FOREWORD

Electric Power Quality is an ancient subject and more concern to Electrical Engineering since Edison’s days. The major issues faced by the customers are related to the voltage flicker, momentary events of voltage sags/swells and harmonics. The supply reliability and its long term effect on the product quality, loss of production as well de-rated operation has an adverse economical impact. The steel rolling is one of the most important contributors in the economic growth of our country. The wide variety from small scale to large steel re-rolling industries has different scale of problems related to power quality. Presently the norms defined by the concern authorities are not fully adopted and followed due to techno-commercial problems faced by the industries. Further distribution licensees are not equipped for accurate and proper measurement, verification and enforcement.

It is indeed an important industrial audit on the power quality related to re-rolling steel industries. The topics concerned spans from the basic definition to the analysis of actual data from these industries. The process of re-rolling with load behaviour which causes the current harmonics is explained with the actual facts observed through this power quality audit. The impact on operational performance of the electrical motors and transformers is presented. The operational reliability of the existing infrastructure and its long term impact is presented. The observations on the electrical installations in these industries and their contribution in power quality are elaborated. The conventional and advanced mitigation techniques are incorporated in this application note. There are case studies in which the impact of reduction in harmonics has been evaluated which help in reducing economic losses and increased life of equipment.

This application note is a valuable guide of these re-rolling steel industries having concern to power quality. It is useful to maintenance engineers, equipment designer and utility engineers. The common understanding about the power quality problems can be addressed in the view of national/international standard requires to be adopted in the future.

R. B. Goenka
Director, MSEB Holding Company Ltd.

FOREWORD

I am happy to learn that International Copper Association India under Asia Power Quality Initiative has done an exhaustive study on Power Quality in Steel Re-Rolling Mills. In the present scenario of power utilization and consumption, the importance of power quality is vital for a continuous and effective power supply. The features of power quality play a major role in the effective power utilization along with the control and improvement measures for various factors affecting it. Iron and steel industry has been growing increasingly in the country in the last decade. These industries are frequently challenged by quality of power. Energy intensive operations of steel mills require stable and strong power supply even when remarkable load changes occur. Furthermore, the plants are usually connected to public power grid which means that operation of the plants can cause severe problems to the other consumers in the power grid. Power quality can have different kinds of impact on operations and production. There are numerous causes of poor power quality. Simultaneously, there are options to solve them and many of them are extremely affordable thereby controlling economic losses for steel mill owners and eradicating disturbance to other power consumers. Improved power quality in steel making leads to substantial benefits resulting in bigger capacity and lower operating cost per ton of steel produced.

Adequate supply of skilled manpower also is a big challenge for the secondary steel industry. Most of the SMEs of Steel industries are being operated with non-technical manpower who have nil or limited knowledge of power quality. At the current levels of operations itself, there is a shortage of technical manpower at various levels of the steel industry that are well-versed with power quality aspects. Lack of proper training and unskilled manpower are hurting the industry. There is a huge need for skilled manpower in the industry having knowhow of Power Quality.

This study is a mode for providing information about the Power Quality to the Steel industry which shall provide an opportunity to them to know the technological advancements in Power Quality. I wish all the Steel industries shall reap benefit from this study on Power Quality.

Shailendra Kumar Shukla
CEO, CREDA
Steel industry plays an important role in economic development of any nation. India occupies third place in the world in terms of crude steel production (around 90 million ton in 2015). Steel rerolling industries compliment Indian steel making significantly, contributing to 65% of country’s long steel production. It’s estimated, India’s steel production is likely to double in next five years where steel re-rolling sector is expected to play a very crucial role in this growth.

Steel industry is one of the major energy consumer where steel rerolling mills themselves consume over 25% of energy in the form of - (1) Thermal energy, and (2) Electricity.

Due to rapid growth of non-linear loads and electronic controlled manufacturing processes, area of Power Quality (PQ) is drawing increasing interest amongst users. During our interaction with OEMs, we gathered few shortcomings in the secondary steel sector especially Steel Re Rolling Mills (SRRM) like -

• Absence of technical understanding about PQ though they are affected most from economic loss; further constrained being in MSME sector
• Absence of any credible and structured platform for manufacturers of secondary steel and rerolling industry to understand the impact of poor PQ on their production and energy efficiency etc.
• Absence of ‘easy to understand’ good practice guide and application note to address PQ issues in more informed manner etc.

The publication in first of its kind, focuses on analyzing and documenting PQ and harmonics in small steel rerolling mills. The document explains the basic definitions of PQ and its associated terms. It presents the baseline consumptions through case studies, and highlights requirement for better PQ management. It also presents set of available technical solutions to reduce the electrical losses thereby help save energy, and money.

SRRMs under umbrella of Vidarbha Industries Association, Nagpur and Chhattisgarh State Renewable Energy Development Agency, Raipur has been very receptive to the interventions. We complement all steel units which participated in this initiative.

This publication hopes to draw the attention of steel unit owners, steel associations, energy auditors and service providers, in improving power quality and energy efficiency which can contribute to improving the competitiveness of the industry while meeting environmental challenges.

Sanjeev Ranjan  Manas Kundu
Registered Office: International Copper Association India - 302, Alpha, Hiranandai Business Park, Powai, Mumbai 400076 India.
Phone +91 (22) 6114 7300 Fax +91 (22) 6693 9282 Website: www.copperindia.org • CIN: U91110MH2001NPL131676

United Nations Development Programme

India is one of the world’s largest producers of steel and has ambitious targets to scale up steel production by 2025. Contributing to 65 percent the country’s long steel production, the steel re-rolling sector is crucial to these ambitious plans.

The steel industry is a major consumer of energy, contributing significantly to greenhouse gas emissions. Even as the country steps up steel production, a key challenge will be to address its environmental impacts. For over a decade, a partnership between the Ministry of Steel and the United Nations Development Programme has demonstrated technologies and approaches to improving energy efficiency in small scale steel re-rolling mills. The collaboration was supported by the Global Environment Facility and AusAID.

Our experience which resulted in average energy savings of 30 percent and paybacks on investments in 12 months, highlighted the importance of power quality in supporting a low-carbon growth path for these mills.

I compliment the Asia Power Quality Initiative (APQI) India and Electrical Engineering Department, Visvesvaraya National Institute of Technology, Nagpur supported by International Copper Association, for this important contribution to the discourse on documenting power quality and harmonics in small steel re-rolling industry.

I hope this publication supports the efforts of steel unit owners, associations, energy auditors and service providers, in improving power quality and energy efficiency which can contribute to improving the competitiveness of the industry while meeting environmental challenges.

Jaco Cilliers
Country Director, UNDP
VISVESVARAYA NATIONAL INSTITUTE OF TECHNOLOGY, NAGPUR (VNIT, NAGPUR)

Visvesvaraya National Institute of Technology, Nagpur is one of the thirty National Institutes of Technology in the country. The Govt. of India conferred on the Institute, the Deemed to be University status (under University Grants Commission Act, 1956 (3 of 1956)) with effect from 26th June 2002. Subsequently, the Central Govt. by Act of Parliament (National Institutes of Technology Act, 2007 (29 of 2007)) declared VNIT Nagpur as an Institute of National Importance along with all other NITs. The Act was brought into force from 15th August 2007.

Earlier, the Institute was known as Visvesvaraya Regional College of Engineering (VRCE). It was established in the year 1960 under the scheme sponsored by Govt. of India and Govt. of Maharashtra. The college was started in June 1960 by amalgamating the State Govt. Engineering College functioning at Nagpur since July 1956. In the meeting held in October 1962, the Governing Board of the College resolved to name it after the eminent engineer, planner, and statesman of the country Sir M.Visvesvaraya.

The electrical department was established in 1960 with a UG programme in Electrical Engineering. The postgraduate programme in 'Integrated Power System' was started in 1968. Later, another postgraduate program in 'Power Electronics and Drives' was introduced. The sanctioned intake for UG programme i.e. B.Tech. (Electrical and Electronics Engineering) is 92. The sanctioned intake for the PG programmes i.e. M.Tech. (IPS) and M.Tech. (PED) is 30 each.

The Department is recognised as QIP Centre for M.Tech and Ph.D. programmes.

The National Board of Accreditation has accredited the department with the highest grade ‘A’ for UG as well as PG programme in both the accreditation exercise undertaken so far (one in 1996 and other in 2001).

High Voltage Engineering and Electrical Drives Laboratories are important laboratories with state of art facilities. High Voltage lab has various facilities for industries to evaluate their products as well as energy audit. Drives lab is also equipped with all facilities required to undertake the research in the field of power quality and energy conversion systems.

INTERNATIONAL COPPER ASSOCIATION INDIA (ICA INDIA)

The International Copper Association India (ICA) is a member of Copper Alliance and the Indian arm of the International Copper Association Limited (ICA), the leading not for profit organization for the promotion of copper worldwide set up in 1959. ICA India was formed in 1998 to actively associate with the growing number of copper users in India. The objective is to “Defend and grow markets for copper based on its superior technical performance and its contribution to a higher quality of life worldwide”. ICA India conducts various programs in the interest of Electrical Safety, Energy Efficiency and Sustainability. Employing a mix of market development and regulation advocacy approach to encourage the use of copper.

Thereby, accelerating changes and transforming the long-term markets for Copper in a sustainable way through its various major initiatives such as:

- Encourage safe house wiring practices in the Building Construction sector.
- Increase awareness of Power Quality through Asia Power Quality Initiative (APQI) Platform.
- Propagate the use of Energy Efficient Motors for energy savings in Industries.
- Promote 5 mm Microgroove Copper Tube heat exchangers technology to OEMs.
- Promote the use of High Energy Efficient Motors and Copper Motor Rotors to Industries.
- Reduce distribution losses in the Power sector through the use of low loss Distribution Transformers.
- Encourage Renewable Energy Technologies like solar water heaters.

ICA India drives its initiatives through seminars, workshops and training programs across India in collaboration with other organizations, institutions and trade bodies. It also publishes technical handbooks and information booklets and brochures aimed at spreading general awareness of the benefits of Copper. The organization receives support from its global-level members and from major Indian copper producers, fabricators, cable and wire manufacturers and EE motor manufacturers. Other global development organizations also support some of ICA India programs.
APQI, or the Asia Power Quality Initiative, is a joint effort of the International Copper Association, the International Copper Association India (ICAI), the Electrical and Electronics Institute, Thailand, the University of Bergamo (Italy) and the European Copper Institute (ECI, Belgium). APQI created an independent platform that would build awareness and capacities on issues related to Power Quality. The initiative has local chapters in as many as seven Asian and Southeast Asian countries. In India, the International Copper Association India (ICAI) leads the initiative.

APQI has been established with financial support from the European Union’s Asia-Invest programme. The initiative builds on the previous success of the Leonardo Power Quality Initiative (LPQI) established in Europe by the European Copper Institute, Belgium, with financial support from the European Commission.

The APQI is currently in its eighth year. This neutral platform continues to carry out activities towards capacity building and awareness raising amongst various stakeholders especially in Commercial building and Industrial sector. APQI as a national platform on PQ issues while raising awareness among decision-makers continues to build the capacity of electrical engineers and designers, consultants and other PQ professionals. We are also actively working to facilitate regulatory and standards initiative in respective country.

CHHATTISGARH STATE RENEWABLE ENERGY DEVELOPMENT AGENCY, RAIPUR (CREDA, RAIPUR)

Chhattisgarh State Renewable Energy Development Agency (CREDA) has been constituted on 25th May 2001 under the Department of Energy, Government of Chhattisgarh for implementation of various schemes pertaining to Renewable Energy sources and Energy Conservation activities. CREDA is established as the State Nodal Agency (SNA) by State Govt. for development and promotion of Non-Conventional and Renewable Sources of Energy. Most of the scheme like National Programme on Bio-gas Development, Solar Thermal, Solar Photo Voltaic, Remote Village Electrification and Biomass Gasifier, sponsored by Ministry of Non-Conventional and Renewable Energy Sources (MNRE), Government of India are implemented by CREDA.

Government of Chhattisgarh has notified CREDA as the State Designated Agency (SDA) to coordinate, regulate and enforce the provision of the Energy Conservation Act-2001 and implement schemes under the Act within the State of Chhattisgarh. This is a significant step forward for CREDA having additional responsibility of promoting energy efficiency and developing energy conservation projects besides facilitating renewable energy development within Chhattisgarh State. Within a short span, CREDA has done a pioneering job in various energy efficiency activities in Chhattisgarh.

Since its inception, CREDA did extensive work in the field of Renewable Energy focusing on rural areas and stand alone devices. It has implemented projects in the field of power generation from renewable energy and environment friendly sources. To undertake this onerous responsibility, CREDA has positioned itself as an organization with enough financial and human capabilities having a professional organizational structure. It has also undertaken extensive human resource development activities which has created a modern working environment for its staff.

Some of the Awards conferred to CREDA:

- As recognition of the excellent performance in the field of promoting energy efficiency, CREDA has received 03 National Awards by Ministry of Power, Govt. of India. It was adjudged as the Best SDA in India and awarded FIRST PRIZE during “National Energy Conservation Award 2009” and awarded CERTIFICATE OF MERIT during “National Energy Conservation Award 2011 & 2015”
- CREDA won HUDCO Award for Best Practices in Improving the Living Environment for 2012-13.
- It has been awarded as Best Performing State Nodal Agency (SNA) by MNRE for Solar Rooftop Programme in the Country for 2014-15
PREFACE

Steel industry is one of the biggest energy consumers in our country. The electrical energy is key component mostly used for the heating/rolling or electronic control applications. The productivity and economics of the steel re-rolling is associated with power supply reliability and its quality. In present scenario, power quality aspect has not given due importance due to its awareness and enforcement. This application note is addressed towards the power quality issues in the steel re-rolling industries. These steel re-rolling industries are spans from few kW to MW considering their production capacities and product profiles. The power quality assessment is conducted through realistic measurements at different locations to accommodate the maximum spectra of these industries. Therefore, these industries are categorised into micro, small and medium size on their power consumption and capacity. The selected re-rolling mills are identified from the central part of India (Nagpur and Raipur).

The actual data at site is collected to understand the one of the major power quality issue, i.e. harmonics. The power analyser records with various operating conditions have given a structured data of various harmonics, power factor, and flicker events during steel re-rolling operation. These measurements reveal that the non-linear behaviour of the loads and their contribution in to the harmonic generation. This information is related to the operating conditions and also with the electrical distribution structure adopted by these industries.

This application note provides the brief introduction of the power quality definitions and relevant standards. The effect of power quality on reliability, efficiency and productivity is discussed.

In this application note, impact of harmonics on transformers, motors, capacitors and supply conductors is elaborated. This is useful in estimating the economic impact due to power quality in these industries. The modification or proper selection of the component rating is also included through the sample calculations for field engineers. This application note suggests the few mitigation techniques for such harmonics. From the presented analysis, few recommendations are given and shall be useful at the operational and planning levels. The improvements/suggestions, if incorporated at the design stage with marginal incremental cost can reduce the operating cost and enhance life of the infrastructure.

This application note preparation project is undertaken by Asia Power Quality Initiative and funded by the International Copper Association, India. The support in identifying the steel re-rolling mills by VIA, Nagpur and CREDA, Raipur helped to generate the factual data on power quality. This task of walk-through power quality audit is carried out by Electrical Engineering Department, VNIT, Nagpur using the advanced Power Analyser.

