THE IMPACT OF POWER QUALITY ON INDUSTRIAL PRODUCT:

"Steel Plant AC - EAF Case Study"

BY

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This thesis, written by Abdullah Ali Al-Elyani under the direction of his thesis advisor and approved by his thesis committee, has been presented to and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN ELECTRICAL ENGINEERING.

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Dedicated to

My Mother, Wife

And

Children.

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Praise and glory to Allah the most gracious and merciful, who gave me courage and patience to carry out this work. Peace and blessing of Allah be upon last Prophet Muhammad (Peace Be upon Him).

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THESIS ABSTRACT

Full Name	:	Abdullah Ali Al-Elyani
Thesis Title	:	The Impact of Power Quality on Industrial Product: “Steel Plant AC - EAF Case Study”
Major Field	:	Electrical Engineering
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The objective of this Thesis is to find the impact of the power quality parameters on the quality of an industrial steel product and to determine whether a relationship exists between the two. This is may be used in order to determine one variable by finding the other. To reach to this goal, electrical measurements were conducted in an electric arc furnace at steel plant at 34.5 kV level for recording power quality data for a period of 210 hours (210 heats). Currently, chemical analysis for the same 210 heats is obtained from the chemical laboratory. The power quality parameters values and chemical elements values in the industrial steel were analyzed and are found to be within the limits defined by standards.

The collected data analyzed thoroughly for the possible relationship between the power quality parameters and the chemical elements were discussed. The results were stipulated and relationship is found to be weak. Conclusions with recommendations for further studies were presented.

Master of Science Degree

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ملخص الرساله

الاسم : عبدالله علي عبدالرحمن العلياني

عنوان الرساله : **اثر جودة الطاقه الكهربائيه على المنتج الصناعي ـ دراسه فرن القوس الكهربائي في مصنع الصلب**

التخصص : هندسه كهربائيه

التاريخ : يونيو 2011

الهدف من هذه الرسالة هو معرفة تأثير معايير جودة الطاقة الكهربائية على جودة منتجات الصلب الصناعية والعثور على علاقة فيما بينهما ان وجدت. ومن الممكن استخدام هذه العلاقه لاستنتاج احد المتغيرين من خلال معرفة المتغير الأخر. وللوصول إلى هذا الهدف ، أجريت القياسات الكهربائية اللازمة على مستوى 34,5 كيلو فولت المغذي لفرن القوس الكهربائي في مصنع للصلب لتسجيل بيانات جودة الطاقة الكهربائية اللازمه لمدة 210 ساعة (210 صبه حديد مصهور). في الوقت نفسه، يتم الحصول على التحليل الكيميائي للعناصر اللازمه من المختبر الكيميائي للعينات المأخوذه من 210 صبه حديد مصهور تم إنتاجها. كل القيم التي تم الحصول عليها من القياسات الكهربائيه ومن التحليل الكيميائي للعينات المأخوذه وجدت في حدود المعايير العالميه في هذا الشأن.

تم تحليل البيانات التي تم جمعها بدقة وتمت مناقشة العلاقة بين كل من جودة الطاقة الكهربائيه من جهه والعناصر الكيميائية من جهة اخرى والتي افضت الدراسه الى كون هذه العلاقه ضعيفة. تضمن البحث كذلك ختام لما توصلت له الدراسه مع توصيات لمزيد من الدراسات القادمه.

درجة الماجستير

جامعة الملك فهد للبترول والمعادن

يوليو 2011

CHAPTER 1

INTRODUCTION

Electrical power is an important ingredient of modern life. It is required in sufficient capacity and excellent quality. Power Quality is important to both utilities and electricity consumers at all levels of usage. The term power quality has been widely used by many industrial and commercial electricity end-users in the last decade and includes all aspects of events in the system that deviates from normal operation.

The industrial sector is affected by the electricity quality even though this sector is the main contributor to most of the power quality problems. The automation of industrial processes has lead to effective increase in production and reduction in cost. However this is coupled with concerns about the level and requirements of power quality as nonlinear industrial loads contribute significantly to producing harmonics distortions into the supply. These loads includes converters, switch mode power supplies, and arc furnace, etc.

Introducing the electric arc furnaces (EAF) to the industry of steel making has increased the amount of produced steel worldwide. At the same time, it is one of main sources for power quality problems introduced especially in terms of harmonics and voltage fluctuations or flickers.

This Thesis will investigate and study the relationship between the industrial steel product at an electric arc furnace (EAF) and power quality measured at the same location(s). The objective of the Thesis is to assess the existence of correlation between the quality of industrial product and power. This work will be achieved by:

- Conducting a measurement scheme for the power quality parameters at EAF power source for period of time.

- Assessing the steel product quality analysis using chemical analysis in the EAF, LF, and CCM.

- Analyzing the results for both power quality parameters and steel product chemical analysis to find the relationship / correlation between them.

Chapter one gives an overview of the subject and lists the contents of the Thesis. Chapter two presents a literature survey to document the power quality works that have been undertaken. It documents the work done in steel making process and the phenomena or parameters may affect this industry. Chapter three gives details about steel making starting from mining till finishing mills throughout the direct reduction process, steelmaking process, casting process, etc. It also gives an overview about the using of blast furnaces, base oxygen furnace with more details about the electric arc furnace since it will be the subject investigated in this study. Chapter four gives an overview of power quality issues, and presents the most commonly used concepts, indices, and standards.

Chapter five presents the design method and calculations for the static var compensator (SVC) used for electric arc furnace. The information is related to the systems used in the plant where this study was conducted. Chapter six gives definition to the two main items for this study; 1) the power quality parameters measured during the study, and 2) the industrial steel product with its chemical analysis standards and limitations. The procedure used for collecting both the power quality data and the steel product data is also documented and demonstrated with some examples. At the end of this chapter, representations to the results or the data collected throughout the study is made. Chapter seven presents the complete analysis for the collected data for both power and product. The methods used were explained in enough details to furnish the conclusion of the work. The correlation or relationship between the power quality parameters and the product chemical analysis elements is studied. It concentrates on the relationship of carbon and carbon equivalent as the most effective two elements in steel production as correlated with the power quality parameters. Chapter eight presents conclusion and recommendations. A list of references is enclosed at the end of the Thesis.

The Thesis contains a number of appendices.

CHAPTER 2

LITERATURE REVIEW

Several studies have been carried out to measure the parameters of the power quality to:

1. Monitor the power quality within the acceptable level as applicable to various customers.
2. Develop or enhance the way of protecting the equipments from the impact of power quality problems such as harmonics, sag, swell, interruption etc.
3. Manufacturer equipments with less generation to the power quality parameters.
4. Reduce the impact to the users.
5. Others.

However, research in correlating the power quality to the industrial product quality in general is limited.

2.1 POWER QUALITY

This section reviews the research work related to power quality. There are different assessment approaches either direct or indirect in this field.

Several authors have described a data stream architecture for electrical power quality (PQ) data [1]. It is the first attempt to model PQ data as data streams, and shows its feasibility on real-world (field) PQ data. PQStream is developed to process and manage time-evolving data coming from the country-wide mobile measurements of electrical PQ parameters of the Turkish Electricity Transmission System.

The power quality parameters, as defined in IEC 61000-4-30, are specified and used in the power quality assessment [2].

James C. Worley studied the power quality in 85 distribution substations for three years to achieve two goals; to characterize the power quality of a typical rural distribution substation and to gain insight into what variables affect the power quality on the distribution system. Both of these goals were accomplished [3].

Masoud Aliakbar Golkar described types of power quality variations and presented the methods of characterizing each type with measurements. Also advances in power quality monitoring equipment and tools for analyzing power quality measurement results are described [4].

Different methods/techniques to classify the power quality problems such as Artificial Neural Networks, Support Vector Machine, etc were discussed in [5-6].

The power quality applications in industries, steel plants in particular, were discussed with real time measurements [7]. For a steel producer, optimum performance namely cost-efficient production, is of primary interest. The use and impact of power quality equipments such as Static Var Compensator (SVC), is justified only if it enables increased production or energy savings were discussed [8-9].

A power quality survey at 33 KV industrial sites is reported [10]. It describes the changes in the power quality levels in the national grid due to the failure to enforce the PQ standards. Results with solutions and recommendations were presented for industries, commercial, utilities, and the government to avoid increasing the PQ problems.

Wide studies and evaluations of flickers in supply system and other power quality parameters with their effect on industries customers such as arc furnace were discussed and compared to other works [11-12].

R. C. Sermon, discussed various standards and guidelines on power quality from the end users point of view [13]. Two main standards were used, 1) The Information Technology Industry (ITI), “CBEMA” curve, and 2) The Semiconductor Equipment and Materials International (SEMI) specification. It is shown how these two standards may help the end user in design and procurement.

Robert D. Henderson, and Patrick J. Rose, studied the effect of harmonic distortion on the industrial power system [14]. The study is made on 480 V, three-phase, variable speed drives. The results showed the effects of harmonics on transformers in industrial systems. The study includes the recommendations for correction of the problems resulting from harmonic distortions.

It is worth reported that Keith H. Sueker presented comments in several points which are subject to misinterpretation by readers of the above paper "Harmonics: The Effects on Power Quality and Transformers" [15].

Amaya Barona, Francisco Ferrandis, Javier Olarte, and Jose L. Iribarren, presented solutions offers the some disturbances compensation capabilities [16]. Aspects such as Voltage dips/swells, Voltage distortion, Voltage flicker, etc were included. These solutions have been validated in a variety of industrial facilities.

Jeff G. Dougherty, and Wayne L. Stebbins, defined power disturbances in industry accepted terms, examine the sources and effects of these disturbances (for both the utility and the industry), and explore economical solutions based on the compatibility of the equipment and the electrical environment [17].

At the BC hydro power smart, it looked at the customer as the main focus and the financial impact as the main concern for the users [18]. The author has studied the impact of poor power quality on their business. Few areas of hidden costs were looked at and checklist for compiling basic power quality cost data were developed.

2.2 INDUSTRIAL PRODUCT QUALITY

This section presents the work undertaken in relation to the quality of industrial product.

M. N. N. Hisyamudin, S. Yokoyama, and M. Umemo discussed improving the quality of steel by fixing CO_2 into the electric arc furnace (EAF) [19]. This will reduce slag from stainless steelmaking process under wet grinding method. This method was investigated and the main results were obtained.

A. McLean, expressed that the steel industry has been transformed by major technological changes during the past century. Coupled with that, demands for improving steel quality have been increased [20]. These demands have been met by advances in the knowledge and understanding of the chemical, physical and thermal interactions between steel, gas, slag and refractory phases, which occur within individual reaction vessels and also during transfer operations between the primary furnace and the casting mold. He showed how the transfer operations must be controlled precisely otherwise, these transfer steps become destroyers of quality.

The author also discussed the steel quality as result of interactions between oxygen and elements such as carbon, manganese, chromium, silicon, aluminum and calcium. Control of oxygen potential throughout steelmaking operations is essential for quality.

Influence of the complete process on the quality of steel, rebar as finished product, were discussed throughout the process starting from melting and passing by casting process and finally during rolling. Ignorance about the influence of the metallurgical and production characteristics has an impact on the mechanical properties of structural steel.

To be able to take informed decisions about the quality of steel rebars in a holistic manner, it is imperative that structural engineers are conversant with the steel-making characteristics that have a bearing on the mechanical properties of the rebars. These and more discussed in [21].

M. H. Joulazadeh reported that using scrap tires in the EAF process can lead to total elimination of the coke and coal charge from the EAF steelmaking process. Scrap tires are put to useful applications as a carbon source for a variety of steels including low, medium, and high carbon steels. It can also provide a decrease in electrical and chemical energy consumption. He also discussed the impact on pollution and energy saving during the melting process in EAF [22].

Mark Atkinson, and Robert Kolarik wrote about the technology roadmaps which are dynamic documents [23]. They also talked about the importance of the regular updates to reflect important changes in the industry and the world in which it operates. The update shall be in response to technological advances, changes in the global market, and new technical insights. The Yield Loss in the Steel Industry concern was discussed and the Opportunities to Improve Yield via R&D.

Per Hansson studied the carbon and carbon equivalent and their importance for the weldability and hardenability [24]. The hardenability described in the carbon equivalents used in welding and the hardenability of quenched and tempered steels using the Grossmann formalism are two different descriptions of the same phenomenon. The author linked these two formalisms together and use the knowledge from the heat affected zone (HAZ) hardenability to design quenched and tempered tool steels.

The technical literature for the two subjects of power quality and industrial steel product quality or steel chemical analysis and alloys are very rich individually.

There are few articles that address the relationship between the two processes. No previous study was found that deals with determination of power quality and industrial product.

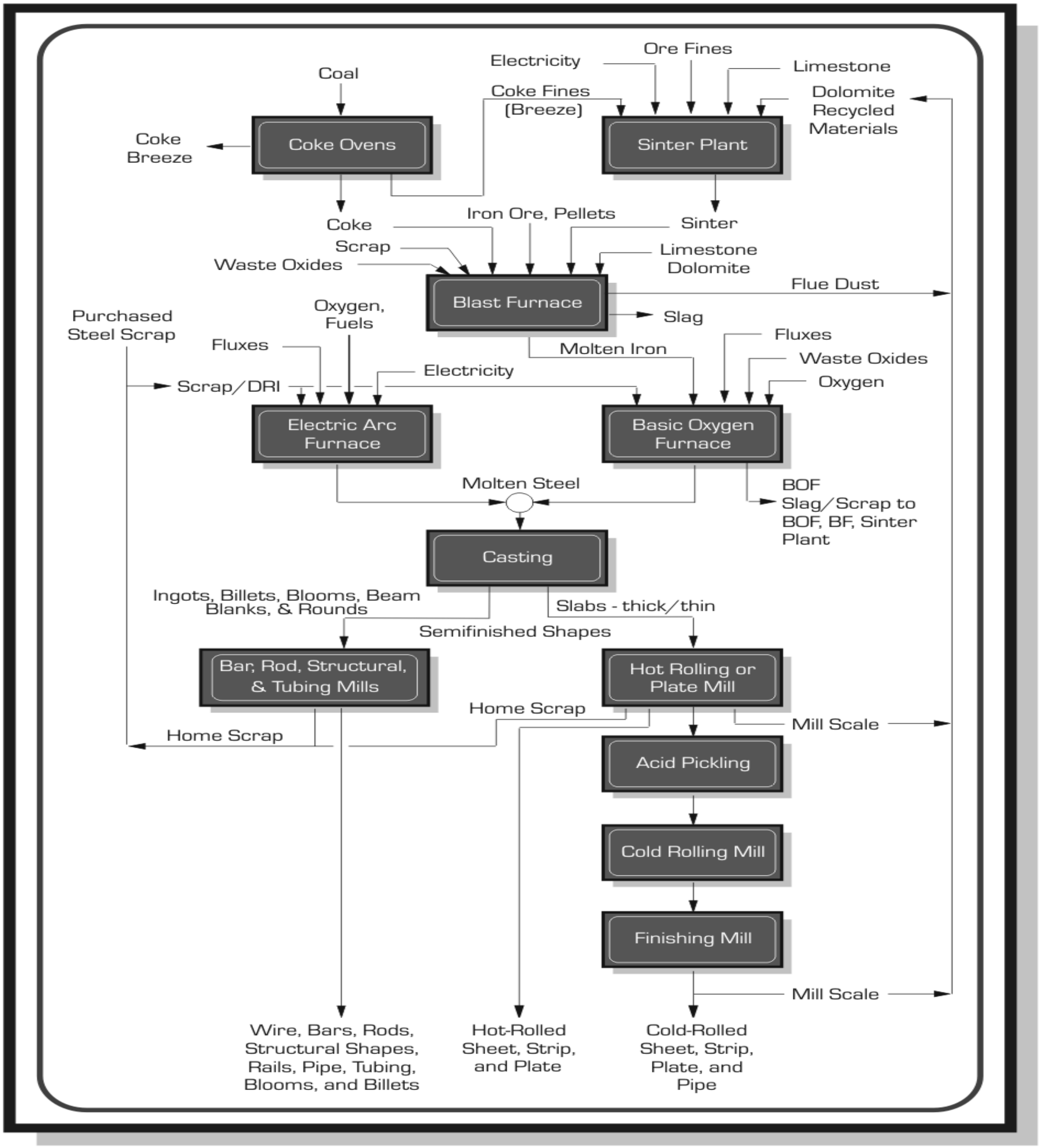
CHAPTER 3

GENERAL UNDERSTANDING OF STEELMAKING

Steelmaking is a dynamic, ever-changing industry. The manufacture of steel involves many processes that consume raw or recycled materials, producing thousands of products and by-products as shown in Fig. 3.1. Over the past 150 years, steelmaking processes have improved dramatically. Some processes, such as the Bessemer process, flourished initially but were then replaced completely [23]. Other processes, such as the blast furnace, electric arc furnace, and hot strip mill, have evolved continuously over the decades and are likely to remain a part of steelmaking in the future. Currently, the two major steelmaking routes use either the basic oxygen furnace (BOF) or the electric arc furnace (EAF) or some combination of the two.

Advances in steelmaking, including the EAF and BOF processes, have historically evolved in response to factors such as industrial expansion, world wars, technological innovation, competition and sheer creativity. Global competition requires that the steelmakers to be low cost providers to the market, and it is this rule of economic survival that will drive innovation [25].

This chapter presents an overview of the steelmaking process. This is needed as the analysis of the steel is a cornerstone of this research.



Source: Adapted from U.S. Council on Wage and Price Stability, Report to the President on Prices and Costs in the United States Steel Industry, 1977 (COWPS, October 1977).

Fig. 3.1: Overview of Steelmaking Processes

3.1 STEELMAKING PROCESS PHASES

The process toward producing steel passes through many parts. They will be briefly listed. More elaborate about Electric Arc Furnace (EAF) will be reported in this chapter [26-31].

The main process are as follows:

- ***Cokemaking***
- **Ironmaking:** There are three basic methods of producing iron: the blast furnace method, direct reduction, and iron smelting.
- ***Basic Oxygen Furnace (BOF)***
- ***Electric Arc Furnace (EAF)***
- ***Ladle Refining (Furnace)***
- ***Casting***
- ***Rolling Mill***: Plate, Sheet, Hot Strip Mills, Structural, Bar & Rod Mills.

3.2 UNDERSTANDING OF ELECTRIC ARC FURNACE OPERATION

The electric arc furnace operates as a batch melting process producing batches of molten steel known as "heats". The electric arc furnace operating cycle is called the tap-to-tap cycle and is made up of the following operations [25]:

- Furnace charging
- Melting

- Refining
- De-slagging
- Tapping
- Furnace turn-around

3.2.1 Furnace Charging

The first step in the production of any heat is to select the grade of steel to be made. Usually a schedule is developed prior to each production shift. Thus the melter and the scrap yard operator know that in advance. Preparation of the charge basket is an important operation, not only to ensure proper melt-in chemistry but also to ensure good melting conditions. The scrap must be layered in the basket according to size and density. It helps also in protecting the water cooled panel of the EAF and avoid breaking electrodes.

In some operation, the heat is not purely scrap. After charging the scrap basket, continuous feed of DRI will be fed direct to the furnace with certain feed rate to obtain the required grade.

3.2.2 Melting

The melting period is the heart of EAF operations. Melting is accomplished by supplying energy to the furnace interior. This energy can be electrical or chemical. Electrical energy is supplied via the graphite electrodes. Chemical energy is be supplied via several sources including oxygen-fuel burners and oxygen lances. The reaction of oxygen with carbon in the bath produces carbon monoxide, which either burns in the furnace if there is sufficient oxygen, and/or is exhausted through the direct evacuation system where it is burned and conveyed to the pollution control system (bag house system).

Once the scrap is fully melted then a bath temperature and sample for chemical analysis will be taken.

3.2.3 Refining

Refining operations in the electric arc furnace have traditionally involved the removal of phosphorus, sulfur, aluminum, silicon, manganese and carbon from the steel.

At the end of refining, a bath temperature measurement and a bath sample are taken. If the temperature is too low, power may be applied to the bath. This is not a big concern in modern meltshops where temperature adjustment is carried out in the ladle furnace.

3.2.4 De-Slagging

De-slagging operations are carried out to remove impurities from the furnace. During melting and refining operations, some of the undesirable materials within the bath are oxidized and enter the slag phase.

3.2.5 Tapping

Once the desired steel composition and temperature are achieved in the furnace, the tap-hole is opened, the furnace is tilted, and the steel pours into a ladle for transfer to the next batch operation, usually to a ladle furnace.

3.2.6 Furnace Turn-around

Furnace turn-around is the period following completion of tapping until the furnace is recharged for the next heat. During this period, the electrodes and roof are raised and the furnace lining is inspected for refractory damage. In the case of a bottom-tapping furnace, the taphole is filled with sand.

3.3 MECHANICAL SYSTEM OF EAF

Mechanical systems are integral to the operation of the EAF and many are inter-related [25]. The EAF has several primary functions:

1. Containment of steel scrap
2. Heating and melting of steel scrap
3. Transfer of molten steel to the next processing stage

It is easy to see that the first function, scrap containment can only be properly carried out if the furnace shell is properly maintained. The furnace shell consists of a refractory lined bottom that helps contain the liquid steel and typically, a water-cooled upper section that only comes into contact with scrap and slag. Heating and melting of the scrap are accomplished by supplying electrical energy through the electrodes and chemical energy through the use of burners and oxygen lances. Transfer of the liquid steel to the ladle is accomplished by tilting the furnace and opening either a tapping spout or a bottom tap-hole to allow the steel to flow from the furnace. It is apparent that many sub-systems come into play throughout the tap-to-tap cycle. Many of these systems are dependent of the following systems in order to be able to function properly:

1. Hydraulic system
2. Cooling water system
3. Lubrication System

In addition to the major mechanical systems associated with the EAF, there are also many auxiliary systems that are integral to furnace operation and performance. These are as follows:

1. Oxygen Lance System
2. Carbon Injection System
3. Oxygen-Fuel Burner System
4. Electrode Spray Cooling System
5. Temperature Sampling System
6. Offgas Direct Evacuation System

3.4 ELECTRICAL SYSTEM OF EAF

Electrical systems in an EAF meltshop usually consist of a primary system which supplies power from the electrical utility; and the secondary electrical system which steps down the voltage from the utility and supplies the power to the EAF.

3.4.1 Vacuum Switch

The vacuum switch is a long life switch that is generally used in all electric furnace applications. The traditional vacuum switch allows for the secondary electrical circuit to be broken either under load or without load.

3.4.2 Motorized Disconnect Switch

The motorized disconnect switch (MDS) is typically a motorized knife gate switch which is capable of physically isolating the EAF from the primary power supply off load.

3.4.3 EAF Transformer

The EAF transformer receives the primary low current, high voltage power and transforms this to a high current, low voltage power for use in the EAF. Reliable operation of the EAF is totally dependent on reliable operation of the EAF transformer. The furnace transformer is equipped with a **tap-changer.**

3.5 SECONDARY ELECTRICAL CIRCUIT OF EAF

The secondary circuit of the EAF electrical system consists of five major components: delta closure, power cable, bus tube/conducting arm, electrode clamp/holder and the electrode.

3.5.1 Furnace Power Cables

The water-cooled furnace power cables provide the only flexible connection in the secondary circuit. These cables must be flexible to permit movement of the electrode arms up and down and to allow swinging the electrode arms and roof when charging of the furnace.

3.5.2 Busbar / Current Conducting Arm

The bus-bar provides the electrical connection between the power cables and the electrode holder. Bus-bars consist of a rigid, round, copper pipe. Good insulation must be installed between the bus tube and its' supporting members to ensure that arcing which could destroy the bust tube does not take place.

3.5.3 Electrode Heads / Contact Pads

The Electrode heads and contact pads provide the final connection between the power supply and the graphite electrode. Typically cooling water requirements will vary depending on the electrode size, water quality, clamping force and maintenance of a clean contact area.

3.5.4 Electrodes

One of the most important elements in the electric circuit and consumable cost in electric furnace steelmaking are the electrodes. The electrodes deliver the power to the furnace in the form of an electric arc between the electrode and the furnace charge.

3.5.5 Electrodes Regulation

The electrode/arm/mast/cable assembly is moved vertically for control purposes by a hydraulic cylinder incorporated in the mast. Since the arc length is dependent, amongst other things, on the ever changing level of scrap or liquid under the electrode it is necessary to have an automatic control over electrode position, the regulation system.

The regulation system influences many important aspects of furnace performance, such as energy input, mean current, arc stability, scrap melting pattern, energy losses to water-cooled panels, energy, electrode and refractory consumption.

CHAPTER 4

POWER QUALITY: STANDARDS, DEFINITIONS AND TERMINOLOGY

This chapter gives an overview of the power quality issues and typical characteristics of power system electromagnetic phenomena. General sources of the power quality problems and solutions are presented as well.

Brief harmonic indices in common use, flickers and standards for harmonic limits are described.

4.1 OVERVIEW OF POWER QUALITY ISSUES

There are many ways to categorize power quality problems and content. One way is with regard to the frequency spectrum that is impacted by a given power quality problem. Power Quality problems include a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion, impulse transient, and interruptions. For example, noise may be a very high-frequency phenomenon; flicker is a low frequency phenomenon [32-33].

Table 4.1, based on the Table 2 in IEEE Std. 1159-2009, shows the categories and typical characteristics of power system electromagnetic phenomena, main power quality events.

Table 4.1: Categories and typical characteristics of power system electromagnetic phenomena.

Categories	Typical characteristics
Overvoltage transients:	
Impulsive:	Nanosecond: 5ns rise time for < 50 ns
	Microsecond: 1us rise time for 50ns-1ms
	Millisecond: 0.1ms rise time for >1ms
Oscillatory:	Low freq.: <5kHz for 0.3-50ms at 0-4 pu
	Med. freq.: 5-500kHz for 20μs at 0-8 pu
	High freq.: 0.5-5MHz for 5μs at 0-4 pu
Short duration voltage variations:	
Interruption	Momentary: < 0.1pu for 0.5 cycles-3 s
	Temporary: < 0.1pu for 3 s-1 min
Sag	Instantaneous: 0.1-0.9pu for 0.5-30 cycles
	Momentary: 0.1-0.9 pu for 30 cycles-3 s
	Temporary: 0.1-0.9 pu for 3 s – 1 min
Swell	Instantaneous: 1.1-1.8pu for 0.5-30 cycles
	Momentary: 1.1-1.4pu for 30 cycles-3 s
	Temporary: 1.1-1.2pu for 3 s-1 min
Long duration voltage variations:	
Interruption	Sustained: 0.0pu for > 1 min
Undervoltages	0.8-0.9 pu for > 1 min
Overvoltages	1.1-1.2 pu for > 1 min
Voltage waveform distortions:	
DC offset	0-0.1%
Harmonics	0-100th H with 0-20% magnitude
Interharmonics	0-6 kHz with 0-2% magnitude
Notching	
Voltage fluctuations:	
Intermittent	< 25 Hz with 0.1-7% magnitude

4.1.1 Sources of Power Quality Problems

Power quality problems are defined as ‘Any power problem that results in failure or misoperation of customer equipment, manifests itself as an economic burden to the user, or produces negative impacts on the environment.’

The main sources of power quality problems are listed and explained briefly below [34-35]:

- **Power electronic devices**

  Power electronic devices are non-linear loads that create harmonic distortion and can be susceptible to voltage dips if not adequately protected. Variable Speed Drives (VSD) or inverters are common power quality problem and highly susceptible to voltage dip disturbances and cause particular problems in industry process.

- **IT and office equipment**

  IT equipment power supplies consist of a switched mode power supply (SMPS) are the causes of a significant increase in the level of 3^{rd} , 5^{th} and 7^{th} harmonic voltage distortion in recent years.

- **Arching devices**

  Electric arc furnace (EAF), arc welders and electric discharge lamps are all forms of electric arching device. These devices are highly non-linear loads. All arcing devices are sources of harmonic distortion and voltage flicker.

- **Load switching**

The effect of heavy load switching on the local network is a common problem causing transients that propagate through to other "electrically close" equipment. These transients can be of a large voltage magnitude, but have very little energy due to their short duration, which is normally measured in terms of milliseconds. Loss of transmission lines is considered similar to heavy switching. Sensitive electronic devices exposed to these voltage impulses can have their operation impaired.

- **Large motor starting**

The dynamic nature of induction machines means that they draw current depending on the mode of operation. During start-ups this current can be as high as six times the normal rated current. The increased loading on the local network has an effect causing voltage dip, the magnitude depends on the system impedance.

- **Distributed generation**

Increasing levels of distributed generation have an effect on power quality. An increased amount of distributed generation at substation level and below will lead to increased fault current levels in the feeders.

- **Sensitive equipment**

Equipment manufacturers are designing and manufacturing ever more sophisticated equipment, much of which is increasingly susceptible to variations in power quality.

- **Storm and environment related damage**

Lighting strikes are a cause of transient overvoltage often leading to faults on the electric supply networks. High winds and storm conditions cause widespread disruption to the supply networks. Snow and ice build-up have a severe effect on the reliability of overhead lines. These have obvious power quality or quality of supply consequences.

4.1.2 Solutions for Power Quality Problems

The subject of power quality contains a very wide range of problems for both systems and customers. There are many requirements for appropriate solutions such as [36-38]:

- Simple power factor correction of a load.
- FACTS (Flexible AC Transmission System) technology.
- Passive filter.
- Active filter.
- Static Var Compensation (SVC).
- STATCOM.

- Dynamic Voltage Restorer (DVR).
- Unified Power Flow Controller (UPFC).

4.2 HARMONIC INDICES

In harmonic analysis there are several important indices used to describe the effects of harmonics on power system components and communication systems. This section describes those harmonic indices in common use [39 - 42].

Total Harmonic Distortion (THD)

It is the most commonly used measure of the quality of a periodic waveform. It is define as the ratio of the r.m.s. value of the sum of all the harmonic components up to a specified order (recommended notation: H) to the r.m.s. value of the fundamental component. It is given as:

$$THD = \sqrt{\sum_{h=2}^{h=H} \left(\frac{Q_h}{Q_1} \right)^2} \tag{4.1}$$

Where;

Q	represents either current or voltage
Q_1	is the r.m.s. value of the fundamental component
h	is the harmonic order
Q_h	is the r.m.s. value of the harmonic component of order h
H	is generally equal to 50, but equal to 25 when the risk of resonance at higher orders is low.

Total Demand Distortion (TDD)

It is the total root-sum-square harmonic current distortion, in percent of the maximum demand load current I_L (15 or 30 min demand). It is given as:

$$TDD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_L} \quad \textbf{(4.2)}$$

Where;

I_n is the magnitude of individual harmonic current components.

I_L is the maximum demand load current

IEEE Std 519-1992 defines this term TDD which is the same as the THD except that the distortion is expressed as a percent of current selected load current, such as the peak demand, rather than as a percent of the rms fundamental current magnitude.

Transformer K-Factor

Transformer K-factor is an index used to calculate the derating of standard transformers when harmonic currents are present. The K-factor is defined as:

$$K - Factor = \frac{\sum_{h=1}^{\infty} I_h^2 h^2}{\sum_{h=1} I_h^2} \quad \textbf{(4.3)}$$

Where;

h is the harmonic order

I_h is the rms value of the h-th current harmonic.

Communication Interference Factors (TIF)

Telephone influence factor (TIF) index is a measure of examining the interference between communication circuits and power systems. It is given as:

$$TIF = \frac{\sqrt{\sum_{i=1}^{\infty} w_i^2 I_i}}{I_{rms}} \qquad \textbf{(4.4)}$$

Where;

w_i is a certain weights provided in textbook and standards for different frequencies.

I_i is the rms value of the i-th current harmonic.

I_{rms} is the rms value of the fundamental harmonic current

V.T and I.T Products

Another distortion index that gives a measure of harmonic interference on audio circuits similar to *TIF* is the *V.T* or *I.T* product, where *V* is rms voltage in volts, *I* is rms current in amperes, and *T* is the *TIF*. In practice, telephone interference is often expressed as *V.T* or *I.T*, which is given as:

$$V.T = \sqrt{\sum_{i=1}^{\infty} w_i^2 V_i^2} \qquad \textbf{(4.5)}$$

$$I.T = \sqrt{\sum_{i=1}^{\infty} w_i^2 I_i^2} \qquad \textbf{(4.6)}$$

Where;

W_i is a certain weights provided in textbook and standards for different frequencies.

V_i is the rms value of the i-th harmonic voltage.

I_i is the rms value of the i-th harmonic current.

C message index

C message index is a measure of examining the interference between communication circuits and power systems similar to *TIF*. It is given as:

$$C \text{ index} = \frac{\sqrt{\sum_{i=1}^{\infty} C_i^2 I_i}}{I_{rms}} \tag{4.7}$$

Where C_i is a certain weights for different frequencies.

4.3 FLICKERS

Voltage fluctuations in low voltage networks can cause flicker. Flicker severity is measured in accordance with IEC 61000-4-15 and assessed in accordance with IEC 61000-3-3. Flicker severity is calculated with respect to both short and long term effects [42].

The short term severity level, denoted by P_{st}, is determined for a 10-minute period. Fig. 4.1 shows the threshold curve of permissible flicker for standard lamps, arising from rectangular voltage changes at different repetition rates. This curve corresponds to $P_{st} = 1$.

The severity of flicker resulting from non-rectangular voltage fluctuations may be found either by measurement with a flickermeter or by the application of correction factors, as indicated in IEC standard 61000-3-3.

The long-term severity level, denoted by P_{lt}, is calculated for a two-hour period. It is derived as follows from the values of P_{st} for 12 consecutive 10-minute periods.

$$P_{lt} = \sqrt[3]{\frac{1}{12} \cdot \sum_{i=1}^{\infty} P_{sti}^{3}} \qquad \textbf{(4.8)}$$

where P_{sti} (i = 1, 2 ....12) are 12 consecutive values of P_{st} (IEC 61000-4-15)

Compatibility levels are as follows:

short-term: $P_{st} = 1$;

long-term: $P_{lt} = 0{,}8$.

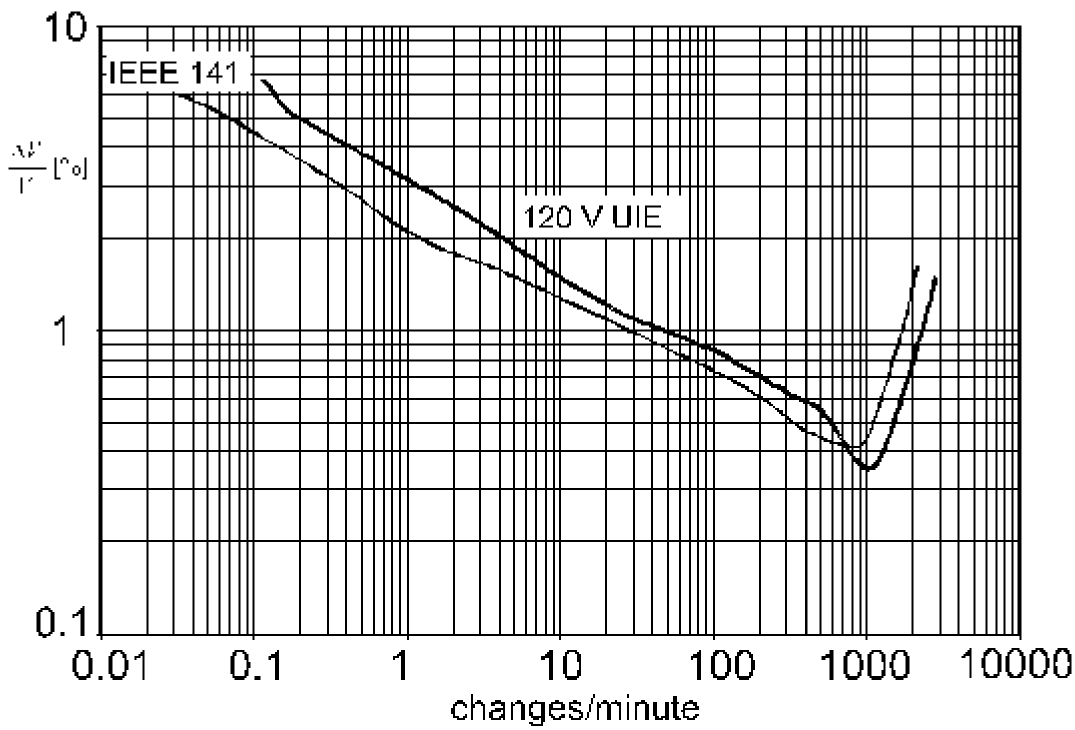


Figure 4.1: Flicker - Curve of equal severity (*P*st = 1) for rectangular voltage changes on LV power supply systems.

4.4 POWER QUALITY LIMITATIONS AND STANDARDS

Below are some of the standards used during this study or in general for the power quality measurements and limitations.

Table 4.2 illustrates typical harmonic content of arc furnace current at two stages of the melting cycle in a typical arc furnace for the production of steel.

Table 4.2: Harmonic Content of Arc Furnace Current at Two Stages of the Melting Cycle.

Harmonic Current % of Fundamental					
Harmonic order	**2**	**3**	**4**	**5**	**7**
Initial melting (active arc)	7.7	5.8	2.5	4.2	3.1
Refining (stable arc)	0.0	2.0	0.0	2.1	0.0

Table 4.3 shows the IEC 1000-3-3 and IEC 1000-3-5 equipments limits for flickers.

Table 4.3: IEC 1000-3-5 for voltage unbalance and flickers.

Limits of Flickers		
Voltage Level	**Pst (pu)**	**Plt (pu)**
LV	1	o.74
MV	1	0.74
HV	0.85	0.62
EHV	0.7	0.5

Table 4.4 shows the harmonic voltages compatibility level, IEC 1000-2-2.

Table 4.4: IEC 1000-2-2 for harmonic voltage compatibility level.

ODD HARMONICS						EVEN HARMONICS		
Not multiple of 3			**Multiple of 3**			**Order h**	**Harmonics Voltage (%)**	
Order h	**Harmonic Voltage (%)**		**Order h**	**Harmonic Voltage (%)**				
	LV-MV	**HV**		**LV-MV**	**HV**		**LV-MV**	**HV**
5	6	2	3	5	2	2	2	2
7	5	2	9	1.5	1	4	1	1
11	3.5	1.5	15	0.3	0.3	6	0.5	0.5
13	3	1.5	21	0.2	0.2	8	0.5	0.5
17	2	1	>21	0.2	0.2	10	0.2	0.5
19	1.5	1				12	0.2	0.2
23	1.5	0.7				>12	0.2	0.2
25	1.5	0.7						
>25	0.2-1.3	0.2-0.5						
THD Limit = 8% for LV-MV systems								

Table 4.5 shows the IEEE 519 standard for harmonic voltage limits, utilities responsibility.

Table 4.5: IEEE 519 for harmonic voltage limits.

Bus Voltage	Max individual harmonic componenet (%)	Maximum THD (%)
69 kV and below	3	5
115 kV to 161 kV	1.5	2.5
Above 161 kV	1	1.5

Table 4.6 shows the IEEE 519 standards for the harmonic current limits, customer responsibility.

Table 4.6: IEEE 519 for harmonic current limits (Odd Harmonics) (120 V – 69 kV).

SCR=Isc/ I_L	<11	11<h<17	17<h<23	23<h<35	35<h	TDD
<20	4	2	1.5	0.6	0.3	5
20-50	7	3.5	2.5	1	0.5	8
50-100	10	4.5	4	1.5	0.7	12
100-1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1.4	20

Note:

Maximum Harmonic Current Distortion in Percent of IL

Even harmonics are limited to 25% of the odd harmonic limits above.

SCR = Short Circuit Ratio

I_{sc}: Maximum short-circuit current at the Point of Common Coupling (PCC).

I_L: Maximum demand load current (fundamental) at the PCC.

CHAPTER 5

STUDY AND DESIGN OF STATIC VAR COMPENSATOR (SVC) FOR ELECTRIC ARC FURNACES (EAF)

In this chapter, general understanding of calculating and designing of Static Var Compensation [43].

5.1 GENERAL

This section represents the result of the basic design for an Electric Arc furnace SVC system. It shows the design data of the major SVC equipment as well as the relevant resulting electrical quantities compared with their limits.

The SVC system consists of a Thyristor Controlled Reactor (TCR, variable inductive power) and System of Filter Circuits (FC, constant capacitive power), Fig. 5.1 below.

A Filter Circuit is a tuned circuit, which consists of capacitor banks (capacitance) and tuned reactor coils (inductance) connected in series. Filter circuits will reduce the negative influence of the loads like:

- Harmonic distortion.
- Poor power factor.

Careful choice of the tuning frequencies of the filter circuits with respect to the generated harmonic frequencies and amplitudes will reduce the harmonic levels.

At fundamental frequency filter circuits behave like capacitors and therefore provide power factor improvement.

The TCR consists of thyristor valves in series with reactors directly connected to the medium voltage plant busbar (34.5 kV).

The TCR will reduce the negative influence of the loads like:

- Flicker
- Voltage fluctuation
- Voltage unbalance

The so-called “indirect compensation” is proposed for voltage stabilization. The lagging reactive currents of the TCR are controlled by this method in such a way that for each phase the sum of the load reactive current and the TCR current gives a constant value at any instant. This is compensated by the capacitive current of the filter system.

This results in the following reactive power equilibrium and therefore minimum voltage variation and flicker:

$$Q_{load} + Q_{TCR} - Q_{FC} = O \qquad \textbf{(5.1)}$$

Q_{load} : reactive power of EAF / LF (fluctuating with process).

Q_{TCR} : reactive power of Thyristor Controlled Reactor (controlled by SVC system).

Q_{FC} : reactive power of Filter Circuits (constant).

5.2 PLANT AND SYSTEM DATA

Point of Common Coupling (PCC):

The main substation where the EAF connected is fed from two different 230 kV lines. Minimum and maximum short circuit at the PCC will be considered for this main substations (MSS). The data of the system at PCC is shown in Table 5.1.

Table 5.1: Data of the system at PCC.

Rated Voltage	230 kV (max deviation ± 5%)
Short circuit capacity	min. (MSS) 10238 MVA max. (MSS) 13302 MVA Guarantee value 8125 MVA
Frequency	60 Hz
Step-down transformer rating	120 / 150 MVA
Impedance voltage	13 / 17.2 %
Ratio	230 kV / 34.5 kV
On-load tap changer	Yes, ± 10 x 1% at HV side
Number of transformers operating in parallel (normal operation)	1

230 kV Cable Data:

Table 5.2: 230 kV cable data of the system feeding EAF.

Cable type	Single core, 630mm² XLPE
Inductance	0.446 mH / km
Capacitance	0.17 μF / km
Resistance	0.0283 Ω / km

Medium Voltage System:

Table 5.3: Medium voltage system data.

Rated voltage	34.5 kV (max deviation ± 5%)
34.5 kV Cable:	
Cable type	Single core, 300mm², XLPE
Inductance	0.382 mH / km
Capacitance	0.24 μF / km
Resistance	0.0805 Ω / km

AC-Electric Arc Furnace:

Table 5.4: Load data, EAF.

Rated power	130 MVA
Furnace Series Reactor at 34.5 kV:	
Rated impedance	1.02 Ω
Taps	100/75/50/25/0 %
34.5/1.3 kV Furnace Transformer:	
Rated power	130 MVA
Primary voltage	34.5 kV
Secondary voltage range	700-1305 V
Impedance at highest voltage tap (1305 V)	8 %
High Current System:	
Reactance	4.1 mΩ

EAF Working Points (WP):

Secondary furnace transformer voltage: 1134 V

Furnace series reactor: 0.26 Ω (25 %)

Furnace short circuit power: < 240 MVA

Furnace Arc Voltage: 463 V

Table 5.5: Working points of EAF.

Working Points	**Charge mix**	**Max. power [MW]**	**Power factor**
WP #1	35 % scrap, 65 % DRI	103.2	0.75 – 0.8
WP #2	100 % DRI	103.2	0.75 – 0.8
WP #3	100 % scrap	103.2	0.75 – 0.8

Typical harmonic generation from the EAF:

Table 5.6: Harmonic currents of EAF.

Harmonic order	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Harmonic current %	7.5	7.0	3.5	4.5	2.0	2.5	1.3	1.2	1.0	1.0	0.8	0.8	0.7	0.5

Ladle (Refining) Furnace (LF)

Table 5.7: Load data, LF.

Ladle furnace transformer	
Rated power	25 MVA
Voltage ratio	34.5 kV / 265 … 385 V
Impedance at highest voltage tap (385 V)	8 %
High Current System:	
Reactance	2.86 mΩ

LF Working Points (WP):

Table 5.8: Working points of LF.

Working Points	Max. power [MW]	Power factor
WP #1	19.1	0.65 – 0.73
WP #2	16.5	0.62 – 0.68

Typical harmonic generation from the LF:

Table 5.9: Harmonic currents of LF.

Harmonic order	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Harmonic current %	1.5	3.5	0.7	2.8	0.5	1.5	0.2	0.1	-	0.1	-	0.1	-	-

Harmonic currents used for calculation:

The currents shown in Table 5-10 are used for calculation and are based on 34.5 kV. They are taking into consideration the EAF, LF and TCR harmonics, as well as the interharmonic currents.

Table 5.10: Results of harmonic current calculations

Order number	2	3	4	5	6	7	8	9	10
Calculated current (A)	163.0	215.0	90.8	235.0	43.5	118.0	31.1	34.1	27.3
Order number	11	12	13	14	15	16	17	18	19
Calculated current (A)	35.0	17.4	25.8	15.7	15.0	0.0	11.0	0.0	9.0

5.3 SVC CALCULATIONS FOR 34.5 KV BUSBAR

Fig. 5.1 shows simplified single line diagram and described in section 5.1. Only parameters necessary for the calculation tools are considered.

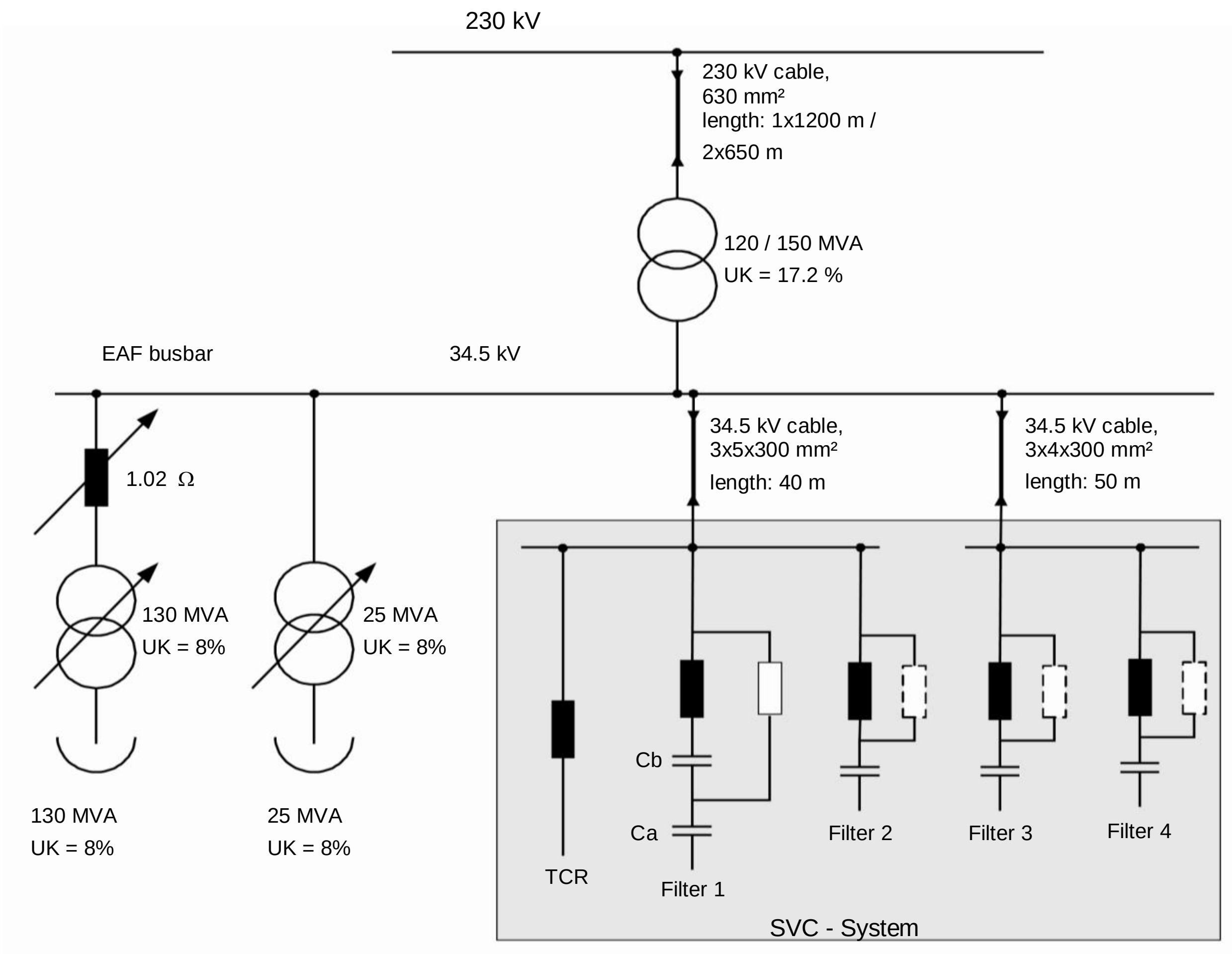


Fig. 5.1: General overview for system under study.

Electrical Requirements and assumptions:

The compensation system is designed so that the following electrical values, caused by the specified loads are kept at the 230 kV bus (PCC):

- Total harmonic voltage distortion (n = 2 … 19) $\leq$ 1.3 %
- Individual odd harmonic voltage distortion $\leq$ 0.8 %
- Individual even harmonic voltage distortion $\leq$ 0.3 %
- Flicker level Pst (99%): $\leq$ 1.0
- Inductive power factor $\geq$ 0.9 (weekly average power factor)

The voltage fluctuations caused by the 230 kV network (utilities network) cannot be compensated with the compensation system. So for the calculations, the existing harmonic level at the 230 kV power supply is assumed to be zero. Existing values (harmonic distortion, fluctuations) to be deducted.

