The novel strategy of electrical arc furnace design and control approach for voltage flicker investigation

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Article Info

ABSTRACT

Voltage flickers and harmonics are power quality (PQ) problems in the electric system during a variation and arc furnace (AF) adaptability. AF creations must determine a harmonic and flicker. This article evaluates complex AF systems. This article presents a newly established time domain (TD) static become to on an AF's V-I attributes (VIA). Static arc configurations are useful for harmonic analyses, but dynamic methods are needed for PQ studies, especially voltage flicker analysis. The MATLAB-based dynamic AF configuration is simulated for four different configurations. A response with configurations 1 and 4 varies from the real AF outcomes. The simulation results and numerical finding shows that configurations 2 and 3 are much more appropriate and produce better results for minimum 3rd harmonics for arc current, arc voltage, and point of common coupling (PCC) voltage. The novelty of this configuration is that the energy transferred to the load by the AF during the cycle of operation has been identified, making the developed scheme more reliable and dependent on the load's operational conditions. After that, effective applications of these configurations and other configurations' accuracy should be clarified.

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1. INTRODUCTION

The arc furnace (AF) appears to become an unstable, non-linearity, and time-varying load which could produce several power quality (PQ) problems throughout the power grid. Instability, harmonics, inter-harmonics, and voltage flicker may result from the AF load. To comprehend the effect of an AF [1], [2] the dependable three-phase AF framework for harmonic analysis and flicker compensation is developed. Even though arc melting is a static probabilistic structure, making a proper simple technology for AF load seems to be challenging. The melting or refining materials, the placement of the membrane, the influence of an electrode arm, as wellandltage and impedance of a supply line appear to be variables that influence the execution of the AF [3]-[5]. As a result, the characterization of an AF load is responsible for key factors: i.e. arc voltage (Varc), arc current (Iarc) as well as arc length (Larc).

The various AF configurations can be divided into "time domain (TD)" and "frequency domain (FD)" methods. The FD methodology takes into account the Varc as well as the Iarc of its harmonic [6], [7]. A power system circuit model is established between each input frequency, and an AF has been designed as a voltage source at the same frequency [8], [9]. The overall system action is noted by superimposing a control performance at each frequency [10], [11]. Another requirement for the FD analysis is predefined Varc and current calculated data to obtain a harmonic voltage source methodology. One such configuration has been used without evaluation. A few descriptions [12]-[15] have formed the harmonic domain simulation model of a nonlinear differential approximation. Such approximations support a relationship between the arc radius and the Iarc. These other frameworks include some testing procedures to evaluate the execution of the AF. Because of all of these intriguing new and imprecise variables, such designs aren't widely used. Although the electrical arc is a non-linear concept with varying times, a summary of its behaviour and attitude in the TD is simpler than in the FD [13]. TD methodologies are now the most common type of flicker investigation throughout electric arc furnaces (EAF). VIA and equivalent circuit methods (ECM) are the two types of TD methodologies.

The ECM techniques are being learned through arc deployment; the periodic alteration of the Varc, as well as the resistance shown by the arc, could have been used to determine the AF configuration [16], [17]. Much more standardization in the estimation of the prototype could affect the prediction's ability [18]. The VIC techniques usually focus on the AF's VIA derived from correlation, respectively V_{arc} and Iarc using the VIA. Such a technique has been commonly used to configure the static and dynamic execution of the EAF [19]. Numerical AF configurations with differing degrees of accuracy are extracted from the VIA. Numerical simulations also will be presented [20]-[23]. The dynamic response of the revised flicker simulations is then addressed. A unique TD framework for the AF is discussed thoroughly. The new technique is being analyzed by MATLAB simulation software [24]-[28].

The structure of an article is as follows; sections 2 define the EAF's static and dynamic execution. It also describes the proposed flicker analysis technique with EAF. Section 3 presents the results of the system modelling for simulation used in the study. Finally, in section 4, AF is represented for both frequency and TD, with the conclusion.

