KAUNAS UNIVERSITY OF TECHNOLOGY

FUCULTY OF ELECTRICAL AND ELECTRONICS ENGINEERING

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DATA ACQUISITION AND ANALYSIS USING SIEMENS CLOUD AND ARTIFICIAL NEURAL NETWORKS

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"Data Acquisition and Analysis using Siemens Cloud and Artificial Neural Networks"

DECLARATION OF ACADEMIC INTEGRITY

25 May 2018
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Research area and field: Electrical and Electronics Engineering, Technological science. Keywords: Internet of things, Online Monitoring, MindSphere, Synchronous motor, Torque, Neural Network.

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SUMMARY

The aim of the project is to create a universal measurement system for the main parameters of the electrical equivalent diagram of the electric machine, which allows real-time monitoring of the ongoing experiment remotely, sharing experiment data and results with interested parties, regardless of their geographic location, to detect machine torque correlation with stator voltage using artificial neural networks, Combine different data gathering devices that communicate on different protocols using the Siemens cloud MindSphere and MindConnect Nano device, which collects all data from the "Schneider Electric" analyzer PM 8000 and gateway Com'x 510.

In this work, Online monitoring, Internet of things, Cloud Computing, are reviewed. Also, a review of electric motors faults and the causes of failure and their types. During the experiment first, permanent magnet synchronous machine was used as a generator and the nominal voltage which was 302V average between phases was measured. Second, using that voltage in permanent magnet synchronous machine as a motor and there were seven experiments done at nominal voltages also lower and higher side with different (20V) voltage steps. From that experiment there were calculations of efficiency done with the 92.08% — maximum among the all experiment, while using nominal 302V, maximum torque of 6.8 Nm was also achieved before loosing synchronism. During the experiment data using two measuring devices data was gathered by Schneider (Com'X) and lorenz platform. After that, data were acquired from the cloud platform which accessed by siemens cloud gateway device. Using this data and artificial neural network with Levenberg Marquart (trainlm) training function, mean squared error of 0.0482 was achieved. After training the neural network torque meter was successfully simulated with 99.1% accuracy.

Harpalsinh Yashvantsinh Matroja. Duomenų surinkimas ir analizė naudojant Siemens debesį ir dirbtinius neuroninius tinklus. Magistro baigiamasis projektas / lekt. dr. Jonas Vanagas. Kauno technologijos universitetas, Elektros ir elektronikos fakultetas, Elektros energetikos sistemų katedra.

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Reikšminiai žodžiai: daiktų internetas, nepertraukiama stebėsena, MindSpher, sinchoninis variklis, sukimo momentas, neuroninis tinklas.

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SANTRAUKA

Projekto tikslas - sukurti universalią sinchroninės mašinos su pastoviaisiais magnetais atstojamosios schemos pagrindinių parametrų matavimo sistemą, kuri leistų nuotoliniu būdu stebėti vykstantį eksperimentą realiuoju laiku, dalintis eksperimento duomenimis ir rezultatais su suinteresuotosiomis šalimis, nepriklausomai nuo jų geografinės padėties. Naudojant dirbtinius neuroninius tinklus, nustatyti mašinos sukimo momento koreliaciją su statoriaus įtampomis. Iš skirtinguose protokoluose veikiančių įrenginų sukelti eksperimentui reikalingus duomenis į "Siemens Cloud MindSphere" debesį, naudojant tinklų sąsają "MindConnect Nano", kuri surenka visus duomenis iš "Schneider Electric" analizatorių PM 8000 ir Com'x 510 duomenų magistralės.

Šiame darbe buvo apžvelgta stebėsena internetu, daiktų internetas ir debesų technologijos. Tai pat buvo apžvelgti tipiniai elektros mašinų gedimai bei jų priežastys. Eksperimento metų buvo nustatyta tiriamos nuolatinių magnetų sinchroninės elektros mašinos elektrovara naudojant mašina generatoriaus režimu, kuri buvo lygi 302V. Eksperimentų metu buvo paskaičiuotas nuolatinių magnetų sinchroninio elektros variklio efektyvumas prie įtampos lygios jo elektrovarai ir gautas 92.08% efektyvumas esant 6.8 Nm sukimo momentui. Tai pat buvo apskaičiuotas variklio efektyvumas prie naudojant skirtingas įtampas: 240V, 260V, 280V, 320V, 340V ir 360V. Eksperimentų metu duomenys buvo surinkti naudojant Schneider (Com‘X) ir lorenz programas, po to naudojant tinklo sąsają duomenis buvo perkelti į Siemens debesį. Gauti duomenis buvo apdoroti neuroninio tinklo Levenberg Marquart (trainlm) mokymo funkciją buvo pasiekta 0.0482 vidutinė kvadratinė paklaida. Pritaikant apmokytą neuroninį tinklą galima prognozuoti variklio sukimo momentą 99.1% tikslumu.

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Introduction:

Nowadays in this technological era, whole the world is engrossed in the internet of things, smart things, also with a digital twin. The internet of things is changed all attitude our lives it means to say that there is everything is changed like how we think, how we are doing work, education, entertainment and so on. The internet of Things is one of the fastest growing industries in this modernization and innovation times. Each and every sector requirement the internet of things. Online monitoring is the part of the internet of things and it is also expanding exceedingly. Companies are nowadays adopting this programmable online monitoring automation system, with that they can reduce enormously cost by many ways. They can reduce manpower with the help of this automatic system. In this online monitoring system, there are many devices available which have an abounding capacity for contrasting parameter. They can monitor they can be gathered the data there are many features available.

Cloud computing also a wide platform for getting the data also for transferring the data for analysis, nowadays Siemens have the wide platform which is MindSphere and it has a variety of devices accessible. MindConnect Nano is the one of the best devices for getting the data in the cloud. Schneider has smart panels for online monitoring, also Com'x platform which is very crucial nowadays for companies they can use those smart meters for getting data and from that it can easily transfer those data to Com'X and from that to cloud by the help of MindConnect Nano. Here you can find modern internet of things and wireless sensors which is crucial for monitoring system also an artificial neural network for collecting those data and making an analysis which is going to help for companies also those all who work with this internet of things devices.

The aim of this work also simplify the data which was collected from the permanent magnet synchronous machine by using smart panels and siemens cloud (MindConnect Nano), and using artificial neural network for getting maximum efficiency, calculating complex equations and for prognosis torque and replicate the torque meter for reduce cost.

Aim: The aim of the project is to create a universal measurement system for the main parameters of the electrical equivalent diagram of the electric machine, which allows real-time monitoring of the ongoing experiment remotely, sharing experiment data and results with interested parties, regardless of their geographic location, to detect machine torque correlation with stator voltage using artificial neural networks, Combine different data gathering devices that communicate on different protocols using the Siemens cloud MindSphere and MindConnect Nano device, which collects all data from the Schneider Electric gateway Com'x 510.

Task:

1. In order to analysis the main parameters of permanent magnet synchronous machine .
2. Data acqusition using smart panels and Com‘X 510. Transfer and process data to the siemense cloud.
3. Create a neural network for permanent magnet synchronous machine parameters development/enhancement/ Improvement also for prosnose torque.
4. Define Problem in Permanent magnet synchronous machine.

1. Overview of Online Monitoring

1.1. Online Monitoring.

“The system covers all related data and information about the all projects in one system. These data and information can then be accessed by different monitors (committees department, beneficiaries, controllers, the joint secretariat etc.) it is depending on the user rights of each user and what them requirement or what they need to know.” All projects handling such as application of project, project reporting, changes, first level control designation, day-to-day communication) we will look through the online monitoring system will fully support the maximum majority of programme operation and activity. [1]

1.2. Types of Electrical Parameters for Online Monitoring

There are different types of monitoring which we can monitors directly online, moreover we can monitors wherever and whenever we want, that is the most beneficial part of online monitoring we can see any time anywhere on our display. There are different types of monitoring we can monitors online, but we will discuss about electrically related monitoring such as, Power Monitoring, Voltage, Current, Torque, Speed, Total Harmonic Distortion(THD), Efficiency, electrical waveform, Temperature, Frequency, Power Factor, among all types we will discuss here some types of monitoring.

- **Online Power Monitoring**

Justify an investment in an aptitude infrastructure can be a troublesome expectation for any plant or field engineer and technician, they need to often rationalize. Investments that assume “low-risk” by upper-level management and they get a fast return in compare to investment are typically easiest to confirm.

Because power monitoring systems operate all over the world, they can get extensive historical records that help end – users cut down the energy which forward to and consumed by electrical systems in their facility.

Moreover, increased energy rates have become a bigger effect on the balance sheet, there are many infrastructures do not take benefits of opportunities to better manage these expenses. Those all are without power monitoring systems they did not understand what they lost and how much they use energy;

- **Users of Power Monitoring system.**

Power monitoring is an asset for all who need power, and for all energy consumers. Energy consumers have a big opportunity where energy usage is involved. In general, there is four basic categories of consumers:-(i) industrial, (ii) commercial, (iii) governmental, and (iv) residential. While each has a different aim for energy consumption and different prospects from its energy producer.

Energy cost/usage and the accuracy of the electrical system are a big issues for every energy consumers. There is different rate structure exist for every category of consumers. Small residential consumers have an effect on billing structure rate about them energy usage. More critical loads, such as industrial and commercial consumers, for that type of consumers, have a more critical issue related with energy usage and variation of power demand. Power monitoring system is the most useful for heavier consumers.

The monitoring system is more beneficial for consumers who have a low tolerance for electrical disruption, for example, pharmaceutical industries and or semiconductor fabrication. In this case, the consumers want reliable and accurate power source which helps for energy loss as well as equipment protection. For this type of consumers, monitoring systems are used to fast identify and resolve error occurring on their electrical system.

Because Power Monitoring systems are working 24/7 basis. Continuous logging of power related record and waveforms, furthermore, characteristics of an electrical system. This include where, when and how the energy being is consumed, and what type of load consumed by energy. This type of knowledge helps reduces the energy going to and consumed by your system of electrical. [2]

- **The reason of install a Power Monitoring system.**

There are several types of benefits to installing a power monitoring system – few of the strongly interrelated with each other. Well designed and proper install monitoring system provides good results as well as operational parameters of the facility's electrical system.

There are some factors why we must have installed a monitoring system,
Environmental: - A good knowledge of how energy is used within a facility showing you to justify an array of expectation to improve efficiency, reduce waste, and decrease energy consumption, after that allowing the better natural resources.

- Reliability: - Judgment of data from the Monitoring systems can explain existing and immediate problems which can adversely affect the operation as well as a product within a

facility. Historical data from power monitoring system it finds and solved both sharp and constant problem. In that case, increased productivity.

- Maintenance: - Data trends can forecast and justify, and people can close that equipment parameters before it will go to exceed, you can decide ahead instead of facing unexpected shutdown.
- Safety: - In fast growing of industrialized and modernized country, the producers and factory are reasons for natural pollutions and negative effects on community health. Monitoring systems can offer every time indicating from the hazardous situation and saving remote status and operation parameters of equipment within risky areas. Some monitoring devices provide some parameters like pressure, temperature, flow rate, vibration, status indicators, etc,
- Financial: - every benefit discusses above either directly or indirectly connected with business's line. [3]
- **Online Voltage Monitoring:**

Recently, with the rising demand for electric energy and the increasing complexity of energy networks, smart grids with self-healing characteristics are of the enormous interest in power system research [4]. Self-healing grids it has a function like it can continuously execute online self-assessment anticipate the problems the grid may encounter, determine existing and immediate problems and instantly take control or implements corrective measures to provide a reliability, safe side, good power quality and last but most important efficiency of the grid.

In this case, smart monitoring elimination system coordinate advance monitoring, control and protection technology are needed in that case provide real-time monitoring, online recognition and smart restriction for the potential overvoltage during the operation of the power system, which will be very crucial for the development of smart grid. Overvoltage is the direct consideration of power system faults. Online monitoring is the great development of researcher for the all industrial consumers. [5]

- **Overvoltage sensor**

The evolution of an overvoltage sensor is the very crucial part of any online monitoring system, are frequently dependent on the potential transformer system and resistor or capacitor voltage-dividing system. The voltage sensor is designed and located to the bushing voltage divider system to voltage signals in the form of capacitance bushing. The voltage sensor is located on the top of the bushing,

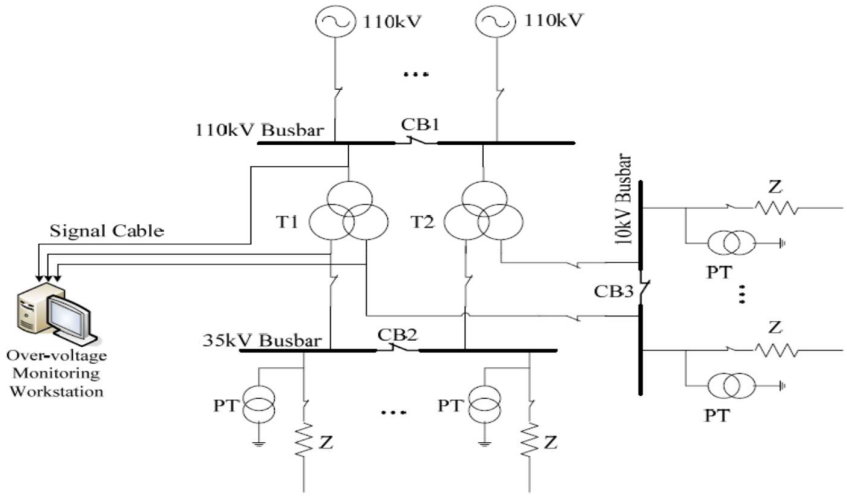

Figure 1.1. Wiring diagram of the monitoring system in the substation [5]

The intelligent monitoring systems put into operation, you can see clearly the wiring diagram of the monitoring system in figure1.1. in that substation, it contains three different voltage levels. We can see clearly there are six feeders on the 35 KV busbar, and there are 5 feeders on the 10 KV busbar. The main transformer is the T1 and T2, and each transformer has capacity about 31.5 MVA. Current breakers are CB1 to CB2. The voltages of 110 KV, 10 KV, and 35 KV are monitored by three sensors. The sensors are connected to the monitoring workstation with the use of signal cable.

- **Overvoltage identification:**

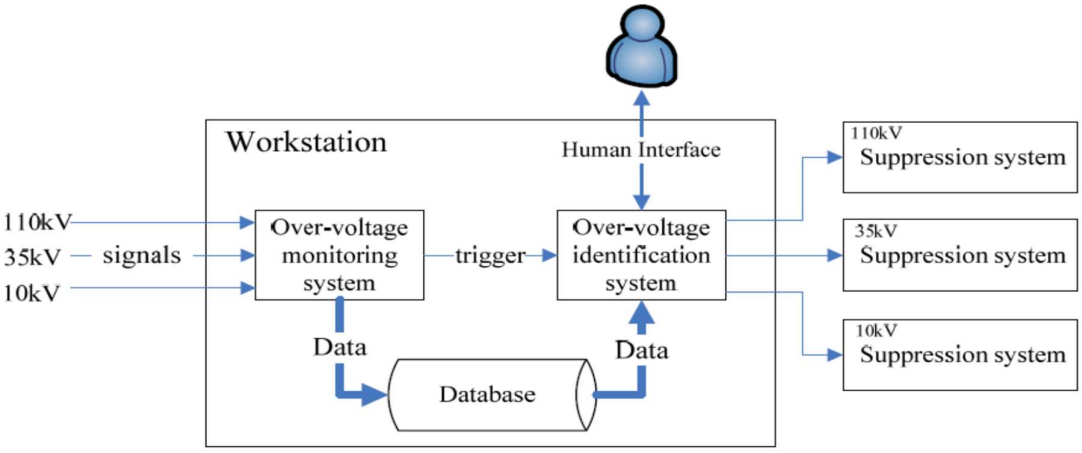

Figure 1.2. Workflow of overvoltage monitoring identification suppression system [5]

in the workstation the software of monitoring system and identification system both are installed respectively. Whenever amplitude of the voltage is over limit the threshold, at the same time the monitoring system record the waveforms of voltage and stores them in the database where it can be discrete data.

- **Online Current Monitoring**

In all over the world Electric Motors are consumed more than fifty percent (50%) of the total power generated. For the continuing of process and the chain of production there are mostly use in industry variable speed drive motors, motors depend on variety of condition monitoring techniques, so motor does not stop while it's in process; to minimize the maintenance cost as well as unwanted shutdown, there will be continuous monitoring will be needed, among the all techniques electric current is the most crucial techniques to detect the fault of the motor.

The experiment of current sensor monitoring: In the experimental setup current sensor have 3 magnetic fields to voltage transducers as well as output represents the current. In this experiment sensors, data are collected via the data acquisition board. [6]

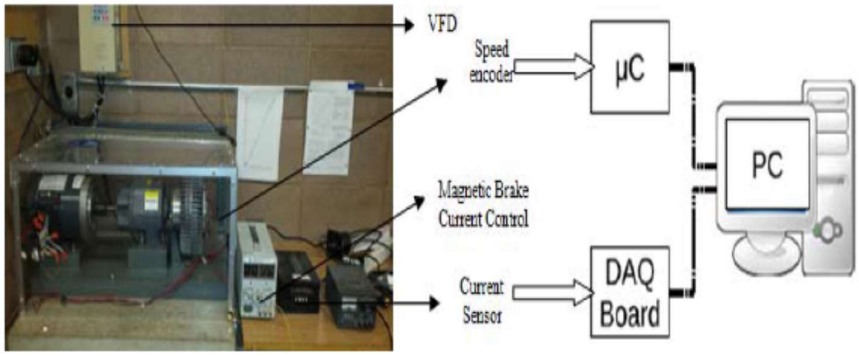

Figure 1.3. Experiment of Online current sensor monitoring [6]

- **Online Power Factor Monitoring**

Power factor is a powerful element in power systems which is described as the angle difference between voltages and currents that produce power fluctuation between sources and loads. In the industry, 40-50% of consumption of electrical energy is induction machine which is inductive loads, in that case, it's a very important factor to monitoring often power factor because it's necessary to protect the whole system of industry. [7] especially, to monitor the operating power factor of the induction machine, either measurement of current and voltage waveforms is needed to measure the angle difference in the between current and voltage with displacement method or measurement of the voltage, there is current and active power in root mean square value. Those methods are demand both voltage and current with a required operating device which is not so expensive [8].

- **Power Factor Estimation Using Zero Crossing Method:** one of the best methods of monitoring power factor is the zero-crossing method where it is needed measuring the voltage and current waveforms and a sensor in the case to characterize the difference between current

and voltage waveforms. In this method, you can see the voltage is the reference with this help current gives power factor [7].

Although, in the 50 Hz supply, the period of voltage and current signals would be 20 ms approx. which covers 360º. In that case, if there is a $\pm \Delta t$ ms difference between the current and voltage we will get zero crossing, then the power factor is given by this equation (1).

$$PF = Cos\left(\frac{\pm \Delta t}{T}\right) * 360 \quad [1.1]$$

Where the $\pm \Delta t$ = distance between current and voltage waveforms,
T = duration of one cycle as well as is the reciprocal of the frequency.

- **Power Factor Estimation Using Instantaneous Power:**

There is another crucial method to monitor power factor we can call it instantaneous method. In this method, the power factor will be calculated by the instantaneous power measurement per phase in point by point multiplication of the two waveforms along the synchronized supply and the motor current measurements by the oscilloscope. It's given this equation (2) [7]

$$PF = \frac{\overline{P}}{V*I} \quad [1.2]$$

P = average active power,
V = RMS voltage
I = RMS motor current [2]

- **Total Harmonic Distortion Monitoring (THD)**

Nowadays, in the field of electric power system harmonic distortion is a power quality problem, evaluate the total harmonic distortion create by nonlinear loads in power system, in some cases harmonic contents metering has been used to describe nonlinear loads behavior,

To find harmonic sources and distortion in power system. There are some contents its required to the analysis of waveform distortion in power system, such as linear loads, non-linear loads, equipment, and steady-state waveform Fourier analysis [9].

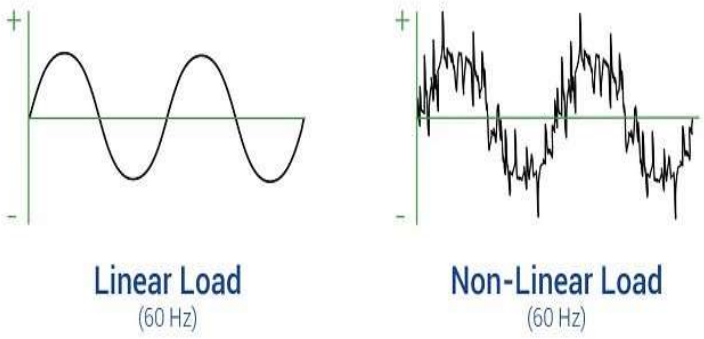

Figure 1.4. Waveform of Total Harmonic Distortion(THD) [9]

The aim of the researcher on the smart grid the transformation of conventional electrical power systems, rising its controllability and reliability, accordingly with the ability to connect renewable sources up using power electronic converter. In this digitalized of a smart grid, the industries should be able to be giving high-quality voltage to its consumers, with accurate levels of harmonic pollution [10].

1.3. Data Acquisition System (DAS)

DAS is an interface between sensor and computer. The basic function of DAS is to convert analog signal coming from sensor to digital via A to D converter and fed to the computer. DAS measure the quantity it may be physical or electrical like temperature, current, voltage, flow, level, pressure, sound etc. sensor may be photosensor, microphone, potentiometer, accelerometer, thermistor, a strain gauge.

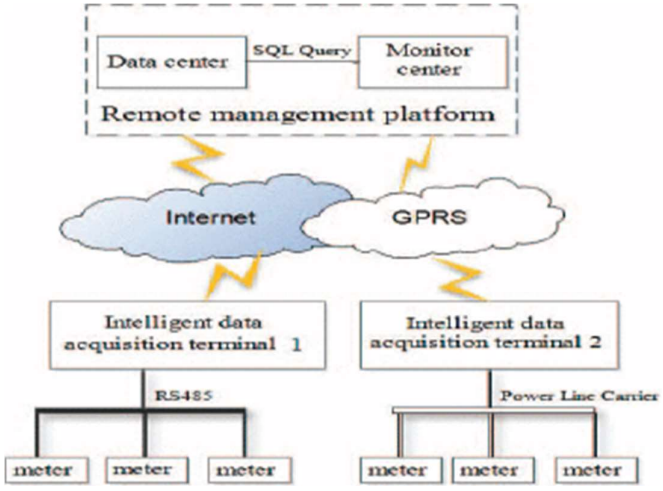

Figure 1.5. Components of Data Acquisition System [11]

In most cases after going through sensor signal may need to get amplified. The sensor converts the measuring quantity into unified form and then sampled by DAS. The sensor is connected to DAS

hardware and DAS is connected to the computer via Universal Serial Bus(USB). DAS hardware is microcontroller and combination of A to D, D to A converters and multiplexers, Random Access Memory (RAM) etc. For supporting Das hardware there is a driver's software on the computer. Computer measures and store the data as well as analyze those phenomena.