It is assumed that the line impedance of the PCC is linear with the frequency, no resonances /cable capacitances are taken into account.

5.4 FLICKERS

Due to UIE the uncompensated flicker level of an AC arc furnace during melting can be calculated as follows:

$$P_{st,99\%} = K_{st} . \frac{S_{ccf}}{S_{ccn}} \qquad \textbf{(5.2)}$$

Where;

S_{ccf} is the furnace short circuit level.

S_{ccn} is the level fault level at PCC.

K_{st} is the furnace severity factor describing the furnace characteristics as a flicker generator.

The K_{st} factor varies from furnace to furnace (a range of 48 ... 85 is reported by the International Union for Electroheat) and is influenced by:

- Furnace operation point (arc power, arc voltage/length, power factor)
- Mechanical furnace data (pitch circle diameter, resonance behavior of electrode arms)
- Electrode control system
- Furnace temperature (cold or hot furnace)
- Charge mix (quality of scrap, size of scrap, charging of hot metal)
- Charging (bucket charge or via shaft)

A K_{st} factor for WP #1 is assumed to be up to 67. For WP #2 assumed a K_{st} factor of up to 45 and for WP #3 up to 85.

<u>Flicker calculation with furnace reactor (25 % tap), for WP #1</u>

Furnace reactor:

$X_{FR} = 0.26\ \Omega$

Impedance of the furnace transformer :

$$u_k\text{ (used tap)} \approx u_k\text{ (highest tap)} \cdot \frac{u_{Tr}(\text{highest tap})^2}{u_{Tr}(\text{used tap})^2} \qquad (5.3)$$

$$= 0.08 \cdot \frac{(1305\,V)^2}{(1134\,V)^2} = 0.106$$

$$X_{FT} = \frac{(0.106)\,(34.5)^2}{130} = 0.97\ \Omega$$

Furnace secondary impedance:

$$X_{FS} = 0.0041 \cdot \frac{34.5^2}{1.134^2} = 3.79\ \Omega$$

The total impedance (transformer + furnace reactor) results in:

$$X_{total} = (0.26 + 0.97 + 3.79)\ \Omega = 5.02\ \Omega$$

The furnace short circuit level (transformer + furnace reactor) is then:

$$S_{ccf} = \frac{34.5^2}{5.02} = 237\ \text{MVA}$$

Based on the design fault level, the uncompensated flicker without SVC is:

$$P_{st,99\%} = 67 \cdot \frac{237}{8125} \approx 1.95$$

Remark:

The same power and power factor as for operation with SVC is considered, i.e. operation with infinite bus short circuit capacity. Adaption of the furnace reactor tap and/or furnace transformer tap could be required to enable such operation without SVC.

A well designed SVC system can reduce the flicker produced by the furnace and its operation by a factor of approximately 2.0, which results in the following value:

Flicker with SVC during the above phase:

$$P_{st,99\%} = \frac{1.95}{2} \approx 0.98$$

The LF has no influence on flicker.

Flicker calculation with furnace reactor (0 % tap), for WP #1

Without furnace reactor, a higher K_{st} factor than 67 is possible because of the heavier operating point. The furnace short circuit level S_{ccf} during the scrap melting phase can be derived as follows:

Furnace reactor is $X_{FR} = 0.0\ \Omega$

Similarly,

The total impedance (transformer + furnace reactor) results in:

$$X_{total} = (0.0 + 0.97 + 3.79)\ \Omega = 4.76\ \Omega$$

The furnace short circuit level (transformer + furnace reactor) is then:

$$S_{ccf} = \frac{34.5^2}{4.76} = 250 \text{ MVA}$$

Based on the design fault level, the uncompensated flicker without SVC is:

$$P_{st,99\%} = 67 \cdot \frac{250}{8125} \approx 2.06$$

Considering the factor of well designed SVC (Aprox. 2), then flicker with SVC during the above phase:

$$P_{st,99\%} = \frac{2.06}{2} \approx 1.03$$

Also, the LF has no influence on flicker.

Calculations with the WPs and short circuit capacities according to chapter 5.2 above are leading to the results in Table 5.11 below. Same power, power factor, charge mix etc. are considered.

Table 5.11: P_{st} values for different short circuit capacities and furnace reactor tap 25% and 0%

Fault level (MVA)	EAF Working Point (WP)	Flicker level without SVC Pst 99 %		Flicker level with SVC Pst 99 %	
		furnace reactor tap 25%	furnace reactor tap 0%	furnace reactor tap 25%	furnace reactor tap 0%
8125	WP # 1	1.95	2.06	0.98	1.03
	WP # 2	1.31	1.38	0.65	0.69
	WP # 3	2.48	2.61	1.24	1.30
10238	WP # 1	1.55	1.63	0.78	0.82
	WP # 2	1.04	1.10	0.52	0.55
	WP # 3	1.97	2.07	0.98	1.03
13302	WP # 1	1.19	1.26	0.60	0.63
	WP # 2	0.80	0.84	0.40	0.42
	WP # 3	1.51	1.60	0.75	0.80

From the calculations above, it can be seen that the furnace reactor has an influence on flicker generation of the arc furnace.

By experience with similar installations and best practice, for a one (1) furnace application, a flicker reduction factor of approximately 2.0 can be achieved with a SVC system rated as:

$$Q_{FC} \approx 1.3 \cdot S_{EAF} = 1.3 \cdot 130 \text{ Mvar} = 169 \text{ Mvar}$$

$$Q_{TCR} \approx 1.12 \cdot Q_{FC} = 1.12 \cdot 169 \text{ Mvar} = 189 \text{ Mvar}$$

Where 1.3 and 1.12 are the correction factors considered as best practice within SIEMENS standards.

Therefore, based on the given furnace and network data a SVC rating of 170 / 190 Mvar is selected.

$$Q_{FC} = 170 \text{ Mvar}$$

$$Q_{TCR} = 190 \text{ Mvar}$$

5.5 UNBALANCE VOLTAGE

The worst case of unbalance voltage occurs if there is a two phase short circuit. In that case the apparent power of the furnace is:

$$S_F = U_N \cdot I_N = 75 \text{ MVA}$$

Compared to the three phase short circuit, where the furnace has an apparent power of:

$$S_F = \sqrt{3} \cdot U_N \cdot I_N = 130 \text{ MVA.}$$

The unbalance voltage without SVC can be calculated as on Table 5.12:

Table 5.12: Furnace unbalance voltage without SVC

S_K (MVA)	S_F (MVA)	S_F/S_K (%)
8125	75	0.9
10238	75	0.7
13302	75	0.6
14222	75	0.5
20245	75	0.4

The two phase short circuit is a worst case scenario and real operation will lead to lower values of unbalance. At the same time the operating SVC will be lowering the unbalance value and for example a limit value of 1.4 % according to IEC 61000-3-13:2008 can be hold for the specified short circuit capacities.

5.6 HARMONICS

5.6.1 Layout of Filter-Circuits

A total Compensation Power of 170 Mvar is selected for the filter circuits at the 34.5 kV busbar.

For the determination of tuning frequencies and the distribution of the corresponding compensation power to the filter-circuits, the frequency response of the network impedance at the 34.5 kV should be analyzed.

In a second step the harmonic currents identified for operation of the loads to be injected into the resulting network configuration and to find out the compliance with the harmonic limits as defined.

Generally filter circuits are used to:

- Filter the harmonic currents out of the 34.5 kV system.
- Compensate the inductive reactive power, i.e. to relieve the transformers and network of reactive loading, thereby improving the system power factor.

A filter circuit is a tuned circuit which consists of reactor coils (inductance) and capacitor banks (capacitance) connected in series. Hereby the size and capacity of the reactors and capacitances are selected in such a way, that the (series) resonant frequency of the individual circuits corresponds with the frequency of the individual system generated main harmonics.

However installing a filter circuit will always cause an increase in system impedance, as the filter circuits in combination with the network impedance will lead to a parallel resonance.

The height of resonance peaks can be decreased by reducing the natural quality factor of the filter reactor. This can be achieved by the use of damping resistors, which are connected in parallel to the reactors or by reactor damping rings.

Table 5.13: Choice of tuning frequencies and splitting of compensation power including damping

EAF busbar	Tuning Frequency	Compensation Power	Damping
34.5 kV	118 Hz	40 Mvar	106 Ω
34.5 kV	178 Hz	50 Mvar	-
34.5 kV	240 Hz	20 Mvar	damping rings
34.5 kV	297 Hz	60 Mvar	-

5.6.2 Harmonic Calculations

The harmonic currents flowing from EAF busbar into the PCC for this configuration are listed in Table 5.14 below.

Table 5.14: Results of harmonic current calculations

Order number	2	3	4	5	6	7	8	9	10
Calculated current (A)	16.7	1.4	0.9	0.1	0.8	3.0	0.9	1.1	1.0
Order number	11	12	13	14	15	16	17	18	19
Calculated current (A)	1.2	0.6	1.0	0.6	0.6	0.0	0.5	0.0	0.4

The harmonic voltage distortion values at the PCC, which is caused by the loads on EAF busbar, for this configuration are listed in Table 5.14 below.

The calculated values are compared with the harmonic voltage distortion limit values. The calculated voltage distortion [%] for the short circuit capacity are presented in Table 5.15 below.

Table 5.15: Results of harmonic voltage calculations.

Harm. order	limits [%]	8125 MVA	10238 MVA	13302 MVA
2	0.3	0.18	0.15	0.11
3	0.8	0.02	0.02	0.01
4	0.3	0.02	0.02	0.01
5	0.8	0.00	0.00	0.00
6	0.3	0.03	0.02	0.02
7	0.8	0.11	0.09	0.07
8	0.3	0.04	0.03	0.02
9	0.8	0.05	0.04	0.03
10	0.3	0.05	0.04	0.03
11	0.8	0.07	0.06	0.04
12	0.3	0.04	0.03	0.03
13	0.8	0.07	0.05	0.04
14	0.3	0.05	0.04	0.03
15	0.8	0.05	0.04	0.03
16	0.3	0.00	0.00	0.00
17	0.8	0.04	0.03	0.03
18	0.3	0.00	0.00	0.00
19	0.8	0.04	0.03	0.02
THD	**1.3**	**0.27**	**0.22**	**0.17**

CHAPTER 6

DATA COLLECTION AND PROCEDURE

In this chapter, definitions of the collected data will be illustrated. Also, the data collection procedure will be explained. At the end of the chapter, representation of the results or the data collected throughout the study will be demonstrated.

6.1 INTRODUCTION

The main load connected to the network subject for study in this work is Electric Arc Furnace (EAF). Normally the AC- Electric Arc Furnace is running for a complete cycle of process for about one hour from power-on till power-off. This cycle called **"Heat"**.

This heat is repeated on continuous basis and during that the EAF typically consumed around 100 MW power and 80 MVAR reactive power.

The average consumptions during the measurements are 92 MW power and 63 MVAR reactive power at 0.82 PF with the Static Var Compensator (SVC) in normal operation.

Two types of data were collected; the Power Quality measurements data, which are collected at the source feeding Electric Arc Furnace (EAF) and Ladle Furnace (LF) at 34.5 kV voltage level using **Fluke 434/435** "Three Phase Power Quality Analyzer" [44]. The other type of collected data is chemical analysis data for the industrial steel product in a form of molten steel. The same analysis is taken at two or three different locations as applicable. These different locations are Electric Arc Furnace (EAF), Ladle Furnace (LF), and Continuous Casting Machine (CCM).

6.2 DEFINITIONS OF POWER QUALITY DATA

Basic electric power definitions and brief descriptions of the power quality parameters are well known and widely defined for possible usage during the power quality studies [1, 17], [45-46].

The most common power quality indices are:

i. Power
ii. Voltage and Current RMS
iii. Power factor
iv. Frequency
v. Harmonics (THD and individuals harmonics for currents and voltages)
vi. Voltage Fluctuations
vii. Flicker
viii. Voltage Sag
ix. Voltage Swell
x. Unbalance
xi. Interruption (momentary interruption, temporary interruption, and long term interruption or outage)

6.3 DEFINITION OF PRODUCT QUALITY DATA

The chemical analysis for the industrial steel product during melting in the electric arc furnace (EAF) is the main deciding step towards defining the grade of the produced steel.

There are two types of chemical analysis that are being considered in this study depending on the steel grade. The first grade is produced with the chemical code 200 and the second grade is produced with the chemical code 2910.

The two chemical analysis codes are different from each other depending on the value of each element in the produced steel.

The chemical analysis usually measures many elements to assess their presence in the steel. This work will concentrate only on eight (8) elements which are the components of the Carbon Equivalent Equation (CE), namely; Carbon (C), Manganese (Mn), Silicon (Si), Copper (Cu), Nickel (Ni), Chromium (Cr), Molybdenum (Mo), and Vanadium (V).

Table 6.1 shows the said eight chemical elements considered during the study. This table contains two codes for the chemical analysis which are 200 and 2910. These two codes are local quality references for the melters to monitor the presence of the elements in the molten steel throughout the process in EAF, LF and CCM.

The table shows also the maximum percentage of each chemical element in the industrial steel during production process. Carbon (C) element has minimum percentage of 0.04% for chemical code 200 and 0.08% for chemical code 2910. Carbon also has maximum of 0.07% for chemical grade 200 and 0.1% for chemical code 2910. The aims are 0.06% for chemical grade 200 and 0.09% for chemical code 2910.

The elements present in the grade based on their importance. This is the main purpose of having minimum and maximum for each one of them. In some elements they should not exceeds certain value as define for each code with no minimum.

In addition, the table defines the summation of four elements (copper, chromium, nickel, and molybdenum) which should not exceed 0.25% for chemical code 200. For chemical analysis code 2910, calcium has also minimum and maximum value which have to be met.

Table 6.1: Chemical Analysis codes and Limits.

Chemical Analysis	%	C	Si	Mn	Cr	Ni	Mo	Cu	V	Comments
0200	MIN	0.04		0.15						Cu + Cr + Ni + Mo = 0.25 max.
	AIM	0.06		0.2						
	MAX	0.07	0.03	0.25	0.08	0.12	0.015	0.11	0.008	
2910	MIN	0.08	0.2	1.25						% Ca min. 0.0010 max. 0.0050
	AIM	0.09	0.3	1.3						
	MAX	0.1	0.35	1.35	0.06	0.06	0.05	0.06	0.01	

Brief definitions, applications, importance of the chemical elements in steel are described hereunder [47].

Knowing that the Carbon (C) element is very important in steel making, continuous monitoring of its presence during the melting, treating, and casting processes is always considered. The higher the carbon in steel product the good hardenability it has and the lower the carbon in steel the better for weldability.

Carbon is a non-metallic element, which is an important alloying element in all-ferrous metal based materials. Carbon is always present in metallic alloys, i.e. in all grades of stainless steel and heat resistant alloys. Carbon is very strong austenitizer and increases the strength of steel. The principal effect of carbon on corrosion resistance is determined by the way in which it exists in the alloy.

Silicon (Si) is a metalloid (non-metallic element) produced by the reduction of silica (SiO_2) at high temperatures. Silicon is an important alloying element for both ferrous and non-ferrous metals. It is used extensively as a deoxidiser in steel making (carbon steel and stainless steel). In heat resisting stainless steels its presence improves oxidation at high temperatures. In cast irons silicon acts as graphitiser since it decomposes and so reduces the amount of combined carbon. It confers on electrical steels (up to 5% Si) some specific magnetic properties.

In small amounts, silicon confers mild hardenability on steels. Small amounts of silicon and copper are usually added to the austenitic stainless steels containing molybdenum to improve corrosion resistance in sulphuric acid.

Silicon is commonly added to stainless steels to improve their oxidation resistance and is a ferrite stabilizer. In austenitic stainless steels, high-silicon content not only improves resistance to oxidation but also prevents carburizing at elevated temperatures.

Manganese (Mn) is essential to steel making because of two key properties: its ability to combine with sulphur and its powerful deoxidation capacity. Some 30% of the world production of manganese is used for its properties as a sulphide former and deoxidiser. The balance of 70% is used as an alloying element. Relatively small quantities of manganese have been used for alloying with non-ferrous alloys, mainly in the aluminum industry. Its ability to stabilize the austenite in steel is used in the "200 series” of austenitic stainless steels.

The properties of manganese enable it to act as an alloying element and a deoxidizer in steel. When added to molten steel, manganese will react with oxygen to form manganese oxide (MnO). Manganese will also combine preferentially with sulphur to form manganese sulphide, (Mn S). Besides entering into combination with oxygen and sulphur, manganese also influences the behavior of steel. The presence of manganese increases the hardenability of the steel. Manganese is usually found as an alloying element in all types of steel (carbon steels and stainless steels) to assist the deoxidation of the steel and to prevent the formation of iron sulphide inclusions which may cause hot cracking problems.

Chromium (Cr) is about 85% of the chromite mined is used in metallurgy. Due to its strength and its high resistance to corrosion, chromium is often used in plating and metal finishing. The properties that distinguish stainless steels from other corrosion-resistant materials depend essentially on chromium. The high degree of reactivity of chromium is the basis for the effectiveness of chromium as an alloying element in stainless steels.

Nickel (Ni) is about 65% of nickel production is used in stainless steels, compared to 45% few years ago. High-performance alloys represent another growing metallurgical end-use for nickel. In stainless steels, nickel has no direct influence on the passive layer but exerts a beneficial effect, particularly in sulphuric acid environments. Nickel promotes the resistance to corrosion of the nickel-based alloys as compared with the iron-based alloys under conditions where the passive layers may be absent, or may be destroyed locally or uniformly.

Molybdenum (Mo) with high melting point makes it important for giving strength to steel and other metallic alloys at high temperatures. It is also added to metallic alloys because of its resistance to corrosion. Although low alloy steels, stainless steels and cast iron makes up the biggest market segment, molybdenum is also used in certain high performance alloys, such as the Hastelloys and Inconel. Molybdenum is also used as electrodes in electrically heated furnaces, as filament for electronic applications and as catalyst for the refining of petroleum. Molybdenum is used in stainless steels and powerful effects in improving the resistance to pitting in chloride environments. Molybdenum reduces the intensity of the oxidizing effect required to insure passivity and decrease the tendency of previously formed passive films to break down.

Copper (Cu) has the chief commercial use of it based on its electrical conductivity. About half the total annual output of copper is employed in the manufacture of electrical apparatus and wire. Copper is also used extensively as roofing, in making copper utensils, and for coins and metalwork. Copper tubing is used in plumbing and in heat-exchanging devices such as refrigerator and air-conditioner coils because of its high heat conductivity. An important use of copper is in alloys such as brass, bronze, gunmetal, Monel metal, and German silver. Compounds of copper are widely used as insecticides and fungicides, as pigments in paints, as mordants (fixatives) in dyeing, and in electroplating.

Vanadium (V) is metallic chemical element and it is not found uncombined in nature but occurs widely distributed in minerals. It is corrosion resistant at normal temperatures, but oxidizes above 660°C. It resists attack by hydrochloric and sulfuric acids, saltwater, or alkali. The principal use of vanadium is in alloys, especially with steel. In tool and spring steels it is a powerful alloying agent, a small amount adds strength, toughness, and heat resistance. It is usually added in the form of ferrovanadium, a vanadium-iron alloy.

Vanadium compounds are used in the ceramics, glass, and dye industries. It is also important as catalysts in the chemical industry.

Table 6.2 shows only two chemical analysis codes 200 and 2910. Each one of them is suitable for many standards and many steel grades types. The base for that is the carbon percentage, applications, and the required thickness in addition to mechanical prosperities such as yield strength and tensile strength.

The international standards used for steel producers and the users are ASTM, DIN, EN, API, etc. The customers usually use the standards and the steel grades while ordering certain type of steel grade. The international standards are also used to define the required specification and applications for the steel.

The chemical analysis codes 200 and 2910 used in this study are internally developed by the user as a simplified method for the melters to use during melting, treating, and casting processes.

Table 6.2: Product Quality Standards and Grades for Steel.

Chemical Analysis	Standard	Steel Grade	Comments
0200	ASTM A366: 1997	Type A	
0200	DIN 1623.1	St12	
0200	EN 10130: 1991	FeP01	
0200	JIS G3141: 1996	SPCC	
0200	JIS G3141: 2000	SPCCT	
0200	EN 10142: 1995	FeP02 LFQ	
0200	JIS G3302: 1994	SGCC	
0200	ASTM A653: 1995	CQ	
0200	ASTM A653: 1995	LFQ	
0200	ASTM A653: 1997	CS-Type B	
0200	ASTM A653: 1999	CS-Type A	
0200	ASTM A653: 1999	CS-Type B	
0200	ASTM A653: 1999	CS-Type C	
0200	EN 10142: 1995	DX51D	
0200	ASTM A653: 1999	CQ	Thk 0.37
0200	ASTM A653: 1997	SQ550	
0200	ASTM A653: 1995	SQ230	
0200	AISI 1006	AISI 1006	Thk<=8mm
0200	SAE J403	1006 M	Thk<=8mm
0200	DIN 1614 Part2: 1986	STW23	Thk<=8mm
0200	EN 10111: 1998	DD12 or DQ	Thk<=8mm
0200	JIS G3131: 1996	SPHD	Thk<=14mm
0200	ASTM A569: 1998	CQ	Thk<=4mm (skin pass)
0200	DIN 1614 Part2: 1986	STW22	Thk<=4mm (skin pass)
0200	EN 10111: 1998	DD11	Thk<=4mm (skin pass)
0200	JIS G3131: 1996	SPHC	
0200	DIN 17100: 1980	St33	
0200	EN 10025: 1994	S185	
0200	JIS G3101: 1995	SS330	
2910	API 5L: 2007	X56	Thk>12 to 16mm
2910	API 5L: 2007	X60	8<Thk<11.5mm
2910	ISO 3183-3: 1999(E)	L415MC	8<Thk<11.5mm
2910	API 5L: 2007	X65	Thk 5 to 6.5mm
2910	ISO 3183-3: 1999(E)	L450MC	Thk 5 to 6.5mm
2910	API 5L: 2007	X65	Thk 6.6 to 8mm
2910	ISO 3183-3: 1999(E)	L450MC	Thk 6.6 to 8mm

The common applications for some steel product based on the steel grade mentioned in the above table are as follows:

1. ***Steel Grade CQ:***

   Steel used for commercial purpose is called commercial quality steel or CQ steel. This steel is generally low carbon steel with carbon level less than 0.10%.

   Application: Fabrication, furniture, tube manufacturers.

2. ***Steel Grade DQ***:

   Steels used for application where drawing of sheet is involved in the process. These steels are generally having lower carbon than CQ grade. Carbon percentage can be upto 0.06%.

   Application: Furniture industry, Metal containers, etc.

3. ***Steel Grade SQ550:***

   This type of steel is used to fabricate any type of metal structures. It can be used to fabricate machines, shelves, building structures, etc.

   Minimum Yield strength = 550 Mpa.

4. ***Steel Grade SQ230:***

   Same as SQ550 but with minimum Yield strength = 230 Mpa.

5. ***Steel Grade API X56 :***

   It is the American Petroleum Institute (API). The purpose of this specification is to provide standards for pipe suitable for use in conveying gas, water, and oil in both the oil and natural gas industries. This specification covers also seamless and welded steel line pipe.

   X56: Yield Strength = 56,000 psi, Tensile strength = 71,000 psi.

6. ***Steel Grade API X60 :***

   Same as API X56 but with Yield Strength = 60,000 psi, Tensile strength = 75,000 psi.

7. ***Steel Grade API X65*** :

   Same as API X56 but with Yield Strength = 65,000 psi, Tensile strength = 77,000 psi.

Carbon Equivalent (CE) is an empirical value in weight percent, relating the combined effects of different alloying elements used in the making of carbon steels to an equivalent amount of carbon. This value can be calculated using a mathematical equation. By varying the amount of carbon and other alloying elements in the steel, the desired strength levels can be achieved by proper heat treatment. A better weldability and low temperature notch toughness can also be obtained [48].

In terms of welding, the Carbon Equivalent governs the hardenability of the parent metal. It is a rating of weldability related to carbon, manganese, chromium, molybdenum, vanadium, nickel, silicon and copper content. There are several commonly used equations for expressing Carbon Equivalent. One example of such mathematical formula is:

$$CE = \%C + \frac{\%Mn + \%Si}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Cu + \%Ni}{15} \qquad \textbf{(6.1)}$$

The ability to form hard metallurgical constituents such as hard phases is dependent on the carbon equivalent and the cooling rate of the steel involved in cooling from the transformation temperature. The higher the carbon equivalent value, the faster the cooling rate, the higher the tendency for hard, brittle phases to form during cooling.

The metallurgical characteristics of steels are mainly determined by its chemical composition. As such, any small changes in its chemical composition of the base and filler metals can substantially increase cracking tendency. The risk of cracking also increases with increasing hardness of the Heat Affected Zone (HAZ) in welding for a particular hydrogen level and joint restraint [49].

As such, the value of the Carbon Equivalent is a useful guide to the possibility of cracking in alloy steels by comparison with an equivalent plain carbon steel. The two main problems faced in the cracking of the welded metals are hot cracking and cold cracking.

Hot cracking occurs immediately after solidification in a weld, caused by the segregation of certain alloying elements during the solidification process. Sulphur, boron and other elements that tend to segregate excessively are reduced in order to prevent hot cracking. Cold cracking, also known as delayed or hydrogen-induced cracking, develops after solidification of the fusion zone as the result of residual stress. It generally occurs below 200°C, sometimes several hours, or even days after welding [50].

Although a carbon equivalent is sometimes useful in planning welding procedures, its value is limited because only the chemical composition of the steel is considered. The section size being welded and joint restraint is of equal or greater importance, because of their relations to heat input and cooling rate. CE results from the melt related to electric arc furnace.

6.4 PROCEDURE FOR COLLECTING POWER QUALITY DATA

The power quality data are collected from the main electrical substation which is feeding the Electric Arc Furnace (EAF) and Ladle Furnace (LF).

Fig. 6-1 shows the system subject for study and the location of measuring point where the **Fluke 434/435** Device is connected.

The system in Fig. 6.1 shows the power source coming from utilities company, the load connected, and the Static Var Compensator (SVC) system.

This plant receives the power at 230 kV level via transmission line to a gantry area. 230 kV XLPE Cable system uses from gantry area to the 150 MVA step down transformer 230/34.5 kV at the main substation (MSS). The loads connected to the 34.5 kV bus bar are electric arc furnace (EAF) and ladle furnace (LF) with SVC connected to the same bus bar. The EAF load connected to the MSS using cables to 130 MVA step down transformer with tap changer 34.5 kV/ 690 – 1200 V. The LF also connected to the MSS using cable to the 25 MVA step down transformer with tap changer.

The SVC located at MSS and connected to the 34.5 kV bus bar. It consists of a Thyristor Controlled Reactor (TCR, variable inductive power) and system of Filter Circuits (FC, constant capacitive power). The FC is a tuned circuit for second, third, fourth, and fifth harmonics. FC consists of capacitor banks (capacitance) and tuned reactor coils (inductance) connected in series. The TCR consists of thyristor valves in series with reactors directly connected to the 34.5 kV busbar.

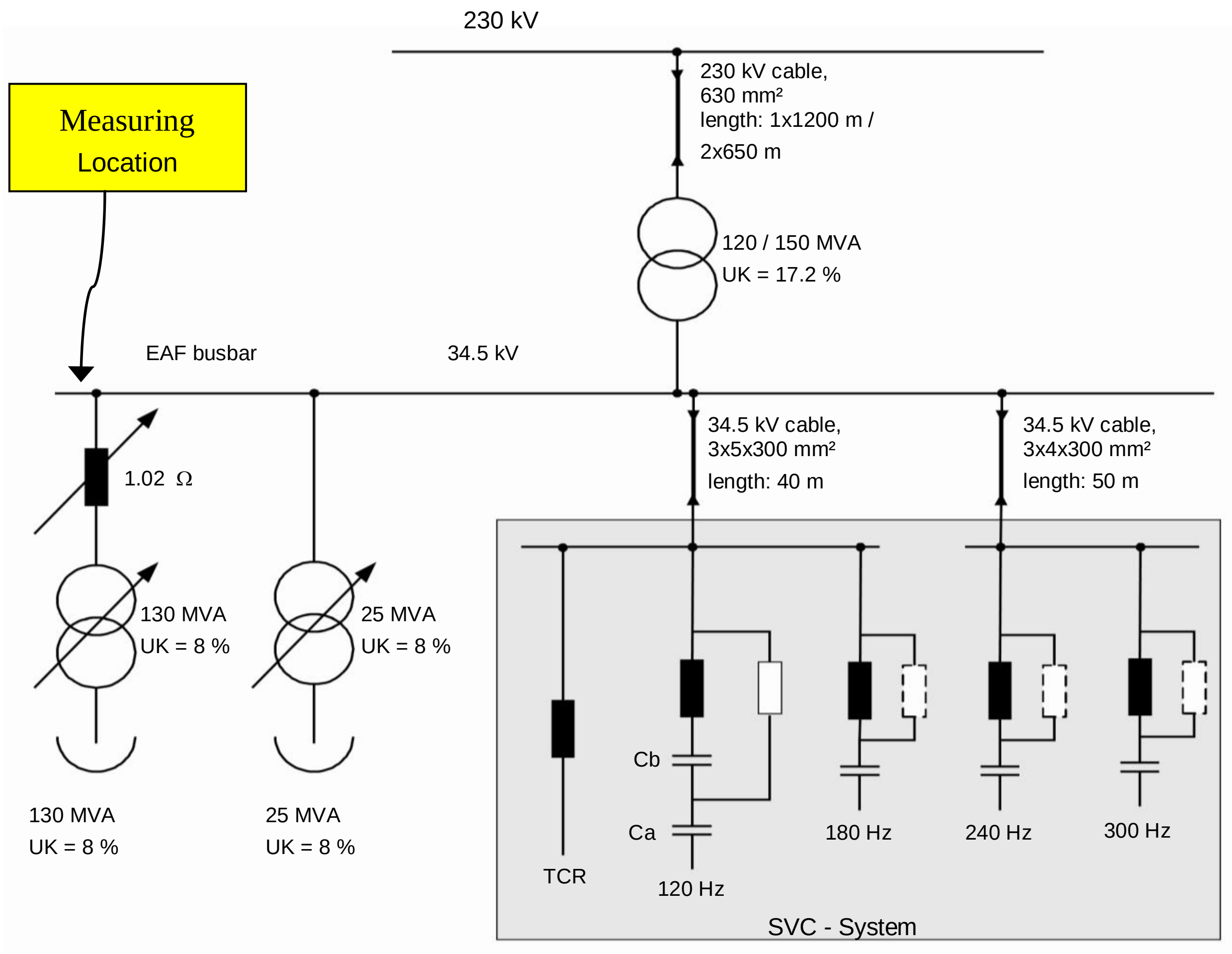


Figure 6.1: Measurement point location and system used.

The **Fluke 434/435** Device "Three Phase Power Quality Analyzer" was connected at the measuring point location for period of time to measure the required electrical parameters. These parameters are RMS Voltage, RMS Current, Voltage THD, Current THD, individual harmonics, Active Power in MW, Reactive Power in MVAR, Power Factor

(PF), Energy in kWh/Ton (in some cases), and Flickers for Long Term (**P_{lt}**) and Short Term (**P_{st}**).

Every heat takes about an hour starting from scrap charging and Direct Reduced Iron (DRI) feed to the EAF till tapping time. The electrical data is recorded using the Fluke device during the melting process in the EAF and stored in the Fluke repeatedly for 24 hours. The stored/collected data for the past 24 hours will be downloaded to a personal computer to carry out the required analysis. During the data extracting using the Fluke software program, the data recorded in excel sheet for further study and analysis.

This sequence is repeated from the beginning of data recording till end of the recording period which lasted for about two months.

Since the steel grades produced in the plant (in the EAF) are many, then only the electrical data recorded for the produced heats with steel grads 200 and 2910 will be taken in consideration and the rest will be neglected because they are out of the case study's scope. Two hundreds and ten (210) hours period of measurements conducted and the power quality data is analyzed and evaluated.

The data are referred to the IEEE and IEC standards to see whether they are within the limits defined in the standards or not.

For more illustration to the above procedure, one example is demonstrated for the full understanding. The electrical data for Heat # 1024054, grade of code 200, was recorded on 14.06.2010 for a duration between 17:09 hr and 18:14 hr. Extracting the data shall go through the following steps:

7. Find the average voltage and current from the recorded graph shown in Fig. 6.2. It shows the minimum, maximum, and average of phase-2 for voltage and current at this particular heat. The average voltage for this heat is found to be V_{rms} = 34.7 kV and the average current is found to be I_{rms} = 1878 Amps.

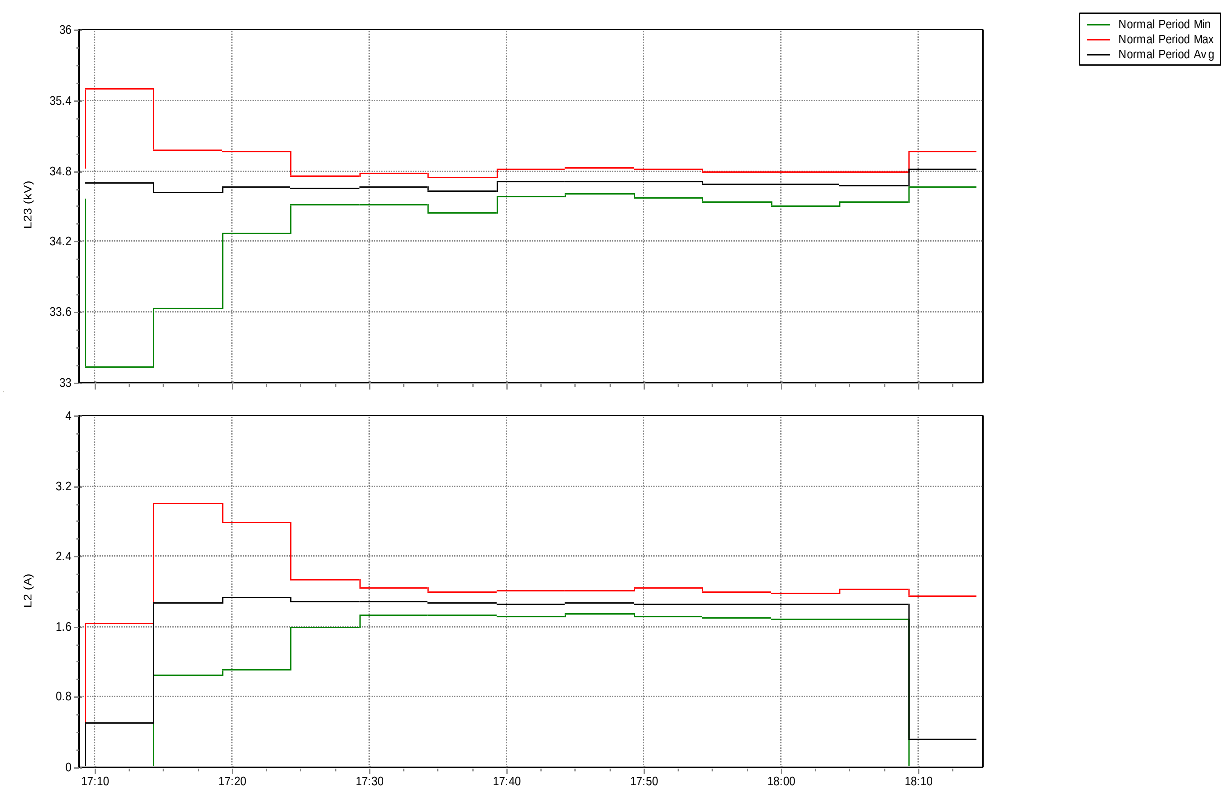


Figure 6.2: Average Vrms and Irms for Heat # 1024054.

8. Search for the events (Dips and Swells) that occur during the particular heat and record them when available. This particular heat has no such event.

9. Find the Voltage Total Harmonic Distortion (THD V). The calculated THD is 1.52%. This is found to be below the limits defined in IEEE 519-1992 Harmonic voltages limits [45].

10. Find the individual harmonics voltage. Fig. 6.3a shows general view for the individual harmonics voltage from 2nd till 50th. Fig. 6.3b shows more focus on individual harmonics voltage from 2nd till 11th. All found to be below the limits (< 3%) defined in IEEE 519-1992 Harmonic voltages limits [45].

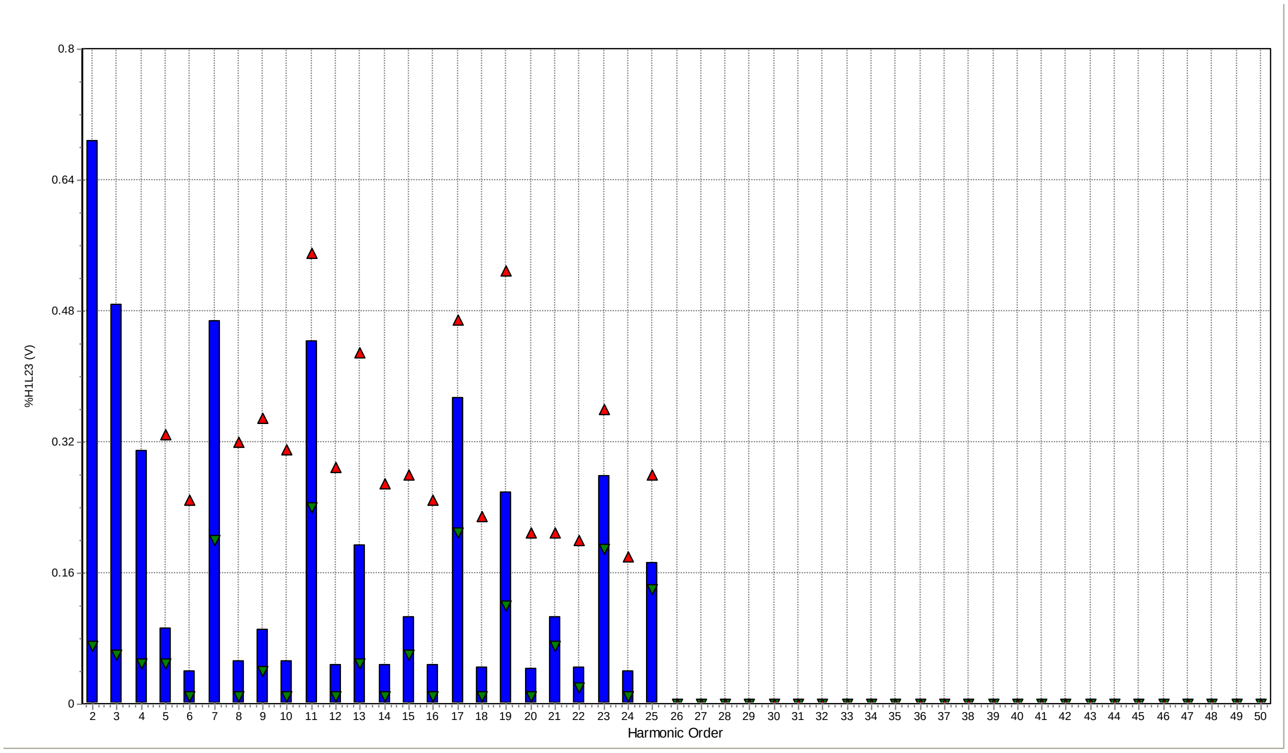


Figure 6.3a: Individual Harmonics voltage (H2 – H50).

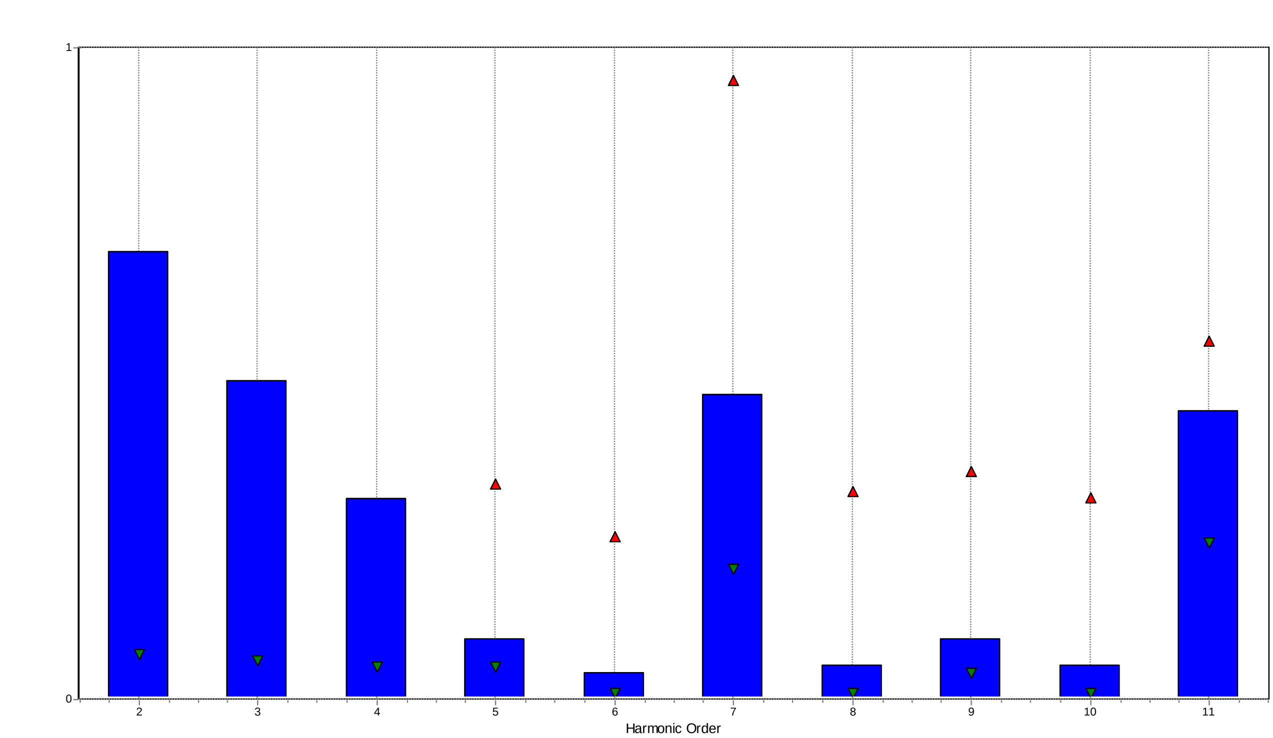


Figure 6.3b: Individual Harmonics Voltage from H2 to H11 only.

Fig. 6.4 shows the histogram of the harmonics. This figure shows red and green triangles. The Fluke is recording the Maximum, the Minimum, and the average sample. The red triangle is the maximum reading, the green is the minimum and the actually blue bar shown is the average.

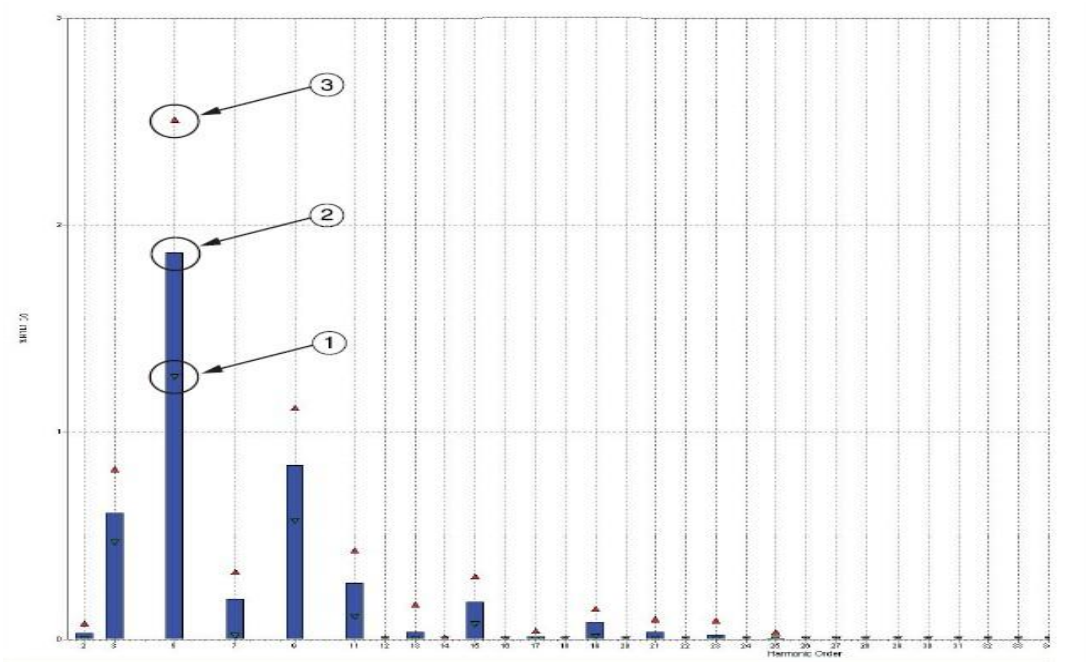


Figure 6.4: Harmonics Histogram.

Explanations:

1 Minimum

2 Average

3 Maximum

Table 6.3 shows the individuals voltage harmonics values for this heat as measured.

Table 6.3: Results of Individual Voltage Harmonics for the heat # 1024054.

V_h	2	3	4	5	6	7	8	9	10	11	>11
%	0.6	0.4	0.3	0.09	0.04	0.47	0.05	0.09	0.05	0.42	<0.36

11. Find the Current Total Harmonic Distortion (THD I). The THD I is 7% in this measured heat.

12. Find the individual harmonics currents. Fig. 6.5 shows general view for the individual harmonics current from 2nd till 11th.

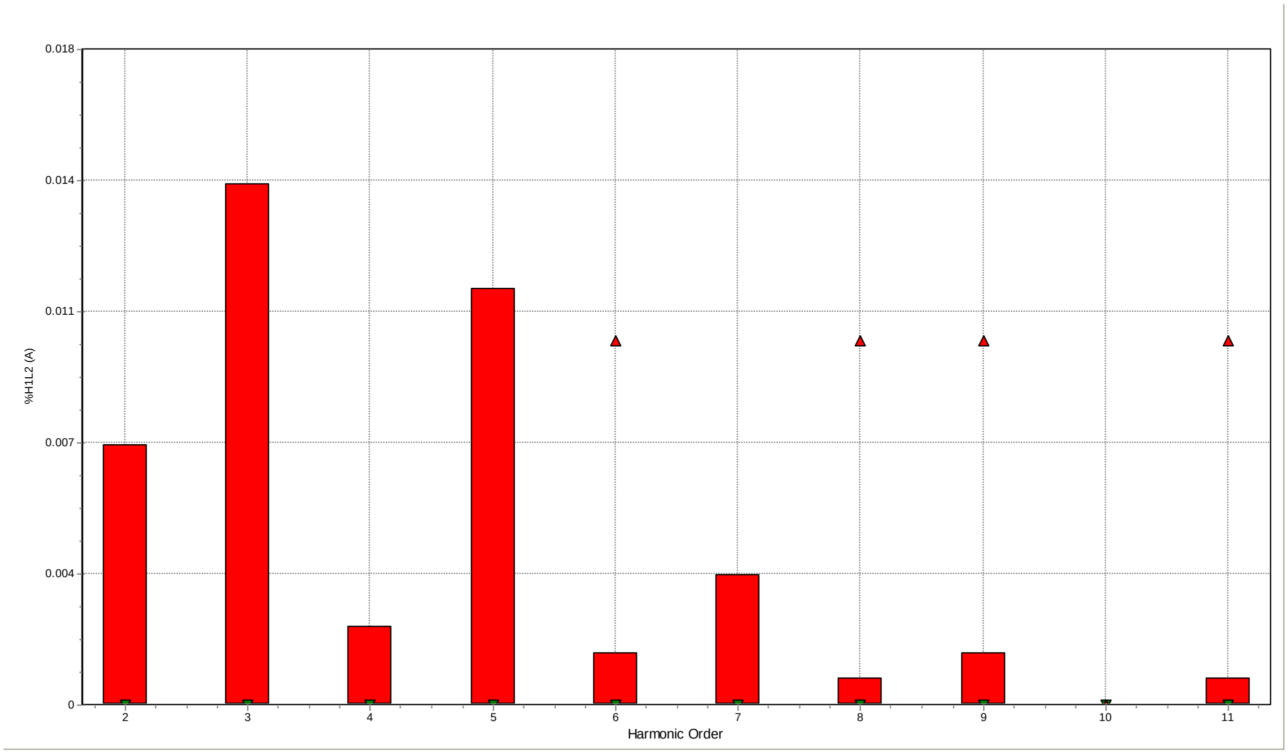


Figure 6.5: Individual Harmonics Current from H2 to H11 only.

Table 6.4 shows the individuals current harmonics values for this heat as measured and obtained as shown in Fig. 6.4.

Table 6.4: Results of Individual Current Harmonics for the heat.

H. Order	h<11	11<h<17	17<h<23	23<h<35	h>35
Limit	4	2	1.5	0.6	0.3
Measured	0.01	<<	<<	<<	<<

The individuals harmonics currents are found to be much lesser than the limits defined by the IEEE 519-1992 standards for harmonic current limits [45]. This is common at all heats throughout the study. The plant operates with SVC as per the utility's requirements.

