Evaluating the Flicker caused by Electric Arc Furnace through the Multi-scale Entropy MSE Algorithm SampEn

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Abstract — This paper presents a new method to evaluate the Arc voltage quality in electric arc furnace (EAF). It has been shown that is possible to allow the representation of nonlinear dynamics and coupling effects between different waves for irregularity of electrical signals issued by electrical components though multi-scale entropy algorithm SampEn. This work shows the behavior of the feature extraction with SampEn when it’s used to evaluate the signals that deviate the arc voltage in (EAF). Flicker effect with voltage imbalances are analyzed by means of the SampEn concept.

Keywords — Entropy, Arc voltage signals quality, Flicker effect and voltage imbalance.

I. INTRODUCTION

The study of signal phenomenon in the electric arc furnace (EAF) is belonging to the concept of power quality [1]. This approach had interest of the process systems engineering [2] because they are integral to the successful execution of planned operations and to improving process productivity. Flicker effect and voltage imbalance phenomenon [3] and recorded through data acquisition systems at many time points. The resulting data sets are monitored after pretreatment of considerable noise characteristics of superpower (EAF) [4]. The different electrical disturbances affect elements of the arc furnace control system, especially in an enclosed environment [5].

The supervision of the arc furnace system is fundamental and in the same time is the subject of increased development because of the increasing demands on reliability and safety [6]. An important aspect to guarantee a reliable and quality of the voltage measurement is the earlier detection of incipient faults in the arc furnace elements and the location and removal of the factors causing such events, than is possible by conventional limit and trend checks [7]. There are a lot of ways to reduce the effects of the arc disturbances by invasive or no-invasive methods [8]. These are determined by the utility system to which the furnace is to be connected and some of them do not, and it is influenced especially by the size and stability of the power grid.

Developing a method in order to achieve the best performance of the monitoring and also allows obtaining a power quality index in (EAF) attracts the attention of many researchers [9]. Estrada and al [10] developed a method and verified that the entropy of arc voltage signals, rises when the respective wave suffers deformations owing to distortions produced by harmonics. This works have focuses on a robust method for evaluating Arc voltage signals quality from (EAF). The present work goes further in the study of the multi-scale entropy behavior on different signals simulated under faulty cases.

II. MULTI-SCALE ENTROPY MEASUREMENTS

The application of the Multi-scale entropy (MSE) for the supervision of EAF is an advantage because this strategy makes it possible to improve EAF power quality and make into accounts not only the dynamic non-linearity, but also effects of interaction and coupling between the systems components [11]. Though MSE analysis, a coarse time series is firstly constructed from the original time series \( \{X_1, \cdots, X_N\} \) of length \( N \), the time series \( \{y^{(i)}\} \) is calculated with the scaling factor \( \tau \) \( \{ \tau = 1.2, \cdots \} \) through the equation:

\[
y^{(i)}_j = 1/\tau \sum_{x=(j-1)\tau+1}^j X_x
\]

Where \( \tau \) represents the scale factor, and we have: \( 1 \leq j \leq N / \tau \).

The time series of \( N \) points is given by: \( \{X(1),\cdots,X(x),\cdots,X(N)\} \), and the algorithm SampEn can be defined as follows [12-18]:

Train \( m \) length vectors \( X_m'(x) \)

\[
X_m'(v) = \{X_{x},X_{x+1},\cdots,X_{x+m-1}\}
\]

\[1 \leq x \leq N - m + 1 \]

(2)
The distance that separates the vectors is calculated as the maximum absolute value of the difference vector’s components.

\[ d[X'_m(v),X'_m(j)] = \max_{k\in[1,m-1]}|X(x+k) - X(j+k)| \]

(3)

For each \( X'_m(x) \) and the fixed tolerance \( r \), leave \( A_x \) the number of vectors satisfying \( d[X'_m(x),X'_m(j)] \leq r \), then \( B^m_x(r) \) as follows:

\[ B^m_x(r) = \frac{A_x}{N-m+1} \quad 1 \leq x \leq N-m \]

(4)

The average \( B^m_x(r) \) is designed as:

\[ B^m(r) = \frac{1}{N-m} \sum_{x=1}^{N-m} B^m_x(r) \]

(5)

By increasing the dimension of \( m+1 \) and repeating the previous steps to find \( B^{m+1}(r) \), the SampEn is calculated through the equation:

\[ \text{SampEn}(m,r) = \sum_{N=\infty}^{N-\infty} -\ln\frac{B^{m+1}(r)}{B^{m}(r)} \]

(6)

For a finite number of data points \( N \) we have:

\[ \text{SampEn}(m,r,N) = -\ln\frac{B^{m+1}(r)}{B^{m}(r)} \]

(7)

III. RESULTS AND DISCUSSION

In order to analyze the flicker effect caused by the electrical Arc, the simulation results obtained by using the different variation of the flicker percentage and the comparison of the data measured in the case of Teta =110 us and with unbalanced conditions E1=200 V, E2=180 V and E3=250V. The aptitude of MSE to analyze the flicker and voltage imbalances caused by EAF depends on their calculated optimized of the parameters of SampEn, by analyzing the voltage waveforms from obtained model of EAF [19].

We can see from the figure 2 that the MSE over 20 scales can be used to detect flicker irregularities, MSE vary from a signal to another, this is due to scaling change where the samples that make the signal are averaged and new discretization of its temporal series is observed.

Five statistics during MSE are extracted as seen in figure 3 using the following measures:

- Max: Maximum of the multi-scale SampEn.
- Min : Minimum of the multi-scale SampEn.
- Mean : Mean of the multi-scale SampEn.
- Geo-Mean : Geometric mean of the multi-scale SampEn.
- STD : Standard deviation of the multi-scale SampEn.

Fig. 1. Waveforms of Arc voltage with flicker percentage variations in the case of unbalance conditions.

Fig. 2. Waveforms of flicker percentage variations in the case with unbalance conditions. (1): MSE over 20 scales.

Fig. 3. Waveforms of flicker percentage variations in the case with unbalance conditions. (1): Teta=110us: Five statistics during MSE.
IV. CONCLUSION

A new method to evaluating the flicker effect in Arc furnaces has been presented. The Multi-scale entropy across 20 scales is evaluated through five indicators (Maximum value, Minimum value, Mean, Geo-mean and standard deviation of multi-scale SampEn). The approaches used can be effective for evaluating the level of the abrupt change of Flicker from the viewpoint of signal irregularity. The advantage of the calculation of the Multi-scale SampEn is that it doesn’t required knowing of the signal amplitude but only waveform of the signal. The complexity measure using MSE across 20 scales was used to extract features that allow well evaluation of the different interactions between the magnetic, electric and dielectric circuits.

REFERENCES