Acknowledgement

Author: Prof. Mohan V. Aware, Electrical Engineering Department, VNIT, Nagpur

The author would like to thank Mr. Manas Kundu, APQI India coordinator, ICAI, Mumbai for providing us this opportunity to undertake the power quality audit in the steel re-rolling mills. The special thanks for all the participating industries for providing us the live learning platform for this study. Their concern about the power quality is deeply felt through the discussion on these emerging problems. The initiation of this work with much needed encouragements could be possible only through Mr. R. B. Goenka, Director, MSEB Holding Company Ltd., Nagpur and Shri Sanjeev Jain, Chief Engineer, CREDA, Raipur. It was indeed my post graduate students Mr. Deepak Jain and Mr. Ajay Bhoyar, who helped me in field data collection and compilation of this application note. I sincerely thank to Dr. N.S. Chaudhari, Director VNIT, Nagpur for his permission and support.

Reviewer: Prof. Bhim Singh, Electrical Engineering Department, IIT, Delhi

It is timely needed work, where our industries and professionals in the area of power quality should be aware and ready to face the upcoming challenges. This study with actual facts enlightens the detailed operational difficulties arising out of power quality issues. Application note is more a technical resolve in context of the facts identified and explained in a proper order. A theoretical support and design example with the factual data enhances the confidences of the all stakeholders related to the Power Quality. This document is a ready reference for the practicing engineers working in the steel industries, which enables them to improve product quality and reliable operation of the plant.
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Annexure – I: Industries Participated in Power Quality Audit
Annexure – II: Program for “Analysis and Impact of Harmonics on the Motor, Transformer, Capacitor and Cables”
1. EXECUTIVE SUMMARY

This application note is focused on the power quality (PQ) issues related to the steel re-rolling mills. This comprehensive analysis is presented in context of the present operating situation across the micro, small and medium level steel re-rolling industries in central India. The emergence of power quality issues and their impact on steel re-rolling mills during operating conditions are investigated.

The observed records on the electrical energy supply quality across the few industries are compared with the international standards. The basic terminologies associated with the power quality definitions are explained.

The walk-through power quality audit is carried out in micro, small and medium size steel re-rolling industries located in different geographical location (Nagpur and Raipur) in central India. The observations on voltages/currents trends during the rolling process are the indicators of the power supply situation and design considerations of the electrical network by these industries. It is also observed that the harmonics contents in the current during the process has a typical pattern and are due to non-linear behaviour of the existing loads during operation. The impact of the harmonics on the operational performance of the electrical motors and transformers is analysed. The impact of harmonics on the existing infrastructural utilisation and its life is presented in this report.

To improve the power quality in these plants, various mitigation techniques are discussed. The primitive and latest state-of-art solutions are suggested with the proper design procedure. This report shall be helpful to the operating personal in steel re-rolling mills with the awareness of the power quality in the existing industries and adopt the practices to mitigate them. The understanding of power quality issues will enhance the productivity, quality of the product. By redesigning or with appropriate modification in the planning at a reasonable capital cost will benefit to the growing re-rolling steel industries. This note shall provide the guidelines for the green field project proposer as well purchaser while planning the future projects.

2. INTRODUCTION

This application note is primarily presented to focus on the power quality aspects of the steel re-rolling industries. The growth in steel manufacturing in India since its independence has been a key factor to recognise its development. The state owned and privately operated steel plants have contributed to maintain the growth and now India becomes a fourth largest crude steel producer with 83.2 MT (2014) production reported by Ministry of Steel [1]. The secondary steel production is approximately around 57% of the total steel production in India [2]. It is mainly taking place in the steel re-rolling mills (SRRM). These are mostly (75%) in small and medium scale sector and around 1200 units are running across the country. In this application note only steel re-rolling industries are focused to investigate the issues related to power quality.

The Asia Power Quality Initiative (APQI) is a capacity building regional platform to help industry and commercial building sector to address Power Quality issues. This institute is carrying out various projects related to power quality and presenting these resources in open access and free of charge to stakeholders.

In the following section, the details are provided with reference to steel re-rolling industrial units.

2.1 Present Scenario

The future projection of per-capita steel consumption is expected to be increased to 12 kg by 2020. The initiative of the government in liberalization and projection of the infrastructural growth in India has initiated large number of steel processing plants set-up in different parts of the country. The modernisation and expansion of the new small/medium scale units of steel re-rolling mills with cost effective and state-of-the-art technologies are poised to come so as to beat the competition in this sector with international counterparts. The major concern is to improve the product quality and productivity. One of the key contributors on this front is the electricity. This also has to be shaped to cope with the demand of these industries.

2.2 Steel Processing and Major Energy Demand

In the SRRM, direct energy used includes the heating fuels (furnace oil, natural gas and coal) and electric energy. This is estimated to be around 25-30% of the overall production cost. These units are mostly a small/medium scale industries and utilise the outdated and low investment technologies and practices. Many of these industries lack in-house engineering and technical manpower to implement energy-efficient measures as well have limited insight to understand impact of poor power quality on the product quality and productivity. This further impedes their capacity to compete in open and global economy.

2.3 Technology Update

It is observed that the financial constraints and global competition has restricted to adopt the new technologies in this sector. The new high end technologies are having potential to improve the energy saving up to 30-40% and low-end technologies up to 20-25% as suggested in the UNDP (2013) report [1]. It is targeted to reach power consumption of electricity to 60-80 kWh/T from the 90-120 kWh/T as the suggested measures in the report. The use of energy efficient motors and variable speed drives are the major focus in this implementation. Similarly, the operation of the electrical network with its rated capacity and utilisation of infrastructure to improve the electrical network efficiency contributes to this mission.

2.4 Power Quality Focus

1. What are the PQ issues those normally plague them?

An important issue is the voltage sags and false tripping due to this in steel re-rolling mills. Each pass of the rolling will cause the voltage variation. It is also observed that the transformer (HT)
3. OBJECTIVES

This application note is developed with following objectives:

- Case studies investigate the present power quality status in the steel re-rolling mills (SRRM).
- Collect the power quality data and analyse in view of its compliance with the standards available.
- Identify the sources of the poor power quality and power quality issues plaguing the sector through power quality audit.
- Financial implication of poor power quality (Considering the loss of production/maintenance/quality of the finished product).
- Scenario of available mitigation techniques and its impact.
- Prepare the educational material for these industries to create awareness about the effects of the poor power quality.

4. STEEL RE-ROLLING PROCESS AND ENERGY FLOW

The steel re-rolling is the process of converting raw/unprocessed steel into finished steel products by rolling and re-rolling them in their hot state into desired shapes such as bars, TMT (thermo-mechanically treated) rods, sectional products, and wires. The production process in a typical SRRM unit begins with hot charging of raw billets, ingots or blooms in an oil-, coal- or gas- fired re-heating furnace. Once the raw material achieves the desired temperature, it is manually or automatically pushed out into the rolling floor, where iron rollers (also called drums) are used to squeeze and stretch them into finished steel products.

4.1 Steel Re-rolling in Brief

The SRRMs in India are typically of two types, each having its own technical specifications. Bar mills are ingot-/ billet-based rolling mills, with a typical capacity of 50–100 tonnes per day (TPD). They are equipped with a roughing mill, an intermediate mill, a finishing mill, rotary shearing, repeaters, and a thermo-mechanically treated (TMT) line with a cooling system (i.e., TMT cooling line, hot water pump, cold water pump, pinch roll, controls, and DC motors).

The second type of re-rolling mill observed in India is the structural rolling mill. Their main products are structural steel products such as flats and angles, and have a typical capacity of 50–200 TPD. These mills could be either semi-automatic or manual, employing coal- or oil-fired furnaces. Their primary raw material may be ingots/billets. Standard equipment in such mills includes rolling mill stands, pinion and reduction gear boxes, fly wheels, electric motors, and hot
and cold shearing machines. The material flow in a typical SRRM unit is shown in Fig.1 for better understanding of the whole process. Similarly, Fig.2 depicts the cumulative energy consumption pattern in the SRRM sector [1].

Main sources of direct energy-use in the sector as a whole include firing agents (coal, furnace oil, or in some cases natural gas) for the furnace and electrical energy for the rolling process. The direct energy cost in SRRMs is estimated at 25%–30% of the conversion cost. However, the sector is also characterized by high indirect energy usage, accounted for by the use of energy-intensive raw materials and obsolete technology. These indirect losses result in higher energy costs, scale loss, and low yields. SRRM units also consume electrical energy during the rolling process as well as for the operation of auxiliary installations (e.g. fans, lights, and pumps etc.).

4.2 Energy Flow
Flowchart showing energy consumed in various stages is called as energy flow diagram. Pictorial representation of energy flow of steel re-rolling plant is shown in Fig.3.

4.3 Electrical Energy Network
The electrical supply in these industries is mostly a single point entry through the 11kV feeder with step down transformer installation in the premises. The industries categorised with medium level steel re-rolling mills are having 220 kV / 33 kV supply point and having internal distribution as per their requirements. It is observed that the motors used for roughing, intermediate or finishing are three phase, 415 V, Wound Rotor Induction Motor (WRIM). Depending on the product line, the scheme may have AC/DC drives and are supplied with different configuration of the electrical network with their control equipment. A typical power distribution with the metering points is shown in Fig.4.
5. MAJOR ISSUES IN ELECTRICAL POWER UTILISATION

These steel rolling mills are supplied from 220 kV to 11 kV grids depending upon the capacity of the plant. Mostly small rolling mills are connected to the 11 kV/440 V utility supply through the step down transformer. The power quality problems affect all concerned utilities, customers, and manufacturers directly or indirectly in terms of major financial losses due to interruption of process, equipment damage, production loss, wastage of raw material, loss of important data, and so on [4]. The major steel plant is having following specifications and characteristics for their transformers/motors having standard operating characteristics.

5.1 Load Characteristics
Load characteristics will be changing from time to time and may affect the system voltage stability to some extent. As far as power quality of steel re-rolling industry is concerned, load characteristics of three important equipments need to be understood i.e. Motor, Transformer and Capacitor. Hence, load characteristics of motor, transformer and capacitor in relevance with the effects of poor power quality and their analysis are discussed in this section.

5.1.1 Motor
Motors convert electrical energy into mechanical energy by the interaction between the magnetic fields set up in the stator and rotor windings. Industrial electric motors can be broadly classified as direct current motors, induction motors or synchronous motors. All motor types have the same four operating components: stator (stationary windings), rotor (rotating windings), bearings, and frame (enclosure). Induction motors are the most commonly used prime mover for various equipments in industrial applications. In SRRMs also, induction motors are used as prime mover to rotate the rollers to produce the steel sections.

A) Efficiency Curves
The main attribute relating to efficiency of electricity use by A.C. induction motors is efficiency ($\eta$), defined as the ratio of the mechanical energy delivered at the rotating shaft to the electrical energy input at its terminals. The other attribute should be considered during operation of the motor is power Factor. Motors, like other inductive loads, are characterized by power factors less than one. As a result, the total current draw needed to deliver the same real power is higher than for a load characterized by a higher PF (resistive). An important effect of operating with a PF less than one is that resistive losses in wiring upstream of the motor will be higher, since these are proportional to the square of the current. Thus, both a high value for $\eta$ and a PF close to unity are desired for efficient overall operation in a plant. The Fig.5 shows the effect of load on power factor and efficiency. It can be seen that power factor drops sharply at part loads.
B) Duty of the Motor – Steel Industries

A 3-phase, 50 Hz, 415V (low voltage or low tension) slip ring induction motors with rotor resistance starter are generally used for steel re-rolling mills. Duty type of these motors are normally said to be mill duty induction motors.

Rolling mill duty motors are critical prime movers for the rolling mill industry. These motors are designed and manufactured to sustain stringent electrical and mechanical requirements. This fact results from the different modes of operational requirements of the mill, where the load demand varies from traditional continuous duty and contains sustained periodic overloading throughout the operating cycles. These motors are incorporated with the high torque and variable speed characteristics to meet the various functional requirements in rolling mill industries.

Variations in supply voltage and frequency are allowed as per IS 12360:1988. Three phase induction motor specifications up-to 11 kV should comply with the IS325:1996. The stators and wound rotors of mill duty induction motors are generally wound with copper strip conductors with class F insulation. Stator windings are brazed and wound rotor overhangs are banded with resin impregnated glass fibre tape to withstand momentary overloadings and peak loads. The motors are basically rated for S1 (continuous duty) but can be adapted to other duties such as S6, S7, S8 etc. These motors are designed to run at 75% of rated supply voltage for duration of five minutes.

C) Energy Efficient Motors

Energy-efficient motors (EEM) are the ones in which, design improvements are incorporated specifically to increase operating efficiency over motors of standard design (Fig.6). Design improvements focus on reducing intrinsic motor losses. Improvements include the use of lower-loss silicon steel, a longer core (to increase active material), thicker wires (to reduce resistance), thinner laminations, smaller air gap between stator and rotor, copper instead of aluminium bars in the rotor, superior bearings and a smaller fan, etc. The motor efficiency for IE1-IE4 with the rated power is shown in Fig.6.

Standards for Energy Efficient Motors

The standards making body in India, Bureau of Indian Standards, first introduced an exclusive standard for energy efficiency motors in 1989 (IS 12615) which covered 4 pole motors up to 37kW. Later, the same standard was revised in 2004 with a proactive approach from the motor manufacturers. This revision covered the scope for all standard continuous duty motors up to 160kW (2 pole and 4 pole), 132 kW (6 pole) and up to 110kW (8 pole). Based on CEMEP, efficiency levels eff2 (improved efficiency) and eff1 (high efficiency) had been defined. Apart from the efficiency class this standard also specifies other performance parameters like breakaway torque, breakaway current, minimum speed, maximum full load current etc. for each of the rating. In other words, this outlines performance specifications for energy efficient motors.

Upon the introduction of the new IEC standard 60034-30 for the efficiency classification of induction motors and subsequent regulations based on the same adopted by different countries, all stakeholders (the Indian manufacturers, Bureau of Indian Standards (BIS), Bureau of Energy Efficiency (BEE)) has together taken-up the activity of harmonization of efficiency classes and testing methods for the Indian motor industry in-line with the latest IEC standards. On the basis of IEC 60034-30 and the performance parameters specified in the existing version of IS 12615: 2004, the revised standard IS 12615:2011 has been published in August 2011.

In the year 2014, BIS has updated the standard IS12615:2011 (By removing IE1motors from standard and IE2 as minimum efficiency level) and also obsoleting the standard IS-325, which has been shared with all licenced manufacturers.

The main features of the revised standard are:

- The ranges covered are from 0.37 kW to 375 kW for 2, 4 and 6 poles
- Intermediate ratings are considered based on the Indian markets.
- The efficiency classes are in line with IEC 60034-30 termed as IE2 and IE3
- The testing method specified is as per IEC 60034-2-1.
- The other performance parameters like starting torque and starting current are considered and specified for all three levels (IE2 and IE3).

A new development in motors is a copper die-cast rotor technology that has been developed specifically for premium efficiency motors (IE4 motors). Energy-efficient motors now available in India with the efficiencies that are typically 3 to 4 percentage points higher than standard motors and complying with the IS 12615:2011. In keeping with the stipulations of the BIS, energy-efficient motors are designed to operate without loss in efficiency at loads between 65% and 100% of rated capacity. This may result in major benefits in varying load applications. The power factor is about the same or may be higher than for standard motors. Furthermore, energy-efficient motors have lower operating temperatures and noise levels, greater ability to accelerate higher-inertia loads, and are less affected by supply voltage fluctuations. To be
considered energy efficient, a motor’s performance must equal or exceed the nominal full-load efficiency values provided by the standard IS12615:2011.

In addition to energy savings, other benefits of high efficiency motors over standard motors include:

1) Cooler operating temperatures due to lower heat generation, resulting in lower maintenance and a longer life.
2) Improved tolerance to voltage variations and harmonics, hence sustainability to extend in poor power quality environment.
3) Extended manufacturers’ warranties.
4) Rebates and tax incentives in some regions from utilities and municipalities.