In recent two decades, the technology of the communication as well as the technology of network communication, as per the cost of network communication in the different region, wireless data transmission methods, for example, ADSL, GPRS/CDMA, LAN and the same type of systems are adapted to energy monitoring sector [12-13].

The arrangement of the network is made up of electrical power meters, remote management platform, and lastly the intelligent data acquisition terminals. These electric energy meters are answerable for measuring the power record and forwarding the record to the acquisition terminals by the help of RS – 485 or power line carrier channel, on the other hand, the remote management platform by GPRS channel is useful for saving data, remote monitoring, analysis, and management of energy data [12].

- **Components of Data Acquisition System**

In Data Acquisition System there are mainly four components and that each of the four components has also many components, here I am showing that four main names of components.

- Sensors
- Signal Conditioners
- Analog – to – Digital and Digital to Analog Converter
- Software.

Acquired data include measurement that the indicate the condition of process an element such as pressure, flow, vibration and temperature, host software that monitors this data, and it makes the critical decisions based on pre-set parameters and sense voltage, current or discrete signal to control valve, pumps, switches and other equipment thereby the control the application.

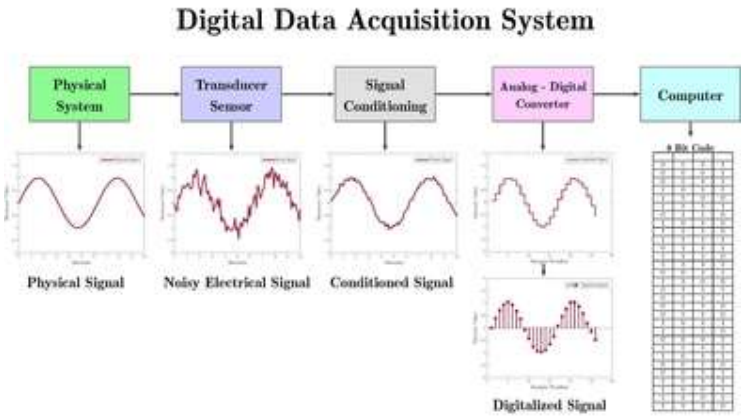

Figure 1.6. Components of Data Acquisition System [11]

Application for the data acquisition systems includes factory automation test and measurement process control and machine control. Industries using this system range from military aerospace to power and energy oil and gas and environmental monitoring, in the end without accurate and dependable data acquisition and control, today's high tech industrial environment simply not exist, this critical element turns real-world conditions into usable measurements which then make possible reliable process control, fail-safe factory and machine automation and unquestionable quality assurance [11].

1.4. Internet of Things(IoT)

The Internet has changed approximately all attitude of our lives, it means to say there is everything changed like how we think, how we are doing work, education, entertain personally, and now the time has reached for the Internet of Things (IoT).

The Internet of Things is a showing the transformation of mobiles, homes, and embedded systems. Every IoTs device must have a physical layer, an interface also there will be internet protocol [IP] address.

After that whenever these devices and systems transfer data over the cloud and interpret they can convert our businesses, lives, and global in countless ways. The internet connects developing economy. The IoTs has developed enormously since it was first introduced in the late 1990s [14 - 16] and it is hoping to develop still more n the future.

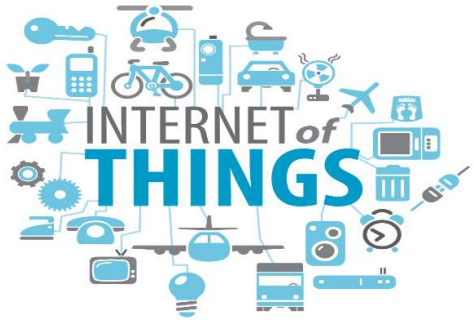

Figure 1.7. Internet of things [Buzz things.com]

Also, it will connect to the World Wide Web(WWW) far more than happens recently, with the device connected ranging from smartphones, automated teller machine to industries, their product as well as their shipping containers. As reported by [14] figure 1.8 shows the predictable growth of IoTs corresponding to the population by the year 2020.

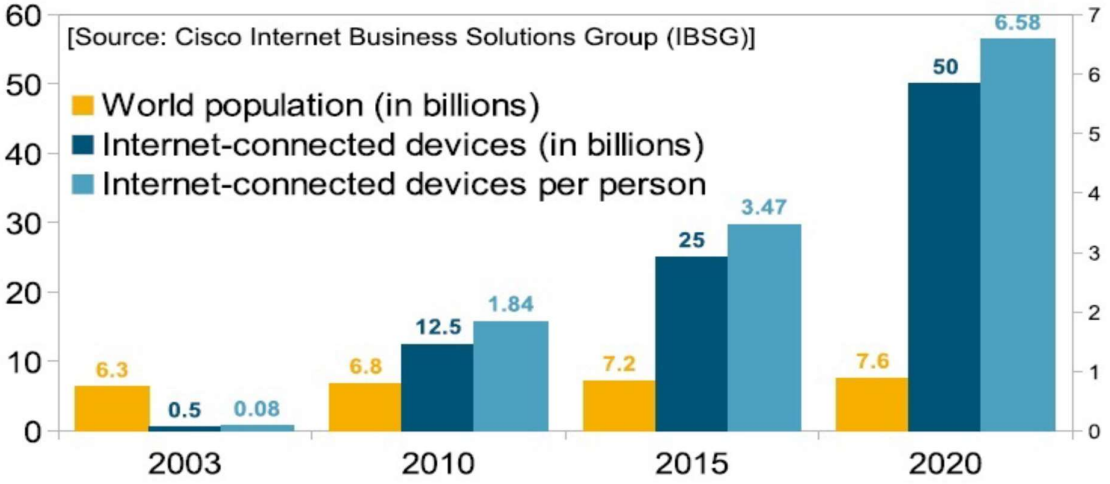

Figure 1.8. The Growth of Interconnected Devices by the Year 2020 [14].

Internet of Things is one of the fastest growing industries in the world in this present situation. Internet of Things is a developing model of internet connected things that allow to there is another physical objects or things to connect, collaborate and communicate with each other like the way which way now a day's humans are going with the web. It associates systems, sensors, and actuators instruments to the broader internet.

The applications of the Internet of Things have no bonds, but it has an enormous range of application like energy systems, homes, industries, cities, agriculture, health, logistics and so on. The goal of IOT is not only just hook up things for ex, machines, devices, and appliances, but also allows the things to communicate, exchange, control data and other necessary information.

It consists of IoT devices that have uncommon characters and abilities of performing remote sensing, monitoring, and actuating tasks. These devices have unique features, able to be connecting with each other directly or indirectly and data collections are working in locally as well as remotely via cloud base application. These devices can be data gathering device to which variety of sensors are connected such as temperature, humidity, light, etc[14].

1.4.1. Role of the Internet of things for Intelligent Electric Power Networks

Electrical power and Electrical networks are constituting of Generation, transmission, and distribution networks and their customers, including (residential, commercials, and industrial) [17]. EPESs are now a day facing plentiful limitations with balancing the fuel mix, accuracy of power delivery and quality, asset level visibility, finding new revenue sources, developing the workforce, knowledge gain and technology combination.

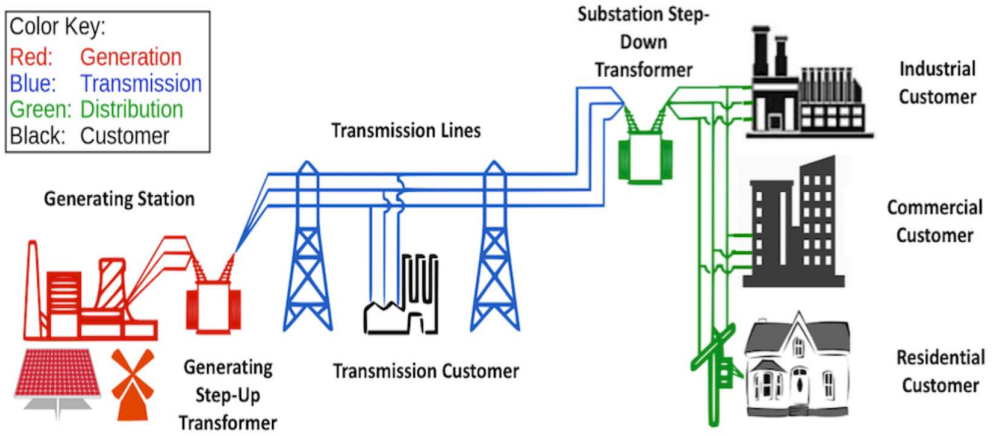

Figure 1.9. Power and Energy system [17]

IoTs has been an essential part of the revolution towards intelligent electric power networks. Examples of IoTs technologies now a day very fast growing with Advanced metering infrastructure(AMI) and supervisory control and data acquisition (SCADA) [17, 19]. There are several benefits of expanding IoTs in intelligent electric power networks.

Increase reliability, resiliency, adaptability, and energy efficiency.

- Decreased number of communication protocols
- Networked operation and as well as increase information operation capabilities.
- Upgrade control over house appliances.
- Permit on-demand information access and end to end service provisioning.
- Develop sensing capabilities.

- Decrease damages from natural disasters
- Reduce physical attacks also for ex, substation breakdown, on EPESs by continuously monitoring the electric power networks improve assets in real time.

Accomplishing the full potential of Internet of Things is demanding to increase the operations, the flexibility, asset management, and reliability of intelligent electric power networks.

It is very important to record the fluctuation introduced by decentralized generation from distributed energy resources. To increase the enablement of electric power networks, if we talk about this situation there will be one more features coming nowadays, IoTs devices and technologies such as advanced distribution management system(ADMS) gather, evaluate, and circulate data to every electric power network stakeholders (customers, services, and regulators). After this data gain by stakeholders, they can make a decision whatever however they want to face a predictable problem with their difficulties and resulting in efficient utilization of electrical power network resources and great efficient power network [17].

1.4.2. Impact of IoTs on Electric Power and Energy Systems

Internet of Things have some impacts on economic related, environment-related as well as the societal impact of IoTs on EPESs lets we discuss here,

- **Economic impacts of the Internet of Things on Electric Power and Energy Systems**

Now a day whatever economic amount is available, but some researcher investigates about this economy it will going to rise in next decade. There is one institute its name, McKinsey Global Institute has predicted that in the year of 2025, the economic impact of IoTs for Energy and power systems will be going to rise from 200 billion dollars to 500 billion dollars [17, 20]. As per investigation the market of internet of things sensors for EPESs is increases enormously height as well there will come more opportunity for IoTs development and growth also, and in this case the cost of energy will reduce per sensor so, IoTs sensors are currently stand in top position and it will go to so popular in next few years for industrial and consumer application [21].

Recently in the market some critical issues available related to IoTs there are some obstacle with connection related, cybersecurity, recording big data, personal privacy, continuous fewer price resources, and with the high price of sensors, capable, and reliable. There is no doubt in next few decades if this obstacle will solve to ensure there will continuously growing IOTs for EPESs.

- **Environmental Impact of IoT on Electrical Power and Energy Systems**

Internet of Things has great future, with the help of IoTs installed in EPESs, we can see there is one best result that is the power is utilized correct way as well as efficiently. Also, there is one most important factors are generated that is the renewable sources with the help of IoTs we can optimize for maximize power consumption from renewable sources such as solar and Wind [22]. Nowaday's Catastrophic gas, as well as pollution, is the biggest issues for the environment and in this case with IoTs has a positive impact on the environment side, it means to say if EPESs is working with IoTs there less energy waste and decrease the harmful gas emission such as carbon dioxide (CO2). There is one prediction in the year of 2020 there are 2 Gigatons annual reduction in CO2 emission is forecast [17].

- **Societal Impact of IoTs on Electric Power and Energy Systems**

As globalization continuous rise, there is necessary for care to available resources, but nowadays lifestyle going to standards in that case all have a comfort zone and they have personal priorities. And internet of things will look all this priority, needs desires to sense, collect, transmit, analyze. With this, all demand organize if IoTs installed in EPESs so it will reduce energy waste.

1.4.3. Internet of things in Electric motors.

Nowadays in the industries, they are suffering from a different type of problems related with many equipments like electric motors, electric Generators, Transformers and so on. In the field of electric motors will play a most important role, and it gives to better efficiency to producers, but they will be suffering from some problems, in that case, Internet of Things will give better measuring process as well as accuracy and precision, IoTs are more effectively monitors and gives better results.In the field of induction motors, there are different faults occurring, such as rotor faults, stator faults, bearing fault as well as winding faults [23]. Internet of things makes Electrical Motors Maintenance easier.

System Condition Monitoring: Electric motors nowadays totally change with IoTs because it will not use a bundle of wires, because of that in this system using wireless sensors on the device it will give an easy process for motors parameters acquisition like temperature, vibration, and current/voltage sensors data. It means, when Electric motors going to overheat in the plant, in that case, that motor sensor will catch the real-time data and forward the data to the application via the cloud, organizers can use this data and forward this data to maintenance team for quick checking and for solving this problem soon. It can not see only real data in this system they can see past records also.

Figure 1.10. IoTs using in Electrical Motors measuring [24]

Save Money and Time: because of the unexpected shutdown is the most prestigious things in industrial surroundings. Vibration, temperature and Current these three disruptive factors in an electric motor, with this type of situation in the field of electric motors, they can suffer from mechanical failure, bearing failure, electrical imbalances, also its reduce working life. This IoTs monitoring system will give early warning for attention regarding vibration, current/voltage and temperature failures and problems [23].

IoTs monitoring systems save money because it will detect harmful problems in the motors before it will come its failure. This type of systems saves time as money as well as time also because before the failure it gives the alert signal to producers and it saves unexpected failure and shutdown, so it saves time for that.

Energy savings: there is no doubt if electric motor producers will use IoTs they will save energy. Because the whole electrical motor has a function for energy conversion device, it converts electrical energy to heat or some other energy. Whenever electrical motors will be going to over excited situation, energy utilization is rising, and electric motors speed will be going to downwards. But IoTs monitoring system will give where and when energy will be consuming and what place it needs and where not needed in that case we can save energy a lot.

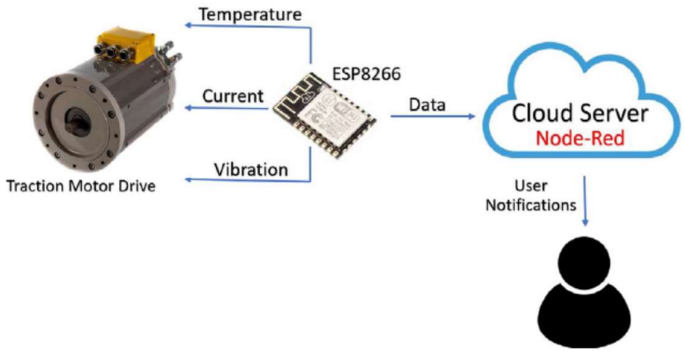

Figure 1.11. Traction motor parameter monitoring using IoTs [25]

There are using one method with IoTs to measure temperature, vibration, and current for the motor. In that practical, he used three different type of sensors which are called accelerometer (ADXL345) for vibration measuring, for a current measure he used (ACS712) lastly for temperature he used a probe (DS18B20) of the motor and in bearing area. And most importantly there is one connection for all three sensors it means all three sensors are connected in one IoTs chip it called ESP8266 it is powered by Lithium-ion battery in system diagram we can see clearly [25].

This chip ESP8266 is a single chip device with 4MB of flash memory build inside it has functioned with this MB it can connect to Wi-Fi module. it is wireless, small cost, in this research he uses Nod-red software it is browser-based, using for connection online devices. In the process if we see then motors will be working then sensors will sense the data and system will receive that all data from the sensors after that those all data will be going to analyzed and forward by Node-red cloud database.

After that, if inside the motors any abnormality will be detected by this data it will automatically show in our system and we can inform to maintenance team for the clearance this problem. It can transfer notification with any applications like e-mail, Facebook, Tweeter, Instagram, Line and so on. We can see the results of temperature, vibration, and current in normal and abnormal condition with images in the [25] reference, there will clearly showing all results that he gets while he is testing this traction motors with those three different sensors.

1.4.4. Mind-Sphere

We all relate to IoTs and nowadays 90 percentage people are using mobile as well, so everyone connected with internet and it will give very predictive life as well as more easy and smart lifestyle we can live with mobile internet technology. This same thing we have to do with our machines or our assets which are we using in our industries, the machine, they have been serving us so long and working so hard for us since, the beginning of industrialization but they are kind of offline and lonely also, in that case, we want to connect them we want to make them smarter we want to make them more intelligent or more predictable, we want to know the problem before the problem will occur. And we want to save many important services and customer products, but for all this, we have one big question tag how? And there we have an answer, is Siemens MindSphere, the Siemens IoT operating system it is an open ecosystem.

Figure 1.12. MindSphere Structure view [47]

In the Mind-Sphere there are three layers in the Mind-Sphere IoT operating system, mind-connect MindSphere and mind-apps those all three are the whole structure of MindSphere IoT operating system. With the help of mind-connect, we can connect our machine our industrial assets, plant and entire fleet and collect data and upload data to the mind-sphere cloud. Between the Mind-sphere cloud and mind-connect, there is an option for connection to MindSphere, MindConnect Nano MindConnect IoT 2040, MindConnect software, Integration in SIMATIC and other Siemens product.

With the help of this devices, you can grasp your machine your industrial assets your also your plant data and transfer to securely to MindSphere you do not need anything to attach if you are using this device. It is called the main gateway of MindSphere IoT operating system. And in the MindSphere you can host your data, once if you have your data you can do something meaningful with that data. You can save your industrial essential equipment and you don't need to check often to our machines or you do not need to shut down your systems.

MindSphere is the platform for industries to become digitalization, it has enormous benefits for industries, Internet of things solutions will faster than before with it. There will be available open platform as a service with wide accessibility, make the product more efficient and more practical.

You can save your time, and money too with this system, you can predict for your essential equipment like when and what type of services they need. Nowadays you can use MindSphere in every sector, you can use in cities for traffic for trains and for energy management and so on. You can use in marine systems, you can use in airport airlines and many things you can connect with IoT operating system MindSphere [47].

1.5. Cloud Computing:

Cloud computing is the use of remote servers on the internet to store data, networking software analytic and more over the cloud or internet. There is the organization they provide cloud computing services and its call cloud providers, and they will take charge typically for usage of your system, its

like same as how we are paying the bills of water and electricity. Users can access that software and application which they took from cloud providers wherever as well as whenever they need.

We all are using cloud computing nowadays if you do not believe it. If you are using online service for the use of sending mail edit some documentation, watching TV or movies, music plays some games and so on, that all related to cloud computing. If we are talking about life without cloud computing, we must face critical situations. Any kind of traditional business will be expensive without it, they have to pay more than the amount for hardware and software to run them. also, they need to expert teal for the installation, analyzation, run, test, secure, and update them.

In that case, if we use cloud computing, we can defeat that all critical situation that come with your own records, because you don't need to handle software and hardware, it will take all responsibility to as a responsible person like salesforce.com. you don't need to pay for extra anything you have to pay just what you will use and what you need, and sometimes for upgrades.

- **Benefits of cloud computing**

There are many benefits of using the cloud computing, among the all we will discuss some important benefits here,

- **Cost:** Cloud computing does not need any type of software and hardware, so it will defeat all that capital expense of buying also maintenance for that and every time connecting with datacentre also it will save manpower, you don't need to built boxes of server, you don't need power and cooling for the managing of IT department also for infrastructure.

- **Speed:** There is most cloud computing services are available for on self-service also on demand, so instead of enormous investment in the resources compared to clouds will give in one-minute solution for that, just one click on the mouse and they will provide a maximum business with flexibility and reliable situation.

- **Global Scale:** It means cloud computing services is the all over the world, there is no bonding, it is delivered to the true amount of Information technology assets. Whenever and wherever it needed of power demand or storage also it will fulfill around the world.

- **Productivity:** On the field recording data also to install a lot of hardware and software set up, if we installed those much of software and hardware obviously it's for the burden on IT organization. If we are using cloud computing there is no doubt it will neglect all those barriers in that case IT organization and all teams can spend a maximum of time to achieving more beneficial goals.

- **Performance:** The top cloud computing services working on a worldwide network of protected record center, it will often have upgraded to the totally fast and accurate computing hardware. It has a lot of useful features, as well as reduced network discontinuance for applications and maximum economies of scale.

- **Reliability:** Cloud computing has many features related to reliable operation it has data store option, also catastrophic recovery and business continuity easier and minimum expense. We can see data at multiple sites in our system.

- **Security:** If you don't have cloud there is no doubt you will save your data in the computer and if it's lost then all your data will have gone, bundles of your files will have lost in one second, so cloud is the best security for that you can save your data in the cloud. You can access you all data by cloud whenever wherever you want.

1.5.1. Types of Cloud Services

There are two types of the cloud model, it namely (i) service model, (ii) Deployment model. We will describe here in detail about these model, first, we will discuss service model,

Service Model: it means the kind of service that cloud offers, this service can be divided into further modules and then you have to deployment module, how you can install your application, how you can upload your applications on the cloud and what ways you will deploy that all applications. There are two types of different model in cloud computing, we will discuss here on by one.

Basic three kind of service model in cloud computing

- Infrastructure as a service (IaaS)
- Platform as a service (PaaS)
- Software as a service (SaaS)

- **Infrastructure as a Service (IaaS):**

If we are talking about IaaS then just we have to imagine like, you get a server on the cloud, you choose as an operating system and you will get that server on the cloud, for example, you want Linux system on the cloud. So you will request to your service provider for the Linux system and you will get fresh system, also they will give IP address and password, you can remote desktop on to that server and now that server also fresh you can install anything on that server, for example, web server, database server, you can install. After that you have the access to the operating system of your server, it provides virtualized computing resource over the internet.

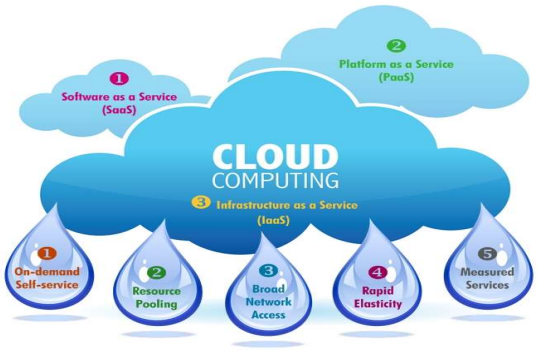

Figure 1.13. Types of cloud computing [28]

In the IaaS you don't have to worried about the essential physical machine, you don't have to manage the physical machine, there will all of that manage by the cloud providers.

