Power Quality
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Lecture - 01
Power Quality: An Introduction

Well, good morning to all of you. This course is on Power Quality. Myself Bhim Singh from IIT, Delhi. So, we will cover today the Introduction to the course on this Power Quality.

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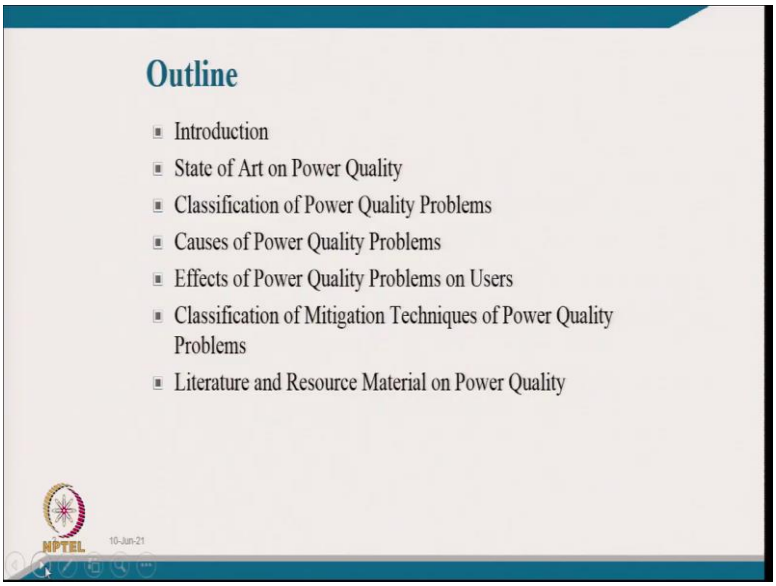

Well, we will cover today the introduction part like state of art on the power quality, then we will classify the power quality problems. We will discuss about the cause of power quality problem and the effects of power quality problems on the users.

We will give a classification of mitigation technique of these power quality problems and we will discuss about the literature as well as resource material on power quality.

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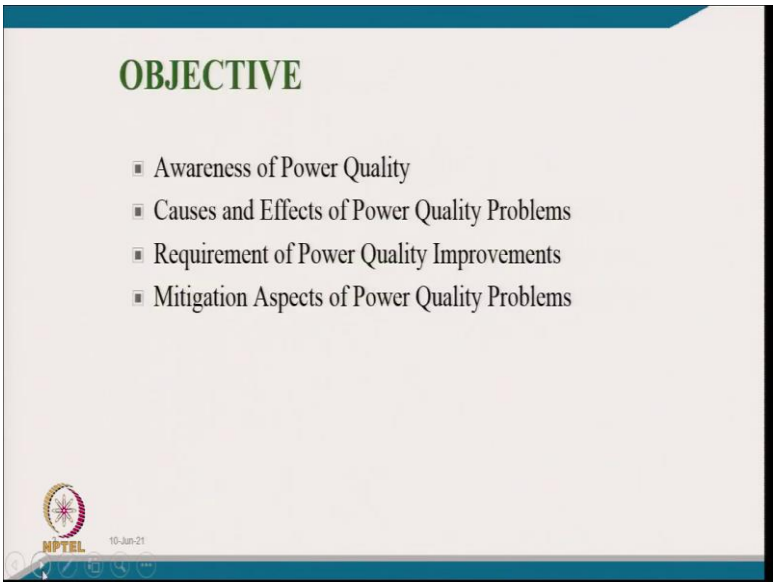

Well, the objective of today's lecture: We will talk about the awareness of the power quality. We will discuss causes and effects of power quality problems, then the requirement of power quality improvement and mitigation aspect of the power quality problems like on.

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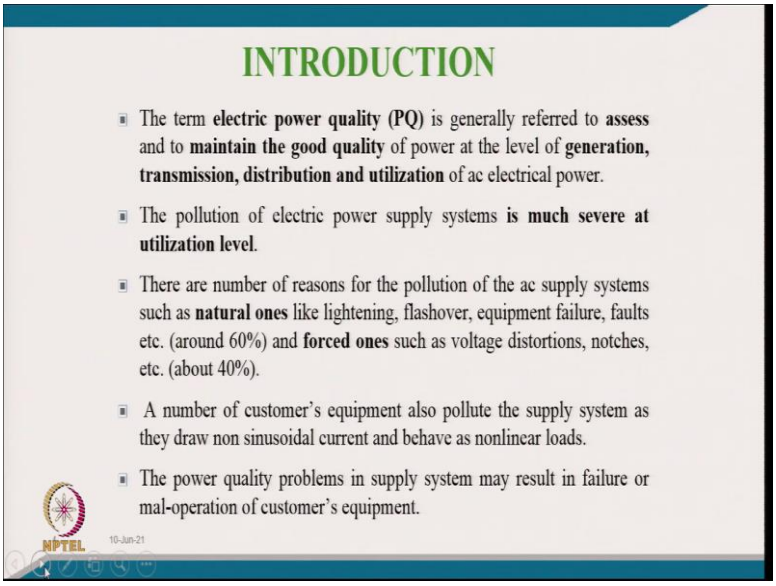

Well, as a part of introduction the term electric power quality, we also call it sometime power quality, generally referred to assess and to maintain the good quality of power at the level of generation, transmission, distribution and utilization of an AC electric power. The pollution of

electric power quality systems is much severe at utilization level because of the variety of the equipment or loads connected at the utilization level.