A summary of energy efficiency improvements in EEMs is given Fig.7 below:

![Fig.7 Improved Induction Motor](Ref: 6)

5.1.2 Transformer

Whether in infrastructure systems, industry or households, distribution transformers always play a key role in the reliable transmission and distribution of power. The construction, rated power, voltage level and scope of the application are all key factors that determine the transformer’s design. A transformer is an electrical device that transfers energy between two or more circuits through electromagnetic induction. Rating of transformer is always specified in kilovolt ampere (kVA) only. It is the product of voltage appears across a transformer and current flows through the windings of a transformer. For a 3-phase transformer, it is given by:

\[ \text{kVA rating of a transformer} = \sqrt{3} \times V \times I, \]

where, \( V \) = Line voltage (between two phases)
\( I \) = Line current (flowing through any of three line)

**K-Rated Transformers:** Transformers are designed to deliver the required power to the connected loads with minimum losses at fundamental frequency. In practical, transformers are not only supplying fundamental power but also supplying harmonic power to non-linear loads present in the utility system. Transformers that are required to supply large nonlinear loads must be de-rated to handle the harmonics. This derating factor is based on the percentage of the harmonic currents in the load and the rated winding eddy current losses. The harmonic currents increase the net RMS current flowing in the transformer windings which results in additional IR losses. Winding eddy current losses are also increased. The winding eddy current losses increase as the square of the harmonic current and as the square of the frequency of the current. Thus, the eddy current loss (EC) is proportional to \( L \times I^2 \), where \( L \) is the RMS value of the harmonic current of order \( h \), and \( h \) is the harmonic frequency order or number (7). Harmonic distortion of the current, in particular, as well as of the voltage will contribute significantly to additional heating.

One well-established method by which transformers may be rated for suitability to handle harmonic loads is by ‘K’ factor ratings. The ‘K’ factor is equal to the sum of the square of the harmonic frequency currents (expressed as a ratio of the total RMS current) multiplied by the square of the harmonic frequency numbers:

\[ K = \sum_{h=1}^{n} \frac{I^2}{h^2} \]

where,

\( n \) = harmonic frequency current \( = \) ratio of the \( h^{th} \) harmonic current to total RMS current
\( h \) = harmonic order or number

Typically, transformers are marked with k-ratings of 4, 9, 13, 20, 30, 40, and 50. Such a transformer would have the capability to carry the full RMS load current and handle winding eddy current losses equal to \( k \) times the normal rated eddy current losses. The ‘K’ factor concept
is derived from the ANSI/IEEE C57.110 standard, Recommended Practices for Establishing Transformer Capability When Supplying Non-Sinusoidal Load Currents.

The rms of distorted current is derived in terms of 'k' factor is as under:

$$I_{rms} = \sum_{n} I_{n} = \frac{1}{\sqrt{1 + k \times P_{EC-R} (\text{pu})}}$$

Where,

- $P_{EC-R} (\text{pu})$ = winding eddy current loss under rated conditions (per unit of rated I2R loss)
- $h$ = harmonic number or order.

The de-rating of transformer can be estimated by knowing the per unit winding eddy current loss factor. This is obtained from transformer designer or from Table 1 [7].

<table>
<thead>
<tr>
<th>Type</th>
<th>MVA</th>
<th>Voltage</th>
<th>PEC-R %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>&lt; 1</td>
<td>–</td>
<td>3 to 8</td>
</tr>
<tr>
<td></td>
<td>\geq 1.5</td>
<td>5 kV HV</td>
<td>12 to 20</td>
</tr>
<tr>
<td></td>
<td>&lt; 1.5</td>
<td>15 kV HV</td>
<td>9 to 15</td>
</tr>
<tr>
<td>Oil-filled</td>
<td>&lt; 2.5</td>
<td>480 V LV</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2.5 - 5</td>
<td>480 V LV</td>
<td>1 to 5</td>
</tr>
<tr>
<td></td>
<td>&gt; 5</td>
<td>480 V LV</td>
<td>9 to 15</td>
</tr>
</tbody>
</table>


Bureau of Indian standards has notified the revised standard for Distribution Transformers (DTs) IS1180 (Part1):2014. In the revised version the scope of the standard has been extended to 2500 kVA, 3 phase and single phase up to 25 kVA rating, at voltage (11 to 33 kV) have also been included to make it a comprehensive standard on DTs. The standard ratings prescribed under the relevant tables shall be adhered to, and Non-standard ratings shall not be permitted to manufacture, stored and used.

The following are brief points on the Standard IS1180:2014 and Mandatory Quality control order:

1. IS1180:2014 standard is a comprehensive revised and updated standard covering the scope of all distribution transformers up to and including 2500 kVA and single phase up to 25 kVA (for 11kV, 22kV and 33kV).
2. The energy efficiency levels (Level -1, Level -2 and Level-3) are fixed for all individual ratings covered in the scope (corresponding to 3 star, 4 star and 5 star labelled transformers earlier notified by BEE).
3. As per the quality control order and its amendments issued by Department of Heavy Industries on 27th January 2014 amended on 14th November 2016, mandating BIS certification/marking up to 2500 kVA as per IS1180 (Part 1):2014 with effect from 1st February 2016 and all stakeholders (Manufacturer and End user) shall manufacture or store, sale, sell or distribute any DT’s only conforming to IS1180:2014.
4. IS1180 specifies standards ratings in KVA and other Non-standard ratings will not be certified by BIS. Hence use of Non-standard rating should be stopped.
5. Mandatory Quality control order of IS1180:2014 implementation date is effective from 01 February 2016. (Quality control order was issued on 27 January 2014 and effective date was extended till 31 January 2016).

5.1.3 Capacitor

All these plants are provided with the power factor correction capacitors at the motor terminals. The presence of the capacitors connected at the terminals of the steel rolling could lead to higher voltages in no-load operation. This could lead to the rolling motors driving in to the saturation (non-linear load condition) causing harmonics in the supply system. The interaction of these harmonics between the capacitors and service transformer could lead to harmonic magnification. This is a condition of harmonic resonance or parallel resonance. If the resonance frequency of this LC circuit coincides with one of the harmonic present, the amplitude of the harmonic current flowing through such LC circuit is multiplied several times causing the damage to the capacitors, supply transformers and other network components. The resonance condition is determined as

$$f_r = \sqrt{\frac{kVA_{sc}}{kVA_{cap}}}$$

where,

- $f_r$ = resonant frequency as a multiple of the fundamental
- $kVA_{sc}$ = Short circuit rating at the point of installation
- $kVA_{cap}$ = Capacitor rating at the installation
If $f_n$ is equal to or close to characteristics harmonics such as 5th or 7th, then there is a possibility that the resonance condition could occur.

With the other harmonic frequencies, capacitor impedance decreases, so it offers low impedance path to the harmonic currents. These additional currents with fundamental current through the capacitor can produce dangerous current overloads on the capacitors. Each of these harmonic currents causes the voltage drop across the capacitor which is added to the fundamental voltage. Therefore, in presence of the harmonics, higher voltage rating of the capacitor is preferred which may be more than the 10% provided by the manufacturer.

### 5.2 Non-Linear Loads

Whenever a transformer or motor draws distorted current i.e. including the harmonic components due to the saturation operation, is called as non-linear behaviour of linear loads. In true sense, most of the electrical loads have nonlinear behaviour at the AC mains. As they draw harmonic currents of various types such as characteristic harmonics, non characteristic harmonics, inter harmonics, sub harmonics, reactive power component of current, fluctuating current, unbalanced currents from the AC mains, these loads are known as nonlinear loads [4]. Equipment in this category includes transformers and other electromagnetic devices with a steel core, including motors. Harmonics are generated due to the nonlinear magnetizing characteristics of the steel i.e. core material. So, for understanding this non-linear behaviour of linear loads, loads which are exhibiting non-linear characteristics are classified into two categories:

1. **Active non-linear loads**
2. **Passive non-linear loads**

#### 5.2.1 Active Non-Linear Loads

In this category, all electronics and power electronics instruments and equipment like rectifiers, converters, inverters, electronics devices (diodes, thyristors, etc.) are behaving as non-linear loads. Following figures showing distorted current and voltage due to these non-linear loads:

Fig.8 showing the switch mode power supply (SMPS) current contains 3rd harmonic component as major component of current because SMPS uses single phase bridge rectifier with variety of electronic equipment.

#### 5.2.2 Passive Non-Linear Loads

Saturable devices like transformer, motor, inductor, non-linear resistor, etc. come into this category. Following are some figures showing non-linear characteristics during certain conditions:

Fig.10 is showing non-linear characteristic of transformer. It is also called as B-H curve of a transformer. Characteristic is linear up to rated i.e. 100% voltage, but it becomes non-linear whenever voltage beyond the 100% is applied.
to transformer because core of transformer gets saturated. For small change in voltage, it shows large change in current due to the saturation of core material of transformer and hence it draws harmonic current components from the source to meet the higher demand of saturated magnetizing current. Fig. 11 is showing the transformer magnetizing current and its harmonic spectrum during saturation condition due to voltage higher than the rated value.

When a motor is also excited with the voltage more than the rated value, it also goes into saturation condition and exhibits same magnetizing current characteristic as the transformer shown above. Magnetizing current also will be same (refer Fig. 11) under saturation condition provided that motor stator is connected in star configuration. But, if it is connected in delta configuration, then nature and shape of magnetizing current of motor will be somewhat different (nature of motor magnetizing characteristic will be same) in such a way that it will have 5th and 7th harmonic components as the major components and not the 3rd harmonics. Fig. 12 is showing the motor magnetizing current and its harmonic spectrum during saturation condition due to voltage higher than the rated value when motor is connected in delta configuration.

**Operation under Unbalanced Voltages:** There are many such conditions which cause the linear loads to behave as non-linear loads. However, every condition is not to be discussed. Here, only those conditions are discussed which are in the interest of this application note. Unbalanced voltages are created due to an open neutral cable (also called as a neutral shift) or supplying non-linear loads. When a transformer or a motor is excited by the unbalanced voltages, then there is a generation of saturation condition due to the high voltage in any one of the three phases. Hence, it exhibits the same abnormal operation as shown above in Fig. 11 and Fig. 12.

**5.3 Energy Efficiency of Electrical Equipment**

Energy efficiency of any electrical equipment is defined as the ratio between the output energy (in kW-h) and the input energy (in kW-h). Variation of efficiency vs. load curve for linear load is same for both transformer and motor and it is shown in Fig. 5 in section 5.1.1. But, when non-linear loads are connected on secondary side of a transformer, efficiency is not same as that for the linear loads of same rating. The efficiency gets dropped down due to harmonic components. It produces more losses, overheating, de-rating or overloading, etc.; hence, efficiency vs. load curve of transformer is not same when supplying non-linear loads and it is shifted down to original curve. Therefore, non-linear loads and their harmonic components need to be taken care to some extent and to be eliminated from the system with the help of filter (i.e. combination of reactor and capacitor).

**6. POWER QUALITY DEFINITIONS AND INTERNATIONAL STANDARDS**

Electrical energy is a product and, like any other product, should satisfy the proper power quality requirements. Both electric utilities and end users of electric power are becoming increasingly concerned about the quality of electric power. The term power quality has become one of the most prolific buzzwords in the power industry since the late 1980s. If electrical equipment is to operate correctly, it requires electrical energy to be supplied at a voltage that is within a specified range around the rated value. A significant part of the equipment in use today, especially electronic and computer devices require good power quality (PQ). Power quality is ultimately a consumer-driven issue, and the end user’s point of reference takes precedence. Power quality is a term that means different things to different people. Some PQ definitions are given below in next section.

**6.1 Classical Power Quality Definitions**

Some important terms related to power quality are defined by IEEE-1100 and presented below:
- Flicker: According to IEEE std. 1100, “A variation of input voltage sufficient in duration to allow visual observation of a change in electric light source intensity.” According to IEEE std. 1159, “Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.” Voltage fluctuations are shown in Fig.13.

- Harmonic distortion: According to IEEE std. 1100, “The mathematical representation of the distortion of the pure sine waveform.” Fig.14 indicates it.

- Inrush current: According to IEEE std. 1100, “The amount of current that a load draws when it is first turned on.” Inrush current waveform is represented in Fig.15.

- Voltage Interruption: According to IEEE std. 1100, “A voltage interruption is a large decrease in RMS voltage to less than a small percentile of the nominal voltage, or the complete loss of voltage for a time period.” According to IEEE std. 1159, “The disappearance of the supply voltage on one or more phases. It is usually qualified by an additional term indicating the duration of the interruption (e.g., momentary, temporary, sustained)” Fig.16 represents the interruptions in voltage.

- Noise: According to IEEE std. 1100, “Electrical noise is unwanted electrical signals that produce undesirable effects in the circuits of the control systems in which they occur.” Fig.17 shows a voltage noise.

- Notch: According to IEEE std. 1100, “A switching (or other) disturbance of the normal power voltage waveform, lasting less than a half-cycle; which is initially of opposite polarity than the waveform, and is thus subtractive from the normal waveform in terms of the peak value of the disturbance voltage. This includes complete loss of voltage up to a half-cycle.” Notches in voltage waveform are indicated in Fig.18.

- Voltage Sag: According to IEEE std. 1100, “An rms reduction in the ac voltage, at the power frequency, for durations from a half-cycle to a few seconds.” Or “Sag is a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycles to 1 min. This definition has been presented in Fig.19.

- Slew rate: Rate of change of (ac voltage) frequency.

- Voltage Swell: According to IEEE std. 1100, “An rms increase in the ac voltage, at the power frequency, for durations from a half-cycle to a few seconds.” Or “Swell is defined as an increase to between 1.1 and 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.”
6.1 Classical Power Quality Definitions

Definitions are given below in next section.

Quality is ultimately a consumer-driven issue, and the end user's point of reference takes increasingly concerned about the quality of electric power. The term power quality has become international standards available and followed by the industries.

IEEE 519 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems. Following Table 2 gives voltage distortion limits for general distribution systems according to this standard:

<table>
<thead>
<tr>
<th>Bus Voltage at PCC</th>
<th>Individual Voltage Distortion (%)</th>
<th>Total Voltage Distortion THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>69 kV and below</td>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td>69.001 kV through 161 kV</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>161.001 kV and above</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

NOTE: High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.

Follows Table 3 gives current distortion limits for general distribution systems according to this standard:

<table>
<thead>
<tr>
<th>Table 3 Current Distortion Limits for General Distribution Systems (120 V Through 69000 V) [13]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Harmonic Current Distortion in Percent of IL</td>
</tr>
<tr>
<td>Individual Harmonic Order (Odd Harmonics)</td>
</tr>
<tr>
<td>$I_n/I_1$</td>
</tr>
<tr>
<td>&lt; 20*</td>
</tr>
<tr>
<td>20 &lt; 50</td>
</tr>
<tr>
<td>50 &lt; 100</td>
</tr>
<tr>
<td>100 &lt; 1000</td>
</tr>
<tr>
<td>&gt; 1000</td>
</tr>
</tbody>
</table>

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

Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.

* All power generation equipment is limited to these values of current distortion, regardless of actual $I_n/I_1$.

Where

- $I_n$ = maximum short-circuit current at PCC.
- $I_1$ = maximum demand load current (fundamental frequency component) at PCC.
- TDD = Total demand distortion, harmonic current distortion in % of maximum demand load current (15 or 30 min demand).
- PCC = Point of common coupling.

IEEE 1100 - Recommended Practice for Powering and Grounding Sensitive Electronic Equipment.

IEEE 1159 - Recommended Practice for Monitoring Electric Power Quality.

EN50160 is a new standard that covers flicker, inter-harmonics, mains signalling, voltage deviations, and more.

IEC 61000-4-15 is a flicker measurement standard that includes design specifications for flicker meters.