2. STATIC CONFIGURATIONS AND METHOD

Figure 1 represents the real VIA and the piecewise linear configuration of the AF [20]-[22]. The arc ignition (V_{ig}) and extinction voltage (V_{ex}) have been based on the length of a Vig, mostly during AF operation. Besides estimating the real VIA of the AF, different TD structures were given by the following.
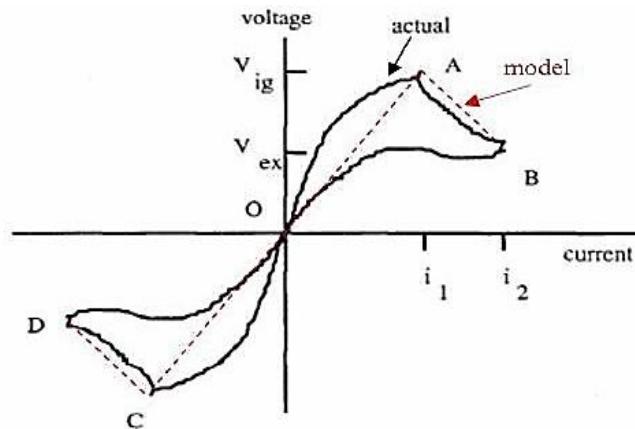

Figure 1. Real and piecewise linear estimation of the VIA of the AF load

2.1. Configuration 1

Two linear functions are used to compute the AF's true configuration. Let R_1, R_2 be the slopes of its OA and AB boundaries, respectively. As a result, throughout this approach, the link between V_{arc} and current for a single cycle is explained as (1)-(3). Figure 2 illustrates the simulated VIA of configuration 1 using MATLAB simulation software.

$$v = \begin{cases} R_1 i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots -i_1 \leq i < i_1 \\ R_2 i + v_{ig}\left(1 - \frac{R_2}{R_1}\right)\dots\dots\dots\dots i_1 < i \leq i_2 \\ R_2 i - V_{ig}\left(1 - \frac{R_2}{R_1}\right)\dots\dots -i_2 \leq i < -i_1 \end{cases} \tag{1}$$

Where

$$i_1 = \frac{v_{ig}}{R_1} \tag{2}$$

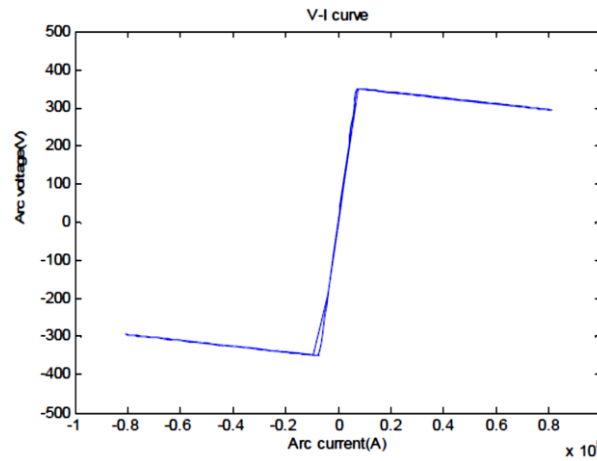$$i_2 = \frac{v_{ex}}{R_2} - v_{ig}\left(\frac{1}{R_2} - \frac{1}{R_1}\right) \tag{3}$$

Figure 2. VIA of configuration 1

2.2. Configuration 2

Apart from looking at some of the attributes in further additional detail, a slightly more precise non-linear estimation arrangement can be formed. The overall VIA of the non-linear setup 2 [1] is depicted in Figure 3. Throughout its configuration, an arc melting system is divided into three sections. The amplitude of an applied voltage is rise from its V_{ex} to the V_{ig} in the first section. The AF acts as just a resistor in this segment [23], and the I_{arc} modifies its directivity from $-i_3$ to i_1. The second section depicts the start of the arc melting. As this exponential voltage throughout the membrane changes dramatically, the V_{arc} decreases from V_{ig} to V_{st}, as well as the I_{arc} gradually increases from i_1 to i_2. The third part appears to be the arc's normal melting procedure. V_{arc} drops from V_{ex} in a linear, slow, and efficient manner. In (4) and (5) contain the formulas that demonstrate such differences. Figure 3 illustrates the modelling VIA of configuration 3 MATLAB/Simulink software was used.
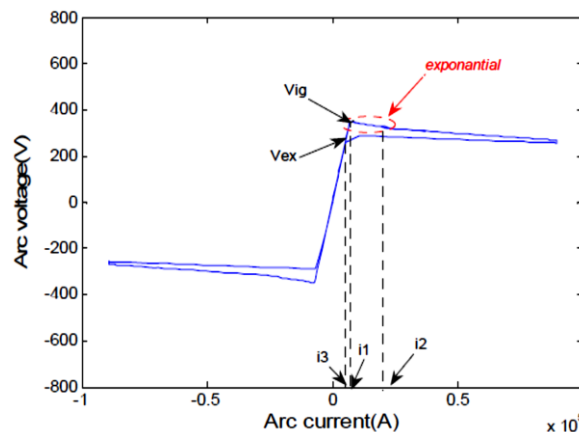

