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REAL TIME MONITORING OF IMPACTS OF POWER QUALITY ON INDUSTRIAL MOTOR EFFICIENCY

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OFTHE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

IN

POWER SYSTEM

SUBMITTED BY:

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2022

DECLARATION

I hereby certify that the work which is presented in the Major Project – II entitled "Real time monitoring of impacts of power quality on industrial motor efficiency" in fulfillment of the requirement for the award of the Degree of Master of Technology in Power System and submitted to the Department of Electrical Engineering, Delhi Technological University, Delhi is an authentic record of my own, carried out during a period from January to May 2022, under the supervision of Prof. Narendra Kumar.

The matter presented in this report has not been submitted by me for the award of any other degree of this or any other Institute/University. The work has been accepted in peer reviewed Scopus indexed conference with following details:

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To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere. I further certify that publication and indexing information given by the student is correct.

Prof. Narendra Kumar

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Place: Delhi

Date: 31.05.2022

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ABSTRACT

This work focused on Impacts of power quality on an online induction motor in a real time basis. The work involves creating variable conditions in the input power supply and analyzing its impacts on motor performance specially efficiency. Input power supply is modulated in two aspects, first one is voltage fluctuation and second one is voltage unbalance.

For the conduct of test a 10 HP induction motor is selected which is run under test condition for half an hour. During test input supply voltage is varied on both sides of the rated voltage of the motor with the help of servo voltage stabilizer. In process voltage unbalance condition was also implied on the motor by varying the voltage across three phases. All measurement parameters during test are recorded with the help of Fluke 438 II Power quality and motor analyzer.

The test results have indicated that motor efficiency deteriorates whenever there is a deviation from rated voltage of the motor. It also shown the same trend when voltage unbalance is increased. Thus, it implies that power quality plays a major role in the performance of the motor.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Power quality is a term popular in electrical engineering which describes the degree a supply system resembles or conforms to established specification of an ideal supply system.

It comprises of various aspects of power supply system such as Voltage, Frequency, Waveform which when deviates from their specified requirements results into poor power quality.

1.2 NEED OF POWER QUALITY

Power quality is getting disturbed due increase in use of renewable energy sources such as wind/solar, application of nonlinear devices such as energy efficient LED luminaries, variable frequency drives.

Poor power quality not only causes degradation in performances but also results in premature failure of electrical equipment's. In addition to that it also results in lower efficiency of the system, financial losses.

1.3 FACTORS AFFECTING POWER QUALITY

Power quality parameters can be affected by the following two categories:

I. Steady State (Continuous)
II. Disturbances

- Steady state power quality parameters comprise of frequency deviations, Harmonics (Waveform distortion), voltage unbalance, voltage fluctuation etc.
- Disturbances includes Transients, swells, dips, outages etc.

1.4 MAJOR PARAMETERS OF POWER QUALITY

Some of the Major Power quality Parameters are discussed below: -

- **Frequency:** Any variation in frequency from the fundamental frequency (50 Hz in India) termed as frequency variation. It can be caused by
  - Fault on power system
  - A large load block disconnected
  - Large source of generation goes offline

  Frequency deviation may affect system stability and grid blackout.

- **Voltage:** Voltage affects the power quality in many ways like supply voltage interruption, sag/swell in voltage, voltage harmonics, Voltage unbalance, Voltage fluctuations etc.
- **Flicker:** It is an uncomfortable visual sensation induced due to light stimulus whose luminance or spectral distribution is time fluctuating.
- **Harmonics:** It is the sinusoidal component of periodic voltage/current waveform having a frequency which is an integral multiple of the fundamental frequency.

2.0 SCOPE OF WORK

Power quality is one aspect which remains mostly ignored in the industry as it is understood that it is beyond the control of users (Manufacturer's staff). The advent of non-linear devices such as Variable frequency drives for motor speed control, Automatic power factor controller (APFC), LED luminaries, UPS, etc which are industry's own assets have contributed a lot in deteriorating the power quality. In addition to that fluctuations, transients, frequency deviations and voltage disturbances in the incoming grid supply also worsen the power quality.

This combined effect of industries owns connected assets and dispatched power supply from outside have its own very obvious and deteriorating effect on the performance of the induction motor.

Taking inspiration from these factors the work describes about the impacts of power quality on motor parameters (Primarily efficiency) which is done in Real time scenario and actual operating conditions of the industry.

The work is conducted to find out the performance of motor under varying power quality since it is done on real time basis the results will provide us an in-depth insight on motor performance in an actual operating condition in an industry.

4.0 OUTLINE OF DISSERTATION

The thesis consists of following chapters-

- **Chapter 1-** Introduction: This chapter is about the theory related to power quality impacts on motor performance.
- **Chapter 2**- Literature review: This chapter presents the review of the research papers on the similar topic.
- **Chapter 3**- Selection and design of test setup: This chapter describes specification of the test motor, Servo voltage stabilizer and Power quality analyzer.

- **Chapter 4-** Methodology: This chapter highlights the methodology put in place for experimentation.
- **Chapter 5-** Measurement & Analysis: This chapter includes set of measurement data which is generated through experimentation. It also includes analysis of the results based on data and plots.
- **Chapter 6-** Impact of power quality on other motor parameters: This chapter describes about the impacts of power quality on other motor performance parameters.
- **Chapter 7-** Conclusion and future scope of work: This chapter put forward the conclusion of the work along with future scope of work.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Many research papers and previous works related to impacts of power quality on motors are reviewed before the start of the work. The review work is mainly done in the fields of –

- Motor efficiency/ Motor Performance
- Power quality

2.2 LITERATURE SURVEY

2.2.1 MOTOR EFFICIENCY

The paper [1] presents an experimental result of an assessment of energy efficiency and power quality impacts on set of motors having different efficiency class IE1, IE2 and IE3. The paper concludes that for increasing percentage of specific harmonics distortion, other harmonics are also increased. It also added that voltage unbalance results in higher current harmonic distortion in all three types of efficiency classes. The Major limitation of the paper was that results are inferenced on small size of samples tested and suggested further exhaustive work.

The impact of voltage variation and voltage unbalances on the different efficiency class of motors ie IE2, IE3 and IE4 is presented [2]. Its finding includes that IE4 motor is least dependent on voltage variations, authors used spearman correlation matrices to understand the impacts on the current harmonic distortion while motor operations. Major takes away from the paper was, IE2 and IE3 motors presented similar operational characteristics. IE4 motors are better suited than both IE2 and IE3 in case of higher load considerations. LSPMM are effective for fixed speed operation and not recommended for frequent start/stop operation, in these motors current harmonic content was found higher during voltage unbalances. It was also observed from the paper that power factor of LSPMM motors is less than IE3 motors for rated power and load condition. A major point worth noting of this paper was that voltage unbalances propagates a much higher current unbalances which culminates into uneven losses and temperature rise in the motor. Power factor trend is observed inverse to the voltage level. Spear correlation matrices was used to analyze harmonics, main findings of the same was that THD is found in inverse relation to positive sequence voltage and in direct relation to negative sequence voltage for under voltage unbalance situation. It is directly proportional for both positive and negative sequence component in case of overvoltage unbalance condition.

There are lot of emerging technologies in context of motor efficiency are available, one such technological paper [3] presented a comparative analysis between Squirrel cage induction motor (SCIM), Permanent magnet synchronous motor (PMSM), Line start PM synchronous motor (LSPM), Synchronous reluctance motor (SynRM) and switched reluctance motor (SRM). The paper put forward its conclusions like PMSM/LSPM and SynRM are more energy efficient than SCIM for lower power range, their higher cost being a disadvantage is now vanning. SCIM are still excellent option for small- medium power ranges with fixed speed applications. For low power ranges the best efficiency comes out from LSPM however higher cost is a concern. For synchronous technology they have a flat efficiency curve which shows they are independent from the variation of the load. The paper stipulates that axial flux structure can be a game changer for VSD fed motors particularly for fans/pumps application, however this technology is best suited for low range motors (< 30 kW). At the end authors recommended the use of IE4/IE5 motors class as the technology is already proven and ready for commercialization.

Motor has various types of application such as pumping, conveying, blowing etc [4] guides us about motor sizing that will be most energy efficient in a pumping system. It put forward the comparative analysis of various technologies of motor in the pumping system, by ways of data presented it tried to cover every characteristic of motor operation like speed, torque, dimension, efficiency and output power. The paper also considered the cost involved in the operation of motors and suggested best suitable technology within a payback of 5 years.

Petr Orság et.al in [5] has analyzed impacts of power quality on motor performance, the power quality indices which are chosen for study are voltage distortion, voltage unbalance and voltage dip on an induction motor of rated 4kW. Motor efficiency and motor power factor are the main parameters that are analyzed while experimentation. The paper presents that greatest impact on motor performance was that of voltage dip, in case of voltage distortion and voltage unbalance the efficiency curve is linear and directly proportional within a range of load. The experimentation was conducted on motor with and without drive. In case of controlled drive, the effect of voltage distortion and unbalance is negligible. This paper is very helpful in understanding the nature of motor parameters under varying power quality indices thus it also resembles closely with the experimentation of my study.

Substitution case study of motor having efficiency class IE0 and IE1 in pumping application [6] presents a technoeconomic analysis to maximize the energy savings and economic advantages. With the exhaustive measurement and data generation the paper tries to put forward the advantages of substitution of the existing motors at the test location. The point worth noting was that rewound motors becomes lesser efficient. It had taken up 2 cases one for basic sector and another of professional sector having 2 set of motor each and various operating parameters such as active power, power factor, energy consumed, voltage are compared for various days. At last conclusion was presented using prevailing tariffs of the location (Peak and off peak) charges.

Online monitoring of impacts of power quality indices mainly voltage distortion, voltage magnitude variation and voltage unbalance on the performance of motor by a virtual, low-cost measurement instrument is referred. The major advantage of the system in [7] was that it can be installed in industry to continuously monitor the power quality which has potential to deteriorate motor efficiency and its life expectancy. The instrument is a combination of voltage transducer, USB data acquisition system, a phased locked loop (PLL) and a laptop. Harmonic voltage factor is computed by discrete Fourier transform (DFT). The paper was useful in understanding the varying trends of power quality during a period of measurement and related computational aspects for deriving the conclusion.

Marine application of motors is a critical application [8] it highlights impacts of power quality like voltage distortion, frequency deviation, unbalance on induction motor which are in marine application. The paper presented the various trends like voltage, THD, frequency with respect to time. The authors opined that frequency deviation is a harmful factor in ship micro grid. Coefficient of voltage energy efficiency and temperature coefficient of power quality are considered complementary to each other which is recommended by authors for energy efficient ship operation.

2.2.2 POWER QUALITY

The following papers/articles were reviewed for power quality-

Power quality plays an important role in the performance of electrical systems [9] put light on ways and effect of harmonic mitigation filter in textile industry. Authors commented that due to low cost and low power consumption, passive filters are best fit for industry. A significant saving in energy is reported in the paper after the application of harmonic mitigating filters. Mechanical anomalies like temperature rise due to harmonics is also discussed with the help of thermal images across motors. It became very helpful to understand harmonic presence and its counter-productive nature. Harmonic filters also played part in reduction of unbalances to the tune of 80% which in turn reduced temperature rise, noise and ripples across motor. Authors also presented their work along with cost benefit analysis and clearly recommended the technology is beneficial for the industry along with fast payback.

Harmonics are distortions in fundamental frequency which are detrimental to smooth functioning of motors. This harmonic can be eliminated by the usage of active filters [10] is about insertion of active filter for mitigation of harmonics during soft start of motors. Both simulation and hardware experiment were performed with and without soft starter on a 22kW induction motor. The results of the experimentation were found on same lines both for simulation and hardware setup. The paper ended with the concluding points that during DOL start motor draws 5-8 times of starting current which can be effectively minimized by applying shunt active filters, it also hampers the rising levels of THD and kept it below 5%. Thus, the scheme can be applied in most of industries which are having large number of 3 phase induction motors. The paper added to the idea of improving power quality in industrial scenarios.

Energy conservation has become paramount in today’s scenario [11] presents a detailed energy audit of an educational institute. It mainly refers to the concept of energy management through analysis of data such as electricity bills, load curve pattern. It also incorporated solar PV as a source and discussed about the fluctuation in voltage and power. The study concluded with suggestion to improvise energy management, however regarding solar the technology is cost effective but not reliable as commented by authors. The paper helped in understanding about energy audit, associated terminologies, methodology along with calculations.

CONCLUSION

Literature review is carried out for the present work "Real time monitoring of impacts of power quality on industrial motor efficiency" The review helped in understanding the concepts of power quality and motor efficiency, it made me aware of the studies done on the topic in the past and made me aware of their methodology adopted and final conclusion.

Research gap

There are many studies and work performed in the area of impact of power quality on induction motors. Since the topic under consideration is itself so wide by the virtue of having so many types of power quality indices and large range of motors having different efficiency class, application, constructional features that there is still need of exhaustive study in the area, despite so many studies and research papers available there are still many power quality indices left which are not considered in these past studies. In addition to that one major research gap that has been noted that there is no paper/work available on direct online monitoring (Hardware setup) of induction motor under varying power quality, since motor efficiency estimation is a complex task while the motor is in operation, it has been made possible due to the use of patented technology of Fluke 438 II motor analyzer.

