HARMONIC ANALYSIS OF A WELDING PROCESS

Ibrahim El-Amin

King Fahd University of Petroleum and Minerals

Dhahran 31261

Saudi Arabia

Email: imelamin@kfupm.edu.sa

ABSTRACT

The order and level of power system harmonics depend on the nature of the nonlinear load being supplied. Nonlinear loads include power converters, arcing devices and many others. The operation of an arc welder and the impact of its control parameters on the power system harmonics are investigated. The parameters are the welding current, arc length, and the diameter of the electrode. Each of the parameters has two possibilities. A number of tests were carried out in order to assess the relationship between the welding parameters and harmonic levels. The experimental setup was designed using a Yates factorial algorithm. A set of basic parameters was used as a bench mark for the harmonic levels. The control parameters were then changed in an orderly manner following the factorial design format. The test results indicate that the levels of the individual harmonics are influenced by the welding parameters.

KEY WORDS

Harmonic levels, Power quality, Welding, Arcing devices furnaces

1. Introduction

Electric utilities and consumers of electrical power are concerned about the quality of electric power. The power quality term is applied to many events on the power system. However, a general definition of power quality is any event that causes voltage, current or frequency deviations that may lead to the improper operation of customer equipment. The causes of power quality events may be attributed to the electric utility or to the type of load. For example, mainly nonlinear loads cause harmonic distortion. The voltage and current of a nonlinear load are not proportional. Nonlinear loads include power converters, satuarble and arcing devices and many others. There are many excellent references that address the subject [1-3]. This paper is concerned with the operation of an arc welder and the impact of its control parameters on the power system harmonics. The parameters are the welding current, arc length, and diameter of the electrode. The quality of the welding is also influenced by the material composition. For example, the carbon contents of the material could decide the arc length and the associated input current

2. Experimental Equipment and Procedure

The apparatus consists of a Tig welding machine, electrodes, and a power system harmonic analyzer with its accessories. The Tig welding machine can be used for automatic argon arc and metal arc processes. These processes do not require an ordinary electrode to strike the arc, but a non-consumable electrode, which deposits no filler material.

The harmonic analyzer is a Drantez power platform meter [4]. It provides the order and level of harmonic contents of voltage and current waveforms. It is interfaced with a PC through an RS232 connection. A current transformer is used in conjunction with the meter. It converts the input welding current to a level that suits the meter. The welding process depends on three variables. First, the welding current can be set at either 60A or 90A. Second, the electrode diameter is either 2.00 mm or 2.6 mm. Third, the arc length is either short or long. As a result, there are three variables each having two possibilities. It means that there are 2^3 main experiments. The experiments thus have to be arranged in a manner that will allow the user to measure and identify the significance of the variables on the power system harmonics. The experimental design requires a statistical analysis algorithm.

3. Statistical Analysis

A Yates' algorithm is applied to the observations after they are arranged in what is called a standard order. A 2^k factorial design is a standard order. To perform a factorial design, an investigator selects a fixed number of "levels" for each of a number of variables (factors) and then conducts the experiments with all possible combinations.

The columns of the design matrix consist of successive minus and/or plus signs. The minus sign represents a low level and the plus sign represents a high level. Another notation uses a 0 and/or 1 in place of the minus and plus signs respectively. The factorial design tells us about the effect of a variable on the measured quantity. For example, it displays the effect of the electrode current on the level of a particular power system harmonic. The data is used to determine the mean affect of the variable on the experiment outcome.

4. Experimental Results and Discussion

The main objective of these experiments is to observe the effects of the welding parameters on the quality of the power system. The power system quality is measured by the level and order of the harmonics. The parameters are the welding current, the electrode diameter and the length of arc.