There are number of reasons for pollution of the AC supply system such as natural ones like lightening, flashover, equipment failure, faults, etc. which are around 60 percent. And the fourth one such as voltage distortion, notches, etc. are about 40 percent.

A number of customer equipment also pollute the supply systems as they draw non sinusoidal currents and behave as non-linear loads. The power quality problems in supply system may result in failure or mal-operation of customer equipment.

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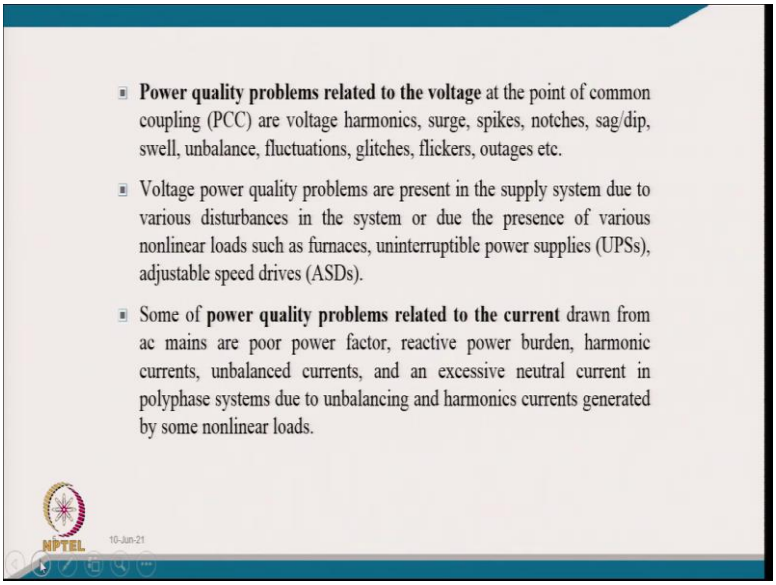

The power quality problems related to the voltage at the point of common coupling where normally the loads are connected, are the voltage harmonics, voltage surge, spikes, notches, sag/dip, voltage swell, voltage unbalances, voltage fluctuations, glitches, voltage flickers and outage.

Well, voltage power quality problems are present in the supply system due to various disturbances in the system or due to presence of various non-linear load such as furnaces, uninterrupted power supply, adjustable speed drive and many other non-linear load used in home appliances as well as domestic sector and industrial sector.

Some of the power quality problems related to current drawn from the AC mains are reactive power burden, harmonics currents, unbalanced current, and excessive neutral current in the distribution system.

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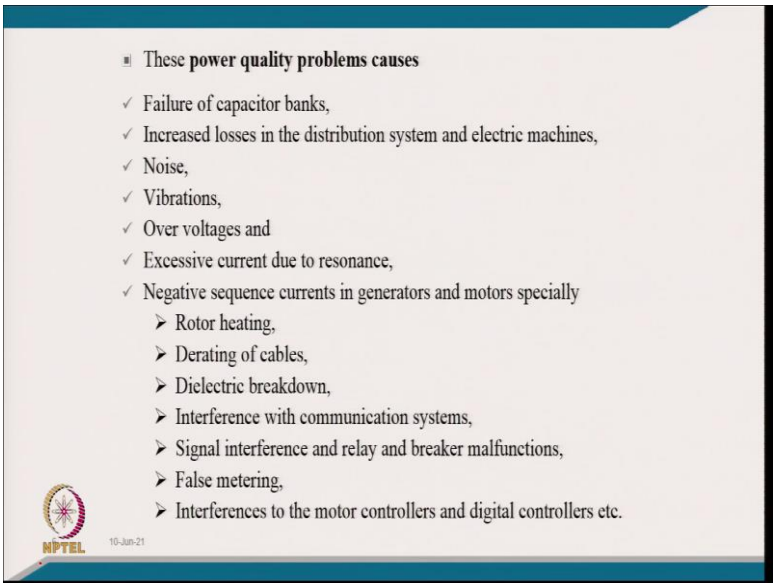

Well, the power quality problems cause the failure of capacitor bank. Why? Because if there is some harmonics in the voltage. The capacitor has a very low impedance and it takes large amount of a harmonic current and thus the capacitor banks get overloaded.

It also causes increased losses in the distribution system and electrical machines. In electrical machines these all power quality problems cause noise and produce harmonics torque.