Motivation

Being a working professional associated with manufacturing industry from past 10 years, I have been closely analyzing the problems that industry is facing due to power quality. There have been regular issue of breakdowns and productivity loss most of them correlates with power quality either directly or indirectly. Squirrel cage induction motors are considered as the work horse of the industry and used in several applications such as Fans, Pumps, Material handling, Mills main motor etc. Also there have been never conducted any study of similar nature which involves direct online monitoring of motor efficiency under varying power quality.

Considering the above discussed scenario, I got motivated to undertake a study of impacts of the most notorious electrical problem of the industry (Power Quality) on most important production assets of the industry (Motors) during real time operations. Literature review of various work performed in the past made it possible to collect loose ends in the studies performed. It helped in overcoming the challenges of setting up the proposed system, measurement and analysis.

CHAPTER 3

SELECTION OF PARAMETERS & DESIGN OF EXPERIMENTAL SETUP

3.1 INTRODUCTION

The work involves real time online monitoring of impacts of power quality on motor efficiency. For the purpose of real time monitoring an online motor is identified for experimentation and data generation.

3.2 SELECTION OF EXPERIMENTAL SETUP

The experimental setup constituted the following instruments:

1. An Induction Motor (of suitable rating)
2. Servo voltage stabilizer (For Varying input power supply)
3. A power quality & Motor Analyzer (For measurement/data logging)

3.3 SELECTION OF EXPERIMENT LOCATION

The location for performance of experiment was chosen at AIIMS (Cardio & Neuroscience Centre) Pump house. This location is chosen due to various factors like easy availability of operational motors, Power quality improvisation techniques availability, long operational hours of the site among few of them.

3.4 SPECIFICATION DETAILS OF INSTRUMENTS

The instruments selected as per 3.2 above, their specification details is discussed below:

3.4.1 Squirrel cage Induction Motor

SCIM motor of 10 HP (7.5kW) is identified for the experimentation, the Nameplate details of the motor is as follows:

Table 1 Motor Name Plate Details

PARAMETERS	SPECIFICATION
Type	Squirrel cage Induction Motor
Phase	3 Phase
Rating	10 HP (7.5 kW)
Full Load Current, I_f	27 A
Rated Power Factor	0.85
Rated Voltage	415 V
Rated Speed	3600 RPM
Service Factor	1.05
Motor Design type	NEMA A
Application	Pumping
Variable frequency Drive	No

3.4.2 Servo Voltage Stabilizer

To Bring into variation in the power quality aspects (Voltage fluctuations and Voltage unbalances) an apparatus called as Servo voltage stabilizer has been used, the detailed specification of the same is as under:

Table 2 Servo voltage Stabilizer Details

PARAMETERS	SPECIFICATION
Capacity	200 KVA
Input Voltage	270 V – 470 V
Output Voltage	400 V +_ 1% Volt
Cycle	50 Hz

3.4.3 Power Quality and Motor Analyzer

For the measurement and logging of parameters of power quality and motor performance, a power quality and motor analyzer has been used. This analyzer uses a patented algorithm for measuring motor efficiency without placing any mechanical sensors or decoupling from operation.

This feature enabled the online real time monitoring of impacts of power quality on motor efficiency. The specification details of Power quality cum motor analyzer are as follows:

Table 3 Power Quality and Motor Analyzer Details

PARAMETERS	SPECIFICATION
Make	FLUKE 438 II
Type	Power Quality Analyzer and Motor Analyzer
Measurement method	IEC61000-4-30 2nd edition class A
POWER QUALITY ANALYZER	
Power quality Measurement Standard	EN 50160
Harmonics Measurement	IEC 61000-4-7
Max Input voltage	1000 V (R.M.S)
Nominal frequency	50Hz, 60Hz
Watt	6000 MW
Power factor	0…..1
Harmonics order (n)	DC, 1st to 50th Grouping: Groups according to IEC 61000-4-7
Volt % unbalance	0.0……..20.0%
Amps % unbalance	0.0……..20.0%
MOTOR ANALYZER	

Mechanical motor power	1 HP to 1000 HP
Rated Current, A	1 A to 1500 A
Torque (Nm)	0 - 25000
RPM	0 - 36000
Efficiency (%)	0 - 100
Unbalance (%)	0 - 100
Motor Design class	NEMA-A, B, C, D, E IEC-H IEC-N Other

CHAPTER 4

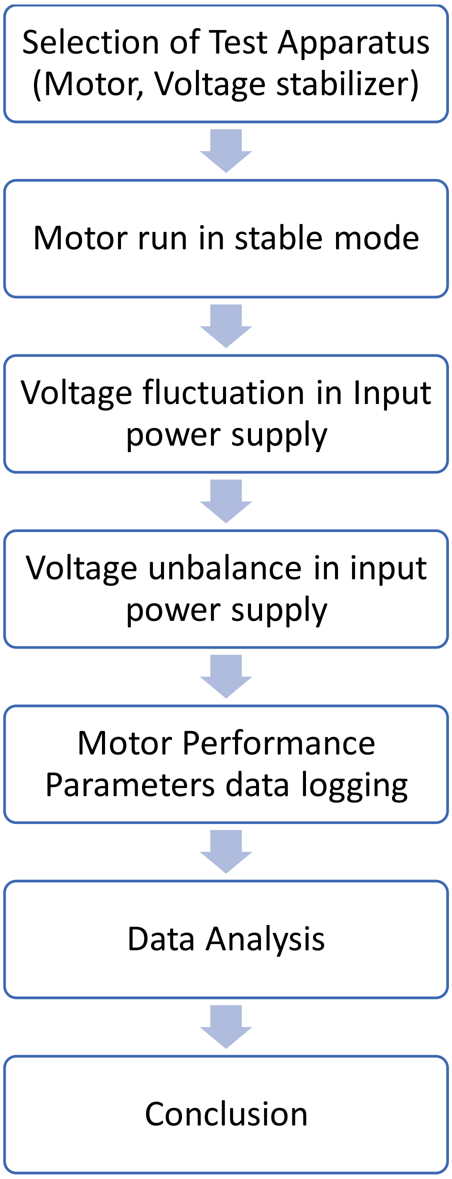
METHODOLOGY

4.1 Introduction

This chapter describes about the methodology adopted for conducting the experiment. As explained in previous chapter an inline 10HP induction motor is coupled through servo voltage stabilizer, The measurements are done with the help of FLUKE 438II Power and Motor analyzer.

4.2 Methodology Flowchart

The below chart presents the flow of activities that has been taken to perform the study



4.3 Setup and working of Fluke 438 II Power Quality and Motor Analyzer

The motor analyzer feature of Fluke 438 II allows measurement of torque, Mechanical power and RPM of a direct-on-line asynchronous motor (driven with/without a variable speed drive). The measurement of variables is done dynamically without use on any additional mechanical sensors or shut down of motor operation.

The Fluke 438-II unit applies a proprietary algorithm to electrical waveforms for providing mechanical parameters measurements such as (Motor RPM, Torque, Load etc). This algorithm uses a combination of physics-based model and data driven model of an induction motor thereby eliminating any pre measurement testing for estimation of motor model parameters.

Estimation of Parameters

- Motor RPM- is estimated by the presence of rotor slot harmonics in the current waveforms.
- Motor shaft torque- is estimated by using complex relation of motor voltage, current and slip.
- Electric power- is measured through voltage and input current.
- Mechanical power- is calculated by motor torque times motor speed.
- The motor efficiency- is calculated by division of the estimated mechanical power to the measured electric power.

4.3.1 Mechanical Parameters of Fluke 438 II

1. **Motor torque:** The rotational force developed by motor and transmitted to a mechanical load is called as Motor torque. It is displayed in (lb. Ft or Nm). It is the most critical parameter that characterizes instantaneous mechanical performance of driven load by electric motor.
2. **Motor speed:** This is the instantaneous motor shaft rotational speed. When Combined with the motor torque, It provides an estimation of the mechanical performance of driven load by electric motors.
3. **Motor mechanical load:** This is the actual mechanical power (shown in HP or kW) which the motor produces. It is a direct indication to overloading conditions without

basing simply on motor drawn current.

4. **Motor efficiency:** It is the ability of the motor to convert electric power into useful mechanical work. It will be helpful in quantifying cost associated with motor energy inefficiency.

4.3.2 Motor Setup

The motor nameplate details have to be pre fed into the analyzer. This information is used for measurement algorithm. This information determines the mechanical parameters from the electrical signals that are used for measurements.

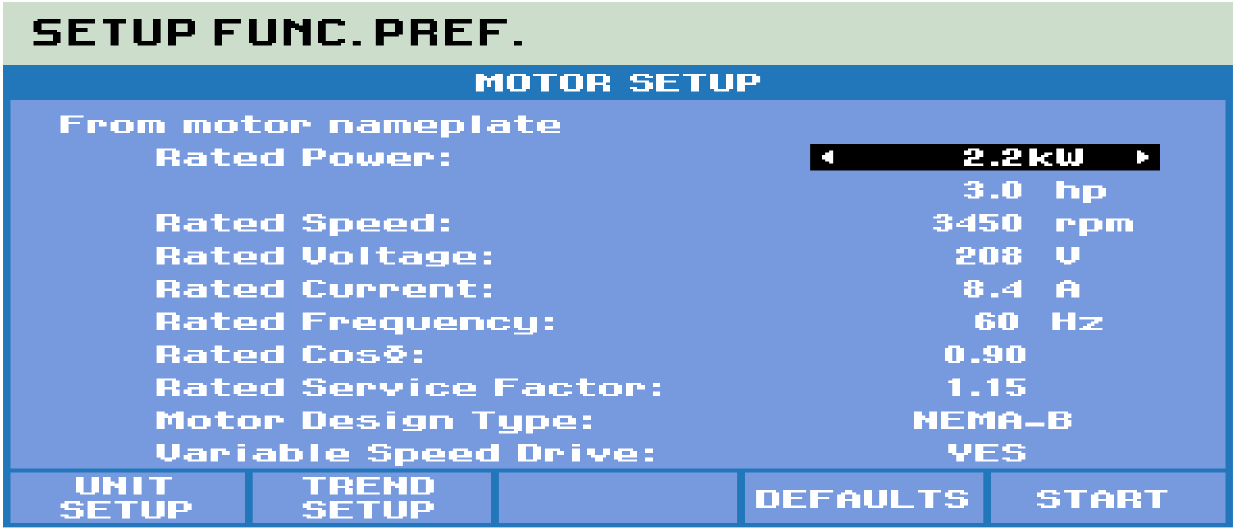


Figure.1. Motor Setup Screen

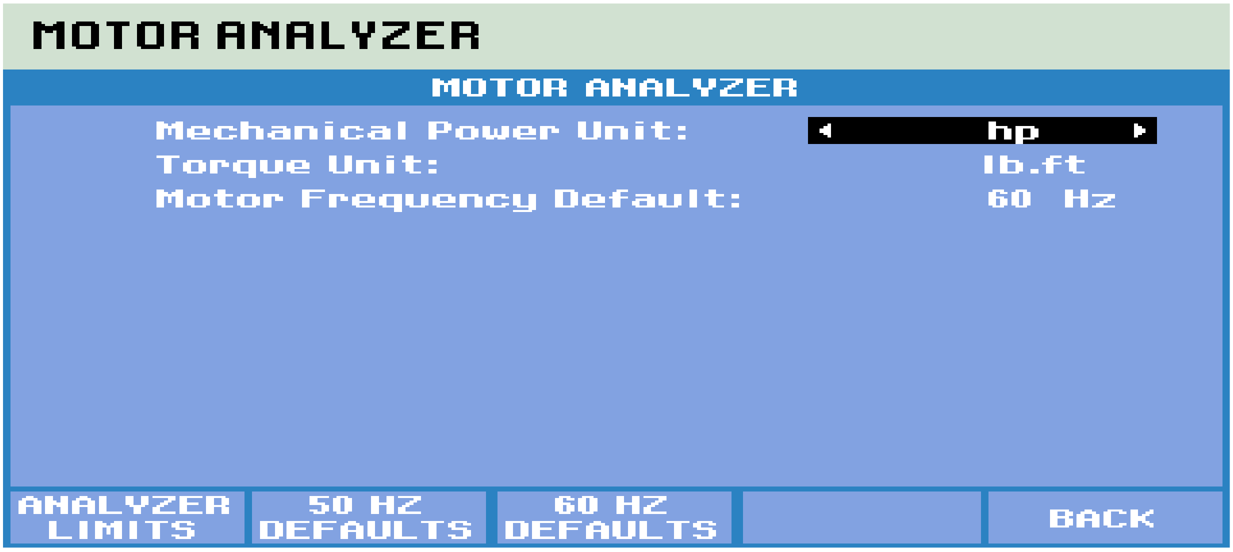


Figure.2. Motor Analyzer screen

4.3.3 Mechanical Parameters in Fluke 438 II

The Mechanical Parameters display comprises of torque, power, and speed. It also displays the Motor efficiency in %.