IEC 61000-4-7 Electromagnetic Compatibility - Testing and Measurement Techniques - General Guides on Harmonics and Inter-harmonics Measurements and Instrumentation.
7. IMPACT OF POWER QUALITY ON THE INDUSTRY

Electrical power is an important raw material for all commercial operations and, like any other raw material, the quality of supply is very important. Lack of power quality may cause damage and the total cost of using electrical energy can be thus doubled. Each defect is with different causes and effects and, of course, different cost implications. Interruptions are costly to the whole society while some industrial sectors like continuous manufacturing (SRRM) or IT are particularly sensitive to voltage dips as well as harmonics. Regardless of whether the origin is a short or long interruption, a voltage dip, a transient or other voltage disturbance, the consequence is an outage. Interruption duration is important but much more so is the frequency of these PQ problems and the serious impact they may have on industrial productivity.

7.1 Power Quality and Reliability

Industrial and commercial electricity consumers are increasingly suffering by poor power quality and reliability (PQ and R). A utility distribution system fault, even hundreds of miles away, can cause widespread voltage sags that shut down susceptible process equipment. The impact of the power quality on the operating equipment is analysed under voltage sag/swells and harmonics. Voltage sags occur when heavy loads are started, most notably large motors starting across the line. They can also occur when there are brief faults on the utility line, like contact with tree branches or other faults that quickly clear themselves. These sometimes lead to momentary outages. The induction motor torque is directly proportional to the square of the applied voltage, if voltage sag is 80% (i.e. voltage dropped by 20%), then the torque reduces by 36% (i.e. torque is to be 64%). Due to reduction in voltage, motor speed also reduces which might disrupt the industrial process so much that the process control trips it. In Adjustable Speed Drives (ASD), the drop in dc bus voltage which results from the sag may cause mal-operation or tripping of the drive controller or of the PWM inverter. The increased ac current during the sag or the post-sag over-currents charging the dc capacitor may cause an over-current trip or blowing of fuses protecting the power electronics components. In transformer, during voltage sag, the fluxes are displaced from the null mean value and when voltage recovers, which causes transformer saturation and inrush currents are produced. However, not all voltage sags produce transformer saturation.

Voltage swells usually occur from slow acting or faulty voltage regulating equipment either on the utility side or the customer side of the meter. Most customers do not have this sort of voltage regulating equipment. Electronic devices, including ASDs, computers, and electronic controllers, may show immediate failure modes during these conditions. Transformers, cables, busses, switchgear, CTs, PTs and rotating machinery may suffer reduced equipment life time. Voltage swell causes the transformer and the motor to go into saturation condition. Due to saturation of transformer and motor, they draw more magnetizing current with harmonic contents (due to non-linear saturation curve) to meet flux requirement. It de-rates (or in other words, over-loads) the transformer and motor, thereby reduces efficiency of the transformer and the motor. It also deteriorates the winding and reduces life of transformer and motor. The torque of motor may increase suddenly more than requirement of load. It may disturb process of industry or break the shaft of motor, gearbox, etc. Frequent voltage swells on a capacitor bank can cause the individual cans to bulge.

Harmonics can come in from the utility but they are usually generated from and within the facility. Amount of actual required current gets increased due to addition of harmonic current components. Therefore, I2R losses get increased in transformer, motor, power cables, etc. Due to voltage harmonics, iron losses, eddy current losses get increased. Therefore, it can cause overheating of rotating equipment, transformers, and current-carrying conductors; premature failure or operation of protective devices (such as fuses); harmonic resonance conditions on the customer’s electric power system that can further deteriorate electrical system operation, and metering inaccuracies. Harmonic voltage distortion propagating on a power system can also cause the same problems to other customers connected in parallel. Occasionally, power electronic devices can mis-operate due to harmonic distortion and cause a malfunction of the customer’s process. Current distortion can do overheating of neutral cables in 4-wire circuits due to zero sequence harmonic components (like 3rd and multiple of 3rd harmonic components). A major concern arising from the use of capacitors in a power system is the possibility of system resonance. Failure of capacitor bank can occur due to high harmonic current. Voltage distortion can increase the losses in directly connected induction motors i.e. without any driving system (power electronics drives). Harmonic voltage distortion at the motor terminals is translated into harmonic fluxes within the motor. Harmonic fluxes do not contribute significantly to motor torque, but rotate at a frequency different than the rotor synchronous frequency, basically inducing high-frequency currents in the rotor. The additional torques move the rotor in the same or opposite direction to that of required. The additional fluxes do little more than induced additional losses. Decreased efficiency along with heating, vibration, and high-pitched noises are indicators of harmonic voltage distortion. The flow of non-sinusoidal current in a conductor causes additional heating over and above what would be expected for the rms value of the waveform. More likely problems of harmonics are reduced efficiency and increased heat loss in motors, overloaded neutrals, increased heating in cables and transformers, and sometimes tripped or blown power factor correcting capacitors.

7.2 Power Quality and Productivity

Deregulation, power quality, harmonics, power factor, are all terms that have become more common in the last two decades, because of the new non-linear technologies that have become accepted for their working efficiency such as variable frequency drives, switching power supplies etc. Increasingly, industrialists are realising that electricity should be viewed as one among many commodities vital for their business. For utilities, power quality is all about power customer preference when choosing supplier, but for industry, power quality is all about assured productivity and cost control. Up to 70 percent of unexplained down time is caused by power quality problems. With this increased awareness, previously hidden costs of poor quality
supply are surfacing. For instance: the interruption of an industrial process due to a power outage or voltage dip can result in very substantial additional costs to the operation. These include lost productivity, labour costs for cleaning and restart, damaged or poor quality products, delays in delivery, reduced customer satisfaction, and possibly even damage to production equipment.

7.3 Incentives/Penalties by Supply Provider

Some states in India imposed the supply code and performance standards with power quality norms. (Delhi Electricity Supply- Code and Performance Standards Regualtions): The licensee shall maintain the voltages at the point of commencement of supply to a consumer within the limits stipulated hereunder, with reference to declared voltage: (a) In the case of Low Voltage, +6% and -6%; (b) in the case of High Voltage, +6% and -9%; and, (c) in the case of Extra High Voltage, +10% and -12.5%. Similarly it is observed that the harmonics penalties are also imposed under the standard of performance (SoP) regulation. As per SoP regulations, it is the job of the licensee to control harmonics at the point of supply. Similarly, Tamil Nadu Electricity Regulatory Commission (TNERC) for HT consumers of Tamil Nadu State, HT consumer has to pay 15% surcharge (of total energy bill) for harmonic distortion going beyond the limits set by Central Electricity Authority (CEA) and it is effective from 01-04-2012. Presently, other utilities in India are considering the formulation of guidelines on power quality.

8. POWER QUALITY SURVEY

Power quality survey has been carried out for fifteen steel re-rolling mills (SRRMs). This survey is concerned with steel re-rolling industries only. Data collection for this audit has been obtained with the help of Megger make PA9 PLUS Power Quality Analyser. This power quality survey is carried out for identifying the power quality problems related to SRRMs with the major focus on main roughing mill drive. After analysis of collected data, power quality related observations are reported as under.

8.1 Major Categorisation of the Steel Re-Rolling Mills

The total fifteen steel re-rolling industries of different capacity in Nagpur/Raipur are surveyed. They are categorized into three categories, like micro, small and medium SRRMs according to their power consumption and production volume. Table 4 shows the major categorization of all these industries.

<table>
<thead>
<tr>
<th>Table 4 Classification of SRRMs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sr. No.</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td><strong>SMALL SRRMs</strong></td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td><strong>MEDIUM SRRMs</strong></td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>12</td>
</tr>
<tr>
<td>13</td>
</tr>
<tr>
<td>14</td>
</tr>
<tr>
<td>15</td>
</tr>
</tbody>
</table>

Disclaimer: The data and information presented from these industries are generalised for this application note.

8.2 Measurements of Power Quality and Equipment Used

Measuring indices of power quality have been discussed already in section 6.1 like voltage sags, voltage swells, interruptions, flickering, harmonic distortion, transients and many more. For this power quality audit, first, phase voltages of three phases (between phase and neutral) and line current of all three phases are taken for record. In every industry, RMS values of voltages and currents of all three phases have been recorded. In addition with these parameters, waveforms
of line currents and phase voltages are captured after every 1 or 3 seconds or sometimes after every 5, 10 or 20 cycles of waveform. Time duration for recording of data is fixed according to the type of rolling process.

Recording of the following power quality information such as:

- Harmonic analysis up-to the 63rd harmonic.
- Reports out-of-limits events.
- Frequency trending and IEC Flicker measurements.
- Waveform capture with event (voltage and current sags, swells, harmonics and sub-cycle transients down to 65 microseconds), time, or harmonic trending limits.

8.3 Micro SRRMs

Micro SRRMs are the units with only a single rolling mill drive without any significant automation. These drives are in the range of 450-800 hp and with manual feeding of the material. The record of the voltages/currents and its analysis for these five units are presented below.

8.3.1 Voltage/Current Profile

Voltage and current variations is one of the power quality problems notified in steel re-rolling industries. For that, voltage and current profiles of these five micro SRRMs are presented. An individual voltage and current profile of each micro SRRMs is given in Fig.21 to Fig.25. These records of voltage/current (rms) are during the rolling pass.
8.3.2 Harmonics

The induction motor is considered as a linear load, though it is drawing the current of harmonic contents from the source during the no-pass period. For that, typical current waveform and its harmonic contents of these five micro SRRMs are analyzed. An individual current waveform and its harmonic spectrum of each micro SRRMs is given in Fig.26 to Fig.30. These waveforms are captured during the process of rolling with no-loading (no-pass condition).

Table 5 Maximum and Minimum values of Voltages and Currents of Micro SRRMs

<table>
<thead>
<tr>
<th>Industry Name</th>
<th>Va RMS (Volts)</th>
<th>Ia RMS (Amps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amrit Roughing Mill</td>
<td>246.3</td>
<td>460.11</td>
</tr>
<tr>
<td>Ujjawal Intermediate Mill</td>
<td>254.9</td>
<td>1927.29</td>
</tr>
<tr>
<td>Kashyap Roughing Mill</td>
<td>246.8</td>
<td>1765.06</td>
</tr>
<tr>
<td>UGAC Roughing Mill</td>
<td>250.26</td>
<td>1765.06</td>
</tr>
<tr>
<td>Kashyap Roughing Mill</td>
<td>257.18</td>
<td>1765.06</td>
</tr>
<tr>
<td>UGAC Roughing Mill</td>
<td>706.05</td>
<td>706.05</td>
</tr>
<tr>
<td>UGAC Roughing Mill</td>
<td>252.99</td>
<td>706.05</td>
</tr>
</tbody>
</table>

The terminal voltage of the motor is around 245 V in most of the cases. This voltage variation on the machine terminal is 4 V to 33 V is observed during the process. A current drawn by the motor depends on the load during that pass.
Fig. 28 Typical Current waveform and its harmonic spectrum of Intermediate Mill of Ujjawal Ispat Ltd.

Current THD = 40.62%

Fig. 29 Typical Current waveform and its harmonic spectrum of Kashyap Steel Pvt. Ltd.

Current THD = 55.23%

Fig. 30 Typical Current waveform and its harmonic spectrum of UGAC Steel Pvt. Ltd.

Current THD = 33.64%

Table 6: Values of 5th and 7th harmonic components of Current of Micro SRRMs

<table>
<thead>
<tr>
<th>Industry Name</th>
<th>Amrit Roughing</th>
<th>Ujjawal Intermediate</th>
<th>Kashyap</th>
<th>UGAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>Ia (%)</td>
<td>Ia (%)</td>
<td>Ia (%)</td>
<td>Ia (%)</td>
</tr>
<tr>
<td>5th</td>
<td>13.56</td>
<td>18.18</td>
<td>27.29</td>
<td>52.71</td>
</tr>
<tr>
<td>7th</td>
<td>8.03</td>
<td>45.67</td>
<td>29.48</td>
<td>16.28</td>
</tr>
</tbody>
</table>

Table 6 indicates the harmonics of the 5th and 7th order in the motor phase current. It is observed that the 5th harmonics is in the range of 13 % to 52 % and 7th in the range of 8 % to 45 %. This confirms the fifth harmonic current is higher than the seventh harmonic in quantum.

8.3.3 Total Harmonics Distortions

Total harmonic distortion (THD) is the measure of harmonic contents in the current and voltage. With reference to above section, the value of THD is also very important for transformer and motor derating purpose. The THD of the current and voltages are given in Table 7.

Table 7: Maximum and Minimum values of THD of Voltages and Currents of Micro SRRMs

<table>
<thead>
<tr>
<th>Industry Name</th>
<th>Amrit Roughing</th>
<th>Ujjawal Intermediate</th>
<th>Kashyap</th>
<th>UGAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>Va (%)</td>
<td>Ia (%)</td>
<td>Va (%)</td>
<td>Ia (%)</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.51</td>
<td>30.62</td>
<td>6.29</td>
<td>49.49</td>
</tr>
<tr>
<td>Minimum</td>
<td>3.76</td>
<td>6.11</td>
<td>3.32</td>
<td>6.21</td>
</tr>
</tbody>
</table>

From Table 7, it is observed that the voltage THD is varying between 0.63 % to 9.67 % and current THD is ranging from 3.19 % to 55 %.

8.4 Small SRRMs

The small category of the SRRMs having roughing drives ratings between 800 - 1200 hp are identified. The power quality audit of three Raipur and two Nagpur units are conducted under this class.

8.4.1 Voltage/Current Profile

Voltage and current profiles of these industries are presented in the following figures. These rms voltage and current values are recorded during the rolling process and given in the Fig.31 to Fig.35.
This rolling process indicates the voltage sag and swell with different material pass. Table 8 shows the minimum and maximum values of the voltages during the rolling process.

<table>
<thead>
<tr>
<th>Industry Name with drive specifications</th>
<th>Shilpa Kamplee (415V, 800hp, 735rpm)</th>
<th>Ramsons Casting (415V, 1000hp, 750rpm)</th>
<th>R R Ispat (415V, 1150kW, 750rpm)</th>
<th>Hira (415V, 1125kW, 720rpm)</th>
<th>Hanukripa (415V, 1000hp, 740rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>Va Ia Va Ia Va Ia Va Ia Va Ia Va Ia</td>
<td>Va Ia Va Ia Va Ia Va Ia Va Ia Va Ia</td>
<td>Va Ia Va Ia Va Ia Va Ia Va Ia Va Ia</td>
<td>Va Ia Va Ia</td>
<td>Va Ia</td>
</tr>
<tr>
<td>Maximum</td>
<td>264.1 781.966 251.5 1615.58 247.5 1193.57 246 1471.79</td>
<td>264.1 781.966 251.5 1615.58 247.5 1193.57 246 1471.79</td>
<td>264.1 781.966 251.5 1615.58 247.5 1193.57 246 1471.79</td>
<td>264.1 781.966 251.5 1615.58 247.5 1193.57 246 1471.79</td>
<td>264.1 781.966 251.5 1615.58 247.5 1193.57 246 1471.79</td>
</tr>
<tr>
<td>Minimum</td>
<td>258.8 2.477 237 116.106 235.5 159.452 237.5 204.347 236.5 165.954</td>
<td>258.8 2.477 237 116.106 235.5 159.452 237.5 204.347 236.5 165.954</td>
<td>258.8 2.477 237 116.106 235.5 159.452 237.5 204.347 236.5 165.954</td>
<td>258.8 2.477 237 116.106 235.5 159.452 237.5 204.347 236.5 165.954</td>
<td>258.8 2.477 237 116.106 235.5 159.452 237.5 204.347 236.5 165.954</td>
</tr>
</tbody>
</table>
The voltage variation of 8 V to 15 V is observed during the process. The maximum voltage across the motor terminal is around 245 V to 264 V. This table indicates that the minimum setting of the motor terminal is always more than 235 V under loading condition.