13. Find Active power (MW), Reactive Power (MVAR), and Power Factor (PF) Fig.6.6.

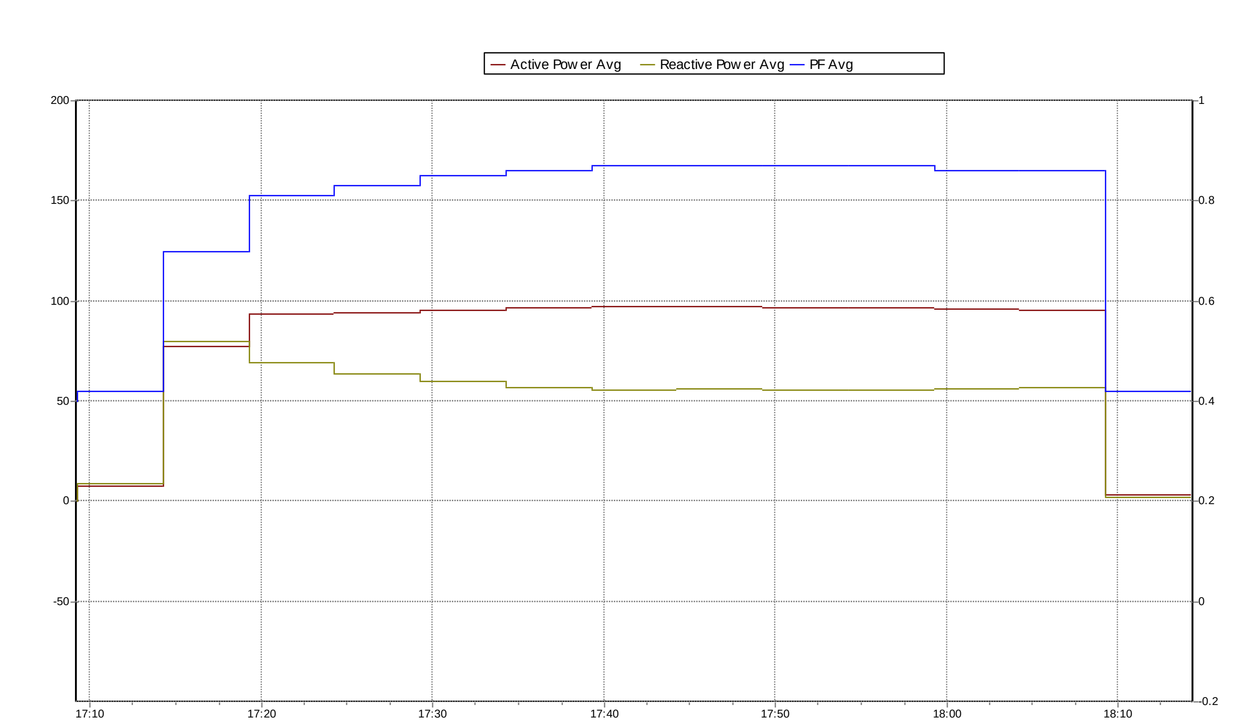


Figure 6.6: Active Power, Reactive Power, and PF for the heat.

For this heat, the active power is P = 94.1 MW, reactive power is Q = 60.9 MVAR, and power factor is PF= 0.84 lagging.

14. Find the frequency variation throughout the individual heat. General overview of the frequency variation for few heats (6 hours) shown in Fig. 6.7.

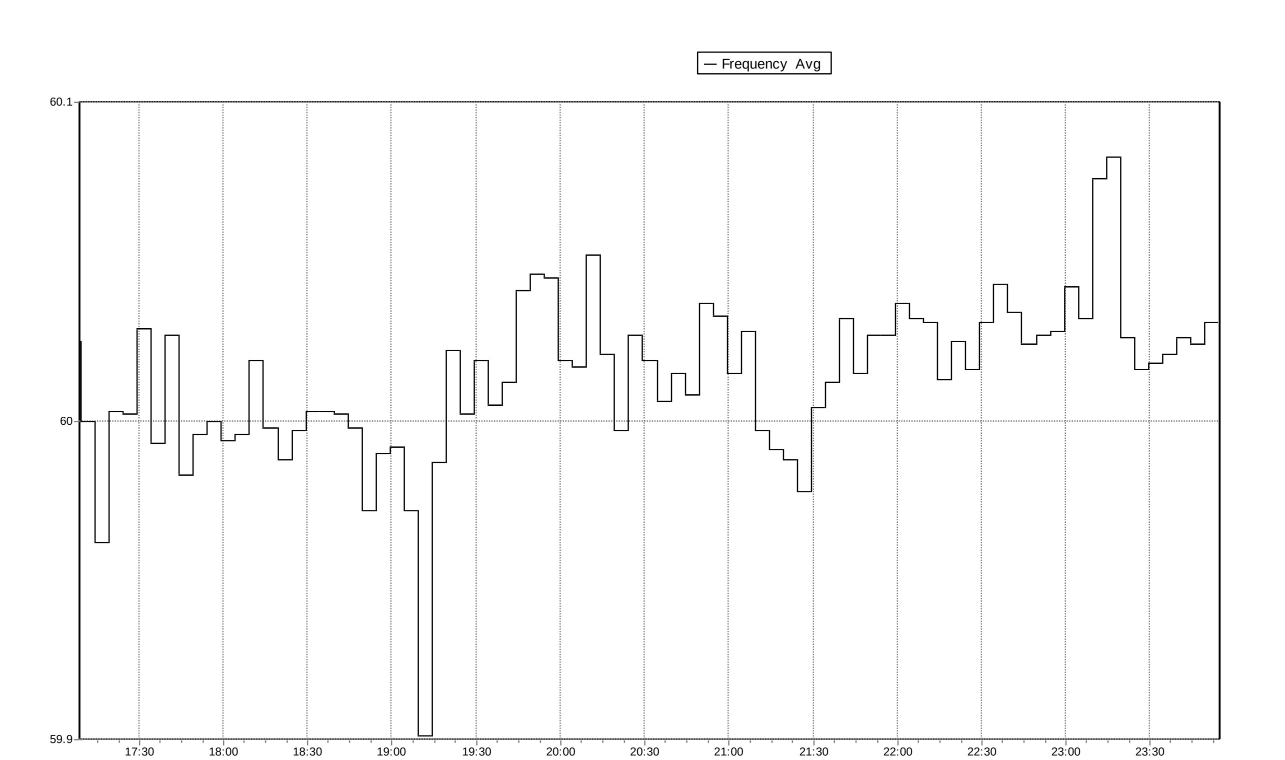


Figure 6.7: Frequency variations for six (6) heats as measured.

For this heat in particular, frequency variations found to be between 59.96 Hz as minimum and 60.029 Hz as maximum.

15. Find the flickers for both short term (P_{st}) and long term (P_{lt}). For this heat Fig.6.8a, the short term flicker is $\mathbf{P_{st}}$ = 2.32 and the long term flicker is $\mathbf{P_{lt}}$ = 0.

The P_{st} is higher than the limits in accordance with the IEC 61000-3-3 and P_{lt} is within the limits. Nevertheless, result of P_{st} at the PCC is reduced by reduction factor of 2 or better to give $\mathbf{P_{st}}$ = 1.16 or less [51].

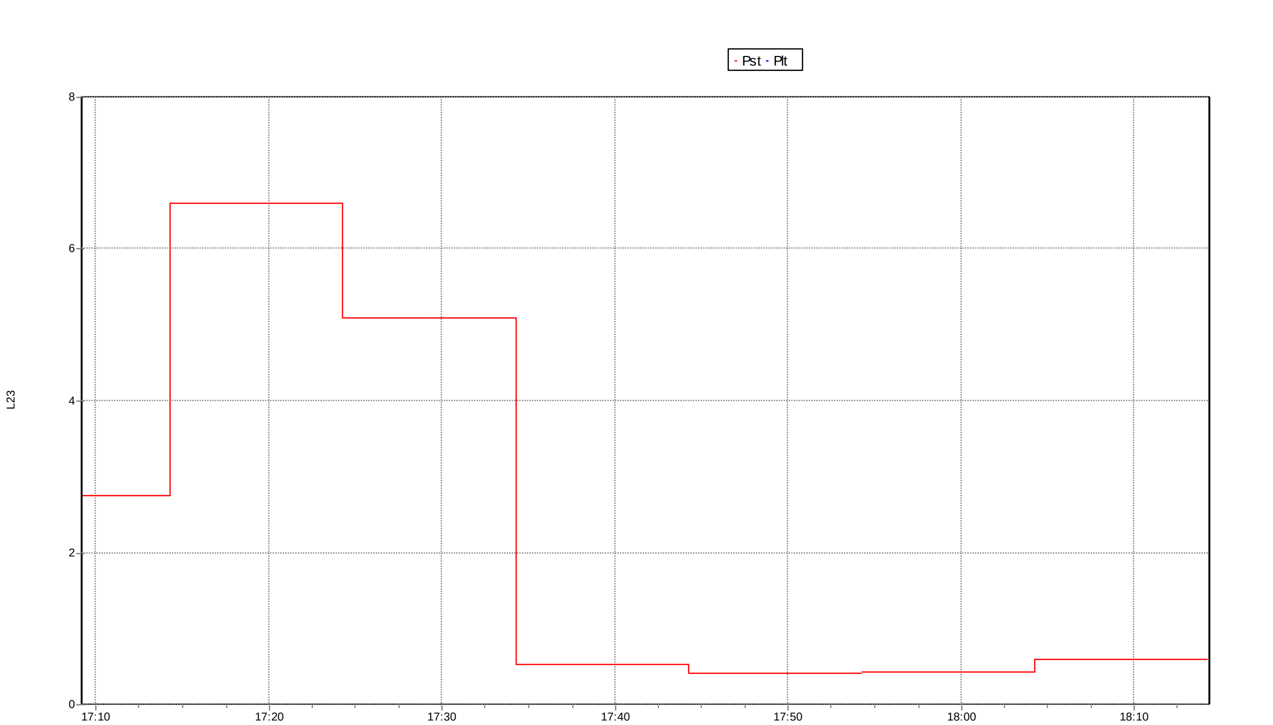


Figure 6.8a: P_{st} and P_{lt} measured for this heat.

Fig. 6.8b shows general overview for period of approximately six (6) hours or six heats.

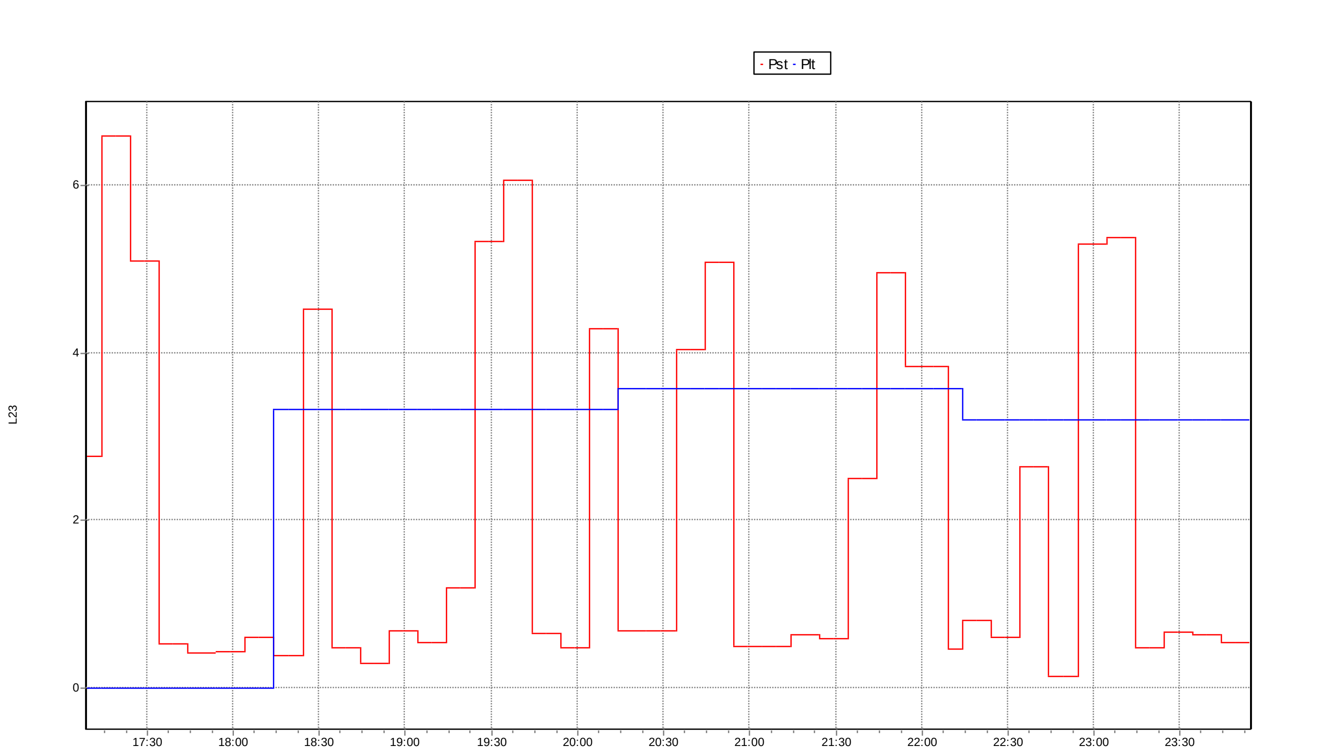


Figure 6.8b: General overview for P_{st} and P_{lt} for six (6) heats as measured.

16. The steps from step # 1 throughout step # 9 repeated till completing the entire electrical data collection.

6.5 PROCEDURE FOR COLLECTING QUALITY DATA OF INDUSTRIAL STEEL PRODUCT

The industrial steel product is produced in the EAF during melting process and treated further in LF (if applicable) before the final casting at CCM. The product quality data is mainly the chemical analysis for the molten steel produced at EAF, LF, and CCM.

Each heat lasts for approximately one hour and at the end of the heat before tapping, the furnace operator (melter) takes sample and sends it to the chemical laboratory. The chemist at chemical laboratory analyzes the sample and sends the result online to the furnace operator with recommendations of what element(s) is (are) exceeding the specified limit for that steel grade under production. Furnace operator adjusts the elements that should be adjusted in the furnace before tapping whenever required. These results are taken in form of excel sheet.

Sample of these data are presented in Table 6.5.

Table 6.5: Chemical analysis for ten (10) heats (Sample only).

Chemical Analysis: 200 **Standard:** EN 10130: 1991 **Steel Grade:** FeP01			Electric Arc Furnace (EAF)								
	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V	C.E.
1	6/14/2010 17:54	1024054	0.0569	0.023	0.003	0.0173	0.0155	0.0067	0.0149	0.00137	0.07
2	6/14/2010 18:57	1024055	0.0802	0.02	0.001	0.0246	0.0144	0.0065	0.01322	0.00076	0.09
3	6/14/2010 20:07	1024056	0.0637	0.019	0.001	0.0151	0.0113	0.0055	0.01304	0.00075	0.07
4	6/14/2010 21:13	1024057	0.066	0.021	0.002	0.0307	0.0196	0.0104	0.01222	0.00119	0.08
5	6/14/2010 22:20	1024058	0.0593	0.02	0.001	0.0244	0.0165	0.0078	0.01457	0.00074	0.07
6	6/14/2010 23:36	1024059	0.0711	0.021	0.001	0.0347	0.0152	0.0104	0.01407	0.00087	0.08
7	6/16/2010 17:15	1024080	0.0288	0.013	0.001	0.0222	0.0165	0.0105	0.00953	0.00013	0.04
8	6/16/2010 18:23	1024081	0.0503	0.011	0.002	0.0311	0.0208	0.0094	0.01023	0.00021	0.06
9	6/16/2010 19:46	1024082	0.0512	0.015	0.003	0.0267	0.0178	0.0111	0.0119	0.00052	0.06
10	6/16/2010 20:57	1024083	0.0484	0.017	0.004	0.0452	0.022	0.0106	0.01265	0.00047	0.06

The eight (8) chemical elements represent the Carbon Equivalent equation will be considered and others chemical elements will not be part of this work.

After obtaining the chemical results, Carbon Equivalent (CE) is calculated using equation (6.1) and recorded as shown in Table 6.5.

The same molten steel produced in EAF is sent after tapping to the LF for further treatment if required. During the treatment process at LF, the sample is sent to chemical laboratory for analysis. The same process of collecting the data for chemical analysis in EAF will be followed to collect the chemical data analysis at LF and CCM.

The process described above is repeated for each heat in three different process stages EAF, LF and CCM until the complete data gathering are obtained for 210 heats.

6.6 MEASUREMENT OF POWER QUALITY INDICES

Results of the power quality measurements in this study for the measured 210 hours throughout approximately two months are illustrated hereunder.

6.6.1 Measurement of PQ Indices for Grade 200

The power quality measurements have been conducted for a period of 120 hours during the process of producing this type of industrial steel with the code 200. The data extracted from the measurements device throughout the measuring period is large and is given in **Appendix-I**. These data are presented in graphs below for general overview with explanation and comments as applicable.

Fig. 6.9 shows the run charts for voltage (kV), current (A), active power (MW), and reactive power (MVAR) for the data measured over a period of 120 hours.

The figure shows low voltage, current, and power for four heats (heat # 7, 8, 9 & 10) which are equivalent to 5 hours and 15 minutes. This was due to the non availability of the static var compensator (SVC).

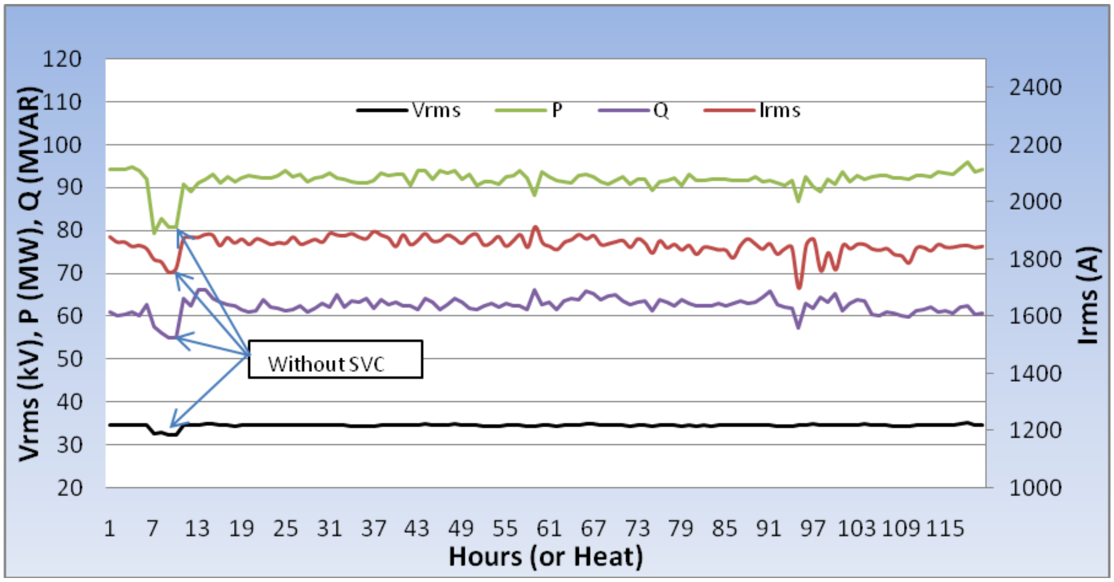


Figure 6.9: Run chart for V, I, P, and Q for a period of 120 hr.

Fig. 6.10 shows the run chart of voltage THD (THD V) and current THD (THD I) for the data measured over a period of 120 hours. The graph shows high THDV at heat # 7 and heat 59 which are the first heats after EAF maintenance period and without SVC in case of heat # 7. The EAF in this case is cold and has no hot heel (cold bath). The electrical arc is on contact with hard scrap and DRI without the support of hot heel. This usually causes higher THD V.

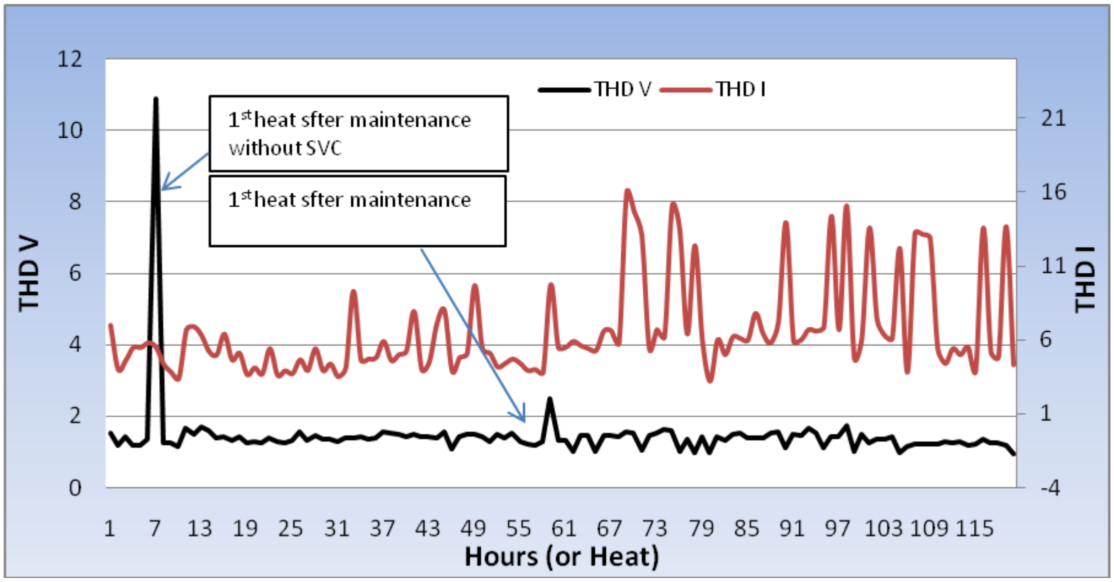


Figure 6.10: Run chart for THD V and THD I for a period of 120 hr.

Fig. 6.11 shows the run chart for 6th, 8th, and 10th harmonics voltage for the data measured over a period of 120 hours. By calculating the correlation coefficient (**r**) using equation (6.2) found that the above three harmonics were having the highest correlation coefficient value with carbon element comparing to the other chemical elements as shown in Table 6.6. This is the reason behind selecting them and neglecting the other PQ parameters.

$$r = \frac{\Sigma XY - \dfrac{\Sigma X \Sigma Y}{N}}{\sqrt{\left(\Sigma X^2 - \dfrac{(\Sigma X)^2}{N}\right)\left(\Sigma Y^2 - \dfrac{(\Sigma Y)^2}{N}\right)}} \qquad \textbf{(6.2)}$$

Table 6.6: Correlation coefficient (r) for four PQ parameters and chemical elements for steel grade 200 at EAF.

PQ parameters	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E.
H6	-0.3	0.0	0.1	0.1	0.2	0.2	0.3	0.0	-0.3
H8	-0.3	0.1	0.1	0.2	0.3	0.3	0.3	0.0	-0.3
H10	-0.3	0.1	0.1	0.3	0.3	0.3	0.2	0.0	-0.2
P_{st}	-0.3	0.1	0.1	0.2	0.2	0.3	0.2	0.0	-0.3

The figures show high values of 6^{th}, 8^{th}, and 10^{th} harmonics voltage in five occasions. These spikes are at heats # 7, 8, 9, 10, and 59 due to the non availability of the compensator (SVC).

Further analysis for possible correlation will be conducted in Chapter 7 of this Thesis.

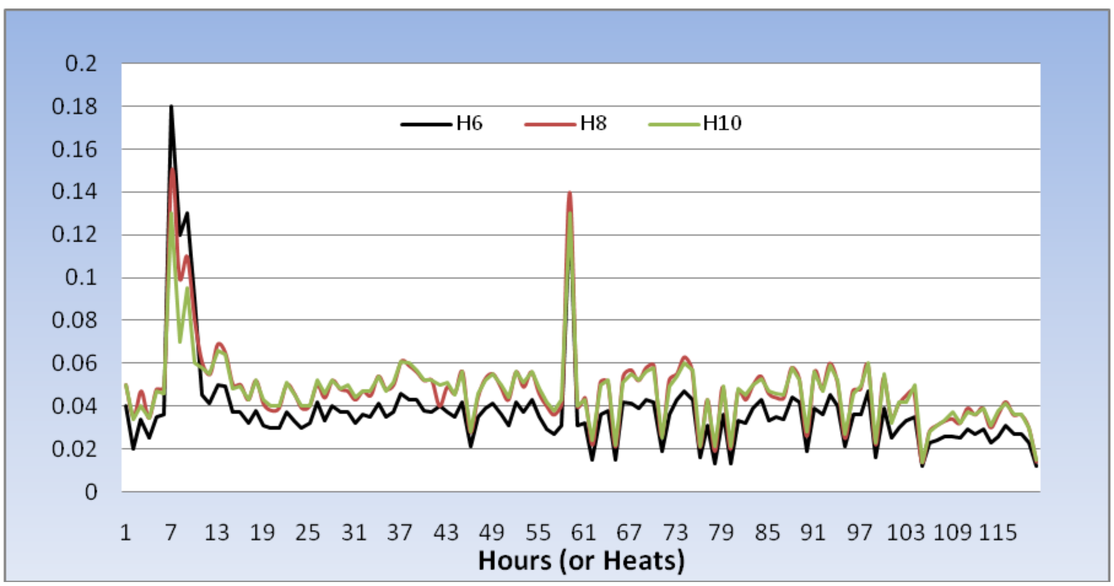


Figure 6.11: Run chart for H2 to >H11 for a period of 120 hr.

Fig. 6.12 shows the run chart for the short term flicker (P_{st}), long term flicker (P_{lt}), and power factor (PF) for the measured data over a period of 120 hours.

The figures shows high values of P_{st} and P_{lt} in six different occasions. For P_{st}, the spikes at heats # 7 and # 59 were due to starting the EAF on cold path as first heat after few hours stoppage for the maintenance activities. The operation under the condition of no hot heel available at the furnace with pure scrap materials causes high voltage fluctuations led to higher flicker.

Also spikes appeared for P_{lt} in heats # 7, 8, 9, 10, 59, and 60. For heats # 7 and 59 is the same reason for appearance of P_{st} as mentioned above. The P_{lt} is continued to be high for heats # 8, 9, and 10 due the non availability of the compensator (SVC).

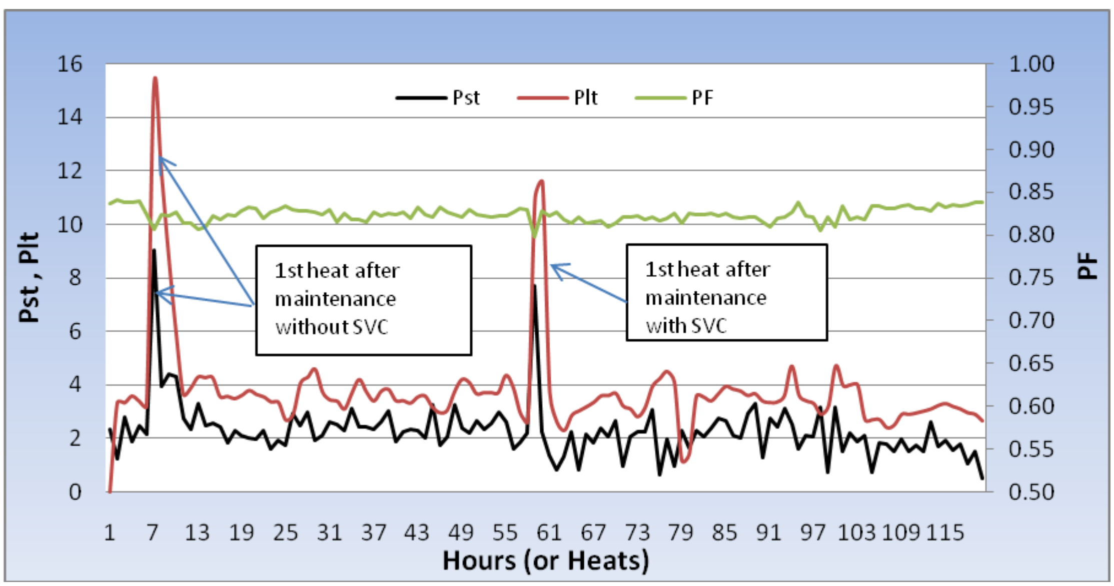


Figure 6.12: Run chart for P_{st}, P_{lt} and PF for a period of 120 hr.

6.6.2 Measurement of PQ Indices for Grade 2910

The power quality measurements have been conducted for a period of 90 hours during the process of producing this type of industrial steel with the code 2910.

The data extracted from the measurements devices throughout the measuring period is large and is given in **Appendix-II**. These data are presented in graphs below for general overview with explanation and comments as applicable.

Fig. 6.13 shows the run chart for voltage (kV), current (A), active power (MW), and reactive power (MVAR) for the data measured over a period of 90 hours.

The figure shows low voltage, current, and power for three heats (heats # 1, 2, & 3) which are equivalent to 3 hours. The same event reoccurred for another two heats (heats # 29 & 30) which are equivalent to 2 hours and 20 minutes. All the above events were due to the non availability of the static var compensator (SVC).

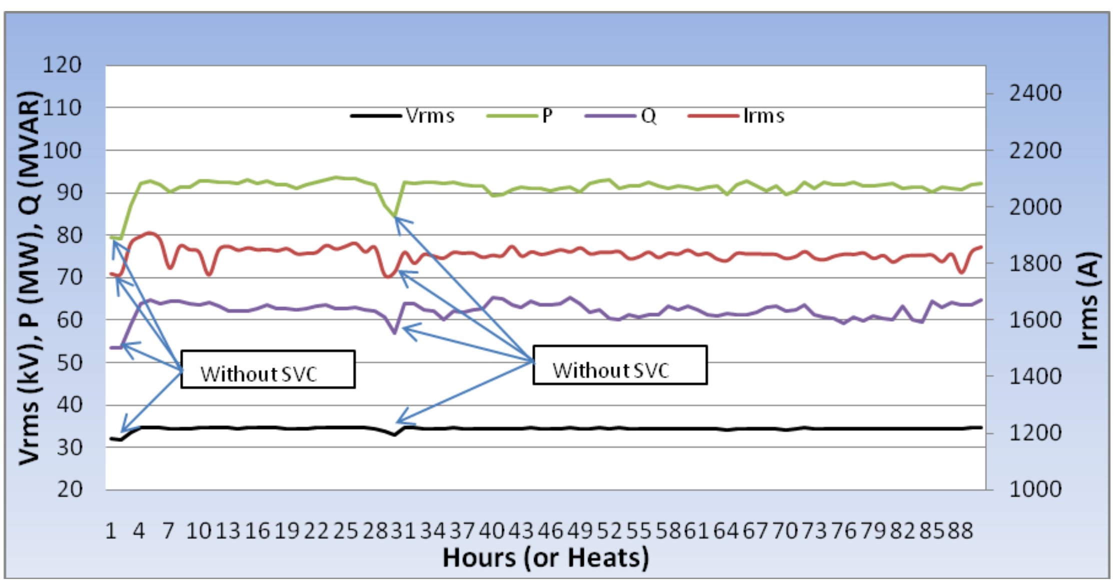


Figure 6.13: Run chart for V, I, P, and Q for a period of 90 hr.

Fig. 6.14 shows the run chart for the voltage THD (THDV) and the current THD (THD I) for the data measured over a period of 90 hours.

The graph shows high THD V at heats # 60. The only events was noticed during this period is power off (Vrms = Zero) for a period of five minutes then restore back the power.

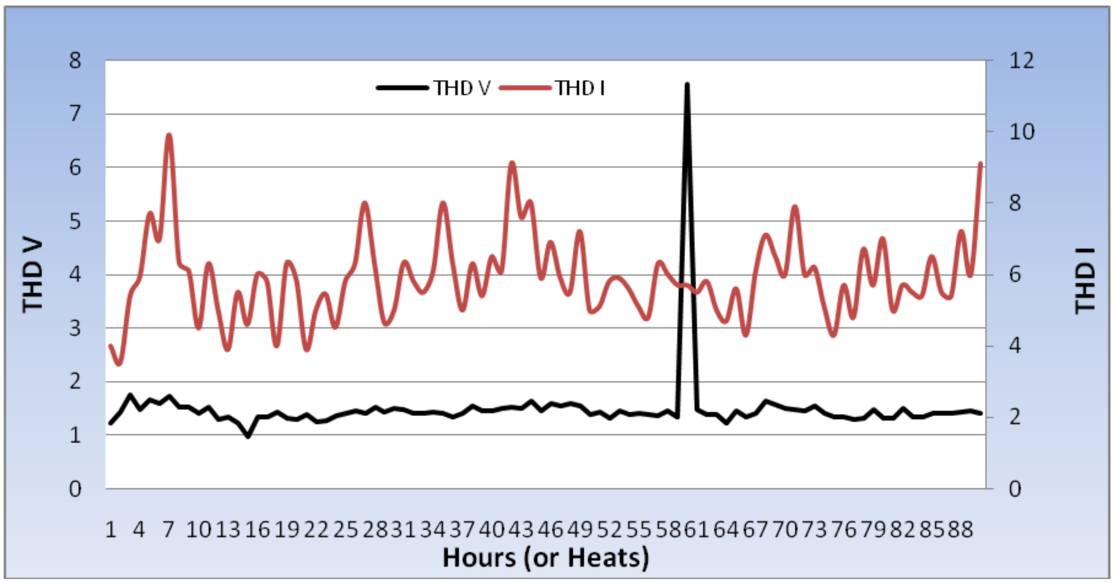


Figure 6.14: Run chart for THD V and THD I for a period of 90 hr.

Fig. 6.15 shows the run chart for 3rd, 4th, 11th, and the highest odd harmonic voltage beyond the eleventh harmonic (> H11) for the data measured over a period of 90 hours. By calculating the correlation coefficient (**r**) using equation (6.2) found that the above four harmonics were having the highest correlation coefficient value with carbon element comparing to the other chemical elements as shown in Table 6.7. This is the reason behind selecting them and neglecting the other PQ parameters.

Table 6.7: Correlation coefficient (r) for four PQ parameters and chemical elements for steel grade 2910 at EAF.

PQ Parameters	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E
H3	-0.4	-0.2	0.0	0.1	0.0	-0.2	-0.1	-0.3	-0.4
H4	-0.3	-0.1	0.0	0.1	0.1	-0.1	0.0	-0.2	-0.3
H11	0.3	0.2	0.0	0.2	0.1	0.4	0.3	0.3	0.4
>H11	0.4	0.3	0.0	0.1	0.1	0.4	0.3	0.3	0.4

Further analysis for possible correlation will be conducted in Chapter 7 of this Thesis.

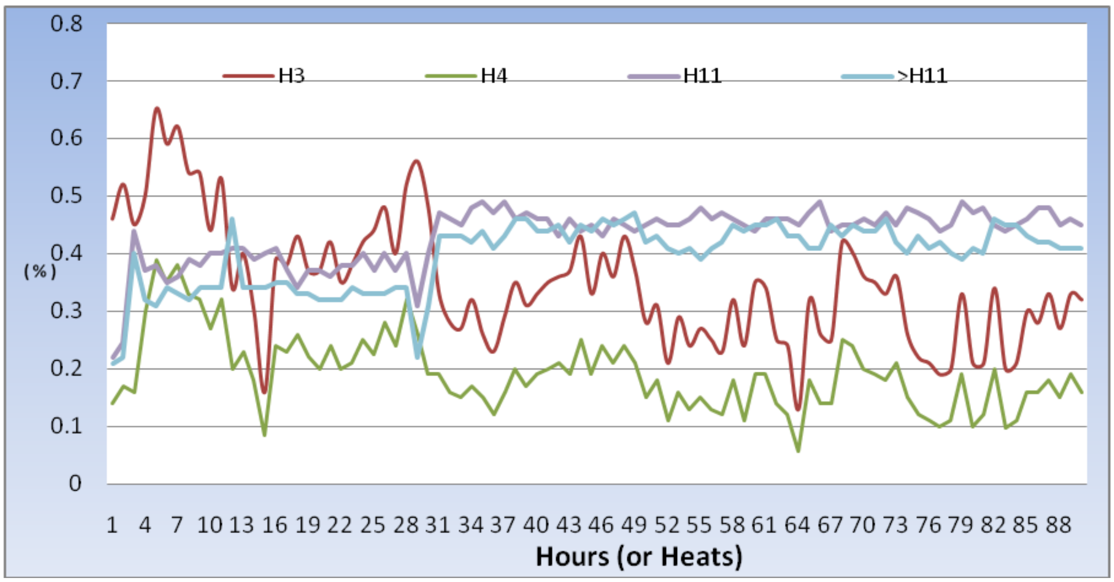


Figure 6.15: Run chart for H2 to >H11 for a period of 90 hr.

Fig. 6.16 shows the run chart for short term flicker (P_{st}), long term flicker (P_{lt}), and power factor (PF) for the measured data over a period of 90 hours.

The figures shows high values of P_{st} and P_{lt} in few different occasions. For P_{st}, the spikes at heats # 3 and 30 were due to the non availability of SVC. For heat # 60 there was an event of power off (Vrms = Zero) for a period of five minutes then restore back the power. The THD V was high as well during this event.

Also spikes appeared for P_{lt} in few heats. The events occurred for heats # 1, 2, 3, and 4 due the non availability of the compensator (SVC). This causes high harmonic and voltage fluctuations which lead to high flicker. For heats # 32, 60, and 61 there were no abnormality observed during these heats either in measurement or furnace operation.

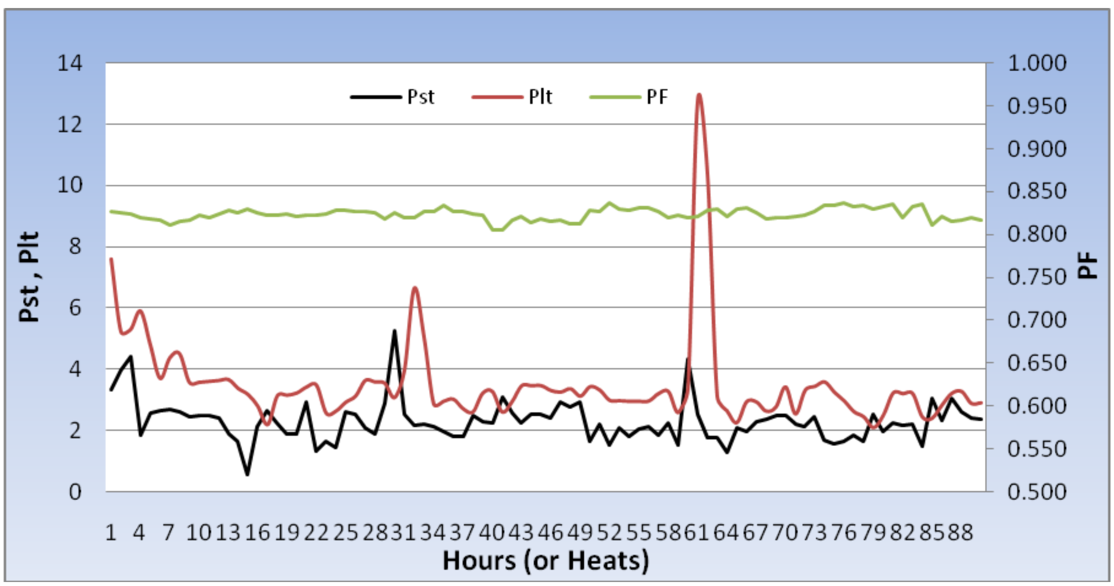


Figure 6.16: Run chart for P_{st}, P_{lt} and PF for a period of 120 hr.

6.7 RESULTS OF STEEL PRODUCT QUALITY ANALYSIS (CHEMICAL ANALYSIS)

The chemical analysis data of the two types of produced steel with the chemical analysis codes of 200 and 2910 are summarized as follows.

6.7.1 Results of Steel Product Analysis for Grade 200

Chemical analysis for the industrial steel product has been conducted for 120 heats during the production processes of grade 200.

The data obtained from the chemical laboratory throughout the analysis processes is large. So, these data cannot be shown hereunder and are thus given in **Appendix-III A** and **Appendix – III B** for EAF and CCM respectively.

Table 6-8 shows sample result of the chemical analysis data for grade 200 in EAF for twenty (20) heats.

The values for the chemical elements as obtained from the laboratory. These data have maximum limits as shown in Table 6.1. The limits should not be exceeded to fulfill certain grade's specifications. All are within the limits except the manganese (Mn) which will be adjusted during treatment or casting.

The mean and standard deviation are calculated for each element in order to use them for calculating the correlation coefficients (**r**).

Table 6.8 : Results of Chemical Analysis for Grade 200 at EAF.

	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V
1	6/14/2010 17:54	1024054	0.0569	0.023	0.003	0.0173	0.0155	0.0067	0.0149	0.00137
2	6/14/2010 18:57	1024055	0.0802	0.02	0.001	0.0246	0.0144	0.0065	0.01322	0.00076
3	6/14/2010 20:07	1024056	0.0637	0.019	0.001	0.0151	0.0113	0.0055	0.01304	0.00075
4	6/14/2010 21:13	1024057	0.066	0.021	0.002	0.0307	0.0196	0.0104	0.01222	0.00119
5	6/14/2010 22:20	1024058	0.0593	0.02	0.001	0.0244	0.0165	0.0078	0.01457	0.00074
6	6/14/2010 23:36	1024059	0.0711	0.021	0.001	0.0347	0.0152	0.0104	0.01407	0.00087
7	6/16/2010 17:15	1024080	0.0288	0.013	0.001	0.0222	0.0165	0.0105	0.00953	0.00013
8	6/16/2010 18:23	1024081	0.0503	0.011	0.002	0.0311	0.0208	0.0094	0.01023	0.00021
9	6/16/2010 19:46	1024082	0.0512	0.015	0.003	0.0267	0.0178	0.0111	0.0119	0.00052
10	6/16/2010 20:57	1024083	0.0484	0.017	0.004	0.0452	0.022	0.0106	0.01265	0.00047
11	7/28/2010 18:18	1030089	0.0507	0.015	0	0.0383	0.0147	0.0068	0.00425	0.0001
12	7/28/2010 19:26	1030090	0.0481	0.014	0.001	0.0359	0.0152	0.0071	0.00445	0.0001
13	7/28/2010 20:42	1030091	0.0491	0.013	0	0.0404	0.0139	0.0072	0.00281	0.0001
14	7/28/2010 21:57	1030092	0.0588	0.016	0	0.0343	0.0154	0.0095	0.00513	0.0001
15	7/28/2010 23:06	1030093	0.0501	0.017	0	0.0307	0.0117	0.0069	0.00465	0.0001
16	7/29/2010 0:10	1030094	0.0563	0.021	0.007	0.0366	0.0144	0.012	0.00436	0.0001
17	7/29/2010 1:14	1030095	0.0515	0.016	0	0.0284	0.0133	0.0067	0.00455	0.0001
18	7/29/2010 2:26	1030096	0.0544	0.014	0	0.0281	0.0137	0.0058	0.0039	0.0001
19	7/29/2010 3:32	1030097	0.0594	0.017	0	0.0288	0.0117	0.0063	0.00357	0.0001
20	7/29/2010 4:35	1030098	0.0776	0.014	0	0.0266	0.0147	0.0099	0.00035	0.0001

Mean =	0.0566	0.017	0.001	0.0300	0.0154	0.0084	0.00822	0.00040
St. Deviation =	0.0115	0.003	0.002	0.0075	0.0029	0.0020	0.00478	0.00041

Table 6.9 shows sample result of the chemical analysis data for industrial steel grade 200 in CCM for twenty (20) heats.

The values for the chemical elements as obtained from the laboratory. These data have maximum limits as shown in Table 6.1. The limits should not be exceeded to fulfill certain grade's specifications. All are within the limits comparing to the data obtained from EAF analysis. The mean and standard deviation are calculated for each element in order to use them for calculating the correlation coefficients (**r**).

Table 6.9 : Results of Chemical Analysis for Grade 200 at CCM.

	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V
1	6/14/2010 17:54	1024054	0.06	0.172	0.007	0.014	0.0139	0.0112	0.00619	0.014
2	6/14/2010 18:57	1024055	0.0605	0.187	0.007	0.0197	0.0138	0.0144	0.00619	0.0197
3	6/14/2010 20:07	1024056	0.058	0.177	0.006	0.014	0.0114	0.013	0.00579	0.014
4	6/14/2010 21:13	1024057	0.051	0.187	0.007	0.026	0.0178	0.0186	0.00649	0.026
5	6/14/2010 22:20	1024058	0.0729	0.207	0.013	0.0182	0.0139	0.0113	0.00606	0.0182
6	6/14/2010 23:36	1024059	0.0645	0.198	0.012	0.0297	0.0149	0.015	0.0069	0.0297
7	6/16/2010 17:15	1024080	0.0609	0.19	0.017	0.0176	0.0129	0.0162	0.00659	0.0176
8	6/16/2010 18:23	1024081	0.0555	0.172	0.005	0.0219	0.0155	0.0144	0.00615	0.0219
9	6/16/2010 19:46	1024082	0.0597	0.184	0.009	0.0219	0.0146	0.016	0.0073	0.0219
10	6/16/2010 20:57	1024083	0.0634	0.18	0.009	0.0325	0.0167	0.0132	0.00635	0.0325
11	7/28/2010 18:18	1030089	0.0625	0.179	0.006	0.0348	0.0131	0.0137	0.00207	0.0001
12	7/28/2010 19:26	1030090	0.0496	0.177	0.004	0.0303	0.0134	0.0124	0.00218	0.0001
13	7/28/2010 20:42	1030091	0.0649	0.167	0.007	0.0336	0.02	0.0144	0.00297	0.0001
14	7/28/2010 21:57	1030092	0.0599	0.163	0.003	0.0289	0.0129	0.0145	0.00213	0.0001
15	7/28/2010 23:06	1030093	0.0571	0.17	0.005	0.0262	0.0103	0.0181	0.00156	0.0001
16	7/29/2010 0:10	1030094	0.0591	0.169	0.008	0.0342	0.0145	0.018	0.00294	0.0001
17	7/29/2010 1:14	1030095	0.0614	0.161	0.003	0.0236	0.0112	0.0123	0.00166	0.0001
18	7/29/2010 2:26	1030096	0.0549	0.172	0.006	0.0242	0.0118	0.0144	0.00196	0.0001
19	7/29/2010 3:32	1030097	0.0591	0.169	0.008	0.0277	0.0116	0.0205	0.00778	0.00013
20	7/29/2010 4:35	1030098	0.0695	0.179	0.004	0.0211	0.0149	0.0165	0.00059	0.0001

Mean =	0.0602	0.178	0.007	0.0250	0.0140	0.0149	0.00449	0.01083
St. Deviation =	0.0055	0.012	0.003	0.0065	0.0023	0.0025	0.00239	0.01181

6.7.2 Results of Steel Product Analysis for Grade 2910

Chemical analysis for the industrial steel product has been conducted for 90 heats during the production processes of grade 2910.

The data obtained from the chemical laboratory analysis processes is large. So, these data cannot be shown hereunder and are thus give in **Appendix - IV A, Appendix - IV B**, and **Appendix – IV C** for EAF, LF and CCM respectively.

Table 6.10 shows sample result of the chemical analysis data for grade 2910 in EAF for twenty (20) heats.

The values for the chemical elements as obtained from the laboratory. These data have maximum limits as shown in Table 6.1. The limits should not be exceeded to fulfill certain grade's specifications. Three chemical elements Carbon (C), Manganese (Mn), and Silicon (Si) are not within the limits. This step of the process is not final and they will be adjusted during the treatment process in LF and during casting in CCM. The other five chemical elements Copper (Cu), Nickel (Ni), Chromium (Cr), Molybdenum (Mo), and Vanadium (V) are within the specified limits. The mean and standard deviation are calculated for each element in order to use them for calculating the correlation coefficients (r).

Table 6.10 : Results of Chemical Analysis for Grade 2910 at EAF.

	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V
1	6/16/2010 23:43	1024085	0.03080	0.009	0.001	0.03550	0.01720	0.00550	0.01064	0.00013
2	6/17/2010 0:58	1024086	0.03410	0.005	0.000	0.02420	0.01440	0.00260	0.00733	0.00013
3	6/17/2010 2:07	1024087	0.03910	0.008	0.002	0.05010	0.02020	0.00500	0.01005	0.00013
4	6/17/2010 3:18	1024088	0.04830	0.009	0.002	0.04870	0.01540	0.00610	0.01150	0.00048
5	6/17/2010 4:32	1024089	0.04810	0.010	0.001	0.02040	0.01150	0.00460	0.01047	0.00017
6	6/17/2010 5:28	1024090	0.04720	0.011	0.000	0.03020	0.02200	0.00660	0.01035	0.00013
7	6/17/2010 6:49	1024091	0.04700	0.009	0.001	0.02830	0.01860	0.00460	0.01250	0.00013
8	6/17/2010 7:54	1024092	0.05860	0.020	0.002	0.03850	0.01960	0.01140	0.01163	0.00049
9	6/17/2010 9:00	1024093	0.05360	0.020	0.003	0.04050	0.01900	0.00870	0.01315	0.00055
10	6/17/2010 10:03	1024094	0.05260	0.023	0.002	0.04440	0.02520	0.01420	0.01658	0.00069
11	6/17/2010 11:09	1024095	0.05440	0.020	0.001	0.03610	0.02130	0.01410	0.00982	0.00029
12	6/17/2010 12:22	1024096	0.05480	0.024	0.003	0.03600	0.02140	0.01020	0.01718	0.00093
13	6/17/2010 13:22	1024097	0.06080	0.017	0.001	0.02850	0.01770	0.00600	0.01459	0.00040
14	6/17/2010 14:27	1024098	0.05360	0.024	0.002	0.02950	0.01640	0.00750	0.01217	0.00034
15	6/17/2010 15:37	1024099	0.11430	0.013	0.001	0.00840	0.01740	0.01130	0.01124	0.00160
16	6/17/2010 16:41	1024100	0.04890	0.022	0.012	0.02500	0.02120	0.00790	0.01254	0.00076
17	6/17/2010 17:45	1024101	0.04890	0.019	0.002	0.03640	0.02390	0.01000	0.01323	0.00049
18	6/17/2010 19:02	1024102	0.05660	0.017	0.003	0.03260	0.01880	0.00810	0.01314	0.00050
19	6/17/2010 20:14	1024103	0.05420	0.013	0.001	0.02420	0.01330	0.00630	0.01165	0.00034
20	6/17/2010 21:33	1024104	0.05040	0.023	0.008	0.04780	0.02310	0.01250	0.01342	0.00043

Mean =	0.0528	0.016	0.002	0.0333	0.0189	0.0082	0.01216	0.00046
St. Deviation =	0.0163	0.006	0.003	0.0104	0.0036	0.0033	0.00292	0.00035

Table 6.11 shows sample result of the chemical analysis data for grade 2910 in LF for twenty (20) heats.