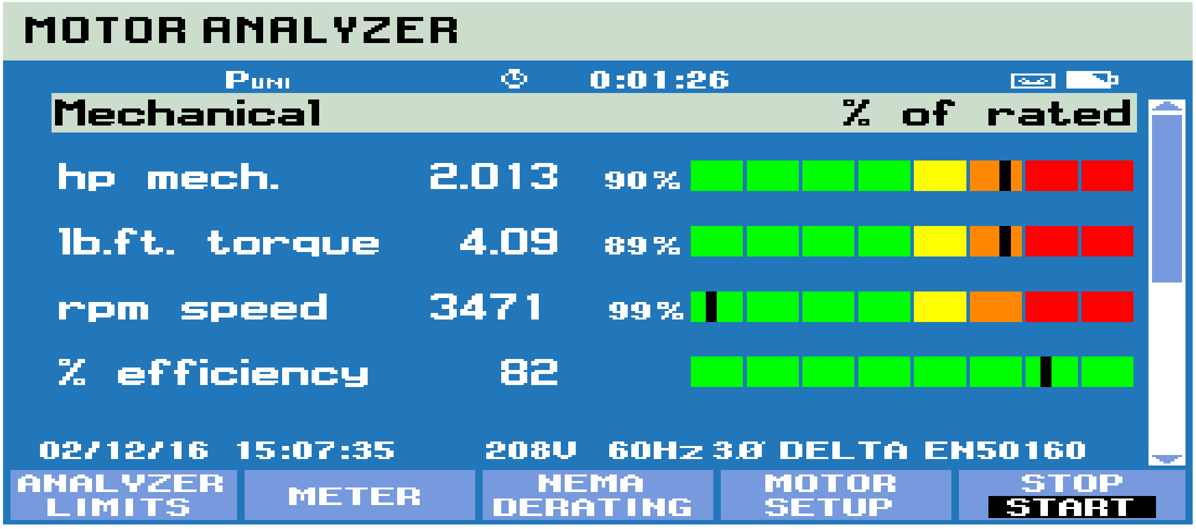


Figure.3. Motor Analyzer (Mechanical Screen)

4.3.4 Electrical parameter in Fluke 438 II

The other screen is of the electrical power and power factor. It also shows the voltage unbalance in % and harmonics voltage factor.

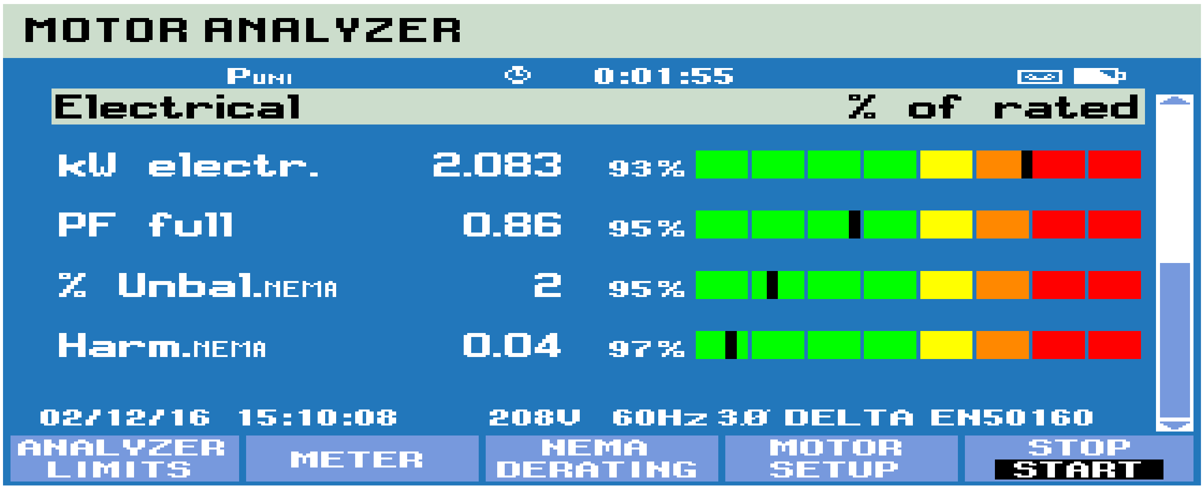


Figure.4. Motor Analyzer (Electrical Screen)

CHAPTER 5

MEASUREMENT & ANALYSIS

5.1 INTRODUCTION

The measurement was conducted across the 10 HP induction motor which is being used for pumping application. The motor is fed input supply through Servo voltage stabilizers through which input power quality is controlled. The performance of motor was monitored in real time during the course of experiment at varying input power quality conditions.

5.2 BLOCK DIAGRAM OF THE SETUP

The following figure represents the block diagram connection of the test setup:

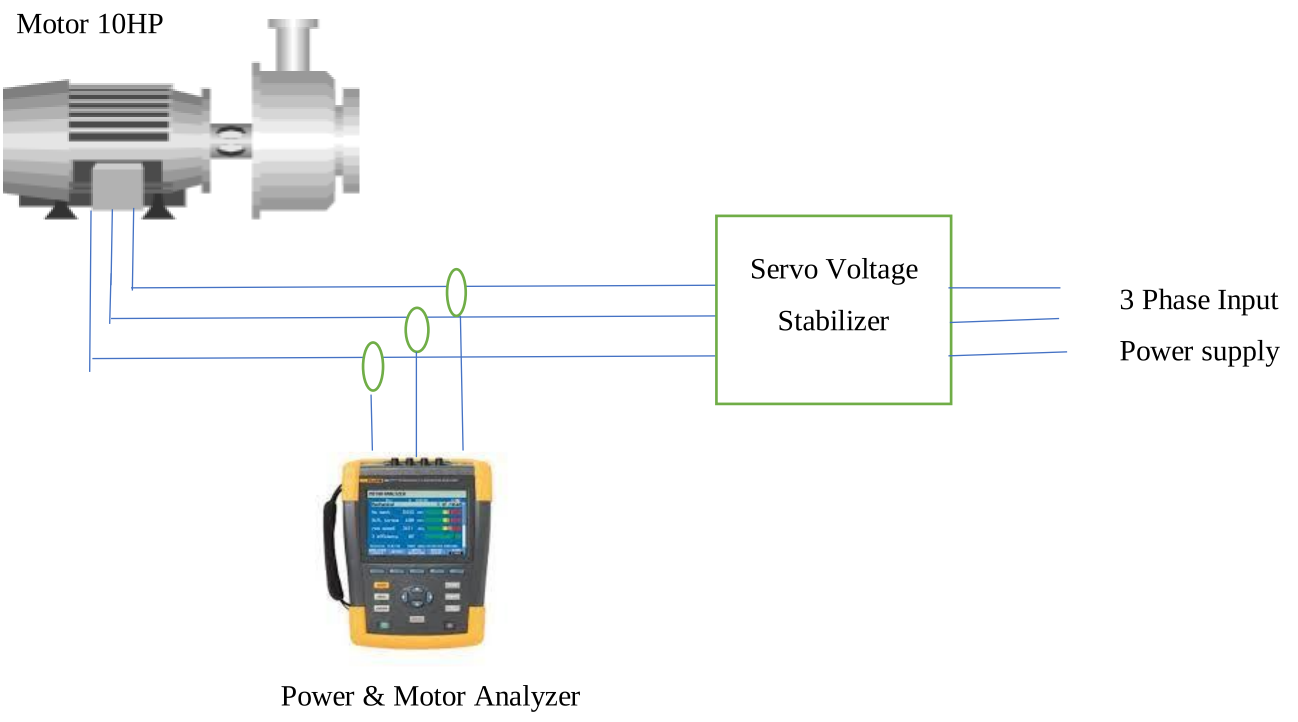


Figure.5 Block Diagram of Test setup

5.3 MEASUREMENT

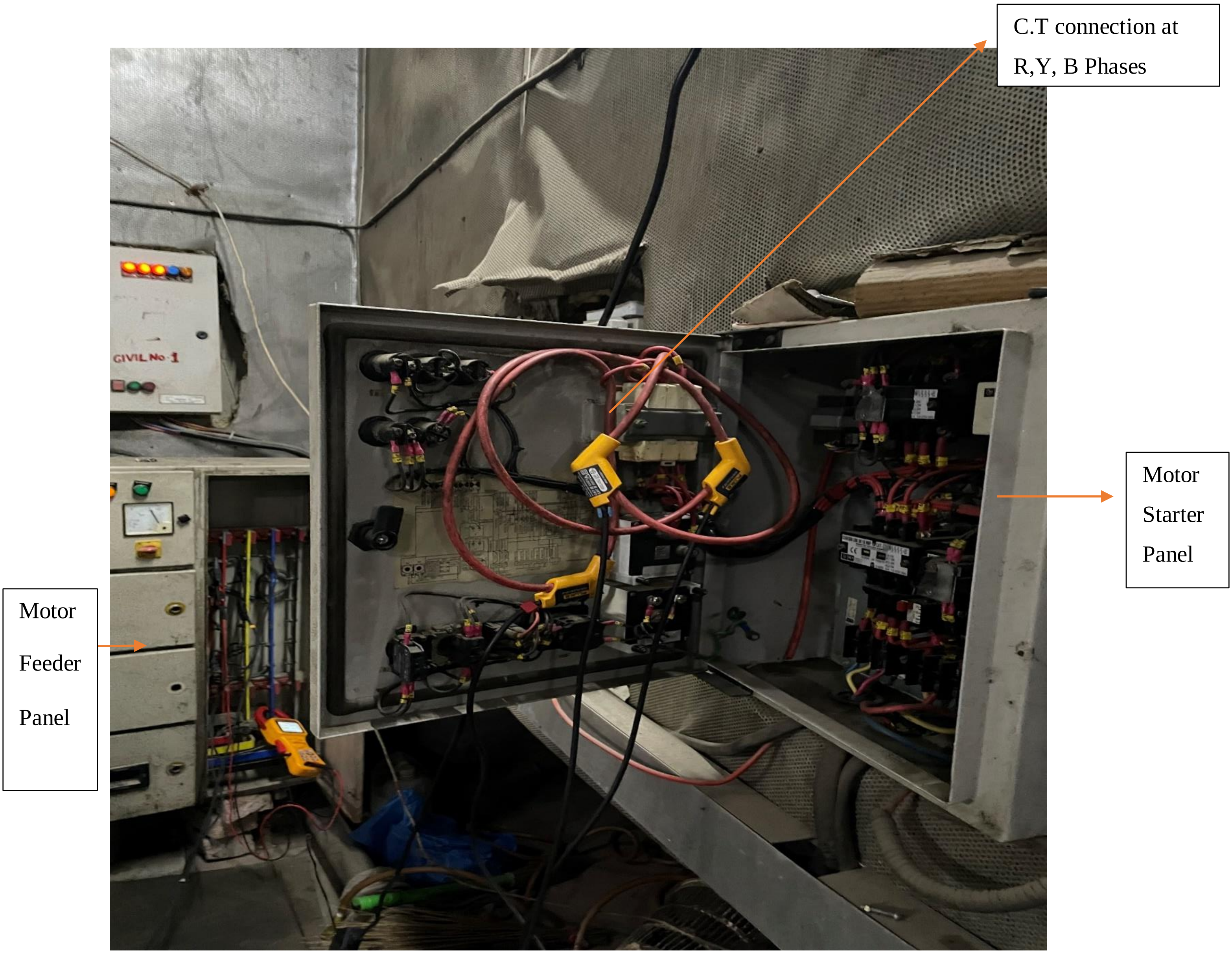
The measurement was conducted across motor under real time operating condition at Cardio & neuroscience center, AIIMS New Delhi At input side power quality variations (under controlled conditions) were applied during experiment. At output side various motor performance parameters and other operational parameters were recorded for analysis.

Table 4 Measurement Parameters

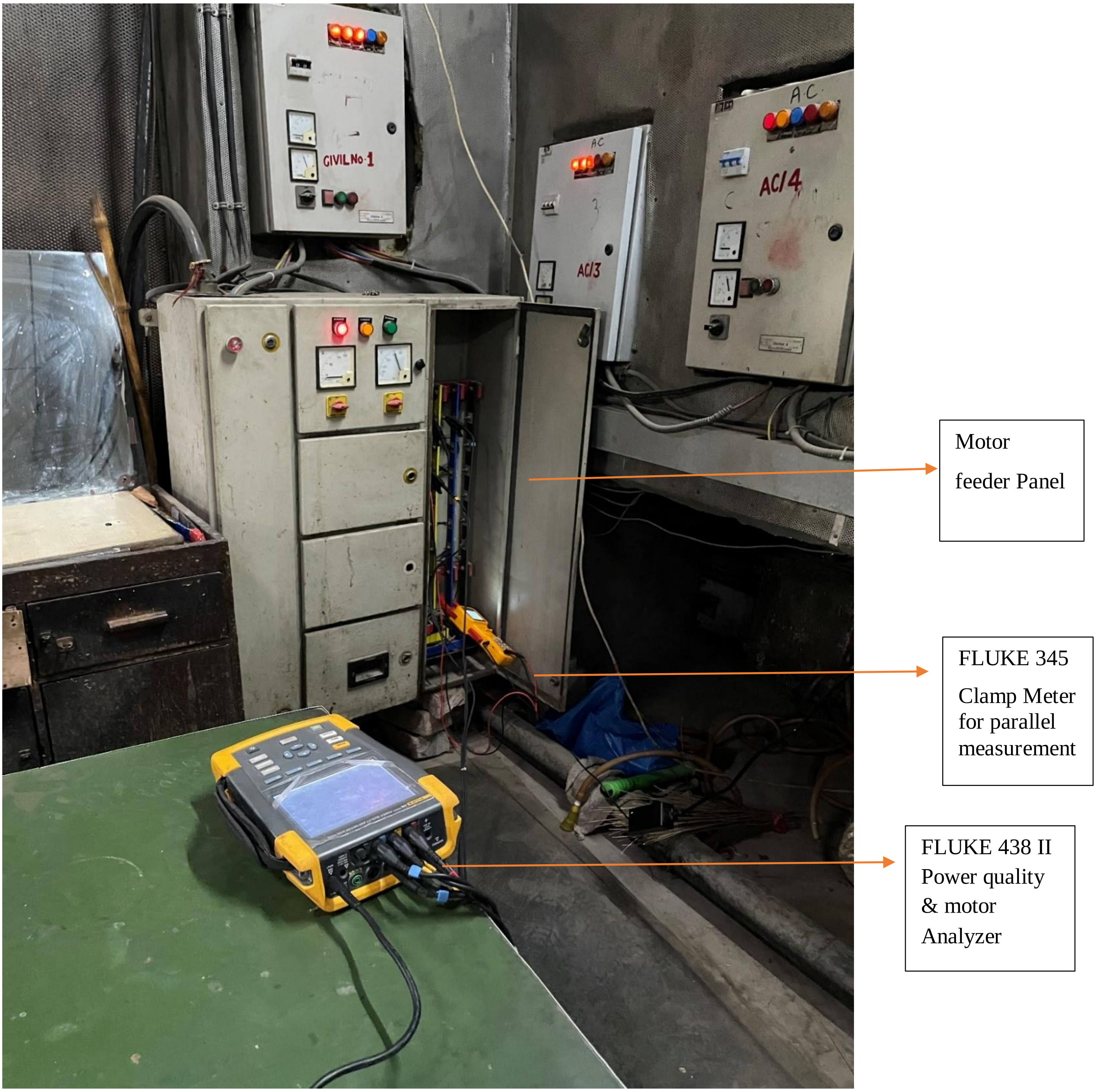
Variable Parameters	Measured Parameters
Voltage magnitude variations	Motor Efficiency
Voltage unbalance	Motor RPM
	Motor Torque
	Motor Mechanical Power
	Power factor
	Motor Current
	Harmonics

