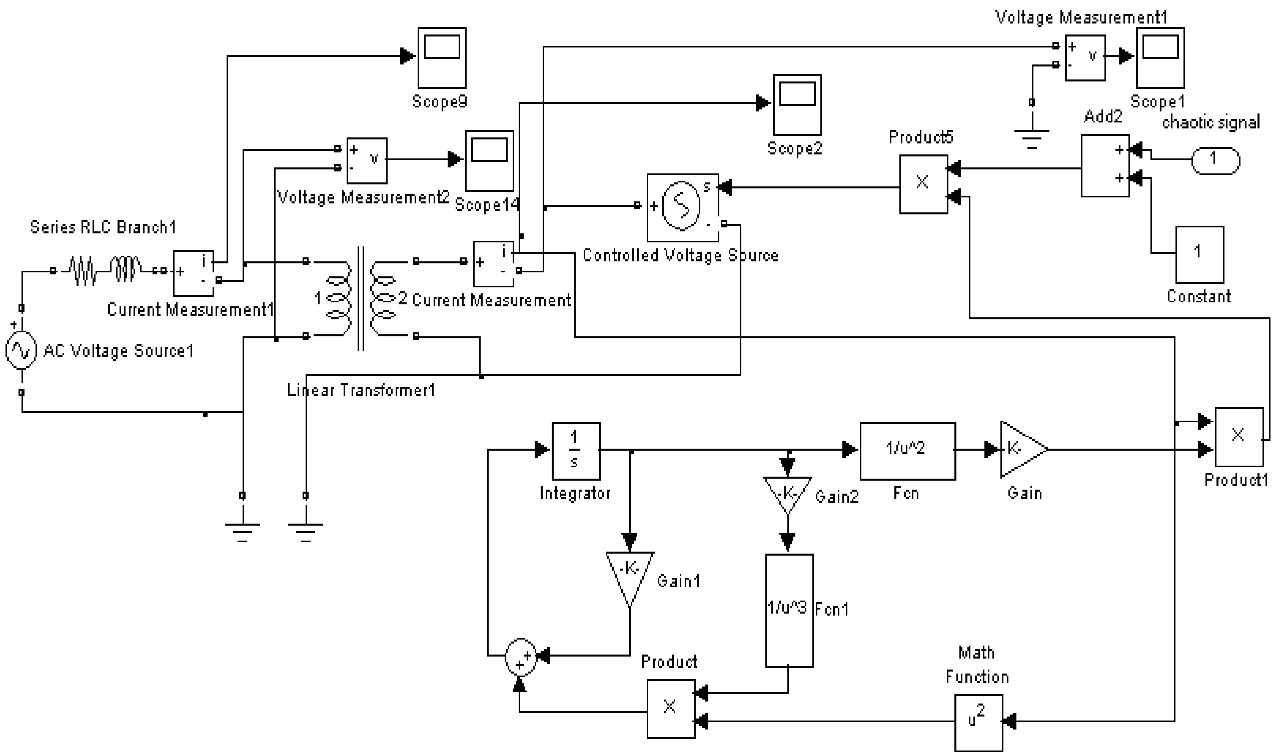

Fig. 4. Simulated model and its connection to the network

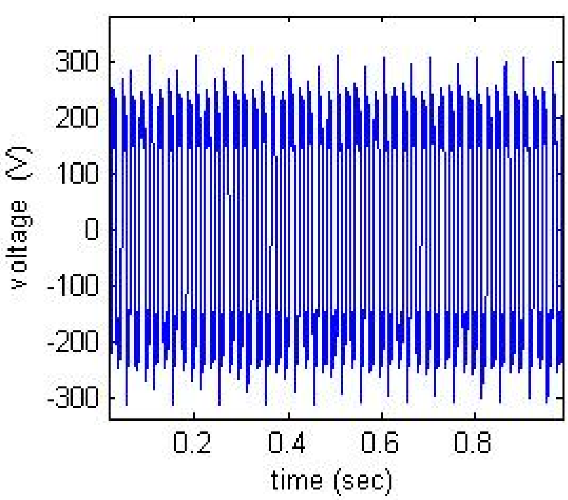

Fig .5. Voltage of the arc furnace

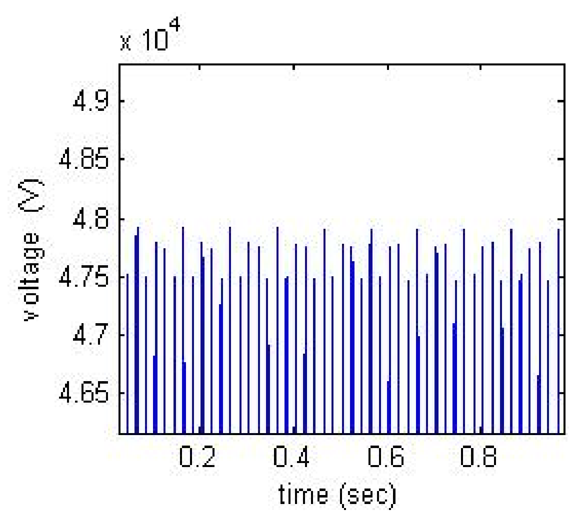

Fig .6. Voltage in PCC

TABLE I:
Simulation results for different kinds of cables

Cross-section area	Impedance	P_{st}	THD
$50mm^2$	0.429+j0.116	0.729	0.0112
$150mm^2$	0.159+j0.097	0.282	0.0065
$300mm^2$	0.079+j0.087	0.169	0.0055