The values for the chemical elements as obtained from the laboratory. These data have maximum limits as shown in Table 6.1. The limits should not b exceeded to fulfill certain grade’s specifications. The Carbon (C) element is not within the limits in some heats. This step of the process is not final and it will be adjusted during the casting process in CCM. The other chemical elements are all within the specified limits. The mean and standard deviation are calculated for each element in order to use them for calculating the correlation coefficients (r).

Table 6.11 : Results of Chemical Analysis for Grade 2910 at LF.

	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V
1	6/16/2010 23:43	1024085	0.0773	1.289	0.229	0.0333	0.0157	0.0119	0.0001	0.00108
2	6/17/2010 0:58	1024086	0.0823	1.29	0.22	0.0229	0.013	0.0106	0.00032	0.00115
3	6/17/2010 2:07	1024087	0.0799	1.288	0.238	0.0475	0.0182	0.0126	0.00157	0.00084
4	6/17/2010 3:18	1024088	0.0927	1.262	0.223	0.0427	0.0162	0.0138	0.00205	0.00106
5	6/17/2010 4:32	1024089	0.0825	1.273	0.241	0.0213	0.0115	0.0113	0.001	0.00155
6	6/17/2010 5:28	1024090	0.086	1.257	0.22	0.0279	0.0187	0.0158	0.00195	0.00125
7	6/17/2010 6:49	1024091	0.0811	1.265	0.214	0.0274	0.0174	0.0151	0.0016	0.0012
8	6/17/2010 7:54	1024092	0.085	1.279	0.244	0.035	0.0182	0.0181	0.00151	0.00187
9	6/17/2010 9:00	1024093	0.0938	1.273	0.241	0.0348	0.0177	0.0171	0.00227	0.00174
10	6/17/2010 10:03	1024094	0.0804	1.264	0.216	0.0377	0.0235	0.0233	0.00515	0.00162
11	6/17/2010 11:09	1024095	0.0861	1.275	0.213	0.0319	0.0192	0.0242	0.00453	0.00116
12	6/17/2010 12:22	1024096	0.0822	1.276	0.229	0.0326	0.0195	0.0178	0.00311	0.0015
13	6/17/2010 13:22	1024097	0.088	1.3	0.235	0.0257	0.0158	0.017	0.0022	0.00159
14	6/17/2010 14:27	1024098	0.0837	1.26	0.208	0.0257	0.0147	0.021	0.00184	0.00131
15	6/17/2010 15:37	1024099	0.0937	1.276	0.2	0.0069	0.0095	0.0215	0.00038	0.00165
16	6/17/2010 16:41	1024100	0.0842	1.26	0.204	0.0213	0.0159	0.0184	0.00142	0.00133
17	6/17/2010 17:45	1024101	0.0792	1.306	0.214	0.0328	0.0215	0.0338	0.00307	0.00155
18	6/17/2010 19:02	1024102	0.086	1.288	0.203	0.0296	0.0157	0.0192	0.00161	0.00126
19	6/17/2010 20:14	1024103	0.0833	1.283	0.229	0.0227	0.0124	0.0279	0.0011	0.00105
20	6/17/2010 21:33	1024104	0.0869	1.253	0.217	0.04	0.0176	0.0238	0.00167	0.00135

	C	Mn	Si	Cu	Ni	Cr	Mo	V
Mean =	0.0847	1.276	0.222	0.0300	0.0166	0.0187	0.00192	0.00136
St. Deviation =	0.0046	0.015	0.013	0.0090	0.0033	0.0059	0.00127	0.00027

Table 6.12 shows sample result of the chemical analysis data for grade 2910 in CCM for twenty (20) heats.

The values for the chemical elements as obtained from the laboratory. These data have maximum limits as shown in Table 6-1. This step is the final step of the process and no further adjustment will be made for any element. Accordingly all the chemical elements are within the specified limits. The mean and standard deviation are calculated for each element in order to use them for calculating the correlation coefficients (r).

Table 6.12: Results of Chemical Analysis for Grade 2910 at CCM.

	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V
1	6/16/2010 23:43	1024085	0.088	1.28	0.264	0.0329	0.0156	0.0132	0.00016	0.00108
2	6/17/2010 0:58	1024086	0.0912	1.293	0.24	0.023	0.0133	0.0147	0.00026	0.00091
3	6/17/2010 2:07	1024087	0.0918	1.312	0.251	0.0465	0.0178	0.0137	0.00198	0.001
4	6/17/2010 3:18	1024088	0.1	1.252	0.244	0.0425	0.0163	0.0149	0.00187	0.00106
5	6/17/2010 4:32	1024089	0.0842	1.277	0.242	0.0213	0.011	0.0116	0.0001	0.00125
6	6/17/2010 5:28	1024090	0.0947	1.256	0.237	0.0277	0.0188	0.0159	0.00214	0.00109
7	6/17/2010 6:49	1024091	0.0937	1.264	0.237	0.0272	0.0182	0.0156	0.00127	0.00111
8	6/17/2010 7:54	1024092	0.0988	1.28	0.265	0.0346	0.0194	0.0198	0.00256	0.00186
9	6/17/2010 9:00	1024093	0.0946	1.275	0.249	0.0356	0.0178	0.0199	0.00337	0.00172
10	6/17/2010 10:03	1024094	0.0911	1.274	0.24	0.0372	0.0217	0.0248	0.00297	0.0014
11	6/17/2010 11:09	1024095	0.0928	1.283	0.229	0.0316	0.0186	0.024	0.00179	0.00102
12	6/17/2010 12:22	1024096	0.0814	1.257	0.245	0.0323	0.0191	0.0203	0.00197	0.00136
13	6/17/2010 13:22	1024097	0.0938	1.288	0.25	0.0251	0.0147	0.0172	0.00127	0.00152
14	6/17/2010 14:27	1024098	0.0983	1.275	0.235	0.0256	0.0145	0.0224	0.00171	0.00123
15	6/17/2010 15:37	1024099	0.0979	1.28	0.226	0.0072	0.0093	0.022	0.00031	0.00157
16	6/17/2010 16:41	1024100	0.0921	1.278	0.225	0.0214	0.017	0.0204	0.00119	0.0013
17	6/17/2010 17:45	1024101	0.0941	1.301	0.236	0.032	0.0216	0.0332	0.00303	0.00112
18	6/17/2010 19:02	1024102	0.1	1.286	0.231	0.0292	0.0165	0.0215	0.00295	0.00126
19	6/17/2010 20:14	1024103	0.0922	1.296	0.25	0.0227	0.0123	0.0287	0.00213	0.00125
20	6/17/2010 21:33	1024104	0.0984	1.269	0.239	0.0401	0.0185	0.0272	0.00172	0.00131

Mean =	0.0935	1.279	0.242	0.0298	0.0166	0.0201	0.00174	0.00127
St. Deviation =	0.0049	0.015	0.011	0.0088	0.0033	0.0057	0.00099	0.00025

CHAPTER 7

ANALYSIS AND RESULTS

Power quality measurements and product quality analysis (chemical analysis) are made for two different types of produced steel (two different grades namely 200 and 2910) in two or three different locations, as applicable, in different timing. Analysis of the results and discussions are made hereunder.

7.1 INDUSTRIAL STEEL'S STATISTICAL ANALYSIS FOR BOTH GRADES 200 AND 2910.

The power quality measurements and chemical analysis for the industrial steel grade 200 was conducted for 120 hours and data obtained and recorded. The same measurements and analysis are made for industrial steel grade 2910 for 90 hours and data obtained and recorded.

To study the characteristics of the data for the produced industrial steel, the frequency distribution and histogram methods were selected for describing the data sets in a graphical way to help analyzing such large data and for better understanding [52].

A ***frequency distribution*** is a rearrangement of raw data in ascending or descending order of magnitude, such that the quality characteristic is subdivided into classes and the number of occurrences in each class is presented.

A ***histogram*** is a graphical display of data such that the characteristic is subdivided into classes. In a frequency histogram, the vertical axis usually represents the number of observation in each class. The following steps are used to construct a frequency histogram:

1. Find the range of the observations or data which is the difference between the largest and smallest value.
2. Choose the number of classes. Usually 5-20 classes should be selected. If too few classes are chosen, specific details of the data are lost. On the other hand, if too many classes are selected, a summary of how the data is distributed (which is the objective of a histogram) will not be achieved. As a rule of thumb, if n represents the number of data points, the number of classes should be approximately $\sqrt{n}$.
3. Determine the width of the classes. Usually, all classes are of equal width except for the first of last class. If outliers are present, the first or last class can be kept open-ended to include them. The class width is found by dividing the range by the number of classes.
4. Determine the class boundaries. Find the number of observations in each class. Make sure the classes are not overlapping.
5. Draw the frequency histogram.

A ***frequency*** is the number of occurrences of observations data in each class boundaries.

A ***relative frequency*** in each class is the frequency in each class divided by the total number of observations.

The ***cumulative frequency*** for a given class is the number of observations in that class and in all classes preceding it.

The ***cumulative relative frequency*** of a class is simply the cumulative frequency for that class divided by the total number of observations.

Out of the eight (8) elements measured, carbon element is selected due to its effect and importance on the steel industrial product. The carbon equivalent (CE) is calculated accordingly and used for the statistical analysis of the data.

7.1.1 Statistical Analysis for industrial steel product grade 200

For the data of the industrial steel product grade 200 that are produced at EAF and are recorded in Appendix-III A; the range is 0.150-0.029 = 0.121, the number of the classes are $\sqrt{120} \approx 11$, and the class width is 0.121/11 = 0.011.

Using the above data, Table 7.1 is constructed to show the frequency distribution for carbon in steel product grade 200 at EAF.

Table 7.1: Frequency distribution for carbon in steel product at EAF.

C in EAF for Grade 200					
	Range (C) =	0.121			
	Classes (C) =	11			
	Width (C) =	0.011			
	Class Boundaries (%)	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cumulative Relative Frequency**
1	0.029 ≤ X ≤ 0.040	1	0.01	1	0.01
2	0.040 ≤ X ≤ 0.051	14	0.12	15	0.13
3	0.051 ≤ X ≤ 0.062	55	0.46	70	0.58
4	0.062 ≤ X ≤ 0.073	32	0.27	102	0.85
5	0.073 ≤ X ≤ 0.084	12	0.10	114	0.95
6	0.084 ≤ X ≤ 0.095	3	0.03	117	0.98
7	0.095 ≤ X ≤ 0.106	2	0.02	119	0.99
8	0.106 ≤ X ≤ 0.117	0	0.00	119	0.99
9	0.117 ≤ X ≤ 0.128	0	0.00	119	0.99
10	0.128 ≤ X ≤ 0.139	0	0.00	119	0.99
11	0.139 ≤ X ≤ 0.150	1	0.01	120	1.00
	Total	**120**	**1.00**		

Using the same method and data recorded in Appendix-III A, Table 7.2 is constructed to show the frequency distribution for carbon equivalent (CE) in steel product grade 200 at EAF.

Table 7.2: Frequency distribution for carbon equivalent at EAF.

CE in EAF for Grade 200					
	Range (CE) =	0.121			
	Classes (CE) =	11			
	Width (CE) =	0.011			
	Class Boundaries (%)	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cumulative Relative Frequency**
1	0.038 ≤ X ≤ 0.049	1	0.01	1	0.01
2	0.049 ≤ X ≤ 0.060	14	0.12	15	0.13
3	0.060 ≤ X ≤ 0.071	54	0.45	69	0.58
4	0.071 ≤ X ≤ 0.082	30	0.25	99	0.83
5	0.082 ≤ X ≤ 0.093	13	0.11	112	0.93
6	0.093 ≤ X ≤ 0.104	5	0.04	117	0.98
7	0.104 ≤ X ≤ 0.115	1	0.01	118	0.98
8	0.115 ≤ X ≤ 0.126	1	0.01	119	0.99
9	0.126 ≤ X ≤ 0.137	0	0.00	119	0.99
10	0.137 ≤ X ≤ 0.148	0	0.00	119	0.99
11	0.148 ≤ X ≤ 0.159	1	0.01	120	1.00
	Total	**120**	**1.00**		

From both data sets in Table 7.1 and Table 7.2 above, the frequency distributions for carbon (C) and carbon equivalent (CE) at EAF are shown in Fig. 7.1. The cumulative frequency histograms for carbon (C) and carbon equivalent (CE) at EAF are shown in Fig. 7.2.

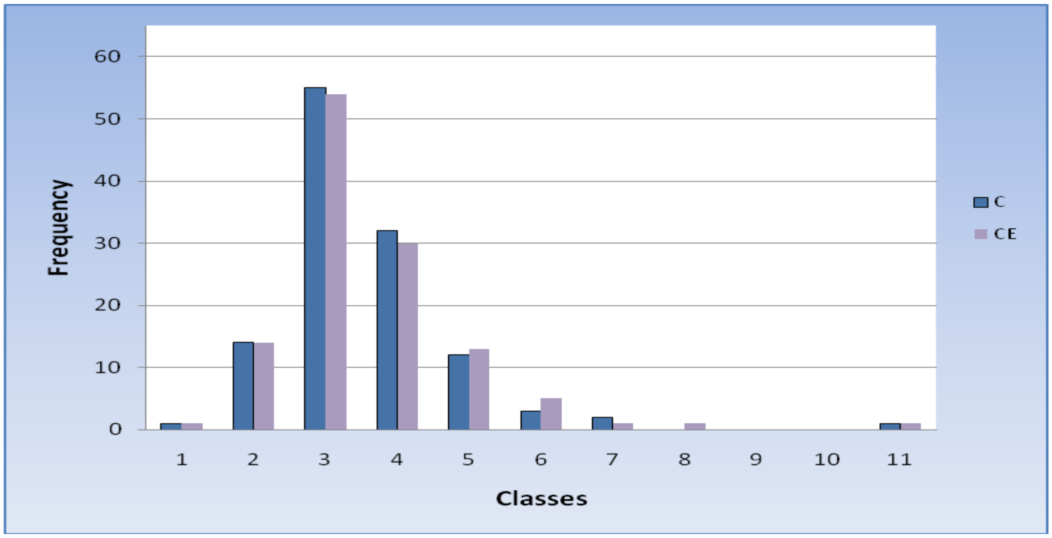


Fig. 7.1: Frequency histogram for “C” and “CE” at EAF (Grade 200).

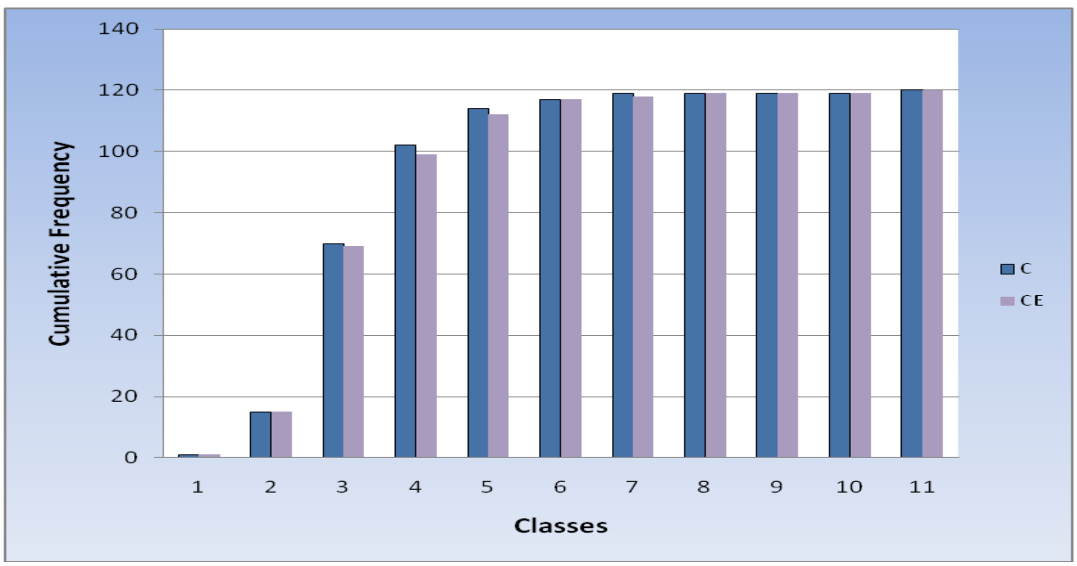


Fig. 7.2: Cumulative frequency histogram for “C” and “CE” at EAF (Grade 200).

Fig. 7.1 shows the frequency histogram for carbon and carbon equivalent for grade 200 analyzed at EAF. This histogram gives a sense of where is the carbon and carbon equivalent contents cluster and the degree of its variability. Such histogram is used also to check whether there are outliers (item 11 in Table 7.1 is an example for outlier) and provide information regarding the uniformity of the steel industrial process.

Furthermore, they determine the conformance of the process with respect to established specification limits.

For better illustration, Fig. 7.3 shows the percentage of the carbon in the direct reduced iron (DRI) coming from the direct reduction (DR) plant. DRI has higher carbon value than what is needed in EAF for two reasons; 1) to avoid adding carbon during the melting process as much as possible and 2) as source for heating energy. The heating energy from carbon will be obtained by the chemical reaction between carbon and oxygen in the EAF. Heating energy will be produced and used in EAF which will reduce the consumption of the electrical energy. At the same time, carbon value comes down during the process to meet the required limits. Carbon value might be found below the required limit in the molten steel at EAF which is well expected as beginning step of the steelmaking process. The value will be adjusted during the treatment in LF or during the casting in CCM.

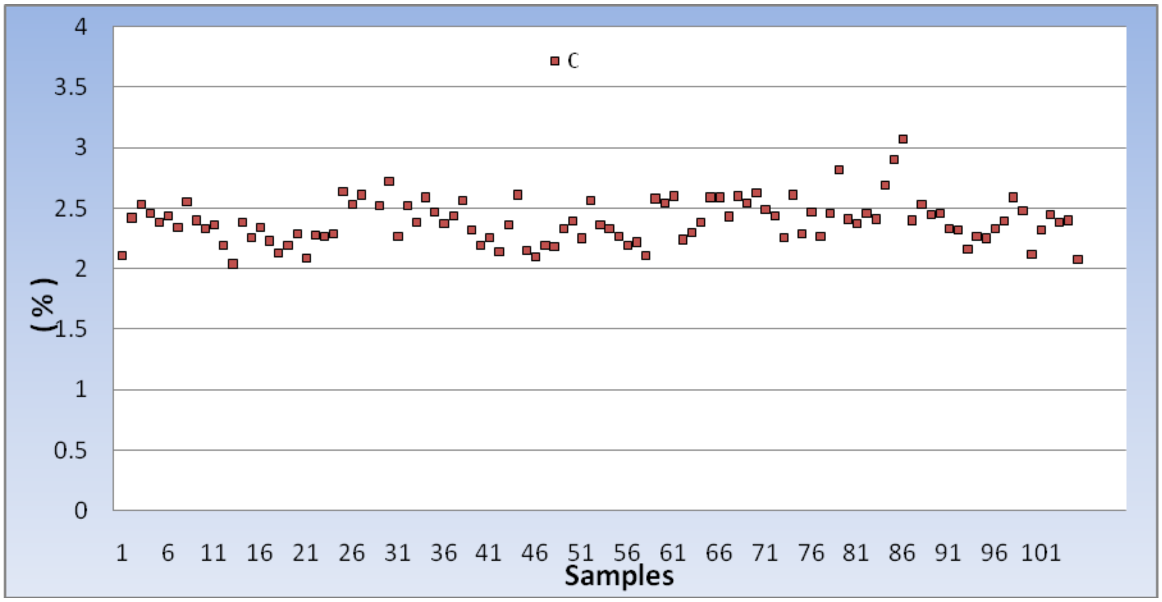


Fig. 7.3: "C" values in the DRI feeding to the EAF.

Fig. 7.4 shows the carbon values for 120 heats of industrial steel grade 200 analyzed at EAF. It also shows the upper limit (MAX) and lower limit (MIN) defined by the standard. 85% of the analyzed values for the carbon at EAF are within the desired limits. Further adjustment to the carbon values takes place during the next process which is casting at CCM. This explains having some values out of range.

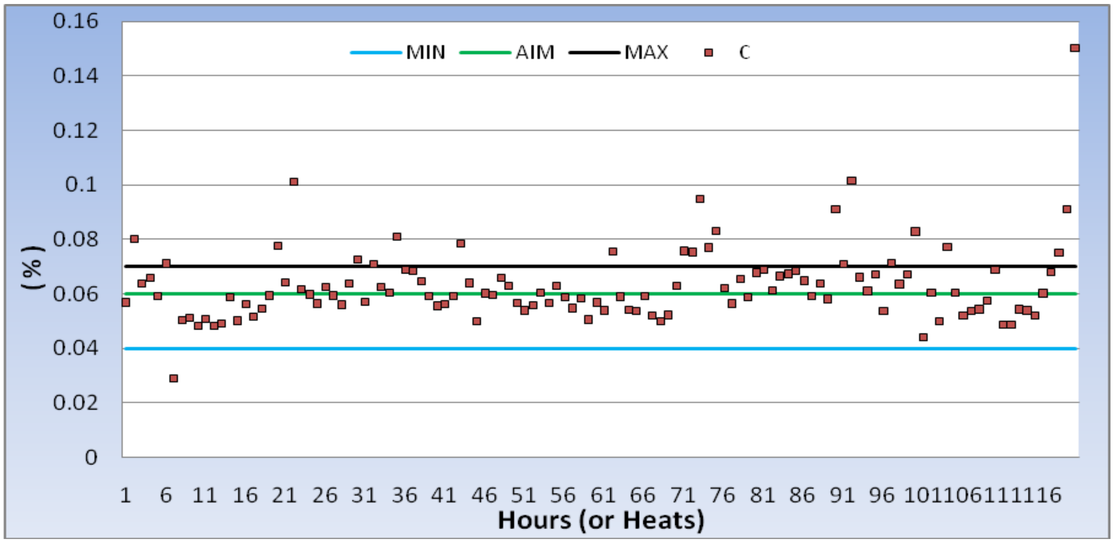


Fig. 7.4: "C" values in EAF with Upper and Lower limits (Grade 200).

By analyzing the above tables and graphs, it is found that the percentage (%) of the carbon value in industrial steel for grade 200 produced at EAF are statically as follows:

- 73% of the carbon values between 0.051% and 0.073%.
- 85% of the carbon values between 0.04% and 0.073%, within the limits.
- 1% of the carbon value below the limit.
- 14% of the carbon value above the limit.

The treatment of this type of industrial steel grade 200 takes place at the EAF then final adjustment for some chemical elements such as carbon take place at CCM (most of the steel production of this grade 200 do not go through LF). Based on that, statistical analysis for the carbon at CCM is conducted.

For the data of the industrial steel product grade 200 that are casted at CCM and are recorded in Appendix-III B; the range, number of the classes, and the class width are calculated. Using the above data, Table 7.3 is constructed to show the frequency distribution for carbon in steel product grade 200 at CCM.

Table 7.3: Frequency distribution for carbon in steel product at CCM.

C in CCM for Grade 200					
	Range (C) =	0.033			
	Classes (C) =	11			
	Width (C) =	0.003			
	Class Boundaries	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cumulative Relative Frequency**
1	0.045 ≤ X ≤ 0.048	2	0.02	2	0.02
2	0.048 ≤ X ≤ 0.051	4	0.03	6	0.05
3	0.051 ≤ X ≤ 0.054	6	0.05	12	0.10
4	0.054 ≤ X ≤ 0.057	21	0.18	33	0.28
5	0.057 ≤ X ≤ 0.060	24	0.20	57	0.48
6	0.060 ≤ X ≤ 0.063	25	0.21	82	0.68
7	0.063 ≤ X ≤ 0.066	22	0.18	104	0.87
8	0.066 ≤ X ≤ 0.069	6	0.05	110	0.92
9	0.069 ≤ X ≤ 0.072	6	0.05	116	0.97
10	0.072 ≤ X ≤ 0.075	4	0.03	120	1.00
11	0.075 ≤ X ≤ 0.078	0	0.00	120	1.00
	Total	**120**	**1.00**		

Using the same method and data recorded in Appendix-III B, Table 7.4 is constructed to show the frequency distribution for carbon equivalent (CE) in steel product grade 200 at CCM.

Table 7.4: Frequency distribution for carbon equivalent at CCM.

CE in CCM for Grade 200					
	Range (CE) =	0.037			
	Classes (CE) =	11			
	Width (CE) =	0.003			
	Class Boundaries	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cumulative Relative Frequency**
1	0.082 ≤ X ≤ 0.085	3	0.03	3	0.03
2	0.085 ≤ X ≤ 0.088	3	0.03	6	0.05
3	0.088 ≤ X ≤ 0.091	12	0.10	18	0.15
4	0.091 ≤ X ≤ 0.094	26	0.22	44	0.37
5	0.094 ≤ X ≤ 0.097	21	0.18	65	0.54
6	0.097 ≤ X ≤ 0.100	19	0.16	84	0.70
7	0.100 ≤ X ≤ 0.103	13	0.11	97	0.81
8	0.103 ≤ X ≤ 0.106	12	0.10	109	0.91
9	0.106 ≤ X ≤ 0.109	4	0.03	113	0.94
10	0.109 ≤ X ≤ 0.112	4	0.03	117	0.98
11	0.112 ≤ X ≤ 0.119	3	0.03	120	1.00
	Total	**120**	**1.00**		

From both data sets in Table 7.3 and Table 7.4 above, the frequency distributions for carbon (C) and carbon equivalent (CE) at CCM are shown in Fig. 7.5. The cumulative frequency histograms for carbon (C) and carbon equivalent (CE) at CCM are shown in Fig. 7.6.

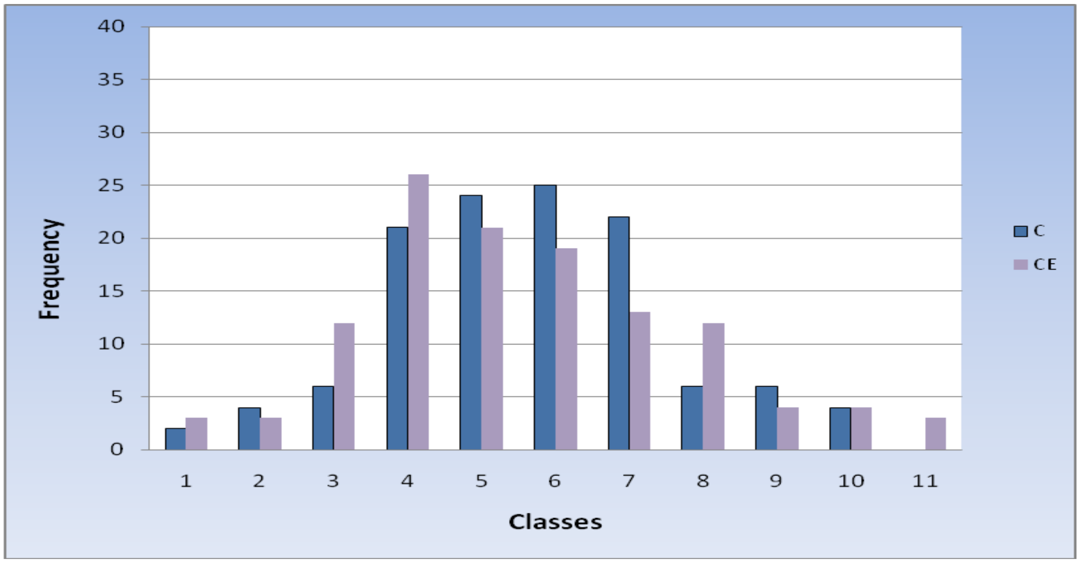


Fig. 7.5: Frequency histogram for “C” and “CE” at CCM (Grade 200).

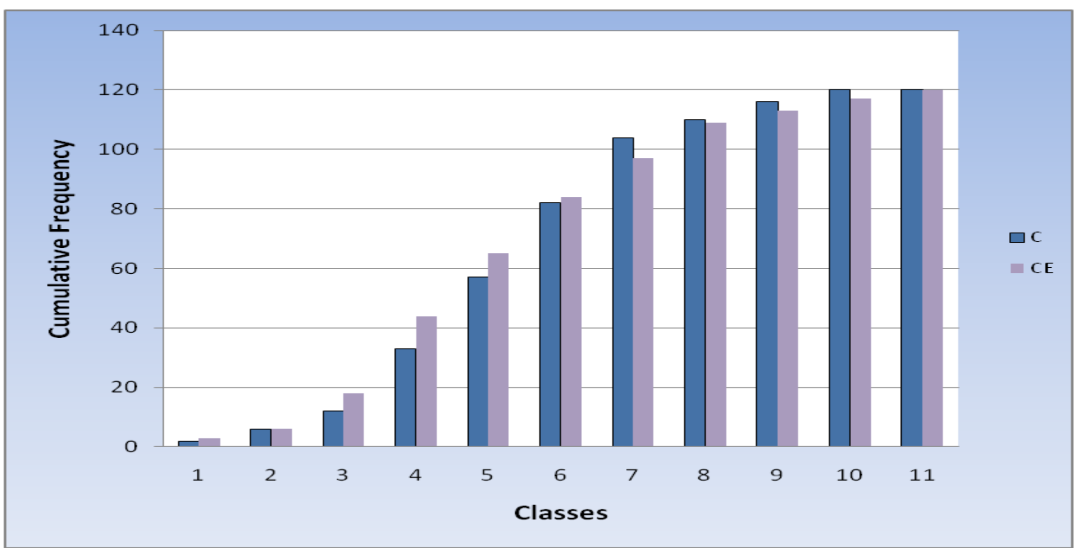


Fig. 7.6: Cumulative Frequency histogram for “C” and “CE” at CCM (Grade 200).

Fig. 7.7 shows the carbon values for 120 heats of industrial steel grade 200 analyzed at CCM. It also shows the upper limit (MAX) and lower limit (MIN) defined by the standard. 92% of the analyzed values for the carbon at CCM are within the desired limits.

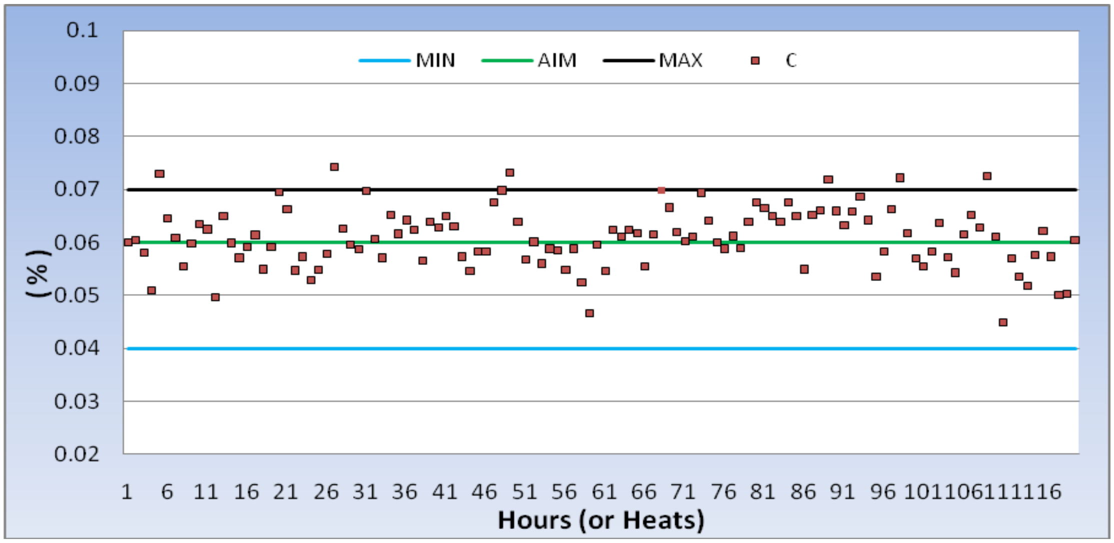


Fig. 7.7: "C" values in CCM with Upper and Lower limits (Grade 200).

By analyzing the above tables and graphs, it is found that the percentage (%) of the carbon value in industrial steel for grade 200 casted at CCM are statically as follows:

- 92% of the carbon values between 0.040% and 0.070%, within the required range.
- 8% of the carbon values between 0.070% and 0.074%.

7.1.2 Statistical analysis for industrial steel product grade 2910.

For the data of the industrial steel product grade 2910 that are produced at EAF and are recorded in Appendix-IV A; the range is 0.192-0.031 = 0.161, the number of the classes are $\sqrt{90} \approx 10$, and the class width is 0.161/10 = 0.016, 0.01 is used for satisfying the classes and outliers.

Using the above data, Table 7.5 is constructed to show the frequency distribution for carbon in steel product grade 2910 at EAF.

Table 7.5: Frequency distribution for carbon in steel product at EAF.

C in EAF for Grade 2910					
	Range (C) =	0.161			
	Classes (C) =	10			
	Width (C) =	0.016	Used	0.01	
	Class Boundaries	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cumulative Relative Frequency**
1	0.031 ≤ X ≤ 0.041	3	0.03	3	0.03
2	0.041 ≤ X ≤ 0.051	12	0.13	15	0.17
3	0.051 ≤ X ≤ 0.061	36	0.40	51	0.57
4	0.061 ≤ X ≤ 0.071	26	0.29	77	0.86
5	0.071 ≤ X ≤ 0.081	8	0.09	85	0.94
6	0.081 ≤ X ≤ 0.091	1	0.01	86	0.96
7	0.091 ≤ X ≤ 0.101	1	0.01	87	0.97
8	0.101 ≤ X ≤ 0.111	1	0.01	88	0.98
9	0.111 ≤ X ≤ 0.121	1	0.01	89	0.99
10	0.121 ≤ X ≤ 0.192	1	0.01	90	1.00
	Total	**90**	**1.00**		

Using the same method and data recorded in Appendix-IV A, Table 7.6 is constructed to show the frequency distribution for carbon equivalent (CE) in steel product grade 2910 at EAF.

Table 7.6: Frequency distribution for carbon equivalent at EAF.

CE in EAF for Grade 2910					
	Range (CE) =	0.164			
	Classes (CE) =	10			
	Width (CE) =	0.0164	Used	0.01	
	Class Boundaries	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cumulative Relative Frequency**
1	0.039 ≤ X ≤ 0.049	3	0.03	3	0.03
2	0.049 ≤ X ≤ 0.059	5	0.06	8	0.09
3	0.059 ≤ X ≤ 0.069	30	0.33	38	0.42
4	0.069 ≤ X ≤ 0.079	27	0.30	65	0.72
5	0.079 ≤ X ≤ 0.089	16	0.18	81	0.90
6	0.089 ≤ X ≤ 0.099	4	0.04	85	0.94
7	0.099 ≤ X ≤ 0.109	1	0.01	86	0.96
8	0.109 ≤ X ≤ 0.119	1	0.01	87	0.97
9	0.119 ≤ X ≤ 0.129	1	0.01	88	0.98
10	0.129 ≤ X ≤ 0.203	2	0.02	90	1.00
	Total	**90**	**1.00**		

From both data sets in Table 7.5 and Table 7.6 above, the frequency distributions for carbon (C) and carbon equivalent (CE) at EAF are shown in Fig. 7.8. The cumulative frequency histograms for carbon (C) and carbon equivalent (CE) at EAF are shown in Fig. 7.9.

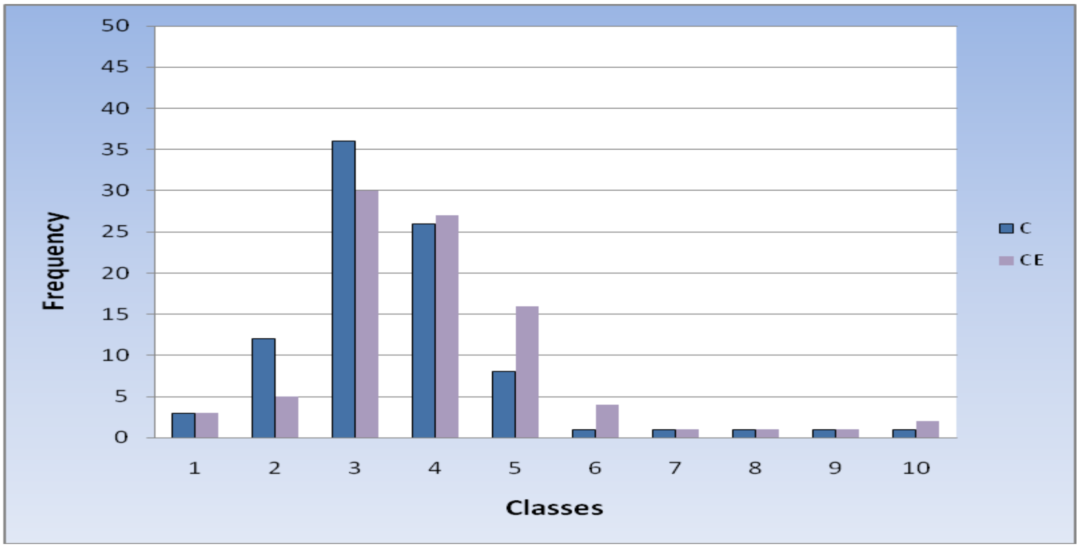


Fig. 7.8: Frequency histogram for “C” and “CE” at EAF (Grade 2910).

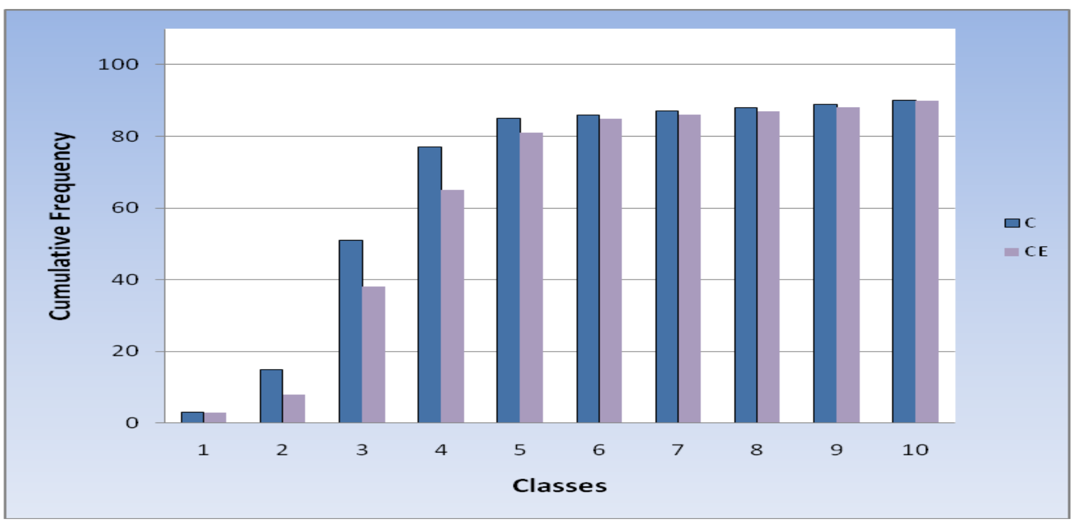


Fig. 7.9: Cumulative Frequency histogram for “C” and “CE” at EAF (Grade 2910).

Fig. 7.10 shows the carbon values for 90 heats of industrial steel grade 2910 analyzed at EAF. It also shows the upper limit (MAX) and lower limit (MIN) as defined by the standard. Further adjustments to the carbon values take place during the next processes which are treatment at ladle furnace (LF) and casting at CCM. This explains having majority of the values below the minimum.

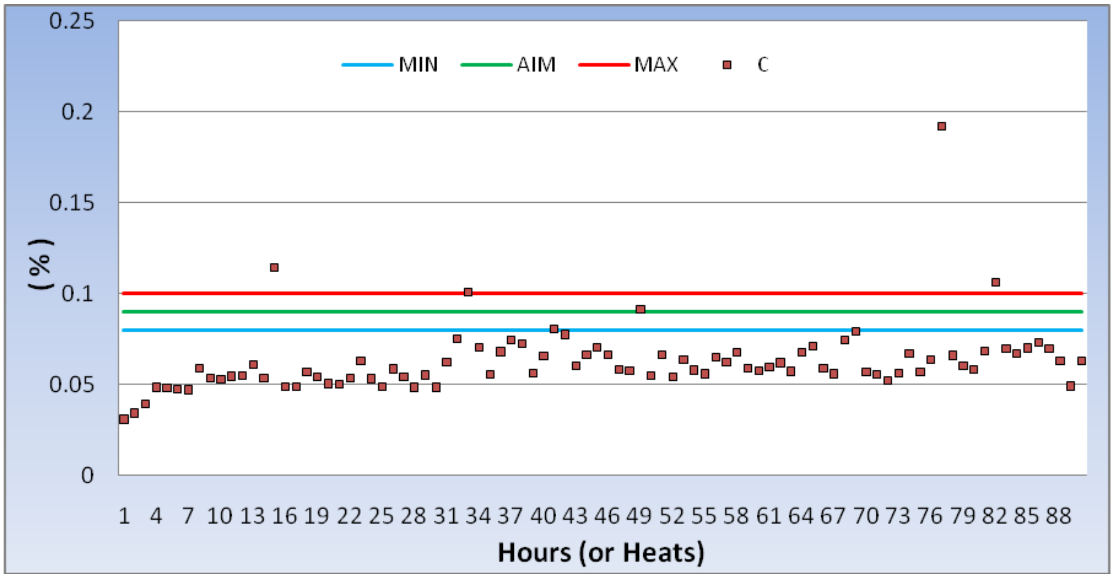


Fig. 7.10: "C" values in EAF with Upper and Lower limits (Grade 2910).

By analyzing the above tables and graphs, it is found that the percentage (%) of the carbon value in industrial steel for grade 2910 at EAF are statically as follows:

- 69% of the carbon values between 0.051% and 0.071%.
- 91% of the carbon values between 0.041% and 0.081%.
- 3% of the carbon value below 0.041%.
- 6% of the carbon value above 0.081%.

The above data analysis shows that the carbon is not within the required range considering the specified limits. This is because the main treatment of this type of grade 2910 usually takes place at the LF with final adjustment for the chemical elements specifically carbon element at CCM.

For the data of the industrial steel product grade 2910 that are treated at ladle furnace (LF) are recorded in Appendix-IV B; the range, number of the classes, and the class width are calculated. Using the above data, Table 7.7 is constructed to show the frequency distribution for carbon in steel product grade 2910 at LF.

Table 7.7: Frequency distribution for carbon in steel product at LF.

C in LF for Grade 2910					
	Range (C) =	0.021			
	Classes (C) =	10			
	Width (C) =	0.002			
	Class Boundaries	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cumulative Relative Frequency**
1	0.074 ≤ X ≤ 0.076	6	0.07	6	0.07
2	0.076 ≤ X ≤ 0.078	5	0.06	11	0.12
3	0.078 ≤ X ≤ 0.080	10	0.11	21	0.23
4	0.080 ≤ X ≤ 0.082	20	0.22	41	0.46
5	0.082 ≤ X ≤ 0.084	19	0.21	60	0.67
6	0.084 ≤ X ≤ 0.086	14	0.16	74	0.82
7	0.086 ≤ X ≤ 0.088	6	0.07	80	0.89
8	0.088 ≤ X ≤ 0.091	4	0.04	84	0.93
9	0.091 ≤ X ≤ 0.093	3	0.03	87	0.97
10	0.093 ≤ X ≤ 0.095	3	0.03	90	1.00
	Total	**90**	**1.00**		

Using the same method and data recorded in Appendix-IV B, Table 7.8 is constructed to show the frequency distribution for carbon equivalent (CE) in steel product grade 2910 at LF.

Table 7.8: Frequency distribution for carbon equivalent at LF.

CE in LF for Grade 2910					
	Range (CE) =	0.04			
	Classes (CE) =	10			
	Width (CE) =	0.004			
	Class Boundaries	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cumulative Relative Frequency**
1	0.327 ≤ X ≤ 0.331	5	0.06	5	0.06
2	0.331 ≤ X ≤ 0.335	4	0.04	9	0.10
3	0.335 ≤ X ≤ 0.339	18	0.20	27	0.30
4	0.339 ≤ X ≤ 0.343	29	0.32	56	0.62
5	0.343 ≤ X ≤ 0.347	15	0.17	71	0.79
6	0.347 ≤ X ≤ 0.351	8	0.09	79	0.88
7	0.351 ≤ X ≤ 0.355	8	0.09	87	0.97
8	0.355 ≤ X ≤ 0.359	2	0.02	89	0.99
9	0.359 ≤ X ≤ 0.363	1	0.01	90	1.00
10	0.363 ≤ X ≤ 0.367	0	0.00	90	1.00
	Total	**90**	**1.00**		

From both data sets in Table 7.7 and Table 7.8 above, the frequency distributions for carbon (C) and carbon equivalent (CE) at ladle furnace (LF) are shown in Fig. 7.11. The cumulative frequency histograms for carbon (C) and carbon equivalent (CE) at LF are shown in Fig. 7.12.

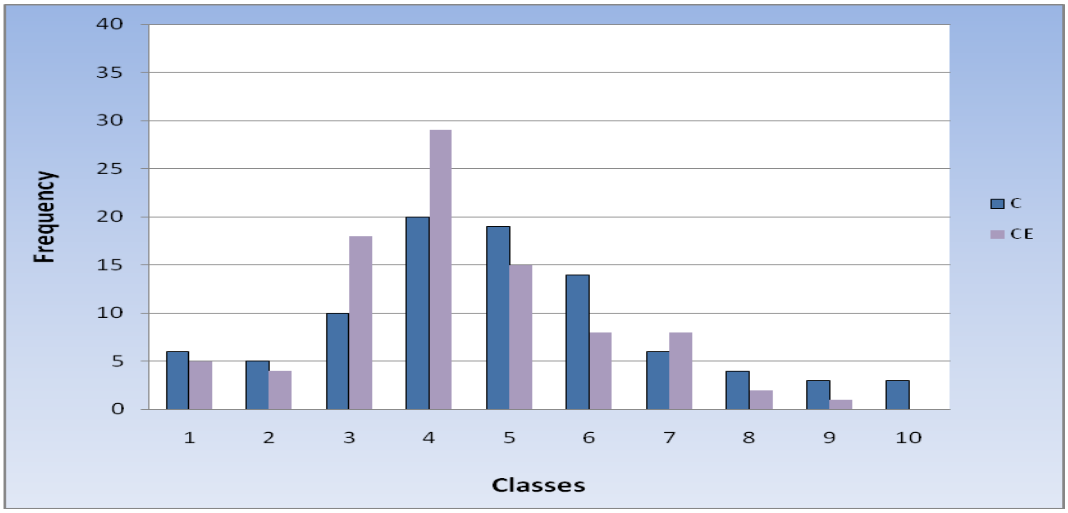


Fig. 7.11: Frequency histogram for “C” and “CE” at LF (Grade 2910).

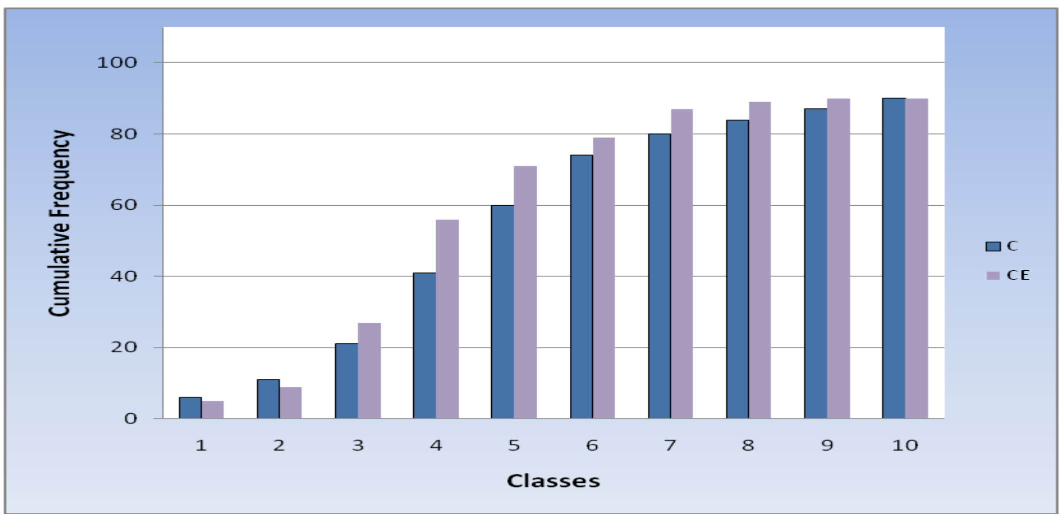


Fig. 7.12: Cumulative Frequency histogram for “C” and “CE” at LF (Grade 2910).

Fig. 7.13 shows the carbon values for 90 heats of industrial steel grade 2910 analyzed at LF. It also shows the upper limit (MAX) and lower limit (MIN) as defined by the standard. 77% of the analyzed values for the carbon at LF are within the desired limits. Final adjustment to the carbon values takes place during the casting process at CCM. This explains having some values out of range.

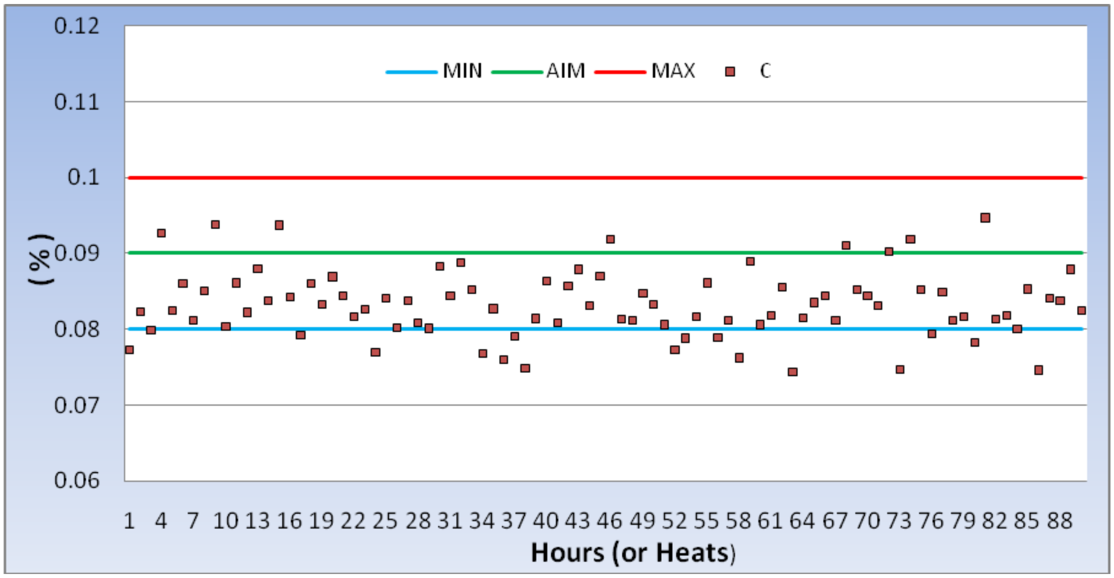


Fig. 7.13: "C" values in LF with Upper and Lower limits (Grade 2910).