5.3.1 MEASUREMENT SETUP AT SITE (CNC, AIIMS)

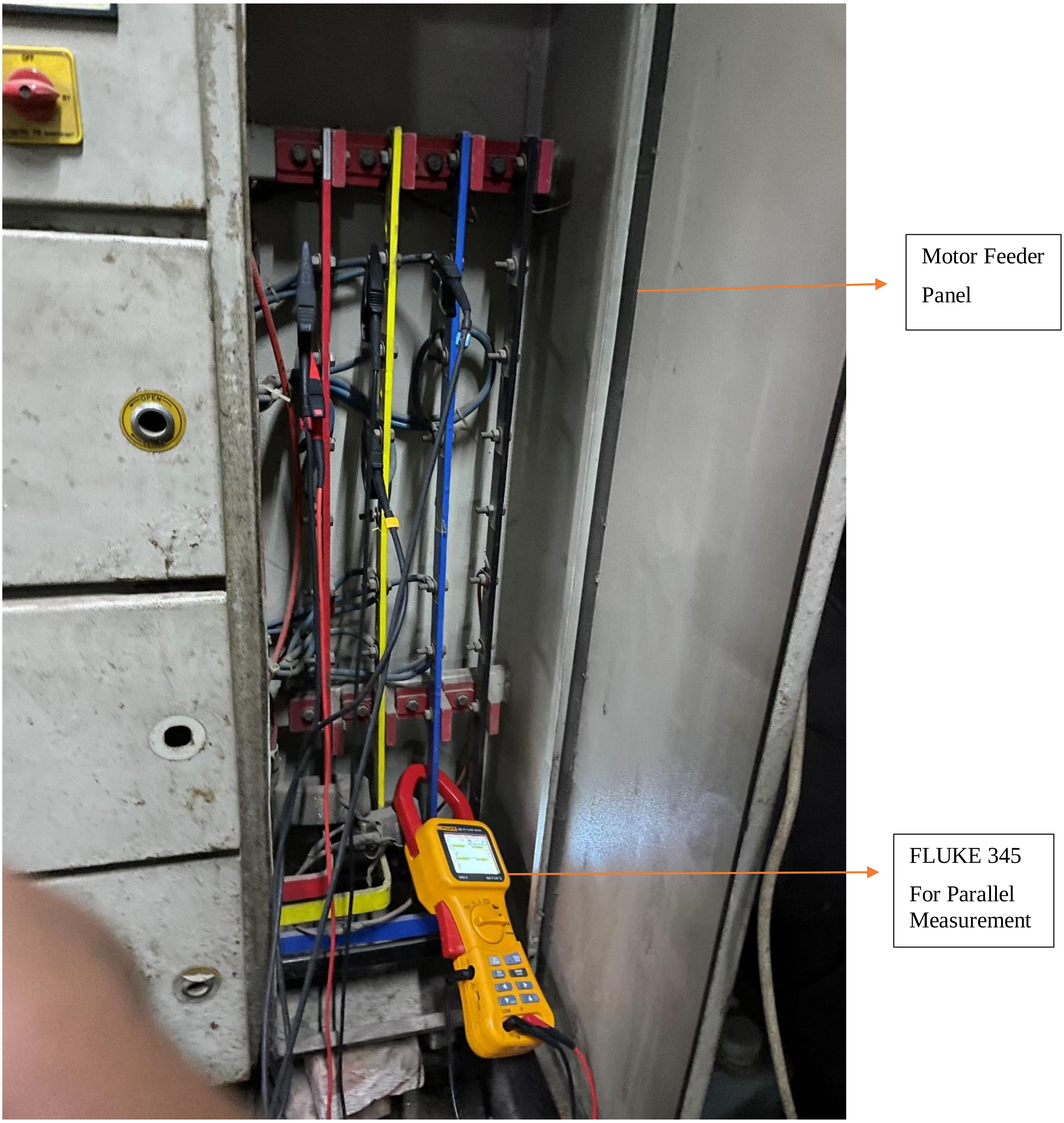
The hardware setup for experimentation was established at Cardio and Neuroscience center at AIIMS, Delhi. Below are the actual site pics of the setup during the course of test performance and measurement.



Picture 1 CT Connection across motor starter panel during measurement



Picture 2 Parallel measurement across Motor feeder panel and Motor starter panel



Picture 3. Motor Feeder panel measurement

FLUKE 438 II

Power quality & Motor Analyzer

(While logging)

Picture 4. FLUKE 438 II Data Logging

Servo Voltage Stabilizer

Picture 5. Servo Voltage Stabilizer

Servo Voltage stabilizer

(Input voltage can be varied)

Picture 6. Servo Voltage Stabilizer

5.4 TEST RESULTS

5.4.1 Voltage fluctuations vs Motor Efficiency

To perform this condition of experimentation, The setup (input power supply) is connected to the test load (10 HP Motor). The voltage across motor is varied with the help of servo voltage stabilizer. All changes/ parameters are recorded with the help of Power quality and motor analyzer. The data so generated are presented below:

TABLE: 5

Recorded Data (Voltage Vs Motor Efficiency)

Date	Time	$V\ L_{12}$	$V\ L_{23}$		$V\ L_{31}$	Efficiency
18-05-2022	15:30:30.321	395.020	391.540		391.540	91.180
18-05-2022	15:31:30.321	395.980	392.000		392.280	91.200
18-05-2022	15:32:30.321	396.860	393.280		393.740	91.270
18-05-2022	15:33:30.321	397.000	393.280		393.920	91.290
18-05-2022	15:34:30.321	396.660	393.400	(*f*)	393.280	91.260
18-05-2022	15:35:30.321	397.080	394.260	(*f*)	394.280	91.320
18-05-2022	15:36:30.321	397.140	394.560	(*f*)	394.240	91.310
18-05-2022	15:37:30.321	389.460	382.680	(*f*)	385.820	90.950
18-05-2022	15:38:30.321	390.520	383.360	(*f*)	385.980	90.940
18-05-2022	15:39:30.321	390.740	383.400	(*f*)	386.500	90.950
18-05-2022	15:40:30.321	389.700	383.780	(*f*)	387.140	90.990
18-05-2022	15:41:30.321	407.540	391.980	(*f*)	396.880	90.710
18-05-2022	15:42:30.321	409.060	397.240		401.840	91.040
18-05-2022	15:43:30.321	408.980	403.780		407.060	91.550
18-05-2022	15:44:30.321	414.520	408.640		406.680	91.540
18-05-2022	15:45:30.321	416.340	410.740		409.140	91.610

18-05-2022	15:46:30.321	398.960	400.780		400.900	91.500
18-05-2022	15:47:30.321	398.820	392.960		394.460	91.240
18-05-2022	15:48:30.321	401.860	398.660	(f)	396.400	91.350
18-05-2022	15:49:30.321	400.760	397.480	(f)	397.220	91.370
18-05-2022	15:50:30.321	401.000	393.700	(f)	393.240	91.110
18-05-2022	15:51:30.321	396.580	396.020	(f)	391.640	91.250
18-05-2022	15:52:30.321	402.640	397.340	(f)	397.300	91.320
18-05-2022	15:53:30.321	401.780	396.740		397.780	91.330
18-05-2022	15:54:30.321	402.000	396.040	(f)	397.880	91.310
18-05-2022	15:55:30.321	402.880	397.400	(f)	398.980	91.350
18-05-2022	15:56:30.321	402.640	396.540		398.040	91.260
18-05-2022	15:57:30.321	402.500	396.660		398.460	91.270