Figure 3. VIA of configuration 2

$$v = \begin{cases} R_1 i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (-i_3 \le i < i_1, inc) \, or \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (-i_1 \le i < i_1, dec) \\ v_{st} + (v_{ig} - v_{st}) \exp((i_1 - i)/i_T) \dots\dots\dots i_1 \le i < i_2, inc \\ v_{st} + (i - i_2)R_2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots i_1 \ge i_2, inc \\ v_{ex} + (i - i_3)R_3 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots i_1 \ge i_3, dec \\ -v_{st} + (v_{st} - v_{ig}) \exp((i_1 + i)/i_T) \dots\dots -i_2 \le i < -i_1, dec \\ -v_{st} + (i_1 + i_2)R_2 \dots\dots\dots\dots\dots\dots\dots\dots i < -i_2, dec \\ -v_{ex} + (i + i_3)R_3 \dots\dots\dots\dots\dots\dots\dots\dots i < -i_3, inc \end{cases} \tag{4}$$

Within which R_1, R_2, and R_3 are just the slopes of the respective segments.

$$i_1 = \frac{v_{ig}}{R_1}, \, i_T = 1.5 i_1, \, i_2 = 3 i_1, \, i_3 = \frac{v_{ex}}{R_1} \tag{5}$$

2.3. Configuration 3

An arc melting mechanism can indeed be classified into three types by analyzing an AF's actual VIA. In this setup, a few other assumptions have been made under these three stages, as explained in [19]. Over the first duration, an arc initiates to resurface from destruction. Whenever the V_{arc} drops to zero, this same I_{arc} also attains its own zero point of intersection. Even though V_{arc} reaches the resignation voltage V_{ig}, the equivalent circuit remains open. The low current will have flowed parallel to an arc V_{ia} the foamy slag. The foamy slag does have a constant resistance of R_g, as well as the resignation voltage has been presumed to be proportional to the reciprocal of the arc [18].

The arc was formed in the second quarter. At the beginning of the arc melting, a transient method tends to appear in the waveform. The V_{arc} rate varies from Vig to the constant V_d, which is unusual. One such phase is almost certainly defined as either an exponential function with such a time constant of T_1. The arc begins to leave the area during the third period. Except for an indicated extent after the arc is extinguished, the V_{arc} begins to deteriorate smoothly. This is presumed that the mechanism is mentioned by an exponential with a time constant T_2.

Following all of the preceding examples, the EAF was developed as a current-controlled non-linear resistance, as shown in Figure 4. Numerical depictions of the EAF shall be prepared by (6). The I-R graph can be seen in Figure 5 and the expression of Vig current and instantaneous voltage is shown in (7).

$$R_a = \begin{cases} R_1 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots ; \left| 0 \le I < i_{ig}, \frac{dI}{dt} > 0 \right. \\ \frac{[v_d + (v_{ig} - v_d)\exp(-(I - i_{ig})/\tau_1)]}{I} \dots ; I \ge i_{ig}, \frac{dI}{dt} > 0 \\ \left[\frac{v_t + (v_{ig} - v_t)\exp(-I/\tau_2)}{I + i_{ig}} \dots\dots\dots\dots ; \frac{dI}{dt} < 0 \right. \end{cases} \tag{6}$$

Where $I = |i(t)|$, $v_{ig} = 1.15 v_d$

$$i_{ig} = \frac{v_{ig}}{R_1}, \, V_t = \left[\frac{Iig_{max}}{I_{max}}\right] v_d \tag{7}$$
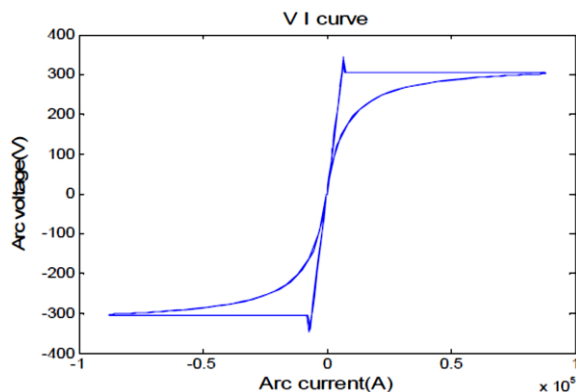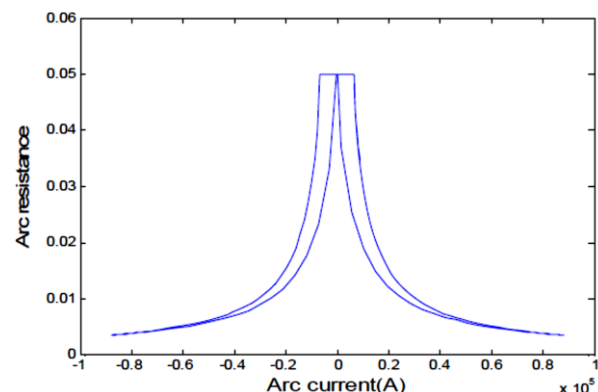