By analyzing the above tables and graphs, it is found that the percentage (%) of the carbon value in industrial steel for grade 2910 treated at LF are statically as follows:

- 70% of the carbon values between 0.078% and 0.086%.
- 12% of the carbon values below 0.078%.
- 18% of the carbon values above 0.086%.
- 77% of the carbon values are within the range.

For the data of the industrial steel product grade 2910 that are casted at CCM and are recorded in Appendix-IV C; the range, number of the classes, and the class width are calculated. Using the above data, Table 7.9 is constructed to show the frequency distribution for carbon in steel product grade 2910 at CCM.

Table 7.9: Frequency distribution for carbon in steel product at CCM.

C in CCM for Grade 2910					
	Range (C) =	0.019			
	Classes (C) =	10			
	Width (C) =	0.002			
	Class Boundaries	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cumulative Relative Frequency**
1	0.081 ≤ X ≤ 0.083	4	0.04	4	0.04
2	0.083 ≤ X ≤ 0.085	3	0.03	7	0.08
3	0.085 ≤ X ≤ 0.087	6	0.07	13	0.14
4	0.087 ≤ X ≤ 0.089	12	0.13	25	0.28
5	0.089 ≤ X ≤ 0.091	15	0.17	40	0.44
6	0.091 ≤ X ≤ 0.093	18	0.20	58	0.64
7	0.093 ≤ X ≤ 0.095	12	0.13	70	0.78
8	0.095 ≤ X ≤ 0.097	7	0.08	77	0.86
9	0.097 ≤ X ≤ 0.099	7	0.08	84	0.93
10	0.099 ≤ X ≤ 0.100	6	0.07	90	1.00
	Total	**90**	**1.00**		

Using the same method and data recorded in Appendix-IV C, Table 7.10 is constructed to show the frequency distribution for carbon equivalent (CE) in steel product grade 2910 at CCM.

Table 7.10: Frequency distribution for carbon equivalent at CCM.

CE in CCM for Grade 2910					
	Range (CE) =	0.028			
	Classes (CE) =	10			
	Width (CE) =	0.003			
	Class Boundaries	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cumulative Relative Frequency**
1	0.340 ≤ X ≤ 0.343	5	0.06	5	0.06
2	0.343 ≤ X ≤ 0.346	4	0.04	9	0.10
3	0.346 ≤ X ≤ 0.349	5	0.06	14	0.16
4	0.349 ≤ X ≤ 0.352	17	0.19	31	0.34
5	0.352 ≤ X ≤ 0.355	26	0.29	57	0.63
6	0.355 ≤ X ≤ 0.358	18	0.20	75	0.83
7	0.358 ≤ X ≤ 0.361	9	0.10	84	0.93
8	0.361 ≤ X ≤ 0.364	3	0.03	87	0.97
9	0.364 ≤ X ≤ 0.367	2	0.02	89	0.99
10	0.367 ≤ X ≤ 0.368	1	0.01	90	1.00
	Total	**90**	**1.00**		

From both data sets in Table 7.9 and Table 7.10 above, the frequency distributions for carbon (C) and carbon equivalent (CE) at CCM are shown in Fig. 7.14. The cumulative frequency histograms for carbon (C) and carbon equivalent (CE) at LF are shown in Fig. 7.15.

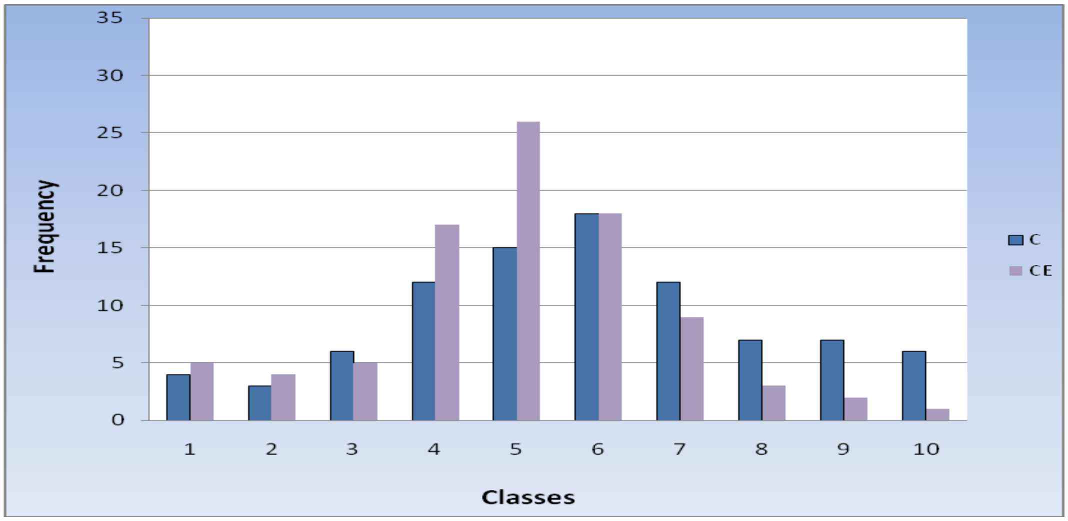


Fig. 7.14: Frequency histogram for "C" and "CE" at CCM (Grade 2910).

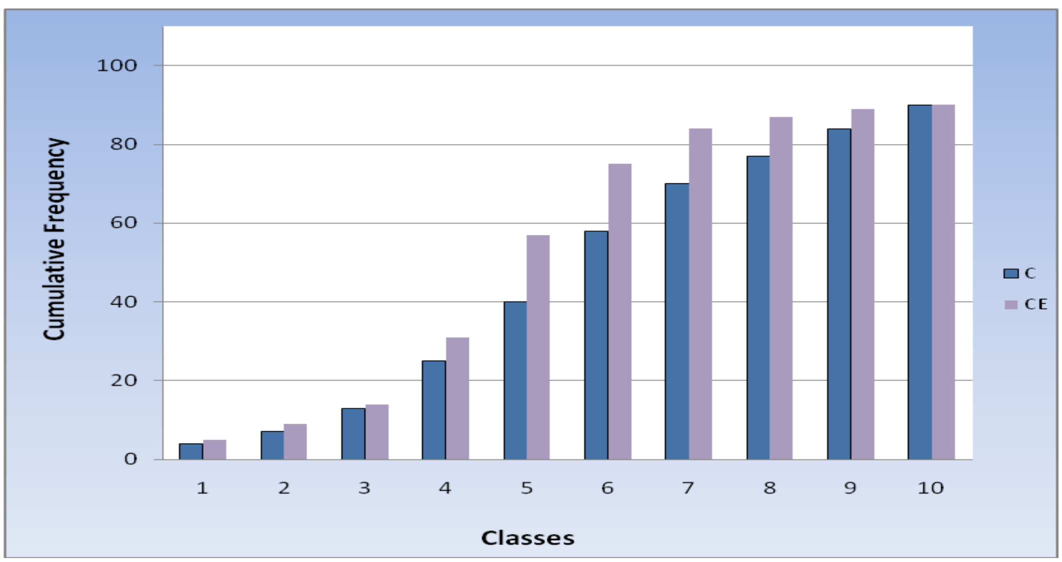


Fig. 7.15: Cumulative Frequency histogram for "C" and "CE" at CCM (Grade 2910).

Fig. 7.16 shows the carbon values for 90 heats of industrial steel grade 2910 analyzed at CCM. It also shows the upper limit (MAX) and lower limit (MIN) as defined by the standard. As final process, 100% of the analyzed values for the carbon at CCM are within the desired limits.

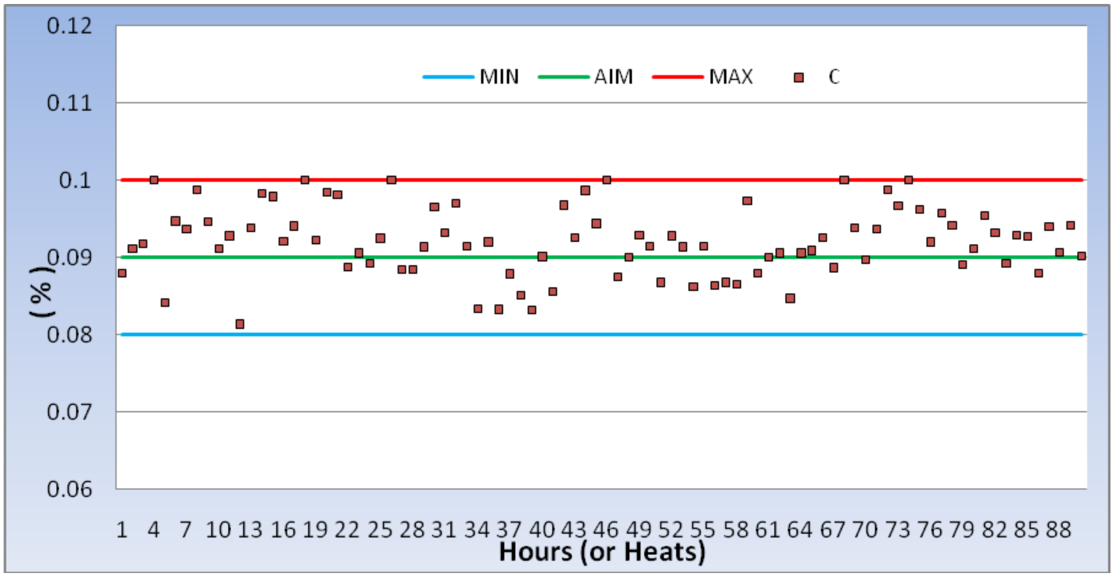


Fig. 7.16: "C" values in CCM with Upper and Lower limits (Grade 2910).

As the casting process at CCM is the final treatment, the above analysis for the carbon values at CCM shows that the percentage (%) of the carbon in industrial steel for grade 2910 are as follows:

- 100% of the carbon values are within the required range.
- 63% of the carbon values between 0.087% and 0.095%, around the AIM value.

Generally, it is concluded from the above analysis in sections 7.1.1 and 7.1.2 that the there is good uniformity and conformity of the process with respect to the established specification limits. It is good step for trusting the available data for analysis and results.

7.1.3 Relationship Between Carbon and Carbon Equivalent

The carbon is main element existing in the carbon equivalent. Fig 7.17 shows the similarity of the behavior of both carbon and carbon equivalent.

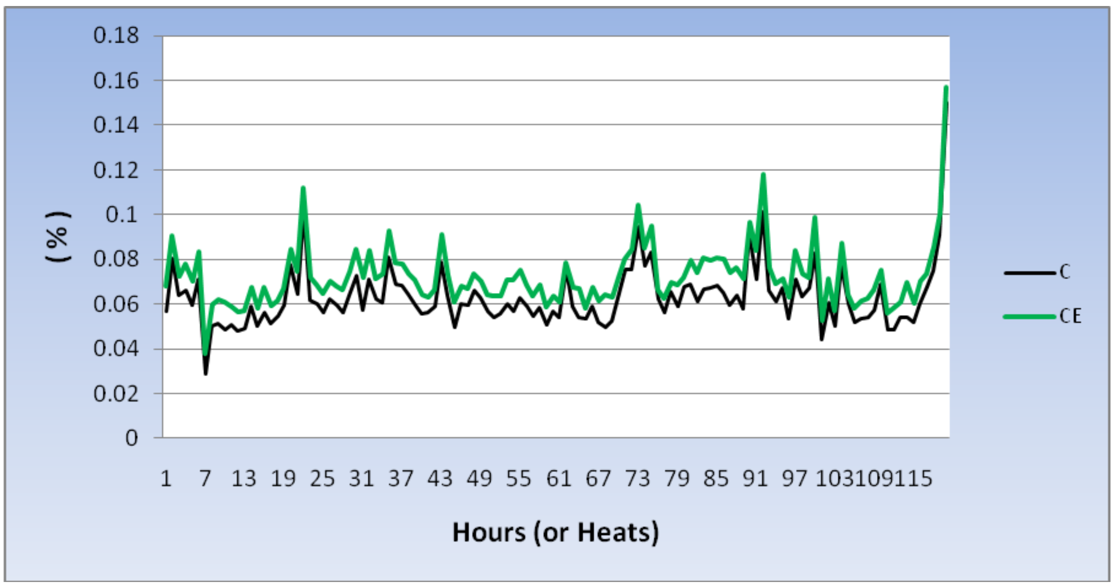


Fig. 7.17: Sample of "C" and "CE" behavior.

The correlation coefficients (**r**) between carbon and carbon equivalent are calculated at EAF, LF and CCM for both grades 200 and 2910 and proved strong correlation. It is calculated for grade 200 and found to be 0.981 and 0.83 at EAF and CCM respectively. It is also calculated for grade 2910 and found to be 0.983, 0.999, and 0.726 at EAF, LF and CCM respectively.

Fig. 7.18a, Fig. 7.18b, and Fig. 7.18c show the correlation by plotting the linear regression for carbon and carbon equivalent at EAF, LF, and CCM.

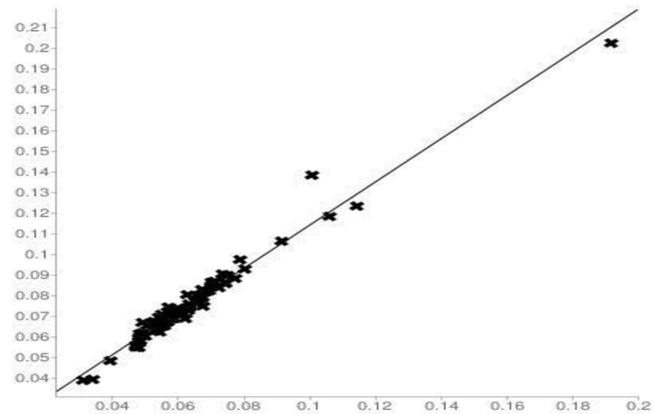


Fig. 7.18a: Correlation between "C" and "CE" at EAF.

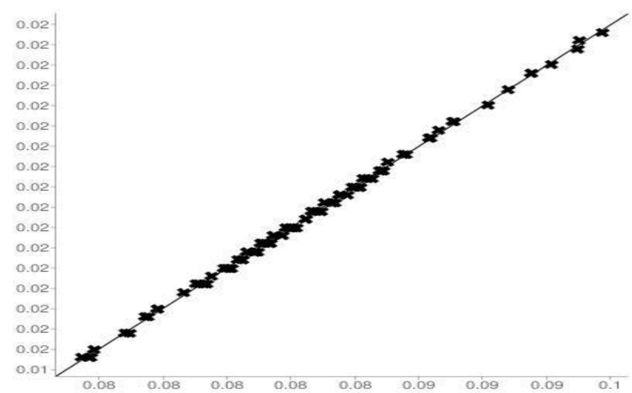


Fig. 7.18b: Correlation between "C" and "CE" at LF.

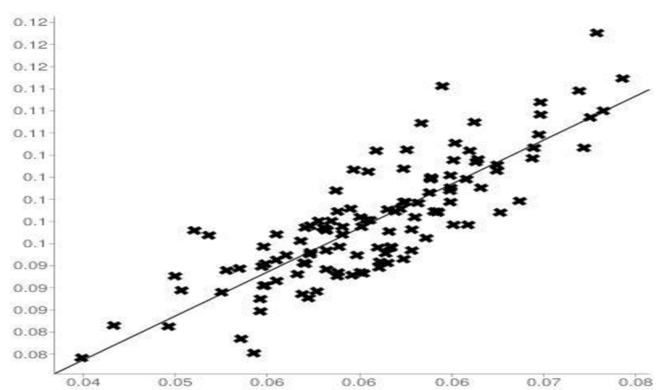


Fig. 7.18c: Correlation between "C" and "CE" at CCM.

It is observed from the above correlation coefficients and plots that the relationship between carbon and carbon equivalent is strong. Accordingly, all analysis will be made considering the carbon element and the same will be relatively applied to the carbon equivalent.

7.2 RELATIONSHIP OR CORRELATION BETWEEN POWER QUALITY PARAMETERS AND STEEL PRODUCT QUALITY

The objective of this work is to find a relationship between the power quality indices and the product quality in order to predict one of them by measuring the other.

In this regard, the following analysis will investigate the possible correlation or relationship between the power quality parameters measured or any of them as applicable and the steel product quality parameters (chemical analysis) or any of them.

Correlation is a statistical technique that can show whether and how strongly pairs of variables are related. Although this correlation is fairly obvious, the data may contain unsuspected correlations. An intelligent correlation analysis can lead to a greater understanding of the data.

The correlation coefficient is a measure of the strength of the liner relationship between two variables. If two variables are donated by X and Y, then the correlation coefficient (**r**) is found from the following equation [39]:

$$r = \frac{\Sigma XY - \frac{\Sigma X \Sigma Y}{N}}{\sqrt{\left(\Sigma X^2 - \frac{(\Sigma X)^2}{N}\right)\left(\Sigma Y^2 - \frac{(\Sigma Y)^2}{N}\right)}} \quad \textbf{(7.1)}$$

A correlation coefficient is a number between -1 and 1 which measures the degree to which two variables are linearly related. If there is perfect linear relationship with positive slope between the two variables, then there is a correlation coefficient of 1; if there is positive correlation, whenever one variable has a high (low) value, so does the other. If there is a perfect linear relationship with negative slope between the two variables, then there is a correlation coefficient of -1; if there is negative correlation, whenever one variable has a high (low) value, the other has a low (high) value. A correlation coefficient of 0 means that there is no linear relationship between the variables. A correlation coefficient near zero thus indicates the relationship between the variables is weak.

Correlation coefficient in range of ±0.8 indicates dependable linear relationship where it can be used to predict one variable by knowing the other one [52].

This work studies two types of steel product and the analysis is made in two separate studies: one for steel product grade 200 and the other for steel product grade 2910. They may or may not have different correlation with power quality parameters. Elaboration for both cases are made hereunder.

7.2.1 Study the Relationship/Correlation between PQ parameters and chemical elements for Grade 200

Many ways and techniques used to come up with relationship or correlation between any two variables of the power quality parameters and the industrial steel product (chemical analysis). Work started by using Run Charts [52] which is a plot of the power characteristics and chemical elements for the steel product as a function of time point-by-point in the order in which it is obtained.

Run Charts were made for twenty (20) cases in this grade 200. In each chart plot all the eight (8) chemical elements with one of the power quality parameters as a function of time (number of heats). Fig. 7.19 shows variations of the 6th harmonic, as PQ parameter, with the most significant two elements carbon and carbon equivalent in EAF for grade 200.

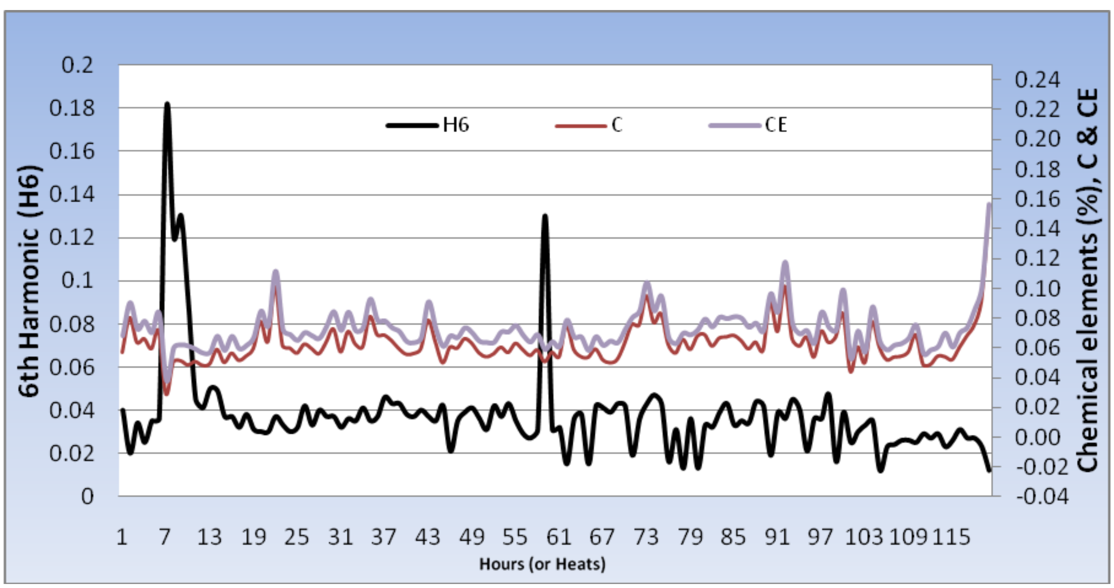


Fig. 7.19: Run chart for chemical elements with 6th Harmonic in EAF (Grade 200).

Fig. 7.19 provides some idea of the general trend and degree of variability present of the carbon during the melting process in the EAF and the carbon equivalent.

The correlation coefficient (**r**) is calculated to find out the strength of the correlation between both power quality parameters and the chemical elements of the steel product. Table 7.11a and Table 7.11b show the correlation coefficient (**r**) calculated value between all PQ parameters and the eight chemical elements at two different locations of the process EAF and CCM for grade 200.

Table 7.11a: Correlation coefficient (r) for PQ parameters and chemical elements for steel grade 200 at EAF.

PQ parameters	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E.
Vrms	0.2	0.1	-0.2	0.0	-0.1	0.0	-0.3	-0.1	0.2
Irms	-0.1	0.0	-0.3	0.1	0.0	0.1	-0.2	-0.1	-0.1
THD V	-0.3	0.0	0.0	0.0	0.1	0.1	0.1	0.0	-0.2
H2	-0.1	0.3	0.0	0.4	0.3	0.3	0.0	-0.1	-0.1
H3	-0.2	0.2	0.1	0.3	0.3	0.3	0.1	0.0	-0.2
H4	-0.2	0.3	0.0	0.4	0.3	0.3	0.1	0.0	-0.1
H5	-0.3	-0.1	0.2	0.0	0.1	0.1	0.4	0.1	-0.2
H6	-0.3	0.0	0.1	0.1	0.2	0.2	0.3	0.0	-0.3
H7	-0.1	0.2	0.2	-0.1	0.0	0.0	0.2	0.1	-0.1
H8	-0.3	0.1	0.1	0.2	0.3	0.3	0.3	0.0	-0.3
H9	-0.2	0.1	0.1	0.1	0.2	0.3	0.2	0.0	-0.1
H10	-0.3	0.1	0.1	0.3	0.3	0.3	0.2	0.0	-0.2
H11	0.1	0.0	-0.2	-0.1	0.0	0.0	0.0	0.3	0.1
>H11	0.3	0.2	-0.1	-0.2	-0.2	-0.1	0.0	0.2	0.2
THD I	0.0	0.0	0.2	-0.2	-0.1	-0.2	-0.1	-0.1	0.0
P	0.2	0.1	-0.2	0.0	-0.1	-0.1	-0.2	0.0	0.2
Q	0.1	0.2	-0.1	0.1	-0.1	0.1	-0.3	-0.3	0.1
P. F.	0.1	-0.1	0.0	-0.2	0.0	-0.2	0.1	0.3	0.1
Pst	-0.3	0.1	0.1	0.2	0.2	0.3	0.2	0.0	-0.3
Plt	-0.3	-0.1	0.1	-0.1	0.0	0.1	0.1	-0.1	-0.3

Table 7.11b: Correlation coefficient (r) for PQ parameters and chemical elements for steel grade 200 at CCM.

PQ parameters	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E
Vrms	0.0	-0.1	-0.2	0.1	-0.1	0.0	-0.3	-0.6	-0.2
Irms	0.0	0.1	-0.1	0.2	0.0	0.2	-0.1	-0.3	0.0
THD V	0.0	0.1	0.3	0.0	0.0	0.1	0.2	0.2	0.1
H2	0.1	0.0	0.0	0.4	0.3	0.3	0.0	-0.2	0.2
H3	0.1	0.1	0.1	0.3	0.3	0.3	0.2	0.1	0.2
H4	0.1	0.0	0.1	0.4	0.3	0.3	0.0	-0.1	0.2
H5	0.0	0.1	0.2	-0.1	0.1	0.1	0.4	0.6	0.2
H6	0.0	0.1	0.3	0.1	0.1	0.2	0.3	0.4	0.2
H7	0.0	-0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0
H8	0.0	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.2
H9	0.0	0.0	0.1	0.1	0.1	0.3	0.2	0.2	0.1
H10	0.0	0.1	0.2	0.2	0.2	0.3	0.2	0.2	0.2
H11	-0.1	0.2	0.2	-0.1	0.0	0.0	0.0	0.0	0.0
>H11	0.0	0.0	-0.1	-0.1	0.0	-0.1	-0.1	-0.3	-0.1
THD I	0.1	-0.2	0.0	-0.2	-0.1	-0.2	-0.2	-0.2	-0.1
P	0.0	0.0	-0.1	0.0	0.0	0.0	-0.2	-0.4	-0.1
Q	0.1	-0.2	-0.2	0.2	0.0	0.1	-0.3	-0.6	-0.1
P. F.	-0.1	0.2	0.1	-0.2	0.0	-0.2	0.1	0.2	0.0
Pst	0.0	0.2	0.3	0.2	0.2	0.3	0.2	0.3	0.3
Plt	-0.1	0.1	0.2	-0.1	0.0	0.1	0.2	0.3	0.0

By analyzing the above correlation coefficients (r), it is found that the correlation is weak. However, the most important element in industrial steel product is the carbon element and the calculated carbon equivalent.

From the above two tables, correlation coefficients for carbon and power quality parameters at EAF and CCM are plotted together to show the strength of the correlations as shown in Fig. 7.20.

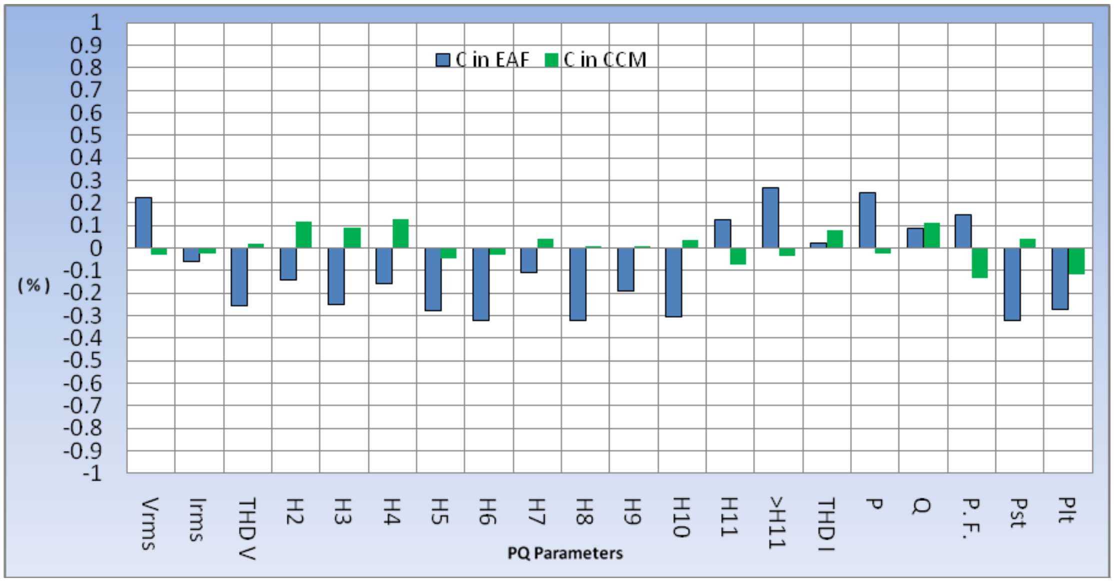


Fig. 7.20: Correlation coefficients (r) for Carbon and PQ parameters in EAF and CCM.

From the above tables and charts, there is no correlation coefficient (**r**) higher than 0.3. The highest (**r**) numbers between carbon and any of the power quality parameters will be taken for studying and analyzing purpose. Accordingly, correlation coefficient between carbon and 6th harmonic, 8th harmonic, 10th harmonic and the P_{st} at EAF are found to be the highest and they are selected.

In order to find a linear relationship, scatter charts plotted for the carbon element against the 6th harmonic, the 8th harmonic, 10th harmonic, and short term flicker (P_{st}).

Scatter plot with linear regression for carbon and 6th harmonic of grade 200 at EAF is plotted as shown in Fig. 7.21. It represents the relationship between the carbon and the 6th harmonic. It is observed that there is no relationship or correlation between them.

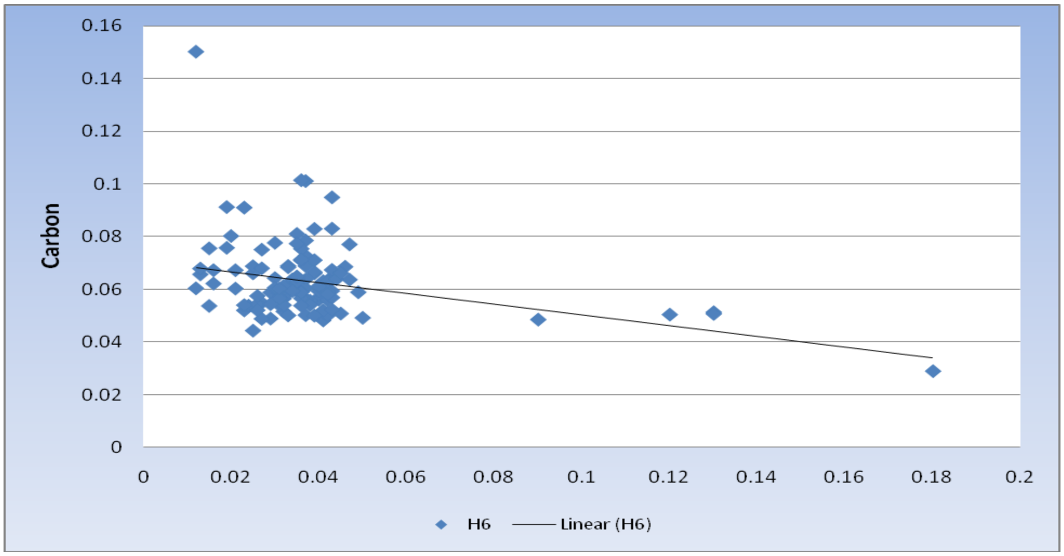


Fig. 7.21: Scatter plot for carbon and 6th harmonic at EAF (Grade 200).

Scatter plot with linear regression for carbon and 8th harmonic of grade 200 at EAF is plotted as shown in Fig. 7.22. It represents the relationship between the carbon and the 8th harmonic. It is observed that there is no relationship or correlation between them.

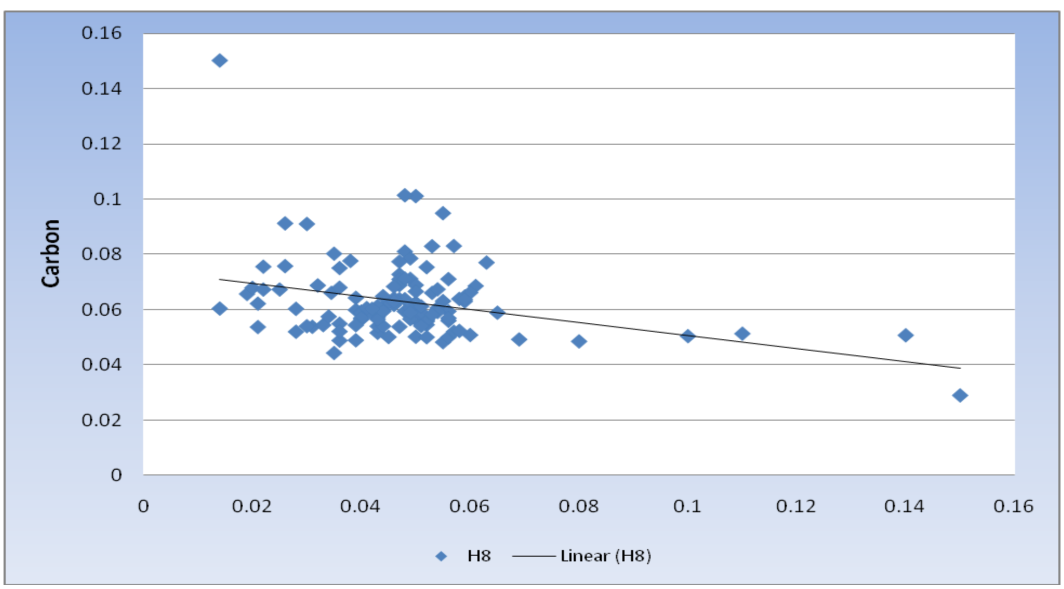


Fig. 7.22: Scatter plot for carbon and 8th harmonic at EAF (Grade 200).

Scatter plot with linear regression for carbon and 10th harmonic of grade 200 at EAF is plotted as shown in Fig. 7.23. It represents the relationship between the carbon and the 10th harmonic. It is observed that there is no relationship or correlation between them.

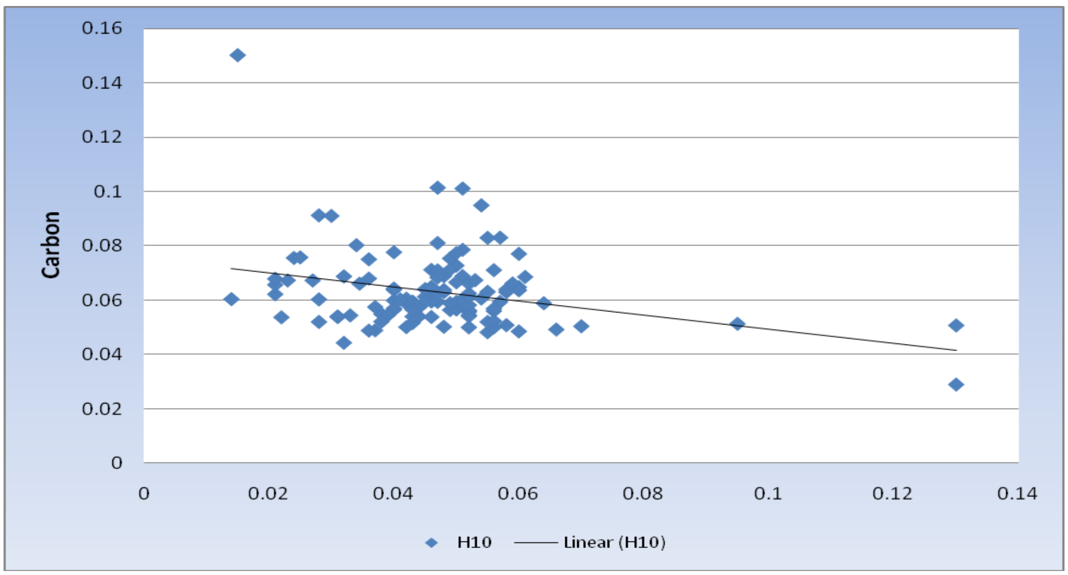


Fig. 7.23: Scatter plot for carbon and 10th harmonic at EAF (Grade 200).

Scatter plot with linear regression for carbon and short term flicker (P_{st}) harmonic of grade 200 at EAF is plotted as shown in Fig. 7.24. It represents the relationship between the carbon and the P_{st} harmonic. It is observed that there is no relationship or correlation between them.

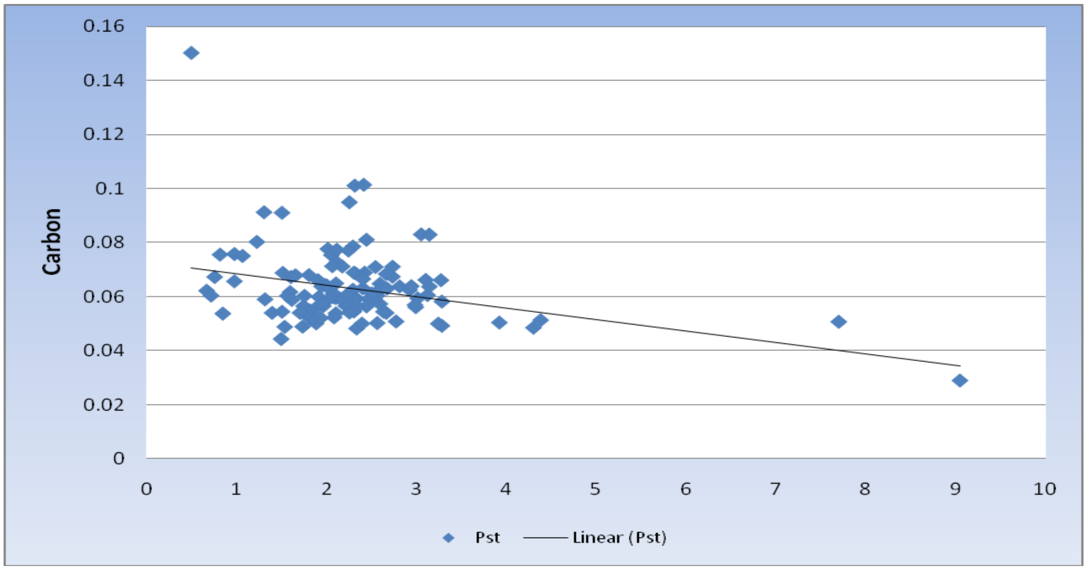


Fig. 7.24: Scatter plot for carbon and P_{st} at EAF (Grade 200).

It is evident from tables and graphs that there is no correlation or relationship between the power quality parameters and the industrial steel product elements (chemical elements).

7.2.2 Study the Relationship/Correlation between PQ parameters and chemical elements for Grade 2910

The same analysis sequence made for the industrial steel product grade 200 on section 7.2.1 is also followed for analyzing this grade 2910. Grade 2910 goes through one more step of the production process which is the LF treatment stage in addition to the melting at EAF and casting at CCM.

Run Charts were made for twenty (20) cases to analyze grade 2910. In each chart plot all the eight (8) chemical elements with one of the power quality parameters as a function of time (number of heats). Fig. 7.25 shows varieties of the 3rd harmonic, as PQ parameter, with the most significant two elements carbon and carbon equivalent in EAF for grade 2910.

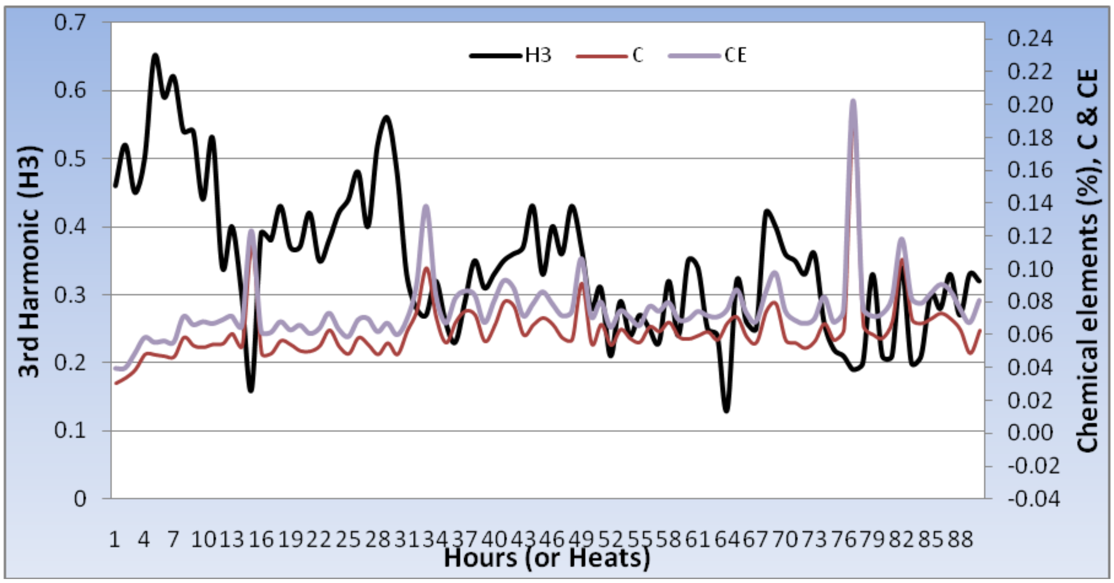


Fig. 7.25: Run chart for chemical elements with 3rd Harmonic in EAF (Grade 2910).

Fig. 7.25 provides some idea of the general trend and degree of variability present of the carbon during the melting process in the EAF and the carbon equivalent.

The correlation coefficient (**r**) is calculated to find out the strength of the correlation between both power quality parameters and the chemical elements of the steel product. Table 7.12a, Table 7.12b, and Table 7.12c show the correlation coefficient (**r**) calculated value between all PQ parameters and the eight chemical elements at three different locations of the process EAF, LF, and CCM for grade 2910.

Table 7.12a: Correlation coefficient (r) for PQ parameters and chemical elements for steel grade 2910 at EAF.

PQ Parameters	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E
Vrms	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3
Irms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
THD V	-0.1	0.0	-0.1	0.0	0.0	0.0	-0.1	-0.1	-0.1
H2	-0.2	-0.1	0.0	0.1	0.1	0.0	0.0	-0.1	-0.2
H3	-0.4	-0.2	0.0	0.1	0.0	-0.2	-0.1	-0.3	-0.4
H4	-0.3	-0.1	0.0	0.1	0.1	-0.1	0.0	-0.2	-0.3
H5	-0.2	-0.1	-0.1	0.0	-0.1	-0.3	-0.2	-0.2	-0.3
H6	-0.3	-0.1	-0.1	0.0	0.0	-0.2	-0.1	-0.2	-0.3
H7	0.0	0.1	0.0	0.2	0.1	0.0	0.1	0.0	0.0
H8	-0.2	-0.1	0.0	0.0	-0.1	-0.2	-0.1	-0.2	-0.2
H9	0.2	0.2	-0.1	0.2	0.1	0.3	0.2	0.2	0.3
H10	0.0	-0.1	-0.1	0.3	0.0	-0.1	-0.1	0.0	0.0
H11	0.3	0.2	0.0	0.2	0.1	0.4	0.3	0.3	0.4
>H11	0.4	0.3	0.0	0.1	0.1	0.4	0.3	0.3	0.4
THD I	0.0	0.0	0.0	0.1	0.0	0.1	0.0	-0.1	0.0
P	0.2	0.1	0.1	0.0	0.1	0.2	0.2	0.2	0.3
Q	0.1	0.1	0.1	0.1	0.1	0.3	0.2	0.1	0.2
P. F.	0.1	0.0	0.0	-0.1	0.0	-0.2	0.0	0.0	0.0
E	0.0	-0.2	-0.2	-0.3	-0.2	-0.3	-0.3	-0.2	-0.1
Pst	-0.3	0.0	-0.1	0.2	0.0	0.0	-0.1	-0.3	-0.2
Plt	-0.2	0.0	0.0	0.0	0.0	-0.2	-0.1	-0.2	-0.1

Table 7.12b: Correlation coefficient (r) for PQ parameters and chemical elements for steel grade 2910 at LF.

PQ Parameters	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E
Vrms	0.1	-0.3	-0.2	0.1	0.1	0.3	0.2	0.1	-0.1
Irms	0.1	-0.2	0.1	0.0	0.0	-0.1	0.0	-0.2	-0.1
THD V	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0
H2	0.1	-0.1	0.2	0.1	0.2	-0.1	0.2	-0.4	-0.1
H3	0.1	0.1	0.4	0.1	0.2	-0.3	0.0	-0.5	0.0
H4	0.1	0.0	0.3	0.1	0.2	-0.2	0.1	-0.5	-0.1
H5	-0.1	0.3	0.3	0.1	0.0	-0.4	-0.2	-0.1	0.1
H6	0.0	0.3	0.3	0.0	0.0	-0.3	-0.1	-0.2	0.1
H7	-0.1	0.0	0.0	0.3	0.1	-0.1	0.1	0.1	-0.1
H8	0.0	0.1	0.2	0.0	0.0	-0.2	-0.1	-0.3	0.0
H9	-0.1	0.1	-0.2	0.2	0.1	0.2	0.2	0.6	0.2
H10	-0.2	0.0	0.0	0.2	0.0	-0.1	0.0	-0.3	-0.3
H11	0.0	-0.1	-0.3	0.2	0.1	0.4	0.3	0.5	0.2
>H11	-0.1	-0.1	-0.3	0.1	0.1	0.3	0.3	0.4	0.1
THD I	0.0	-0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.0
P	0.1	-0.3	-0.2	0.0	0.1	0.3	0.2	0.1	-0.1
Q	0.2	-0.2	-0.1	0.1	0.1	0.3	0.3	-0.1	0.0
P. F.	-0.2	0.0	-0.1	-0.1	0.0	-0.1	-0.2	0.3	0.0
E	0.1	0.1	0.2	-0.3	-0.2	0.0	-0.2	-0.2	0.0
Pst	0.0	0.4	0.2	0.2	0.1	-0.1	0.0	-0.1	0.1
Plt	0.1	0.1	0.1	0.0	0.0	-0.2	-0.1	-0.1	0.0

Table 7.12c: Correlation coefficient (r) for PQ parameters and chemical elements for steel grade 2910 at CCM.

PQ Parameters	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E
Vrms	0.0	-0.1	-0.2	0.1	0.1	0.3	0.2	0.1	0.0
Irms	0.1	-0.1	0.1	0.0	0.0	-0.1	0.0	0.1	0.0
THD V	-0.1	-0.2	-0.1	0.0	0.0	0.0	0.0	-0.1	-0.2
H2	0.2	-0.2	0.0	0.1	0.2	-0.1	0.2	0.1	0.1
H3	0.1	-0.2	0.2	0.1	0.2	-0.3	0.1	0.0	0.1
H4	0.2	-0.2	0.1	0.1	0.2	-0.2	0.1	0.1	0.1
H5	-0.1	0.1	0.2	0.1	-0.1	-0.3	-0.1	-0.2	0.0
H6	0.1	0.1	0.2	0.0	0.1	-0.3	0.0	-0.1	0.2
H7	0.0	0.0	-0.1	0.3	0.0	-0.1	0.1	-0.1	-0.1
H8	0.0	0.0	0.2	0.0	0.0	-0.2	0.0	0.1	0.0
H9	-0.2	0.2	-0.2	0.2	0.1	0.2	0.1	0.0	0.0
H10	-0.2	0.0	0.1	0.3	0.0	-0.1	0.0	0.1	-0.2
H11	-0.2	0.1	-0.3	0.2	0.1	0.3	0.2	0.1	-0.1
>H11	-0.2	0.0	-0.3	0.1	0.1	0.3	0.3	0.0	-0.2
THD I	0.1	-0.1	0.0	0.1	0.0	0.0	0.1	-0.1	0.0
P	0.0	0.0	-0.2	0.0	0.1	0.2	0.1	0.2	0.0
Q	0.1	-0.2	-0.2	0.1	0.1	0.3	0.3	0.0	0.0
P. F.	0.0	0.2	0.1	-0.1	0.0	-0.1	-0.2	0.1	0.0
E	-0.1	0.1	0.3	-0.3	-0.3	0.0	-0.2	-0.2	0.0
Pst	0.0	-0.1	0.0	0.2	0.1	-0.1	0.1	-0.2	-0.1
Plt	0.0	0.1	0.0	0.0	0.0	-0.2	-0.1	0.0	0.0

By analyzing the above correlation coefficients, it is found that the correlation is weak. Carbon and carbon equivalent are selected for further analysis with the power quality parameters. Carbon results can be applied to the carbon equivalent since the correlation coefficient between them is strong.

From the above three tables, correlation coefficients for carbon and power quality parameters at EAF, LF and CCM plotted together to show the strength of the correlations as shown in Fig. 7.26.

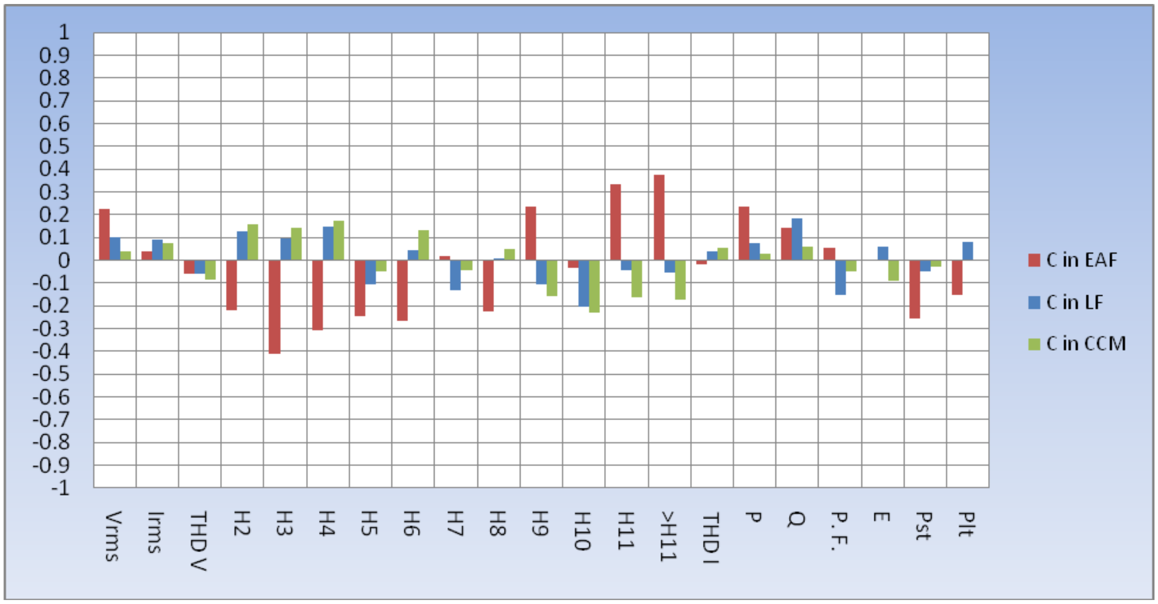


Fig. 7.26: Correlation coefficients (r) for Carbon and PQ parameters in EAF, LF and CCM.