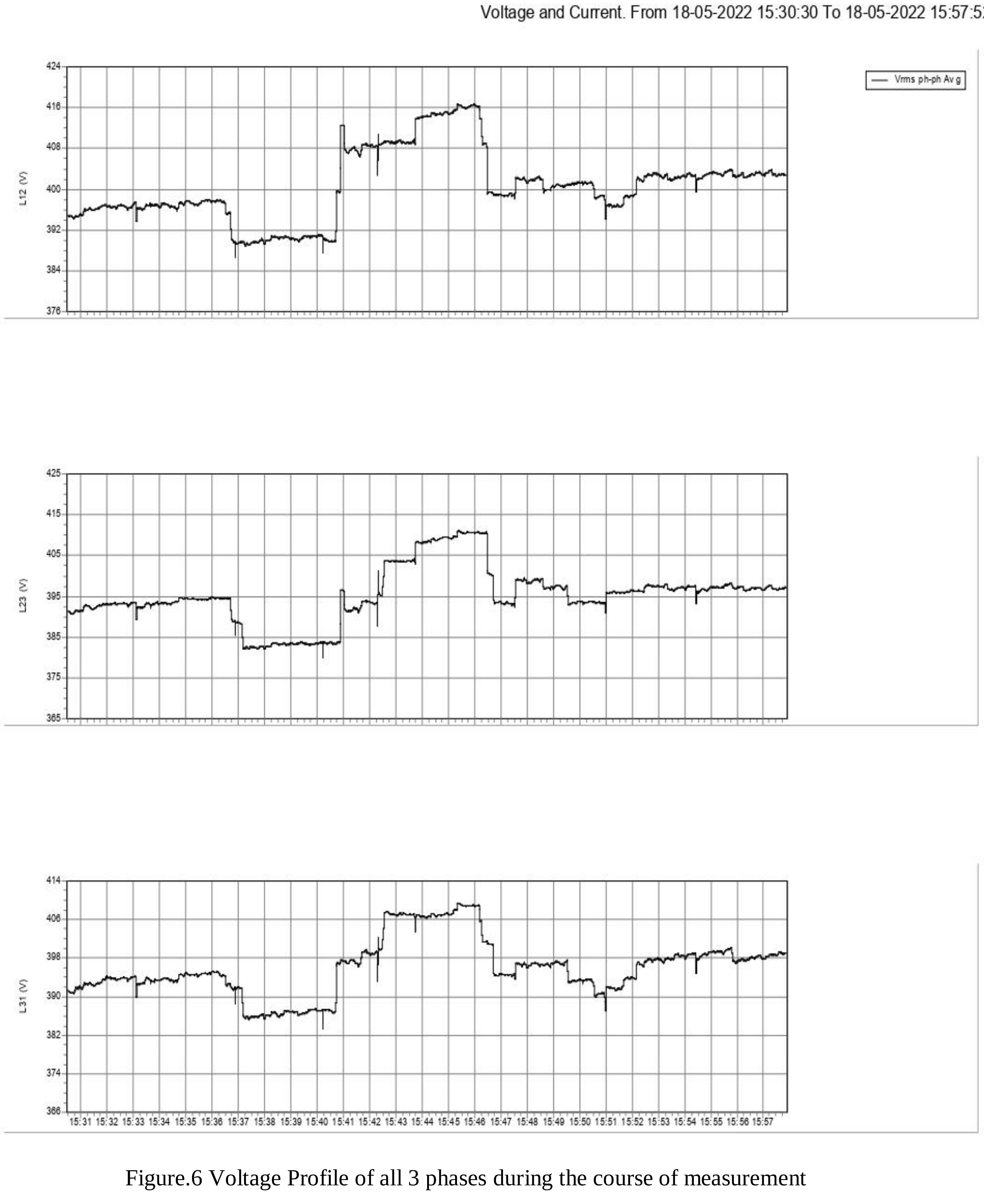


Figure.6 Voltage Profile of all 3 phases during the course of measurement

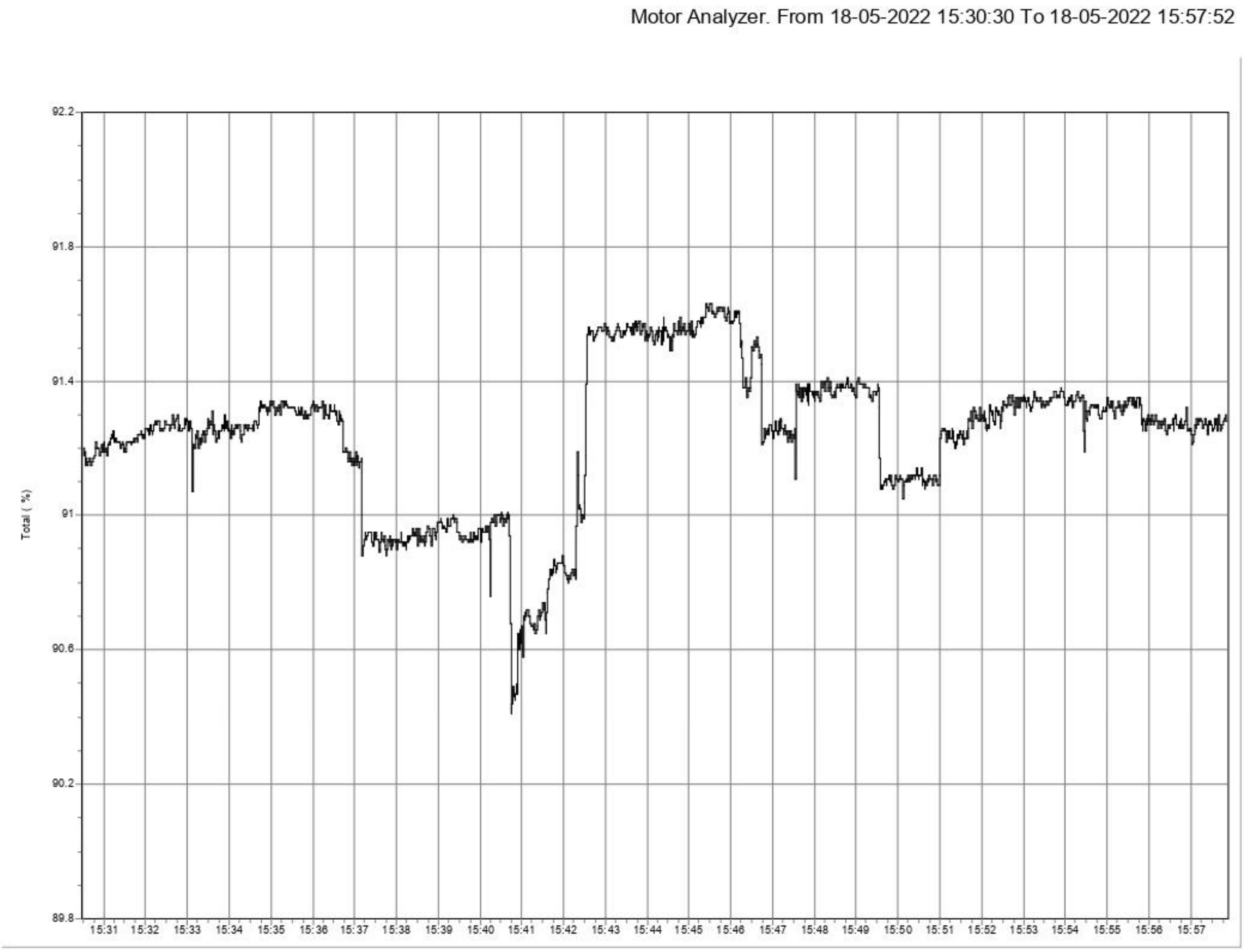


Figure.7 Motor Efficiency curve during the course of measurement

5.3.2 OBSERVATION

Voltage fluctuations were inserted in the input power supply starting from **15:36:30 hrs** up to **15:45:30 hrs**. The data recorded by Motor analyzer is presented below in the Table. 6. The plot for the same period is charted as per Figure 7.

Table.6 Voltage Fluctuation vs Motor Efficiency

Date	**Time**	**V_a**	**V_b**	**V_c**	**Motor Efficiency (%)**
18-05-2022	15:36:30.321	397.140	394.560	394.240	91.310
18-05-2022	15:37:30.321	389.460	382.680	385.820	90.950
18-05-2022	15:38:30.321	390.520	383.360	385.980	90.940
18-05-2022	15:39:30.321	390.740	383.400	386.500	90.950
18-05-2022	15:40:30.321	389.700	383.780	387.140	**90.990**
18-05-2022	15:41:30.321	407.540	391.980	396.880	90.710
18-05-2022	15:42:30.321	409.060	401.840	397.240	91.040
18-05-2022	15:43:30.321	408.980	403.780	407.060	91.550
18-05-2022	15:44:30.321	414.520	408.640	406.680	91.540
18-05-2022	15:45:30.321	416.340	410.740	409.140	**91.610**

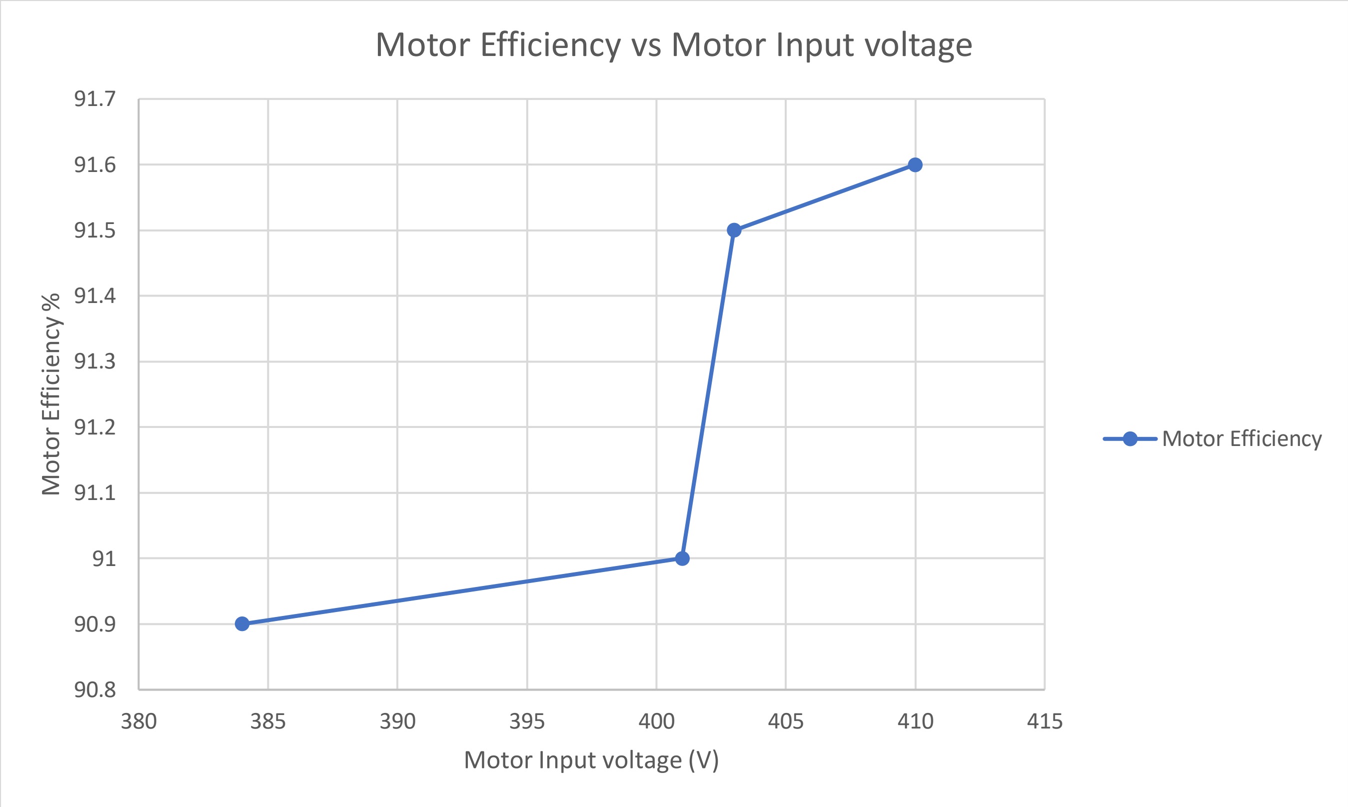
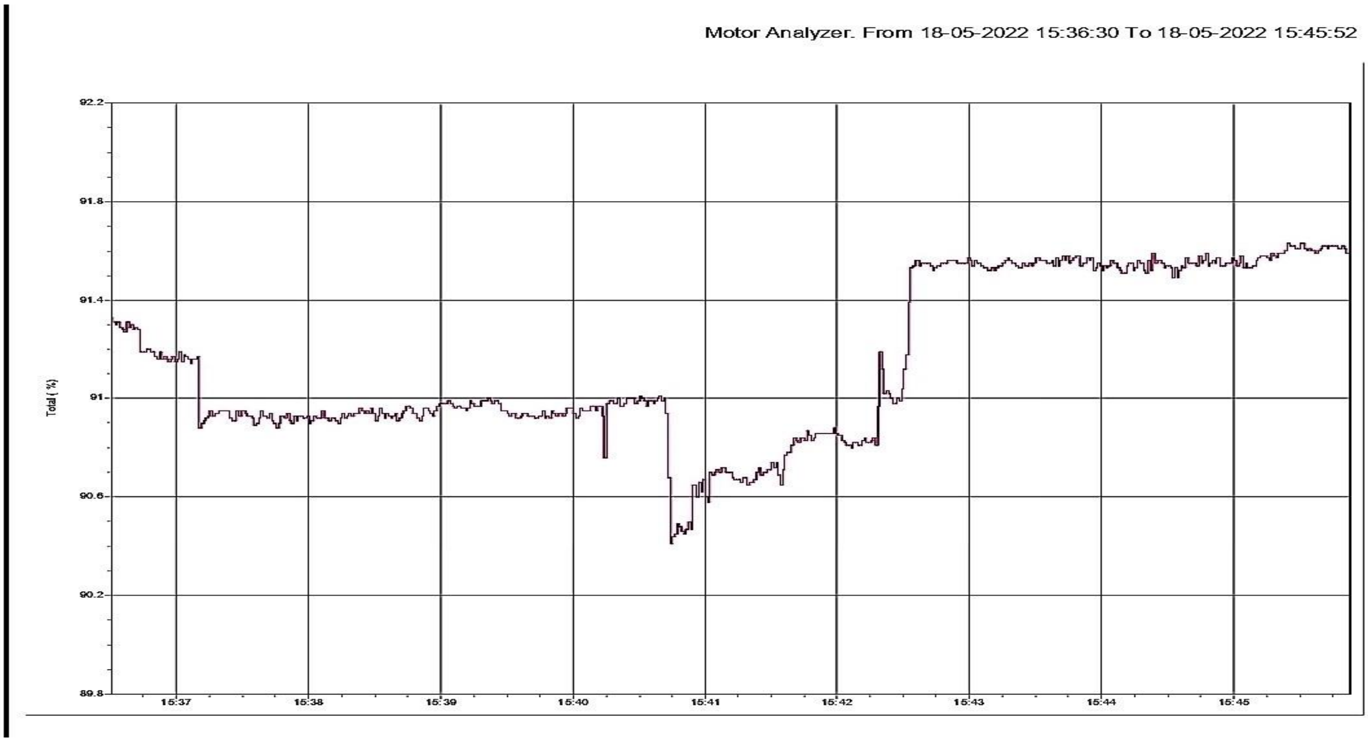


Figure.8 Motor Efficiency vs Motor Input voltage

Table.7 Comparative analysis of Voltage fluctuation impact on Motor Efficiency

Mean Average Voltage (V)	**Motor Efficiency (%)**	**Change in Voltage from rated Voltage (%)**	**Change in Motor Efficiency from its rated efficiency (%)**
384	90.9	7	-1.6
401	91.0	3	-1.5
403	91.5	2	-1.0
410	91.6	1.2	- 0.9



