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Research Article

The Effect of an Induction Heating System on Power Quality Parameters

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Abstract

This study was conducted to determine the Power Quality (PQ) parameters of 900 kHz, 2.8 kW Ultra High Frequency Induction Heating System (UHFIHS) during heat treatment of TI-6Al-4V based material. The material is one of the most important titanium alloys in the industry applications. All current and voltage data of the induction system are collected under laboratory conditions with special analog sensors and recorded to the computer by using NI LabVIEW™ program. The collected data are analyzed by Discrete Fourier Transform (DFT) and the effect of the device on power quality parameters during operation was examined. When the DFT frequency spectrum is analyzed, it is seen that the 3rd (150 Hz), 5th (250 Hz), and 7th (350 Hz) harmonic components are quite higher than 10 %, while the others are below 10 % in the Period I and Period II. Period I indicates the time until the sample to be heated reaches a temperature of 700 ° C and period II indicates the time after the sample has reached the desired temperature level.

Keywords: Power Quality, Harmonics, Induction Heating System, Titanium Alloys, Signal Processing.

İndüksiyonlu Bir Isıtma Sisteminin Güç Kalitesi Parametrelerine Etkisi

Öz

Bu çalışma TI-6Al-4V bazlı malzemenin ısıl işlemi sırasında 900 kHz, 2.8 kW Ultra Yüksek Frekanslı İndüksiyon Isıtma Sisteminin (UHFIHS) Güç Kalitesi (PQ) parametrelerini belirlemek için yapılmıştır. Bu malzeme, endüstri uygulamalarında en önemli titanyum alaşımlarından biridir. İndüksiyon sisteminin tüm akım ve gerilim verileri, özel analog sensörlerle laboratuvar koşullarında toplanmış ve NI LabVIEW™ programı kullanılarak bilgisayara kaydedilmiştir. Toplanan veriler Ayrık Fourier Dönüşümü (DFT) ile analiz edilmiş ve cihazın çalışması sırasında güç kalitesi parametreleri üzerindeki etkisi incelenmiştir. DFT frekans spektrumu incelendiğinde, Periyot I ve Periyot II'de, 3. (150 Hz), 5. (250 Hz) ve 7. (350 Hz) harmonik bileşenlerin % 10'dan oldukça yüksek olduğu, diğerlerinin % 10'un altında olduğu görülmektedir. Periyot I, ısıtılacak numunenin 700 ° C sıcaklığa ulaşma sürecini ve periyot II, numunenin istenen sıcaklık seviyesine ulaşmasından sonraki süreci gösterir.

Anahtar Kelimeler: Güç Kalitesi, Harmonikler, İndüksiyon Isıtma Sistemi, Titanyum Alaşımlar, Sinyal İşleme.

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1. Introduction

Power Quality (PQ) refers to the smoothness of the voltage and current sinusoidal waveform. If the pure sinusoidal form changes, the power quality deteriorates (Gökozan et al, 2015), (Gökozan, 2011). Quality of electrical energy is highly important for accurate and efficient operation of electrical machines. Power quality is becoming an important issue nowadays in domestic and industrial fields (Arrillaga et al, 2000). Electromagnetic Induction is a method used to fast heat magnetic materials. Induction heating (IH) systems are widely used in industry. UHFIH Treatment is one of the rapid heat process (Taştan et al, 2015). Induction heating offers a number of advantages over conventional furnace techniques, such as: quick heating, fast start-up, energy saving, high production rates, and less scale loss (Çavdar, 2014). Typical power conversion flow in an IH system is shown in Figure 1.