Figure 4. VIA of configuration 3

Figure 5. Arc I-R graph

2.4. Configuration 4

A different type of arrangement, as well as simplicity of the real attribute, has been seen in Figure 6 [8]-[12]. So, the V_{arc} alters polarity so rapidly, one such configuration ignores the increasing voltage time, resulting in a huge change in the V_{arc} so when the Iarc has been at nil. Thus, the ideal cycle of the VIC has been demonstrated as (8):

$$v = sign(i)[v_{at} + \frac{c}{D+|i|}] \tag{8}$$

Let "l" be the Larc, A and B are the coefficients from the experimental formula, then:

$$v_{at} = A + B.l \tag{9}$$

Where, V_{at} reflects the AF operating condition as indicated in (8) and (9).

Voltage flicker has become a stochastic and time-variation phenomenon that occurs in RMS voltage variation in the range of frequencies (0.5-25 Hz). A dynamic AF setup is done [24] to assess the flicker produced by AF. The slop, including its VIA throughout Figure 1 has been modified mostly as a sinusoidal wave to construct dynamic characteristics of an AF which uses different structures. These same dynamic load implementations throughout configurations 1, 2, and 3 take into account periodic changes in the R_{arc} to the rating provided on every setup. Throughout the scenario of sinusoidal variance, the R_{arc} is defined when:

$$R_1(t) = R_1(1 + m\,sin(w_f t)) \tag{10}$$

In which R_1 is just the constant resistance of an AF when the arc is off but the EAF acts as an open circuit, 1 R_f =5-007 is just the frequency of the flicker and the coefficient of modulation. Its voltage throughout (8) had already influenced a different loading configuration in setup 4, so the voltage could've been considered in (11):

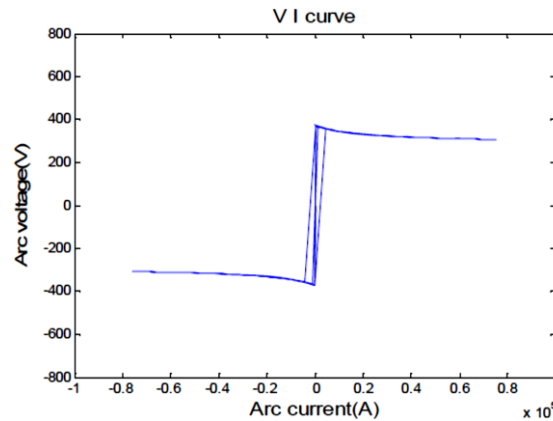$$v_{at}(t) = v_{at}(1 + m\,sin(w_f t)) \tag{11}$$

Figure 6. VIA of configuration 4

2.5. Proposed flicker analysis technique with EAF

The dynamic AF configuration has been produced by (10), which is an R_1 change in the aspects discussed (say R_1 modulation). Concerning the AF's VIC, this same R_1 has been associated with the low current cycle of a furnace cycle. The R_2 has been associated with the effective phase of the cycle; then the more current passes through the membranes, the more flickers are intended.

If using R_2 modulation to produce the furnace's dynamic behaviour, many flickers have been produced, and the results appear to be relevant to the actual ones. Whereas more power has been obtained from the furnace throughout portion AB of a VIC, many flickers have been assumed, and the use of R_1 transduction contributes to an inaccurate produced flicker scenario. When the duration of the arc changes, a large proportion of flickers are produced, so this timeframe is in portion AB of the attribute. The dynamic configuration of a combustion chamber could therefore be produced by modulating R_2, as shown in (12):