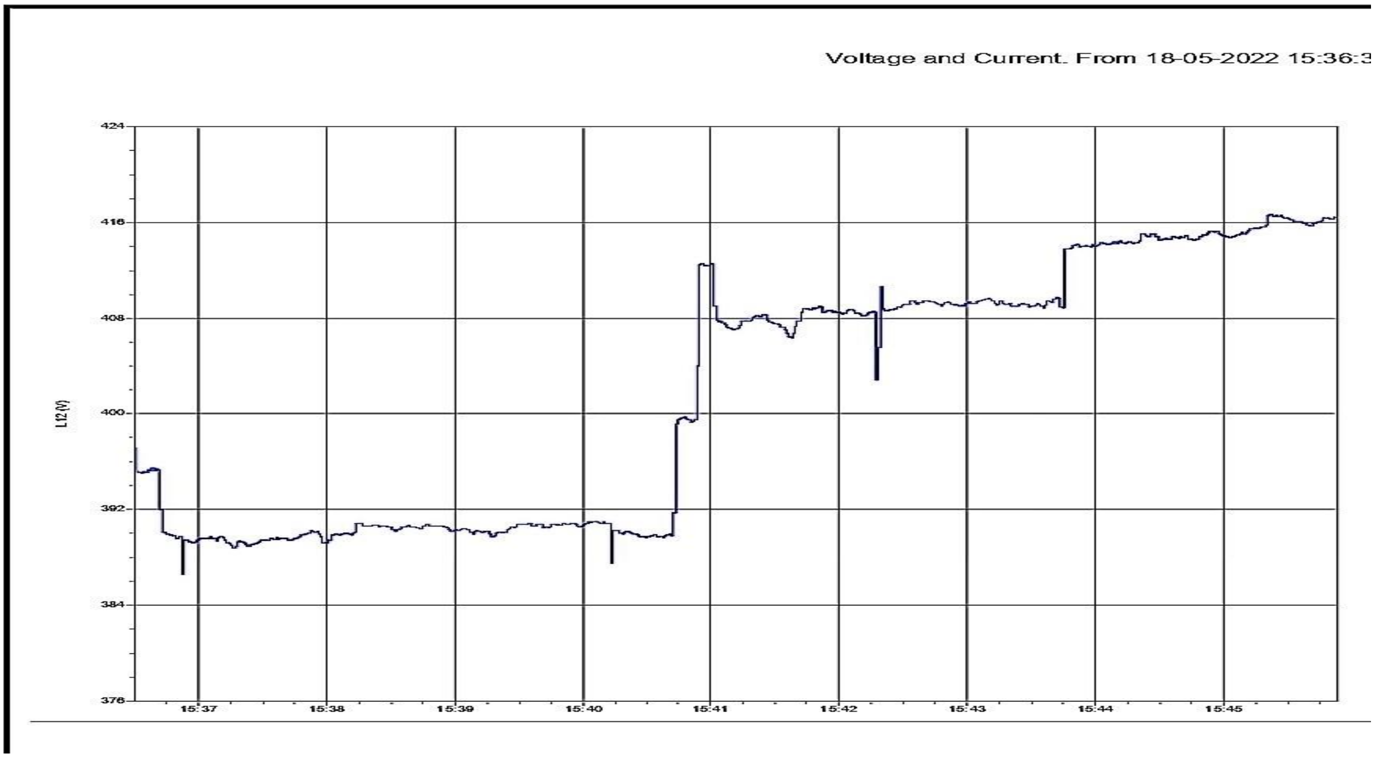


Figure.9 Voltage fluctuations vs Motor Efficiency curve

5.3.3 Conclusion

The above observation as per Table.6 comprises of set of measurement data from the time period (15:36:30 up to 15:45:30), a total of 10 Minutes. It was observed from the data between (15:36:30 to 15:40:30) that motor efficiency decreases gradually from 91.3% to 90.9% as voltage is reduced from 393V to 383V.

From (15:40:30 to 15:45:30) voltage is again increased from 383V to 410V which resulted in increase in motor efficiency from 90.9% to 91.6%. It is evident from the data presented in Table.6 that motor efficiency tends to decrease as input power voltage is varied away from its rated voltage (415V). the motor achieved its highest efficiency at 410V which corroborated the interpreted conclusion.

Figure.8 is a plot with motor input voltage at X axis and motor efficiency at Y axis the plot depicts an upward trend with increase in input supply voltage, there is sharp rise in motor efficiency between voltage level 401V and 403V, however the overall trends depict the same conclusion that motor efficiency tends to rise as input supply voltage tends to approach its rated voltage.

Table.7 is a comparative analysis of impact of voltage fluctuation on motor efficiency, this table is prepared by taking reference of motor rated voltage and motor rated efficiency which is 415V and 92.5% respectively. The values of table highlight as % deviation in input supply voltage from rated voltage is increased, the % deviation in observed motor efficiency from rated motor efficiency is also increased. Figure.9 is the curve generated by the analyzer during the course of measurement. It clearly points out that at instants when voltage fluctuation is inserted in the input supply voltage, there is a change observed in motor efficiency.

From the above it can finally be concluded that motor tends to achieve its rated efficiency whenever it is operated at its rated voltage. The voltage fluctuation impacts motor efficiency in a drastic manner, however a direct relation between voltage fluctuation and motor efficiency could not be established with this set of data and testing performed.

5.4 Impact of Voltage Unbalance on Motor Efficiency

To perform this condition of experimentation, The setup (input power supply) is connected to the test load (10 HP Motor). The voltage unbalance across 3 Phases were created with the help of servo voltage stabilizer. All changes / parameters are recorded with the help of Power quality and motor analyzer. The data so generated are presented below:

Table.8 Recorded Data (Unbalance (%) and Efficiency)

Date	**Time**	**Unbalance (%)**	**Efficiency (%)**
18-05-2022	15:30:30.321	0.590	91.180
18-05-2022	15:31:30.321	0.650	91.200
18-05-2022	15:32:30.321	0.570	91.270
18-05-2022	15:33:30.321	0.580	91.290
18-05-2022	15:34:30.321	0.560	91.260
18-05-2022	15:35:30.321	0.480	91.320
18-05-2022	15:36:30.321	0.470	91.310
18-05-2022	15:37:30.321	1.020	90.950
18-05-2022	15:38:30.321	1.080	90.940
18-05-2022	15:39:30.321	1.100	90.950
18-05-2022	15:40:30.321	0.890	90.990
18-05-2022	15:41:30.321	2.310	90.710
18-05-2022	15:42:30.321	1.710	91.040
18-05-2022	15:43:30.321	0.750	91.550
18-05-2022	15:44:30.321	1.150	91.540
18-05-2022	15:45:30.321	1.060	91.610
18-05-2022	15:46:30.321	0.310	91.500
18-05-2022	15:47:30.321	0.890	91.240

18-05-2022	15:48:30.321	0.800	91.350
18-05-2022	15:49:30.321	0.570	91.370
18-05-2022	15:50:30.321	1.280	91.110
18-05-2022	15:51:30.321	0.790	91.250
18-05-2022	15:52:30.321	0.890	91.320
18-05-2022	15:53:30.321	0.770	91.330
18-05-2022	15:54:30.321	0.890	91.310
18-05-2022	15:55:30.321	0.820	91.350
18-05-2022	15:56:30.321	0.920	91.260
18-05-2022	15:57:30.321	0.870	91.270

5.4.1 OBSERVATION

Voltage unbalance were inserted in the input power supply starting from **15:41:30 hrs** up to **15:46:30 hrs**. The data recorded by Motor analyzer is presented below in table 7. The plot for the same period is charted as per Figure 8

Table .9 Voltage unbalance (%) vs Motor Efficiency (%)

Date	**Time**	**V_a**	**V_b**	**Vc**	**Unbalance (%)**	**Motor Efficiency (%)**
18-05-2022	15:41:30.321	407.540	391.980	396.880	2.310	90.710
18-05-2022	15:46:30.321	398.960	400.780	400.900	0.310	91.500

Table.10 Comparative analysis of Voltage Unbalance impact on Motor Efficiency

Voltage Unbalance (%)	**Motor Efficiency (%)**	**Drop in Motor Efficiency from its rated efficiency (%)**
0.310	91.5	1.0
2.310	90.7	1.8

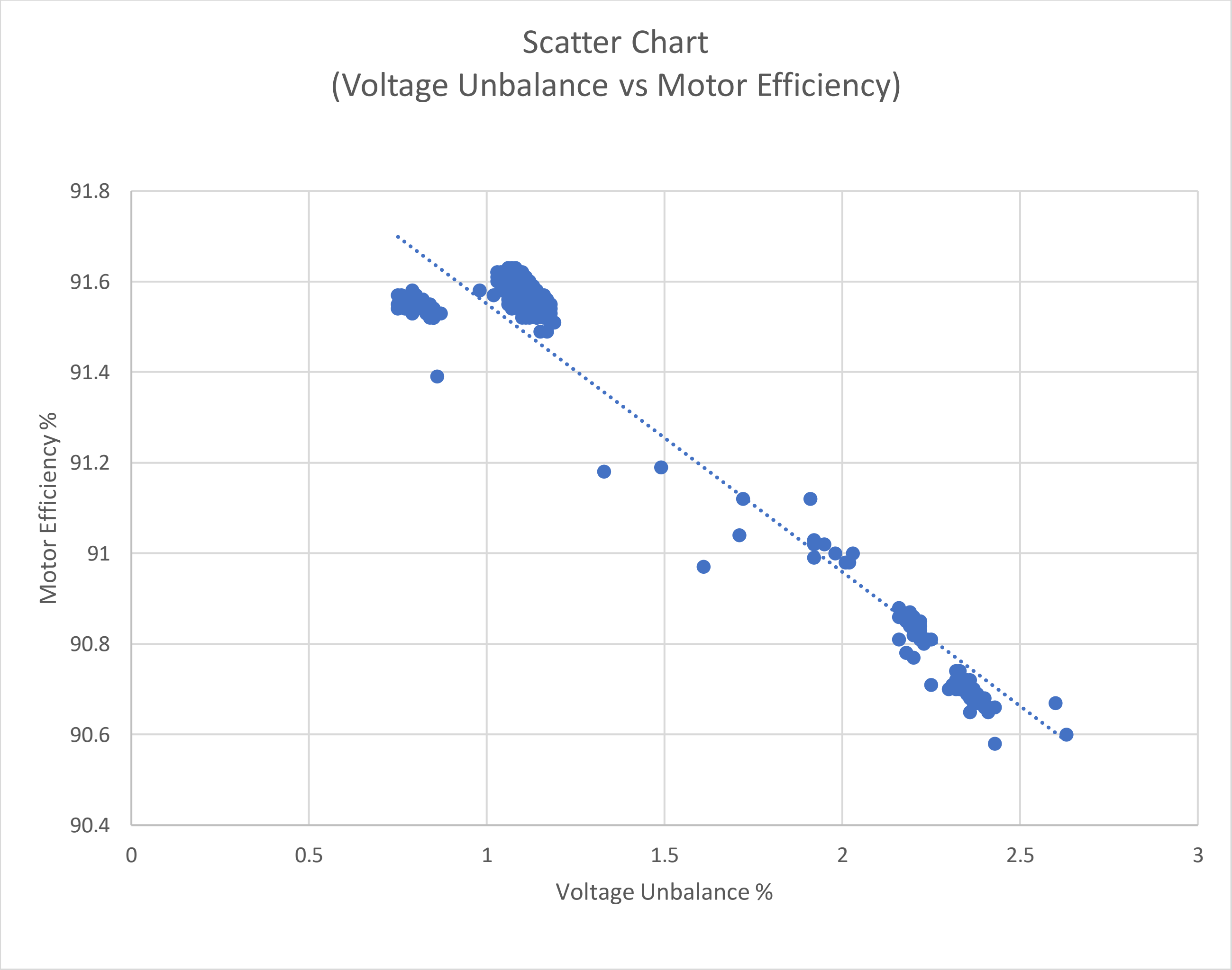


Figure.10 Scatter chart (Voltage Unbalance vs Motor Efficiency)