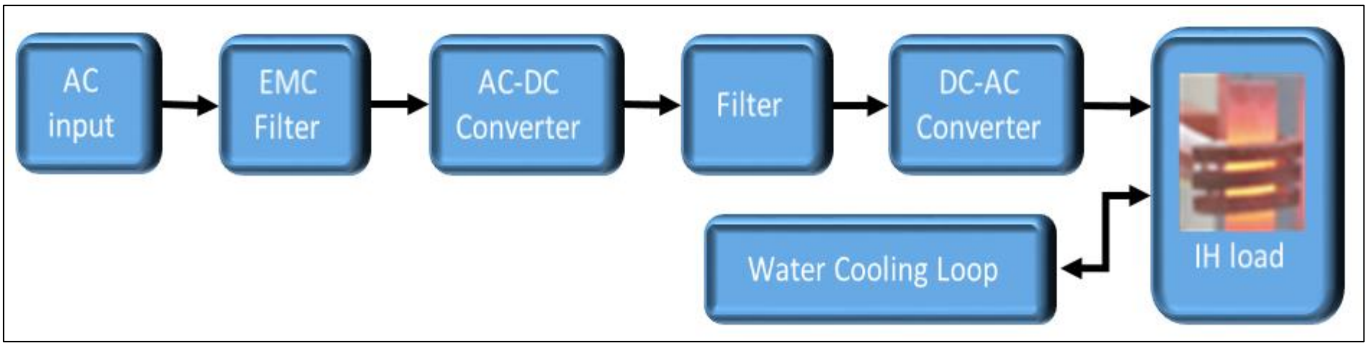

Figure 1. Power Conversion Flow in an Induction Heating System

In industry, power electronics-based devices that contain semiconductor elements are one of the non-linear loads. Such and similar loads disrupt the sinusoidal form of voltage and current and create a harmonic effect (Gökozan, 2019). Waves other than the fundamental voltage and current frequency are called "harmonic" (Gökozan, 2011). Therefore, it is necessary to eliminate the effects of harmonics in order to provide that the power quality of the system is at the desired value. Harmonics which are one of the most important parameters in the field of energy/power systems determine the power quality (Vatansever & Kuyu, 2019), (Yumusak et al, 2004). Poor power quality may cause manufacturing interruptions, loss of production, product damage, energy waste and decreased equipment life (Gökozan et al, 2015), (Taskin & Gokozan, 2011).

Power quality problems in a plant can be caused either by the distorting effects produced by another consumer or by the distorting effects caused by devices operating in their plant (Sallam & Malik, 2019). Chargers and charging stations used to charge the batteries of electric vehicles produce harmonics and affect power quality (Karmaker et al, 2019). Methods for measuring and interpreting electrical parameters in 50/60 Hz power systems are defined in IEEE-519-1992, EN 50160, IEC 61000-4-7 and IEC 61000-4-30 standards. There are various signal processing techniques used to determine the properties of electrical signals. Power quality is analyzed using techniques such as artificial intelligence, heuristic optimization, and signal processing. The most active methods in optimization, artificial intelligence and signal processing are Genetic Algorithms, Particle Swarm Optimization, Artificial Neural Network, Fuzzy Logic, Wavelet Transform and Fourier analysis.

Comprehensive literature review on digital signal processing, artificial intelligence, optimization techniques and their applications in the classification of PQ disorders is presented in the references (Khokhar et al, 2015), (Mahela et al, 2015), (Granados-Lieberman et al, 2011), (Montoya et al, 2016). The final state of signal processing techniques used for feature extraction of PQ distortions is shown in Figure 2 (Khokhar et al, 2015).