From the above tables and charts, there is no correlation coefficient (**r**) higher than 0.4. The highest (**r**) numbers between carbon and any of the power quality parameters will be taken for studying and analyzing purpose. Accordingly, correlation coefficient between carbon and 3rd harmonic, 4th harmonic, 11th harmonic and the odd harmonics greater than 11th harmonic (>H11) at EAF are found to be the highest and they were selected.

In order to find a linear relationship, scatter charts plotted for the carbon element against the 3rd harmonic, 4th harmonic, 11th harmonic and the odd harmonics greater than 11th harmonic (>H11).

Scatter plot with linear regression for carbon and 3rd harmonic of grade 2910 at EAF is plotted as shown in Fig. 7.27. It represents the relationship between the carbon and the 3rd harmonic. It is observed that there is weak correlation between carbon element and 3rd harmonic. This correlation is negative with correlation coefficient (r) of 0.413. This cannot be considered strong or perfect linear relationship.

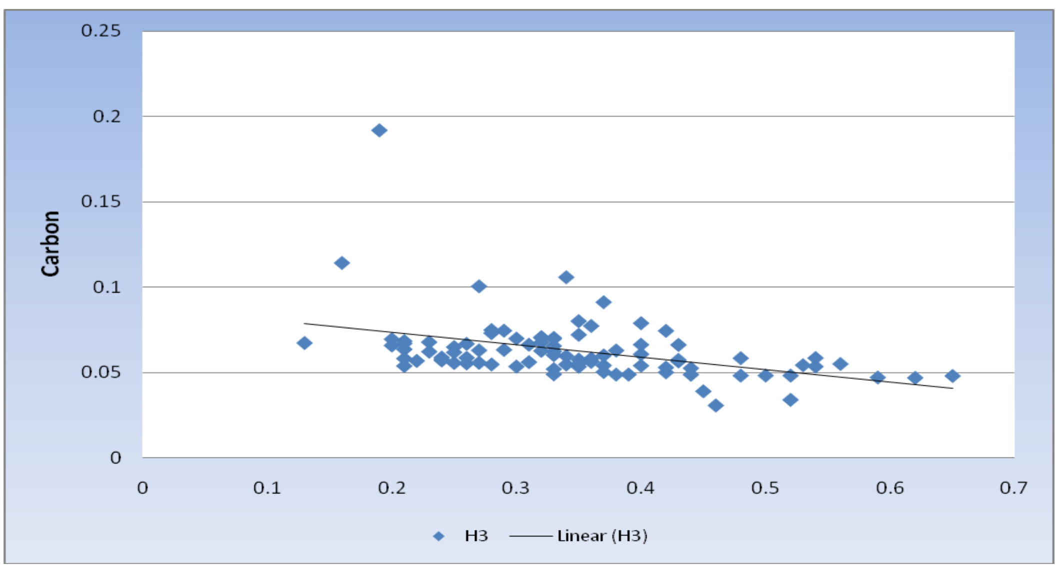


Fig. 7.27: Scatter plot for carbon and 3rd harmonic at EAF (Grade 2910).

Scatter plot with linear regression for carbon and 4th harmonic of grade 2910 at EAF is plotted as shown in Fig. 7.28. It represents the relationship between the carbon and the 4^{th} harmonic. It is observed that there is weak relationship or correlation between them.

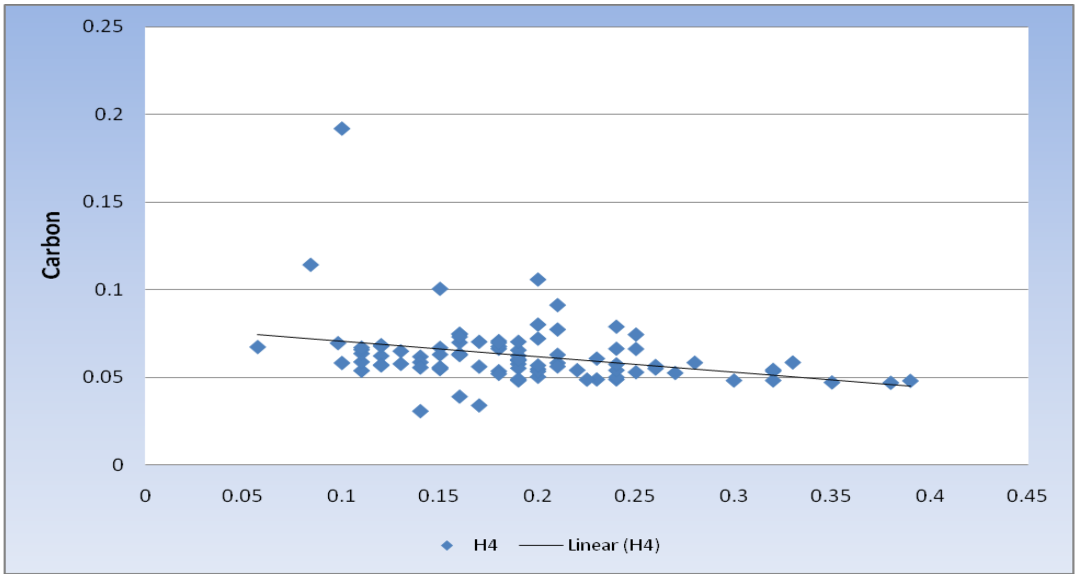


Fig. 7.28: Scatter plot for carbon and 4^{th} harmonic at EAF (Grade 2910).

Scatter plot with linear regression for carbon and 11^{th} harmonic of grade 2910 at EAF is plotted as shown in Fig. 7.29. It represents the relationship between the carbon and the 11^{th} harmonic. It is observed that there is no relationship or correlation between them.

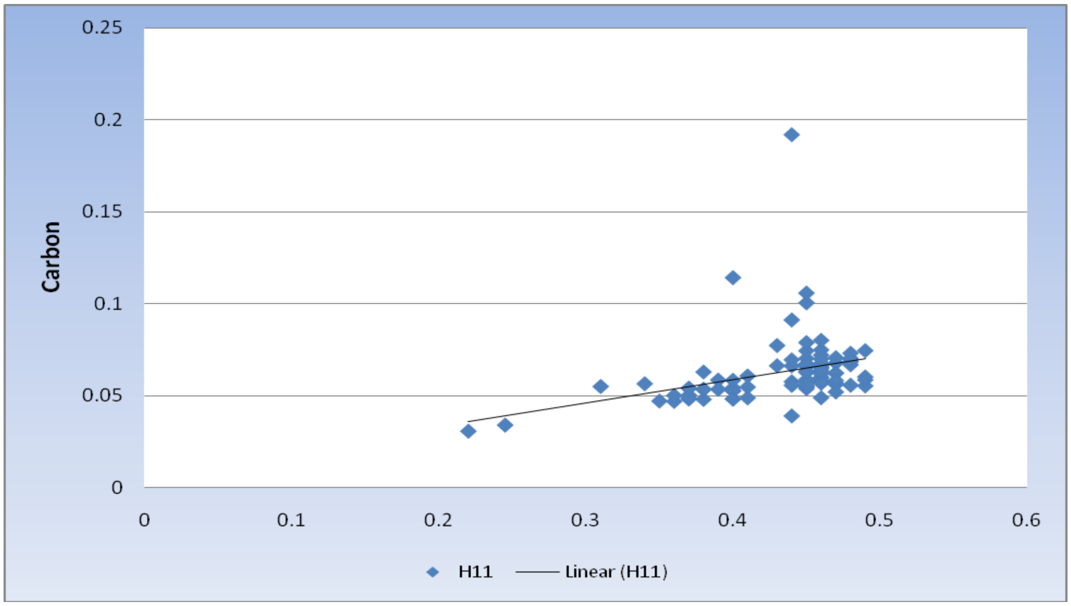


Fig. 7.29: Scatter plot for carbon and 11th harmonic at EAF (Grade 2910).

Scatter plot with linear regression for carbon and the odd harmonics greater than 11th harmonic (>H11) of grade 2910 at EAF is plotted as shown in Fig. 7.30. It represents the relationship between the carbon and the odd harmonics greater than 11th harmonic (>H11). It is observed that there is no relationship or correlation between them.

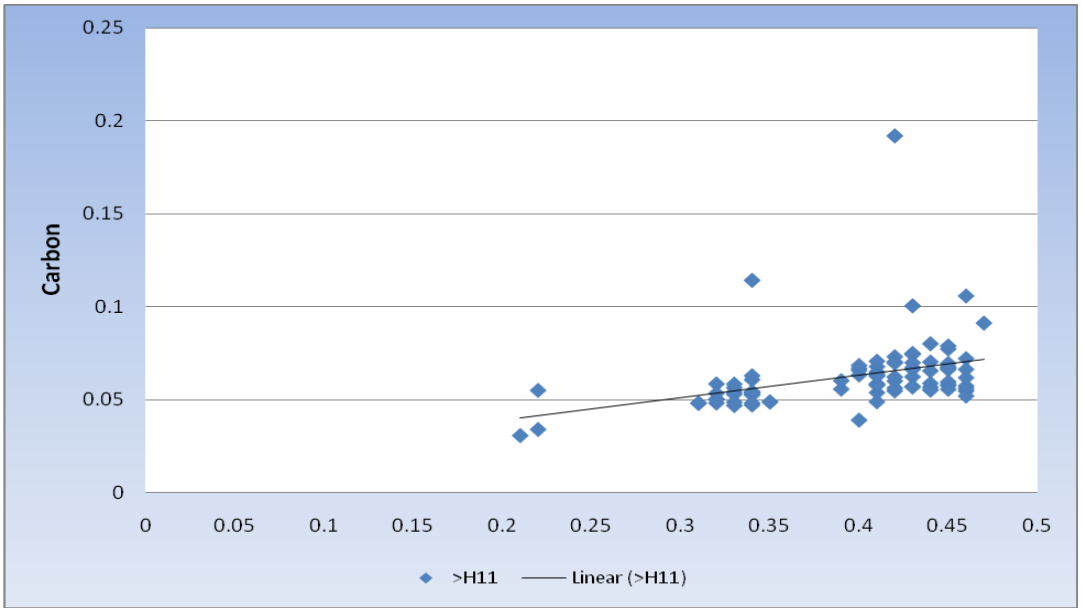


Fig. 7.30: Scatter plot for carbon and >11th harmonic at EAF (Grade 2910).

The considerable correlation coefficient (r) is in the range of 0.8 where it can be used for prediction. The highest (r) obtained is 0.413 which cannot be considered strong or perfect linear relationship as shown in Fig. 7.27 and Fig. 7.28.

Fig. 7.29 and Fig. 7.30 are evident that there is no correlation or relationship between the carbon and the 11th harmonic or >11th harmonic.

CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

8.1 CONCLUSION

In order to study the impact of power quality parameters on steel industry product, power quality measurement and chemical analysis for steel industrial product were conducted. The power quality measurements were conducted at 34.5 kV electrical busbar while producing steel grades 200 and 2910. The power quality measurements for industrial steel grade 200 were conducted over a period of 120 heats. The power quality indices that were measured are total harmonic distortion for voltage and current (THD V, THD I), individual harmonics, and flickers for short and long terms (P_{st}, P_{lt}). In addition, other electrical parameters were measured as well such as voltage (V_{rms}), current (I_{rms}), active power (P), reactive power (Q), power factor (PF), and frequency. The same electrical parameters were measured while producing the industrial steel of grade 2910 over a period of 90 heats. All power quality parameters for both study cases were found to be within the IEEE and IEC standards.

Simultaneously, the analysis of the chemical elements for the industrial steel were also made for both grades of industrial steel, 200 and 2910. The analysis is made for 120 heats of grade 200 and 90 heats of grade 2910. The chemical elements that were analyzed are Carbon (C), Manganese (Mn), Silicon (Si), Copper (Cu), Nickel (Ni), Chromium (Cr), Molybdenum (Mo), and Vanadium (V). All measured chemical elements in both cases were found to be within the specified standards and limits as applicable.

This work investigated both types and resulted to the followings:

1. **For industrial steel code 200**: the correlation coefficients (r) calculated to measure the strength of the relationship between the eight chemical elements and the power quality parameters. The highest correlation coefficient was found to be in range of ±0.3. The relationship between carbon element and PQ elements was studied in details due to its importance to the steelmaking. It is also one of the highest values of the correlation coefficients (r). The study concludes that there is no correlation or direct relationship between the power quality parameters and the carbon element. This is true and applicable for the remaining chemical elements when tested against the power quality parameters.

2. **For industrial steel code 2910**: similar to the above, the correlation coefficients (r) were calculated for the same purpose, to find the strength of the correlation between the eight chemical elements and the power quality parameters. The highest correlation coefficient factors were found to be between the third (3^{rd}) harmonic and the carbon element by -0.413 (-41.3%). The correlation between the fourth (4^{th}) harmonic and the carbon element was found to be -0.306 (30.6%). This is not strong or perfect negative linear relationship but also cannot be considered as uncorrelated. The analysis concludes that there is weak negative correlation between carbon and 3^{rd} & 4^{th} harmonics. This correlations can be used by finding one element to predict the other but not certainly true.

   The same analysis concludes that there is no correlation or relationship between the power quality parameters and the other seven chemical elements.

8.2 RECOMMENDATIONS

This work was recording the chemical analysis at the end of each heat without looking to the changes in the percentage of each chemical element throughout the heat process. The operator and chemist are obliged to meet the limits of the elements in the molten steel (the steel product) before the casting process. So it is very much expected to find the chemistry of the steel product well within the limits in all products approximately. For further work, it might be recommended to measure the power quality online and monitor the changes in the chemical online during one complete heat only. This might indicate the correlation if any.

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APPENDIX

Appendix - I

Results of Power Quality Measurements (For Grade 200)

S. No.	Heat #, Date, Time	Vrms (kV)	Irms (A)	THD V (%)	H2 (%)	H3 (%)	H4 (%)	H5 (%)	H6 (%)	H7 (%)	H8 (%)	H9 (%)	H10 (%)	H11 (%)	> H11 (%) Less Than	THD I (%)	P (MW)	Q (MVAR)	P.F.	Pst	Plt	Remarks
1	1024054, 14.06.2010 @ 17:09 hr to 18:14 hr	34.7	1878	1.52	0.6	0.4	0.300	0.09	0.04	0.47	0.05	0.09	0.05	0.42	0.36	7	94.1	60.9	0.837	2.32	0	
2	1024055, 14.06.2010 @ 18:19 hr to 19:19 hr	34.6	1860	1.2	0.43	0.3	0.170	0.07	0.02	0.4	0.035	0.08	0.034	0.42	0.34	4	94.2	60.0	0.841	1.22	3.33	
3	1024056, 14.06.2010 @ 19:24 hr to 20:29 hr	34.7	1860	1.42	0.6	0.43	0.260	0.09	0.034	0.47	0.047	0.1	0.04	0.4	0.34	4.6	94.3	60.4	0.839	2.81	3.33	
4	1024057, 14.06.2010 @ 20:34 hr to 21:39 hr	34.7	1845	1.2	0.42	0.28	0.170	0.07	0.025	0.42	0.0345	0.08	0.0345	0.435	0.37	5.48	94.7	60.9	0.838	1.9	3.58	
5	1024058, 14.06.2010 @ 21:44 hr to 22:39 hr	34.5	1848	1.2	0.6	0.43	0.260	0.085	0.035	0.42	0.048	0.093	0.047	0.4	0.32	5.48	93.9	60.0	0.840	2.48	3.388	
6	1024059, 14.06.2010 @ 22:54 hr to 23:54 hr	34.6	1837	1.35	0.56	0.41	0.230	0.085	0.036	0.44	0.049	0.1	0.046	0.41	0.35	5.8	92.0	62.6	0.823	2.17	3.2	
7	1024080, 16.06.2010 @ 16:09 hr to 17:39 hr	32.5	1800	10.9	0.34	0.67	0.230	0.9	0.18	0.54	0.15	0.22	0.13	0.34	0.22	5.5	79.3	57.5	0.807	9.05	15.12	First heat after maintenance down day, without SVC
8	1024081, 16.06.2010 @ 17:44 hr to 18:54 hr	32.8	1791	1.25	0.25	0.56	0.160	0.78	0.12	0.45	0.1	0.15	0.07	0.28	0.18	4.35	82.8	56.2	0.824	3.92	11.99	Without SVC
9	1024082, 16.06.2010 @ 18:59 hr to 20:09 hr	32.3	1756	1.25	0.28	0.57	0.180	0.82	0.13	0.42	0.11	0.17	0.095	0.28	0.19	3.8	80.7	54.9	0.823	4.38	8.84	Without SVC
10	1024083, 16.06.2010 @ 20:14 hr to 21:24 hr	32.3	1767	1.16	0.22	0.5	0.130	0.8	0.09	0.38	0.08	0.12	0.06	0.24	0.16	3.4	80.7	54.9	0.826	4.3	6	Without SVC
11	1030089, 28.07.2010 @ 17:34 hr to 18:32 hr	34.5	1870	1.65	0.76	0.57	0.330	0.1	0.045	0.52	0.06	0.11	0.058	0.33	0.29	6.7	90.7	64.1	0.813	2.77	3.65	
12	1030090, 28.07.2010 @ 18:40 hr to 19:40 hr	34.5	1877	1.5	0.69	0.5	0.290	0.09	0.041	0.49	0.055	0.11	0.055	0.35	0.3	6.9	89.1	62.5	0.813	2.33	3.87	
13	1030091, 28.07.2010 @ 20:00 hr to 21:00 hr	34.7	1876	1.69	0.86	0.62	0.380	0.095	0.05	0.46	0.069	0.127	0.066	0.31	0.3	6.3	91.1	66.0	0.807	3.28	4.29	
14	1030092, 28.07.2010 @ 21: 11 hr to 22:09 hr	34.8	1886	1.6	0.8	0.6	0.360	0.092	0.049	0.42	0.065	0.11	0.064	0.32	0.3	5.2	92.0	66.1	0.809	2.47	4.27	
15	1030093, 28.07.2010 @ 22:17 hr to 23:13 hr	34.8	1884	1.38	0.6	0.43	0.250	0.07	0.037	0.42	0.05	0.09	0.048	0.31	0.29	5	93.2	64.0	0.822	2.56	4.27	
16	1030094, 28.07.2010 @ 23:20 hr to 00:22 hr	34.5	1848	1.44	0.6	0.45	0.260	0.087	0.037	0.42	0.05	0.096	0.049	0.36	0.31	6.4	91.1	63.2	0.818	2.44	3.57	
17	1030095, 29.07.2010 @ 00:29 hr to 01:25 hr	34.6	1875	1.31	0.51	0.37	0.210	0.081	0.032	0.4	0.043	0.086	0.043	0.36	0.3	4.65	92.4	62.8	0.824	1.84	3.57	
18	1030096, 29.07.2010 @ 01:39 hr to 02:36 hr	34.4	1857	1.44	0.63	0.45	0.260	0.086	0.038	0.38	0.052	0.1	0.052	0.37	0.3	5.1	91.4	62.4	0.823	2.3	3.49	
19	1030097, 29.07.2010 @ 02:46 hr to 03:43 hr	34.5	1870	1.25	0.47	0.34	0.190	0.078	0.031	0.33	0.041	0.085	0.043	0.39	0.31	3.64	92.2	61.5	0.829	2.1	3.61	
20	1030098, 29.07.2010 @ 03:51 hr to 04:50 hr	34.5	1852	1.28	0.48	0.33	0.190	0.076	0.03	0.36	0.038	0.084	0.04	0.38	0.32	4.1	92.7	61.0	0.832	2.01	3.79	
21	1030099, 29.07.2010 @ 04:58 hr to 05:55 hr	34.5	1871	1.27	0.48	0.34	0.190	0.079	0.03	0.33	0.039	0.079	0.04	0.39	0.32	3.7	92.6	61.1	0.831	1.98	3.64	
22	1030100, 29.07.2010 @ 06:04 hr to 07:04 hr	34.6	1863	1.4	0.59	0.44	0.240	0.082	0.037	0.42	0.05	0.11	0.051	0.34	0.29	5.4	92.2	63.7	0.820	2.31	3.55	
23	1030101, 29.07.2010 @ 07:13 hr to 08:10 hr	34.6	1852	1.29	0.51	0.37	0.200	0.075	0.033	0.38	0.046	0.096	0.046	0.33	0.29	3.6	92.3	62.3	0.826	1.59	3.36	
24	1030102, 29.07.2010 @ 08:18 hr to 09:14 hr	34.6	1858	1.25	0.47	0.32	0.180	0.078	0.03	0.34	0.039	0.08	0.04	0.4	0.32	3.9	92.9	61.8	0.829	1.91	3.34	
25	1030103, 29.07.2010 @ 09:21 hr to 10:16 hr	34.7	1856	1.31	0.52	0.37	0.200	0.077	0.032	0.35	0.04	0.085	0.04	0.39	0.32	3.72	93.8	61.3	0.833	1.74	2.68	
26	1030104, 29.07.2010 @ 10:33 hr to 11:30 hr	34.6	1877	1.55	0.71	0.49	0.290	0.09	0.042	0.36	0.05	0.09	0.052	0.38	0.31	4.65	92.7	61.5	0.830	2.92	2.91	
27	1030105, 29.07.2010 @ 11:42 hr to 12:39 hr	34.6	1853	1.33	0.53	0.37	0.210	0.079	0.033	0.37	0.044	0.09	0.046	0.36	0.29	3.93	93.0	62.3	0.828	2.49	4.07	
28	1030106, 29.07.2010 @ 12:47 hr to 13:43 hr	34.6	1860	1.45	0.63	0.46	0.280	0.089	0.04	0.38	0.052	0.107	0.052	0.39	0.3	5.4	91.4	61.0	0.828	2.99	4.29	
29	1030107, 29.07.2010 @ 13:59 hr to 14:57 hr	34.5	1869	1.35	0.58	0.41	0.220	0.078	0.037	0.39	0.048	0.099	0.048	0.34	0.29	3.92	92.2	62.0	0.826	1.94	4.58	
30	1030108, 29.07.2010 @ 15:07 hr to 16:04 hr	34.6	1860	1.35	0.56	0.4	0.230	0.084	0.037	0.36	0.047	0.098	0.05	0.37	0.3	4.37	92.5	63.1	0.823	2.11	3.73	
31	1030109, 29.07.2010 @ 16:11 hr to 17:06 hr	34.7	1890	1.28	0.51	0.35	0.200	0.08	0.032	0.33	0.043	0.091	0.044	0.4	0.31	3.5	93.4	62.2	0.829	2.59	3.44	
32	1030112, 29.07.2010 @ 17:15 hr to 18:12 hr	34.7	1884	1.38	0.59	0.43	0.240	0.083	0.036	0.37	0.047	0.092	0.047	0.37	0.3	4.1	92.3	65.0	0.816	2.54	3.39	
33	1030113, 29.07.2010 @ 20:28 hr to 21:25 hr	34.5	1882	1.38	0.56	0.4	0.230	0.081	0.035	0.39	0.045	0.091	0.047	0.36	0.3	9.3	91.9	62.2	0.825	2.29	3.1	
34	1030114, 29.07.2010 @ 21:34 hr to 22:32 hr	34.5	1889	1.42	0.6	0.44	0.240	0.081	0.041	0.45	0.054	0.13	0.054	0.33	0.32	4.63	91.5	63.5	0.818	3.12	3.69	
35	1030116, 29.07.2010 @ 23:54 hr to 00:50 hr	34.4	1877	1.36	0.54	0.4	0.220	0.079	0.035	0.41	0.048	0.11	0.047	0.35	0.3	4.7	91.0	63.3	0.818	2.44	4.2	
36	1030117, 29.07.2010 @ 00:57 hr to 01:53 hr	34.5	1872	1.38	0.59	0.42	0.240	0.081	0.037	0.43	0.05	0.1	0.051	0.34	0.3	4.8	91.1	64.2	0.815	2.42	3.73	
37	1030118, 29.07.2010 @ 02:01 hr to 02:59 hr	34.4	1897	1.58	0.74	0.55	0.320	0.094	0.046	0.42	0.061	0.13	0.061	0.36	0.29	5.9	91.6	61.8	0.827	2.32	3.4	
38	1030119, 30.07.2010 @ 03:10 hr to 04:08 hr	34.7	1884	1.54	0.71	0.52	0.300	0.09	0.043	0.44	0.059	0.11	0.06	0.34	0.31	4.6	93.5	64.0	0.822	2.59	3.76	
39	1030120, 30.07.2010 @ 04:16 hr to 05:13 hr	34.7	1874	1.48	0.69	0.5	0.290	0.092	0.043	0.39	0.056	0.12	0.057	0.37	0.29	5	92.9	62.7	0.825	3.01	3.83	
40	1030121, 30.07.2010 @ 05:20 hr to 06:17 hr	34.7	1845	1.42	0.61	0.44	0.260	0.086	0.038	0.42	0.052	0.095	0.052	0.35	0.28	5.25	93.2	63.4	0.824	1.87	3.41	
41	1030122, 30.07.2010 @ 06:24 hr to 07:20 hr	34.7	1885	1.48	0.64	0.48	0.280	0.086	0.037	0.44	0.052	0.087	0.052	0.34	0.28	7.93	93.2	62.6	0.827	2.24	3.41	
42	1030123, 30.07.2010 @ 07:35 hr to 08:32 hr	34.7	1851	1.42	0.61	0.44	0.250	0.084	0.04	0.38	0.04	0.088	0.05	0.36	0.29	4	90.6	62.5	0.820	2.33	3.32	
43	1030124, 30.07.2010 @ 08:40 hr to 09:39 hr	34.7	1866	1.41	0.6	0.43	0.250	0.086	0.037	0.38	0.049	0.088	0.051	0.37	0.3	4.5	94.0	61.7	0.833	2.29	3.55	
44	1030126, 30.07.2010 @ 10:50 hr to 11:48 hr	34.8	1889	1.38	0.56	0.41	0.240	0.083	0.035	0.4	0.046	0.082	0.045	0.37	0.29	7.1	93.9	64.1	0.824	2	3.58	
45	1030127, 30.07.2010 @ 11:55 hr to 12:48 hr	34.5	1864	1.57	0.74	0.51	0.310	0.095	0.042	0.45	0.056	0.11	0.056	0.37	0.3	8	91.9	63.2	0.820	3.24	3.16	Two (2) scrap baskets
46	1031001, 31.07.2010 @ 06:36 hr to 07:33 hr	34.7	1865	1.09	0.32	0.23	0.120	0.066	0.021	0.36	0.028	0.068	0.028	0.36	0.31	3.9	94.0	61.7	0.833	1.75	2.96	
47	1031002, 31.07.2010 @ 07:51 hr to 08:47 hr	34.7	1884	1.42	0.61	0.42	0.240	0.086	0.035	0.37	0.044	0.082	0.046	0.39	0.31	4.8	93.4	62.6	0.827	2.07	3.05	
48	1031003, 31.07.2010 @ 08:54 hr to 09:50 hr	34.8	1873	1.5	0.64	0.47	0.270	0.086	0.039	0.44	0.053	0.12	0.052	0.34	0.3	5.1	93.9	64.1	0.824	3.27	3.74	
49	1031005, 31.07.2010 @ 11:026 hr to 12:01 hr	34.5	1856	1.48	0.64	0.5	0.280	0.09	0.041	0.42	0.055	0.1	0.055	0.37	0.29	9.7	91.9	63.2	0.820	2.4	4.2	
50	1031006, 31.07.2010 @ 12:08 hr to 13:04 hr	34.5	1879	1.41	0.6	0.43	0.250	0.087	0.036	0.36	0.049	0.085	0.05	0.41	0.32	5.4	93.0	61.9	0.829	2.21	4.09	
51	1031008, 31.07.2010 @ 14:25 hr to 15:25 hr	34.5	1887	1.3	0.51	0.36	0.200	0.079	0.031	0.38	0.043	0.11	0.044	0.38	0.3	5.1	90.5	61.5	0.823	2.66	3.67	
52	1031009, 31.07.2010 @ 15:45 hr to 16:45 hr	34.5	1850	1.48	0.67	0.51	0.280	0.088	0.042	0.37	0.056	0.1	0.056	0.39	0.3	4.17	91.5	62.5	0.822	2.33	3.71	
53	1031010, 31.07.2010 @ 16:52 hr to 17:53 hr	34.4	1858	1.4	0.59	0.44	0.240	0.081	0.037	0.4	0.049	0.1	0.051	0.35	0.29	4.4	91.5	62.8	0.821	2.56	3.71	
54	1031011, 31.07.2010 @ 18:07 hr to 19:08 hr	34.4	1879	1.54	0.71	0.51	0.300	0.091	0.043	0.37	0.056	0.11	0.056	0.38	0.3	4.7	90.7	62.0	0.822	2.98	3.72	
55	1031012, 31.07.2010 @ 19:15 hr to 20:17 hr	34.7	1846	1.28	0.5	0.38	0.210	0.077	0.035	0.39	0.046	0.12	0.048	0.37	0.3	4.4	92.6	63.0	0.823	2.6	4.35	
56	1031013, 31.07.2010 @ 20:40 hr to 21:40 hr	34.6	1864	1.22	0.46	0.34	0.180	0.074	0.029	0.38	0.04	0.096	0.042	0.37	0.3	3.92	92.7	62.3	0.826	1.61	3.91	
57	1031014, 31.07.2010 @ 21:47 hr to 22:44 hr	34.7	1885	1.19	0.4	0.31	0.160	0.07	0.027	0.37	0.036	0.084	0.038	0.39	0.31	4	94.1	62.3	0.831	1.81	2.93	
58	1031015, 31.07.2010 @ 23:26 hr to 00:28 hr	34.4	1842	1.29	0.51	0.36	0.200	0.073	0.031	0.39	0.042	0.088	0.043	0.36	0.29	3.8	92.2	61.4	0.830	2.22	2.63	

59	1032044, 09.08.2010 @ 16:04 hr to 17:29 hr	34.4	1913	2.5	1.34	1.1	0.600	0.28	0.13	0.57	0.14	0.22	0.13	0.38	0.3	9.75	88.2	66.1	0.798	7.7	11	First heat after maintenance down day.
60	1032045, 09.08.2010 @ 17:34 hr to 18:39 hr	34.7	1858	1.32	0.5	0.35	0.210	0.082	0.031	0.36	0.04	0.083	0.04	0.41	0.34	5.5	93.7	62.6	0.828	2.24	11.55	
61	1032046, 09.08.2010 @ 18:49 hr to 19:44 hr	34.6	1845	1.32	0.5	0.35	0.210	0.084	0.032	0.36	0.044	0.093	0.043	0.41	0.33	5.5	92.4	63.2	0.822	1.39	3.7	
62	1032047, 09.08.2010 @ 20:09 hr to 21:14 hr	34.4	1834	1	0.17	0.15	0.081	0.06	0.015	0.38	0.022	0.086	0.024	0.37	0.32	5.9	91.6	61.6	0.827	0.81	2.59	
63	1032048, 09.08.2010 @ 21:29 hr to 22:29 hr	34.5	1859	1.45	0.63	0.45	0.260	0.083	0.036	0.46	0.051	0.095	0.05	0.32	0.28	5.6	91.3	63.6	0.818	1.31	2.3	
64	1032049, 09.08.2010 @ 22:44 hr to 23:44 hr	34.6	1869	1.47	0.63	0.44	0.260	0.084	0.038	0.47	0.051	0.108	0.052	0.3	0.31	5.4	91.1	64.3	0.814	2.25	2.86	
65	1032050, 10.08.2010 @ 23:54 hr to 00:59 hr	34.7	1886	1.02	0.2	0.16	0.085	0.058	0.015	0.47	0.021	0.078	0.022	0.3	0.3	5.3	92.7	63.8	0.821	0.84	3.03	
66	1032051, 10.08.2010 @ 01:04 hr to 02:04 hr	34.8	1871	1.47	0.63	0.49	0.280	0.087	0.042	0.49	0.054	0.1	0.051	0.35	0.3	6.6	93.0	65.7	0.814	2.15	3.18	
67	1032052, 10.08.2010 @ 02:09 hr to 03:04 hr	34.8	1882	1.46	0.64	0.48	0.290	0.089	0.041	0.47	0.057	0.098	0.055	0.35	0.29	6.6	92.6	65.4	0.815	1.81	3.35	
68	1032087, 11.08.2010 @ 17:04 hr to 17:59 hr	34.5	1851	1.44	0.61	0.46	0.270	0.084	0.039	0.43	0.052	0.105	0.052	0.35	0.29	5.8	91.5	63.9	0.817	2.39	3.59	
69	1032088, 11.08.2010 @ 18:09 hr to 19:04 hr	34.5	1854	1.55	0.7	0.53	0.310	0.091	0.043	0.44	0.058	0.12	0.056	0.35	0.31	16	90.7	64.8	0.810	2.08	3.6	
70	1032089, 11.08.2010 @ 19:09 hr to 20:09 hr	34.6	1861	1.52	0.68	0.53	0.300	0.088	0.042	0.46	0.059	0.125	0.058	0.36	0.3	14.7	91.8	65.0	0.814	2.67	3.68	
71	1032090, 11.08.2010 @ 20:14 hr to 21:14 hr	34.6	1865	1.04	0.25	0.23	0.110	0.06	0.019	0.44	0.026	0.087	0.025	0.34	0.3	13.1	92.4	63.6	0.821	0.97	3.21	
72	1032091, 11.08.2010 @ 21:24 hr to 22:29 hr	34.3	1842	1.46	0.62	0.46	0.270	0.083	0.036	0.44	0.052	0.101	0.049	0.34	0.29	5.4	90.8	62.6	0.821	2.05	3.1	
73	1032092, 11.08.2010 @ 22:34 hr to 23:34 hr	34.5	1871	1.54	0.67	0.5	0.310	0.088	0.043	0.45	0.055	0.105	0.054	0.36	0.36	6.7	92.0	63.3	0.822	2.25	2.81	
74	1032093, 11.08.2010 @ 23:39 hr to 00:39 hr	34.6	1856	1.62	0.75	0.58	0.356	0.096	0.047	0.44	0.063	0.115	0.06	0.35	0.3	6.2	91.9	63.7	0.819	2.24	3.15	
75	1032094, 12.08.2010 @ 00:44 hr to 01:44 hr	34.4	1822	1.6	0.72	0.53	0.330	0.095	0.043	0.45	0.057	0.14	0.057	0.34	0.31	15.07	89.4	61.3	0.821	3.05	3.94	
76	1032095, 12.08.2010 @ 01:54 hr to 02:54 hr	34.6	1864	1	0.23	0.19	0.100	0.057	0.016	0.43	0.021	0.069	0.021	0.31	0.3	13.5	91.3	63.9	0.817	0.66	4.23	
77	1032096, 12.08.2010 @ 02:59 hr to 03:59 hr	34.6	1840	1.34	0.52	0.38	0.220	0.076	0.031	0.42	0.043	0.093	0.043	0.33	0.32	6.4	91.6	63.4	0.819	1.96	4.5	
78	1032098, 12.08.2010 @ 05:19 hr to 06:24 hr	34.5	1852	0.98	0.19	0.16	0.082	0.058	0.013	0.37	0.019	0.08	0.021	0.36	0.34	12.4	92.1	62.3	0.826	0.97	4.1	
79	1032099, 12.08.2010 @ 06:34 hr to 07:34 hr	34.4	1833	1.43	0.6	0.45	0.270	0.083	0.036	0.41	0.049	0.1	0.049	0.36	0.32	5.9	90.5	63.9	0.814	2.31	1.18	
80	1032100, 12.08.2010 @ 07:39 hr to 08:34 hr	34.7	1848	0.98	0.19	0.15	0.078	0.054	0.013	0.39	0.02	0.077	0.021	0.36	0.31	3.2	93.0	63.0	0.825	1.65	1.4	
81	1032101, 12.08.2010 @ 08:39 hr to 09:39 hr	34.4	1818	1.41	0.56	0.41	0.250	0.081	0.033	0.43	0.047	0.097	0.048	0.37	0.32	6	91.5	62.3	0.824	2.3	3.58	
82	1032102, 12.08.2010 @ 09:44 hr to 10:39 hr	34.6	1842	1.33	0.55	0.39	0.230	0.077	0.032	0.37	0.043	0.089	0.045	0.39	0.32	5	91.7	62.4	0.823	2.07	3.54	
83	1032103, 12.08.2010 @ 10:44 hr to 11:44 hr	34.5	1840	1.51	0.63	0.48	0.280	0.085	0.039	0.42	0.05	0.1	0.05	0.37	0.32	6.2	91.9	62.4	0.825	2.4	3.4	
84	1032104, 12.08.2010 @ 11:49 hr to 12:49 hr	34.6	1833	1.52	0.65	0.49	0.290	0.086	0.043	0.45	0.054	0.11	0.053	0.37	0.31	6.1	92.1	63.0	0.822	2.73	3.67	
85	1032105, 12.08.2010 @ 12:54 hr to 13:54 hr	34.5	1832	1.4	0.55	0.39	0.230	0.079	0.033	0.43	0.046	0.104	0.047	0.34	0.32	6	92.0	62.4	0.825	2.66	3.94	
86	1032106, 12.08.2010 @ 13:59 hr to 14:59 hr	34.5	1805	1.38	0.54	0.42	0.240	0.078	0.035	0.46	0.044	0.103	0.046	0.33	0.31	7.8	91.6	63.1	0.821	2.1	3.84	
87	1032107, 12.08.2010 @ 15:04 hr to 16:04 hr	34.5	1848	1.38	0.53	0.4	0.230	0.078	0.034	0.48	0.044	0.104	0.045	0.35	0.3	6.4	91.7	63.7	0.819	2.03	3.77	
88	1032108, 12.08.2010 @ 16:09 hr to 17:04 hr	34.5	1871	1.54	0.7	0.51	0.300	0.087	0.044	0.44	0.058	0.11	0.058	0.34	0.28	5.8	91.7	63.0	0.821	2.94	3.6	
89	1032109, 12.08.2010 @ 17:09 hr to 18:09 hr	34.7	1854	1.55	0.64	0.49	0.290	0.087	0.042	0.47	0.053	0.12	0.052	0.36	0.32	7.2	92.5	63.4	0.821	3.28	3.67	
90	1032110, 12.08.2010 @ 18:14 hr to 19:19 hr	34.5	1836	1.1	0.25	0.22	0.110	0.063	0.019	0.48	0.026	0.108	0.028	0.34	0.3	13.97	91.4	64.4	0.815	1.3	3.4	
91	1032111, 12.08.2010 @ 19:24 hr to 20:19 hr	34.7	1854	1.51	0.67	0.5	0.280	0.086	0.039	0.47	0.056	0.136	0.056	0.33	0.3	5.9	91.7	65.9	0.810	2.73	3.34	
92	1032112, 12.08.2010 @ 20:29 hr to 21:29 hr	34.4	1819	1.45	0.59	0.42	0.250	0.082	0.036	0.44	0.048	0.1	0.047	0.35	0.3	6	91.0	62.8	0.820	2.41	3.36	
93	1032113, 12.08.2010 @ 21:34 hr to 22:34 hr	34.4	1836	1.66	0.78	0.57	0.350	0.092	0.045	0.46	0.06	0.115	0.059	0.34	0.3	6.7	90.5	62.2	0.821	3.1	3.59	
94	1032114, 12.08.2010 @ 22:39 hr to 23:39 hr	34.4	1842	1.52	0.64	0.48	0.290	0.089	0.04	0.45	0.051	0.091	0.052	0.38	0.32	6.6	91.7	61.9	0.826	2.5	4.7	
95	1032116, 13.08.2010 @ 00:54 hr to 01:59 hr	34.7	1700	1.11	0.27	0.2	0.120	0.06	0.021	0.41	0.025	0.17	0.027	0.37	0.31	6.9	86.9	57.2	0.838	1.6	3.6	
96	1032117, 13.08.2010 @ 02:04 hr to 03:04 hr	34.7	1851	1.43	0.58	0.41	0.250	0.08	0.036	0.44	0.047	0.094	0.046	0.35	0.31	14.4	92.5	63.0	0.823	2.1	3.4	
97	1032118, 13.08.2010 @ 03:09 hr to 04:09 hr	34.8	1869	1.42	0.56	0.41	0.260	0.08	0.036	0.44	0.048	0.115	0.049	0.34	0.31	6.7	90.2	61.8	0.821	2.06	3.3	
98	1032119, 13.08.2010 @ 04:24 hr to 05:29 hr	34.5	1760	1.74	0.82	0.58	0.360	0.096	0.047	0.45	0.059	0.124	0.06	0.35	0.32	15.1	89.1	64.5	0.805	3.14	2.9	
99	1032120, 13.08.2010 @ 05:34 hr to 06:19 hr	34.6	1823	1	0.2	0.17	0.094	0.057	0.016	0.41	0.022	0.08	0.023	0.32	0.3	4.8	91.9	63.2	0.821	0.75	3.2	
100	1032121, 13.08.2010 @ 06:39 hr to 07:34 hr	34.6	1764	1.5	0.64	0.47	0.276	0.085	0.039	0.47	0.053	0.123	0.055	0.32	0.28	6.1	90.9	65.2	0.810	3.14	4.71	
101	1035031, 29.08.2010 @ 18:54 hr to 19:59 hr	34.6	1849	1.26	0.38	0.27	0.160	0.07	0.025	0.43	0.035	0.082	0.032	0.37	0.34	13.6	93.8	61.4	0.834	1.49	3.98	
102	1035032, 29.08.2010 @ 20:09 hr to 21:14 hr	34.7	1837	1.35	0.49	0.36	0.220	0.079	0.03	0.42	0.041	0.105	0.042	0.38	0.33	7.4	91.5	63.0	0.818	2.22	4	
103	1035033, 29.08.2010 @ 21:24 hr to 22:29 hr	34.7	1853	1.36	0.54	0.38	0.230	0.077	0.033	0.44	0.045	0.092	0.042	0.35	0.33	6.3	92.8	64.0	0.820	1.88	3.99	
104	1035034, 29.08.2010 @ 22:34 hr to 23:39 hr	34.8	1851	1.43	0.55	0.41	0.260	0.079	0.035	0.43	0.047	0.12	0.05	0.33	0.31	6.1	91.9	63.6	0.818	2.11	2.7	
105	1035035, 30.08.2010 @ 00:19 hr to 01:24 hr	34.5	1836	0.98	0.15	0.12	0.064	0.053	0.012	0.41	0.014	0.06	0.014	0.35	0.31	12.2	92.6	60.4	0.835	0.71	2.7	
106	1035036, 30.08.2010 @ 01:29 hr to 02:24 hr	34.5	1832	1.16	0.36	0.24	0.140	0.065	0.023	0.35	0.028	0.068	0.028	0.39	0.33	3.8	92.8	60.3	0.835	1.85	2.7	
107	1035037, 30.08.2010 @ 02:29 hr to 03:29 hr	34.6	1837	1.23	0.38	0.25	0.150	0.067	0.024	0.39	0.031	0.077	0.031	0.38	0.34	13.26	92.9	61.1	0.831	1.78	2.4	
108	1035038, 30.08.2010 @ 03:34 hr to 04:34 hr	34.4	1817	1.21	0.37	0.26	0.150	0.067	0.026	0.38	0.033	0.08	0.033	0.38	0.34	13.16	92.3	60.7	0.831	1.5	2.5	
109	1035039, 30.08.2010 @ 04:39 hr to 05:34 hr	34.4	1812	1.23	0.43	0.3	0.170	0.069	0.026	0.34	0.034	0.084	0.037	0.4	0.34	12.9	92.3	60.3	0.834	1.95	2.9	
110	1035040, 30.08.2010 @ 05:39 hr to 06:39 hr	34.3	1788	1.21	0.39	0.29	0.170	0.069	0.025	0.39	0.032	0.087	0.032	0.37	0.33	5.4	92.1	59.7	0.836	1.51	2.9	
111	1035041, 30.08.2010 @ 06:44 hr to 07:44 hr	34.5	1839	1.3	0.48	0.34	0.200	0.074	0.029	0.4	0.039	0.08	0.037	0.35	0.31	4.4	92.8	61.1	0.831	1.73	2.95	
112	1035042, 30.08.2010 @ 07:49 hr to 08:49 hr	34.5	1841	1.25	0.4	0.27	0.170	0.072	0.027	0.39	0.036	0.075	0.036	0.4	0.36	5.4	92.7	61.5	0.830	1.53	3.02	
113	1035043, 30.08.2010 @ 08:54 hr to 09:54 hr	34.6	1830	1.28	0.46	0.32	0.190	0.073	0.029	0.39	0.039	0.083	0.039	0.37	0.31	5	92.6	62.1	0.829	2.63	3.1	
114	1035044, 30.08.2010 @ 09:59 hr to 10:59 hr	34.7	1852	1.17	0.35	0.25	0.150	0.07	0.023	0.38	0.03	0.083	0.031	0.4	0.36	5.5	93.7	60.9	0.836	1.7	3.23	
115	1035045, 30.08.2010 @ 11:04 hr to 11:59 hr	34.6	1842	1.22	0.42	0.3	0.170	0.07	0.026	0.36	0.036	0.089	0.038	0.36	0.31	3.93	93.2	61.4	0.833	1.93	3.3	
116	1035046, 30.08.2010 @ 12:09 hr to 13:04 hr	34.6	1842	1.37	0.53	0.35	0.210	0.072	0.031	0.42	0.042	0.09	0.041	0.34	0.29	13.6	93.2	60.6	0.836	1.56	3.19	
117	1035047, 30.08.2010 @ 13:09 hr to 14:09 hr	34.8	1847	1.25	0.43	0.29	0.180	0.071	0.027	0.39	0.036	0.073	0.036	0.4	0.34	5.2	94.7	62.1	0.834	1.8	3.1	
118	1035048, 30.08.2010 @ 14:14 hr to 15:14 hr	35.0	1848	1.26	0.41	0.3	0.175	0.07	0.027	0.38	0.036	0.088	0.036	0.38	0.34	4.83	95.8	62.5	0.835	1.06	2.96	
119	1035049, 30.08.2010 @ 15:29 hr to 16:29 hr	34.6	1841	1.17	0.32	0.23	0.140	0.066	0.023	0.38	0.03	0.067	0.03	0.4	0.35	13.7	93.7	60.3	0.838	1.5	2.9	
120	1035050, 30.08.2010 @ 16:34 hr to 17:39 hr	34.6	1845	0.96	0.12	0.1	0.053	0.053	0.012	0.34	0.014	0.052	0.015	0.41	0.36	4.3	94.3	60.6	0.839	0.49	2.66	

Appendix - II

Results of Power Quality Measurements (For grade 2910)