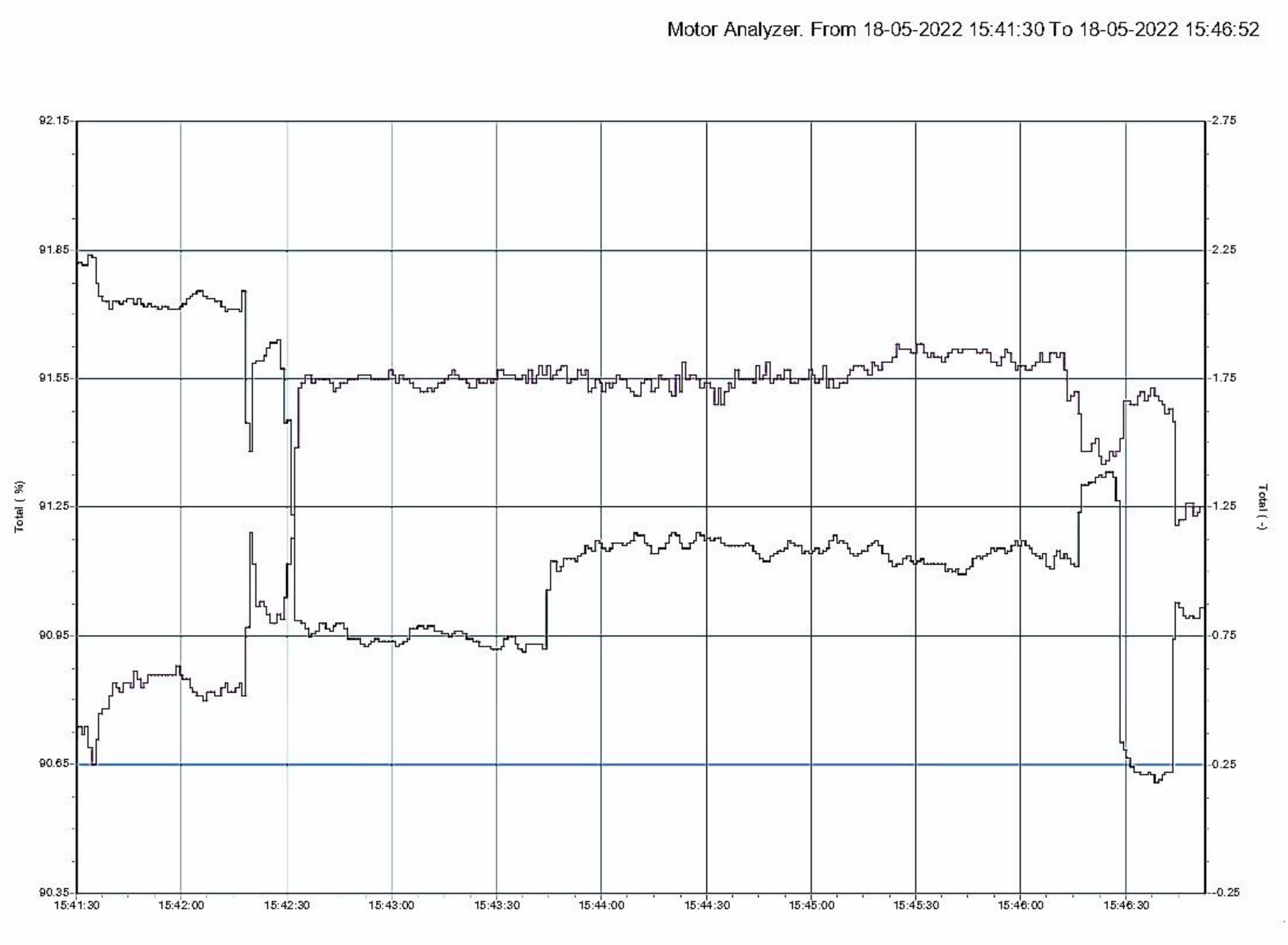


Figure.11 Voltage Unbalance vs Motor Efficiency Curve

5.4.2 Conclusion

The Table.8 presents the recorded data by the analyzer at an interval of 1 minute. The unbalance between the phases were introduced and motor efficiency at various level are recorded. The observation table.9 comprises of set of measurement data from the time period (15:41:30 up to 15:46:30), a total of 5 Minutes. It is a comparative table which includes maximum and minimum voltage unbalance (%) and its corresponding impact on motor efficiency (%). From the set of data, it is evident that when voltage unbalance is highest ie 2.31% motor efficiency is lowest ie 90.7% as unbalance is reduced to 0.31% motor efficiency peaks up to 91.5%. In continuation to table.9 the next table.10 shows % change in motor efficiency from its rated efficiency of 92.5% at various voltage unbalance levels. There is 1.8%

reduction in motor efficiency was observed at a voltage unbalance of 2.31%

Figure.10 is scatter chart plotted by considering all the recorded values by the analyzer, The motor efficiency is plotted on X axis and voltage unbalance is plotted on Y axis. The blue line is the trend line which is linear in shape and indicates the general trend from the observed values. The trend shows that motor efficiency is lower at a higher voltage unbalance in the input power supply. Figure.11 is the actual plot generated by the analyzer, the plot of voltage unbalance and motor efficiency during the course of measurement is combined on a single plot paper, it helps in better observation of the trend and analyzing impact of voltage unbalance on motor efficiency. The plot shows that for every unbalance in voltage there is corresponding change in motor efficiency, during constant unbalance voltage the efficiency also remained range bound.

From the above analysis, it can be stated that motor tends to achieve higher efficiency when voltage unbalance in the input supply tends to minimum. The voltage unbalance has a deteriorating impact on motor efficiency, however a direct relation between voltage unbalance and motor efficiency could not be established with this set of data and testing performed. There is further need of experimentation with exhaustive set of data to generate a concluding theory.

CHAPTER 6

IMPACT OF POWER QUALITY ON OTHER MOTOR PARAMETERS

6.1 INTRODUCTION

The impact of power quality indices (Voltage unbalance) is analyzed on other performance aspects of motor such as Current drawn and Torque.

6.2 VOLTAGE UNBALANCE IMPACT ON CURRENT

6.2.1 Measurement Data

The following is the data of voltage unbalance and current unbalance during the measurement period.

Table.11 Recorded data (Voltage unbalance and Current unbalance)

Date	Time	Unbal Vn	Unbal An
18-05-2022	15:30:30.321	0.590	3.150
18-05-2022	15:31:30.321	0.650	3.340
18-05-2022	15:32:30.321	0.570	2.870
18-05-2022	15:33:30.321	0.580	2.810
18-05-2022	15:34:30.321	0.560	3.000
18-05-2022	15:35:30.321	0.480	2.560
18-05-2022	15:36:30.321	0.470	2.680
18-05-2022	15:37:30.321	1.020	4.360
18-05-2022	15:38:30.321	1.080	4.920
18-05-2022	15:39:30.321	1.100	4.870
18-05-2022	15:40:30.321	0.890	3.590
18-05-2022	15:41:30.321	2.310	12.010
18-05-2022	15:42:30.321	1.710	8.670
18-05-2022	15:43:30.321	0.750	3.050
18-05-2022	15:44:30.321	1.150	6.690
18-05-2022	15:45:30.321	1.060	6.120
18-05-2022	15:46:30.321	0.310	2.670

18-05-2022	15:47:30.321	0.890	4.190
18-05-2022	15:48:30.321	0.800	4.790
18-05-2022	15:49:30.321	0.570	3.080
18-05-2022	15:50:30.321	1.280	6.680
18-05-2022	15:51:30.321	0.790	5.310
18-05-2022	15:52:30.321	0.890	4.580
18-05-2022	15:53:30.321	0.770	3.650
18-05-2022	15:54:30.321	0.890	4.120
18-05-2022	15:55:30.321	0.820	3.740
18-05-2022	15:56:30.321	0.920	4.410
18-05-2022	15:57:30.321	0.870	3.990

6.2.2 OBSERVATION & ANAYSIS

The above recorded data presents the unbalance observed in current for its corresponding voltage unbalance. The data can be depicted by the graph below:

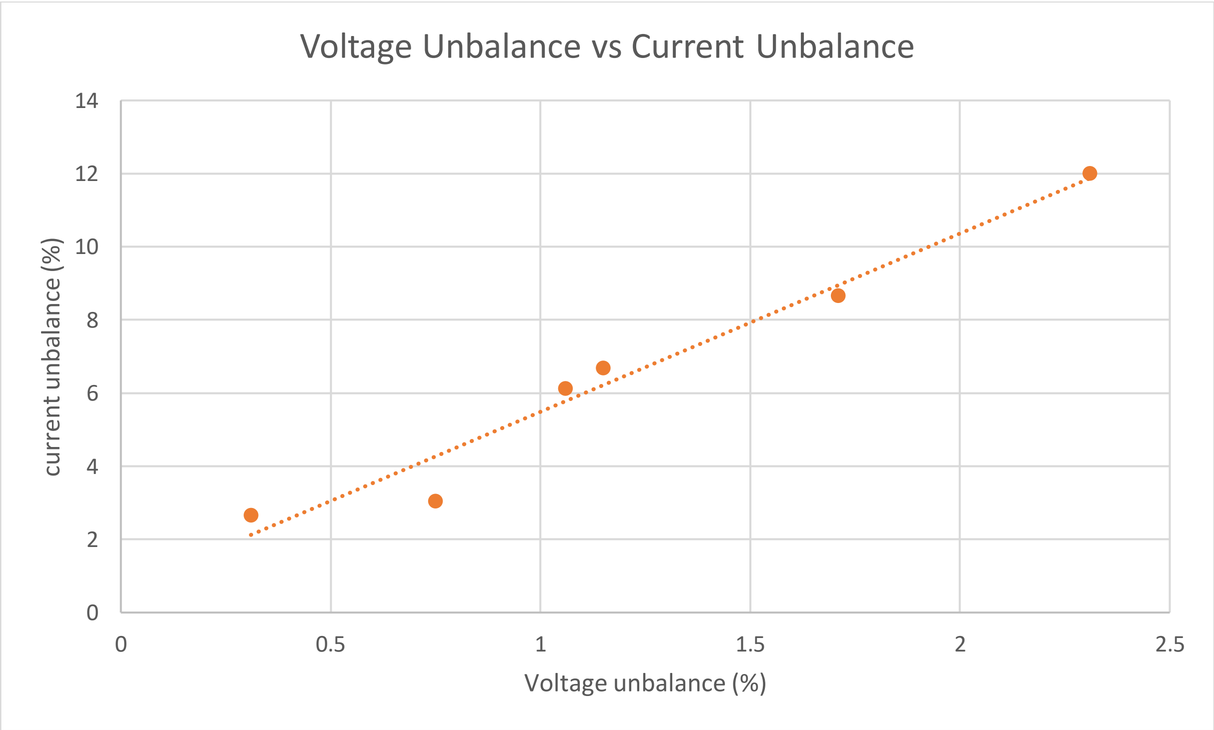


Figure.12 Voltage unbalance vs Current unbalance trendline

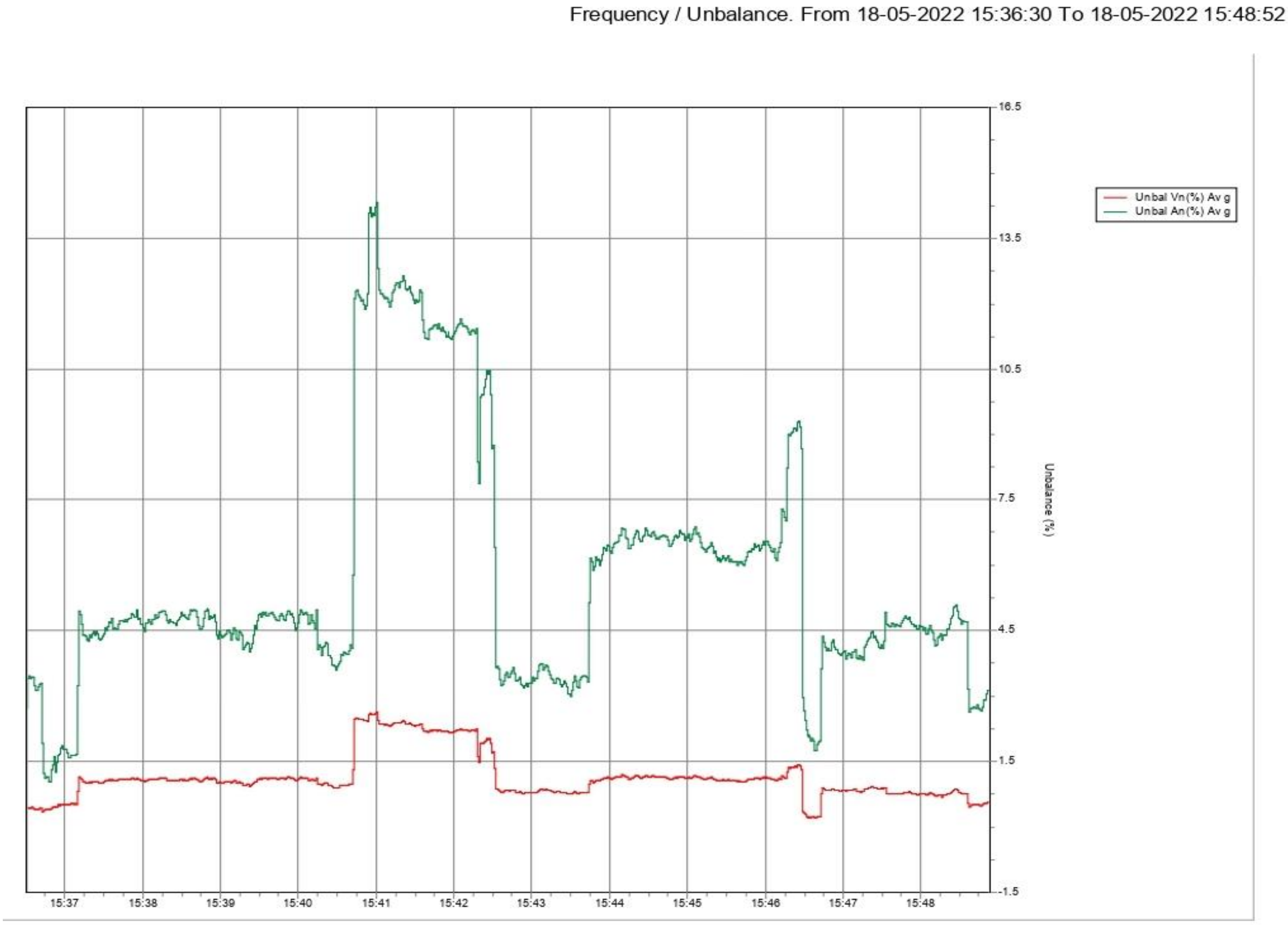


Figure.13 Voltage unbalance impact on current unbalance

6.2.3 CONCLUSION

Table.11 comprises of recorded set of data on voltage unbalance and current unbalance by the analyzer. The data is recorded for 15:30 hrs. to 15:57 hrs. Figure 12. is a scatter plot which is plotted by assigning X axis to voltage unbalance and Y axis to current unbalance. The orange line is a trend line which is linear in shape, the line depicts a direct relation between voltage unbalance and current unbalance in other words as voltage unbalance is increased current balance is also increased.

Figure.13 shows the plot curves of voltage unbalance (red) and current unbalance (green). The plots help in understanding the impacts of voltage unbalance on current drawn by the motor. It is observed that whenever voltage unbalance is introduced in the input power supply there is deviation observed in current unbalance. From observing plot it can be concluded that there is much higher levels of current unbalance is introduced for even a smaller % of voltage unbalance.

From the above it can be finally concluded that even a small % voltage unbalance brings in a much higher % current unbalance which may deteriorate the motor performance by increasing unbalance power and temperature rise.