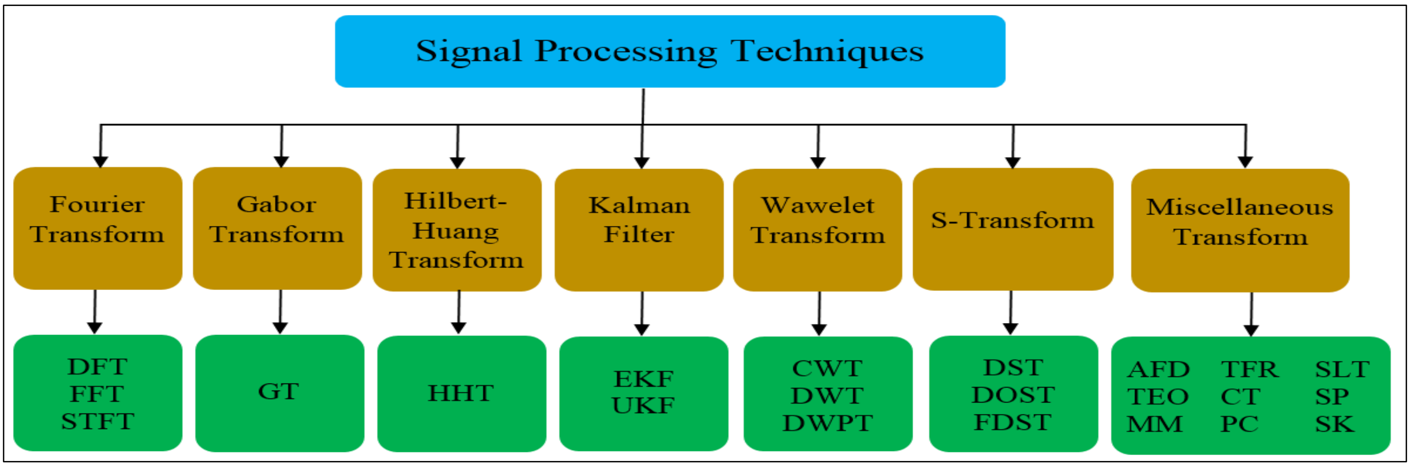

Figure 2. The Final State of Signal Processing Techniques

2. Material and Method

The analysis in this study is based upon the Fourier based techniques like power spectral density calculation and Discrete Fourier Transform approach. Fast Fourier Transform (FFT) and DFT are widely used for harmonic analysis due to its effectiveness in measurement. DFT is used to determine the properties of electrical signals. More information on the mathematical background of this study is presented in the reference (Gökozan et al, 2015).

The analysis of this current signal, which involves the fundamental component and harmonic components obtained in the filter output, is conducted with the DFT method suggested by IEC. The DFT analysis took N=1000 samples as the reference for t=0.2s, and used T=10/ f windows with 5 Hz resolution for f=50 Hz, as suggested in IEC 61000-4-7. The Total Harmonic Distortion (THD) is calculated with the formula given in Equation 1(Gökozan, 2011).

$$THD_{(I)} = \sqrt{\frac{\sum_{n=2}^{\infty} I_n^2}{I_1^2}} \qquad (1)$$

Where;

THD $_{(I)}$: Total Harmonic Distortion of the current,
In : Effective value of n. order of harmonic in the load current,
I_1 : Effective value of the load current in the fundamental frequency,
n : Harmonic order.

2.1. Measurement System

The measurement system is designed with LabVIEW™ graphical program. The necessary information about this system is clearly described in reference (Gökozan et al, 2015), (Gökozan, 2011), (Taştan et al, 2015) and (Taskin & Gokozan, 2011). With this system, Power quality values of electrical power systems can be measured.

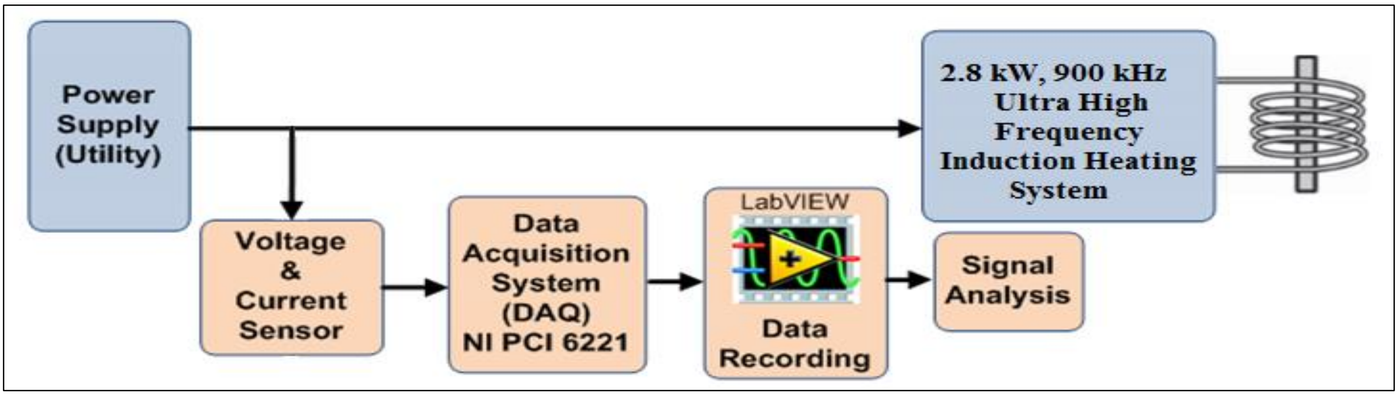

Figure 3. Power Quality Measurement System Set-Up

During the measurement, the necessary operations are performed with the help of real-time data. The system set-up is shown in Figure 3 and see Figure 4 and References (Gökozan et al, 2015), (Gökozan, 2011), (Taştan et al, 2015), (Taskin & Gokozan, 2011), (Gokozan et al, 2016), (Taştan, 2019) for the user interface.