8.4.2 Harmonics

The profile of the current harmonics is given in the following record while the no-load pass. A typical current waveform and its harmonic contents of these five SRRMs are presented in Fig.36 to Fig.40.

\[ I = \sqrt{I_1^2 + I_2^2 + \ldots + I_n^2}, \text{ therefore, } I_h = 127.97 \text{ A} \]

\[ \text{Fundamental RMS Current } = I_{fund} = 231.64 \text{ A} \]

\[ \text{Odd harmonic contribution } = 55.19\% \]

Current Total Harmonic Distortion = 55.23%

\[ \text{Current THD } = 53.50\% \]

\[ \text{Current THD } = 23.28\% \]

\[ \text{Current THD } = 32.94\% \]

\[ \text{Current THD } = 34.28\% \]

\[ \text{Current THD } = 264.92\% \]
The harmonic content in these industries are compiled and presented in Table 9. The 5th and 7th harmonic contents are in the range of 8% to 50% and 4% to 27% respectively.

<table>
<thead>
<tr>
<th>Industry Name</th>
<th>Shilpa Kamptee</th>
<th>Ramsons</th>
<th>R Rispat</th>
<th>Hira</th>
<th>Hanukripa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic Order</td>
<td>Ia (%)</td>
<td>Ia (%)</td>
<td>Ia (%)</td>
<td>Ia (%)</td>
<td>Ia (%)</td>
</tr>
<tr>
<td>5th</td>
<td>49.78</td>
<td>14.47</td>
<td>Not considered</td>
<td>18.94</td>
<td>8.69</td>
</tr>
<tr>
<td>7th</td>
<td>19.35</td>
<td>13.98</td>
<td>27.33</td>
<td>22.79</td>
<td>4.89</td>
</tr>
</tbody>
</table>

**8.4.3 Total Harmonics Distortions**
Total harmonic distortion (THD) is measured for the voltages and currents and presented in Table 10.

<table>
<thead>
<tr>
<th>Industry Name</th>
<th>Shilpa Kamptee</th>
<th>Ramsons</th>
<th>R Rispat</th>
<th>Hira</th>
<th>Hanukripa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity Va (%)</td>
<td>Ia (%)</td>
<td>Va (%)</td>
<td>Ia (%)</td>
<td>Va (%)</td>
<td>Ia (%)</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.8</td>
<td>53.49</td>
<td>3.24</td>
<td>23.18</td>
<td>5.67</td>
</tr>
<tr>
<td>Minimum</td>
<td>3.56</td>
<td>21.09</td>
<td>0.78</td>
<td>2.43</td>
<td>1.92</td>
</tr>
</tbody>
</table>

It is observed that the THD in the current is varying between 2% to 21% while voltage THD is in between 1% to 4%. It is also observed that the voltage profile is maintained in these industries while current distortion is also small compared with the micro SRRMs.

**8.5 Medium SRRMs**
Medium SRRMs are those mills having various operation (DC drives for TMT operation) along with roughing mill having drives ratings above 1000 hp. These four SRRMs in Nagpur and one in Raipur are audited and their observations are noted as under.

**8.5.1 Voltage/Current Profile**
The voltage and current profile of these five medium SRRMs is shown in Fig.41 to Fig.45.
The voltage variation from 233 V minimum to 249 V maximum is observed. These variations are of the order of 10 V while rolling. This indicates that the supply side does have stiff supply configuration that helps in maintaining the voltage across the motor which attributes to the electrical network configuration.

### 8.5.2 Harmonics

The profile of the medium SRRM current harmonics across the main supply bus to the main roughing drive is given in the following record while the no-load pass. A typical current waveform and its harmonic contents of these five small SRRMs are presented in Fig.46 to Fig.50.

**Fig.44 RMS Voltage and Current variations of Roughing Mill of Shree Nakoda Ispat Ltd.**

**Fig.45 RMS Voltage and Current variations on 11kV side of Sanvijay Rolling & Engg. Ltd.**

In these mills the recording is done across the roughing mill motor as aim is to identify the problems across the bus supplying the motor. In one of the mill (Sanvijay, Butibori), this record is carried out on the HT (11 kV) bus. The maximum and minimum values of the voltages and currents are given in Table.11.

<table>
<thead>
<tr>
<th>Industry Name</th>
<th>Shilpa Butibori</th>
<th>Shilpa Butibori</th>
<th>Sharda Shee</th>
<th>Shri Nakoda</th>
<th>Sanvijay Rolling</th>
</tr>
</thead>
<tbody>
<tr>
<td>with drive specifications</td>
<td>Mill 1 (415V, 8000hp, 743rpm)</td>
<td>Mill 2 (415V, 10000hp, 710rpm)</td>
<td>(440V, Finishing Mill DC Drives)</td>
<td>(115V, 1125KV, 715rpm)</td>
<td>(On 11kV side)</td>
</tr>
<tr>
<td>Quantity</td>
<td>Va</td>
<td>Ia</td>
<td>Va</td>
<td>Va</td>
<td>Ia</td>
</tr>
<tr>
<td>Maximum</td>
<td>241.2</td>
<td>839.927</td>
<td>243.1</td>
<td>1762.64</td>
<td>248.97</td>
</tr>
<tr>
<td>Minimum</td>
<td>233.9</td>
<td>186.265</td>
<td>238.1</td>
<td>75.856</td>
<td>238.72</td>
</tr>
</tbody>
</table>

**Fig.46 Typical Current waveform and its harmonic spectrum of Roughing Mill 1 of Shilpa Steel & Power Ltd.**

**Fig.47 Typical Current waveform and its harmonic spectrum of Roughing Mill 2 of Shilpa Steel & Power Ltd.**

The trend of voltage variation indicates that the medium SRRM has small variations as much in all these industries but the current THD is ranging from 1% to 264%. The current contents are presented in Table.21. The THD values are also presented for voltages and currents from the records of fifteen SRRM, the variation of voltages and currents with the harmonics of recorded voltage harmonic components of an event no.20.

**Table.11 Maximum and Minimum values of Voltages and Currents of Medium SRRMs**

**Micro SRRMs:**

The voltage variation from 233 V minimum to 249 V maximum is observed. These variations are of the order of 10 V while rolling. This indicates that the supply side does have stiff supply configuration that helps in maintaining the voltage across the motor which attributes to the electrical network configuration.

### 8.5.2 Harmonics

The profile of the medium SRRM current harmonics across the main supply bus to the main roughing drive is given in the following record while the no-load pass. A typical current waveform and its harmonic contents of these five small SRRMs are presented in Fig.46 to Fig.50.

**Fig.44 RMS Voltage and Current variations of Roughing Mill of Shree Nakoda Ispat Ltd.**

**Fig.45 RMS Voltage and Current variations on 11kV side of Sanvijay Rolling & Engg. Ltd.**

In these mills the recording is done across the roughing mill motor as aim is to identify the problems across the bus supplying the motor. In one of the mill (Sanvijay, Butibori), this record is carried out on the HT (11 kV) bus. The maximum and minimum values of the voltages and currents are given in Table.11.

**Table.11 Maximum and Minimum values of Voltages and Currents of Medium SRRMs**

**Industry Name | Shilpa Butibori | Shilpa Butibori | Sharda Shee | Shri Nakoda | Sanvijay Rolling |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>with drive specifications</td>
<td>Mill 1 (415V, 8000hp, 743rpm)</td>
<td>Mill 2 (415V, 10000hp, 710rpm)</td>
<td>(440V, Finishing Mill DC Drives)</td>
<td>(115V, 1125KV, 715rpm)</td>
<td>(On 11kV side)</td>
</tr>
<tr>
<td>Quantity</td>
<td>Va</td>
<td>Ia</td>
<td>Va</td>
<td>Va</td>
<td>Ia</td>
</tr>
<tr>
<td>Maximum</td>
<td>241.2</td>
<td>839.927</td>
<td>243.1</td>
<td>1762.64</td>
<td>248.97</td>
</tr>
<tr>
<td>Minimum</td>
<td>233.9</td>
<td>186.265</td>
<td>238.1</td>
<td>75.856</td>
<td>238.72</td>
</tr>
</tbody>
</table>

**Fig.46 Typical Current waveform and its harmonic spectrum of Roughing Mill 1 of Shilpa Steel & Power Ltd.**

**Fig.47 Typical Current waveform and its harmonic spectrum of Roughing Mill 2 of Shilpa Steel & Power Ltd.**

The voltage variation from 233 V minimum to 249 V maximum is observed. These variations are of the order of 10 V while rolling. This indicates that the supply side does have stiff supply configuration that helps in maintaining the voltage across the motor which attributes to the electrical network configuration.

### 8.5.2 Harmonics

The profile of the medium SRRM current harmonics across the main supply bus to the main roughing drive is given in the following record while the no-load pass. A typical current waveform and its harmonic contents of these five small SRRMs are presented in Fig.46 to Fig.50.

**Fig.44 RMS Voltage and Current variations of Roughing Mill of Shree Nakoda Ispat Ltd.**

**Fig.45 RMS Voltage and Current variations on 11kV side of Sanvijay Rolling & Engg. Ltd.**

In these mills the recording is done across the roughing mill motor as aim is to identify the problems across the bus supplying the motor. In one of the mill (Sanvijay, Butibori), this record is carried out on the HT (11 kV) bus. The maximum and minimum values of the voltages and currents are given in Table.11.

**Table.11 Maximum and Minimum values of Voltages and Currents of Medium SRRMs**

**Industry Name | Shilpa Butibori | Shilpa Butibori | Sharda Shee | Shri Nakoda | Sanvijay Rolling |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>with drive specifications</td>
<td>Mill 1 (415V, 8000hp, 743rpm)</td>
<td>Mill 2 (415V, 10000hp, 710rpm)</td>
<td>(440V, Finishing Mill DC Drives)</td>
<td>(115V, 1125KV, 715rpm)</td>
<td>(On 11kV side)</td>
</tr>
<tr>
<td>Quantity</td>
<td>Va</td>
<td>Ia</td>
<td>Va</td>
<td>Va</td>
<td>Ia</td>
</tr>
</tbody>
</table>
| Maximum | 241.2 | 839.927 | 243.1 | 1762.64 ...
Fundamental RMS Current = I\text{ fund} = 286.67 A

Even harmonic contribution = 1.01%

Current Total Harmonic Distortion = 53.50%

Example: Shilpa Steel & Power Limited, Kamptee Road, Pili Nadi, Nagpur

\[ IT = \sqrt{I_{\text{fund}}^2 + I_{\text{h}}} \]

\[ I_{\text{h}} = \frac{5}{7} \times I_{\text{fund}} \]

\[ I_{\text{h}} = 127.97 A \]

Total RMS current = (Fundamental + Harmonics) RMS Current = \( I_T \)

\[ I_T = \sqrt{I_{\text{fund}}^2 + I_{\text{h}}^2} \]

\[ I_T = 95.47 A \]

**REMARKS:**

Event No.20, Date: 10-01-2015, Time: 17:45:24 (as shown in Fig.47)

**Table.16.**

<table>
<thead>
<tr>
<th>V</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage voltage drop in a supplying transformer is calculated by using Z</td>
<td></td>
</tr>
</tbody>
</table>

Transformer Specifications: 3-ph, 50Hz, 1600KVA, 11KV/433V, 84A/2134A, 5.61% Imp., Dyn11.

Example: Shilpa Steel & Power Limited, Kamptee Road, Pili Nadi, Nagpur

Transformer Specifications: 3-ph, 50Hz, 1000KVA, 11KV/433V, 52.5A/1333.4A, 4.72% Imp.,

9.2.2 Voltage Drop across the Transformer Impedance due to Harmonics

\[ Z_{02ph} = 8.8495 \text{ m/uni03A9} \text{ at } f = 50Hz \text{ and therefore, } Z_{02phn} = n \times Z_{02ph} \text{ at } nf = n \times f. \]

Impedance is dependent on frequency as \[ Z = R + jX, \text{ where } X = 2 \times \pi \times f \times L. \]

\[ |Z| = |X| \text{ as } R \]

\[ Z_{02ph} = 153.37 A \]

**REMARKS:**

Event No.8, Date: 04-01-2015, Time: 15:39:25 (as shown in Fig.36)

**Table.12 Values of 5th and 7th harmonic components of Current of Medium SRRMs**

<table>
<thead>
<tr>
<th>Industry Name</th>
<th>ShilpaButibori MILL 1</th>
<th>ShilpaButibori MILL 2</th>
<th>Sharda Shree</th>
<th>Shree Nakoda</th>
<th>Sanvijay Rolling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity Ia (%)</td>
<td>5th</td>
<td>29.9</td>
<td>66.45</td>
<td>23.5</td>
<td>5.32</td>
</tr>
<tr>
<td>7th</td>
<td>3.25</td>
<td>10.34</td>
<td>6.13</td>
<td>4.6</td>
<td>1.56</td>
</tr>
</tbody>
</table>

The current harmonics in the line current are in the range of 2 \% to 66 \% for 5th harmonics and for 7th harmonics, they are in the range of 1.5 \% to 10 \%. These harmonic contents are indicating that the saturation levels in these industries are not very high due to small voltage variations.

**9.5.3 Total Harmonic Distortions**

Total harmonic distortion (THD) is the measured and tabulated in Table.13. Measurements are carried out at the HT (11 kV) in the Sanvijay Industry, Butibori, Nagpur.

The variation in the THD of the voltage is from 2 \% to 16 \% and current THD is in between 1 \% to 70 \%. This also indicates that the voltage is maintained almost constant and motors are still driven in to the saturation. This is due to the high voltages appearing across the motor terminals.

**Table.13 Maximum and Minimum values of THD of Voltages and Currents of Medium SRRMs**

<table>
<thead>
<tr>
<th>Industry Name</th>
<th>Shilpa Butibori MILL 1</th>
<th>Shilpa Butibori MILL 2</th>
<th>Sharda Shree</th>
<th>Shree Nakoda</th>
<th>Sanvijay Rolling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity Va (%)</td>
<td>5th</td>
<td>3.7</td>
<td>34.43</td>
<td>3.43</td>
<td>70.87</td>
</tr>
<tr>
<td>7th</td>
<td>3.74</td>
<td>7.32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>1.48</td>
<td>7.59</td>
<td>2.21</td>
<td>6.91</td>
<td>0.66</td>
</tr>
</tbody>
</table>

**9 POWER QUALITY – ANALYSIS**

These observed results are compared together in the following section. The variation in voltages and harmonic distortion are presented to compare the typical type of industries.

9.1 Generalised Configuration of Electrical Network

Fig.51 is showing electrical distribution network of Shilpa Steel & Power Limited, MIDC Butibori, Nagpur. Transformers are sharing the load in parallel. This provides rigid support to the bus voltage. Therefore, variation in voltage is less during loading and unloading operation on rolling motors. It also reduces burden on single transformer due to coupled bus bar (shown in
Fig. 51 below) operation. This type of parallel operation of transformers offers minimum impact on bus voltage variation and thus an advantageous configuration to adopt.

Fig. 51 Power Distribution Network of Shilpa Steel & Power Limited

Fig. 52 is showing electrical distribution network of Shree Nakoda Ispat Limited, Raipur. AC and DC drives both are connected to same AC bus bar. The harmonics generated by DC drives affect the AC drives performance. It also affects the incoming transformer.

Fig. 52 Power Distribution Network of Shree Nakoda Ispat Limited

Fig. 53 is showing electrical distribution network of Ujjwal Ispat Limited, MIDC Hingna, Hingna Road, Nagpur. Transformers are not sharing the load in parallel operation. Therefore, variation in voltage is more during loading and unloading operation on rolling motors and hence, it does not provide rigid support to bus bar. It is opposite to Shilpa Steel & Power Limited, MIDC Butibori, Butibori, Nagpur. This operation affects the transformer bus voltage. Hence, their transformer bus voltage does not remain stiff and it creates the problem to other loads (auxiliary loads) connected on same transformer and to the other customers connected on same supply feeder.