$$R_2(t) = R_2(1 + m\,sin(w_f t)) \tag{12}$$

3. RESULTS AND DISCUSSION

When comparing AF configurations, a simple AF system has been developed in some kind of single phase. The system's configuration is depicted in Figure 7. All across Figure 7, the system's impedance would be stipulated as mentioned earlier: the point of common coupling (PCC) bus denotes a PCC, and the AF bus did appear to become the low voltage side of the transformer, the impedance of it has been supplied. Table 1 includes the modeling schematic in Figure 8 and also the control variables as well as configurations by each structural system.
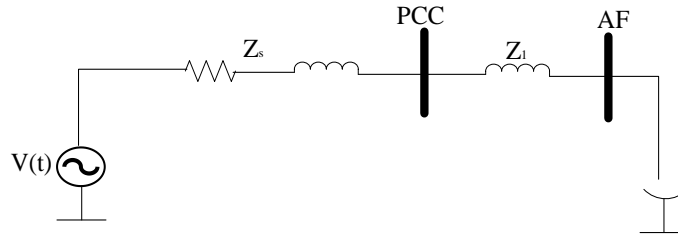
Figure 7. Study system of AF

Table 1. Study system parameters with EAF

Study system	$V=566$ V; $f=60$ H_Z; $Z_l=0.3366+j3.22$ mΩ; $Z_s=0.0528+j0.468$ mΩ
Configuration 1	$V_{ig}=350.75$ V; $V_{ex}=289.75$ V; $i_1=7015$ A; $i_2=87.278$ kA; $R_1=0.5$ Ω; $R_2=-0.76$ mΩ
Configuration 2	$V_{ig}=350.75$ V; $R_1=0.5$ Ω; $V_{st}=350.75$ V; $V_{ex}=289.75$ V; $R_2=-0.76$ mΩ; $R_3=-0.39$ mΩ
Configuration 3	$V_{ig}=350.75$ V; $I_{max}=100$ kA; $\tau_1=0.01$ sec; $\tau_2=0.02$ sec
Configuration 4	$V_{at}=289.75$ V; $C=1.68$ MW, $D=20.65$ kA
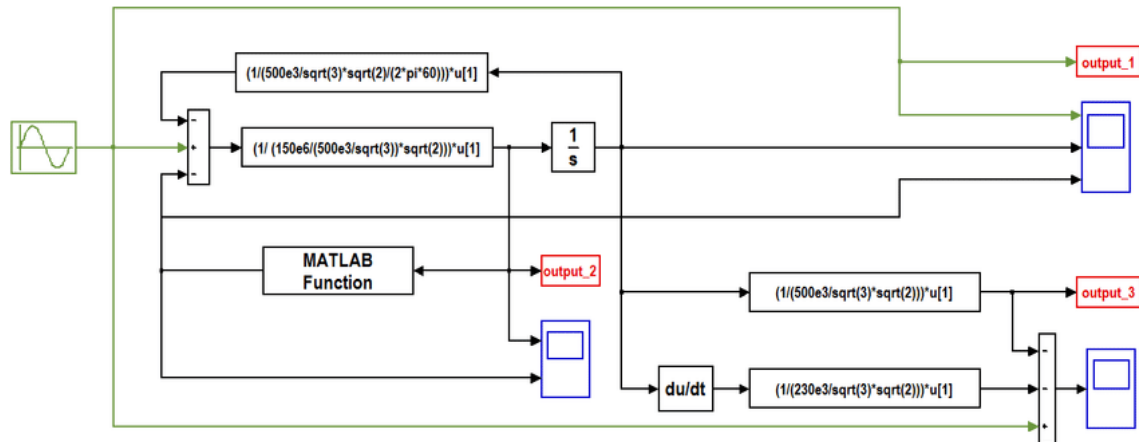
Figure 8. The sub-system of EAF in MATLAB

To use the specifications shown here in Table 1, the four distinct configurations of an AF are explored and the outcomes have been presented in Figures 9-12. The V_{arc}, a V_{pcc} as well as the Iarc have been seen in each figure. All current waveforms in figures have been sized to 200 to align the waveform of the voltage. The harmonic V_{arc}, Iarc, and V_{pcc} elements by each structure have been seen in Table 2. The dynamic arrangement of an EAF must be analyzed in analysis to define the flicker presented by EAF on the PCC bus.

The dynamic approach is founded on alterations in Larc. The nonlinear as well as time-variable attributes of the length of an arc lead to changes in the resistance of the arc and, therefore the curve of the VIA. One reason for selecting an adaptable component would be to produce a justifiable flicker while limiting the variations within slop including its VIA. *V-I* waveforms of configurations 1-4 are shown in Figures 9-12 serially.