- **Platform as a Service (PaaS)**

In compare to IaaS, if you have IaaS then wherever you can be getting to access the operating system, you can anything with it but in **PaaS,** you do not get access to the operating system, all you get access to the user interface.

For example you want to host a website, you take a service from AWS, you have to say like I want platform I don't want the whole infrastructure, so what that cloud provider do, they will launch the server and they will do not give you IP address and password to it so, you don't get the access to the operating system, what they give you, is a button, you have to click on that button which uploads your website on to it, you do not install any software, you do not have to manage the files over there, you do not want to do anything, just you have to upload your file and that file will be automatically deploying whatever link or website they provide. You do not have to manage operating system at all this.

- **Software as a Service (SaaS)**

Software as a service which means, you do not get a server, you do not get any infrastructure, just you will get basically software. With the SaaS, you do not want to think about how that software will work and about maintenance also how that essential infrastructure will be managed.

You just have to think how that you will use that particular system, there is one common example, web-based email where you can send and receive in a simple way, you do not need to think about how to manage that features and maintenance about that server or operating system [29].

Deployment model:

In deployment model, there are also three kinds of cloud,

- Public Cloud

- Hybrid Cloud
- Private Cloud

Public Cloud: is basically when you are sharing your server with the host of different people, there no physical control over the infrastructure.

Private Cloud: It means using a cloud network particular to one person or organization, it is not shared with others, the industry or company have an option to choose private cloud. Also, it will be expensive for that private clients. But they do not have the physical control on the organization.

Hybrid Cloud: It's a mixture of public cloud and private cloud, t means if you have applied for cloud and you will use public as well as private cloud also then its called hybrid cloud [29].

1.6. Artificial Intelligence

Nowadays one word is going to so famous and using enormous places for different prospectus its name is "Artificial Intelligence" here, Artificial means non-natural and intelligence means the ability to understand think and learn the system. There are many definitions available for Artificial intelligence but here I will write one basic definition is,

"Artificial Intelligence is basically a study of how to make a system which can think and behave acts exactly or better than what a human being can act or react. There are many examples you can see in your real life related to AI like computer playing chess and self-driving car those depend on deep learning as well as neural languages."

Nowadays, Artificial Intelligence rising in a many ways, such as mobile phones, video games characters, GPS/voice recognition, Robotics, Chess playing computers, self-driving cars and so on it will play a big roll in Artificial Intelligent (AI). Also, Google has many features in past few decades or still it's going on the same way as a deep learning, it means machine learning depends on the algorithms.

1.7. Neural Network

- **The process of Neural Network**

The neural network we can also call the artificial neural network, it's a connectionist diagram with each other. Neural network is the same type of working which neurons are doing in human brain, its related to biological brain system, that's the same direction they both are working, you can see in neuron diagram, it is compared as the following measure components which are dendrites by taking a inputs from other neurons in the form of electrical impulses, the cell body to generate influence from those inputs and it will decide what action to take.

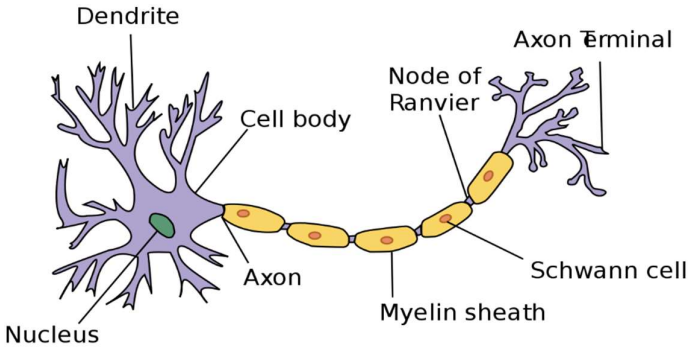

Figure 1.14. Structure of neuron [30]

As you can see in this diagram we have X1, X2, X3, …. xm it is an input from this process with this input and there will connected weights and each input has connected corresponding weight, weight is the information which neural network will use for solving the problems, it will make strong strength of neuron that it will specify as that neuron interconnection inside it's loose or strong. That is the reason that every input has weight and that every weight input will make a summation.

In this first unit every X1 input multiply with w1, and every X2 will multiply with w2, as it will add after in next unit. Moreover after summed it will be check, basically if its greater than zero (>0) or less than zero (<0), also one concept of Bias will add there with the total summed value, in some cases weighted sum is zero showing, that the time of bias it will add to make the output is not zero or scale up to the process feedback. Bias must have one point it is input and weight always equal to one.

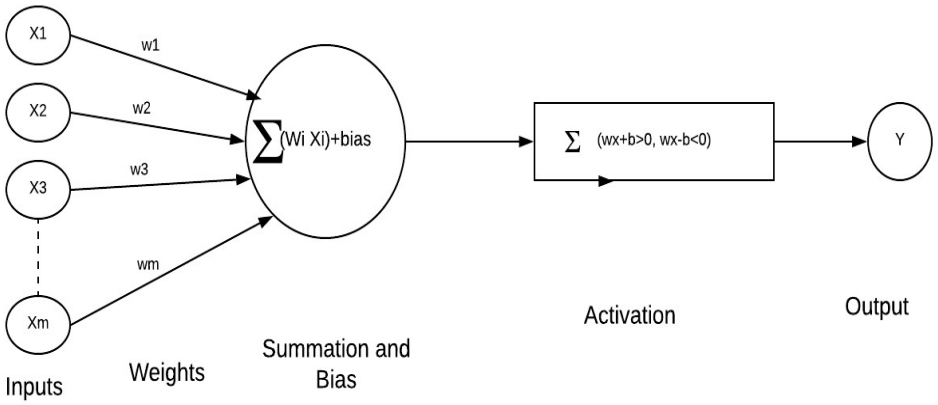

Figure 1.15 Structure of Artificial Neural Network

In that case, which will get the sum in final it is always not zero, that summed will corresponding to any numerical value zero to-infinitives (∞), so we must set up on the threshold, and for that, we will use activation. We have linear activation and a nonlinear activation function, we have to send that summed value to activation function [31].

If we write mathematically then we can write neuron j will be explained as

$$u_j = \sum_{i=1}^{I} w_{ji} x_i \quad [1.3]$$

and

$$yi = f(u_j - \theta_j) \quad [1.4]$$

Where,

$x_{1,}\, x_{2,} \ldots\ldots\ldots, x_{n,}$ are denoted by input values,

$w_{ji}, w_{j2,} \ldots\ldots\ldots\ldots w_{jI}$ this value is showing as a synaptic weight of the neuron,

u_j is the denoted by linear output,

θ_j is denoted by the threshold value,

$f(.)$ is the active function,

y_j is consider output signal value

On the other side, we have two concepts in the simple neuron, training mode (being learned) and user mode (after being learned), because it is supervising learning.

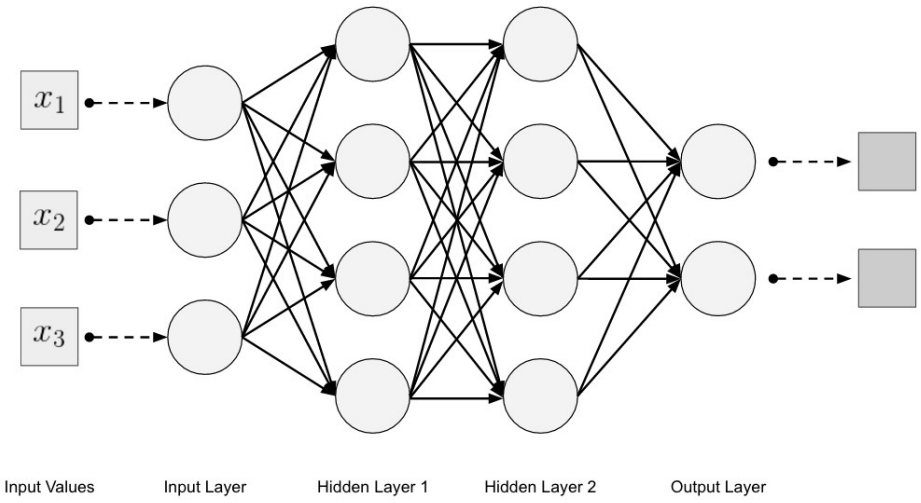

Figure 1.16. Multilayer Artificial Neural Network [32]

After that input unit will triggered to other units that is hidden layer unit hidden layer is two sides if that is multilayer neuron so it will input side one hidden and output side one hidden layer available so its called hidden layer, in that means in multi-layer neural network has three layers which are called, input layer, hidden layer, and output layer, each layer indicating some information with between nodes which show in diagram. Input layer will take information from outside after that

hidden layer will do all calculation inside this layer and it will transfer information to output layer and then it will decide what is correct information [30].

1.7.1. Machine Learning

In this world nowadays, a lot of data will produce such as pictures, music, videos, text and so on, and if we see this then we can imagine like it will not going to lower in near decades also. Machine learning is one of the units that will bring challenge it will derive that all of data meaning, machine learning is the base that you must get your answers and questions with the use of our data. If we can see the definition then there is smallest definition we have for machine learning,

“Using data to answer and the question”.
Now here we can part this definition into two parts, using data also the answer or questions, this both parts have their benefits and they both have significant. Using data, we can arrange with it to training and answer or question we can see as a prediction or assumption.

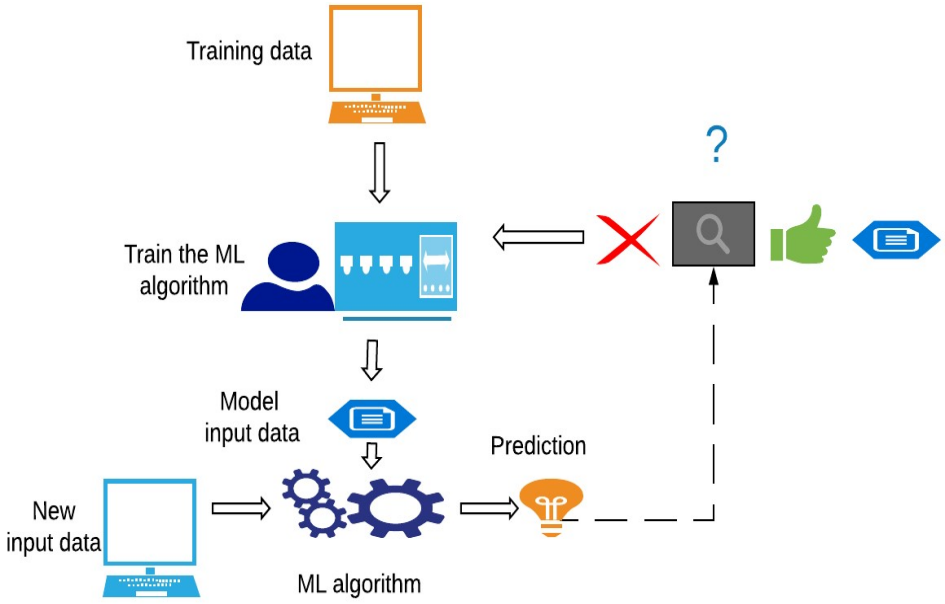

Figure 1.17. Working process of machine learning

Now we will see in to briefly then training is the way that we can manage our data with the algorithm and we can create a new predictive model. This predictive model we can use for the creation for unseen data and we can create a new model, as you can see in the diagram as more data gathered then new assumption model will arrange. Prediction is evaluating for accuracy if their answer will not be going to match or correct then machine learning algorithm is deployed if it's not accurate then it will be working again and again till it will not accept.

Machine learning is depending on this basic points:

- Gathering data
- Preparing that data
- Choosing a model
- Training
- Evaluation
- Hyperparameter tuning
- Prediction.

- **Examples of machine learning**

1st we all are using emails, as you can see there is some of the mail are in your inbox and some others are in spam box, that is one type of machine learning, because there is enormous data in the cloud or world and your system and algorithm are made such a manner so it will automatically predict weather this email is spam or this is essential email so it has to deliver In your inbox, it is also not always correct sometimes you can see your some good email are goes in spam and some spam email comes to your inbox so that is basic example of machine learning.

Second, you all are using nowadays mobiles so you all are related with some kind of application that will predict how you look in your 60s and 80s also how's your face going to in which shape, this all base on machine learning.

- **Types of Machine learning**

As we can see in the chart there is three type of machine learning, supervised, unsupervised and reinforcement machine learning.

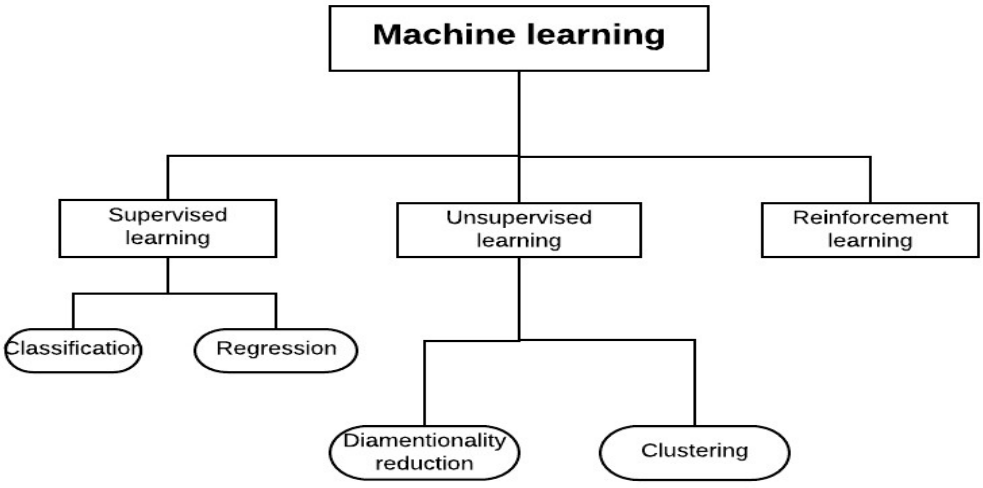

Figure 1.18. Machine learning process

Supervised learning: as we know in this type of learning there is input, as well as a label, are available.

Ex; for the summation of two numbers we can see one example here,

a = 5, b = 6, result = 11, input is here 5,6 and label here is the 11.

Here we will first teach the model with amounts of training data.

Figure 1.19. Supervised learning process

Unsupervised learning: in this system, we do not have a target, so we cannot decide to a system where it must go or where to come it must decide by itself.

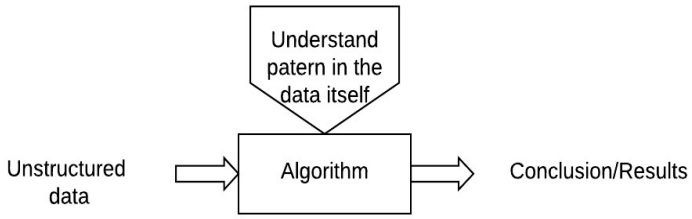

Figure 1.20. Unsupervised learning process

- **Training Function in multilayer neural network.**

It is too difficult to decide which training algorithm is going to quick solve, it is totally bank on many aspects, along with complication of the difficulties, the training set also some number of data, weight, and biases in the system, there is one type of network and we can use that for pattern finding and function nearness. Here, in this table, we have some algorithm and acronym with some description available.

We can see the comparison of the accuracy of this all algorithms by some results which are already proved. The induction motor is the one of the essential element in the field of the industry for electrical to mechanical transformation because it's accurate, compact in use, reliable results, and so on.

There is some data after checking the induction motor faults using Motor Current Signature Analysis (MCSA) after that here they showed all algorithm accuracy with one table, and we can see clearly from that which one is more accurate. As we know about the multilayer perceptron is one type of feedforward neural network and it useful frequent in pattern recognition, also they used tan-sigmoid transfer function.

Table 1.1 Algorithm and Acronym for tested and for identify [33].

Acronym	Algorithm	Description
LM	trainlm	Levenberg-Marquardt
BFG	trainbfg	BFGS Quasi-Newton
RP	trainrp	Resilient Backpropagation
SCG	trainscg	Scaled Conjugate Gradient
CGB	traincgb	Conjugate gradient with Powell
CGF	traincg	Fletcher-Powell Conjugate Gradient
CGP	traincgp	Polak-Ribiere Conjugate Gradient
OSS	trainoss	One step Scent
GDX	traingdx	Variable Learning Rate Backpropagation

The data for MLP neural network, there are four targets for comparison all algorithm. These four targets are generated from stator current frequency spectrum, in that case, there will be 1000Hz frequency spectrum.

1st – Healthy motor = 1000

2nd – Unbalanced voltage = 0100

3rd – Broken rotor bars = 0010

4th – Stator winding fault = 0000 [34].

Table 1.2 Performance comparison of the different algorithm (LM, SCG, GD, GDX, CGB, and BFGS) [34]

Training Algorithm	Accuracy, (%)	MSE, %	Iteration	Time, Sec.
LM	97.20	0.59	58.45	1.87
SCG	78.36	9.68	66.80	2.20
GD	50.22	18.56	1000.00	8.60
GDX	69.42	11.84	174.60	2.60
CGB	85.50	7.37	80.60	3.20
BFGS	75.56	12.13	65.77	2.95

With the help of generated results, it is distinguishing in the three-part one is 60% for data training in the neural network second one is 20% for validation purpose and 20 % in the field of testing the neural network. In this paper, researcher obtains comparison result of six different type of algorithm which we can clearly see in the table no 2.

We can see clearly from the table there is LM (Levenberge-Marquardt) is the most accurate algorithm compare to all, there is 97.20 % accuracy proved, after that CGB with 85.50 % of accuracy.

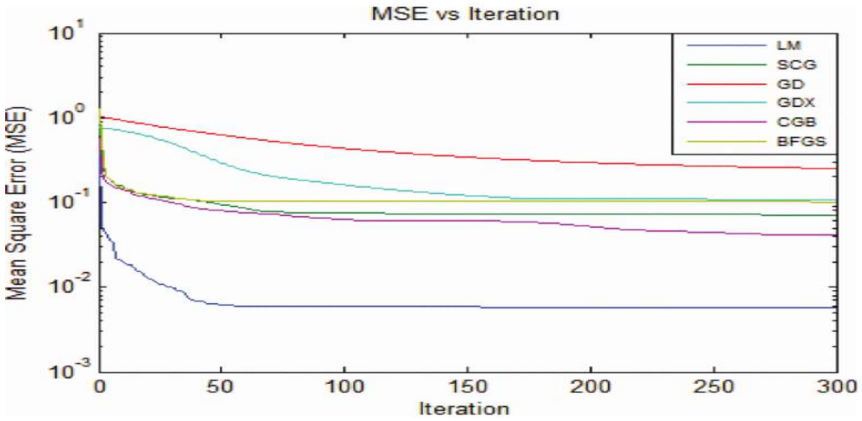

Figure 1.21. MSE vs number of training iterations [34]

Also, we can see in the graph also we can predict there is least number of iteration LM has so it's obviously for MSE, it will take also minimum time for showing results, with help of graph as well as that data table we can say like GD is the most unsuitable algorithm from MSE with the highest iteration also time and low accuracy percentage.

The most and crucial moto of the Neural Network is the decrease generalization of error [35]. One of the first and most step of the finding and complete the task of ANN is to deliver data into that way which is adequate with ANN. After that, the second step is to choose input and output for the ANN.

Let's we will discuss one of the most useful algorithms and it is enough even for my thesis work.

- **Levenberge Marquardt Algorithm.**

Criticism complications a more and mostly in the least square curve fitting. The LMA we can be handled in many software applications for finding the generic curve-fitting problems. LMA is including with the Gauss-Newton algorithm (GNA) and the technique of Gradient Descent. LMA is powerful than the GNA, trainlm is a network function it will helpful for the refurbish weight and bias numbers and data with the help of Levenberge Marquardt Algorithm. It will be using more memory compared to another algorithm.

- **Transfer Functions of Neural Network.**

Table 1.3 Transfer Function

1	Linear Function
2	Sigmoid Function
3	Hyperbolic Tangent Function

4	Gaussian Function
5	Heaviside (Step) Function
6	Ramp Function

The Sigmoid Function

Equation:

$$f(x_i) = \frac{1}{1+e^{-x_i}}, f'(x_i) = \sigma(x_i)\big(1-\sigma(x_i)\big) \dots\dots\dots (36) \qquad [1.5]$$

Log-Sigmoid transfer function

In this function, logsig input will be always we can see in between 0 and 1, not equal to 0 and 1. From this, we can assume like if the input is positive means output of nodes maybe high. And if its negative then nodes will be low. This function often uses for the derivative.

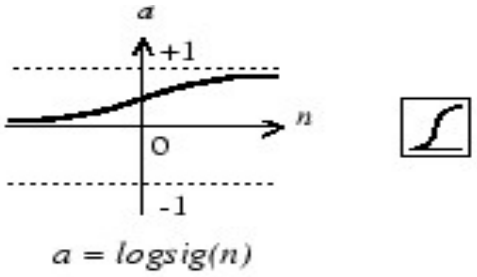

Figure 1.22. log-sigmoid Transfer Function [36]

Tan-Sigmoid Transfer Function

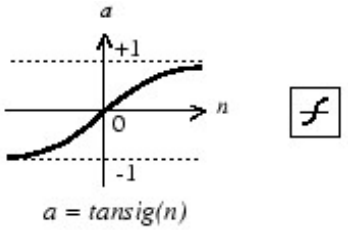

Figure 1.23. Tan Sigmoid Transfer Function [36].

Multilayer tan-sigmoid method also using sometimes, Sigmoid functions are useful for pattern identification complications and on the other site, linear function will essential for fitting complications.

Linear Function

$$f(x_i) = x_i$$

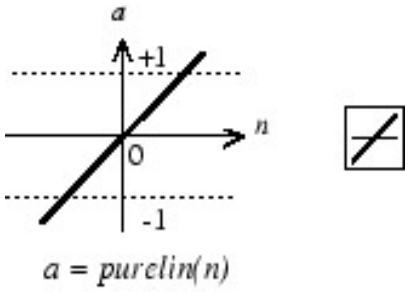

Figure 1.24. Linear Transfer Function [36]

If we want to output, but you do not want to apply your threshold value then you can use the linear function for that type of condition.

1.8. Electrical Motors and Mechanical Failure

1.8.1. Asynchronous and synchronous machine.

The population of the electric motors is going to increase day by day, if we look worldwide then we can see 50 % of the global electric power consumption are considering induction motor. The asynchronous motor has mainly two components one is rotor and the second one is stator, the rotor is a deal with rotating part and stator just name indicate it is a stationary part. The stator turns the rotor by performing to the field, firstly the stator will generate electric current in the rotor, without any type of part touching, secondly, the stator will turn the rotor without any moving part.