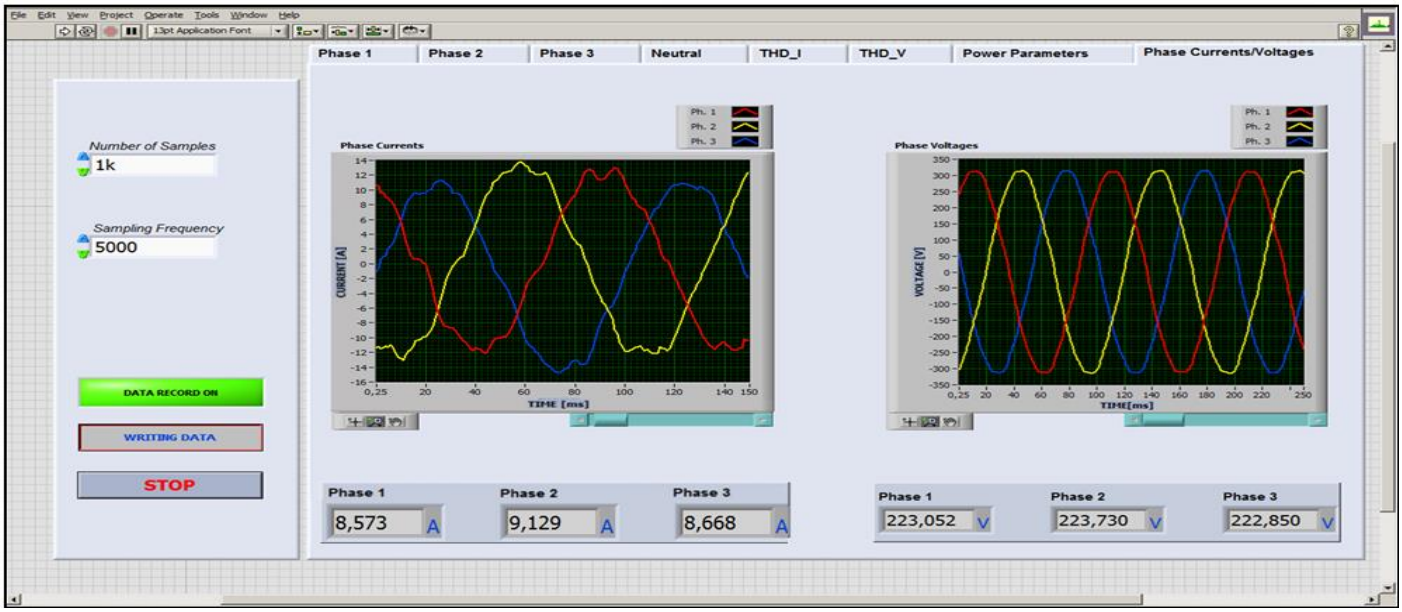

Figure 4. The Power Quality Measurement System User Interface

3. Results and Discussion

The related standards are taken into account during the measurements. In order to analyze up to 50th harmonic, data are measured with a sampling rate of 5000 S / s. Titanium material with a diameter of 16 mm and a height of 5 mm was heated to 700 °C degrees. The temperature of the material was measured and fixed by an infrared laser thermometer (±5 °C). The Current-Time graph obtained from the data collected during the study is given in Figure 5.