The dynamic VIA is depicted in Figures 13-20 including all configuration. The assessment of the voltage flicker leads to the formulation of the system V_{rms} modification and also the frequency with which the

deviation occurs, therefore the percent voltage flicker, as well as flicker frequency, have become significant [13]. The direct connections, as well as a description of the cyclic voltage flicker, have been mentioned throughout the reference [13]. Out of the estimations, the percent deviation of ΔV/V at 10 hertz for 4 setups can be seen in Table 3. It is shown that configurations 3 and 1 have very less deviation as compared to the other 3 AF configurations.
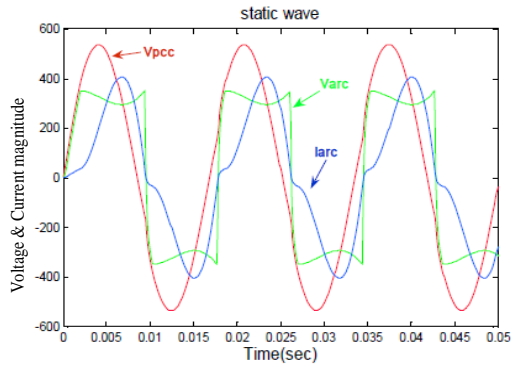

Figure 9. V-I waveform of configuration 1 in a stationary condition
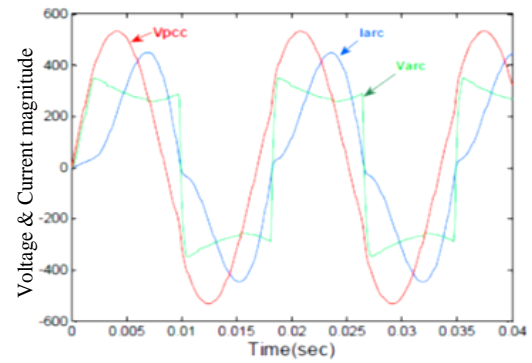
Figure 10. V-I waveform of configuration 2 in a stationary condition
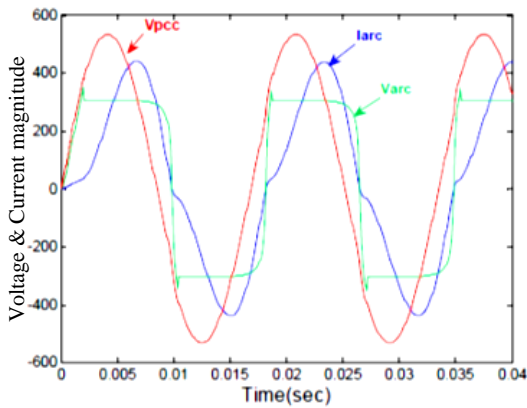
Figure 11. V-I waveform of configuration 3 in a stationary condition
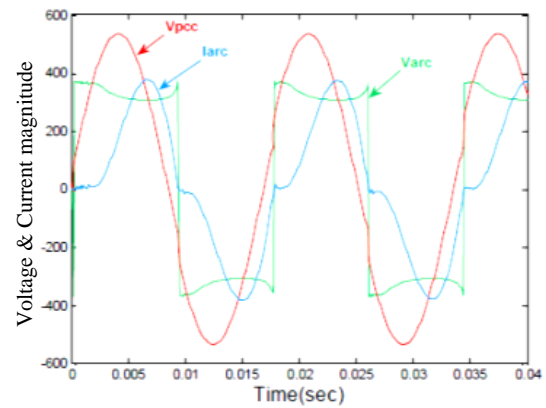
Figure 12. V-I waveform of configuration 4 in a stationary condition