4.1 Test Procedure

The first test has the welding current set at 60A, the electrode diameter is 2.0 mm and the welding arc is short. The values are referred to as the basic parameters. The harmonics of the ac input current are collected while the welding is performed. The average value of each harmonic is obtained and will be used for data analysis.
Table 1 shows the harmonic components for the basic welding parameters. The third harmonic is predominant. It is also worth noting that the level of the second harmonic is significantly high when compared to other harmonics. The presence of the even harmonic confirms the complexity of the process and shows that the arc welding process is nonlinear.

Table 1: Harmonic Components for Basic Welding Parameters

Test parameters	Harmonic level (%) of the fundamental					
60-A, 2.0 mm and short arc	2	3	4	5	7	11
	.02867	.07967	.003	.005	.00267	

The welding current is then increased to 90A and the power system harmonics are obtained. The other variables remain at their original levels. The welding is then performed with 60A welding current, an electrode diameter of 2.6 mm and with a short welding arc. The corresponding current harmonics are collected. Subsequent tests were conducted in a similar manner, changing the welding parameters one at a time. Table 2 shows the tests order and the corresponding value of the welding variables.
Table 3 shows the coded data. The coded data represents the quantitative variables and a qualitative description of the arc. It is referred to as the design matrix table. The minus sign represents the low value of the quantity (current/diameter) and it also refers to a short arc length.

Table 2: Test Order and Original variables

Test Condition	Welding Current (A)	Electrode Diameter (mm)	Arc Length
1	60	2.0	Short
2	90	2.0	Short
3	60	2.6	Short
4	90	2.6	Short
5	60	2.0	Long
6	90	2.0	Long
7	60	2.6	Long
8	90	2.6	Long

Table 3: Design Matrix Coded Data

Test no.	Current level	Electrode diameter	Arc length
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

The second row represents the basic welding parameters. The minus sign refers to the original values of the current, the electrode diameter and the short arc length. The third row exhibits a plus sign in the second column two while the remaining entries have not changed. This represents an increase in the current while both the electrode diameter and the arc length remain unchanged from their original settings.
The second column of the design matrix consists of successive minus and plus signs. The third column contains successive pairs of minus and plus signs. The fourth column consists of four minus signs followed by four plus signs. In general, the *k*ith column consists of 2^{k-2} minus sign followed by 2^{k-2} plus signs. The Yates calculations for the welding experiments are discussed in the following section.

4.2 Application of Yates' Algorithm

Table 4 shows the application of the Yates algorithm to the average second harmonic for each test. The algorithm will identify the effect of varying a parameter on the average harmonic current. Column (1) identifies the test condition. Column (2) is the average of the second order harmonic of each test. For example, the average value of the first test is 0.02867 percent of the fundamental. The welding parameters are 60A, 2.0 mm and a short arc length. The average values of column (2) are considered in successive pairs. The first four entries in column (3) are obtained by adding the pairs together. Thus 0.02867 + 0.039 = 0.06767, and so on. The second four entries are obtained by subtracting the top number from the bottom number of each pair. Thus 0.039 – 0.02867 is equal to 0.01033. Column (4) is obtained from the pairs of column (3) in the same manner as column (3) was derived from column (2). Finally column (5) is obtained from column (4) in a similar manner. The entries in column (5) are the precise values obtained by combining the average harmonic current with the appropriate column signs of Table 3. To obtain the effect one has to divide by the appropriate divisors. These are equal to 8 for the first entry and 4 for all other entries. Thus the grand average harmonic current is 0.03606 percent of the fundamental. Locating a plus sign from Table 3 illustrates the effect on the grand average. For example, an increase in the current from 60A to 90A results in a decrease of the second harmonic by 22.3×10^{-3} percent. However, an increase in the electrode diameter from 2.0 mm to 2.6 mm causes the harmonic current to increase by 9.79×10^{-3} percent. The combined effect of both the current and diameter is an increase of 0.96×10^{-3} percent. If only the arc length is increased, the harmonic current is increased by 7.37×10^{-3} percent. However the simultaneous increase of the diameter and the arc length cause an increase of 12.73x 10^{-3} percent. When all the three variables are increased simultaneously, the average harmonic current is increased by 9.54×10^{-3} percent. Similar tables were generated for the 3rd, 4th, 5th, 7th, and 11th harmonic. The third harmonic is relatively high. It reaches 0.0797 percent.