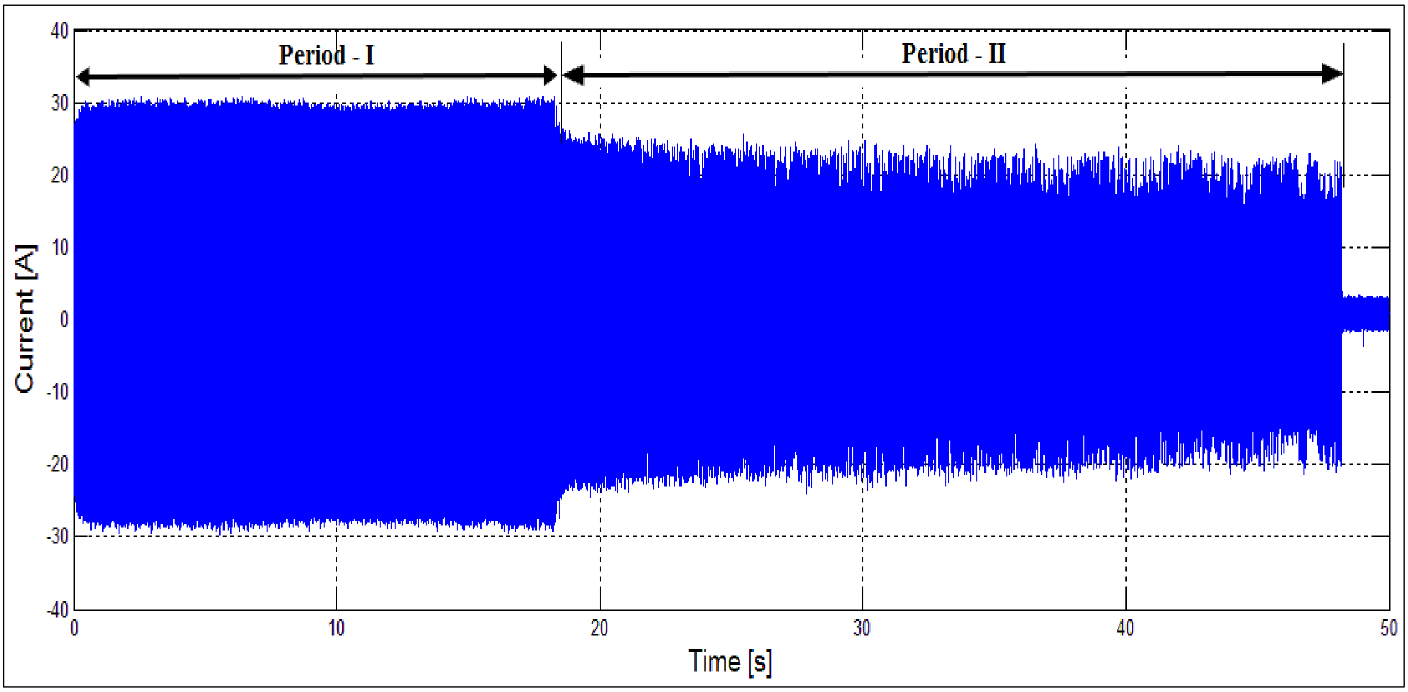

Figure 5. Current Change of the Induction Heating System Under 700 °C.

Figure 5 clearly shows that the current and power consumption of the heating system is high in the first 18 seconds (Period-I) but is lower in the next period (Period-II). Period I specifies the time for the titanium material to be heated to reach 700 ° C and period II refers to the time after the material reaches the desired temperature level (Taştan et al, 2015).

Figure 6 and Figure 7 shows DFT frequency spectrum of the Period-I and Period-II current signals. When the DFT frequency spectrum is analyzed, it is seen that the 3rd (150 Hz), 5th (250 Hz), and 7th (350 Hz) harmonic components are quite higher than 10 %, while the others are below 10 %. Values of below 5% are not shown in this figures.