Fig. 53 Power Distribution Network of Ujjwal Ispat Limited

Fig. 54 is showing electrical distribution network of Hira Steel Limited, Raipur. This company has done one good thing that is provided the separate transformer for DC drives. It is opposite to Shree Nakoda Ispat Limited, Raipur. Therefore, in this company, less voltage distortion (in wave shape) and voltage THD (in %) are observed. This is the good practice of distribution network configuration while using DC drives.

Fig. 54 Power Distribution Network of Hira Steel Limited, Raipur

9.2.1 K-Rated Transformer

Micro SRRMs:

Medium SRRMs:

Large SRRMs:
9.2 Power Quality - Impact

From the records of fifteen SRRM, the variation of voltages and currents with the harmonics contents are presented in Table.15. The THD values are also presented for voltages and currents in these industries.

The trend of voltage variation indicates that the medium SRRM has small variations as compared to the micro SRRM. Similarly, it is observed that the distortions in the voltages are not much in all these industries but the current THD is ranging from 1% to 264%. The current harmonic of 5th is large as compared to the 7th harmonics. This is expected but all these lead to the heating and de-rating of the motors and transformers. A typical example is provided for obtaining the performance indices for three categories of SRRMs.

9.2.1 K-Rated Transformer

A. Micro SRRMs:
Example: Kashyap Steel Private Limited, MIDC Butibori, Butibori, Nagpur
Event No.36, Date: 24-03-2015, Time: 16:49:32 (as shown in Fig.29)
Current Total Harmonic Distortion = 55.23%
Odd harmonic contribution = 55.19%
Even harmonic contribution = 2.09%
Fundamental RMS Current = I_fund = 231.64 A
Total RMS current = (Fundamental + Harmonics) RMS Current = I_T = 264.64 A

I_T = \sqrt{(I_{fund}^2 + \sum I_h^2)}

K factor = \frac{\sum I_h^2}{I_T^2}

Where,
I_h = hth harmonic current
h = harmonic order or number

Hence, K factor for the above mentioned event is calculated and equal to 7.17 (from n = 1 to 63).

Table.15 Overview of Total Analysis

<table>
<thead>
<tr>
<th>SRRM’s Type</th>
<th>RMS Variation</th>
<th>THD</th>
<th>I_h Harmonics (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Va (V)</td>
<td>Ia (A)</td>
<td>Va</td>
<td>Ia</td>
</tr>
<tr>
<td>Micro</td>
<td>237-250</td>
<td>38</td>
<td>1-9</td>
</tr>
<tr>
<td>Small</td>
<td>235-264</td>
<td>29</td>
<td>1-6</td>
</tr>
<tr>
<td>Medium</td>
<td>234-250</td>
<td>16</td>
<td>1-16</td>
</tr>
</tbody>
</table>

Fig.54 Power Distribution Network of Hira Steel Limited

15 SRRMs have been divided into three categories, with 5 industries under each group namely; Micro, Small and Medium SRRMs, depends upon industry configuration, size and plant capacity. Brief idea of this segregation is showcased in Table.14.

Table.14 Generalised Information about Electrical Distribution Network of Re-Rolling Mills

<table>
<thead>
<tr>
<th>SRRM’s Type</th>
<th>Micro SRRMs</th>
<th>Small SRRMs</th>
<th>Medium SRRMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incoming Voltage at PCC</td>
<td>11KV</td>
<td>Mostly 33KV and somewhere 11KV</td>
<td>Mostly 33KV and somewhere 11KV or 220KV</td>
</tr>
<tr>
<td>Transformer Configuration</td>
<td>Separate Transformer for each mill</td>
<td>Separate Transformer for each mill or single transformer of appropriate size for both AC and DC drives</td>
<td>Separate Transformer for each mill or Transformers operating in parallel supplying more than one mill</td>
</tr>
<tr>
<td>Network Configuration</td>
<td>Fig.53</td>
<td>Fig.54</td>
<td>Fig.51 and 52</td>
</tr>
</tbody>
</table>

Example: Shilpa Steel & Power Limited, MIDC Butibori, Butibori, Nagpur (Plant II)
Event No.8, Date: 04-01-2015, Time: 15:39:25 (as shown in Fig.36)
B. Small SRRMs:
Example: Shilpa Steel & Power Limited, Kamptee Road, Pili Nadi, Nagpur
Event No.8, Date: 04-01-2015, Time: 15:39:25 (as shown in Fig.36)
Current Total Harmonic Distortion = 53.50%
Odd harmonic contribution = 53.49%
Even harmonic contribution = 1.01%
Fundamental RMS Current = I_{fund} = 286.67 A
Total RMS current = (Fundamental + Harmonics) RMS Current = I_t = 325.12 A
\[ I_t = \sqrt{I_{fund}^2 + I_h^2}, \] therefore, \[ I_h = 153.37 A. \]
K factor for the above mentioned event is calculated and equal to 7.22 (from n = 1 to 63).

C. Medium SRRMs:
Example: Shilpa Steel & Power Limited, MIDC Butibori, Butibori, Nagpur (Plant II)
Event No.20, Date: 10-01-2015, Time: 17:45:24 (as shown in Fig.47)
Current Total Harmonic Distortion = 70.92%
Odd harmonic contribution = 70.80%
Even harmonic contribution = 4.21%
Fundamental RMS Current = I_{fund} = 77.83 A
Total RMS current = (Fundamental + Harmonics) RMS Current = I_t = 95.47 A
\[ I_t = \sqrt{I_{fund}^2 + I_h^2}, \] therefore, \[ I_h = 55.29 A. \]
K factor for the above mentioned event is calculated and equal to 18.56 (from n = 1 to 63).

REMARKS: It is observed that the 'K' factor consideration in transformer rating choice depends on the total harmonic current. The appropriate 'K' rating of the transformer should be selected for the expected total harmonic currents due to operating conditions.

9.2.2 Voltage Drop across the Transformer Impedance due to Harmonics

A. Micro SRRMs:
Example: Kashyap Steel Private Limited, MIDC Butibori, Butibori, Nagpur
Transformer Specifications: 3-ph, 50Hz, 1000KVA, 11KV/433V, 52.5A/1333.4A, 4.72% Imp., Dyn11.
\[ \%Z = \frac{I_{2ph} \times Z_{2ph}}{V_{2ph}} \times 100 \]

Where,
\[ I_{2ph} = \text{Phase Current on Secondary side of Transformer} \]
\[ V_{2ph} = \text{Phase Voltage on Secondary side of Transformer} \]
\[ Z_{2ph} = \text{Total Impedance of each phase on Secondary side of Transformer} \]
\[ I_{2ph} = \frac{1334 \times Z_{2ph}}{433 \sqrt{3}} \times 100 \]
\[ Z_{2ph} = 8.8495 \times 10^{-3} \Omega = 8.85 \text{ m} \Omega \]

Impedance is dependent on frequency as \[ Z=R+jX, \] where \[ X=2\pi f L. \] Considering \[ |Z|=|X| \] as \[ R \]

is very small and it can be neglected while calculating voltage drop in a transformer.
\[ Z_{2ph} = 8.8495 \text{ m} \Omega \text{ at } f = 50\text{Hz} \text{ and therefore, } Z_{2ph,n} = n \times Z_{2ph}, \] at \[ n \times f. \]
Event No.36, Date: 24-03-2015, Time: 16:49:32 (as shown in Fig.29)
Percentage voltage drop in a supplying transformer is calculated by using \[ Z_{2ph,n} \] as shown in Table.16.

<table>
<thead>
<tr>
<th>Current Component In</th>
<th>[ Z_{2ph,n} = n \times Z_{2ph} ]</th>
<th>V.D. in a Trans.</th>
<th>( % ) V.D. = ( \frac{I_x \times Z_{2ph,n}}{1.732V} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_1 = 231.64 A )</td>
<td>( 1 \times 8.8495 \times 10^{-3} \Omega )</td>
<td>2.0499 V</td>
<td>0.8199 %</td>
</tr>
<tr>
<td>( I_2 = 122.1 A )</td>
<td>( 5 \times 8.8495 \times 10^{-3} \Omega )</td>
<td>5.4026 V</td>
<td>2.1611 %</td>
</tr>
<tr>
<td>( I_3 = 37.7 A )</td>
<td>( 7 \times 8.8495 \times 10^{-3} \Omega )</td>
<td>2.3354 V</td>
<td>0.9342 %</td>
</tr>
</tbody>
</table>

B. Small SRRMs:
Example: Shilpa Steel & Power Limited, Kamptee Road, Pili Nadi, Nagpur
Transformer Specifications: 3-ph, 50Hz, 1600KVA, 11KV/433V, 84A/2134A, 5.61% Imp., Dyn11.
difficult circumstances where passive filters cannot operate successfully because of parallel
required in practical applications. For example, in shunt filter applications, a filter for blocking a
harmonic frequency. The high impedance then blocks the low of harmonic currents at the
series-tuned to present low impedance to a particular harmonic current
on the line through the filter [7].

\[
\frac{5.61\%}{\text{Current Total Harmonic Distortion}} = \frac{2134 \times Z_{0\text{ph}}}{433/\sqrt{3}} \times 100
\]

\[
Z_{0\text{ph}} = 6.5738 \times 10^{-3} \Omega = 6.57 \text{ m}\Omega
\]

\[
Z_{0\text{ph}} = 6.5738 \text{ m}\Omega \text{ at } f = 50\text{Hz and therefore, } Z_{0\text{ph}} = n x Z_{0\text{ph}} \text{ at } nf = n x f.
\]

Event No.8, Date: 04-01-2015, Time: 15:39:25 (as shown in Fig.36)

Percentage voltage drop in a transformer is calculated as shown in Table.17 by multiplying the current components obtained from an event no.8 and \(Z_{0\text{ph}}\) evaluated above.

<table>
<thead>
<tr>
<th>Table.17</th>
<th>Impedance Voltage Drop (V.D.) in a Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Component (I_n)</td>
<td>(Z_{0\text{ph}} = n x Z_{0\text{ph}})</td>
</tr>
<tr>
<td>(I_1 = 286.67\text{ A})</td>
<td>1 x 6.5738 \times 10^{-3} \Omega</td>
</tr>
<tr>
<td>(I_2 = 142.7\text{ A})</td>
<td>5 x 6.5738 \times 10^{-3} \Omega</td>
</tr>
<tr>
<td>(I_3 = 55.5\text{ A})</td>
<td>7 x 6.5738 \times 10^{-3} \Omega</td>
</tr>
</tbody>
</table>

C. Medium SRRMs:

Example: Shilpa Steel & Power Limited, MIDC Butibori, Butibori, Nagpur (Plant II)

Transformer Specifications: 3-ph, 50Hz, 16000KVA, 33KV/433V, 28A/2134A, 6.87% Imp., Dyn11.

\[
6.87\% = \frac{2134 \times Z_{0\text{ph}}}{433/\sqrt{3}} \times 100
\]

\[
Z_{0\text{ph}} = 8.0503 \times 10^{-1} \Omega = 8.05 \text{ m}\Omega
\]

\[
Z_{0\text{ph}} = 8.0503 \text{ m}\Omega \text{ at } f = 50\text{Hz and therefore, } Z_{0\text{ph}} = n x Z_{0\text{ph}} \text{ at } nf = n x f.
\]

Event No.20, Date: 10-01-2015, Time: 17:45:24 (as shown in Fig.47)

Percentage voltage drop in a transformer is estimated as shown in Table.18 for an event no.20 from medium SRRMs group.

<table>
<thead>
<tr>
<th>Table.18</th>
<th>Impedance Voltage Drop (V.D.) in a Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Component (I_n)</td>
<td>(Z_{0\text{ph}} = n x Z_{0\text{ph}})</td>
</tr>
<tr>
<td>(I_1 = 77.83\text{ A})</td>
<td>1 x 8.0503 \times 10^{-3} \Omega</td>
</tr>
<tr>
<td>(I_2 = 51.7\text{ A})</td>
<td>5 x 8.0503 \times 10^{-3} \Omega</td>
</tr>
<tr>
<td>(I_3 = 8.0\text{ A})</td>
<td>7 x 8.0503 \times 10^{-3} \Omega</td>
</tr>
</tbody>
</table>

REMARKS: Each of the harmonic current contributes towards the voltage drop across the transformer which contributes in the voltage regulation. This indicates the expected harmonic current if known then the voltage drop can be estimated as above. The power distribution reconfiguration is possible from this information to reduce the voltage regulation effect.

9.2.3 Effect of Harmonics on Capacitor Bank

A. Micro SRRMs:

Example: Kashyap Steel Private Limited, MIDC Butibori, Butibori, Nagpur

Motor Specifications: 3-ph, 50Hz, 415V, 800KW, 1083A, 742rpm, slip ring I.M.

Assuming that the motor is working at 0.8 power factor (p.f.) and it is required to improve it to 1 p.f. by using Capacitor Bank (Taking Y connected).

\[
\Phi_1 = \cos^{-1} 0.8 = 36.86^\circ \text{ and } \Phi_2 = \cos^{-1} 1=0^\circ
\]

KVAR Supplied by the Cap.Bank = KW(\tan\Phi_1 – \tan\Phi_2)

KVAR Supplied by the Cap.Bank = 800 (tan 36.86 – tan0)

KVAR Supplied by the Cap.Bank = 600 KVAR

KVAR Supplied by the Cap.Bank = \(\sqrt{3} \times V_L \times I_L = \sqrt{3} \times V_L \times \frac{V_L}{\sqrt{3} \times X_C}

600 \times 10^3 = \frac{433^2}{X_C} \text{ Hence, } X_C = 0.3125 \Omega \text{ whereas, } X_C = \frac{1}{2\pi f C}

X_C = 0.3125 \Omega \text{ at } f = 50Hz and therefore, } X_{Cap} = X_C / n \text{ at } nf = n x f.

Event No.36, Date: 24-03-2015, Time: 16:49:32 (as shown in Fig.29)

Current harmonic components in a capacitor bank are calculated, by using the voltage components obtained from an event no.36 and \(X_{Cap}\) evaluated, as shown in Table.19.
difficult circumstances where passive filters cannot operate successfully because of parallel tuned frequency only. At fundamental frequency, the filter would be designed to yield low

Fundamental RMS Current = $I_{\text{fund}} = 286.67$ A
Odd harmonic contribution = 53.49%

Even harmonic contribution = 4.21%
Odd harmonic contribution = 70.80%
Current Total Harmonic Distortion = 70.92%

Event No.20, Date: 10-01-2015, Time: 17:45:24 (as shown in Fig.47)
For the expected total harmonic currents due to operating conditions.

REMARKS:
C filters are an alternative to low-pass broadband filters in reducing multiple

1. Passive Filters
2. Active Filters
3. Hybrid Filters

- Micro SRRMs: Example: Kashyap Steel Private Limited, MIDC Butibori, Butibori, Nagpur
- Roughing mill motor is always connected in delta configuration mode as shown in Fig.10.
- If voltages are unbalanced, then also neutral conductor has to handle heavy current as
- VA is taken as a reference for phase angles of all voltage and currents.
- $\cos \Phi = \frac{1}{\sqrt{1 + \frac{I_{\text{THD}}^2}{I_{\text{rms}}^2}}} = \frac{DPF \times I_{\text{rms}}}{I_{\text{rms}}} = DPF \times DPF$
- $\cos \Phi = \frac{1}{\sqrt{1 + \frac{I_{\text{THD}}^2}{I_{\text{rms}}^2}}} = \frac{\text{Fundamental Power Factor}}{\text{Fundamental Power Factor}}$
- 3. Passive Filters
- 2. Zigzag transformers
- 3. Passive filters

Example: Shilpa Steel & Power Limited, Kamptee Road, Pili Nadi, Nagpur
- Motor Specifications: 3-ph, 50Hz, 415V, 600KW, 735rpm, slip ring I.M.
- Assuming that the motor is working at 0.8 p.f. and it is required to improve it to 1 p.f. by using Capacitor Bank (Taking Y connected).