The stator is made by stacking thin slotted highly permeable still laminations inside a still or cast-iron frame. After that winding passes through slots of the stator, and when there 3 phase AC current passes after that there will be one interesting thing will happen, it will produce rotating magnetic field.

Induction motor speed: The induction motor will always be running with speed slow in compare to synchronous speed. There is the difference between motors and synchronous speed and we can called it slip speed [37].

$$n_{slip} = n_{sync} - n_m \quad [1.6]$$

Where,

n_{slip} = slip speed

n_{sync} = speed of the magnetic field

n_m = mechanical shaft speed of the motor

The slip is denoted by,

$$S = \frac{n_{sync} - n_m}{n_{sync}} \quad [1.7]$$

Where S is the slip.

Rotor Frequency: The frequency of the rotor in the motor is a voltage induced by,

$$f_r = \frac{p.n_{slip}}{120} \quad [1.8]$$

Where, f_r= the rotor frequency (Hz)

p = number of stator poles,

n_{slip} = slip speed (rpm) [37]

- **Asynchronous and synchronous machine construction**

We can see clearly parts of the three-phase Asynchronous motor in the figure 1.25.

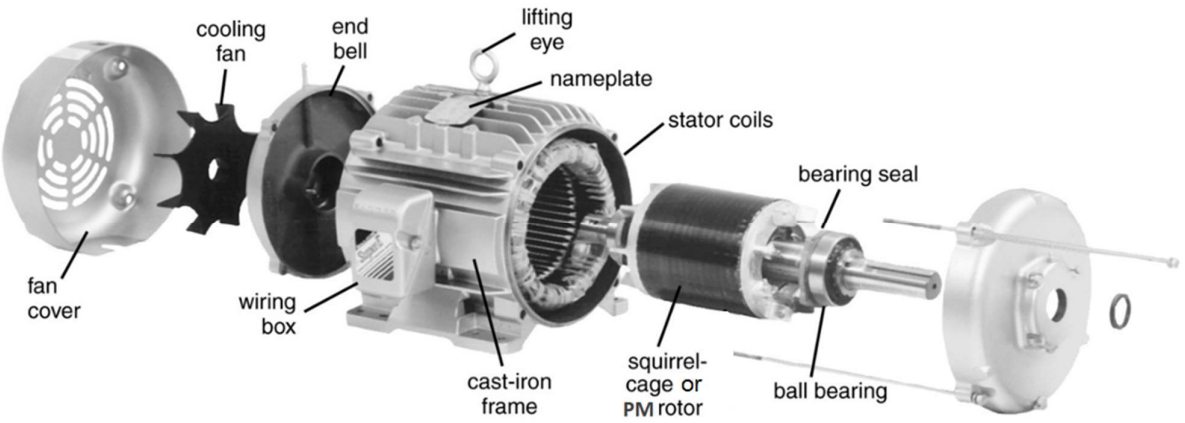

Figure 1.25. Asynchronous and synchronous machine structure and parts [38].

We can see in the structure clearly all parts of the induction motor, but there are main and essential parts among them all is the stator and rotor it's the heart of induction motor, they both create a magnetic field. After that, it will create the torque and rotor will be rotated.

We can also have seen the machine is "totally enclosed, fan cooled" motor, we can also have called it TEFC in a short form, there is fan blade is mount outside of the motor, so it will helpful for the cooling the motor. The stator is the stationary function in the asynchronous motor, Rotor is the rotational part also its connected mechanical load go through the shaft. In rotor, there are two types, 1st squirrel cage rotor, and 2nd wound rotor.

The other parts of the induction motor are also important such as the shaft is made of steel and it's using for a pass on torque to the load. There is one important part is bearing also it is useful for the

support of the shaft which is continuously rotating. There is one of the main problems is the heat while the motor is in working condition because of that only there is one fan mounted for the solve this type of circumstances and for cooling purpose. Lifting eye also mounted on the top of the motor for lifting while place changing and for maintenance purpose. Also, the is 0.4 to 4 mm distance available between stator and rotor and it's called air gap [39].

1.8.2. Causes of Asynchronous and synchronous machine failure.

In the electric motors, there is electrical and mechanical both type of parts is available such as bearing, shaft, winding, end-ring, stator winding, gearbox, the magnet of the rotor, and so on. In this case, there will be unexpected electrical mechanical or chemical failure will come. There are some reason available why electrical motors often fail in the industry as we write below the detail.

Standard lifetime, wrong-rated power, voltage, and current, overload, or unbalanced load, mistake in reparation, and so on, this all types of causes main for electric motor failure. On the other side the main type of motor faults is electrical faults, mechanical faults, and outer drive system problem. Which we can see clearly in this table [40].

Table 1.3 types of faults in Asynchronous and synchronous motor [40]

Electrical fault	**Mechanical fault**	**Outer motor drive system failures**
• Open or short circuit in the motor winding. (Insulation failure in winding) • Wrong connection for winding • More resistance contacts to conductor • Wrong or unstable ground	• Broken rotor bars • Broken magnet • Cracked end-rings • Bent shafts • Bolt Loosening • Bearing Failure • Gearbox Failure • Air-gap irregularity	• Inverter system failure • Unstable voltage/current source • Shorted or opened supply line

There are enormous faults and irregular expression found in the motor, such as frequency problem, degree defects, phase adjustment error, amplitude, variance, and so on. Based on those type of error there are many diagnoses have been already suggested in industrialism, and there are many solutions also available in the market. We will discuss some diagnosis approach accepted in the industry and they have already performed this type of strategies.

This all types of diagnosis approach are helpful in the industry for fault detection, it will warn by some notification or some alarming system for any type of fault occurrence and for prediction purpose also some application useful. This type of diagnosis method will save many costs of the industry as well as it will essential for unexpected to shut down in the industry. In power system line it will most use there because power system line needs more this type of method it will use for time domain-based detection also for the power system. Also, it will analyze frequency domain for machine fault. Moreover, it will essential features for fault decision-making situation, it will decide fault and their existences. Lastly, it will helpful for making a schedule for maintenance in the industry for machines [40].

Table 1.4 Diagnosis techniques using in the industry for fault detection [40]

Signal-based fault diagnosis	**Model-based fault diagnosis**	**Machine-theory-based fault diagnosis**	**Simulation-based fault diagnosis**
• Mechanical vibration analysis • Shock pulse monitoring • Gas analysis • Radio frequency emission monitoring • Partial discharge measurement • Infrared analysis • Motor current signature analysis(MCSA)	• Neural network • Fuzzy logic analysis • Genetic algorithm • Artificial Intelligence • Finite element (FE) magnetic circuit equivalents • Linear-circuit-theory-based mathematical models	• Winding function approach(WFA) • Modified winding function approach(MWFA) • Magnetic equivalent circuit (MEC)	• Finite element analysis (FEA) • Time step coupled finite element state space analysis (TSCF E-SS)

- **Broken Rotor Bar Faults**

Every squirrel cage rotors of an induction motor have rotor bars and end-rings. If there is one or more than one bar broke or even cracked, then that motor is we can say like broken bar fault. In figure 1.27 its clearly seen the one broken bar fault. There are also two types of usage cast and fabricated, from them we can use cast cage rotor are lower rating up to 3000-KW rating we can use it.

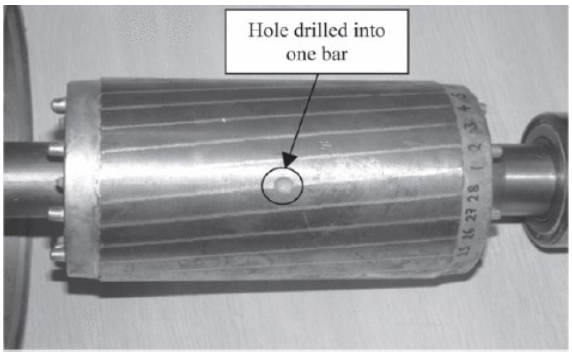

Figure 1.26. Induction motor one broken bar fault [41]

The fabricated cage we can use for higher ratings and for special applications. Cast cage rotors we cannot repair it if it will break once, most cases it will often use in the laboratory for diagnosis system for the practical purpose [41].

There are many methods have been already analyzed for broken rotor bar fault detection most are related to motor current signature analysis (MCSA).

Stator current signature is given here for broken rotor bar frequency denoted by,

$$f_{brb} = f_s[k\left(\frac{1-s}{p}\right)\pm s], \quad [1.9]$$

Where, $f_s =$ electrical supply frequency, $\frac{k}{p} = 1,5,7\ldots$ (normal winding configurations), s = per unit slip, p = number of pole pairs. [41]

- **Bearing Fault**
- **Motor Bearing Vibration Frequency Features**

If we are talking about bearing, balls are useful for manage disengagement between rolling part of bearing. The main aim of the ball bearing is to decrease the friction and bending load. There is more percentage of technical application which is using this ball bearing such as, electric motors they have also ball bearing, bicycles and roller skates also play with this bearing. We know this ball bearing is made by main four essential elements, which is inner raceway, outer raceway, cage, and ball [42]. In the industry and that places where machines moving constant or at high speed there will be more chances of failure of bearing.

As we know most bearing vibrations frequently moving, it is very simple to understand this bearing vibration with the help of FFT technique. There is a lot of publication already studied about this rolling bearing vibrations [35] to [43]. In the bearing basically, there is four main part outer ring inner ring, ball, and cage. This element is dependent on the surface of the inner and outer part if that surface will be going to little bit scratch then it will be going to vibrated and the effect will be rise.

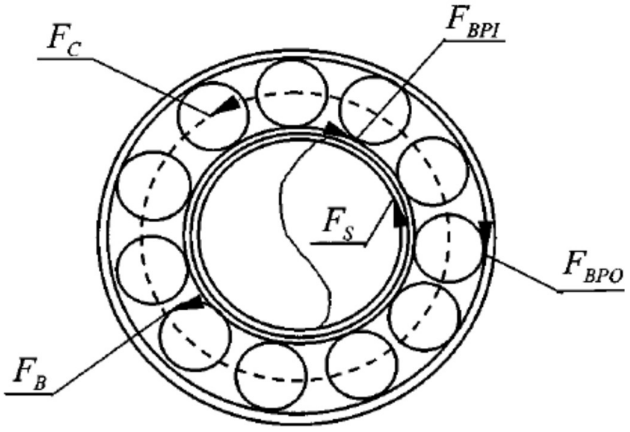

Figure 1.27. Basics Frequency in a bearing [44]

Five basics gestures that are we can use for explaining the important bearing functions, with every movement it has a related frequency. Let's write some equation and some description of all equations. Shaft rotational frequency (f_s), the fundamental cage frequency (f_{cf}) the ball pass inner raceway frequency (f_{BPI}), the ball pass outer raceway frequency (f_{BPO}), and the ball rotational frequency (f_B). Here we can see in figure all frequency functions and we can write some mathematical equations,Fundamental cage frequency

$$(f_{cf}) = \frac{S}{2}\left(1 - \frac{Bd}{Pd}cos\phi\right) \text{ ….. (44)} \quad [1.10]$$

Ball pass inner raceway frequency

$$(f_{BPI}) = \frac{Nb}{2}\, S\, \left(1 + \frac{Bd}{Pd}cos\phi\right) \text{…… (44)} \quad [1.11]$$

Ball pass outer raceway frequency

$$(f_{BPO}) = \frac{Nb}{2}\, S\, \left(1 - \frac{Bd}{Pd}cos\phi\right) \text{…… (44)} \quad [1.12]$$

Ball rotational frequency

$$(f_B) = \frac{Pd}{2Bd}\, S\, \{1 - (\frac{Bd}{Pd})^2(cos\phi)^2\} \text{…….. (44)} \quad [1.13]$$

RPM = Revolution per minute,

S = Revolution per second or relative speed difference between inner and outer race,

Bd = Ball or roller diameter,

Nb = Number of balls or roller,

Pd = Pitch diameter, ϕ = Contact angle,

- **Bearing Vibration Fault Diagnosis Algorithm Using Neural Network**

If we are studying about motor bearing and about its faults, then its most preferable steps first are the algorithm about the diagnosis is capable of accurate bearing problems situations. For the use of

accurate fault data surroundings for example, once get the process of simulation, after that it's very much important that diagnosis algorithm will work with better results or not. In this work that authors used fast prototype motor simulation software, Motor Sim, [49] for the design of the bearing also for vibration fault diagnosis algorithm.

MotorSim is the one of the parts of MATLAB Simulink, we can use for the Simulink of the motor system dynamics. MotorSim is useful for data generating, with contrasting performing and burdening conditions, in some conditions such as worthwhile and time-saving aspects.

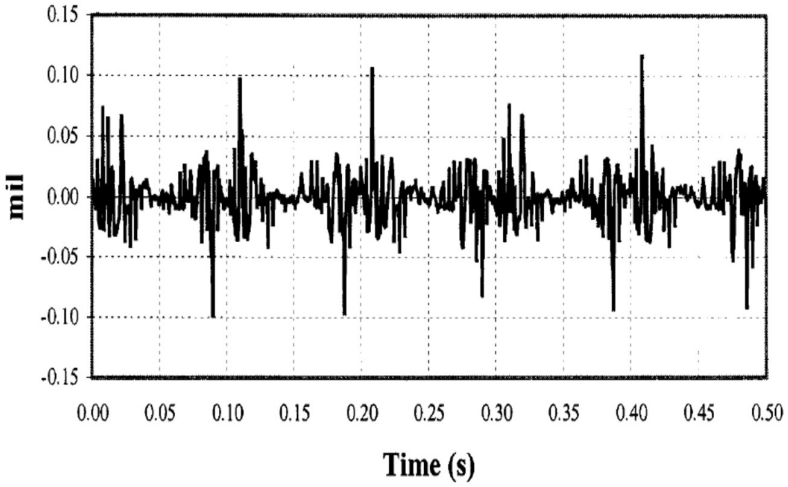

Figure 1.28. Bearing vibration signal generated by Motor Sim [44]

A powerful value of motor fault diagnosis its main prefer one function and it is to detect motor bearing conditions. MotorSim has many features for generating such as time-domain vibration signals for the contrasting situation of bearing failure. Fig. 1.29 is showing the bearing vibration signal achieve by simulation of the bearing weakness and problems on the part of the inner side and rolling moving functions using Motor Sim. Generally, bearing fault is showing mainly three or four types of faults such as inner fault, ball defects, looseness faults and so on.

(a) Outer ring fault (b) Inner ring fault (c) Ball fault

Figure 1.29 Bearing Faults

We can see clearly in this graph there is (a) is denoted normal bearing waveform, (b) is showing the waveform of inner race fault, (c) is showing the waveform of outer racer fault and (d) is showing the waveform of ball fault. Moreover, each has 300 data in this experiment and it is already split in two way one is 200 samples for training function and 100 for testing. The whole data set have grasp 1200 data points and their waveforms showing in four different conditions and the defect size of the diameter and depth will be same for all four conditions 0.1778mm.

From the graph we can say while bearing has no defect then working condition, as well as waveform structure, also will be same and accurate, after rolling element bearing is failing there is time domain signal will automatically change in disruptive waveform, in remaining all three-condition inner race fault, outer race fault, and ball fault respectively [46].

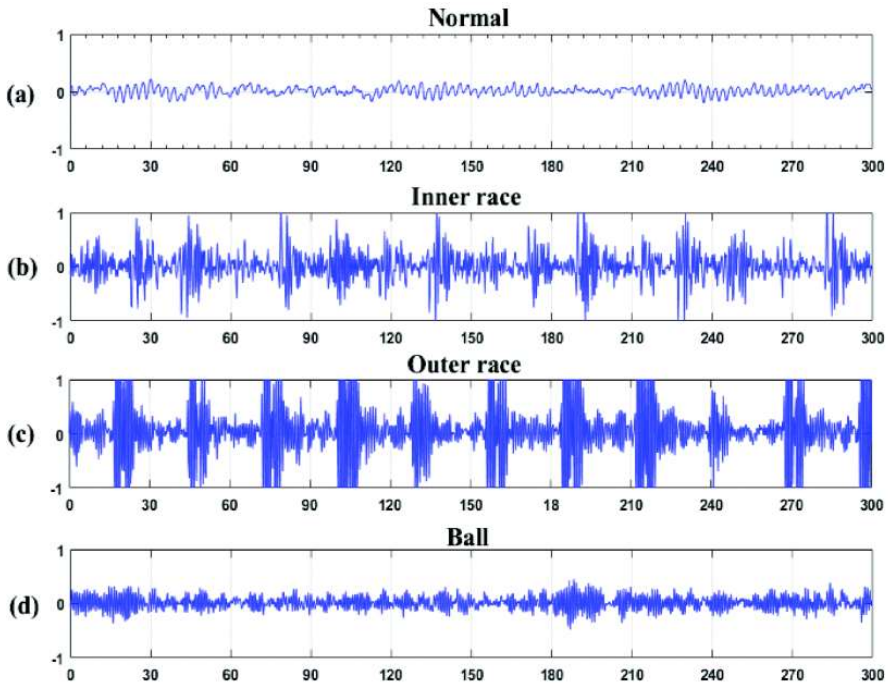

Figure 1.30. Normal and defective bearing waveforms [46]

While we have data for training then we have to choose some functions because each data have their own results but we have to find with neural network so we have to make an option like one result is normal then the second one is failure after that fault is there but inner side and after that fault detects outer side so we have to assign to a particular code such as 0 mean to say result will be ok then 1 is the result will be fail, then 2 is inner fault and 3 is the outer fault or ball fault of the bearing.

- **Synchronous motor**

We all know that the thing is the electrical motors have one function which is fed electrical energy and it will turn into the mechanical energy. And for that, we have two types of different motors which is called synchronous and asynchronous motor, also single and three phase each respectively. In such

cases three phase wires are placed at one angle from one to another then there will electrical field will be generated. After that, the rotating magnetic field is working process and it will rotate at one type of speed and that the speed which we can called it synchronous speed. If there will be electromagnet is available in that rotating magnetic field, the electromagnet probably locked by magnetically with that rotating magnetic field, and after that, it will turns the equal speed of rotating field.

If we are talking about speed, then synchronous motors have only one speed because there is equal rotor speed and rotating magnetic field, synchronism which is applying frequency, the synchronous speed we can write here,

$$n_s = \frac{120f}{p}, \qquad [1.14]$$

Where, f = supply frequency and p = no of poles.

1.8.3. Permanent Magnet Synchronous Motor (PMSM)

For the producing continuous magnetic field, the permanent magnet synchronous motor (PMSM) using permanent magnets in the steel rotor.

The construction is almost same as 3 phase ac motors, with the rotor, stator. Moreover, the stator has frame, core, windings, and the rotor has permanent magnet as well as for rotor we must apply dc supply and for stator, there is 3 phase ac supply we have to apply.

Here we have equivalent circiut diagram of permanent magnet synchronous motor,

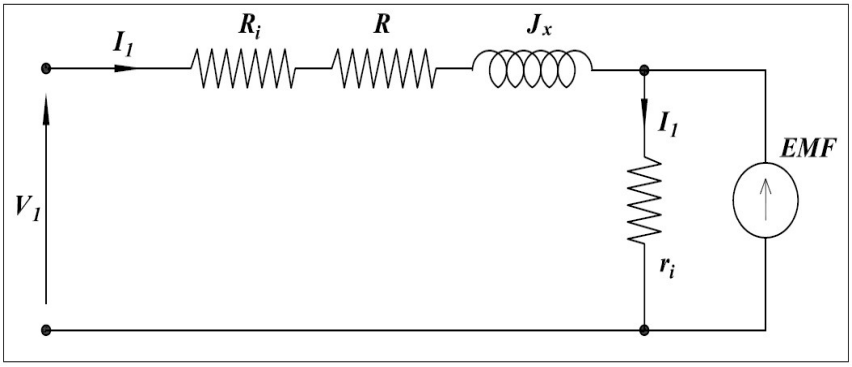

Figure 1.31 Equivalent circuit diagram of Permanent magnet synchronos motor [49]

$$\eta = \frac{3V_1I_1 * p.f. - (R + R_1 + R_1){I_1}^2 - 3{E_1}^2 l\, i}{3V_1I_1 * p.f.} \qquad [1.15]$$

$$V_1 = RI_1 + jXI_1 + E_1 \qquad [1.16]$$

$$R = R_1 + w\frac{3}{2}L_v \sin(2\phi_0 - 2\phi_1), \qquad [1.17]$$

$$X = wL_s + w\frac{3}{2}L_v \cos(2\phi_0 - 2\phi_1), \qquad [1.17]$$

Where, Ri – Reaction iron loss, ri – excitation iron loss, R+jX – Proper impedance of equation.

ϕ_0 *and* ϕ_1 *is phase angle,*

$V_1 I_1 = Voltage\ annd\ current\ respectively,$

$E_1 = Internal\ induced\ voltage$,

$L_v = Sailency\ inductance,$

R = Armature resistance,

When we are applying 3 phase Ac to stator then there we can get rotating magnetic field, and it is rotated speed by n_s, at that time stator south pole and rotor north pole make a magnetic locking and they b,oth rotor and stator will be rotate at sathe me speed so its called synchronous machine. Rotor also rotate the same speed with rotating magnetic field, also it is fixed speed motor, it has only one speed there is no intermediate speed between.

When in the stator heat will be generated in that type of case we can easily remove from the stator. Moreover, the permanent magnet has the greatest efficiency as well as maximum speed performance also. In PMSM we can regulate the motor and actual speed monitoring. Torque we can get smooth in the PMSM.

- **Torque meter**

We can call a torque meter to torque sensor and torque transducer too, it is the device with the help of we can measure and store evident the torque into the shaft, engine, rotating system, crankshaft, gearbox, transmission, and so on. In comparing to dynamic torque static torque is easy for measuring section. It is a sensor that converts the mechanical input to transform into electrical output. Torque we can measure with the help of strain gauges also by stationary proximity sensors.

- **Direct torque control (DTC):**

We must select the essential vector of the voltage for the essential approach which will start to flux moving and getting the main torque. We can be calculated the deliberate current also voltage vectors as we can see in the equation, [56]

$$\lambda_\alpha = \int (V_\alpha - R_S i_\alpha)\mathrm{dt} \qquad [1.18]$$

$$\lambda_\beta = \int (V_\beta - R_S i_\beta)\mathrm{dt} \qquad [1.19]$$

$$\lambda = \sqrt{{\lambda_\alpha}^2 + {\lambda_\beta}^2} \qquad [1.20]$$

Where, $\lambda = stator\ flux\ space\ vector,$ also V_{ds} and V_{qs} is the stator voltage, $i_{ds}\ and\ i_{qs}$ are line current for α-β reference frame and R_s id the stator resistance.

$$T_e = \frac{3}{2} p(\lambda_\alpha i_\beta - \lambda_\beta i_\alpha) \qquad [1.21]$$

Where p is the number of pole pairs. There is the essential framework on DTC is the stator flux vector sector. [45]

- **Tachometer**

Rotation is transmitted to the measuring instrument by an infrared (IR) light beam/laser beam we can get from the laser equipment, that one reflective reverse to the object. While the rotating element is rotated there we have a one reflected spot and the light beam is reflected back. The tachometer is very convenient for use, there is no contact method, we can use safely, accuracy also very good approx ± 0.02%, measuring range also from 100 to 30000rpm.