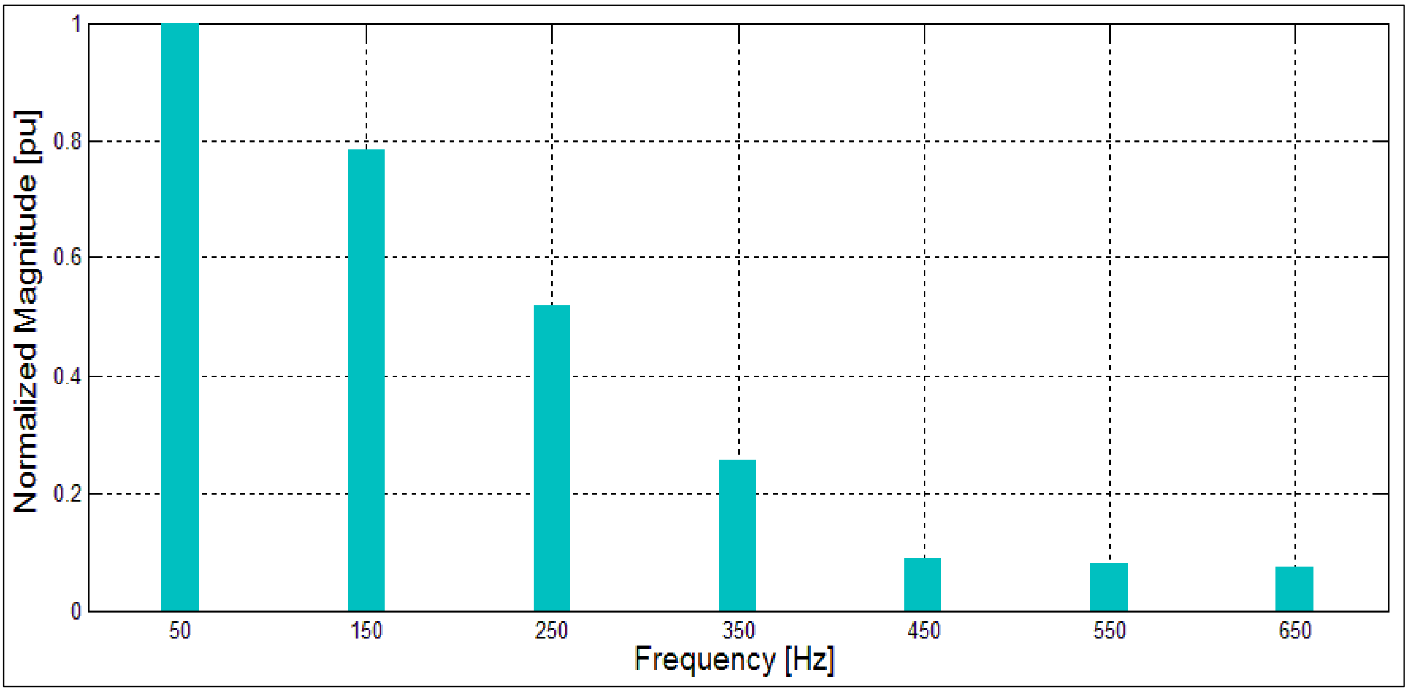

Figure 6. Frequency Spectrum for Period-I Current Signal

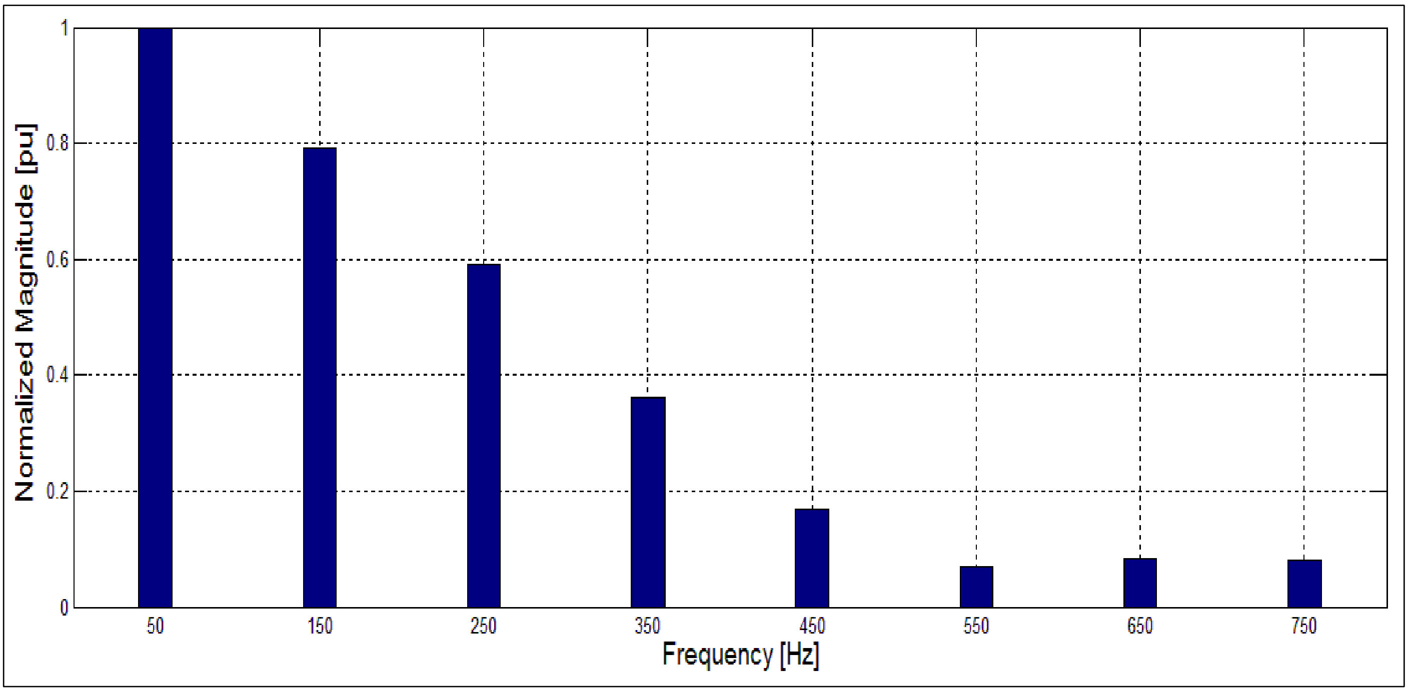

Figure 7. Frequency Spectrum for Period-II Current Signal

The current amplitudes in period I and period II are different. This is related to the power consumption of the induction system. When the harmonic components are examined for both periods, there will be differences. This is directly related to the switching frequencies and operating characteristics of the power electronics elements. Although the amplitude of the current is thought able to require a large harmonic distortion but this value is smaller in stable working.

This study was carried out to determine the 900 kHz, 2.8 kW Ultra High Frequency Induction Heating System (UHFIHS) Power Quality (PQ) parameters during the heat treatment of TI-6Al-4V based material, and it is the first because it was done with the DFT method.

4. Conclusions and Recommendations

This study was conducted to determine the Power Quality (PQ) parameters of this system (UHFIHS) during heat treatment of TI-6Al-4V based material. The data collected were analyzed by Discrete Fourier Transform (DFT) and the effect of the device on power quality parameters during operation was examined.

When the DFT frequency spectrum is analyzed, it is seen that the 3rd harmonic (150 Hz) value was 78%, 5th harmonic (250 Hz) value was 50%, 7th harmonic (350 Hz) value was 24%, 9th harmonic (450 Hz) value was 9%, 11th harmonic (550 Hz) was 8% and 13th harmonic (650 Hz) was 7% in the Period I.

On the other hand it is seen that the 3rd harmonic (150 Hz) value was 79%, 5th harmonic (250 Hz) value was 59%, 7th harmonic (350 Hz) value was 36%, 9th harmonic (450 Hz) value was 18%, 11th harmonic (550 Hz) was 10%, 13th harmonic (650 Hz) was 12% and 15th harmonic (750 Hz) was 13% in the Period II.