Table 5 shows the analysis for the third harmonic. An increase in the welding current causes the third harmonic to increase by 35.7x10^{-3} percent. An increase in the arc length registers an increase in the third harmonic of 51.71×10^{-3} percent. The combined effect of the welding parameters is an increase of 18.46×10^{-3} percent.

Table 6 shows the impact of simultaneously increasing the welding parameters on the harmonic levels. The second and third harmonics increase in level. The higher order harmonics decrease by various levels as indicted by

5. Conclusion

The impact of the control parameters of an arc welder on the levels of the power system harmonics was investigated. The experimental setup was designed using a Yates factorial algorithm. The data collected was arranged by using a design matrix coded format. A set of basic parameters was used as a bench mark for the harmonic levels. The control parameters were then changed in an orderly manner following the factorial design format. The test results indicate that the levels of the individual harmonics are influenced by the welding parameters.

6. Acknowledgements

The author would like to acknowledge the support and facilities of King Fahd University of Petroleum and Minerals, Dhahran , Saudi Arabia

References:

1. Arrillaga, J., Watson, N.R. and Chen, S., '*Power System Quality Assessment'*, John Wiley, &Sons, 2000.

2. Dugan, R.C., McGranaghan, M. and Beaty, H. W., '*Electrical Power System Quality*', McGraw-Hill, 1996.

3. Bollen, M.,' *Understanding Power Quality Problems'*, IEEE Press, 2001.

4. Power Platform PQ-Plus Drantez-BMI Technology Inc. Edison, New Jersey, USA., 1994

Table 4: Yates' Algorithm as Applied to the Second Harmonic

Test Condition	Run Average	(1)	(2)	(3)	Divisor	Estimate	variable
1	0.02867	67.67E-3	129.50E-3	288.50E-3	8	36.06E-3	AVG
2	0.03900	61.83E-3	159.00E-3	-89.50E-3	4	-22.37E-3	C
3	0.03433	57.00E-3	3.50E-3	39.16E-3	4	9.79E-3	D
4	0.02750	102.00E-3	-93.00E-3	3.84E-3	4	0.96E-3	CD
5	0.05700	10.33E-3	-5.84E-3	29.50E-3	4	7.37E-3	L
6	0.00000	-6.83E-3	45.00E-3	-96.50E-3	4	-24.12E-3	CL
7	0.6900	-57.00E-3	-17.16E-3	50.84E-3	4	12.71E-3	DL
8	0.03300	-36.00E-3	21.00E-3	38.16E-3	4	9.54E-3	CDL

Table 5: Yates Algorithm as Applied to the Third Harmonic

Test Condition	Run Average	(1)	(2)	(3)	Divisor	Estimate	Variable
1	0.07967	191.67E-3	425.67E-3	1058.17E-3	8	132.27E-3	AVG
2	0.11200	234.00E-3	632.50E-3	142.83E-3	4	35.71E-3	C
3	0.10800	267.50E-3	50.33E-3	139.83E-3	4	34.96E-3	D
4	0.12600	365.00E-3	92.50E-3	45.17E-3	4	11.29E-3	CD
5	0.12550	32.33E-3	42.33E-3	206.83E-3	4	51.71E-3	L
6	0.14200	18.00E-3	97.50E-3	42.17E-3	4	10.54E-3	CL
7	0.14450	16.50E-3	-14.33E-3	55.17E-3	4	13.79E-3	DL
8	0.22050	76.00E-3	59.50E-3	73.83E-3	4	18.46E-3	CDL

Table 6: Impact of Simultaneous Increase of Welding Parameters

Test parameters	Percentage Change ($x10^{-3}$)					
90-A, 2.6 mm and long arc	2	3	4	5	7	11
	9.54	18.46	-1.5	-3.46	-1.59	-0.08