2. Methodology:

Here the whole overview of my thesis based on this structure which is in this figure.

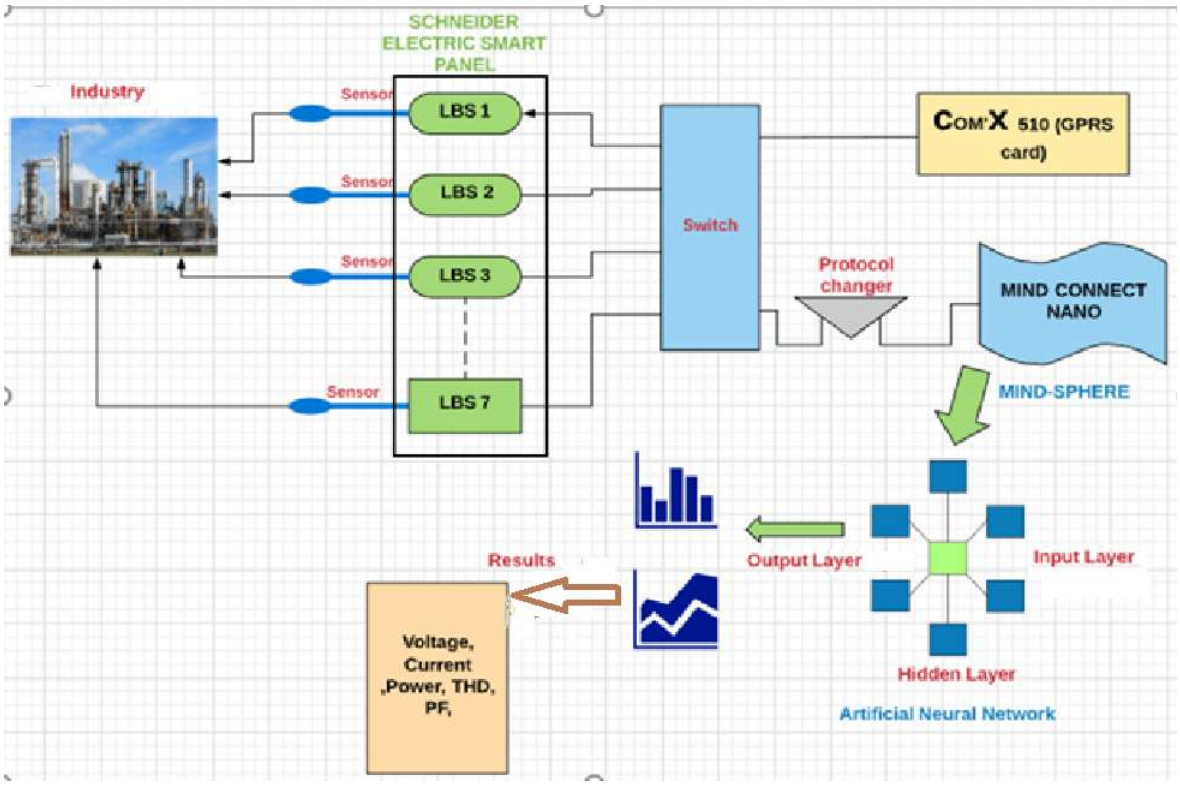

Figure 2.1. Process of my research project

In the methodology part, there was done an experiment on the Permanent Magnet Synchronous Motor Which is specially designed for some company, it has essential features like it can reach nearby 97% efficiency and there is inside used Neodymium magnet. there was done four experiments in that first experiment permanent magnet synchronous machine was used as a generator. The second experiment, done permanent magnet synchronous machine was used as a motor at nominal voltage 302. After that, there was done six more experiment at both side of the nominal voltage lower and higher there were chose 240V,260V, 280V from the lower side of the nominal voltage and 320V, 340V, 360V at the higher side of the nominal voltage. Moreover, for data analysis, prognosis torque there was done one more experiment with a neural network.

- **MindConnect Nano**

Here MindConnect Nano was used, for grasping the data of industrial assets with the help of different protocols and it will transfer directly to the MindSphere (Cloud).

Figure 2.2. MindConnect Nano [48]

This device using the internet and data will transmit securely to MindSphere because this device supports the transferring function with encrypted data by securely. MindConnect Nano is the device which contains protocols for data acquisition. And that protocols are Siemens S7 and OPC UA was used.

- **Function and technical specification of MindConnect Nano**

MindConnect Nano wants internet for connecting the assets as well as for transferring data to MindSphere, it has ports available for internet or ethernet. In that figure you can see many slots and ports I can describe what it is.

First port is showing defensive conductor contact, after that second port is showing Connection for DC 24V, 1.8 A power supply, third port is for USB 3.0, high current and fourth port is for on/off device, fifth port is for USB 2.0, high current X61, X62, X63, sixth and seventh port is for Ethernet connection sixth one is for internet to for MindSphere and seventh port internet for automation department (assets) Moreover, it is capable in 0 ºC to 60 ºC ambient temperature during operation, also for storage/transportation capacity of ambient temperature is -20 ºC to 60 ºC. [48]

In MindSphere the MindConnect Nano is the heart of the whole system, like the gateway of IoT operating system of MindSphere, here whole working process from top to bottom so easy and essential for the industrialist. Just one-time investment and saving from many things and for the long term.

Just connect assets with MindConnect Nano and it has enormous functions that will help you for your assets data to transfer securely in the MindSphere cloud and it will help full for industry with, increase the availability of components, maintenance free in the industrial equipment, continuous operation

without unexpected shutdown, improve energy consumption, optimizing cybersecurity, increase process of industry, essential data recording and transferring to cloud securely and so on.
I used this mind connect nano in my research just getting the data from the cloud, first, all data came to Com‘X platform and from that platform to getting data there was used Mindconnect nano device which is very secure and accurate device nowadays in siemens Mindsphere.

2.1. Permanent magnet synchronous machine as a generator

In figure number 2.3 it is that Permanent magnet synchronous motor which was used in my research experiment.

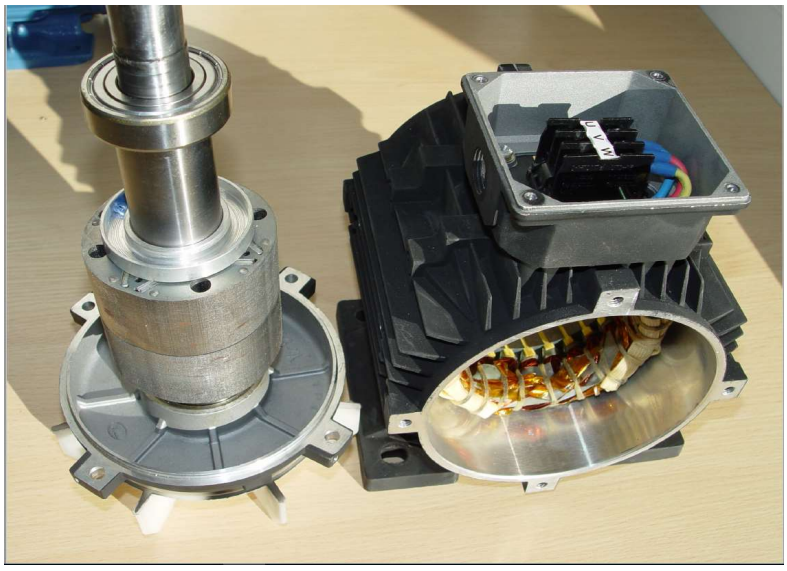

Figure 2.3. Permanent magnet synchronous motor

In this experiment, there was used many electrical and mechanical instrument such as an asynchronous motor, Tachometer, Permanent magnet synchronous motor, Frequency inverter, Schneider smart panel with Com‘x 510 platforms and also there was used Mind-sphere nano for getting data on our system.

At the first in this experiment, checked the nameplate of an asynchronous motor and then add those all parameters in the frequency Inverter which is programmable with that parameter. Revolution per minute(rpm) was added on that inverter, ampere of current, voltage L-L, frequency, power factor, efficiency the connection of winding star or delta, and so on related this type of parameter was uploaded in that frequency inerter with the help of manual as a step by step.

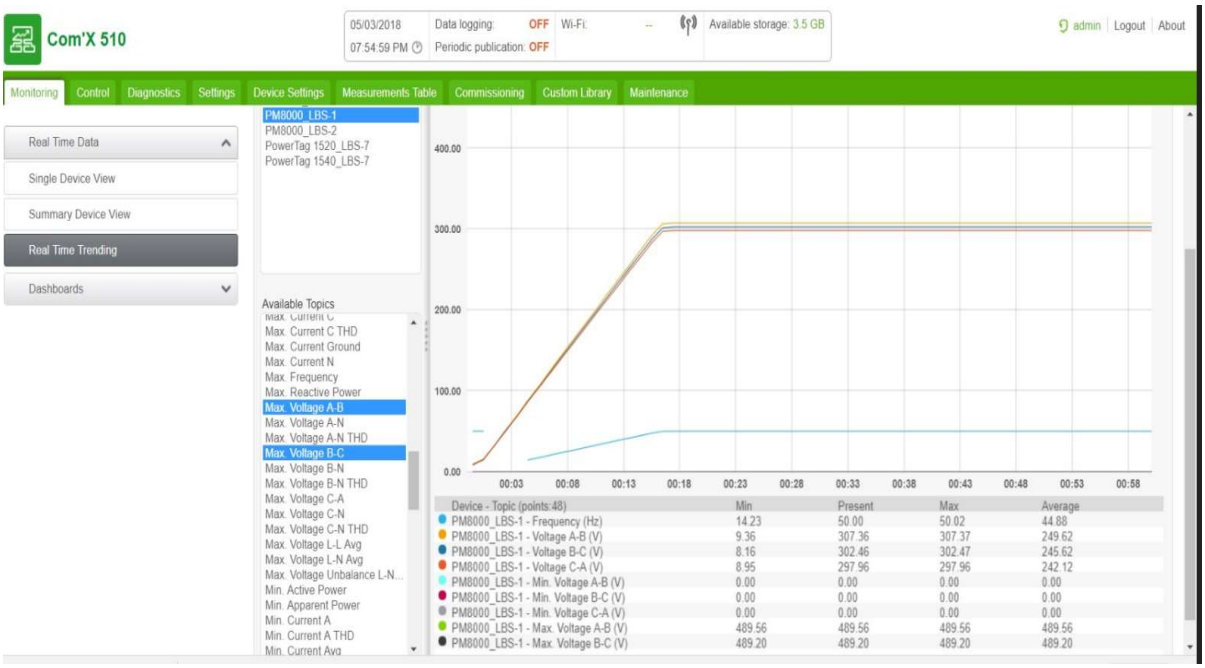

Figure 2.4. Com'X platform for PMSM as a generator Electrical parameters

There was used Com'x 510 for the variety of electrical parameter measuring and getting different graphs. there is each parameter visual clearly in that graph of Com'x, as well as add many parameters such as Line to Line voltage, current, frequency, also minimum voltage from each phase. After there were add all electrical parameters in that Com'x as well as in that Frequency Inverter there was applied rpm to that asynchronous motor with coupled PMSM as a generator, after that there was checked that rpm directly from that motor with the use Tachometer (laser device) and there was metering that same r.p.m which was applied in frequency inverter.

Figure 2.5. Tachometer (Lazer Device)

From that, there were measured continuous voltage and current will be equal or in the same phase passed or not and there was clearly in showing Com‘x server through to our computer system. Because of not enough strength of the magnet and in this case there was to reduce the voltage, when the phase is coming together that means its correct voltage.

If the standard motor is normal then voltage will be 400 Volts that means which was measured that voltage is correct for this PMSM because there was applied 1500 rpm at 50 Hz frequency and there was achieved Line to Line voltage, at A-B phase measured 307.36 V, for B-C phase was measured 302.46 V, and for C-A phase was measured 297.96 and its average around 302.6 in the permanent magnet synchronous machine that was used as a generator.

2.2. Permanent magnet synchronous machine as a motor

For this experiment, there was used a variety of instrument for the measuring and applying purpose. There were tried to eliminate the torque meter by this experiment, from this experiment trying to replicate torque meter for reducing the cost of production in the industries. There are some equipment which was used in research experiment 2 and which was repeat that all. There were used, Asynchronous motor, Permanent magnet synchronous machine, Oscilloscope meter, Voltage divider, current clamp on meter single phase autotransformer 3 device, MindConnect Nano, two platforms for getting data one is Lorenz mess-Technik, and another one is Com’x 510, Schneider smart panel, torque meter, synchronizing panel and so on this all instruments we can see in the figure.

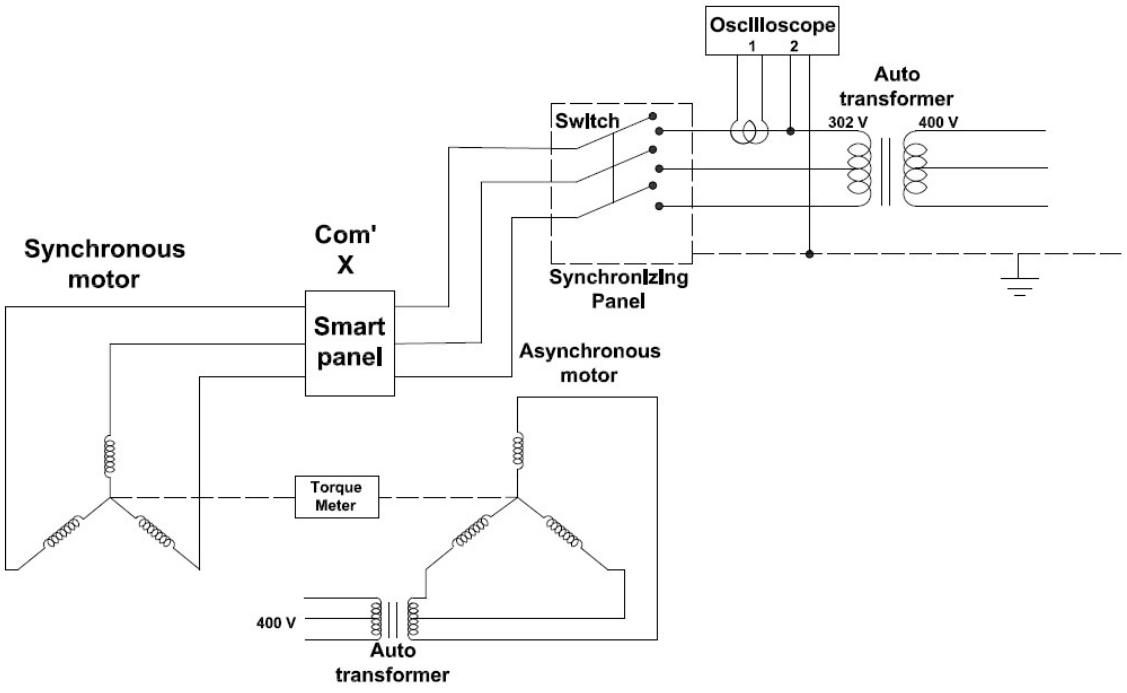

Figure 2.6. Block diagram of PMSM as a Motor

For Analysing the permanent magnet synchronous motor, we know that Permanent magnet synchronous motor it cannot start from the grid, because it has fast frequency as well as it has mass and inertia both, so it cannot spin, in this case, two options to do, either use frequency converter, or choose for this experiment second things which are additional motor. There were applied gradually voltage but still, it has a frequency high, so another motor was used in this experiment which was the asynchronous motor, that is tried to spin in another direction that's why there were applied gradually voltage. For the spinning the motor there was applied more and more torque, if there was apply full voltage then it will just stop the synchronous motor and it will spin in the other direction.

Here, which was used Permanent magnet synchronous motor it is not projected correctly in such cases, so there always need to keep in mind that motors design is not like other motors. For normal motor it can measure easily there were to spin it at 50Hz and it will get 400 v but for this PMSM it has nominal voltage around 302.46 which was already got from the previous experiment. That means there was not enough magnets in a rotor, while it gave 400 voltages to this motor it goes to overheat, so for getting more and accurate results need autotransformer to lower the frequency for it and applied from 0 voltage to gradually more, after that there were achieved more result because it won't overheat, for normal motor do not need autotransformer. Once there was trying to remove some voltage and made start then it was spinned into another side.

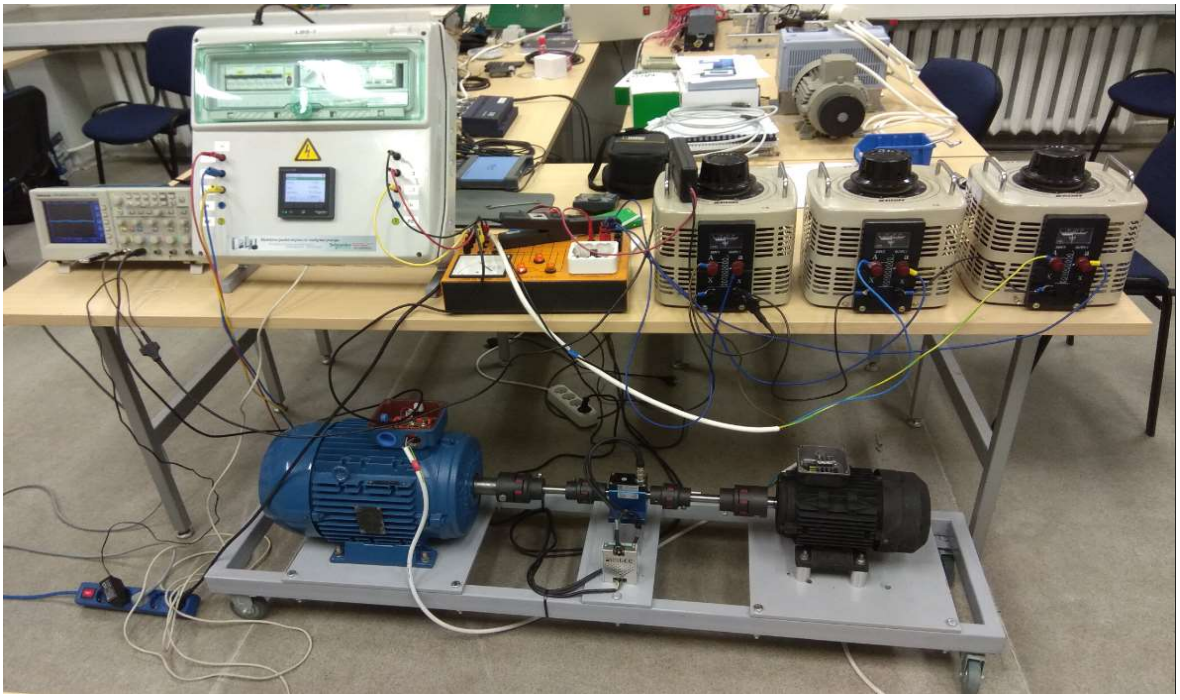

Figure 2.7. PMSM as a motor experiment set up

After that, it was rotates the PMSM and they were phasing to each other, so there was used the synchronizing panel, then need to check if the phase is correct or wrong. If it's wrong, then it moved

in other direction. The Synchronizing panel, it was used to smoothly turn it to the grid at 50 Hz. There were eliminate the frequency converter there was do not need it, after switching the phase it was started to brake the synchronous motor.

First, there were set the nominal voltage for that there was used three single phase autotransformer, and there was set 302 voltage by autotransformer which was nominal for that start the breaker for the load then there were applied voltage for turning the motors then checked the synchronising panel, just check for that wires which were put in right phase or wrong phase because synchronising panel was used for the purpose of smoothly turn it on to the grid.

After turning off the grid switched the phase for autotransformer then turn on and applied gradually load from it while applied the load slowly than in the Lorenz mess-Technik software newton meter graph as well as the digit of the newton meter they both go to gradually increase. Here used two platforms for getting mechanical data as well as electrical data, also used oscilloscope for getting the phase difference data as well as checking the phase difference weather is resistive, inductive or capacitive, here in figure 2.8 is clearly visual while applied nominal 302 voltage for this PMSM that time it was caught the resistive load in oscilloscope both phase are in positive direction.

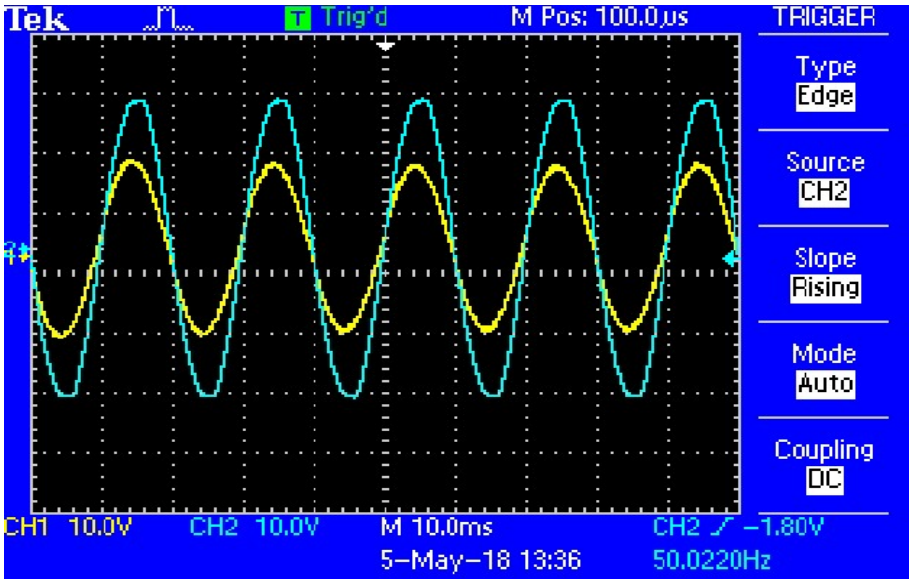

Figure 2.8. The graphics of the nominal voltage waveform 302V and current in same phase.

In figure 2.9 its clearly showing while applied lower voltage compare to nominal voltage then oscilloscop is showing inductive load and waveform was clearly showing while applied 240V then current was lagging voltage.