As a result of the calculations, the total harmonic distortion in the UHFIHS was 96% in period I and 108% in period II. This values is shown in Table 1. These values are much higher than the permissible total harmonic distortion values (6%).

Table 1. Harmonic And THD Values For Period I and Period II.

Harmonic Values %								
Period	**3rd (150 Hz)**	**5th (250 Hz)**	**7th (350 Hz)**	**9th (450 Hz)**	**11th (550 Hz)**	**13th (650 Hz)**	**15th (750 Hz)**	**THD (%)**
I	78	50	24	9	8	7	3	96
II	79	59	36	18	10	12	13	108

In such systems, harmful harmonics should be eliminated using appropriate active or passive filters. While calculating of the harmonic filters, it will be possible to eliminate harmful harmonics in both periods by using the values in the 2nd period. Especially the 3rd, 5th, 7th, 9th and 11th harmonics should be filtered. Otherwise, devices that produce such high harmonic values may adversely affect other networked devices. It is recommended to eliminate the 3th, 5th, 7th, 9th and 11th harmonics with the highest effect value. As a result of the calculations to eliminate these harmonics, the following 5 Passive filters values were found. Table 2 shows these values.

Table 2. Passive Filter Values Required For Eliminate to Specified Harmonics.

Harmonic Value (th)	Resonance Frequency (Hz)	Capacitor Value (kVAr)	Inductance Value (mH)	Resistor Value (Ohm)
3	120	0,25	1,41	3,1
5	210	0,25	0,46	0,96
7	320	0,25	0,2	0,38
9	410	0,25	0,12	0,25
11	520	0,25	0,08	0,2

In industry, power electronics based loads containing semiconductor elements create a harmonic effect by distorting the sinusoidal form of voltage and current. In such systems, harmful harmonics should be eliminated using appropriate active or passive filters. In this way, production interruptions, loss of production and energy, product damage and shortening of equipment life will be prevented.

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