KVAR Supplied by the Cap.Bank=600 (tan 36.86 – tan 0)
KVAR Supplied by the Cap.Bank=450 KVAR
$450 \times 10^3 = 433.2$ = \$X_C$ Hence, \$X_C = 0.4167$ \$\mu$ whereas,\$X_C = \frac{1}{2\pi fC}$
$X_C = 0.4167 \mu$ at $f = 50$Hz and therefore, \$X_C = X_C / n$ at $f = n x f$.

Event No.8, Date: 04-01-2015, Time: 15:39:25 (as shown in Fig.36)
Capacitor current and offered capacitive reactance to each voltage components are estimated as shown in Table. 20 for an event no. 8 from small SRRMs group.

Table.20 Current Harmonic Components in a Capacitor Bank
<table>
<thead>
<tr>
<th>Voltage Component $V_{cn}$</th>
<th>$X_{cn} = X_C / n$</th>
<th>$I_{cn} = V_{cn} / X_{cn}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_1 = 261.8$ V</td>
<td>0.4167 / 1 $\Omega$</td>
<td>628.27 A</td>
</tr>
<tr>
<td>$V_2 = 14.2$ V</td>
<td>0.4167 / 5 $\Omega$</td>
<td>170.41 A</td>
</tr>
<tr>
<td>$V_3 = 3.3$ V</td>
<td>0.4167 / 7 $\Omega$</td>
<td>55.43 A</td>
</tr>
</tbody>
</table>

C. Medium SRRMs:
Example: Shilpa Steel & Power Limited, MIDC Butibori, Butibori, Nagpur (Plant II)
Motor Specifications: 3-ph, 50Hz, 415V, 1000HP (746KW), 1305A, 710rpm, slip ring I.M.
Assuming that the motor is working at 0.8 p.f. and it is required to improve it to 1 p.f. by using Capacitor Bank (Taking Y connected).

KVAR Supplied by the Cap.Bank=746 (tan 36.86 – tan 0)
KVAR Supplied by the Cap.Bank = 559.5 KVAR
$559.5 \times 10^3 = 433.2 = \frac{1}{X_C}$ Hence, $X_C = 0.3333 \mu$ whereas, $X_C = \frac{1}{2\pi fC}$
$X_C = 0.3333 \mu$ at $f = 50$Hz and therefore, $X_C = X_C / n$ at $f = n x f$.

Event No.20, Date: 10-01-2015, Time: 17:45:24 (as shown in Fig.47)
Capacitor bank may draw current harmonic components calculated in Table.21 with the help of recorded voltage harmonic components of an event no.20.

Table.21 Current Harmonic Components in a Capacitor Bank
<table>
<thead>
<tr>
<th>Voltage Component $V_{cn}$</th>
<th>$X_{cn} = X_C / n$</th>
<th>$I_{cn} = V_{cn} / X_{cn}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_1 = 240.2$ V</td>
<td>0.3333 / 1 $\Omega$</td>
<td>720.67 A</td>
</tr>
<tr>
<td>$V_2 = 7.5$ V</td>
<td>0.3333 / 5 $\Omega$</td>
<td>112.51 A</td>
</tr>
<tr>
<td>$V_3 = 0.1$ V</td>
<td>0.3333 / 7 $\Omega$</td>
<td>2.099 A</td>
</tr>
</tbody>
</table>

REMARKS: Each of the harmonic voltage contributes to the increase in the capacitor current. This leads to the over-heating of the capacitors and failures. The information on the capacitor current due to the expected harmonics could lead to decide the rating of the capacitors.

9.2.4 Power Factor – True and Displacement Power Factor
The load is supplied with the true sinusoidal voltage and current, then the power factor defined is a displacement power factor (DPF). However, under the non-sinusoidal supply conditions, it is defined as a True Power Factor (TPF) considering the impact of the Total Harmonic Distortion (THD).

True Power Factor (TPF) is the power factor when current is containing harmonics. It is also called as actual power factor while system is having non-sinusoidal current. It is given by:

$$TPF = \cos \Phi = \frac{1}{\sqrt{1 + \frac{I_{\text{THD}}^2}{I_{\text{rms}}^2}}} = \frac{DPF \times I_{\text{rms}}}{I_{\text{rms}}} = DPF \times DPF$$

Where,

$$\cos \Phi = DPF = \text{Displacement Power Factor} = \frac{1}{\sqrt{1 + \frac{I_{\text{THD}}^2}{I_{\text{rms}}^2}}} = \text{Distortion Power Factor} \times DPF$$

Event chosen for three groups of SRRMs are:
- Micro SRRMs : Event No.36, Date: 24-03-2015, Time: 16:49:32 (as shown in Fig.29) from Kashyap Steel Private Limited, MIDC Butibori, Butibori, Nagpur
- Small SRRMs : Event No.8, Date: 04-01-2015, Time: 15:39:25 (as shown in Fig.36) from Shilpa Steel & Power Limited, Kamptee Road, Pili Nadi, Nagpur
difficult circumstances where passive filters cannot operate successfully because of parallel generated by electronic converters, induction furnaces, cyclo-converters [7].

t) seventh-harmonic filter itself and the lower fifth-harmonic filter [7].

ii) tuned frequency only. At fundamental frequency, the filter would be designed to yield low

REMARKS:
K factor for the above mentioned event is calculated and equal to 18.56 (from n = 1 to 63).
Even harmonic contribution = 4.21%
Odd harmonic contribution = 70.80%

Example: Shilpa Steel & Power Limited, MIDC Butibori, Butibori, Nagpur (Plant II)
K factor for the above mentioned event is calculated and equal to 7.22 (from n = 1 to 63).

Unlike a notch filter which is connected in shunt with the power

Transformer Specifications: 3-ph, 50Hz, 1600KVA, 11KV/433V, 84A/2134A, 5.61% Imp., Dyn11.

Where,

Z_{2ph} = 8.8495 \, \Omega \text{ at } f = 50Hz \text{ and therefore, } Z_{2phn} = n \times Z_{2ph} \text{ at } nf = n \times f.

2+ Ih

02phn

 reality and quality of the infrastructure with better product quality.

9.2.5 Harmonic Current through a Neutral Conductor in Star Connected System

Roughing mill motor is always connected in delta configuration mode as shown in Fig. Motor is in saturated condition and draws harmonic current components.

As motor is delta connected, 3rd harmonic and multiples of 3rd harmonic (triplet harmonics) percentages are very low. Hence, for configuration shown in following Fig.55, neutral conductor of a transformer doesn’t have more burdens (effect) of harmonics.

![Fig.55 General Representation of a SRRM](image)

Let’s take one example of unbalanced voltages for clarification:

Shilpa Steel & Power Limited, MIDC Butibori, Butibori, Nagpur (Plant II), Date:10-01-2015, Time:17:27:00.

V_A is taken as a reference for phase angles of all voltage and currents.

Voltage Imbalance = 0.35 \%, V_A = 243.192 \angle 0^\circ \, V, V_B = 243.192 \angle 240^\circ \, V, V_C = 244.554 \angle 120^\circ \, V.

Current Imbalance = 19.15 \%, I_A = 82.977 \angle 5^\circ \, A, I_B = 119.821 \angle 250^\circ \, A, I_C = 107.437 \angle 109^\circ \, A.

I_A + I_B + I_C = I_N

Where, V_A, V_B and V_C are phase voltage of phase A, B and C respectively.

I_A, I_B, I_C and I_N are phase A, B, C supply line currents and neutral line current respectively.

\therefore I_N = 7.69 \angle -29.42^\circ \, A, \text{ this IN is flowing from earth to neutral point of secondary winding of a transformer.}

Why voltages get unbalanced? Reason: If all the phases (windings) of load (motor) are not symmetrical (even) in all respects, then current drawn through each and every phase of load is different. Hence, voltage drop in each phase (line) is distinct and causes unbalanced voltages to appear across the load. Due to unbalanced currents, neutral conductor has to carry the current and establishes voltage difference between neutral point and ground. This is only one reason but there may be number of reasons like fault, outage, etc.

Therefore, it is required to change the size of neutral conductor due to overloading.

9.2.6 Skin Effect due to Harmonics

When AC is flowing through a conductor, the current is non-uniformly distributed over the cross-section in a manner that the current density is higher at the surface of the conductor and then to decay exponentially toward the centre. This effect becomes more pronounced as frequency is increased. This phenomenon is called skin effect. The AC current density J in a conductor decreases exponentially from its value at the surface J_s according to the depth d from the surface, as follows:

\[ J = J_s e^{-\frac{\delta}{\sqrt{\mu \rho}}} \]

Where, \delta is called the skin depth. The skin depth is thus defined as the depth below the surface of the conductor at which the current density has fallen to 1/e (about 0.37) of J_s. The general formula for the skin depth is:

\[ \delta = \sqrt{\frac{2\rho}{\omega \mu}} \]

Where,

\rho = \text{ resistivity of the conductor}
\omega = \text{ angular frequency of current} = 2\pi \times \text{ frequency}
\mu_r = \text{ relative magnetic permeability of the conductor}
\mu_0 = \text{ the permeability of free space} = 4 \pi \times 10^{-7} \, \text{ H/m}
Active Filters are relatively new types of devices for eliminating harmonics. They are based on harmonic frequencies simultaneously in industrial and utility systems. They can attenuate a harmonic frequency. The high impedance then blocks the flow of harmonic currents at the load where passive filters cannot operate successfully because of parallel bypass of harmonics.

### Passive Filters

Unlike a notch filter which is connected in shunt with the power source, the passive filter is connected in series. For example, Shilpa Steel & Power Limited, Kamptee Road, Pili Nadi, Nagpur, where the transformer which contributes in the voltage regulation. This indicates the expected harmonic distortion in the system.

### Transformer Specifications

- **3-ph, 50Hz, 1000KVA, 11KV/433V, 52.5A/1333.4A, 4.72% Imp.**
- **Fundamental RMS Current = I_{fund} = 231.64 A**
- **Even harmonic contribution = 2.09%**
- **Fundamental RMS Current = I_{fund} = 77.83 A**
- **Relative magnetic permeability of Copper = 0.999995 ≈ 1**
- **Resistivity of Copper = 1.7 x 10^{-8} Ωm**
- **Resistivity of Aluminium = 2.82 x 10^{-8} Ωm**
- **Relative magnetic permeability of Aluminium = 1.00000065 ≈ 1**
- **Example: Shilpa Steel & Power Limited, Kamptee Road, Pili Nadi, Nagpur**

### Skin Effect

When AC is flowing through a conductor, the current is non-uniformly distributed over the cross-sectional area of the conductor. Consequently, the effective conductor resistance is more for AC than for DC and in turns, effective conducting cross-sectional area of the conductor is less for AC than for DC.

### Table.23 Skin Depth and Effective AC Resistance

Consider Cu and Al cable of same cross-sectional area of 400 mm². Therefore, radius of the conductor is \( r = 11.2838 \) mm.

### Table.24 Increase in Voltage Drop caused by Effective AC Resistance

#### Remarks:
Under the harmonics frequencies, the conductor resistance increases. It increases in the range of 70-95% from its fundamental frequency values. This obvious to note that the copper conductors always have 30-40% reduced losses as compared to aluminium conductors considering each frequency owing to their property.

As seen from Table.23 that effective AC resistance increases with increase in frequency. Therefore, skin effect increases as and more higher harmonics come into picture.

Let’s take one example for increase in the voltage drop due to harmonics. Ex: Kashyap Steel Private Limited, MIDC Butibori, Butibori, Nagpur.

### Table.24 Increase in Voltage Drop caused by Effective AC Resistance

<table>
<thead>
<tr>
<th>( R_{AC}, V.D. )</th>
<th>Copper Cable</th>
<th>Aluminium Cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I_1 ) = 231.64 A</td>
<td>0.043884</td>
<td>10.1653</td>
</tr>
<tr>
<td>( R_{AC} ) (Ω/Km)</td>
<td>0.070749</td>
<td>16.3883</td>
</tr>
<tr>
<td>( V.D. ) (V/Km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( I_2 ) = 122.1 A</td>
<td>0.070795</td>
<td>8.6441</td>
</tr>
<tr>
<td>( R_{AC} ) (Ω/Km)</td>
<td>0.097505</td>
<td>11.9054</td>
</tr>
<tr>
<td>( V.D. ) (V/Km)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( I_3 ) = 37.3 A</td>
<td>0.080943</td>
<td>3.0516</td>
</tr>
<tr>
<td>( R_{AC} ) (Ω/Km)</td>
<td>0.110078</td>
<td>4.1499</td>
</tr>
<tr>
<td>( V.D. ) (V/Km)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Remarks:
In the above three cases, it is observed that the harmonic currents have significant influence on voltage drop in the cable. A comparative analysis is provided for the copper and aluminium cables. It is very much clear from the analysis, that the harmonics currents add the voltage drop in to the drop due to the fundamental current. The voltage drop due to harmonics is increased by 100%. This terminal voltages drop certainly depends on the length of conductor and material used. This is more severe in case of the aluminium. The voltage drop in the aluminium is almost 50% higher than that of the copper.

This observation also indicates that the I^2R losses increase due to the increase harmonics. This not only contributes into the energy loss but also the life of the cables. The running cost incurred due to skin effect depends on the loading pattern. It is also proportional to the increased resistance which almost gets doubled in both the type of conductors. Similarly, resistance is 50% higher than the copper in case of aluminium.

### 9.3 Financial Impact of Power Quality

The vital energy support to most of the industries is by electrical power. Its reliability and quality are the major attributes required to realise the industrial production targets. The term of power quality has not been seriously considered till it has started hampering the productivity and product quality. The economical impact on the industries due to poor power quality is not
properly assessed. The economical losses are almost inversely proportional to the power quality. If not taken care well, it may lead to revenue loss due to production interruptions, equipment failures and under utilisation of the infrastructure. The problems associated could be higher operating temperatures in the transformers, motors and cables, humming noise in the capacitors or blasting of the capacitor bank or may be higher energy charges. These could be only be identified by monitoring the electrical systems or through PQ auditing.

The various case studies indicate that the India suffers a staggering loss of Rs 100,000/- crore annually [14] due to nationwide power disturbances. In one of the cement industry [14-15], it is observed that the harmonic distortion in current and voltages are due to Variable Frequency Drives (VFD). These are mitigated by active harmonic filters having impact on huge savings due to reduction in the electricity bills. This has also reduced the losses in the transformer and motors. This is not only saving the recurring losses but also improved the equipment utilisation with added increased productivity. The critical and sensitive loads which are most vulnerable to the power quality are required due attention by designing the proper electrical system and mitigating equipments. If power quality aspect is considered at the plant inception stage, then it helps in the not only savings on the electrical consumption but also improving the utilisation of the infrastructure with better product quality.