Table 2. Comparative analysis of the harmonics of the varying combinations

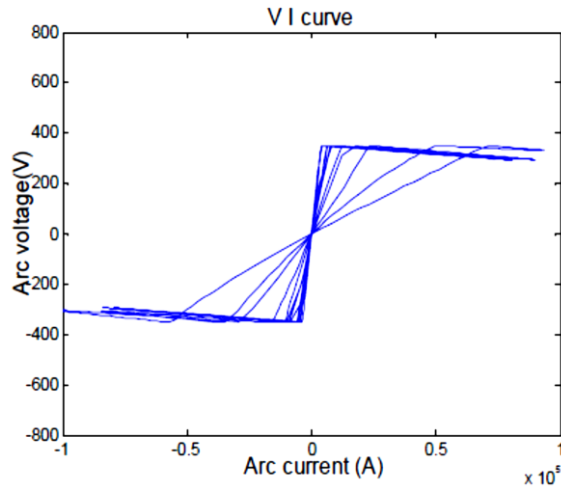| Item	Harmonic (%)	Configuration 1	Configuration 2	Configuration 3	Configuration 4
Arc current	Fund, (kA)	77.226	81.824	80.727	65.56
	3rd	0.1846	0.15068	0.13644	0.20636
	5th	0.06081	0.05095	0.043556	0.07135
	7th	0.02577	0.02125	0.017429	0.0319707
	9th	0.01221	0.012324	0.0091264	0.0162088
	11th	0.00716	0.009785	0.0072054	0.0095027
Arc voltage	Fund, (V)	398.11	362.7	391.3432	407.1365
	3rd	0.3571	0.35842	0.301321	0.364177
	5th	0.1954	0.21053	0.158682	0.213650
	7th	0.1247	0.1412	0.09551	0.147125
	9th	0.08625	0.10191	0.060519	0.11298
	11th	0.06259	0.07885	0.03832	0.09348
Voltage at PCC	Fund, (V)	539.5	534.738	536.387	542.9
	3rd	0.03349	0.030949	0.02805	0.034536
	5th	0.01853	0.018317	0.015553	0.0204236
	7th	0.01182	0.012202	0.010111	0.014127
	9th	0.00811	0.008688	0.007121	0.01083
	11th	0.00581	0.006709	0.005253	0.008902

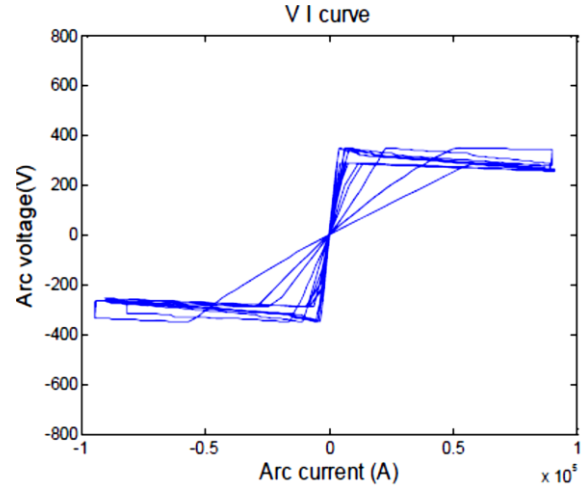Figure 13. VIA of configuration 1 in dynamic
condition

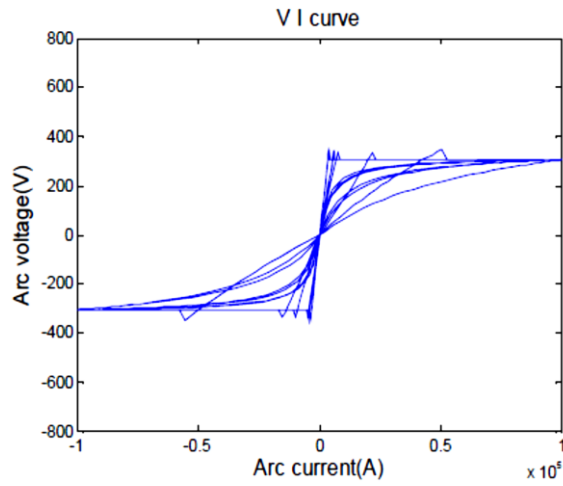Figure 14. VIA of configuration 2 in dynamic
condition

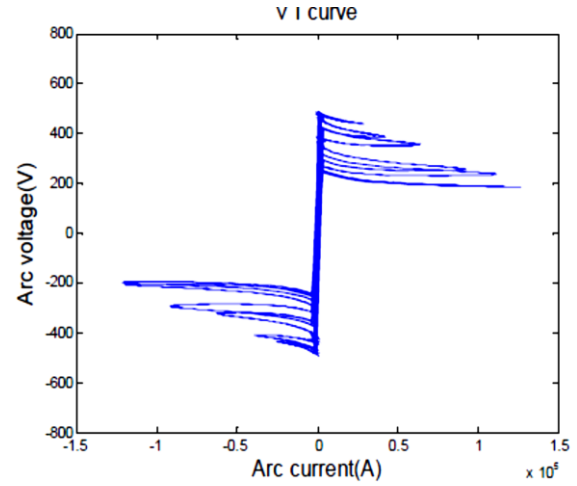Figure 15. VIA of configuration 3 in dynamic
condition