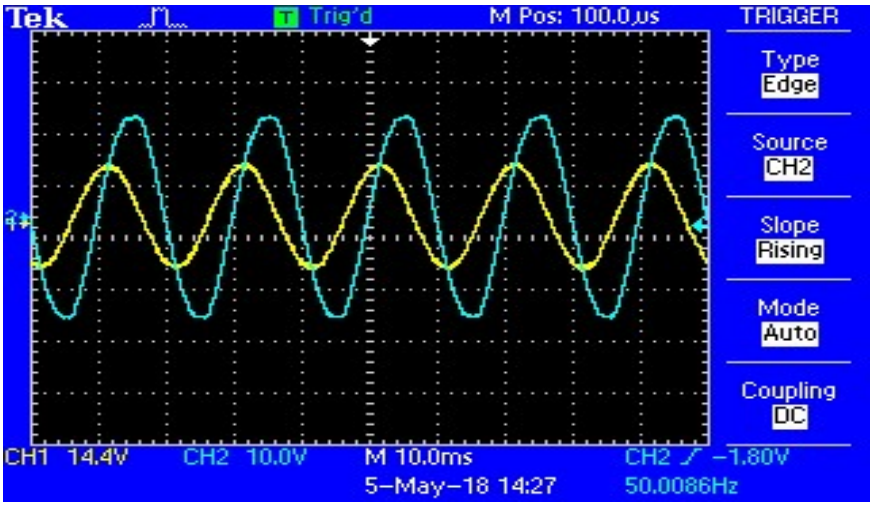

Figure 2.9. The graphics of the below nominal voltage waveform at 240 voltage (Inductive)

In figure 2.10 its clearly showing while applied higher voltage compare to nominal voltage then oscilloscop is showing capacitive load and waveform was clearly showing while applied 360V then current was leading voltage.

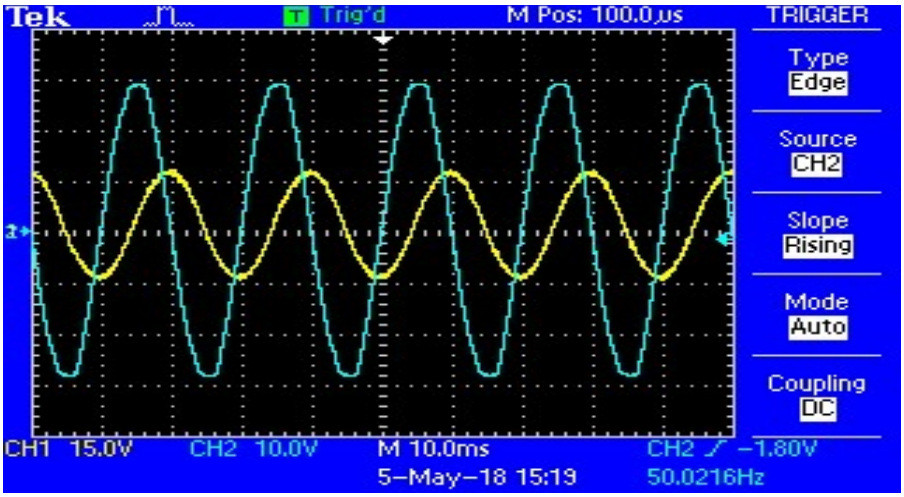

Figure 2.10. The graphics of the above nominal voltage waveform at 360 voltage (capacitive)

For mechanical data (Torque) used Lorenz mess-Technik and got data, on the other side Com'X platform was used for electrical data and from that, got data to the system by Siemens MindConnect-Nano which is the device of Siemens cloud platform in the.

Also, in Com'X platform there was clearly showing those all electrical parameters which were choose for the experiment, which was active power, the voltage from each phase, current also from each phase moreover, reactive and apparent power respectively. In this experiment which was applied 302 nominal voltage, while newton meter reached at one maximum value which was highest 6.8 for that

experiment and at that time it goes to synchronize the motor and then removed the whole load from the autotransformer and turn off the breaker switch and then saved both software graph and data.

Because of Lorenz mess-Technik data is ten times more compared to Com'X data there was adjust the sampling rate then got same data pulse at a same time. Only for data adjustment, there was used sampling rate. After that saved that all multiple data for neural network training part as well as for the calculating maximum efficiency also. There was done six more experiment for getting maximum efficiency at both sides of the nominal voltage lower and higher with 20V steps which was 240V, 260V, 280V, 320V, 340V, and 360V respectively. And measured same parameters as the previous experiment and compared with all for maximum efficiency with highest newton meter Nm.

- **Calculation of efficiency**

$$\text{Mechanical } (K_w) = \frac{Torque(N.m * Speed\ r.p.m)}{9.5488} \quad [2.1]$$

$$Efficiency\ \eta = \frac{Mechanical\ (K_w)}{Electrical\ (K_{w)}} \quad [2.2]$$

$$= Efficiency, \eta,$$

For example, from the experiment there were all those values which were written above in equation, there was calculate those all value for graphs and for the result.

Where, Torque = 6.8 N.m, r.p.m = 1500, (9.5488 = $\frac{60*1000}{2\Pi}$) (Elect Kw = 1.16kw, From Experiment),

$$Mech\ kw = \frac{6.8 * 1500}{9.5488} = 1068.197$$

$$Efficiency, \eta = \frac{1068.197}{1.16} = 92.08\%$$

This calculation which was used for all experiment maximum efficiency calculation as well as the graph for each experiment maximum efficiency comparison with nominal voltage maximum efficiency. Those all graphs are in experimental results.

2.3. Neural Network Training method

In this Research work, there were prognosis torque sensor and its calculation while applying from starting period to till synchronism. Calculating torque equation from current, voltage, and power data so there was preferred neural network, because without its difficult to calculate those much equations and especially while it goes to synchronism period. It was too fluctuating time its quite difficult calculations without a neural network. Neural network finds equations where you can not find. Here torque meter was used as a supervisor because it was supervised learning. With the help of neural network, we will see easily in the plotting graph that same time while applied gradually load to the motor and also caught that graph which showing steps from start to till synchronism period while it loosed the synchronism in torque meter.

In neural networks layers always there, there was set three layer which was Input layer, a hidden layer, and an output layer. There was work with MatLab for training so there were used Feedforward nets = (12) where 12 is the number of neurons in the network. The next step had to choose their input and output values so there was total 11 column of data for that there were closed 10 input values which belonged to the first layer then 12 number of neurons its belongs to hidden layer then final layer which was torque meter data(Nm) and it goes to last in output layer for the training.

Teaching function used [net,tr] = trainlm

I tried almost all of them with same data, there are lists which I tried for getting better results.

Which was,
trainbr - Bayesian Regulation;

trainbfg - BFGS Quasi-Newton;

trainrp - Resilient Backpropagation;

trainscg – Scaled Conjugate Gradient;

traincgb – Conjugate Gradient with Powell;

traincgf – Fletcher-Powell Conjugate Gradient;

traincgp – Polak-Ribiere Conjugate Gradient;

trainoss – One Step Secant;

traingdx – variable learning backpropagation.

There was trying all of them during training. While trainbfg tried then some plot results were going to minus, after that tried trainrp it was quite fast compared to trainlm but there was also error because if choose 200 neurons or validation period also if choose more then also it was quite fast within 2 seconds that training was over so that results were also not so good. Trainscg (Scaled Conjugate gradient) same problem as we discuss before this quite fast if choose more neuron or validation period it was showing results more than 0.135 so it's not closer to zero so this algorithm also not well for this data. traincgb and traincgf had same error while choosing more neurons for those data which I have it goes to result in minus waveform, on the other side if choose less neurons then it goes to validation performance very high 0.183 nearby. traingdx and trainoss results were goes to minus and bad respectively so that was also not for this experiment. but finally preferred to go with the

Levenberg-Marquardt algorithm. After tried all, there was preferred to go with the Levenberg-Marquardt algorithm (trainlm).

Other parameters which was used in the experiment it was used the training learning target = 0 it was impossible to achieve 0 targets but while training it to need to keep in mind that need to go closer than the target, so in that case achieving better results for training. For that other validation, testing, plus training ratio must set which is,

net. divideParam.trainRatio = 80/100;

net. divideParam.valRatio = 10/100;

net. divideParam.testRatio = 10/100;

net.trainParam.max_fail=18;

There were different types of proportion but there was preferred (80%,10%,10% respectively) ratio, whatever will choose neural network training take data randomly and it gives an accurate result for our data. After training was over there were achieved regression plot which was showing scattered data which was chosen as a proportion. Performance plot was also achieved after training.

3. Experimental results

3.1. Permanent magnet synchronous machine as a generator, voltage metering study.

As discuss in methodology there was already put that Com‘X platform which was used for getting parameters here in figure 3.1showing which measured voltage in equal phase while applied 1500 r.p.m from the frequency inverter at 50 Hz.

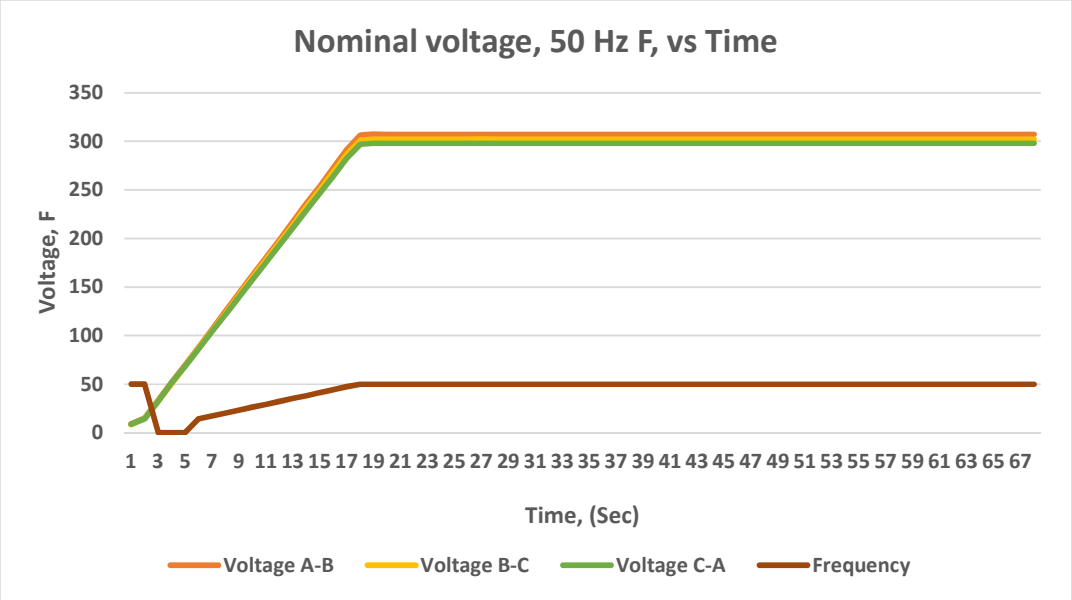

Figure 3.1. PMSM as a generator, Voltage measuring Graph

There were achieved voltage at each phase same such as Line to Line voltage, at A-B phase it was measured 307.36 V, for B-C phase there were measured 302.46 V, and for C-A phase there were measured 297.96 and its average around 302.6 in the permanent magnet synchronous machine that it was used as a generator. There was frequency also in a 50Hz straight line it can get data as much as required. there was a task for us to measure voltage was continuous or not and there was achieved voltage at the same phase which in figure 3.1 it's clearly seen.

3.2. Permanent magnet synchronous machine as a motor, torque prognosis, and maximum efficiency study.

First, there was done experiment with nominal load at 302 voltage which was measured in the first experiment as a generator. From that there were got all electrical parameters in our system with the help of Com‘X as well as our MindConnect Nano (Siemens Cloud), we can see clearly all parameters in figure 3.2 which was chosen for results in that platform. After all, data getting from that system and there was made one graph in excel which showing all parameters. While applied gradually load to that motors we can see that gradually rising active power as well in figure 3.2.

From this figure 3.2 we can see clearly voltage and current are quite in same phase as well as active, reactive and apparent power also not accurate waveform, we can calculate maximum efficiency from this data, active power was taken from those data and there was another platform for mechanical parameters also, so torque meter data was taken from that platform and efficiency was calculated for this experiment which is already describe here with equation as well, in methodology.

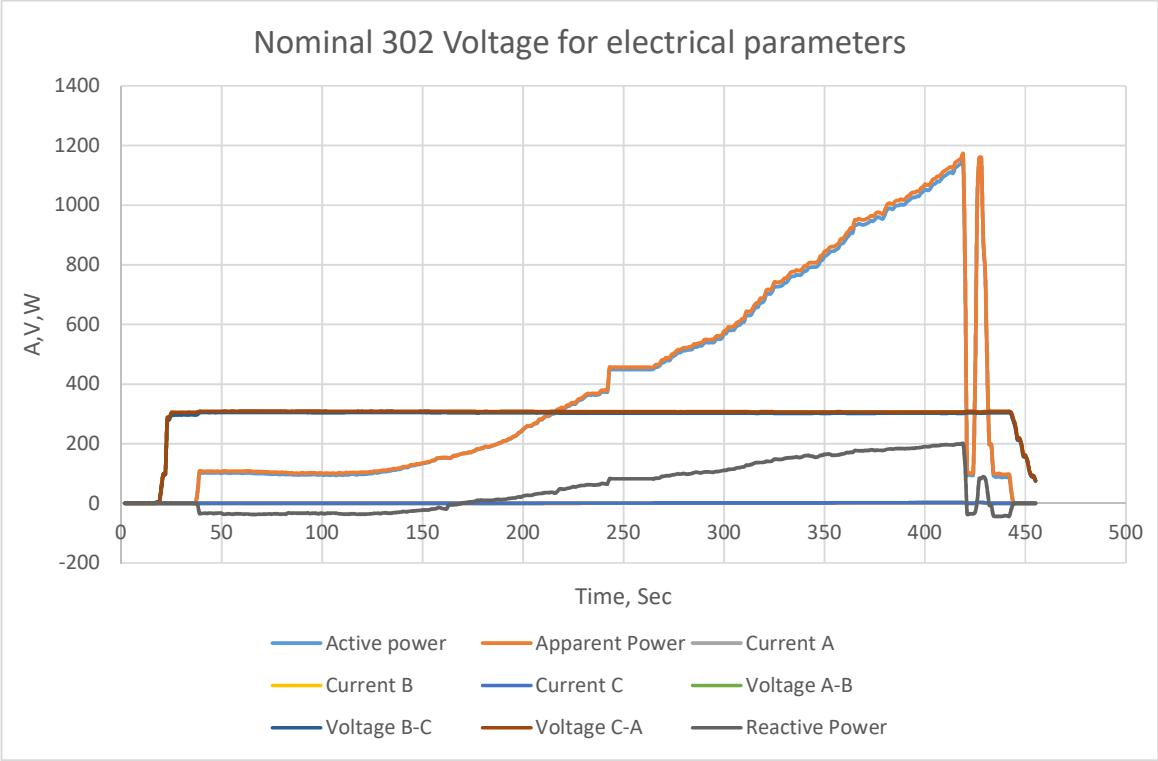

Figure 3.2. Electrical parameters platform of Com'X for PMSM as a Motor at 302 nominal voltage

There was two graph comparison with the lowest side of the nominal voltage at 240 while which was set for the experiment, that time there were quite a high disruption in active power apparent power and reactive power because that voltage was not suitable for that motor, we can see in figure those all parameter with big fluctuating results. Compare to nominal voltage 302 graph and this graph we can easily understand there was a huge disruption. While using lower voltage than nominal voltage.

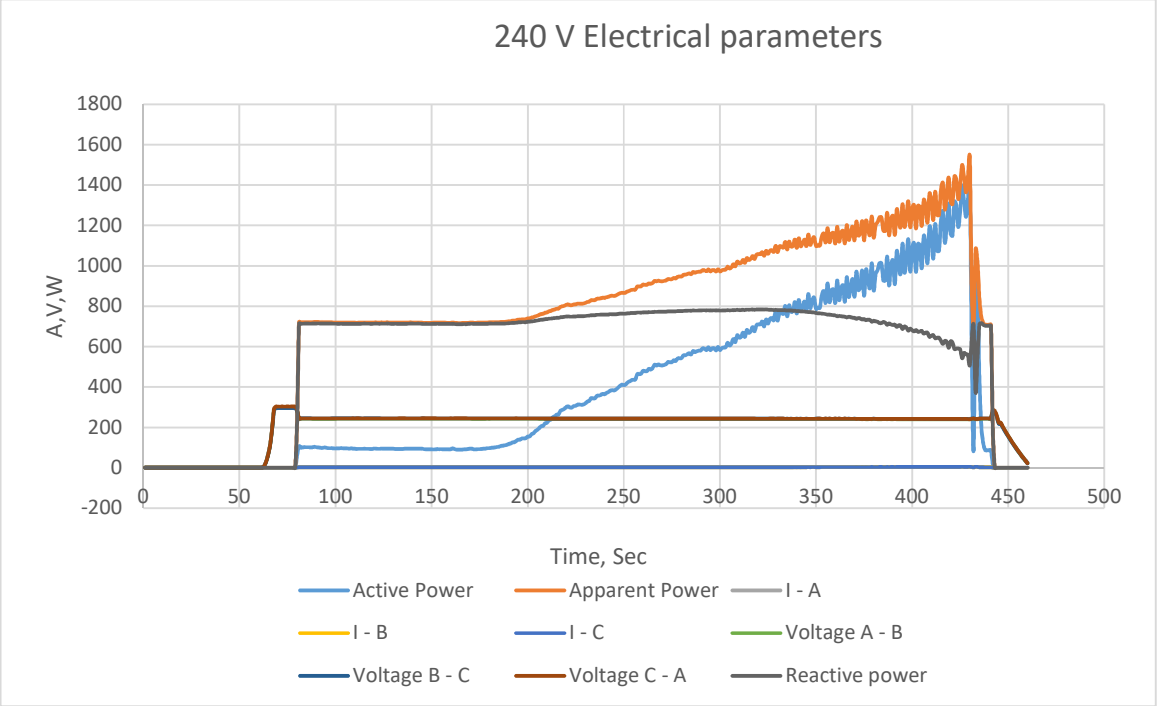

Figure 3.3. Electrical parameters platform of Com'X for PMSM as a Motor at 240V

On the other side, there was choose 360V which was higher voltage than nominal so there were achieved more error compare to all, that reactive power we can see easily it goes to minus. Also, there was active and apparent power quite bad in the figure it can see easily voltage and current are in the same phase which was applied but reactive power goes to huge disruption waveform.

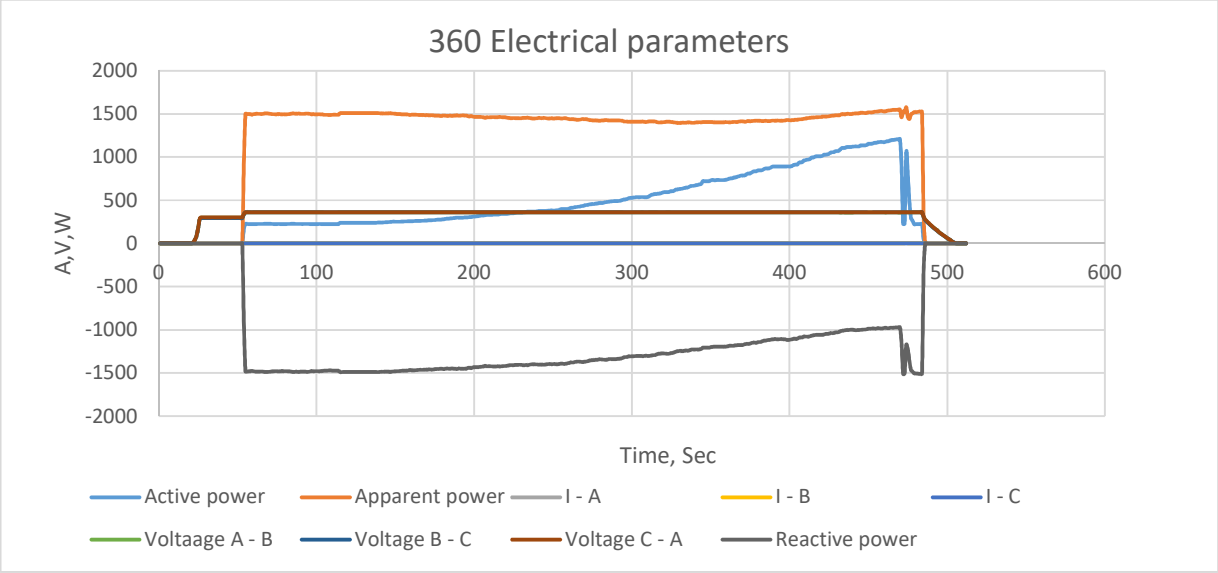

Figure 3.4. Electrical parameters platform of Com'X for PMSM as a Motor at 360V

In this experiment 302 was the nominal voltage for this PMSM, at that point, there was measured 6.8 N.m which was the highest among all experiment which was done for this thesis. And it gives a maximum number of efficiency also which was 92.08% calculated as well. On the other side while applying 360 then I got this 360 nominal graph which is quite different compared to my nominal voltage graph.

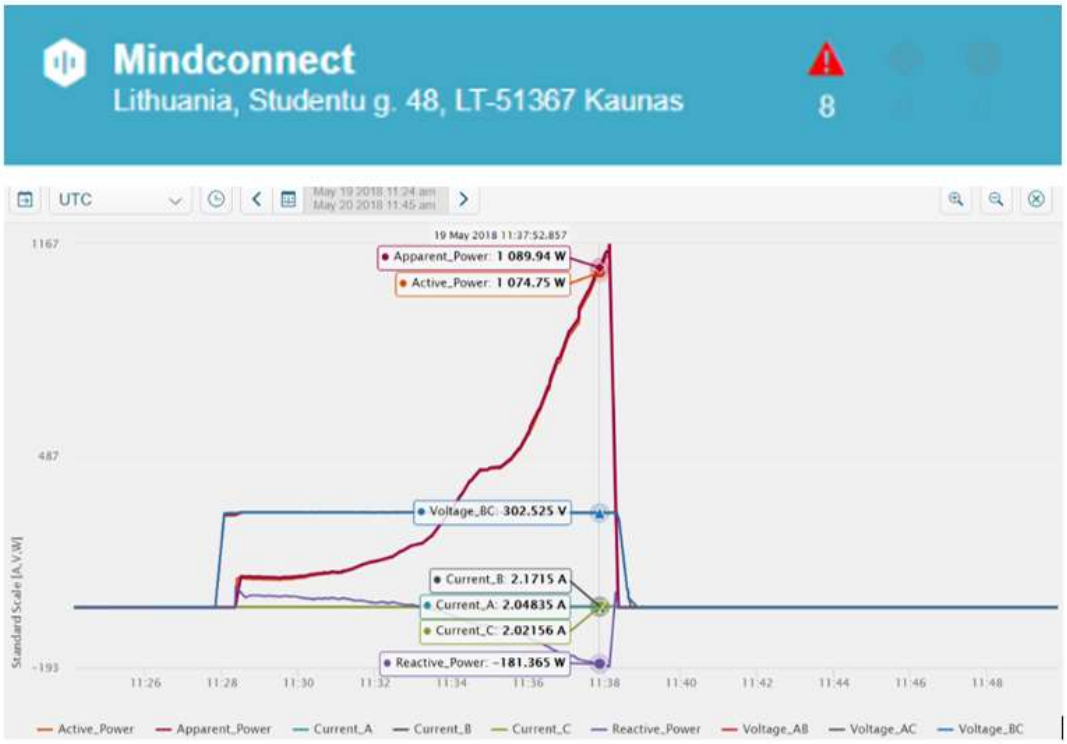

Figure 3.5. Mindconnect Nano platform for electrical parameters

Mindconnect Nano was used for getting parameters, there was in figure 3.5 showing Siemens cloud and Mindcoonect Nano platform which was showing all results which were used in the experiment. From starting load to till synchronyz period there was in figure 3.5.