S. No.	Heat #, Date, Time	Vrms (kV)	Irms (A)	THD V (%)	H2 (%)	H3 (%)	H4 (%)	H5 (%)	H6 (%)	H7 (%)	H8 (%)	H9 (%)	H10 (%)	H11 (%)	> H11 (%) Less than	THD I (%)	P (MW)	Q (MVAR)	P.F.	E (kWh/t)	Pst	Plt	Remarks
1	1024085, 16.06.2010 @ 22.54 hr to 00:04 hr	32.0	1764	1.23	0.24	0.46	0.14	0.82	0.085	0.5	0.075	0.14	0.055	0.22	0.21	4	79.4	53.4	0.827	556.1	3.34	7.60	Without SVC
2	1024086, 17.06.2010 @ 00.09 hr to 01:19 hr	31.9	1764	1.43	0.26	0.52	0.17	0.95	0.11	0.58	0.1	0.175	0.08	0.245	0.22	3.55	79.1	53.4	0.826	577.6	3.98	5.22	Without SVC
3	1024087, 17.06.2010 @ 01.24 hr to 02:29 hr	33.4	1870	1.75	0.3	0.45	0.16	0.9	0.135	0.83	0.12	0.32	0.11	0.44	0.4	5.4	87	58.8	0.824	580	4.42	5.30	SVC energized 20 min after starting this heat
4	1024088, 17.06.2010 @ 02:39 hr to 03:39 hr	34.6	1895	1.47	0.71	0.5	0.3	0.1	0.042	0.56	0.056	0.11	0.055	0.37	0.32	5.95	92.3	63.8	0.820	581.2	1.85	5.90	
5	1024089, 17.06.2010 @ 03:44 hr to 04:44 hr	34.7	1907	1.65	0.85	0.65	0.39	0.11	0.05	0.56	0.07	0.12	0.068	0.38	0.31	7.7	92.9	64.6	0.818	576.2	2.58	4.80	
6	1024090, 17.06.2010 @ 04:49 hr to 05:54 hr	34.6	1884	1.6	0.78	0.59	0.35	0.1	0.047	0.53	0.061	0.12	0.058	0.35	0.34	7	91.8	64.0	0.817	570.3	2.65	3.70	
7	1024091, 17.06.2010 @ 06:04 hr to 07:09 hr	34.5	1784	1.73	0.85	0.62	0.38	0.11	0.05	0.61	0.07	0.13	0.067	0.36	0.33	9.9	90.3	64.5	0.810	495.2	2.70	4.37	
8	1024092, 17.06.2010 @ 07:14 hr to 08:14 hr	34.5	1860	1.52	0.73	0.54	0.33	0.1	0.046	0.49	0.06	0.12	0.06	0.39	0.32	6.34	91.4	64.4	0.815	555.1	2.61	4.50	
9	1024093, 17.06.2010 @ 08:19 hr to 09:19 hr	34.5	1849	1.53	0.71	0.54	0.32	0.095	0.044	0.48	0.06	0.13	0.06	0.38	0.34	6.1	91.4	63.8	0.817	540.6	2.44	3.57	
10	1024094, 17.06.2010 @ 09:24 hr to 10:24 hr	34.6	1840	1.41	0.61	0.44	0.27	0.091	0.038	0.48	0.051	0.12	0.052	0.4	0.34	4.5	92.6	63.6	0.822	548.2	2.47	3.57	
11	1024095, 17.06.2010 @ 10:29 hr to 11:29 hr	34.7	1760	1.53	0.72	0.53	0.32	0.1	0.046	0.48	0.058	0.13	0.06	0.4	0.34	6.3	92.7	64.3	0.820	545.1	2.49	3.60	
12	1024096, 17.06.2010 @ 11:39 hr to 12:39 hr	34.6	1848	1.29	0.47	0.34	0.2	0.085	0.03	0.49	0.042	0.1	0.042	0.41	0.46	5	92.6	63.2	0.823	547.9	2.39	3.63	
13	1024097, 17.06.2010 @ 12:44 hr to 13:44 hr	34.5	1860	1.35	0.54	0.4	0.23	0.087	0.036	0.45	0.046	0.1	0.048	0.41	0.34	3.9	92.5	62.2	0.828	556.2	1.87	3.66	
14	1024098, 17.06.2010 @ 13:49 hr to 14:49 hr	34.5	1847	1.23	0.44	0.3	0.18	0.08	0.03	0.46	0.04	0.1	0.04	0.39	0.34	5.5	92.1	62.3	0.826	547.3	1.65	3.37	
15	1024099, 17.06.2010 @ 14:54 hr to 15:54 hr	34.6	1855	0.97	0.19	0.16	0.084	0.064	0.015	0.42	0.023	0.073	0.023	0.4	0.34	4.6	93.0	62.1	0.829	596.5	0.55	3.17	
16	1024100, 17.06.2010 @ 15:59 hr to 16:59 hr	34.5	1848	1.33	0.53	0.39	0.24	0.09	0.035	0.46	0.046	0.093	0.047	0.41	0.35	6	92.3	62.6	0.825	534.8	2.13	2.79	
17	1024101, 17.06.2010 @ 17:04 hr to 18:04 hr	34.7	1850	1.34	0.53	0.38	0.23	0.084	0.033	0.49	0.045	0.113	0.043	0.37	0.35	5.8	92.8	63.4	0.823	558	2.66	2.19	
18	1024102, 17.06.2010 @ 18:24 hr to 19:19 hr	34.6	1845	1.43	0.63	0.43	0.26	0.085	0.038	0.5	0.051	0.1	0.051	0.34	0.33	4	91.9	62.7	0.822	537.8	2.25	3.13	
19	1024103, 17.06.2010 @ 19:24 hr to 20:29 hr	34.5	1852	1.32	0.52	0.37	0.22	0.082	0.032	0.51	0.045	0.096	0.044	0.37	0.33	6.3	91.8	62.6	0.823	576.4	1.90	3.15	
20	1024104, 17.06.2010 @ 20:54 hr to 21:54 hr	34.4	1834	1.29	0.48	0.37	0.2	0.077	0.031	0.49	0.043	0.11	0.043	0.37	0.32	5.85	91.1	62.5	0.821	551.2	1.89	3.22	
21	1024105, 17.06.2010 @ 21:59 hr to 22:59 hr	34.5	1836	1.38	0.58	0.42	0.24	0.087	0.037	0.5	0.047	0.11	0.049	0.36	0.32	3.9	92.0	62.7	0.823	559.6	2.92	3.42	
22	1024106, 17.06.2010 @ 23:04 hr to 00:04 hr	34.6	1839	1.25	0.47	0.35	0.2	0.08	0.031	0.48	0.041	0.1	0.042	0.38	0.32	5	92.4	63.3	0.823	565.1	1.31	3.48	
23	1024107, 18.06.2010 @ 00:19 hr to 01:19 hr	34.6	1864	1.26	0.49	0.38	0.21	0.081	0.032	0.46	0.045	0.1	0.045	0.38	0.34	5.45	93.0	63.4	0.823	571.7	1.65	2.56	
24	1024108, 18.06.2010 @ 01:29 hr to 02:24 hr	34.7	1851	1.36	0.57	0.42	0.25	0.087	0.038	0.44	0.05	0.1	0.05	0.4	0.33	4.52	93.7	62.7	0.829	555.8	1.43	2.63	
25	1024109, 18.06.2010 @ 02:29 hr to 03:19 hr	34.7	1861	1.42	0.61	0.44	0.225	0.09	0.036	0.5	0.049	0.097	0.049	0.37	0.33	5.8	93.4	62.7	0.828	561.3	2.60	2.92	
26	1024110, 18.06.2010 @ 03:39 hr to 04:34 hr	34.7	1871	1.45	0.67	0.48	0.28	0.092	0.042	0.48	0.055	0.106	0.055	0.4	0.33	6.3	93.3	63.1	0.826	533	2.52	3.12	
27	1024111, 18.06.2010 @ 04:39 hr to 05:44 hr	34.5	1841	1.4	0.54	0.4	0.24	0.087	0.035	0.55	0.046	0.1	0.046	0.37	0.34	8	92.6	62.5	0.827	568.5	2.08	3.63	
28	1024112, 18.06.2010 @ 05:49 hr to 06:49 hr	34.5	1856	1.53	0.71	0.52	0.32	0.099	0.045	0.5	0.057	0.11	0.058	0.4	0.34	6.3	91.9	62.1	0.826	546.3	1.88	3.58	
29	1024113, 18.06.2010 @ 07:04 hr to 08:04 hr	33.7	1759	1.44	0.58	0.56	0.26	0.42	0.049	0.44	0.056	0.1	0.052	0.31	0.22	4.65	87.1	60.6	0.819	545.7	2.89	3.54	Without SVC partially
30	1024114, 18.06.2010 @ 08:19 hr to 09:24 hr	33.0	1770	1.5	0.3	0.48	0.19	0.72	0.14	0.56	0.12	0.25	0.1	0.4	0.31	5	84.3	56.8	0.825	543.2	5.24	3.07	Without SVC partially
31	1024115, 18.06.2010 @ 09:29 hr to 10:29 hr	34.6	1839	1.48	0.48	0.33	0.19	0.16	0.035	0.58	0.044	0.25	0.043	0.47	0.43	6.33	92.4	64.0	0.819	555.9	2.54	3.96	
32	1024116, 18.06.2010 @ 10:34 hr to 11:34 hr	34.6	1801	1.42	0.4	0.28	0.16	0.16	0.029	0.56	0.037	0.25	0.038	0.46	0.43	5.8	92.1	63.9	0.819	542.2	2.15	6.64	
33	1024117, 18.06.2010 @ 11:39 hr to 12:39 hr	34.5	1832	1.4	0.39	0.27	0.15	0.15	0.026	0.57	0.036	0.24	0.037	0.45	0.43	5.5	92.5	62.3	0.827	539.9	2.22	5.06	
34	1024118, 18.06.2010 @ 12:44 hr to 13:44 hr	34.5	1826	1.44	0.46	0.32	0.17	0.15	0.031	0.57	0.038	0.25	0.37	0.48	0.42	6.1	92.4	62.2	0.827	523	2.12	2.86	
35	1024119, 18.06.2010 @ 13:49 hr to 14:49 hr	34.3	1819	1.41	0.4	0.26	0.15	0.15	0.026	0.54	0.33	0.25	0.32	0.49	0.44	8	92.2	60.2	0.834	534.3	1.98	2.95	
36	1024120, 18.06.2010 @ 14:54 hr to 15:54 hr	34.5	1839	1.35	0.33	0.23	0.12	0.15	0.023	0.57	0.029	0.25	0.28	0.47	0.41	6.3	92.5	62.2	0.827	535.9	1.80	3.02	
37	1024121, 18.06.2010 @ 15:59 hr to 16:54 hr	34.5	1836	1.4	0.42	0.29	0.16	0.15	0.031	0.51	0.037	0.29	0.38	0.49	0.43	5	91.8	61.7	0.826	530.9	1.80	2.71	
38	1024122, 18.06.2010 @ 16:59 hr to 17:59 hr	34.5	1837	1.54	0.53	0.35	0.2	0.16	0.036	0.58	0.044	0.28	0.046	0.46	0.46	6.3	91.7	62.4	0.823	549	2.48	2.60	
39	1024123, 18.06.2010 @ 18:04 hr to 19:04 hr	34.4	1822	1.45	0.43	0.31	0.17	0.15	0.031	0.56	0.038	0.26	0.038	0.47	0.46	5.4	91.7	62.8	0.822	551.5	2.27	3.21	
40	1024124, 18.06.2010 @ 19:19 hr to 20:19 hr	34.3	1829	1.46	0.49	0.33	0.19	0.15	0.035	0.55	0.042	0.23	0.044	0.46	0.44	6.5	89.2	65.3	0.805	548.8	2.26	3.27	
41	1024125, 18.06.2010 @ 20:24 hr to 21:24 hr	34.5	1827	1.5	0.54	0.35	0.2	0.15	0.035	0.56	0.046	0.24	0.047	0.46	0.44	6.1	89.6	65.0	0.806	544.2	3.07	2.60	
42	1024126, 18.06.2010 @ 21:34 hr to 22:39 hr	34.4	1860	1.53	0.53	0.36	0.21	0.16	0.038	0.57	0.044	0.27	0.047	0.43	0.45	9.1	90.6	63.4	0.817	556.7	2.57	2.93	
43	1024127, 18.06.2010 @ 22:44 hr to 23:44 hr	34.4	1826	1.49	0.5	0.37	0.19	0.15	0.035	0.54	0.042	0.28	0.044	0.46	0.42	7.6	91.2	63.0	0.820	530.8	2.24	3.46	
44	1024128, 18.06.2010 @ 23:49 hr to 00:49 hr	34.5	1841	1.63	0.63	0.43	0.25	0.15	0.042	0.64	0.051	0.24	0.05	0.44	0.45	8	91.0	64.4	0.813	533.9	2.52	3.46	
45	1024129, 19.06.2010 @ 00:54 hr to 01:49 hr	34.4	1832	1.46	0.5	0.33	0.19	0.15	0.033	0.55	0.042	0.27	0.043	0.45	0.44	5.9	91.0	63.7	0.818	522.1	2.54	3.46	
46	1024130, 19.06.2010 @ 01:54 hr to 02:54 hr	34.3	1839	1.59	0.6	0.4	0.24	0.16	0.04	0.62	0.049	0.25	0.051	0.43	0.46	6.9	90.5	63.6	0.815	535.3	2.39	3.30	
47	1024131, 19.06.2010 @ 03:04 hr to 04:04 hr	34.5	1848	1.55	0.54	0.36	0.21	0.15	0.035	0.61	0.047	0.28	0.046	0.46	0.45	5.9	91.1	63.7	0.817	528.9	2.92	3.25	
48	1024132, 19.06.2010 @ 04:09 hr to 05:09 hr	34.6	1841	1.6	0.63	0.43	0.24	0.15	0.043	0.59	0.053	0.24	0.054	0.45	0.46	5.5	91.3	65.2	0.812	532.8	2.78	3.36	
49	1024133, 19.06.2010 @ 05:14 hr to 06:19 hr	34.5	1855	1.54	0.54	0.37	0.21	0.15	0.037	0.6	0.048	0.24	0.047	0.44	0.47	7.2	90.1	63.8	0.812	548.9	2.92	3.12	
50	1025001, 19.06.2010 @ 06:29 hr to 07:24 hr	34.4	1834	1.38	0.41	0.28	0.15	0.14	0.028	0.53	0.033	0.26	0.035	0.45	0.42	5	92.2	61.9	0.827	515.8	1.66	3.43	
51	1025002, 19.06.2010 @ 07:34 hr to 08:29 hr	34.6	1839	1.43	0.47	0.31	0.18	0.15	0.031	0.55	0.037	0.25	0.039	0.46	0.43	5.1	92.8	62.5	0.826	527.1	2.20	3.31	
52	1025003, 19.06.2010 @ 08:34 hr to 09:34 hr	34.5	1839	1.31	0.29	0.21	0.11	0.14	0.02	0.56	0.024	0.24	0.024	0.45	0.41	5.8	93.0	60.3	0.836	534.4	1.54	2.98	
53	1025004, 19.06.2010 @ 09:39 hr to 10:34 hr	34.5	1842	1.45	0.43	0.29	0.16	0.15	0.03	0.55	0.037	0.26	0.037	0.45	0.4	5.9	90.9	60.2	0.830	521.2	2.07	2.97	
54	1025005, 19.06.2010 @ 10:44 hr to 11:44 hr	34.4	1817	1.38	0.37	0.24	0.13	0.14	0.025	0.55	0.031	0.26	0.03	0.46	0.41	5.6	91.6	61.3	0.828	529.4	1.82	2.95	
55	1025006, 19.06.2010 @ 11:49 hr to 12:49 hr	34.4	1824	1.4	0.4	0.27	0.15	0.15	0.028	0.52	0.033	0.27	0.035	0.48	0.39	5.1	91.6	60.7	0.831	538.4	2.06	2.95	

56	1025007, 19.06.2010 @ 12:54 hr to 13:54 hr	34.4	1840	1.38	0.38	0.25	0.13	0.15	0.026	0.52	0.033	0.26	0.033	0.46	0.41	4.8	92.4	61.2	0.831	556.8	2.14	2.96	
57	1025008, 19.06.2010 @ 13:59 hr to 15:04 hr	34.4	1821	1.37	0.35	0.23	0.12	0.15	0.026	0.51	0.031	0.26	0.032	0.47	0.42	6.3	91.7	61.4	0.827	607.5	1.85	3.20	
58	1025009, 19.06.2010 @ 15:09 hr to 16:04 hr	34.4	1836	1.46	0.48	0.32	0.18	0.15	0.036	0.55	0.044	0.25	0.044	0.46	0.45	6	91.0	63.3	0.819	537	2.25	3.27	
59	1025010, 19.06.2010 @ 16:14 hr to 17:14 hr	34.4	1833	1.33	0.3	0.24	0.11	0.14	0.023	0.56	0.027	0.25	0.029	0.45	0.44	5.7	91.6	62.5	0.823	550.9	1.53	2.58	
60	1025011, 19.06.2010 @ 17:19 hr to 18:19 hr	34.5	1847	7.55	0.5	0.35	0.19	0.14	0.036	0.55	0.043	0.25	0.045	0.44	0.45	5.7	91.4	63.4	0.820	552.6	4.33	3.37	
61	1025012, 19.06.2010 @ 18:24 hr to 19:24 hr	34.3	1831	1.48	0.48	0.34	0.19	0.15	0.037	0.58	0.042	0.28	0.042	0.46	0.45	5.5	90.7	62.4	0.821	551.3	2.51	12.77	
62	1025013, 19.06.2010 @ 19:29 hr to 20:29 hr	34.3	1836	1.39	0.36	0.25	0.14	0.15	0.025	0.25	0.03	0.28	0.03	0.46	0.46	5.8	91.4	61.2	0.827	560	1.75	10.36	
63	1025014, 19.06.2010 @ 20:34 hr to 21:34 hr	34.3	1816	1.38	0.34	0.24	0.12	0.14	0.023	0.55	0.028	0.26	0.028	0.46	0.43	5	91.5	61.0	0.829	554.9	1.78	3.11	
64	1025015, 19.06.2010 @ 21:44 hr to 22:49 hr	34.1	1810	1.22	0.14	0.13	0.057	0.13	0.013	0.52	0.015	0.22	0.017	0.45	0.43	4.7	89.6	61.6	0.821	576.1	1.29	2.64	
65	1025016, 19.06.2010 @ 23:04 hr to 00:04 hr	34.4	1836	1.45	0.46	0.32	0.18	0.15	0.03	0.52	0.037	0.28	0.039	0.47	0.41	5.6	92.0	61.2	0.830	546	2.08	2.25	
66	1025017, 20.06.2010 @ 00:14 hr to 01:09 hr	34.5	1834	1.34	0.37	0.26	0.14	0.15	0.024	0.47	0.03	0.3	0.03	0.49	0.41	4.3	92.7	61.3	0.831	551.3	1.95	2.93	
67	1025018, 20.06.2010 @ 01:14 hr to 02:14 hr	34.4	1834	1.41	0.37	0.25	0.14	0.15	0.026	0.57	0.032	0.24	0.034	0.44	0.45	6.1	91.5	61.8	0.825	544.2	2.30	2.93	
68	1025019, 20.06.2010 @ 02:19 hr to 03:19 hr	34.3	1833	1.64	0.65	0.42	0.25	0.16	0.043	0.55	0.052	0.27	0.053	0.45	0.43	7.1	90.4	63.0	0.818	540.2	2.35	2.63	
69	1025020, 20.06.2010 @ 03:24 hr to 04:24 hr	34.4	1832	1.58	0.57	0.4	0.24	0.17	0.041	0.58	0.049	0.25	0.048	0.45	0.45	6.5	91.5	63.2	0.820	543.6	2.50	2.76	
70	1025021, 20.06.2010 @ 04:29 hr to 05:29 hr	34.1	1818	1.49	0.5	0.36	0.2	0.15	0.037	0.56	0.044	0.26	0.043	0.46	0.44	6	89.6	62.2	0.819	528	2.50	3.42	
71	1025022, 20.06.2010 @ 05:34 hr to 06:34 hr	34.2	1824	1.48	0.48	0.35	0.19	0.15	0.035	0.58	0.042	0.26	0.042	0.45	0.44	7.9	90.4	62.4	0.820	515.5	2.22	2.54	
72	1025023, 20.06.2010 @ 06:39 hr to 07:39 hr	34.6	1842	1.46	0.47	0.33	0.18	0.15	0.033	0.57	0.038	0.26	0.04	0.47	0.46	6	92.6	63.5	0.822	514.4	2.13	3.31	
73	1025024, 20.06.2010 @ 07:44 hr to 08:44 hr	34.3	1818	1.55	0.54	0.36	0.21	0.15	0.037	0.59	0.045	0.24	0.047	0.45	0.42	6.2	91.0	61.3	0.827	521.6	2.46	3.44	
74	1025025, 20.06.2010 @ 08:49 hr to 09:44 hr	34.4	1814	1.4	0.42	0.26	0.15	0.15	0.027	0.52	0.033	0.27	0.034	0.48	0.4	5.1	92.5	60.6	0.834	513.2	1.68	3.58	
75	1025026, 20.06.2010 @ 09:49 hr to 10:44 hr	34.3	1826	1.33	0.34	0.22	0.12	0.13	0.24	0.52	0.03	0.25	0.03	0.47	0.43	4.3	92.0	60.3	0.833	531.3	1.58	3.24	
76	1025027, 20.06.2010 @ 10:49 hr to11:49 hr	34.3	1833	1.34	0.31	0.21	0.11	0.14	0.022	0.54	0.024	0.27	0.026	0.46	0.41	5.7	92.0	59.3	0.837	518.6	1.65	2.96	
77	1025028, 20.06.2010 @ 11:54 hr to 12:54 hr	34.4	1832	1.3	0.29	0.19	0.1	0.14	0.02	0.54	0.026	0.25	0.026	0.44	0.42	4.8	92.3	60.7	0.833	550.1	1.83	2.61	
78	1025029, 20.06.2010 @ 12:59 hr to 13:59 hr	34.3	1837	1.31	0.31	0.2	0.11	0.14	0.022	0.53	0.026	0.26	0.026	0.45	0.4	6.7	91.7	59.9	0.834	554.9	1.64	2.44	
79	1025030, 20.06.2010 @ 14:24 hr to 15:24 hr	34.3	1818	1.47	0.52	0.33	0.19	0.15	0.033	0.49	0.043	0.29	0.043	0.49	0.39	5.7	91.5	61.0	0.829	582.5	2.53	2.09	
80	1025031, 20.06.2010 @ 15:29 hr to 16:34 hr	34.3	1828	1.31	0.28	0.21	0.1	0.14	0.022	0.53	0.024	0.27	0.025	0.47	0.41	7	91.8	60.4	0.832	560.9	1.98	2.50	Two (2) scrap baskets
81	1025032, 20.06.2010 @ 16:39 hr to 17:39 hr	34.3	1805	1.32	0.31	0.21	0.12	0.14	0.02	0.52	0.025	0.25	0.025	0.48	0.4	5	92.2	60.0	0.836	550.7	2.23	3.22	
82	1025033, 20.06.2010 @ 17:59 hr to 18:59 hr	34.4	1824	1.5	0.51	0.34	0.2	0.14	0.034	0.59	0.043	0.24	0.044	0.45	0.46	5.7	91.1	63.3	0.819	552.1	2.17	3.20	
83	1025034, 20.06.2010 @ 19:04 hr to 20:04 hr	34.2	1829	1.33	0.28	0.2	0.098	0.13	0.022	0.59	0.026	0.23	0.026	0.44	0.45	5.5	91.3	60.2	0.833	539.8	2.21	3.20	
84	1025035, 20.06.2010 @ 20:09 hr to 21:09 hr	34.2	1828	1.33	0.31	0.21	0.11	0.13	0.02	0.54	0.026	0.26	0.026	0.45	0.45	5.4	91.2	59.6	0.835	556.5	1.50	2.43	
85	1025036, 20.06.2010 @ 21:24 hr to 22:24 hr	34.4	1830	1.4	0.42	0.3	0.16	0.14	0.028	0.56	0.04	0.23	0.04	0.46	0.43	6.5	90.1	64.5	0.811	543.6	3.04	2.40	
86	1025037, 20.06.2010 @ 22:44 hr to 23:44 hr	34.4	1807	1.4	0.42	0.28	0.16	0.14	0.029	0.54	0.046	0.22	0.039	0.48	0.42	5.5	91.2	63.0	0.820	552.4	2.34	2.83	
87	1025038, 21.06.2010 @ 00:04 hr to 01:04 hr	34.4	1833	1.41	0.48	0.33	0.18	0.15	0.034	0.5	0.045	0.27	0.043	0.48	0.42	5.4	90.9	64.1	0.815	528	3.04	3.21	
88	1025039, 21.06.2010 @ 01:09 hr to 02:14 hr	34.5	1768	1.43	0.4	0.27	0.15	0.15	0.028	0.59	0.034	0.25	0.035	0.45	0.41	7.2	90.8	63.7	0.816	539.7	2.62	3.27	
89	1025040, 21.06.2010 @ 02:19 hr to 03:19 hr	34.5	1840	1.45	0.45	0.33	0.19	0.15	0.035	0.54	0.042	0.26	0.044	0.46	0.41	6	91.8	63.7	0.820	562.3	2.40	2.88	
90	1025041, 21.06.2010 @ 03:24 hr to 04:24 hr	34.6	1858	1.42	0.44	0.32	0.16	0.16	0.031	0.56	0.039	0.26	0.04	0.45	0.41	9.1	92.2	64.6	0.817	519.6	2.36	2.90	

Appendix - III A

Chemical Analysis: 200 **Standard:EN 10130: 1991** **Steel Grade: FeP01**			**Electric Arc Furnace (EAF)**								
	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V	C.E.
1	14/06/10 17:54	1024054	0.0569	0.023	0.003	0.0173	0.0155	0.0067	0.0149	0.00137	0.07
2	14/06/10 18:57	1024055	0.0802	0.02	0.001	0.0246	0.0144	0.0065	0.01322	0.00076	0.09
3	14/06/10 20:07	1024056	0.0637	0.019	0.001	0.0151	0.0113	0.0055	0.01304	0.00075	0.07
4	14/06/10 21:13	1024057	0.066	0.021	0.002	0.0307	0.0196	0.0104	0.01222	0.00119	0.08
5	14/06/10 22:20	1024058	0.0593	0.02	0.001	0.0244	0.0165	0.0078	0.01457	0.00074	0.07
6	14/06/10 23:36	1024059	0.0711	0.021	0.001	0.0347	0.0152	0.0104	0.01407	0.00087	0.08
7	16/06/10 17:15	1024080	0.0288	0.013	0.001	0.0222	0.0165	0.0105	0.00953	0.00013	0.04
8	16/06/10 18:23	1024081	0.0503	0.011	0.002	0.0311	0.0208	0.0094	0.01023	0.00021	0.06
9	16/06/10 19:46	1024082	0.0512	0.015	0.003	0.0267	0.0178	0.0111	0.0119	0.00052	0.06
10	16/06/10 20:57	1024083	0.0484	0.017	0.004	0.0452	0.022	0.0106	0.01265	0.00047	0.06
11	28/07/10 18:18	1030089	0.0507	0.015	0	0.0383	0.0147	0.0068	0.00425	0.0001	0.06
12	28/07/10 19:26	1030090	0.0481	0.014	0.001	0.0359	0.0152	0.0071	0.00445	0.0001	0.06
13	28/07/10 20:42	1030091	0.0491	0.013	0	0.0404	0.0139	0.0072	0.00281	0.0001	0.06
14	28/07/10 21:57	1030092	0.0588	0.016	0	0.0343	0.0154	0.0095	0.00513	0.0001	0.07
15	28/07/10 23:06	1030093	0.0501	0.017	0	0.0307	0.0117	0.0069	0.00465	0.0001	0.06
16	29/07/10 00:10	1030094	0.0563	0.021	0.007	0.0366	0.0144	0.012	0.00436	0.0001	0.07
17	29/07/10 01:14	1030095	0.0515	0.016	0	0.0284	0.0133	0.0067	0.00455	0.0001	0.06
18	29/07/10 02:26	1030096	0.0544	0.014	0	0.0281	0.0137	0.0058	0.0039	0.0001	0.06
19	29/07/10 03:32	1030097	0.0594	0.017	0	0.0288	0.0117	0.0063	0.00357	0.0001	0.07
20	29/07/10 04:35	1030098	0.0776	0.014	0	0.0266	0.0147	0.0099	0.00035	0.0001	0.08
21	29/07/10 05:44	1030099	0.0642	0.015	0.001	0.0292	0.0179	0.0109	0.01322	0.00026	0.07
22	29/07/10 06:51	1030100	0.1011	0.021	0	0.0375	0.0193	0.0145	0.00216	0.0001	0.11
23	29/07/10 07:55	1030101	0.0616	0.016	0	0.0296	0.027	0.0153	0.00458	0.0001	0.07
24	29/07/10 08:58	1030102	0.0598	0.013	0	0.038	0.0155	0.013	0.00345	0.0001	0.07
25	29/07/10 10:03	1030103	0.0564	0.012	0	0.0439	0.0174	0.0086	0.00343	0.0001	0.06
26	29/07/10 11:13	1030104	0.0624	0.012	0	0.0452	0.0144	0.0066	0.00223	0.0001	0.07
27	29/07/10 12:33	1030105	0.0594	0.013	0	0.0485	0.0122	0.0093	0.00268	0.0001	0.07
28	29/07/10 13:25	1030106	0.056	0.016	0	0.0408	0.027	0.0108	0.0042	0.0001	0.07
29	29/07/10 14:47	1030107	0.0637	0.015	0	0.0461	0.0196	0.0139	0.00509	0.0001	0.07
30	29/07/10 15:50	1030108	0.0727	0.024	0	0.0468	0.0156	0.0128	0.004	0.0001	0.08
31	29/07/10 17:01	1030109	0.0572	0.021	0	0.043	0.0359	0.0232	0.00504	0.0001	0.07
32	29/07/10 20:18	1030112	0.0709	0.029	0	0.0422	0.0168	0.0167	0.0049	0.0001	0.08
33	29/07/10 21:12	1030113	0.0625	0.021	0	0.0347	0.0123	0.0085	0.00253	0.0001	0.07
34	29/07/10 22:15	1030114	0.0605	0.025	0.004	0.0464	0.0156	0.0115	0.00765	0.0001	0.07
35	30/07/10 00:35	1030116	0.081	0.027	0	0.0479	0.0136	0.0139	0.00206	0.0001	0.09
36	30/07/10 01:36	1030117	0.0688	0.027	0	0.0278	0.0121	0.0093	0.00311	0.0001	0.08
37	30/07/10 02:45	1030118	0.0685	0.019	0	0.0308	0.0189	0.0113	0.00421	0.0001	0.08
38	30/07/10 03:52	1030119	0.0647	0.019	0	0.0303	0.0169	0.0093	0.00259	0.0001	0.07
39	30/07/10 04:59	1030120	0.0593	0.018	0	0.0519	0.0178	0.0162	0.00337	0.0001	0.07
40	30/07/10 06:04	1030121	0.0556	0.023	0	0.0242	0.0105	0.0092	0.00248	0.0001	0.06
41	30/07/10 07:01	1030122	0.0561	0.017	0	0.0256	0.0101	0.0077	0.00241	0.0001	0.06
42	30/07/10 08:18	1030123	0.0592	0.012	0	0.036	0.0139	0.0074	0.0025	0.0001	0.07
43	30/07/10 09:13	1030124	0.0785	0.018	0	0.067	0.0222	0.0109	0.00669	0.0001	0.09
44	30/07/10 11:17	1030126	0.064	0.014	0	0.0433	0.0248	0.0076	0.00234	0.0001	0.07
45	30/07/10 12:33	1030127	0.0499	0.016	0	0.0676	0.0186	0.0081	0.00449	0.0001	0.06
46	31/07/10 07:28	1031001	0.0602	0.013	0	0.0477	0.0123	0.0065	0.00083	0.0001	0.07
47	31/07/10 08:35	1031002	0.0597	0.013	0	0.0359	0.0122	0.0067	0.00205	0.0001	0.07
48	31/07/10 09:41	1031003	0.066	0.017	0	0.0315	0.0095	0.0079	0.00121	0.0001	0.07
49	31/07/10 11:42	1031005	0.063	0.012	0	0.0363	0.0104	0.0078	0.00142	0.0001	0.07
50	31/07/10 12:59	1031006	0.0565	0.012	0	0.0426	0.0113	0.0083	0.00273	0.0001	0.06
51	31/07/10 15:08	1031008	0.0539	0.012	0	0.0492	0.0174	0.012	0.00364	0.0001	0.06
52	31/07/10 16:30	1031009	0.0559	0.012	0	0.0404	0.0141	0.0065	0.00358	0.0001	0.06
53	31/07/10 17:37	1031010	0.0603	0.018	0	0.0569	0.0132	0.0097	0.00352	0.0001	0.07
54	31/07/10 18:52	1031011	0.0568	0.025	0	0.056	0.0206	0.0184	0.00407	0.0001	0.07
55	31/07/10 19:59	1031012	0.0629	0.022	0	0.0537	0.0212	0.013	0.00381	0.0001	0.07
56	31/07/10 21:23	1031013	0.0587	0.016	0	0.0484	0.0156	0.0112	0.00232	0.0001	0.07

57	31/07/10 22:30	1031014	0.0548	0.013	0	0.0462	0.0191	0.0085	0.00388	0.0001	0.06
58	01/08/10 00:12	1031015	0.0584	0.018	0	0.0571	0.0161	0.0089	0.00329	0.0001	0.07
59	09/08/10 17:11	1032044	0.0506	0.015	0.001	0.0184	0.0103	0.0147	0.00292	0.0001	0.06
60	09/08/10 18:33	1032045	0.0569	0.016	0	0.0207	0.0099	0.0102	0.00123	0.0001	0.06
61	09/08/10 19:36	1032046	0.0539	0.016	0	0.0188	0.0101	0.0105	0.00153	0.0001	0.06
62	09/08/10 20:57	1032047	0.0755	0.01	0	0.0041	0.0038	0.0039	0.00043	0.0001	0.08
63	09/08/10 22:17	1032048	0.0589	0.015	0.001	0.031	0.0141	0.0108	0.00246	0.0001	0.07
64	09/08/10 23:33	1032049	0.054	0.022	0.001	0.0433	0.018	0.0137	0.01232	0.0001	0.07
65	10/08/10 00:34	1032050	0.0536	0.008	0	0.0139	0.007	0.0034	0.00521	0.0001	0.06
66	10/08/10 01:48	1032051	0.0591	0.016	0.003	0.0229	0.0107	0.0086	0.00606	0.0001	0.07
67	10/08/10 02:51	1032052	0.0519	0.019	0.001	0.0431	0.0144	0.0071	0.00499	0.0001	0.06
68	11/08/10 17:49	1032087	0.0499	0.029	0	0.044	0.026	0.019	0.00618	0.0001	0.06
69	11/08/10 18:54	1032088	0.0522	0.022	0	0.0373	0.0193	0.014	0.00428	0.0001	0.06
70	11/08/10 19:53	1032089	0.0629	0.021	0	0.0294	0.0136	0.0106	0.00329	0.0001	0.07
71	11/08/10 20:58	1032090	0.0757	0.016	0	0.0085	0.0055	0.0041	0.00091	0.0001	0.08
72	11/08/10 22:05	1032091	0.0753	0.016	0	0.041	0.0186	0.0117	0.00237	0.0001	0.08
73	11/08/10 23:15	1032092	0.0949	0.025	0	0.0329	0.0202	0.004	0.00336	0.0002	0.10
74	12/08/10 00:21	1032093	0.077	0.018	0	0.0246	0.0198	0.0059	0.00377	0.00033	0.08
75	12/08/10 01:31	1032094	0.083	0.027	0.001	0.0333	0.0217	0.0085	0.00808	0.00024	0.09
76	12/08/10 02:40	1032095	0.0621	0.012	0.001	0.0099	0.0088	0.0023	0.0027	0.0001	0.07
77	12/08/10 03:51	1032096	0.0564	0.017	0.001	0.0187	0.0111	0.005	0.00144	0.0001	0.06
78	12/08/10 06:05	1032098	0.0656	0.012	0	0.0101	0.0064	0.0034	0.00196	0.0001	0.07
79	12/08/10 07:20	1032099	0.0588	0.019	0.001	0.0416	0.0126	0.0103	0.00388	0.0001	0.07
80	12/08/10 08:25	1032100	0.0678	0.011	0	0.0099	0.0058	0.0027	0.00348	0.0001	0.07
81	12/08/10 09:27	1032101	0.0688	0.025	0.001	0.0368	0.016	0.0068	0.00634	0.0001	0.08
82	12/08/10 10:28	1032102	0.0612	0.032	0	0.0404	0.0206	0.0114	0.00564	0.0001	0.07
83	12/08/10 11:35	1032103	0.0665	0.028	0.004	0.0336	0.0177	0.0194	0.00679	0.0001	0.08
84	12/08/10 12:35	1032104	0.0673	0.029	0.001	0.0378	0.0174	0.0137	0.00417	0.0001	0.08
85	12/08/10 13:40	1032105	0.0683	0.026	0	0.0488	0.0181	0.0113	0.00732	0.0001	0.08
86	12/08/10 14:44	1032106	0.0648	0.025	0	0.046	0.024	0.0183	0.01284	0.00013	0.08
87	12/08/10 15:50	1032107	0.0593	0.031	0.001	0.0492	0.0193	0.0168	0.0062	0.0001	0.07
88	12/08/10 16:53	1032108	0.0638	0.025	0	0.0482	0.0215	0.0149	0.00454	0.0001	0.08
89	12/08/10 17:55	1032109	0.0581	0.028	0.001	0.0497	0.0186	0.0147	0.00462	0.0001	0.07
90	12/08/10 19:00	1032110	0.0912	0.014	0	0.0121	0.0084	0.0047	0.00251	0.0001	0.10
91	12/08/10 20:03	1032111	0.071	0.026	0.001	0.0427	0.0212	0.016	0.00546	0.00074	0.08
92	12/08/10 21:14	1032112	0.1014	0.034	0.001	0.0425	0.0319	0.0204	0.00746	0.00031	0.12
93	12/08/10 22:19	1032113	0.0661	0.022	0	0.0301	0.0218	0.0102	0.00366	0.0001	0.08
94	12/08/10 23:28	1032114	0.0611	0.023	0	0.022	0.0178	0.0043	0.00414	0.0001	0.07
95	13/08/10 01:36	1032116	0.0672	0.012	0	0.0096	0.0073	0.0028	0.0027	0.0001	0.07
96	13/08/10 02:57	1032117	0.0537	0.019	0	0.0422	0.0162	0.0079	0.00311	0.0001	0.06
97	13/08/10 03:59	1032118	0.0712	0.027	0	0.052	0.0185	0.0145	0.00356	0.0001	0.08
98	13/08/10 05:23	1032119	0.0636	0.018	0	0.0423	0.0147	0.0091	0.00746	0.0001	0.07
99	13/08/10 06:19	1032120	0.0672	0.012	0	0.0104	0.007	0.0036	0.00387	0.0001	0.07
100	13/08/10 07:27	1032121	0.0829	0.028	0.011	0.0636	0.0176	0.0146	0.00576	0.0001	0.10
101	29/08/10 19:41	1035031	0.0442	0.017	0.003	0.0437	0.0134	0.0035	0.00422	0.0001	0.05
102	29/08/10 20:54	1035032	0.0605	0.028	0.001	0.0251	0.0144	0.0098	0.00629	0.0001	0.07
103	29/08/10 22:14	1035033	0.05	0.017	0	0.0307	0.0149	0.0042	0.00203	0.0001	0.06
104	29/08/10 23:30	1035034	0.0773	0.026	0	0.0312	0.015	0.0086	0.0053	0.0001	0.09
105	30/08/10 01:06	1035035	0.0603	0.012	0	0.0096	0.007	0.0021	0.0016	0.0001	0.06
106	30/08/10 02:13	1035036	0.0519	0.018	0	0.0207	0.0131	0.0038	0.00244	0.0001	0.06
107	30/08/10 03:18	1035037	0.0537	0.019	0.001	0.0257	0.0128	0.0069	0.00308	0.0001	0.06
108	30/08/10 04:22	1035038	0.0543	0.02	0.008	0.0232	0.0132	0.0044	0.00249	0.0001	0.06
109	30/08/10 05:26	1035039	0.0574	0.02	0	0.043	0.0141	0.0069	0.00322	0.0001	0.07
110	30/08/10 06:31	1035040	0.0687	0.015	0	0.0268	0.0119	0.0057	0.00106	0.0001	0.08
111	30/08/10 07:35	1035041	0.0488	0.016	0	0.0298	0.0136	0.0043	0.00326	0.0001	0.06
112	30/08/10 08:39	1035042	0.0487	0.015	0.001	0.031	0.0158	0.0067	0.01259	0.00034	0.06
113	30/08/10 09:40	1035043	0.0543	0.017	0	0.0204	0.0125	0.005	0.00167	0.0001	0.06
114	30/08/10 10:44	1035044	0.0539	0.023	0	0.051	0.018	0.0323	0.00542	0.0001	0.07
115	30/08/10 11:50	1035045	0.052	0.018	0	0.0279	0.0113	0.0107	0.00314	0.0001	0.06
116	30/08/10 12:59	1035046	0.0602	0.018	0.011	0.0274	0.0181	0.007	0.00266	0.0001	0.07
117	30/08/10 13:59	1035047	0.0679	0.017	0	0.0124	0.0102	0.0029	0.00414	0.0001	0.07
118	30/08/10 15:03	1035048	0.075	0.022	0	0.0374	0.0145	0.0098	0.00657	0.0001	0.09
119	30/08/10 16:14	1035049	0.091	0.02	0	0.0255	0.0261	0.008	0.00485	0.00017	0.10
120	30/08/10 17:20	1035050	0.1503	0.021	0	0.0042	0.0141	0.0039	0.00443	0.00078	0.16

Mean =	0.06303	0.01873	0.00074	0.03409	0.01562	0.00954	0.00478	0.000171
St. Deviation =	0.01387	0.00544	0.00184	0.01338	0.00521	0.00474	0.00332	0.000214

Correlation coefficient (C & CE)= **0.981**

Elements Present

	Actual/Measured (%)		Reference Data (%) Min	Aim	Max
Carbon (C) =	0.06303	%	0.04	0.06	0.07
Manganese (Mn) =	0.01873	%	0.15	0.2	0.25
Silicon (Si) =	0.00074	%			0.03
Nickel (Ni) =	0.01562	%			0.12
Chromium (Cr) =	0.00954	%			0.08
Molybdnynum (Mo) =	0.00478	%			0.015
Vanadium (V) =	0.00017	%			0.008
Copper (Cu) =	0.03409	%			0.11

Carbon Equivalent for Weldability

CE = C + Si/6 + Mn/6 + Cr/5 + Mo/5 + V/5 + Ni/15 + Cu/15

Actual / Measured Data
0.07

Reference Data	
Min	**0.11**
Aim	**0.13**
Max	**0.15**

Appendix - III B

Continuous Casting Machine
(CCM)

	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E.
1	14/06/10 17:54	1024054	0.06	0.172	0.007	0.014	0.0139	0.0112	0.00619	0.014	0.10
2	14/06/10 18:57	1024055	0.0605	0.187	0.007	0.0197	0.0138	0.0144	0.00619	0.0197	0.10
3	14/06/10 20:07	1024056	0.058	0.177	0.006	0.014	0.0114	0.013	0.00579	0.014	0.10
4	14/06/10 21:13	1024057	0.051	0.187	0.007	0.026	0.0178	0.0186	0.00649	0.026	0.10
5	14/06/10 22:20	1024058	0.0729	0.207	0.013	0.0182	0.0139	0.0113	0.00606	0.0182	0.12
6	14/06/10 23:36	1024059	0.0645	0.198	0.012	0.0297	0.0149	0.015	0.0069	0.0297	0.11
7	16/06/10 17:15	1024080	0.0609	0.19	0.017	0.0176	0.0129	0.0162	0.00659	0.0176	0.11
8	16/06/10 18:23	1024081	0.0555	0.172	0.005	0.0219	0.0155	0.0144	0.00615	0.0219	0.10
9	16/06/10 19:46	1024082	0.0597	0.184	0.009	0.0219	0.0146	0.016	0.0073	0.0219	0.10
10	16/06/10 20:57	1024083	0.0634	0.18	0.009	0.0325	0.0167	0.0132	0.00635	0.0325	0.11
11	28/07/10 18:18	1030089	0.0625	0.179	0.006	0.0348	0.0131	0.0137	0.00207	0.0001	0.10
12	28/07/10 19:26	1030090	0.0496	0.177	0.004	0.0303	0.0134	0.0124	0.00218	0.0001	0.09
13	28/07/10 20:42	1030091	0.0649	0.167	0.007	0.0336	0.02	0.0144	0.00297	0.0001	0.10
14	28/07/10 21:57	1030092	0.0599	0.163	0.003	0.0289	0.0129	0.0145	0.00213	0.0001	0.09
15	28/07/10 23:06	1030093	0.0571	0.17	0.005	0.0262	0.0103	0.0181	0.00156	0.0001	0.09
16	29/07/10 00:10	1030094	0.0591	0.169	0.008	0.0342	0.0145	0.018	0.00294	0.0001	0.10
17	29/07/10 01:14	1030095	0.0614	0.161	0.003	0.0236	0.0112	0.0123	0.00166	0.0001	0.09
18	29/07/10 02:26	1030096	0.0549	0.172	0.006	0.0242	0.0118	0.0144	0.00196	0.0001	0.09
19	29/07/10 03:32	1030097	0.0591	0.169	0.008	0.0277	0.0116	0.0205	0.00778	0.00013	0.10
20	29/07/10 04:35	1030098	0.0695	0.179	0.004	0.0211	0.0149	0.0165	0.00059	0.0001	0.11
21	29/07/10 05:44	1030099	0.0663	0.183	0.005	0.0285	0.0143	0.0164	0.00197	0.0001	0.10
22	29/07/10 06:51	1030100	0.0547	0.18	0.005	0.0238	0.0218	0.0167	0.00239	0.0001	0.09
23	29/07/10 07:55	1030101	0.0573	0.178	0.004	0.0296	0.0131	0.0149	0.00164	0.0001	0.09
24	29/07/10 08:58	1030102	0.0528	0.188	0.01	0.0351	0.0146	0.0127	0.00141	0.0001	0.09
25	29/07/10 10:03	1030103	0.0548	0.183	0.02	0.0382	0.0131	0.0122	0.0009	0.0001	0.09
26	29/07/10 11:13	1030104	0.0578	0.185	0.012	0.0439	0.0119	0.0145	0.001	0.0001	0.10
27	29/07/10 12:33	1030105	0.0743	0.192	0.006	0.0302	0.0204	0.0123	0.00277	0.0001	0.11
28	29/07/10 13:25	1030106	0.0626	0.187	0.006	0.0412	0.0187	0.0244	0.00967	0.00013	0.11
29	29/07/10 14:47	1030107	0.0595	0.189	0.006	0.0383	0.0132	0.0161	0.00182	0.0001	0.10
30	29/07/10 15:50	1030108	0.0587	0.178	0.004	0.0379	0.0319	0.0347	0.00187	0.0001	0.10
31	29/07/10 17:01	1030109	0.0697	0.17	0.006	0.0376	0.0158	0.0214	0.00216	0.0001	0.11
32	29/07/10 20:18	1030112	0.0606	0.183	0.003	0.0288	0.0112	0.0164	0.00071	0.0001	0.10
33	29/07/10 21:12	1030113	0.0571	0.189	0.007	0.0374	0.0132	0.0168	0.00155	0.0001	0.10
34	29/07/10 22:15	1030114	0.0652	0.172	0.004	0.0709	0.0183	0.0273	0.00204	0.0001	0.11
35	30/07/10 00:35	1030116	0.0616	0.164	0.003	0.0402	0.0117	0.0165	0.0007	0.0001	0.10
36	30/07/10 01:36	1030117	0.0642	0.169	0.008	0.0236	0.0106	0.0127	0.00026	0.0001	0.10
37	30/07/10 02:45	1030118	0.0624	0.174	0.004	0.0266	0.017	0.0199	0.00379	0.0001	0.10
38	30/07/10 03:52	1030119	0.0566	0.167	0.003	0.025	0.0148	0.0186	0.001	0.0001	0.09
39	30/07/10 04:59	1030120	0.0638	0.169	0.005	0.0369	0.0145	0.0219	0.00107	0.0001	0.10
40	30/07/10 06:04	1030121	0.0628	0.171	0.005	0.0187	0.0088	0.0123	0.00084	0.0001	0.10
41	30/07/10 07:01	1030122	0.0649	0.171	0.01	0.0192	0.0086	0.013	0.00077	0.0001	0.10
42	30/07/10 08:18	1030123	0.063	0.169	0.007	0.0299	0.0127	0.0123	0.00165	0.0001	0.10
43	30/07/10 09:13	1030124	0.0573	0.193	0.007	0.0401	0.0138	0.0116	0.00234	0.0001	0.10
44	30/07/10 11:17	1030126	0.0546	0.156	0.014	0.0316	0.0186	0.0108	0.00169	0.0001	0.09
45	30/07/10 12:33	1030127	0.0582	0.172	0.012	0.0519	0.0173	0.0126	0.0022	0.0001	0.10
46	31/07/10 07:28	1031001	0.0582	0.183	0.01	0.0429	0.0118	0.0129	0.0001	0.0001	0.10
47	31/07/10 08:35	1031002	0.0675	0.176	0.009	0.0314	0.0111	0.0135	0.00013	0.0001	0.10
48	31/07/10 09:41	1031003	0.0698	0.197	0.008	0.0302	0.0102	0.0126	0.00214	0.0001	0.11
49	31/07/10 11:42	1031005	0.0732	0.179	0.007	0.0335	0.0102	0.0131	0.0011	0.0001	0.11
50	31/07/10 12:59	1031006	0.0639	0.194	0.004	0.0359	0.0099	0.0114	0.00117	0.0001	0.10
51	31/07/10 15:08	1031008	0.0568	0.183	0.005	0.0404	0.0128	0.0165	0.00151	0.0001	0.10
52	31/07/10 16:30	1031009	0.0601	0.179	0.003	0.036	0.0129	0.014	0.00183	0.0001	0.10
53	31/07/10 17:37	1031010	0.056	0.181	0.003	0.0465	0.0107	0.0148	0.00124	0.0001	0.09
54	31/07/10 18:52	1031011	0.0588	0.181	0.005	0.0489	0.0175	0.0201	0.00167	0.0001	0.10
55	31/07/10 19:59	1031012	0.0585	0.179	0.004	0.0452	0.0182	0.0191	0.00231	0.0001	0.10
56	31/07/10 21:23	1031013	0.0548	0.169	0.002	0.0406	0.0138	0.0143	0.00177	0.0001	0.09
57	31/07/10 22:30	1031014	0.0588	0.154	0.002	0.0392	0.0165	0.0118	0.00222	0.0001	0.09