10 MITIGATION TECHNIQUES

There are many mitigation techniques available today to eliminate voltage sag and swell problem and to eliminate the harmonics. In steel re-rolling industries, voltage sag and swell problem or harmonics drawn due to saturation mode of operation are mitigated with conventional flywheel energy storage or by adopting the tuned passive filters. These are still not been able to completely eliminate these problems as the nature of process dynamics does not allow the perfect matching design. For mitigating the voltage sag and swell problem, FACTS devices like Dynamic Voltage Restorer (DVR), Static VAR Compensator (SVC), Static Synchronous Compensator (STATCOM), etc. can be used, but, these devices are costly. All these devices to mitigate the harmonics are broadly classified as follows:

1. **Passive Filters**
2. **Active Filters**
3. **Hybrid Filters**

10.1 Passive Filters

The passive filters are used for controlling the harmonics and voltage variation across the equipment. The conventional devices are as follows:

1. **In-line reactors or chokes**
   These devices are used for blocking the higher-frequency current and allowing the lower frequency (50 Hz) current with various harmonics generating installations. These are used in series with load producing the harmonics. The effective impedance variation with the harmonic current has blocking effect for the harmonic currents.

2. **Zigzag transformers**
   The two most important problems in industrial/commercial facilities are overloaded neutral conductors and transformer heating. The zigzag connection in power systems are used to trap triplen harmonic (3rd, 9th, 15th, etc.) currents. The windings trap the harmonic currents and prevent them from travelling upstream. Typical results with a zigzag transformer show that it can shunt about 50 percent of the third-harmonic current away from the main circuit neutral conductors. Thus, the zigzag transformer can almost always reduce neutral currents due to zero-sequence harmonics to acceptable levels. A typical connection of the zig-zag transformer is shown in the following Fig.56.

3. **Passive filters**
   Passive filters are inductance, capacitance, and resistance elements configured and tuned to control harmonics. They are commonly used and are relatively inexpensive compared with other means for eliminating harmonic distortion. However, they have the disadvantage of potentially interacting adversely with the power system, and it is important to check all possible system interactions when they are designed. They are employed either to shunt the harmonic currents off the line or to block their flow between parts of the system by tuning the elements to create a resonance at a selected frequency. Fig.57 shows several types of common filter arrangements [7].

![Fig.56 Zigzag transformers](image-url)
i) **Shunt passive filters**: The most common type of passive filter is the single-tuned “notch” filter. The notch filter is series-tuned to present low impedance to a particular harmonic current and is connected in shunt with the power system. Thus, harmonic currents are diverted from their normal flow path on the line through the filter [7].

ii) **Series passive filters**: Unlike a notch filter which is connected in shunt with the power system, a series passive filter is connected in series with the load. The inductance and capacitance are connected in parallel and are tuned to provide high impedance at a selected harmonic frequency. The high impedance then blocks the flow of harmonic currents at the tuned frequency only. At fundamental frequency, the filter would be designed to yield low impedance, thereby allowing the fundamental current to follow with only minor additional impedance and losses [7].

### 10.2 Active Filters
Active filters are relatively new types of devices for eliminating harmonics. They are based on sophisticated power electronics and are much more expensive than passive filters. However, they have the distinct advantage that they do not resonate with the system. Active filters can work independently of the system impedance characteristics. Thus, they can be used in very difficult circumstances where passive filters cannot operate successfully because of parallel resonance problems. They can also address more than one harmonic at a time and combat other power quality problems such as flicker. They are particularly useful for large, rapidly changing distorting loads fed from relatively weak points on the power system. Fig.58 shows general configuration of active filter [7].

![Active Filter Configuration](image)  
**Fig.58** General configuration of active filter [7]

### 10.3 Hybrid Filters
Hybrid filter is the combination of active and passive filter. Hybrid filter can be classified into two categories i.e. series and parallel hybrid filters.

**Series Hybrid Filter**: Series hybrid filter is a series combination of active and passive filter as shown in Fig.59

![Series Hybrid Filter](image)  
**Fig.59** Series Hybrid Filter [17]

**Parallel Hybrid Filter**: Parallel hybrid filter is a parallel combination of active and passive filter as shown in Fig.60.

![Parallel Hybrid Filter](image)  
**Fig.60** Parallel Hybrid Filter [17]

### 11 DISCUSSION AND RECOMMENDATIONS
The steel re-rolling mills are prone to have the current harmonics as observed in the all the measured records. These harmonics values are not following the compliance according to standard values recommended by the various standards, like IEEE 519. The variations of the THD values observed are from 15 % to 60 % with their variations under pass and no-pass conditions. The no-pass THD values are higher than the pass values. This is attributed to the voltage...
variations. The voltage during the pass and no-pass condition varies from 240-255 V (L-N). These variations are well around 5-10% above than that of the rated operating voltages of the motor. The motor used for roughing mill is rated for 415 V (L-L). This overvoltage operation leads to the saturation of the magnetic circuit of the motor and hence indicates the non-linear behaviour of the motor. The micro and small SRRM mills are having higher harmonic currents as compared to the medium SRRM. This could focus to the electrical configurations in the medium SRRM. They are mostly having the two parallel transformer configurations. This leads to the reduction in the equivalent impedance so the drop across the transformer. They also have higher grid supply voltages (33 kV/220 kV) point. It is considered to be stiff and having no voltage variations during the pass and no-pass operation. The impact of the voltage variations also related to the up-keep of the mechanical systems adopted by the SRRMs. The alignments of the motors and effective mechanical resistance cause the drawal of the higher current and hence the drop in the terminal voltage. The general conceptualisation in these industries is to keep the higher tap setting than the nominal on the supply side distribution transformer. This is to maintain the less current fluctuation and better power factor. This has invariably causes the SRRM motors to go into the saturation under the no-pass condition.

The non-linear behaviour of the SRRM motors leads to harmonics having varying magnitudes under pass and no-pass condition and these find path through the up-front transformer. The transformer undergoes the harmonic stress as it is not designed in consideration of these harmonics. The transformer is to have heating (due to effective conductor resistance change) and also causing the localised saturation due to these high frequency currents. This de-rates the transformer and effectively reduces the life of the transformer if not designed properly. Therefore, these harmonic currents not only affect the motor but also the transformer along with the connecting cables and switchgear. This leads to reduce the operating reliability of the infrastructure. The failure of the capacitor is another area due to these harmonic currents and operating voltage variations. They eventually get damaged while drawing the higher currents due to change in the voltages or frequency across the capacitors. In many of the installations, the capacitors are rated for 415 V but operated at the 420-450 V under rolling condition. The expected life of the capacitors gets reduced or they get damaged by drawing the higher harmonics current (trying to escape through these capacitors).

**Summary of Major Power Quality and Operational Issues in SRRMs:**

A. Higher operating voltage across the motor terminals during no-pass operation.
B. Harmonics in the motor current.
C. Transformers are not ‘K’ rated.
D. Capacitors are operated at higher voltages than the rated.
E. Capacitors failures due to harmonic currents.
F. Electrical network configuration not properly designed.
G. Unbalanced voltages cause higher neutral current.

H. Neutral beyond design not properly designed.
1. No tuned filter installed for many of the SRRMs to mitigate the harmonics.
2. Flywheel alignment and sizing is not matching with the loading of the drives.

**Few Recommendations:**

1. Operate motor at rated voltage under no-pass condition by suitable transformer tap selection.
2. Transformer should have low impedance (less than 5%) and suitable for the harmonic currents. (Use of K factor rated transformer).
3. Configure the electrical network for better the voltage regulation. (Parallel operation of the transformer, if more than one transformer is available).
4. Power factor capacitors should be connected across the motor terminals and rated voltage should be maintained across the terminal.
5. Harmonic tuned filters to be designed and installed after the power quality audit.
6. Monitor no-load current to ensure the mechanical alignment is correct.
7. Always separate the supply feeders for roughening mill and DC/AC drive systems. Preferably they should be supplied through the separate transformers.
8. Neutral current to be checked and conductor sizing should be appropriately rated.

**RECOMMENDED PRACTICE:**

A) **During Design:**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Recommended Practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than one transformer operating individually.</td>
<td>Operate in parallel to avoid voltage sag and voltage variations.</td>
</tr>
<tr>
<td>Using the Flywheel of less capability than required.</td>
<td>Use the flywheel of required capacity.</td>
</tr>
<tr>
<td>Running AC &amp; DC drives on same transformer.</td>
<td>Connect AC &amp; DC drives on separate transformers.</td>
</tr>
<tr>
<td>Improper or poor Earthing practices.</td>
<td>Grid for all earth pits below ground.</td>
</tr>
<tr>
<td>Lighting load</td>
<td>Should have separate lighting transformer detuned.</td>
</tr>
<tr>
<td>Neutral Cable</td>
<td>Full/double to avoid heating of neutral conductor due to zero sequence harmonics.</td>
</tr>
</tbody>
</table>
B) During Operation:

<table>
<thead>
<tr>
<th>Power Quality Issues</th>
<th>Probable Reason</th>
<th>Effects</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonics drawn by the motor</td>
<td>Over-voltage across the motor terminal</td>
<td>Failure of Motor due to deterioration, capacitor failure due to drawing of high frequency harmonic current</td>
<td>Apply rated voltage across the motor or voltage compensating devices or harmonic filter.</td>
</tr>
<tr>
<td>Over-Voltage</td>
<td>Regular Practice to avoid voltage sag</td>
<td>Drive card damaging due to overvoltage, light flickering</td>
<td>Provide voltage sag compensating device</td>
</tr>
<tr>
<td>Overvoltage and harmonic distortion</td>
<td>Motor core Saturation</td>
<td>Capacitor failure</td>
<td>Avoid motor saturation by applying rated voltage</td>
</tr>
<tr>
<td>Voltage Sag</td>
<td>Immediate high current</td>
<td>Current Peaks, less light output, reduction in capacitor output</td>
<td>Provide voltage sag compensating device</td>
</tr>
<tr>
<td>Voltage Swell</td>
<td>Immediate unloading of motor</td>
<td>Degradation of electrical contacts, breaking of gearbox, insulation breakdown</td>
<td>Provide voltage sag compensating device</td>
</tr>
<tr>
<td>Harmonics</td>
<td>Motor core Saturation and Induction furnace</td>
<td>Failure and chattering of circuit breaker, derating of motor, capacitor banks and cables</td>
<td>Appropriate filters</td>
</tr>
</tbody>
</table>

12 REFERENCES


[14] APQI Application note on, “Power Quality in the IT. ITES. Data Center”.


ANNEXURE I

Industries Participated in Power Quality Audit:

<table>
<thead>
<tr>
<th>S.No.</th>
<th>List of Industries</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Amrit Steel Rolling Mill, Raipur</td>
<td>Small Rods</td>
</tr>
<tr>
<td>2</td>
<td>Ujjwal Ispat Limited, MIDC Hingna, Hingna Road, Nagpur (Roughing)</td>
<td>Rods</td>
</tr>
<tr>
<td>3</td>
<td>Ujjwal Ispat Limited, MIDC Hingna, Hingna Road, Nagpur (Intermediate)</td>
<td>Rods</td>
</tr>
<tr>
<td>4</td>
<td>Kashyap Steel Private Limited, MIDC Butibori, Butibori, Nagpur</td>
<td>Angles</td>
</tr>
<tr>
<td>5</td>
<td>UGAC Steel Private Limited, MIDC Butibori, Butibori, Nagpur</td>
<td>Bars (Saria)</td>
</tr>
<tr>
<td>6</td>
<td>Shilpa Steel &amp; Power Limited, Kamptee Road, Pili Nadi, Nagpur</td>
<td>Angles</td>
</tr>
<tr>
<td>7</td>
<td>Ramsons Casting Private Limited, MIDC Hingna, Hingna Road, Nagpur</td>
<td>Angles</td>
</tr>
<tr>
<td>8</td>
<td>R R Ispat Private Limited, Raipur</td>
<td>Wire Rod</td>
</tr>
<tr>
<td>9</td>
<td>Hira Steel Limited, Raipur</td>
<td>Steel Wire</td>
</tr>
<tr>
<td>10</td>
<td>Hanukripa Ispat Private Limited, Raipur</td>
<td>Channels</td>
</tr>
<tr>
<td>11</td>
<td>Shilpa Steel &amp; Power Limited, MIDC Butibori, Butibori, Nagpur (Plant I)</td>
<td>Angles</td>
</tr>
<tr>
<td>12</td>
<td>Shilpa Steel &amp; Power Limited, MIDC Butibori, Butibori, Nagpur (Plant II)</td>
<td>Angles</td>
</tr>
<tr>
<td>13</td>
<td>Sharda Shree Ispat Limited, MIDC Butibori, Butibori, Nagpur</td>
<td>TMT Bars</td>
</tr>
<tr>
<td>14</td>
<td>Sanvijay Rolling &amp; Engineering Limited, MIDC Butibori, Butibori, Nagpur</td>
<td>Angles and Channels</td>
</tr>
<tr>
<td>15</td>
<td>Shree Nakoda Ispat Limited, Raipur</td>
<td>TMT Bars</td>
</tr>
</tbody>
</table>

Disclaimer: The presented data is part of the audit which is only meant for preparation of the "Application Note". This is neither meant for any financial claims nor for the legal purpose.

ANNEXURE II

Program for “Analysis and Impact of Harmonics on the Motor, Transformer, Capacitor and Cables”:

Following program is developed to analyse the impact of harmonics on the major component of the industry. This is used to obtain the K-factor, DiPF, TPF, voltage drop and current across the capacitor in the steel rolling plant. The major input to this is the data obtained from the power analyser after the power quality audit. Each event data gives the impact of harmonics on these components. This can be extended to evaluate the filter design to mitigate the harmonics in the steel plant. This program is extended to evaluate the plant energy consumption performance under the power quality domain.

```
START

Enter the Transforme( Motor and Cable Specifications

for x = 1:1:5
(one rolling pass)

Read the input data from Excel file

Calculate k-factor, DiPF & TPF

Calculate Voltage Drop in Transformer, Copper & Aluminium Cable and Capacitor Current for 1st, 5th and 7th harmonic components

Plot Load Cycle, K-factor, DiPF, TPF, Voltage Drop in Transformer, Copper & Aluminium Cable and Capacitor Current versus Event Number

Write the output data to Excel file

STOP

```

Analysis Program is available with Prof. M. V. Aware, Drives Lab, Electrical Engineering Department, VNIT, Nagpur
They can be used in a wide range of steady state and time-varying harmonic and inter harmonic frequencies simultaneously in industrial and utility systems. They can attenuate a harmonic frequency. The high impedance then blocks the flow of harmonic currents at the tuned frequency only. At fundamental frequency, the filter would be designed to yield low impedance and losses [7].

Passive filters are inductance, capacitance, and resistance elements configured and tuned to their normal flow path on the line through the filter [7]. Unlike a notch filter which is connected in shunt with the power system, a filter for blocking a seventh-harmonic itself and the lower fifth-harmonic. The notch filter is series-tuned to present low impedance to a particular harmonic current and is connected in shunt with the power system. Thus, harmonic currents are diverted from the normal flow path on the line through the filter [7].

Multiple stages of both series and shunt filters are often required in practical applications. For example, in shunt filter applications, a filter for blocking a zero-sequence harmonic to acceptable levels. A typical connection of the zig-zag transformer conductors. Thus, the zigzag transformer can almost always reduce neutral currents due to saturation mode of operation are mitigated with other means for eliminating harmonic distortion. However, they have the disadvantage of potentially interacting adversely with the power system, and it is important to check all possible system interactions when they are designed. They are employed either to shunt the harmonic currents off the line or to block their flow between parts of the system by tuning the elements to create a resonance at a selected frequency. Fig. 57 shows several types of common filter arrangements [7].

Compensator (STATCOM), etc. can be used, but, these devices are costly. All these devices to control harmonics. They are commonly used and are relatively inexpensive compared with devices like Dynamic Voltage Restorer (DVR), Static VAR Compensator (SVC), Static Synchronous Compensator (STATCOM), etc. can be used, but, these devices are costly. All these devices to control harmonics. They are commonly used and are relatively inexpensive compared with devices like Dynamic Voltage Restorer (DVR), Static VAR Compensator (SVC), Static Synchronous Compensator (STATCOM), etc.