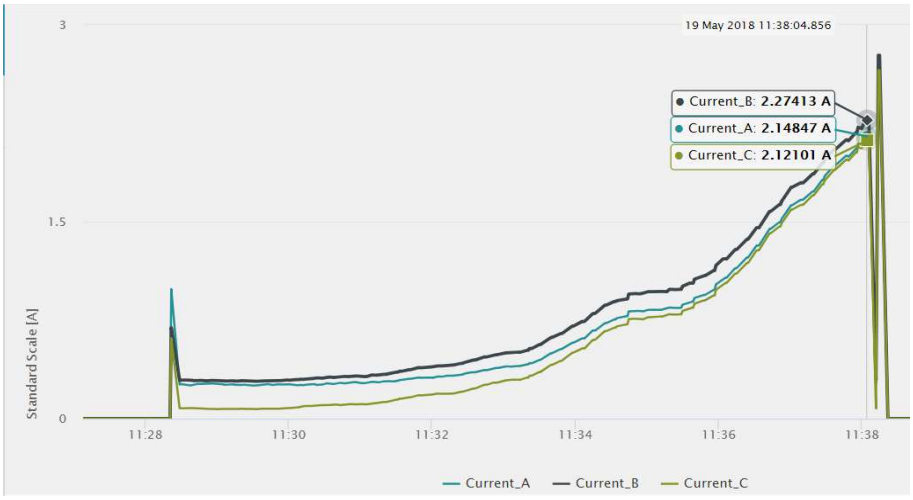

Figure 3.6. Three - phase current during the experiment (Mindcoonect Nano platform)

In figure 3.6 there were Current gradually raised while applied constantly load to the motor during the experiment, here in figure 3.6 clearly showing 3 phase current are risen from 0 to till synchronize time. In figure 3.5 it's not visual so figure 3.6 is separate three-phase current for same results which was in 3.5.

There was two platform for getting the data, there were results showing which was achieved from the mechanical platform for torque (newton meter) data as well as graph also. From that figure 3.7 its can clearly visual while applied gradually load to motor that time torque meter gradually raised and that all step there in this figure 3.7, inside it, was at maximum point of power where there is no more chance to run for a motor because there was load torque and motor torque do not meet as like pull out torque so its get synchronised the motor. The synchronous permanent motor was magnet lock at 50 Hz when it synchronized and it starts to again it pulled it so it lost synchronism that time. The maximum point from the breakdown point it shows there is no point of operation more for that motor so it goes to stop.

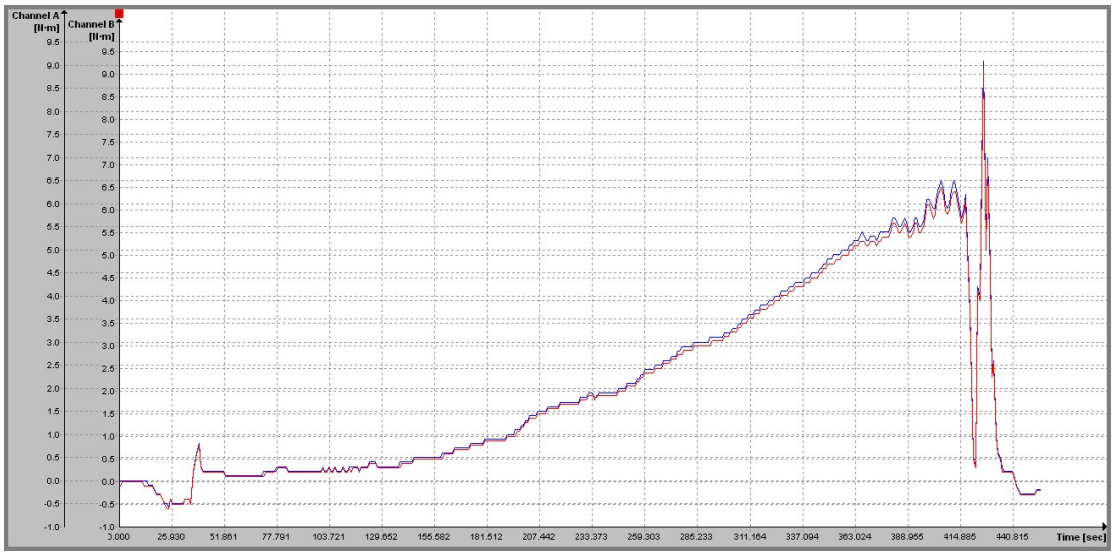

Figure 3.7. Newton-meter rising graph at Lorenz mess-Technik platform

In figure 3.8 showing a nominal 302V efficiency graph which was smooth and highest efficiency compared to those, all was done after that experiment at 20V steps from both sides of the nominal voltage.

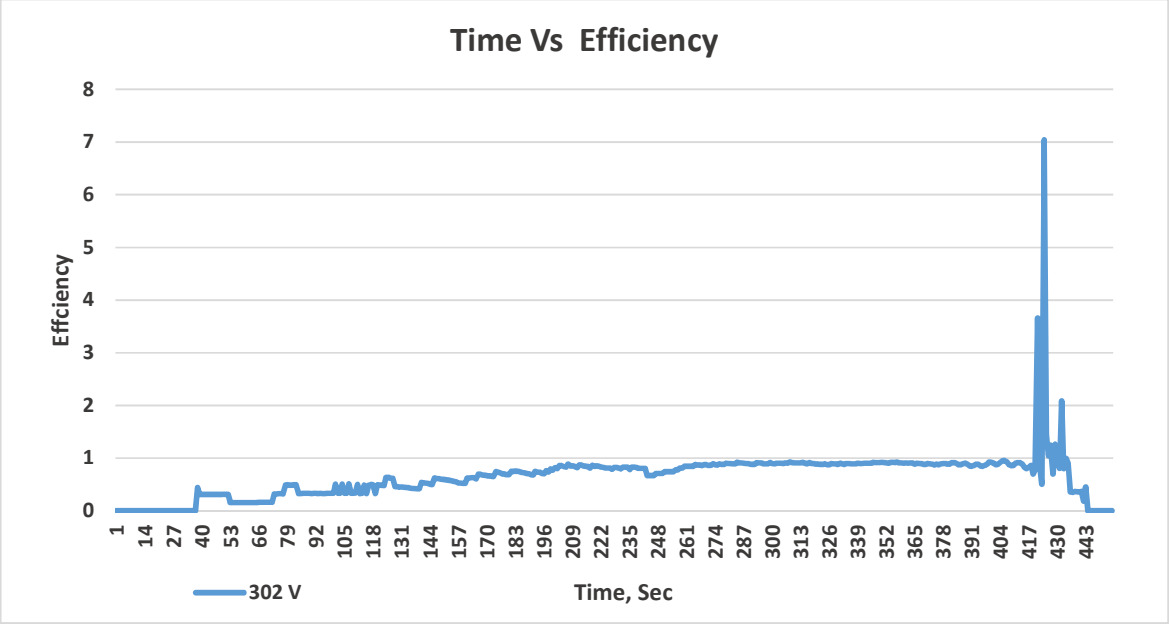

Figure 3.8. Time vs Efficiency at the nominal voltage (302V) in PMSM

After that, there was done six more experiment for comparison with nominal graph and for efficiency calculation. So there were used all data which was achieved from the electrical and mechanical platform from that data there two comparison graph was made. Which is showing efficiency, figure 3.9 showing a lower side of the nominal voltage and figure 3.10 showing a higher side of the nominal voltage.

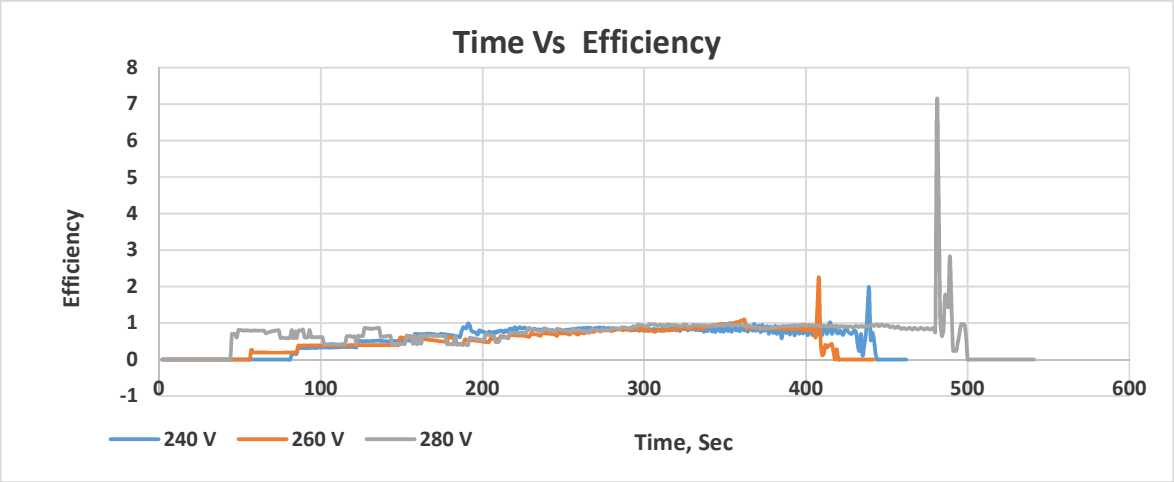

Figure 3.9. Time vs Efficiency on the lower side of the nominal voltage, 240V, 260V, 280V

Figure 3.8 figure 3.9 and 3.10 are showing efficiency vs time curve, from that figure3.9 and 3.10 are comparison graph from 20V steps to the nominal voltage.

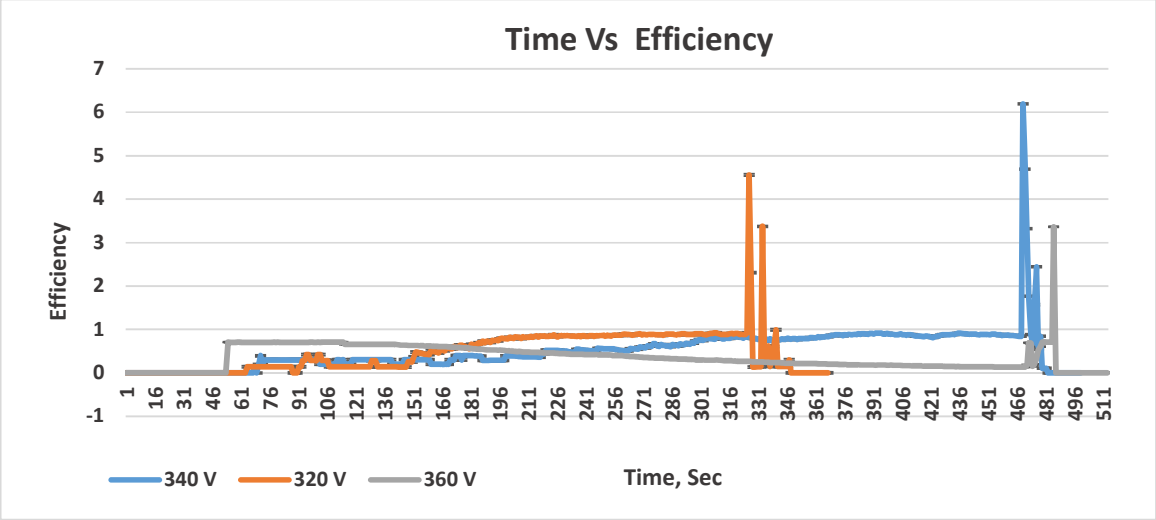

Figure 3.10. Time vs Efficiency on the lower side of the nominal voltage, 320V, 340V, 260V

There was done seven experiment one was at nominal load which was 302 for that permanent magnet synchronous machine and remaing six was which was done at 20V steps from lower and higher side of the nominal voltage which is 240V, 260V, 280V, 320V, 340V, 360V respectively. For efficiency calculation there were choose required parameters which were active power from electrical parameters and Nm from mechanical parameters first there were calculate mechanical Kw for that used 1500 rpm which was measured during experiment after that efficiency was done.

In table 3.1 its clearly visual among the all experiment maximum was 92.08% which was done while using 302V nominal voltage.

Table 3.1 Experimental results of maximum efficiency

Voltage	Nm	RPM	Elect, (w)	Mech, (w)	Efficiency, η%
240	6.5	1500	1450	1021.071	70.41
260	6.1	1500	1230	958.2356	77.9
280	6.4	1500	1180	1005.362	85.2
302	6.8	1500	1160	1068.197	92.08
320	6.2	1500	1150	973.9444	84.6
340	6.2	1500	1220	973.9444	79.3
360	6.5	1500	1370	1021.071	74.5

Figure 3.11 is the summarize the whole experiment with a maximum number of efficiency as well as highest number of newton meter Nm from each experiment vs different voltages. During the experiment, while used lower voltage compared to nominal voltage then there was heard very annoying sound from the motor which was affected by that motor. On the other side same situation while used more voltage than nominal after that also efficiency was going to lower compared to the nominal voltage. Figure 3.11 is the showing all related results from that.

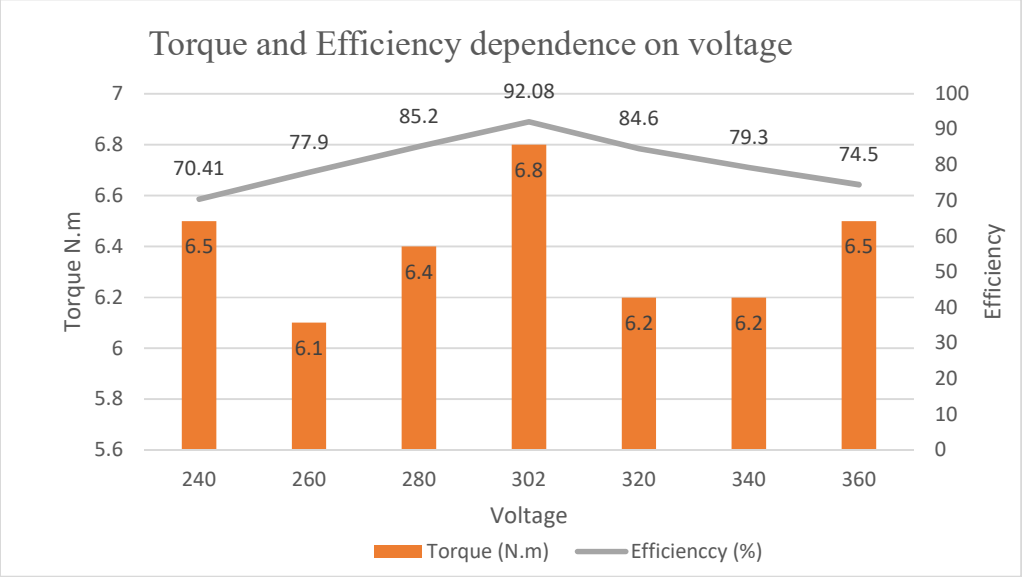

Figure 3.11. Torque and efficiency dependance on voltage

3.3. Neural network Training for prognosis torque meter.

There was done few numbers of training with many different training algorithms as there discuss in methodology which all and there was achieved different results from all of them there were some bad results plotting waveform which was that same parameter which were some higher performance as well. There were different only used another training function which was Conjugate gradient with Powell (traincgb) which was so fast making performance and there was an error also high during experiment which this figure 3.12 showing perfectly that applied values are going in minus.

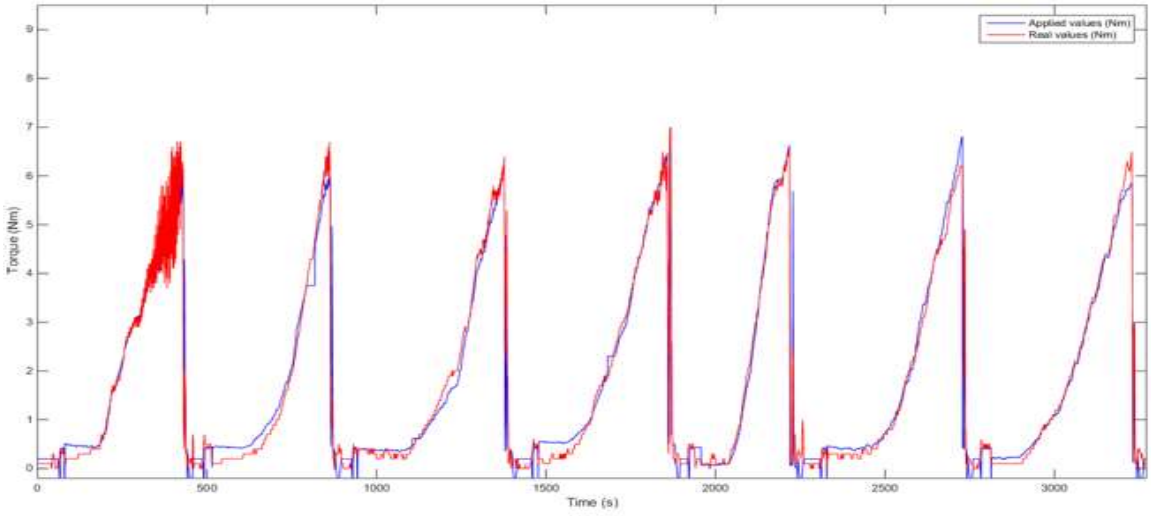

Figure 3.12. Whole experiment torque meter graph summarized with traincgb algorithm

There were so many errors in performance also in the plot while choosing different training function. While traincgb (Conjugate gradient with powell) chose that time overall plot showing minus applied values which were not accurate results for those data also mean square error for training 0.135 was made. Compare to trainlm graph there was more error was done.

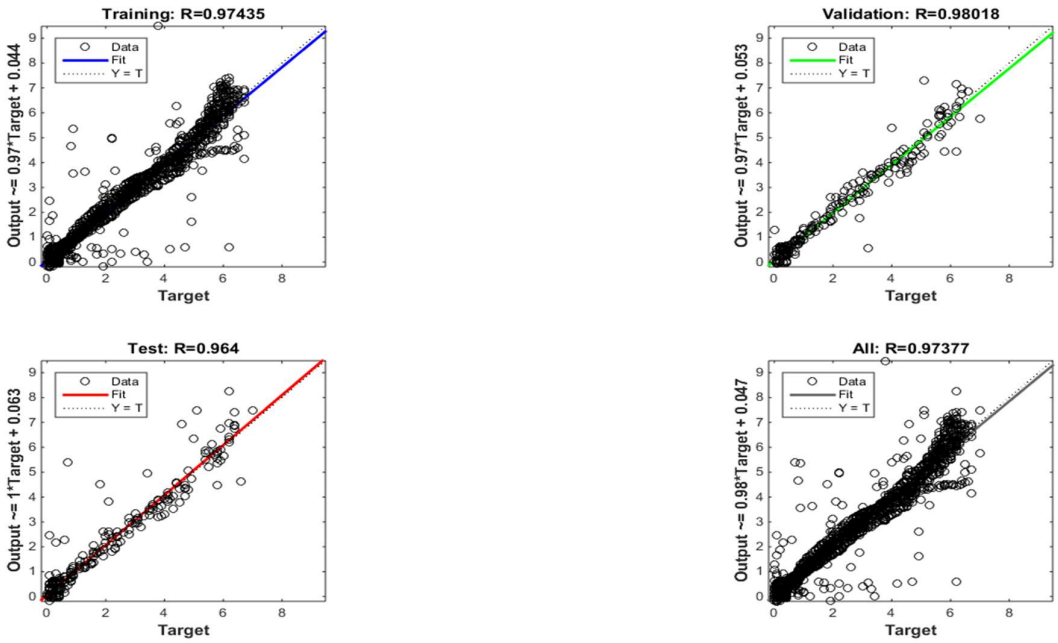

Figure 3.13. Regression with traincgb algorithm bad result

In figure 3.13 those all data which was chosen for training half of the data are scattered and regression performance 97.3% was made. On the other side while choose trainlm for those data regression plot in figure 3.16 was more than accurate with data compare to figure 3.13.

In figure 3.14 is showing final summarize plotting graph from the neural network it was indicates those all experiment which was done for prognosis torque from nominal voltage and both side of the nominal voltage as well. In figure 3.14 from start to till synchronized period showing results for each experiment where blue lines are indicate applied value and the red line is indicated real value.

Figure 3.14 showing every experiment overall results. In that figure clearly showing from starting period to till synchronism time, while the performance of the motor was lost, that's the reason it looks like a fluctuation. From that graph, the middle plot is showing nominal voltage which reached highest 6.8 Nm as well as efficiency 92.08% also. Remaining plot results lower than comparing to nominal voltage for Nm also from efficiency too.