6.3 Voltage unbalance impact on Motor Torque

6.3.1 Measurement Data

The following is the data of voltage unbalance and Motor torque during the measurement period.

Table.12 Recorded data Voltage unbalance and Torque

Date	Time	Unbalance V_n	Torque (Nm)
18-05-2022	15:30:30.321	0.590	29.070
18-05-2022	15:31:30.321	0.650	29.050
18-05-2022	15:32:30.321	0.570	29.040
18-05-2022	15:33:30.321	0.580	29.010
18-05-2022	15:34:30.321	0.560	29.020
18-05-2022	15:35:30.321	0.480	28.990
18-05-2022	15:36:30.321	0.470	29.040
18-05-2022	15:37:30.321	1.020	28.700
18-05-2022	15:38:30.321	1.080	28.760
18-05-2022	15:39:30.321	1.100	28.720
18-05-2022	15:40:30.321	0.890	28.780
18-05-2022	15:41:30.321	2.310	28.920
18-05-2022	15:42:30.321	1.710	29.040
18-05-2022	15:43:30.321	0.750	29.280
18-05-2022	15:44:30.321	1.150	29.310
18-05-2022	15:45:30.321	1.060	29.480
18-05-2022	15:46:30.321	0.310	29.160
18-05-2022	15:47:30.321	0.890	28.960
18-05-2022	15:48:30.321	0.800	29.060
18-05-2022	15:49:30.321	0.570	29.120
18-05-2022	15:50:30.321	1.280	28.990

18-05-2022	15:51:30.321	0.790	28.940
18-05-2022	15:52:30.321	0.890	29.100
18-05-2022	15:53:30.321	0.770	29.120
18-05-2022	15:54:30.321	0.890	29.130
18-05-2022	15:55:30.321	0.820	29.240
18-05-2022	15:56:30.321	0.920	29.280
18-05-2022	15:57:30.321	0.870	29.370

6.3.2 OBSERVATION & ANAYSIS

The above recorded data presents the Motor torque variation due to corresponding voltage unbalance. The data can be depicted by the graph below.

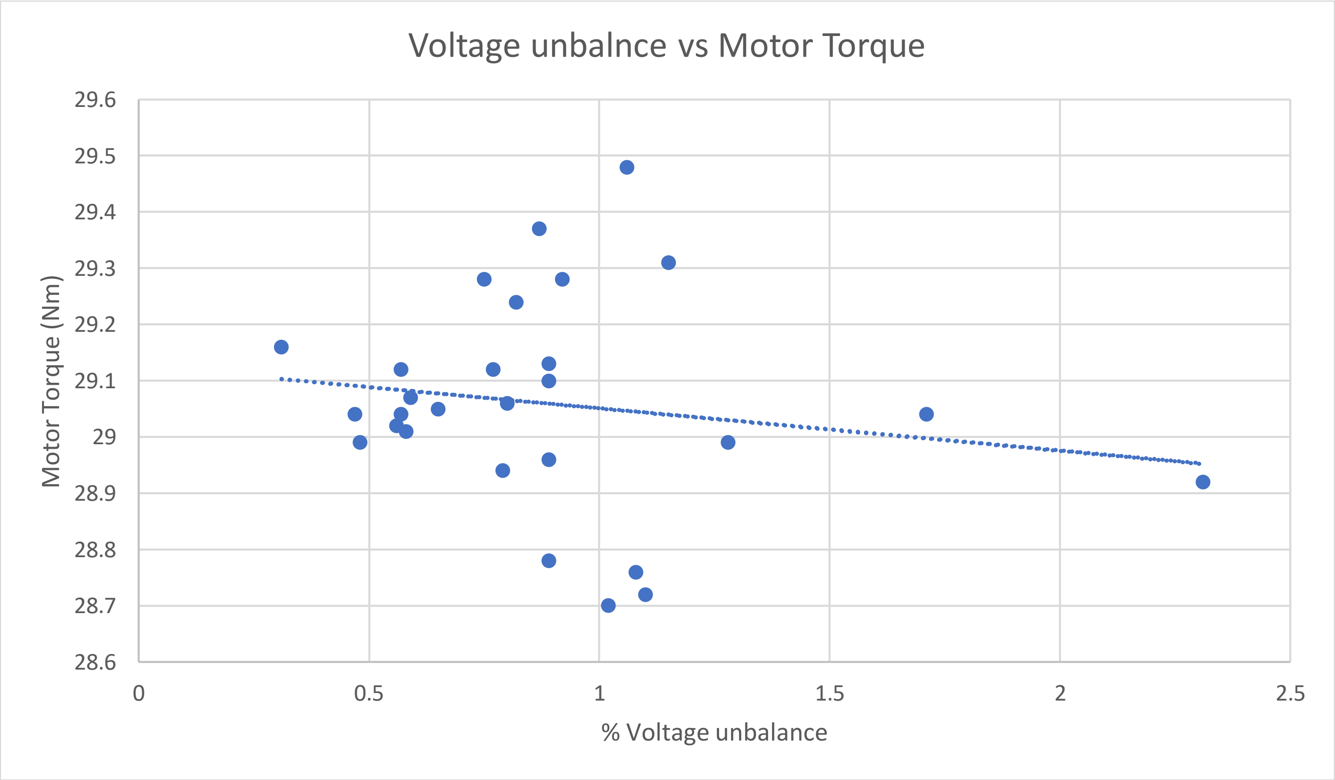


Figure.14 Voltage unbalance vs Motor torque

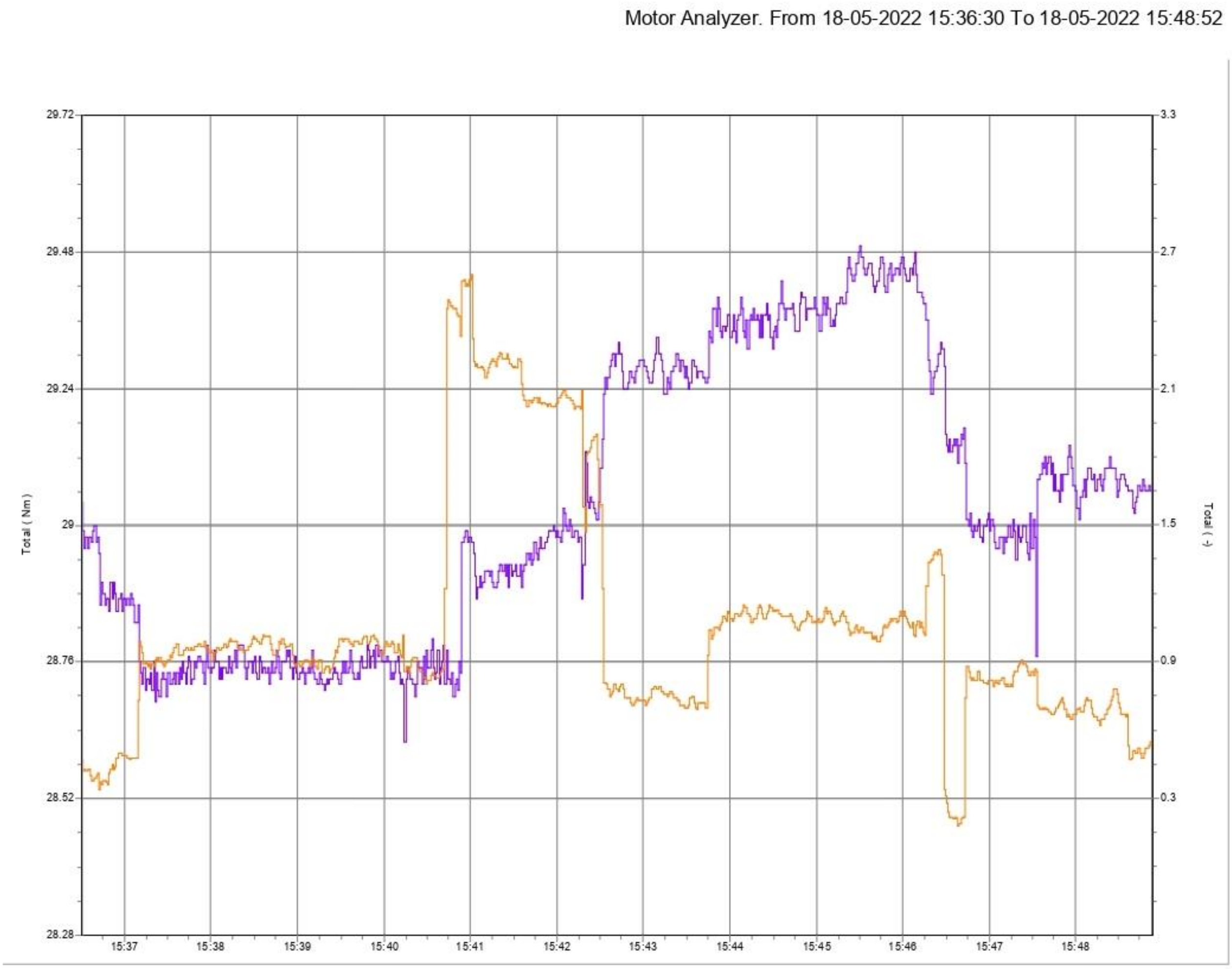


Figure.15 Impact of Voltage Unbalance on Motor torque

6.3.3 CONCLUSION

Table.12 comprises of recorded set of data on voltage unbalance (%) and motor torque (Nm). The measurement was conducted between 15:30 hrs. to 15:57hrs. Figure.14 is the scatter plot between voltage unbalance on X axis and Motor torque on Y axis. The plot is charted considering all the recorded values of the analyzer, A general trend line is observed from the data which is linear in shape and slightly sloped. From the trend line it can inferenced that as voltage unbalance (%) is increased motor torque is decreased which in turn reflects in lower mechanical shaft power and eventually lower motor efficiency.

Figure.15 depict the plots of voltage unbalance and Motor torque generated by the analyzer during the course of measurement. It helps in analyzing the impact of voltage unbalance on motor torque. As per plot Voltage unbalance introduces deviation in motor torque which is detrimental to the performance of the motor and in turn reflects in lower efficiency and higher losses.

From the above discussion it can be concluded that Voltage unbalance impacts motor torque adversely. The drop in torque generated by motor is higher for a higher unbalance in voltage and vice-versa. However, it can’t be generalized with the available limited set of data and the conclusion applies strictly to the motor tested during the experimentation.

CHAPTER 7
CONCLUSION & FUTURE SCOPE OF WORK

7.1 Conclusion

The Purpose of the study is to understand the impacts of power quality indices on induction motor performance under real time operating conditions. The power quality indices selected for performance of the test were- Voltage fluctuations and Voltage unbalance. The impact of above two power quality indices were observed on Motor efficiency, Motor torque, and current unbalance. The study was completed with the help of Power quality and motor analyzer which has recorded the performance of motor parameters under varying input power quality conditions. The analyzer provided results in the form of numerical set of values, plots, trends, and performance curves. The set of data helped in interpretation of the conclusion on motor performance parameters. From the results obtained from the analyzer, the following inferences can be stipulated:

Voltage fluctuation has impact on motor efficiency, as and when voltage is fluctuated away from the rated input voltage there is a change in motor efficiency is observed. Higher the input voltage is deviated from rated voltage higher the drop in motor efficiency is observed. This implies that motor achieves its highest operational efficiency at its rated input voltage and there is drop in efficiency on both side deviations.

Voltage unbalance has drastic impacts on motor efficiency, a unbalance of 2% can bring down the motor efficiency up to 1.8%. This implies motor efficiency is highest when voltage unbalance in the input power supply is minimum. Voltage unbalance also affects current drawn by the motor. It induces unbalance in current which is much higher in magnitude than the unbalance in voltage. The unbalance in current results into unbalance in power. This causes increased loss in the motor thereby reducing its operational efficiency. Voltage unbalance also results in drop in torque generated by the motor, a direct relation could not be established however general trend is reduced motor torque for a higher voltage unbalance.

Limitations

The major limitation of the work was that the tests were conducted on a single motor of 10H.P rating. The set of data generated were also not so exhaustive that a firm conclusion or observance can be made. The results pertain to this particular type of motor only and it can't be generalized to all induction motors. The results present a general depiction of motor performance parameters of a particular type of motor under varying input power quality indices.

The study also not accounted the impact on major mechanical performance parameters of the motor and the losses associated with them.

The control of input supply voltage through servo voltage stabilizer was also in a range with some error, it doesn't provide a fine-tuned set voltage which may creep in some error in the results and interpretation.

7.2 Future scope of Work

Future work is to study, understand and implement the following:

- Establishing relation between voltage fluctuation and voltage unbalance impacts on motor efficiency.
- Impact of other power quality parameters such as harmonics distortion, Transients, flickers etc on induction motor performance.
- Long duration study of power quality impacts on Motor performance.
- Finding out ways to improve power quality and enhance motor efficiency.

PUBLICATIONS

- Vinay Kant, Narendra Kumar, "Real time monitoring of impacts of power quality on induction motor efficiency", International Conference on Recent Developments in Electrical and Power Engineering (ICRDEPE), New Delhi 2022

- Vinay Kant, Narendra Kumar, "Study on consequential effect on induction motor performance due to power quality", International Conference on Electrical, Electronics & Computer Science (ICEECS), Varanasi 2022

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