58	01/08/10 00:12	1031015	0.0525	0.173	0.004	0.0479	0.0138	0.0151	0.00173	0.0001	0.09
59	09/08/10 17:11	1032044	0.0467	0.194	0.006	0.0143	0.0079	0.0202	0.00044	0.0001	0.09
60	09/08/10 18:33	1032045	0.0596	0.155	0.008	0.0167	0.0075	0.0148	0.00024	0.0001	0.09
61	09/08/10 19:36	1032046	0.0546	0.159	0.009	0.0157	0.0088	0.0154	0.00012	0.0001	0.09
62	09/08/10 20:57	1032047	0.0624	0.17	0.003	0.0023	0.0036	0.0084	0.0001	0.0001	0.09
63	09/08/10 22:17	1032048	0.0611	0.15	0.003	0.0266	0.013	0.014	0.00116	0.0001	0.09
64	09/08/10 23:33	1032049	0.0624	0.189	0.004	0.0381	0.016	0.016	0.01055	0.0001	0.10
65	10/08/10 00:34	1032050	0.0617	0.174	0.003	0.0108	0.0062	0.0091	0.00272	0.0001	0.09
66	10/08/10 01:48	1032051	0.0555	0.177	0.004	0.0191	0.0092	0.0123	0.0036	0.0001	0.09
67	10/08/10 02:51	1032052	0.0615	0.178	0.008	0.0321	0.0112	0.0144	0.00253	0.0001	0.10
68	11/08/10 17:49	1032087	0.0698	0.198	0.006	0.0371	0.0155	0.0163	0.00228	0.0001	0.11
69	11/08/10 18:54	1032088	0.0666	0.161	0.01	0.0315	0.014	0.0148	0.00118	0.0001	0.10
70	11/08/10 19:53	1032089	0.062	0.178	0.007	0.0231	0.0117	0.0162	0.00082	0.0001	0.10
71	11/08/10 20:58	1032090	0.0602	0.166	0.004	0.007	0.0052	0.0112	0.0001	0.0001	0.09
72	11/08/10 22:05	1032091	0.0611	0.149	0.007	0.0292	0.0156	0.0138	0.00016	0.0001	0.09
73	11/08/10 23:15	1032092	0.0694	0.172	0.006	0.0294	0.0196	0.0092	0.0019	0.0001	0.10
74	12/08/10 00:21	1032093	0.0641	0.169	0.005	0.0261	0.0206	0.0111	0.0009	0.0001	0.10
75	12/08/10 01:31	1032094	0.06	0.152	0.004	0.0297	0.0203	0.0109	0.0012	0.0001	0.09
76	12/08/10 02:40	1032095	0.0588	0.173	0.007	0.0091	0.009	0.0079	0.00024	0.0001	0.09
77	12/08/10 03:51	1032096	0.0612	0.164	0.003	0.018	0.0114	0.0082	0.00074	0.0001	0.09
78	12/08/10 06:05	1032098	0.0589	0.189	0.004	0.008	0.0075	0.0118	0.00106	0.0001	0.09
79	12/08/10 07:20	1032099	0.0639	0.182	0.007	0.0356	0.0139	0.0157	0.00276	0.0001	0.10
80	12/08/10 08:25	1032100	0.0676	0.166	0.004	0.0086	0.0072	0.0068	0.00066	0.0001	0.10
81	12/08/10 09:27	1032101	0.0664	0.187	0.006	0.0316	0.0149	0.0117	0.00217	0.0001	0.10
82	12/08/10 10:28	1032102	0.0649	0.183	0.004	0.0336	0.0178	0.0136	0.00247	0.0001	0.10
83	12/08/10 11:35	1032103	0.0639	0.177	0.002	0.0306	0.0173	0.0234	0.00325	0.0001	0.10
84	12/08/10 12:35	1032104	0.0675	0.164	0.006	0.0301	0.0166	0.0186	0.00277	0.0001	0.10
85	12/08/10 13:40	1032105	0.0649	0.171	0.003	0.0426	0.0166	0.0142	0.00315	0.0001	0.10
86	12/08/10 14:44	1032106	0.0549	0.177	0.002	0.0378	0.0185	0.0183	0.00272	0.0001	0.09
87	12/08/10 15:50	1032107	0.0651	0.185	0.004	0.0404	0.0148	0.0179	0.00276	0.0001	0.10
88	12/08/10 16:53	1032108	0.066	0.178	0.006	0.0421	0.0198	0.0206	0.00263	0.0001	0.11
89	12/08/10 17:55	1032109	0.0719	0.184	0.004	0.0434	0.0175	0.0215	0.00331	0.0001	0.11
90	12/08/10 19:00	1032110	0.0659	0.158	0.005	0.0117	0.0086	0.0125	0.00066	0.0001	0.10
91	12/08/10 20:03	1032111	0.0632	0.163	0.004	0.0345	0.0189	0.0228	0.00203	0.0001	0.10
92	12/08/10 21:14	1032112	0.0658	0.157	0.007	0.0333	0.0272	0.021	0.00436	0.0001	0.10
93	12/08/10 22:19	1032113	0.0687	0.15	0.005	0.025	0.0197	0.0102	0.00132	0.0001	0.10
94	12/08/10 23:28	1032114	0.0642	0.175	0.006	0.019	0.0177	0.0063	0.00204	0.0001	0.10
95	13/08/10 01:36	1032116	0.0536	0.168	0.005	0.0053	0.0061	0.0047	0.0001	0.0001	0.08
96	13/08/10 02:57	1032117	0.0582	0.175	0.004	0.0369	0.0146	0.0119	0.00171	0.0001	0.09
97	13/08/10 03:59	1032118	0.0662	0.201	0.006	0.0447	0.016	0.0169	0.0029	0.0001	0.11
98	13/08/10 05:23	1032119	0.0722	0.152	0.01	0.0405	0.0147	0.0115	0.00295	0.0001	0.11
99	13/08/10 06:19	1032120	0.0617	0.174	0.003	0.0098	0.0062	0.0103	0.00066	0.0001	0.09
100	13/08/10 07:27	1032121	0.057	0.156	0.008	0.0521	0.0154	0.0175	0.00246	0.0001	0.09
101	29/08/10 19:41	1035031	0.0555	0.19	0.004	0.0365	0.0125	0.0086	0.00106	0.0001	0.09
102	29/08/10 20:54	1035032	0.0582	0.165	0.002	0.0346	0.0166	0.0119	0.0014	0.0001	0.09
103	29/08/10 22:14	1035033	0.0636	0.161	0.002	0.0253	0.0133	0.0105	0.00062	0.0001	0.10
104	29/08/10 23:30	1035034	0.0572	0.154	0.004	0.03	0.0151	0.0113	0.00034	0.0001	0.09
105	30/08/10 01:06	1035035	0.0543	0.151	0.004	0.007	0.0066	0.0074	0.0001	0.0001	0.08
106	30/08/10 02:13	1035036	0.0615	0.164	0.004	0.0151	0.0108	0.0077	0.00012	0.0001	0.09
107	30/08/10 03:18	1035037	0.0651	0.162	0.004	0.0204	0.0112	0.011	0.0001	0.0001	0.10
108	30/08/10 04:22	1035038	0.0628	0.161	0.004	0.0178	0.0109	0.0099	0.0001	0.0001	0.09
109	30/08/10 05:26	1035039	0.0725	0.18	0.005	0.0363	0.0126	0.0125	0.00078	0.0001	0.11
110	30/08/10 06:31	1035040	0.061	0.17	0.004	0.024	0.0115	0.0103	0.0001	0.0001	0.09
111	30/08/10 07:35	1035041	0.0449	0.193	0.004	0.0251	0.0126	0.0084	0.00069	0.0001	0.08
112	30/08/10 08:39	1035042	0.0569	0.168	0.003	0.0261	0.0127	0.006	0.00037	0.0001	0.09
113	30/08/10 09:40	1035043	0.0535	0.186	0.02	0.0201	0.0128	0.0101	0.00063	0.0001	0.09
114	30/08/10 10:44	1035044	0.0518	0.192	0.006	0.0433	0.0161	0.0336	0.00207	0.0001	0.10
115	30/08/10 11:50	1035045	0.0577	0.154	0.003	0.0265	0.0118	0.0144	0.00138	0.0001	0.09
116	30/08/10 12:59	1035046	0.0622	0.185	0.006	0.0218	0.0156	0.0113	0.00097	0.0001	0.10
117	30/08/10 13:59	1035047	0.0573	0.19	0.009	0.0097	0.0118	0.0097	0.00087	0.0001	0.09
118	30/08/10 15:03	1035048	0.05	0.19	0.007	0.0323	0.0139	0.0168	0.00978	0.00028	0.09
119	30/08/10 16:14	1035049	0.0503	0.189	0.008	0.0221	0.0237	0.0154	0.00216	0.0001	0.09
120	30/08/10 17:20	1035050	0.0604	0.182	0.01	0.0052	0.0149	0.0119	0.00618	0.00159	0.10

Mean =	0.06085	0.17506	0.00603	0.02897	0.01391	0.01441	0.00224	0.00190
St. Deviation =	0.00564	0.01254	0.00328	0.01167	0.00427	0.00481	0.00216	0.00619

Correlation coefficient (C & CE)= **0.83030**

Elements Present

	Actual/Measured (%)		Reference Data (%)		
			Min	Aim	Max
Carbon (C) =	0.06085	%	0.04	0.06	0.07
Manganese (Mn) =	0.17506	%	0.15	0.2	0.25
Silicon (Si) =	0.00603	%			0.03
Nickel (Ni) =	0.01391	%			0.12
Chromium (Cr) =	0.01441	%			0.08
Molybdnynum (Mo) =	0.00224	%			0.015
Vanadium (V) =	0.00190	%			0.008
Copper (Cu) =	0.02897	%			0.11

Carbon Equivalent for Weldability

$$CE = C + Si/6 + Mn/6 + Cr/5 + Mo/5 + V/5 + Ni/15 + Cu/15$$

Actual / Measured Data
0.10

Reference Data	
Min	**0.11**
Aim	**0.13**
Max	**0.15**

Appendix - IV A

Chemical Analysis: 2910 **Standard: EN 10130: 1991** **Steel Grade: FeP01**			Electric Arc Furnace (EAF)								
	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E.
1	16/06/10 23:43	1024085	0.03080	0.00900	0.00100	0.03550	0.01720	0.00550	0.01064	0.00013	0.04
2	17/06/10 00:58	1024086	0.03410	0.00500	0.00000	0.02420	0.01440	0.00260	0.00733	0.00013	0.04
3	17/06/10 02:07	1024087	0.03910	0.00800	0.00200	0.05010	0.02020	0.00500	0.01005	0.00013	0.05
4	17/06/10 03:18	1024088	0.04830	0.00900	0.00200	0.04870	0.01540	0.00610	0.01150	0.00048	0.06
5	17/06/10 04:32	1024089	0.04810	0.01000	0.00100	0.02040	0.01150	0.00460	0.01047	0.00017	0.06
6	17/06/10 05:28	1024090	0.04720	0.01100	0.00000	0.03020	0.02200	0.00660	0.01035	0.00013	0.06
7	17/06/10 06:49	1024091	0.04700	0.00900	0.00100	0.02830	0.01860	0.00460	0.01250	0.00013	0.06
8	17/06/10 07:54	1024092	0.05860	0.02000	0.00200	0.03850	0.01960	0.01140	0.01163	0.00049	0.07
9	17/06/10 09:00	1024093	0.05360	0.02000	0.00300	0.04050	0.01900	0.00870	0.01315	0.00055	0.07
10	17/06/10 10:03	1024094	0.05260	0.02300	0.00200	0.04440	0.02520	0.01420	0.01658	0.00069	0.07
11	17/06/10 11:09	1024095	0.05440	0.02000	0.00100	0.03610	0.02130	0.01410	0.00982	0.00029	0.07
12	17/06/10 12:22	1024096	0.05480	0.02400	0.00300	0.03600	0.02140	0.01020	0.01718	0.00093	0.07
13	17/06/10 13:22	1024097	0.06080	0.01700	0.00100	0.02850	0.01770	0.00600	0.01459	0.00040	0.07
14	17/06/10 14:27	1024098	0.05360	0.02400	0.00200	0.02950	0.01640	0.00750	0.01217	0.00034	0.06
15	17/06/10 15:37	1024099	0.11430	0.01300	0.00100	0.00840	0.01740	0.01130	0.01124	0.00160	0.12
16	17/06/10 16:41	1024100	0.04890	0.02200	0.01200	0.02500	0.02120	0.00790	0.01254	0.00076	0.06
17	17/06/10 17:45	1024101	0.04890	0.01900	0.00200	0.03640	0.02390	0.01000	0.01323	0.00049	0.06
18	17/06/10 19:02	1024102	0.05660	0.01700	0.00300	0.03260	0.01880	0.00810	0.01314	0.00050	0.07
19	17/06/10 20:14	1024103	0.05420	0.01300	0.00100	0.02420	0.01330	0.00630	0.01165	0.00034	0.06
20	17/06/10 21:33	1024104	0.05040	0.02300	0.00800	0.04780	0.02310	0.01250	0.01342	0.00043	0.07
21	17/06/10 22:42	1024105	0.05020	0.01700	0.00300	0.02970	0.01430	0.00810	0.01190	0.00043	0.06
22	17/06/10 23:44	1024106	0.05350	0.01800	0.00100	0.02790	0.01510	0.00820	0.01213	0.00019	0.06
23	18/06/10 01:05	1024107	0.06300	0.01800	0.00000	0.02390	0.01410	0.01010	0.01152	0.00058	0.07
24	18/06/10 02:14	1024108	0.05300	0.01700	0.00100	0.02620	0.01490	0.00850	0.01307	0.00047	0.06
25	18/06/10 03:15	1024109	0.04880	0.01700	0.00100	0.03030	0.01440	0.00790	0.01146	0.00013	0.06
26	18/06/10 04:34	1024110	0.05850	0.01700	0.00100	0.03080	0.01410	0.00950	0.01244	0.00031	0.07
27	18/06/10 05:23	1024111	0.05410	0.02400	0.00500	0.04060	0.02250	0.01840	0.01355	0.00053	0.07
28	18/06/10 06:26	1024112	0.04830	0.02400	0.00500	0.03470	0.01710	0.00970	0.01490	0.00063	0.06
29	18/06/10 07:44	1024113	0.05510	0.02300	0.00400	0.03170	0.01340	0.00830	0.01221	0.00050	0.07
30	18/06/10 09:00	1024114	0.04830	0.02500	0.00200	0.02470	0.01550	0.00700	0.01419	0.00040	0.06
31	18/06/10 10:09	1024115	0.06240	0.01700	0.00000	0.01640	0.01410	0.00160	0.00616	0.00010	0.07
32	18/06/10 11:21	1024116	0.07500	0.03200	0.00300	0.03370	0.01820	0.00920	0.01717	0.00096	0.09
33	18/06/10 12:22	1024117	0.10060	0.15500	0.01700	0.00460	0.02200	0.01200	0.02424	0.00013	0.14
34	18/06/10 13:23	1024118	0.07040	0.02500	0.00100	0.04810	0.01700	0.01270	0.01275	0.00061	0.08
35	18/06/10 14:32	1024119	0.05540	0.02100	0.00200	0.03150	0.01490	0.00950	0.01256	0.00047	0.07
36	18/06/10 15:31	1024120	0.06790	0.02200	0.00200	0.05030	0.02240	0.01070	0.01413	0.00092	0.08
37	18/06/10 16:34	1024121	0.07460	0.01800	0.00100	0.04350	0.01810	0.00970	0.01242	0.00079	0.09
38	18/06/10 17:43	1024122	0.07220	0.02000	0.00100	0.03750	0.01730	0.01020	0.01284	0.00074	0.08
39	18/06/10 18:43	1024123	0.05620	0.02100	0.00100	0.02990	0.01380	0.00930	0.01219	0.00072	0.07
40	18/06/10 19:58	1024124	0.06560	0.03200	0.00200	0.03410	0.01840	0.01250	0.01380	0.00098	0.08
41	18/06/10 21:05	1024125	0.08020	0.02400	0.00100	0.03480	0.01470	0.01160	0.01304	0.00089	0.09
42	18/06/10 22:19	1024126	0.07740	0.02000	0.00100	0.02770	0.01560	0.01070	0.01198	0.00061	0.09
43	18/06/10 23:26	1024127	0.06010	0.01800	0.00200	0.02960	0.01560	0.01070	0.01293	0.00054	0.07
44	19/06/10 00:29	1024128	0.06630	0.02600	0.00200	0.02850	0.01460	0.01030	0.01276	0.00052	0.08
45	19/06/10 01:33	1024129	0.07040	0.02600	0.00300	0.03090	0.01490	0.02000	0.01712	0.00103	0.09
46	19/06/10 02:36	1024130	0.06640	0.02100	0.00100	0.02940	0.01550	0.01270	0.01441	0.00072	0.08
47	19/06/10 03:47	1024131	0.05830	0.02200	0.00400	0.03130	0.01510	0.01050	0.01671	0.00126	0.07
48	19/06/10 04:48	1024132	0.05750	0.02400	0.00200	0.05490	0.02670	0.01710	0.01497	0.00084	0.07
49	19/06/10 06:01	1024133	0.09130	0.02800	0.00100	0.04370	0.01860	0.01370	0.01470	0.00161	0.11
50	19/06/10 07:12	1025001	0.05480	0.02400	0.00300	0.04550	0.02300	0.01370	0.02059	0.00080	0.07
51	19/06/10 08:16	1025002	0.06640	0.02200	0.00200	0.03700	0.01900	0.01170	0.01531	0.00107	0.08
52	19/06/10 09:15	1025003	0.05390	0.01800	0.00100	0.03250	0.01340	0.00840	0.01256	0.00027	0.06
53	19/06/10 10:16	1025004	0.06340	0.02300	0.00000	0.03220	0.01860	0.00990	0.00842	0.00046	0.07
54	19/06/10 11:28	1025005	0.05780	0.02000	0.00800	0.02940	0.01730	0.00980	0.01245	0.00086	0.07
55	19/06/10 12:32	1025006	0.05580	0.01500	0.00100	0.02850	0.01270	0.00920	0.01158	0.00034	0.07
56	19/06/10 13:34	1025007	0.06500	0.01900	0.00000	0.04160	0.02180	0.01060	0.01188	0.00052	0.08

57	19/06/10 14:41	1025008	0.06230	0.02400	0.00000	0.03420	0.01590	0.01150	0.01076	0.00052	0.07
58	19/06/10 15:49	1025009	0.06770	0.02800	0.00000	0.02800	0.01490	0.01080	0.00915	0.00062	0.08
59	19/06/10 16:59	1025010	0.05890	0.01800	0.00100	0.02380	0.01260	0.00990	0.01218	0.00062	0.07
60	19/06/10 18:00	1025011	0.05770	0.02300	0.00100	0.03080	0.01660	0.01080	0.01058	0.00047	0.07
61	19/06/10 19:03	1025012	0.05970	0.02700	0.00200	0.03640	0.02220	0.01420	0.01306	0.00037	0.07
62	19/06/10 20:12	1025013	0.06190	0.01800	0.00000	0.02430	0.01480	0.00790	0.01107	0.00037	0.07
63	19/06/10 21:11	1025014	0.05720	0.02000	0.00300	0.03900	0.02420	0.01100	0.01524	0.00077	0.07
64	19/06/10 22:28	1025015	0.06740	0.01200	0.00200	0.01210	0.00950	0.00670	0.01149	0.00071	0.07
65	19/06/10 23:48	1025016	0.07080	0.01800	0.00200	0.03560	0.02760	0.02580	0.01747	0.00117	0.09
66	20/06/10 00:56	1025017	0.05870	0.01400	0.00100	0.04870	0.02830	0.01700	0.01602	0.00091	0.07
67	20/06/10 01:59	1025018	0.05570	0.02000	0.00100	0.03630	0.02040	0.01070	0.01313	0.00071	0.07
68	20/06/10 03:08	1025019	0.07450	0.01900	0.00200	0.02480	0.01810	0.01060	0.01332	0.00069	0.09
69	20/06/10 04:03	1025020	0.07900	0.03200	0.00100	0.02550	0.02960	0.02360	0.02219	0.00063	0.10
70	20/06/10 05:10	1025021	0.05690	0.03200	0.00200	0.04150	0.02570	0.01970	0.01622	0.00064	0.07
71	20/06/10 06:19	1025022	0.05530	0.02000	0.00500	0.03750	0.01890	0.01030	0.01569	0.00088	0.07
72	20/06/10 07:18	1025023	0.05210	0.02700	0.00100	0.03780	0.02190	0.01410	0.01464	0.00084	0.07
73	20/06/10 08:28	1025024	0.05630	0.02200	0.00100	0.04510	0.01990	0.00900	0.01465	0.00094	0.07
74	20/06/10 09:27	1025025	0.06690	0.02300	0.00400	0.04470	0.02410	0.01320	0.01866	0.00227	0.08
75	20/06/10 10:32	1025026	0.05690	0.01800	0.00100	0.02850	0.01690	0.00780	0.01269	0.00069	0.07
76	20/06/10 11:34	1025027	0.06370	0.02000	0.00200	0.03010	0.01420	0.00850	0.01165	0.00073	0.07
77	20/06/10 12:36	1025028	0.19200	0.02500	0.00100	0.02410	0.01490	0.00850	0.00914	0.00083	0.20
78	20/06/10 13:43	1025029	0.06590	0.01600	0.00200	0.03550	0.01410	0.00590	0.01407	0.00060	0.08
79	20/06/10 15:04	1025030	0.06030	0.02000	0.00200	0.03060	0.01720	0.00680	0.01259	0.00049	0.07
80	20/06/10 16:16	1025031	0.05830	0.03000	0.00100	0.03790	0.01720	0.01350	0.01340	0.00041	0.07
81	20/06/10 17:22	1025032	0.06850	0.02900	0.00200	0.02590	0.01790	0.01410	0.01194	0.00041	0.08
82	20/06/10 18:42	1025033	0.10590	0.02400	0.00200	0.03130	0.01570	0.01290	0.01137	0.00017	0.12
83	20/06/10 19:44	1025034	0.06960	0.02500	0.00200	0.02650	0.01580	0.01170	0.01463	0.00039	0.08
84	20/06/10 20:49	1025035	0.06710	0.02500	0.00100	0.02550	0.01500	0.01180	0.01196	0.00028	0.08
85	20/06/10 22:25	1025036	0.07000	0.02900	0.00100	0.03680	0.01560	0.01930	0.01272	0.00037	0.08
86	20/06/10 23:19	1025037	0.07320	0.03500	0.00100	0.04420	0.01990	0.02020	0.01448	0.00018	0.09
87	21/06/10 00:44	1025038	0.06980	0.03000	0.00200	0.05160	0.01910	0.02050	0.01382	0.00017	0.09
88	21/06/10 01:49	1025039	0.06310	0.02100	0.00100	0.04410	0.01860	0.01230	0.01218	0.00020	0.08
89	21/06/10 03:02	1025040	0.04900	0.03700	0.00600	0.03590	0.01600	0.01520	0.02206	0.00067	0.07
90	21/06/10 04:10	1025041	0.06280	0.03600	0.00200	0.04990	0.01810	0.02020	0.01450	0.00052	0.08

Mean =	0.06277	0.02273	0.00212	0.03353	0.01797	0.01103	0.01332	0.00059
St. Deviation =	0.01894	0.01542	0.00244	0.00931	0.00397	0.00440	0.00292	0.00036

Correlation coefficient (C & CE)= **0.98310**

Elements Present

	Actual/Measured (%)	
Carbon (C) =	0.06277	%
Manganese (Mn) =	0.02273	%
Silicon (Si) =	0.00212	%
Nickel (Ni) =	0.01797	%
Chromium (Cr) =	0.01103	%
Molybdnynum (Mo) =	0.01332	%
Vanadium (V) =	0.00059	%
Copper (Cu) =	0.03353	%

Reference Data (%)		
Min	Aim	Max
0.08	0.09	0.1
1.25	1.3	1.35
0.2	0.3	0.35
		0.06
		0.06
		0.05
		0.01
		0.06

Carbon Equivalent for Weldability

CE = C + Si/6 + Mn/6 + Cr/5 + Mo/5 + V/5 + Ni/15 + Cu/15

Actual / Measured Data
0.08

Reference Data	
Min	**0.35**
Aim	**0.39**
Max	**0.42**

Appendix - IV B

Ladle Furnace (LF)											
	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E.
1	16/06/10 23:43	1024085	0.0773	1.289	0.229	0.0333	0.0157	0.0119	0.0001	0.00108	0.34
2	17/06/10 00:58	1024086	0.0823	1.29	0.22	0.0229	0.013	0.0106	0.00032	0.00115	0.34
3	17/06/10 02:07	1024087	0.0799	1.288	0.238	0.0475	0.0182	0.0126	0.00157	0.00084	0.34
4	17/06/10 03:18	1024088	0.0927	1.262	0.223	0.0427	0.0162	0.0138	0.00205	0.00106	0.35
5	17/06/10 04:32	1024089	0.0825	1.273	0.241	0.0213	0.0115	0.0113	0.001	0.00155	0.34
6	17/06/10 05:28	1024090	0.086	1.257	0.22	0.0279	0.0187	0.0158	0.00195	0.00125	0.34
7	17/06/10 06:49	1024091	0.0811	1.265	0.214	0.0274	0.0174	0.0151	0.0016	0.0012	0.33
8	17/06/10 07:54	1024092	0.085	1.279	0.244	0.035	0.0182	0.0181	0.00151	0.00187	0.35
9	17/06/10 09:00	1024093	0.0938	1.273	0.241	0.0348	0.0177	0.0171	0.00227	0.00174	0.35
10	17/06/10 10:03	1024094	0.0804	1.264	0.216	0.0377	0.0235	0.0233	0.00515	0.00162	0.34
11	17/06/10 11:09	1024095	0.0861	1.275	0.213	0.0319	0.0192	0.0242	0.00453	0.00116	0.34
12	17/06/10 12:22	1024096	0.0822	1.276	0.229	0.0326	0.0195	0.0178	0.00311	0.0015	0.34
13	17/06/10 13:22	1024097	0.088	1.3	0.235	0.0257	0.0158	0.017	0.0022	0.00159	0.35
14	17/06/10 14:27	1024098	0.0837	1.26	0.208	0.0257	0.0147	0.021	0.00184	0.00131	0.34
15	17/06/10 15:37	1024099	0.0937	1.276	0.2	0.0069	0.0095	0.0215	0.00038	0.00165	0.35
16	17/06/10 16:41	1024100	0.0842	1.26	0.204	0.0213	0.0159	0.0184	0.00142	0.00133	0.33
17	17/06/10 17:45	1024101	0.0792	1.306	0.214	0.0328	0.0215	0.0338	0.00307	0.00155	0.34
18	17/06/10 19:02	1024102	0.086	1.288	0.203	0.0296	0.0157	0.0192	0.00161	0.00126	0.34
19	17/06/10 20:14	1024103	0.0833	1.283	0.229	0.0227	0.0124	0.0279	0.0011	0.00105	0.34
20	17/06/10 21:33	1024104	0.0869	1.253	0.217	0.04	0.0176	0.0238	0.00167	0.00135	0.34
21	17/06/10 22:42	1024105	0.0844	1.285	0.208	0.0267	0.0127	0.0187	0.0014	0.00158	0.34
22	17/06/10 23:44	1024106	0.0817	1.275	0.218	0.0242	0.0127	0.0189	0.00175	0.00138	0.34
23	18/06/10 01:05	1024107	0.0826	1.264	0.216	0.0225	0.0131	0.0197	0.00198	0.00104	0.34
24	18/06/10 02:14	1024108	0.0769	1.262	0.215	0.0255	0.0143	0.0173	0.00167	0.00117	0.33
25	18/06/10 03:15	1024109	0.0841	1.297	0.207	0.0279	0.0124	0.0173	0.00178	0.00119	0.34
26	18/06/10 04:34	1024110	0.0802	1.26	0.195	0.03	0.0139	0.0195	0.00241	0.00114	0.33
27	18/06/10 05:23	1024111	0.0838	1.276	0.235	0.0362	0.0192	0.0272	0.00402	0.00131	0.35
28	18/06/10 06:26	1024112	0.0808	1.284	0.223	0.0304	0.0147	0.0205	0.00263	0.00138	0.34
29	18/06/10 07:44	1024113	0.0801	1.289	0.231	0.0284	0.0121	0.0182	0.0014	0.00116	0.34
30	18/06/10 09:00	1024114	0.0883	1.367	0.242	0.0205	0.013	0.0195	0.00199	0.0014	0.36
31	18/06/10 10:09	1024115	0.0844	1.275	0.227	0.0171	0.0114	0.0189	0.00184	0.00124	0.34
32	18/06/10 11:21	1024116	0.0888	1.298	0.197	0.0292	0.0151	0.0174	0.00167	0.00116	0.34
33	18/06/10 12:22	1024117	0.0852	1.265	0.195	0.023	0.0139	0.0189	0.00239	0.00152	0.34
34	18/06/10 13:23	1024118	0.0768	1.286	0.211	0.0417	0.0154	0.0219	0.00205	0.00152	0.34
35	18/06/10 14:32	1024119	0.0827	1.272	0.217	0.0296	0.0135	0.0192	0.00177	0.00131	0.34
36	18/06/10 15:31	1024120	0.076	1.257	0.198	0.0434	0.0185	0.0176	0.00334	0.0011	0.33
37	18/06/10 16:34	1024121	0.0791	1.258	0.202	0.0367	0.0143	0.0195	0.00254	0.00125	0.33
38	18/06/10 17:43	1024122	0.0748	1.279	0.205	0.0338	0.015	0.0208	0.00211	0.00154	0.33
39	18/06/10 18:43	1024123	0.0814	1.279	0.214	0.0263	0.0123	0.0212	0.00218	0.00136	0.34
40	18/06/10 19:58	1024124	0.0863	1.289	0.215	0.0297	0.0156	0.0218	0.00311	0.00163	0.35
41	18/06/10 21:05	1024125	0.0808	1.288	0.206	0.0311	0.013	0.0217	0.00214	0.00135	0.34
42	18/06/10 22:19	1024126	0.0857	1.323	0.225	0.0255	0.0135	0.0174	0.0019	0.00136	0.35
43	18/06/10 23:26	1024127	0.0879	1.292	0.221	0.0265	0.0132	0.02	0.00247	0.00138	0.35
44	19/06/10 00:29	1024128	0.0831	1.262	0.209	0.0256	0.0127	0.0179	0.00196	0.00136	0.34
45	19/06/10 01:33	1024129	0.087	1.275	0.203	0.0273	0.0131	0.0223	0.00229	0.00153	0.34
46	19/06/10 02:36	1024130	0.0919	1.261	0.201	0.0261	0.0134	0.019	0.00208	0.00155	0.34
47	19/06/10 03:47	1024131	0.0813	1.274	0.216	0.0273	0.0147	0.0191	0.00239	0.00159	0.34
48	19/06/10 04:48	1024132	0.0811	1.275	0.216	0.0473	0.0234	0.0245	0.00609	0.00114	0.34
49	19/06/10 06:01	1024133	0.0847	1.273	0.204	0.036	0.016	0.0225	0.00341	0.00132	0.34
50	19/06/10 07:12	1025001	0.0833	1.291	0.216	0.0411	0.0202	0.0256	0.00501	0.0411	0.35
51	19/06/10 08:16	1025002	0.0806	1.277	0.207	0.0321	0.0164	0.0191	0.00186	0.0321	0.34
52	19/06/10 09:15	1025003	0.0773	1.265	0.211	0.0294	0.0118	0.0195	0.00184	0.0294	0.34
53	19/06/10 10:16	1025004	0.0788	1.284	0.212	0.0279	0.0161	0.0191	0.00065	0.0279	0.34
54	19/06/10 11:28	1025005	0.0817	1.294	0.219	0.0271	0.0154	0.0211	0.00054	0.0271	0.35
55	19/06/10 12:32	1025006	0.0861	1.317	0.206	0.0295	0.0137	0.0217	0.00047	0.0295	0.35
56	19/06/10 13:34	1025007	0.0789	1.276	0.21	0.0374	0.0186	0.021	0.00126	0.0374	0.34
57	19/06/10 14:41	1025008	0.0812	1.271	0.214	0.0305	0.014	0.0289	0.00182	0.0305	0.34

58	19/06/10 15:49	1025009	0.0762	1.295	0.216	0.0259	0.0134	0.0231	0.00179	0.0259	0.34
59	19/06/10 16:59	1025010	0.0889	1.248	0.197	0.022	0.0118	0.0195	0.00227	0.022	0.34
60	19/06/10 18:00	1025011	0.0806	1.262	0.209	0.0277	0.0142	0.0215	0.00244	0.0277	0.34
61	19/06/10 19:03	1025012	0.0818	1.279	0.208	0.0312	0.0174	0.0245	0.00275	0.0312	0.34
62	19/06/10 20:12	1025013	0.0855	1.294	0.209	0.0224	0.0127	0.0206	0.0018	0.0224	0.35
63	19/06/10 21:11	1025014	0.0743	1.279	0.202	0.0329	0.0208	0.026	0.0019	0.0329	0.34
64	19/06/10 22:28	1025015	0.0815	1.272	0.223	0.0115	0.0087	0.0182	0.00118	0.0115	0.34
65	19/06/10 23:48	1025016	0.0835	1.295	0.224	0.0319	0.0263	0.0304	0.00351	0.0319	0.35
66	20/06/10 00:56	1025017	0.0844	1.268	0.23	0.0445	0.0252	0.026	0.00449	0.0445	0.35
67	20/06/10 01:59	1025018	0.0811	1.259	0.202	0.0336	0.018	0.0184	0.00237	0.0336	0.34
68	20/06/10 03:08	1025019	0.091	1.279	0.217	0.0251	0.0171	0.0205	0.00191	0.0251	0.35
69	20/06/10 04:03	1025020	0.0852	1.262	0.2	0.0226	0.0248	0.0282	0.01064	0.0226	0.34
70	20/06/10 05:10	1025021	0.0844	1.282	0.233	0.0376	0.0225	0.0252	0.00532	0.0376	0.35
71	20/06/10 06:19	1025022	0.0831	1.248	0.208	0.0336	0.0166	0.0178	0.00339	0.0336	0.34
72	20/06/10 07:18	1025023	0.0902	1.266	0.203	0.0344	0.0179	0.0233	0.00414	0.0344	0.35
73	20/06/10 08:28	1025024	0.0747	1.277	0.219	0.0413	0.018	0.0175	0.00279	0.0413	0.34
74	20/06/10 09:27	1025025	0.0919	1.278	0.219	0.0349	0.022	0.019	0.00318	0.0349	0.36
75	20/06/10 10:32	1025026	0.0852	1.287	0.218	0.0259	0.0159	0.0165	0.00229	0.0259	0.35
76	20/06/10 11:34	1025027	0.0794	1.284	0.213	0.0279	0.0143	0.0197	0.00229	0.0279	0.34
77	20/06/10 12:36	1025028	0.0849	1.279	0.226	0.0226	0.0132	0.0161	0.00266	0.0226	0.35
78	20/06/10 13:43	1025029	0.0811	1.274	0.211	0.0338	0.0133	0.0167	0.00214	0.0338	0.34
79	20/06/10 15:04	1025030	0.0817	1.294	0.206	0.0273	0.016	0.0213	0.00211	0.0273	0.34
80	20/06/10 16:16	1025031	0.0783	1.265	0.224	0.0327	0.0136	0.0216	0.00243	0.0327	0.34
81	20/06/10 17:22	1025032	0.0947	1.232	0.168	0.0225	0.0138	0.023	0.00166	0.0225	0.34
82	20/06/10 18:42	1025033	0.0813	1.266	0.219	0.0299	0.0136	0.0242	0.00271	0.0299	0.34
83	20/06/10 19:44	1025034	0.0818	1.282	0.213	0.0239	0.0135	0.0205	0.00181	0.0239	0.34
84	20/06/10 20:49	1025035	0.08	1.261	0.219	0.0225	0.0119	0.0216	0.0018	0.0225	0.34
85	20/06/10 22:25	1025036	0.0853	1.281	0.207	0.0382	0.0158	0.0257	0.00235	0.0382	0.35
86	20/06/10 23:19	1025037	0.0746	1.281	0.213	0.0363	0.0138	0.0264	0.00373	0.0363	0.34
87	21/06/10 00:44	1025038	0.0841	1.259	0.219	0.0441	0.0149	0.0245	0.00363	0.0441	0.35
88	21/06/10 01:49	1025039	0.0837	1.295	0.206	0.0407	0.0161	0.0226	0.00242	0.0407	0.35
89	21/06/10 03:02	1025040	0.0879	1.308	0.22	0.032	0.0134	0.0245	0.002	0.032	0.36
90	21/06/10 04:10	1025041	0.0825	1.281	0.241	0.044	0.0161	0.0271	0.00233	0.044	0.35

Mean =	0.08321	1.27782	0.21497	0.03031	0.01568	0.02067	0.00239	0.01487
St. Deviation =	0.00444	0.01796	0.01258	0.00744	0.00345	0.00410	0.00140	0.01563

Correlation coefficient (C & CE)= **0.99941**

Elements Present

	Actual/Measured (%)	
Carbon (C) =	0.08321	%
Manganese (Mn) =	1.27782	%
Silicon (Si) =	0.21497	%
Nickel (Ni) =	0.01568	%
Chromium (Cr) =	0.02067	%
Molybdnynum (Mo) =	0.00239	%
Vanadium (V) =	0.01487	%
Copper (Cu) =	0.03031	%

Reference Data (%)		
Min	Aim	Max
0.08	0.09	0.1
1.25	1.3	1.35
0.2	0.3	0.35
		0.06
		0.06
		0.05
		0.01
		0.06

Carbon Equivalent for Weldability

CE = C + Si/6 + Mn/6 + Cr/5 + Mo/5 + V/5 + Ni/15 + Cu/15

Actual / Measured Data
0.34

Reference Data	
Min	**0.35**
Aim	**0.39**
Max	**0.42**

Appendix - IV C

Continuous Casting Machine (CCM)

	Date & Sample Time	Heat #	C	Mn	Si	Cu	Ni	Cr	Mo	V	C. E.
1	16/06/10 23:43	1E+06	0.088	1.28	0.264	0.0329	0.0156	0.0132	0.00016	0.00108	0.35
2	17/06/10 00:58	1E+06	0.0912	1.293	0.24	0.023	0.0133	0.0147	0.00026	0.00091	0.35
3	17/06/10 02:07	1E+06	0.0918	1.312	0.251	0.0465	0.0178	0.0137	0.00198	0.001	0.36
4	17/06/10 03:18	1E+06	0.1	1.252	0.244	0.0425	0.0163	0.0149	0.00187	0.00106	0.36
5	17/06/10 04:32	1E+06	0.0842	1.277	0.242	0.0213	0.011	0.0116	0.0001	0.00125	0.34
6	17/06/10 05:28	1E+06	0.0947	1.256	0.237	0.0277	0.0188	0.0159	0.00214	0.00109	0.35
7	17/06/10 06:49	1E+06	0.0937	1.264	0.237	0.0272	0.0182	0.0156	0.00127	0.00111	0.35
8	17/06/10 07:54	1E+06	0.0988	1.28	0.265	0.0346	0.0194	0.0198	0.00256	0.00186	0.36
9	17/06/10 09:00	1E+06	0.0946	1.275	0.249	0.0356	0.0178	0.0199	0.00337	0.00172	0.36
10	17/06/10 10:03	1E+06	0.0911	1.274	0.24	0.0372	0.0217	0.0248	0.00297	0.0014	0.35
11	17/06/10 11:09	1E+06	0.0928	1.283	0.229	0.0316	0.0186	0.024	0.00179	0.00102	0.35
12	17/06/10 12:22	1E+06	0.0814	1.257	0.245	0.0323	0.0191	0.0203	0.00197	0.00136	0.34
13	17/06/10 13:22	1E+06	0.0938	1.288	0.25	0.0251	0.0147	0.0172	0.00127	0.00152	0.36
14	17/06/10 14:27	1E+06	0.0983	1.275	0.235	0.0256	0.0145	0.0224	0.00171	0.00123	0.36
15	17/06/10 15:37	1E+06	0.0979	1.28	0.226	0.0072	0.0093	0.022	0.00031	0.00157	0.35
16	17/06/10 16:41	1E+06	0.0921	1.278	0.225	0.0214	0.017	0.0204	0.00119	0.0013	0.35
17	17/06/10 17:45	1E+06	0.0941	1.301	0.236	0.032	0.0216	0.0332	0.00303	0.00112	0.36
18	17/06/10 19:02	1E+06	0.1	1.286	0.231	0.0292	0.0165	0.0215	0.00295	0.00126	0.36
19	17/06/10 20:14	1E+06	0.0922	1.296	0.25	0.0227	0.0123	0.0287	0.00213	0.00125	0.36
20	17/06/10 21:33	1E+06	0.0984	1.269	0.239	0.0401	0.0185	0.0272	0.00172	0.00131	0.36
21	17/06/10 22:42	1E+06	0.0981	1.283	0.239	0.0271	0.0131	0.0204	0.00298	0.0015	0.36
22	17/06/10 23:44	1E+06	0.0888	1.323	0.246	0.0246	0.0131	0.0207	0.00119	0.0015	0.36
23	18/06/10 01:05	1E+06	0.0906	1.289	0.242	0.0228	0.0135	0.0204	0.00235	0.0009	0.35
24	18/06/10 02:14	1E+06	0.0893	1.268	0.237	0.025	0.0143	0.0181	0.00231	0.00072	0.35
25	18/06/10 03:15	1E+06	0.0925	1.31	0.233	0.0276	0.0132	0.0199	0.00105	0.00093	0.36
26	18/06/10 04:34	1E+06	0.1	1.255	0.237	0.0302	0.0136	0.02	0.00291	0.00094	0.36
27	18/06/10 05:23	1E+06	0.0884	1.277	0.253	0.0355	0.0196	0.0277	0.0035	0.00105	0.35
28	18/06/10 06:26	1E+06	0.0884	1.289	0.244	0.0305	0.0155	0.0215	0.00227	0.00128	0.35
29	18/06/10 07:44	1E+06	0.0914	1.293	0.249	0.0288	0.0144	0.0207	0.00231	0.00136	0.36
30	18/06/10 09:00	1E+06	0.0966	1.268	0.231	0.02	0.013	0.0224	0.00205	0.00091	0.35
31	18/06/10 10:09	1E+06	0.0932	1.274	0.24	0.0173	0.0114	0.0199	0.00129	0.00097	0.35
32	18/06/10 11:21	1E+06	0.097	1.287	0.212	0.0284	0.0149	0.0178	0.00192	0.00095	0.35
33	18/06/10 12:22	1E+06	0.0915	1.306	0.221	0.0234	0.0141	0.0212	0.0022	0.00163	0.35
34	18/06/10 13:23	1E+06	0.0834	1.296	0.24	0.0416	0.015	0.0224	0.0021	0.00154	0.35
35	18/06/10 14:32	1E+06	0.092	1.283	0.248	0.0304	0.014	0.0197	0.00223	0.00156	0.35
36	18/06/10 15:31	1E+06	0.0833	1.278	0.23	0.0428	0.018	0.0193	0.00278	0.00103	0.34
37	18/06/10 16:34	1E+06	0.0879	1.275	0.236	0.0376	0.0145	0.0205	0.00221	0.00127	0.35
38	18/06/10 17:43	1E+06	0.0851	1.287	0.231	0.0341	0.0152	0.0216	0.00221	0.00144	0.35
39	18/06/10 18:43	1E+06	0.0832	1.299	0.238	0.0265	0.0132	0.0215	0.00141	0.00124	0.35
40	18/06/10 19:58	1E+06	0.0901	1.302	0.235	0.0293	0.0161	0.0236	0.00262	0.00133	0.35
41	18/06/10 21:05	1E+06	0.0856	1.292	0.226	0.0309	0.0131	0.0231	0.00212	0.00118	0.35
42	18/06/10 22:19	1E+06	0.0968	1.322	0.26	0.0259	0.0137	0.0199	0.00146	0.00119	0.37
43	18/06/10 23:26	1E+06	0.0926	1.285	0.227	0.0265	0.0135	0.02	0.00193	0.00125	0.35
44	19/06/10 00:29	1E+06	0.0987	1.273	0.236	0.0257	0.0128	0.0198	0.00355	0.00122	0.36
45	19/06/10 01:33	1E+06	0.0944	1.287	0.222	0.0271	0.0136	0.0251	0.00198	0.00127	0.35
46	19/06/10 02:36	1E+06	0.1	1.265	0.224	0.0261	0.0136	0.0204	0.00212	0.00147	0.36
47	19/06/10 03:47	1E+06	0.0875	1.253	0.235	0.0271	0.0137	0.0188	0.00261	0.00135	0.34
48	19/06/10 04:48	1E+06	0.09	1.27	0.224	0.0471	0.023	0.0249	0.00577	0.00112	0.35
49	19/06/10 06:01	1E+06	0.0929	1.281	0.228	0.036	0.0159	0.023	0.00224	0.0012	0.35
50	19/06/10 07:12	1E+06	0.0915	1.311	0.234	0.041	0.0209	0.0259	0.00239	0.00153	0.36
51	19/06/10 08:16	1E+06	0.0868	1.282	0.226	0.032	0.0169	0.0202	0.0011	0.00109	0.35
52	19/06/10 09:15	1E+06	0.0928	1.275	0.232	0.0299	0.0119	0.0204	0.0001	0.00126	0.35
53	19/06/10 10:16	1E+06	0.0914	1.301	0.232	0.0283	0.0161	0.0202	0.0004	0.00115	0.35
54	19/06/10 11:28	1E+06	0.0862	1.299	0.24	0.027	0.0157	0.0217	0.00067	0.00116	0.35
55	19/06/10 12:32	1E+06	0.0915	1.317	0.226	0.0299	0.0134	0.022	0.00042	0.00118	0.36
56	19/06/10 13:34	1E+06	0.0864	1.313	0.231	0.038	0.0189	0.0228	0.00154	0.00102	0.35
57	19/06/10 14:41	1E+06	0.0868	1.292	0.237	0.031	0.0144	0.0298	0.00152	0.00126	0.35

58	19/06/10 15:49	1E+06	0.0865	1.307	0.239	0.0261	0.0143	0.024	0.00175	0.00113	0.35
59	19/06/10 16:59	1E+06	0.0973	1.284	0.213	0.0218	0.0121	0.0211	0.00168	0.0011	0.35
60	19/06/10 18:00	1E+06	0.088	1.248	0.232	0.0272	0.0139	0.0216	0.00189	0.00084	0.34
61	19/06/10 19:03	1E+06	0.09	1.3	0.233	0.0317	0.0176	0.0268	0.0027	0.00112	0.35
62	19/06/10 20:12	1E+06	0.0906	1.296	0.235	0.0232	0.0134	0.0228	0.00152	0.00114	0.35
63	19/06/10 21:11	1E+06	0.0847	1.281	0.231	0.0333	0.0209	0.0266	0.00203	0.00097	0.35
64	19/06/10 22:28	1E+06	0.0906	1.274	0.245	0.0134	0.0103	0.02	0.00076	0.00119	0.35
65	19/06/10 23:48	1E+06	0.0909	1.281	0.235	0.0287	0.0239	0.0323	0.00334	0.00203	0.35
66	20/06/10 00:56	1E+06	0.0926	1.282	0.254	0.044	0.0261	0.0263	0.00392	0.00148	0.36
67	20/06/10 01:59	1E+06	0.0887	1.254	0.227	0.0335	0.0181	0.0198	0.00259	0.00147	0.34
68	20/06/10 03:08	1E+06	0.1	1.284	0.243	0.0269	0.018	0.0227	0.00162	0.00121	0.36
69	20/06/10 04:03	1E+06	0.0938	1.274	0.227	0.0229	0.0254	0.0302	0.01094	0.00158	0.36
70	20/06/10 05:10	1E+06	0.0897	1.297	0.246	0.0376	0.0232	0.0259	0.00573	0.00149	0.36
71	20/06/10 06:19	1E+06	0.0937	1.267	0.226	0.0338	0.0169	0.0194	0.00397	0.00139	0.35
72	20/06/10 07:18	1E+06	0.0988	1.254	0.22	0.0332	0.0185	0.0234	0.00452	0.00164	0.35
73	20/06/10 08:28	1E+06	0.0967	1.305	0.239	0.0418	0.0185	0.0206	0.00234	0.00144	0.36
74	20/06/10 09:27	1E+06	0.1	1.302	0.242	0.0353	0.0227	0.0211	0.00382	0.00148	0.37
75	20/06/10 10:32	1E+06	0.0962	1.301	0.248	0.0276	0.0172	0.0192	0.00281	0.00129	0.36
76	20/06/10 11:34	1E+06	0.092	1.298	0.239	0.0281	0.014	0.02	0.00225	0.00144	0.36
77	20/06/10 12:36	1E+06	0.0958	1.266	0.246	0.022	0.0131	0.0181	0.00243	0.00104	0.35
78	20/06/10 13:43	1E+06	0.0942	1.281	0.241	0.0327	0.0133	0.0179	0.00215	0.00111	0.36
79	20/06/10 15:04	1E+06	0.0891	1.306	0.234	0.0269	0.0148	0.0211	0.00176	0.00118	0.35
80	20/06/10 16:16	1E+06	0.0912	1.293	0.259	0.0333	0.0144	0.0235	0.00248	0.00098	0.36
81	20/06/10 17:22	1E+06	0.0954	1.272	0.225	0.0228	0.0147	0.0245	0.00268	0.0018	0.35
82	20/06/10 18:42	1E+06	0.0932	1.295	0.244	0.0294	0.0138	0.0267	0.00275	0.00094	0.36
83	20/06/10 19:44	1E+06	0.0893	1.291	0.238	0.0243	0.0137	0.0216	0.00134	0.00089	0.35
84	20/06/10 20:49	1E+06	0.0929	1.265	0.25	0.0228	0.0127	0.0224	0.00173	0.00077	0.35
85	20/06/10 22:25	1E+06	0.0927	1.27	0.237	0.0356	0.0148	0.0281	0.00264	0.00075	0.35
86	20/06/10 23:19	1E+06	0.088	1.283	0.234	0.0361	0.0137	0.0271	0.00357	0.0008	0.35
87	21/06/10 00:44	1E+06	0.094	1.279	0.244	0.0433	0.0159	0.0282	0.0027	0.00065	0.36
88	21/06/10 01:49	1E+06	0.0907	1.291	0.23	0.0407	0.0159	0.0242	0.00261	0.00069	0.35
89	21/06/10 03:02	1E+06	0.0942	1.292	0.243	0.0314	0.0134	0.0242	0.0013	0.0008	0.36
90	21/06/10 04:10	1E+06	0.0902	1.289	0.246	0.044	0.0161	0.0282	0.00199	0.00086	0.36

Mean =	0.09204	1.28442	0.23736	0.03027	0.01587	0.02198	0.00225	0.00121
St. Deviation =	0.00446	0.01655	0.01020	0.00725	0.00335	0.00400	0.00140	0.00027

Correlation coefficient (C & CE)= **0.72600**

Elements Present

	Actual/Measured (%)		Reference Data (%) Min	Aim	Max
Carbon (C) =	0.09204	%	0.08	0.09	0.1
Manganese (Mn) =	1.28442	%	1.25	1.3	1.35
Silicon (Si) =	0.23736	%	0.2	0.3	0.35
Nickel (Ni) =	0.01587	%			0.06
Chromium (Cr) =	0.02198	%			0.06
Molybdnynum (Mo) =	0.00225	%			0.05
Vanadium (V) =	0.00121	%			0.01
Copper (Cu) =	0.03027	%			0.06

Carbon Equivalent for Weldability

$$CE = C + Si/6 + Mn/6 + Cr/5 + Mo/5 + V/5 + Ni/15 + Cu/15$$

Actual / Measured Data
0.35

Reference Data	
Min	**0.35**
Aim	**0.39**
Max	**0.42**

VITA

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Bachelor Degree of Electrical Engineering (Power/Machine) from King Abdulaziz University (1996), Jeddah, Saudi Arabia.

Master Degree of Science in Electrical Engineering from King Fahd University of Petroleum & Minerals (July 2011), Dhahran, Saudi Arabia.

EXPERIENCE:

January 1997 – Present (July 2011): Working with the Saudi Iron and Steel Company (HADEED) affiliate of Saudi Basic Industries Corporation (SABIC).

Since July 2011working as Rolling Mills Department Manager.

June 2006 - June 2011 worked as Utilities Department Manager.

Feb 2002 - Jun 2006 worked as section head for the electrical main power station.

January 1997 - January 2002 worked as electrical engineer in steel plan.