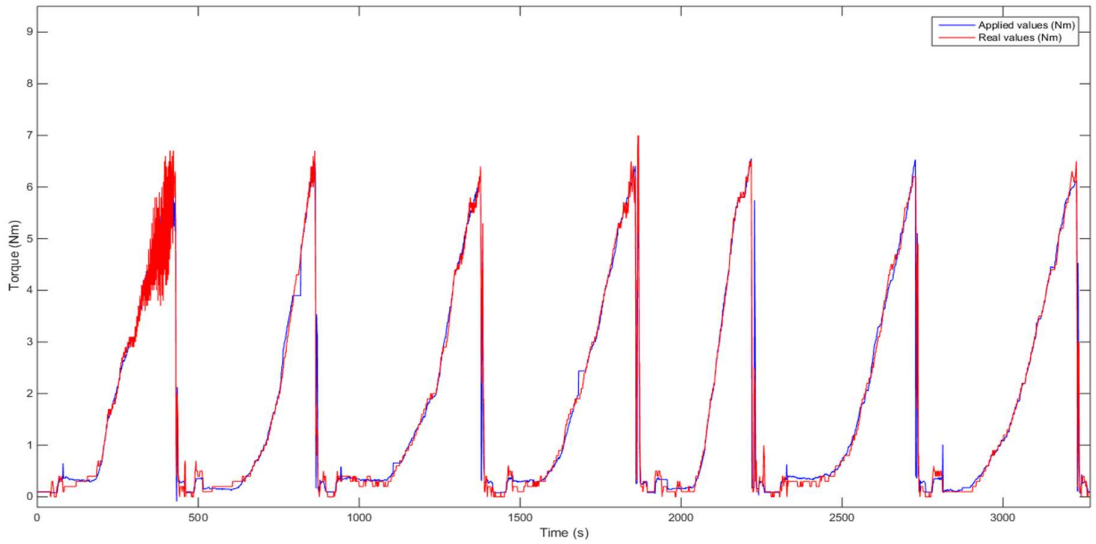

Figure 3.14. Whole experiment torque meter graph summarized with trainlm algorithm

In figure 3.15 showing mean square error for validation which was 0.131 was achieved. In learning process there were showing four colors line grey is showing best point for training, red for testing data blue for training data and green for validation data. Mean square error for training performance 0.0482 was done. After the 26 step training the network performance was up to the requirement. Here this figure shows training and validation error was decreased after it was constant until highlighted epoch. It does not any overfitting data happen until that time, because the validation error does not increase before that epoch.

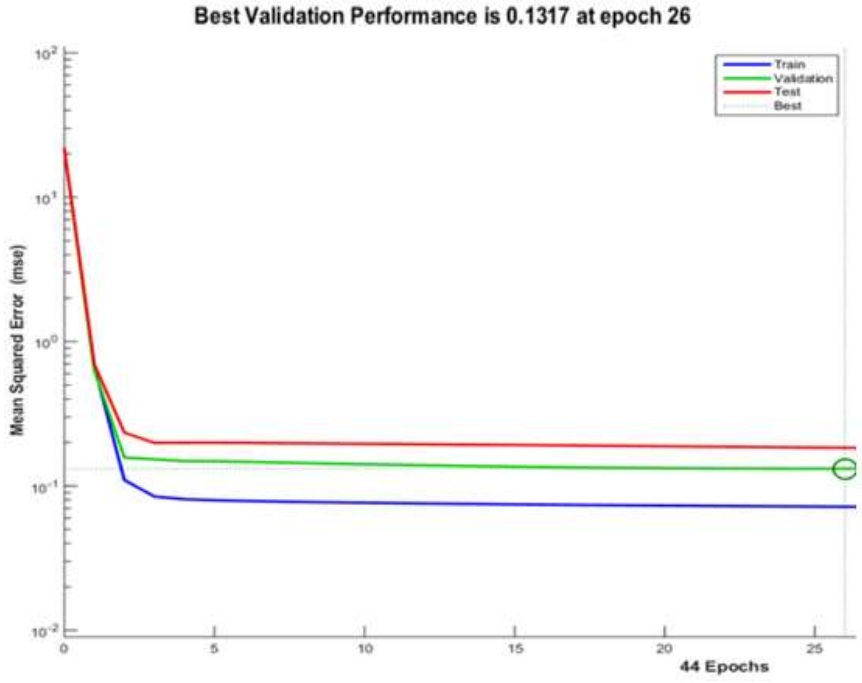

Figure 3.15. Mean square error plot of training process

Figure 3.16 shows the linear regression it shows the target has to be in output if they are equal then an error is low if they are not equal and scattered then it means not an accurate result. There are 4 blocks which were for different parameters colours are indicates same as previous graph, blue is for training, green is for validation, and red is for the testing last blocks showing overall results which were achieved from training.

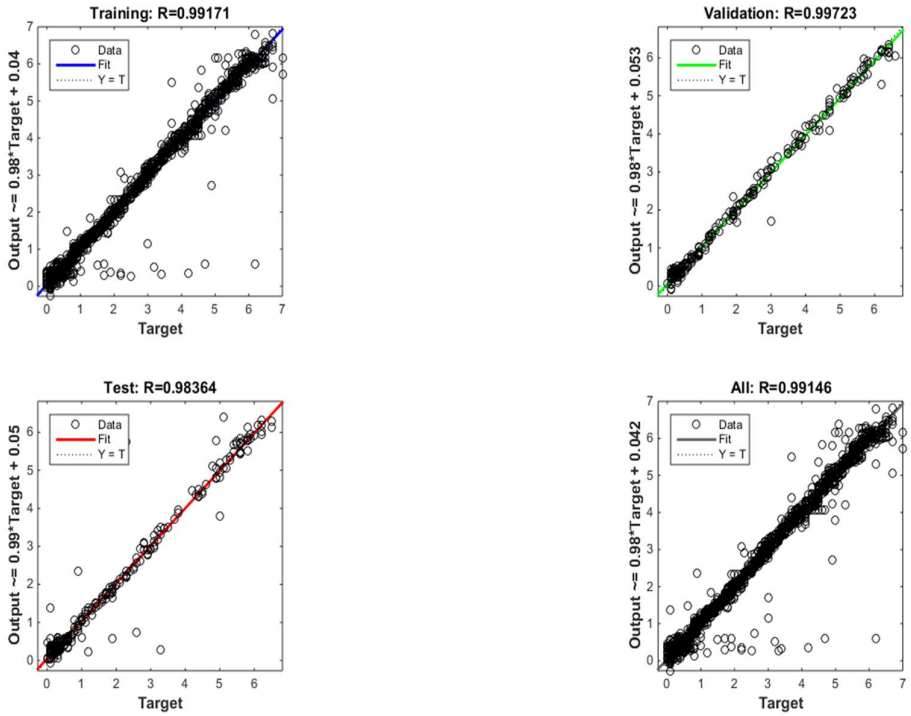

Figure 3.16. Regression by the neural network

In figure 3.16 regression results was done. There were 10% data for validation,10% data for testing and 80% data for training was taken for neural network training. For regression result was 99.1% was done only 0.99% error was there for regression data. Which data was taken for training they are not scattered that's the reason there for this results.

In figure 3.17 showing that number 18 was the minimum number of confirmation times, training is not stopped before 18 iterations or early. There were divide data, it was 80% for training and 10% testing and 10% validation was taken. That was important to properly determine the proportions of this data for good network training. It was necessary to regulate the training of the network and to regulate the training testing and validation data relationships so that the network has enough data for training.

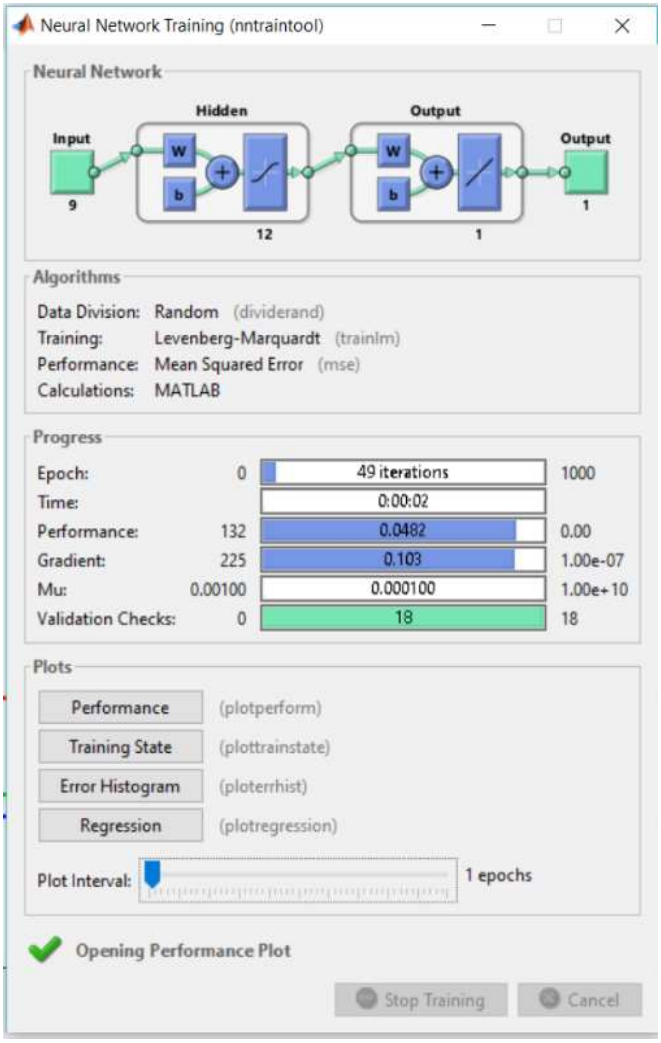

Figure 3.17. Neural network Training

Figure 3.17 is the main training process, from that 9 inputs from electrical data and 12 numbers of the neuron for training and 1 output which was from mechanical data was taken. Afterward, there were data division which was already taken after that showing training function which was used for this training and it was Levenberg-Marquardt (trainlm) was used. Performance mean squared error was 0.0482 was done. All calculation was done by Matlab and those all code is in the appendix. From that performance percentage and that error, it is possible to replicate torque meter successfully.

Conclusion

1. For calculating efficiency and prognosis torque in permanent magnet synchronous machine first there were used permanent magnet synchronous machine as a Generator and achieved nominal voltage (302V) at 1500 r.p.m. which were measured by a tachometer (laser device) also at the 50Hz frequency. After that, there were used that same voltage which was measured in the first experiment 302V was applied and 6 more experiments were done on both sides of nominal voltage(302V) with 20V steps. From those experiments, maximum efficiency 92.08 was calculated by 302 nominal voltage. Maximum 6.8 Nm was achieved with nominal voltage.

2. Electrical data was acquired from Com'X 510 platform, which was voltage phase to phase, current, active power, apparent power, reactive power. The mesured values presents statistics for determining EN50160, IEC 61000-4-30, IEC 62586 compliance. Time synchronization to 1 ms. accuracy, Modbus master, Ethernet gateway protocols supported, Dual port Ethernet (two physical ports, one Ethernet IP address). For all data processing, Siemens cloud was used. Protocol changer needed to change from Com'x data to Siemens Mindconnect Nano (Modbus TCP / IP to OPC UA). A "string" data transfer method is recommended for the recording of electrical transient processes. Mechanical data was obtained from the torque sensor, that accurace class 0.1.

3. After getting the data there were used a neural network for prognosis torque from all experiment. For every training, there was used one data proportion it was 80%,10%,10% respectively. There were trying every training function, from (traincgb) Conjugate gradient with powel regression result 97.3% was done with the scattered plot. After that, there were preferred Levenberg- Marquardt (trainlm) training function and got this results, the mean square error for training was there 0.0482. regression performance 99.1% was achieved, which is better than Conjugate gradient with powel (traincgb). From that performance percentage and that error, it is possible to replicate torque meter successfully.

4. From those experiments and results of permanent magnet synchronous motor, it can be concluded that stator design was correctly but there were not enough magnets in the rotor which explains the nominal 302 voltage of the machine working as a generator motor giving out 302 voltage, instead which should be around 400 voltage.

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Appendix:

- **Smart panel devices for online monitoring**

An accurate Power Monitoring system contains two or three metering points that are interconnected by some system. There are three primary components of a power monitoring system consists, i) meter record data, ii) software for manage and display the data, and iii) a communication line between the software and metering devices.

In my thesis, there were different smart panels used, and each smart panel have contrasting devices, moreover, that all devices that was in our panels they have numerous functions for measuring the varieties of parameters as well as indicate the values, showing waveforms, define alerting signals, and so on.

There are all discuss done about this all devices and that all function and features in briefly. So, as we see in the figure the smart panel have multiple devices, among all device, there is one most crucial and important device is Human Machine Interface, Power $Logic^{TM}$ PM8000 series.

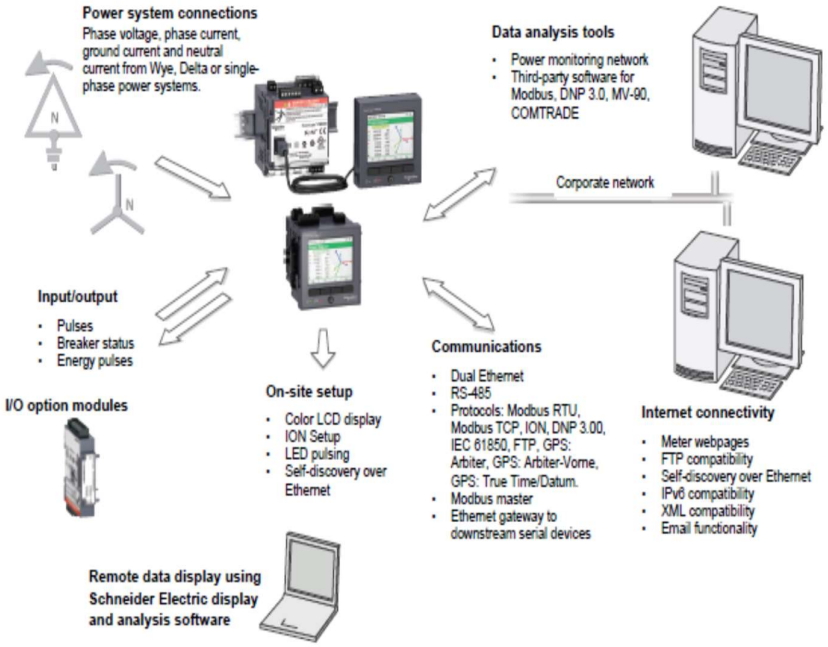
- **Power $Logic^{TM}$ PM8000**

This is Schneider Electric product, this the function that have enormous parameters for measuring any types of features in industry or who needs power there all places and for all consumers.

Figure. Human Machine Interface (Power $Logic^{TM}$ PM8000) [50]

The Power $Logic^{TM}$ PM8000 series power and energy meters it has functions with that help meet the needs of your energy monitoring and expenditure management applications. It is done by international metering accuracy standard.

The PM8000 meters gather and accumulation data. This data from meter it can be used with the help of energy management software to help with trending and forecasting, energy cost administration, network executive, power quality analysis, and more. Here you can see Power $Logic^{TM}$ PM8000 capabilities in an energy management system.



Figur. Power $Logic^{TM}$ PM8000 capabilities in an energy management system [50]

The Power $Logic^{TM}$ PM8000 has enormous features.

Measured parameters:

- Energy

This meter provides active, reactive, and also apparent energy values, along with, kWh, kVARh, kVAh delivered and received, and the most crucial part is the energy parameters it will log directly on a programmed schedule.

- Demand

This meter has supported several demands arithmetic methods, it can measure demand on an instantaneous value and maximum and minimum demand with time and date data, amps, volts, demand.

- Instantaneous

The Power $Logic^{TM}$ PM8000 provides one second and half cycles measurements, each phase or totals for many values, along with: Voltage and current, apparent power (kVA), active power (kW), reactive power (kVAR), Power factor and frequency, Voltage and current unbalance. Also some more features

are there, harmonics, min/max recording, power quality. Comtrade, this quality givess the meter to save the waveform in common format for transient data exchange.

Communication:

The Power $Logic^{TM}$ PM8000 has one RS-485 connection and two Ethernet connection. And that both Ethernet have same IP address. That meter is connected through the RS-485 port, there are 32 we can connect on a single RS-485 bus. In that RS-485 device we have one master device, practically on Ethernet to RS-485 gateway. It gives that means for RS-485 communication with multiple slave meters (ex, devices).

Protocol:

The Power $Logic^{TM}$ PM8000 supports these variety of protocols on its RS-485 serial port.
Namely, Ion, Modbus Rtu, Modbus master, DNP 3.0, Ether Gate, GPS: true time/datum/, etc. This device is the main device of the online monitoring in my thesis work [50].

- **COM'X 510 Energy Server**

The Com'X 510 energy server is an entry level energy management system in a box, the Com'X 510 is the single point of conduction with a new power system to help you log data and turn that data into valuable information.

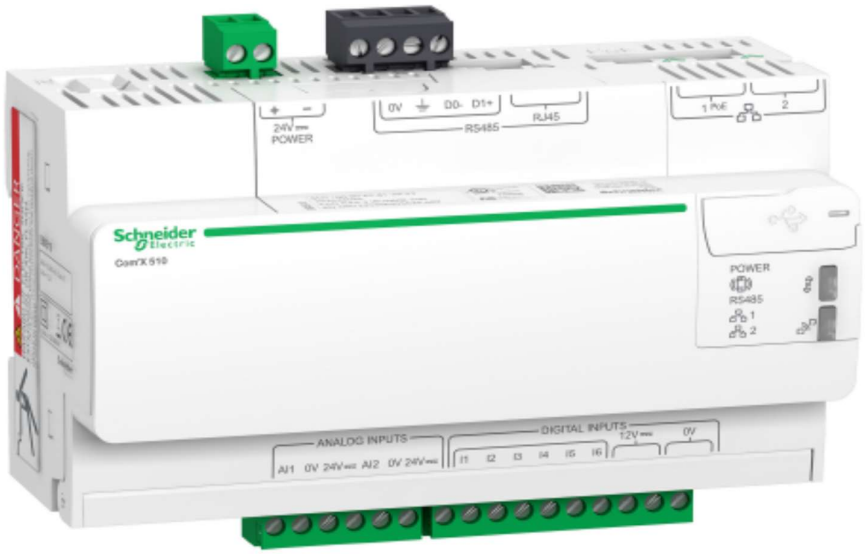


Figure. Com'X 510 [51]

After the login the Com;X 510 showing visualization comparison such as last month consumption pikes and this month to show what will happen, its helpful for trending also for future forecast the . sensors have no software everything is in the Com'X 510 box, just need one IP address and a web browser to see entire system.

You can see sometimes few operations contain multiple sites, the Com'X 510 is the one place to view your whole business, with their addition feature 150 gateway you can connect remote location into one Com'X 510 to gain energy awareness in all your site, that's the power connecting everything, it saves your time and money.

The Com'X 510 energy server is a very thick plug and play gateway also data logger and is a crucial part of an entry level energy management system. It's gather and stores consumption of compensation (Electricity, Water, Air, Gas, and steam) also Environmental parameters like Temperature, humidity and so on. The Com'X 510 gives access to records and important data circuit summary pages, as well as logging for on board. Data will be securely accessed in real time or broadcast as a record to the database server of an internet. When data is ready for it working processed once gain by the server. Data is showing on displayed as web pages by energy administration services giving by Schneider Electric [51].

- **Features of Com'X 510:**

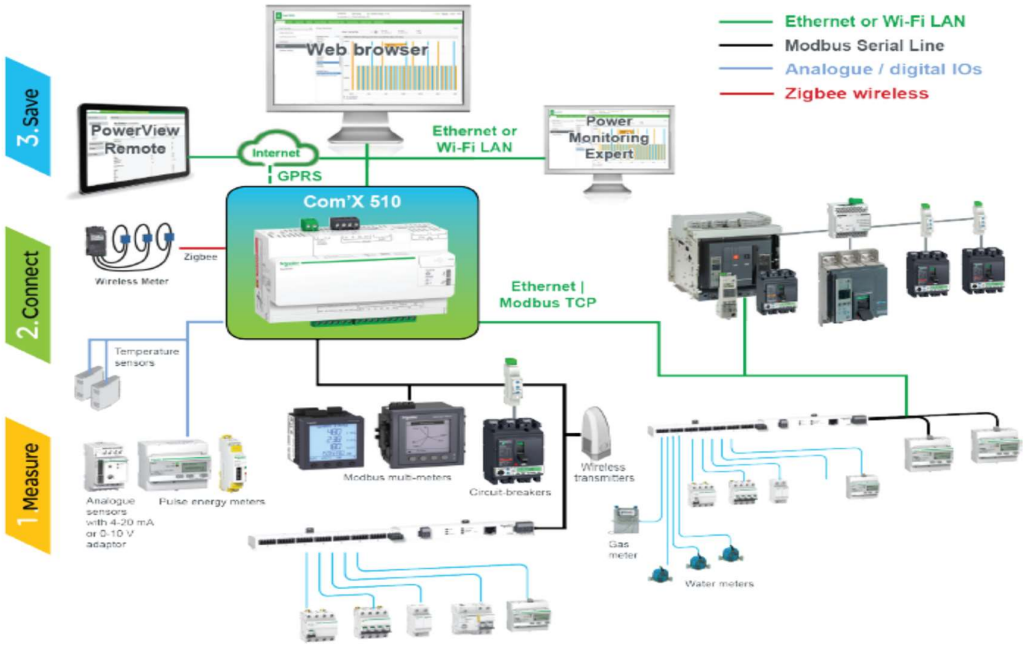


Figure. Com'X 510 Energy server view [51]

The main features of the Com'x 510 are described here, real-time records in easy to understand views, we can see the control panel view for historical recording, it will connect automatically with Modbus device. There are three media for the connection with the cloud namely, GPRS/3G, wired Ethernet, or Wi-Fi Ethernet. There are two Ethernet ports to independent upstream cloud connection from the field device network. If we talk about protocols there are four supported transfer protocols, HTTP, FTP, HTTPS, SMTP with proxy management. Also, there data logging [51].

```
%-------------------------------------------------------------------------------------------------------------
clc                                                 % preparation for work
close all
clear all
load Fine.txt                                         % document with Fine

%corrplot(Fine);

net = feedforwardnet(12);                          % 12 neuron network
x=Fine(:,2:10);                                     % electrical parameters
t=Fine(:,end);                                     % torque

net.divideParam.trainRatio = 80/100;     % training data ratio
net.divideParam.valRatio = 10/100;       % Validation data ratio
net.divideParam.testRatio = 10/100;      % testing data ratio
net.trainParam.max_fail=18; % Aprovenent times, as you reach it trsining is over
[net,tr] = trainlm(net,x',t');                                    % Training function
%performance=perform(net, x, t);                              % Performsnce result
Dx=Fine(:,2:10);                                  %  in order to fit Training data
Dt=Fine(:,end);                             % to take training for making plot
Dtr = sim(net,Dx');                            % crate an erray of displaying data
load Fine.txt                                          % load numbers for sequence
figure(1)
plot(Fine(:,1), Dtr, 'color','b');        % A graphic plot for training scheme
hold on;                                                        % Both side in graph
plot(Fine(:,1), Dt, 'color','r');                  % graphics with reality
legend({'Applied values (Nm)','Real values (Nm)'});% find for real and applied
value
xlabel('Time (s)')                                                % x-axis
ylabel('Torque (Nm)')                                          % y-axis
ylim([-0.2 9.5]);                                    % the boundary of the y axis
xlim([0 3271]);                                       % the boundary of the x


%-------------------------------------------------------------------------------------------------------------
```