TABLE II:
Simulation results for different kinds of lines

Cross-section area	Impedance	P_{st}	THD
$50mm^2$	0.363+j0.351	0.625	0.0226
$150mm^2$	0.117+j0.315	0.422	0.0191
$300mm^2$	0.061+j0.298	0.333	0.0179

IV. USING DIFFERENT CABLE AND LINES

In this stage by using different cables and lines in various cross-section areas, the effect of sizes in producing the voltage flicker is tested. Three kinds of cables and lines that used in distribution systems are tested [13]. To study the effect of flicker, the parameter Pst is used. This parameter is defined as follow:

"short-time flicker intensity index": is the intensity of flicker in a short period of time (10 minutes). Pst =1 is the threshold of eye hurting. This index is defined by the series of data that is gotten by flicker meter. To study the amount of voltage harmonics the THD is calculated too. The THD is given by following equation:

$$THD = \frac{\sqrt{\sum_{i=2}^{\infty} V_i^2}}{V_1} \qquad (4)$$

Above, V_i is i'th harmonic of $V(t)$ and V_1 is the main harmonic.

Simulation results are shown in tables I and II. By reviewing the results it is seen that using different kinds of cables and lines varies the amount of THD and Pst. It is shown that by increasing the conductor size and decreasing the resistance of it, the Pst and THD were decreased. It is also shown that cables in comparison with lines with same sizes, have better performance in production of flicker and harmonics because the impedance of cables are lesser than lines.

V. CONCLUSION

In this paper the effect of using cables and lines with different sizes on voltage flicker and amount of harmonics in distribution systems was studied. For this purpose the arc furnace as one of the major loads with nonlinearity and flicker producers was studied and the voltage of furnace was obtained by modulation of chaotic signals and dynamic characteristics of arc, so a 10 Hz flicker was obtained. Then by using different kinds of cables and lines it was shown that by increasing the size of cables and decreasing the resistance of them, the Pst and THD is decreased. It was also shown that cables in comparison with lines with same sizes, have better performance in production of flicker and harmonics because the impedance of cables are lesser than lines. By these results, it is proposed that using cables in distribution systems is better than using lines, and the cables with bigger sizes is better than smaller one in production of flicker and harmonics.

REFERENCES

[1] Chong Han; Zhanoning Yang; Bin Chen; Huang, A.Q.; Bin Zhang; Ingram, M.R.; Edris, A.-A, " Evaluation of Cascade-Multilevel-Converter-Based STATCOM for Arc Furnace Flicker Mitigation", IEEE Trans. on industry Applications, Vol. 43, NO. 2, pp. 378 – 385, March-april 2007.

[2] Mendis, S.R.; Bishop, M.T, "Investigations of voltage flicker in electric arc furnace power systems" IEEE Industry Applications Magazine, Vol. 2, pp. 28-34, Jan.-Feb. 1996.

[3] Chang, G.; Hatziadoniu, C.; Xu, W.; Ribeiro, P.; Burch, R.; Grady, W.M.; Halpin, M.; Liu, Y.; Ranade, S.; Ruthman, D.; Watson, N.; Ortmeyer, T.; Wikston, J.; Medina, A.; Testa, A.; Gardinier, R.; Dinavahi, V.; Acram, F.; Lehn, P, "Modeling devices with nonlinear Voltage-current Characteristics for harmonic studies", IEEE Trans. on Power Delivery, Vol. 19, NO. 4, pp. 1802 – 1811, Oct. 2004.

[4] S. Leva, A.P. Morando, D. Zaninelli, "Evaluation of Line Voltage Drop in presence of Unbalance, Harmonics and Interharmonics: Theory and Applications", IEEE Transactions on Power Delivery, Vol.20, No.1, pp.390-396, January 2005.

[5] Samet, H.; Golshan, M.E.H. "Employing stochastic models for prediction of arc furnace reactive power to improve compensator performance", IET, Generation, Transmission & Distribution, Vol. 2, NO. 4, pp. 505 – 515, July 2008.

[6] J.C. Sprott, Chaos and Time-series Analysis, Oxford University Press, NY, 2003.

[7] Xinghuo Yu, Guanrong Chen, Yang Xia, Yanxing Song, and Zhenwei Cao," An Invariant-Manifold-Based Method for Chaos Control" IEEE Trans.On Circuits and Systems—: Fundamental Theory and Applications,Vol. 48, No. 8, August 2001.

[8] O. Ozgun and A. Abur, "Flicker Study Using a Novel Arc Furnace Model" IEEE Trans. Power Delivery, Vol. 17, NO. 4, Octobr 2002.

[9] E. Acha, A. Semlyen, and N. Rajakovic, "A harmonic domain computational package for nonlinear problems and its application to electric arcs, " IEEE Trans. Power Delivery, Vol. 5, pp. 1390–1397, July 1990.

[10] M. P. Kennedy, "Three steps to chaos, Part 1: Evolution," IEEE Trans. On Circuit Syst. I, Vol. 40, No. 10, pp. 640–656, October 1993.

[11] M. P. Kennedy "Three steps to chaos, Part 2: A Chua's circuit primer," IEEE Trans. On Circuits Syst. I, Vol. 40, pp. 657–674, Oct. 1993.

[12] L. O. Chua, "The Genesis of Chua's Circuit", AEU 46, 250 (1992).

[13] M. H. J. Bollen, "Understanding power quality problems, voltage sage and interruptions", IEEE PRESS, First Indian Edition 2001.