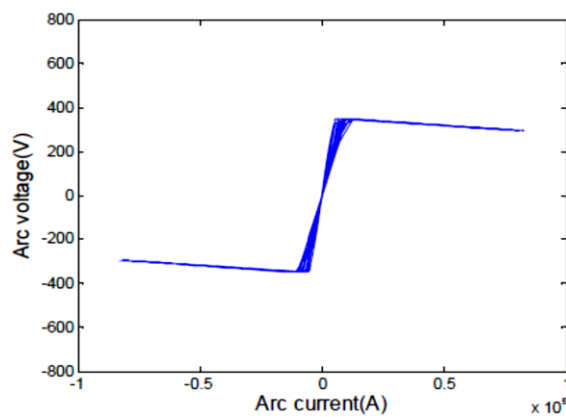Figure 16. VIA of configuration 4 in dynamic
condition

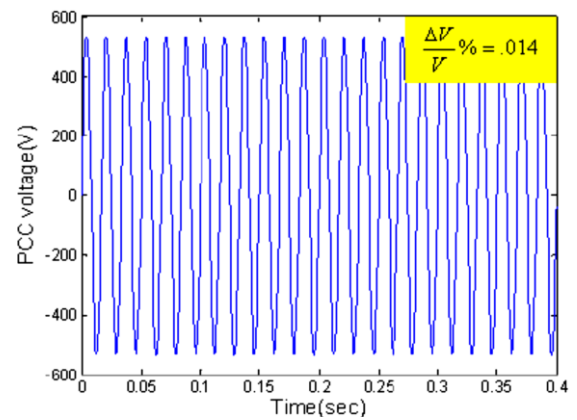Figure 17. VIA of configuration 2 with R_1
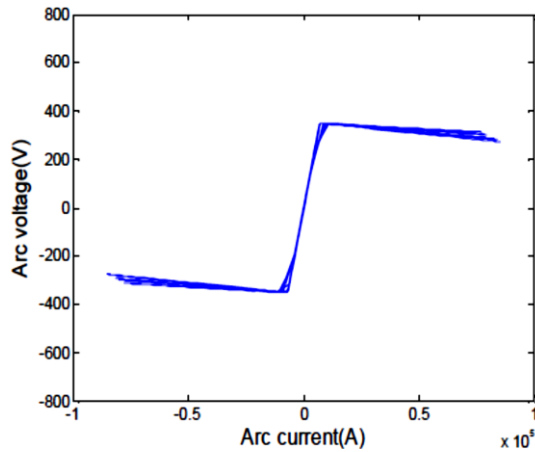modulation

Figure 18. V_{pcc} with M=0.3 for R_1

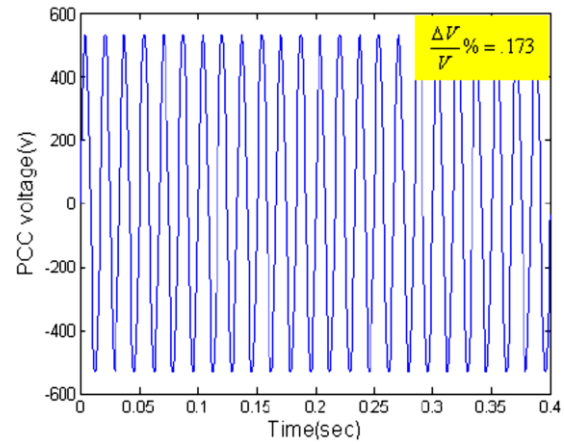Figure 19. VIA of configuration 2 with R_2 modulation

Figure 20. V_{pcc} with M=0.3 for R_2

Table 3. $\frac{\Delta V}{V}$ % at frequency 10 Hz for arc sinusoidal differences

Sr. No.	Configuration type	$\frac{\Delta V}{V}$ (%)
1	Configuration 1	0.2207
2	Configuration 2	0.5956
3	Configuration 3	0.00887
4	Configuration 4	3.047

4. CONCLUSION

TD configuration seems better because frequency domain configuration relies on assumptions that aren't always true. TD-based AF architectures investigated these effects with V-I attributes categorization. The first and fourth configurations lack the data needed to model the third section and respond appropriately. AF differs from configurations first and fourth. Simulation and numerical results show configurations 2 and 3 are better for minimum 3rd harmonics for Iarc, Varc, and PCC voltage. This method uses active AF flicker computations. Configuration 1 includes Rarc optimization. In evaluating the V_{pcc} waveform for modulation using the computation modulation constants, the authors conclude that using R_2 variation to generate a dynamic response of a furnace causes additional flicker and that the results are consistent with the real one. The furnace gives VIC part AB extra time, but R_1 modulation causes flickering. This novel setup is reliable regardless of the load's state of operation because the AF's energy transfer to the load has been isolated.

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