It also causes vibration in machine. And it also sometimes creates over voltage and excessive current due to resonance. The resonance phenomenon occurs by the effect of source impedance and the capacitor bank connected at the point of common coupling. So, this may cause even the failure of the capacitor banks.

A typical example: In induction motor, if there is a 1% negative sequence voltage or 1% unbalance, then there will be a 5% to 6% negative sequence current in induction motor, even though the induction motor is a balanced load.

Another problem relates to the interference in the communication system which may cause malfunction of the relay and breaker operation.

Another drawback is the false metering. If the current and voltage are distorted, the actual energy consumed is not estimated correctly.

Also, it causes interference to the digital control circuitry which are used normally in most of today's motor controllers.

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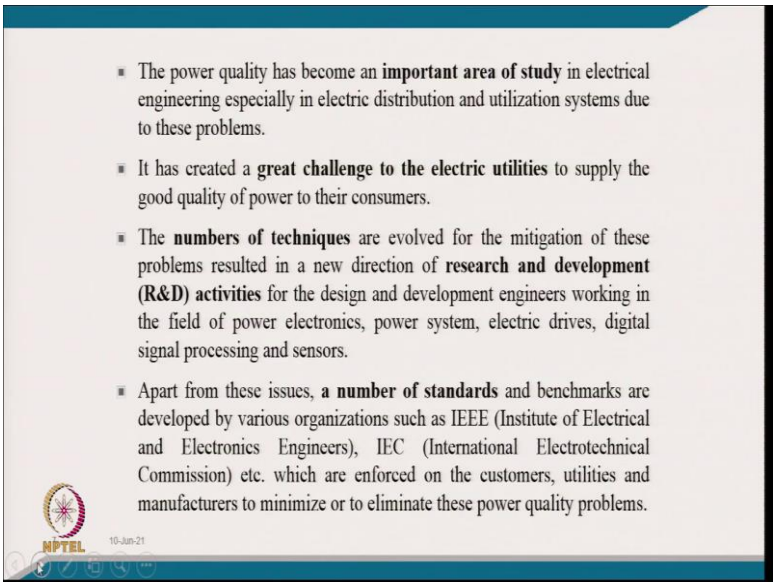

The power quality problem has become an important area of study in electrical engineering especially in electrical distribution system and utilization system due to these problems. And, it has created a great challenge to the electrical utility to supply the good quality of power to their consumers.

The number of techniques are evolved for mitigation of these problems resulting in new direction of research and development activity for the design and development engineers working in the field of power electronics, power system, electric drive, digital signal processing and sensors.

Apart from these issues, a number of standards and benchmarks are developed by various organisations such IEEE Institute of Electrical and Electronics Engineer, IEC International Electro technical Commission, which are enforced on the customers, utility and manufacture to minimize or to eliminate these power quality problems.

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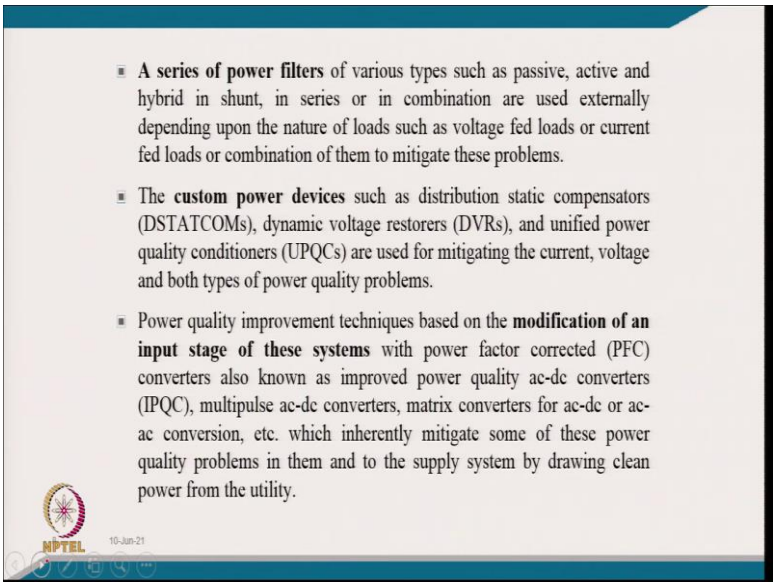

A series of power filters of various types such as passive filters, active filters and hybrid filters especially in shunt are developed to mitigate the problems of power quality.

The hybrid filters can be a hybrid of passive – passive, active – passive or active – active. The devices can are connected in shunt or in series or as a combination of both, depending upon the nature of the load such as voltage fed load.

An example of voltage fed load: If diode rectifier with a capacitor at the DC link, produces constant DC link voltage. So, such load we call it the voltage fed load.

An example of current fed load: A thyristor power controllers like AC to DC converter with a large inductance on the DC side, feeding a current source inverter of the ac motor drive or the dc motor drive. Or you might be feeding some kind of electromagnet or the field excitation of alternators by this control rectifier.

Another type of devices are called custom power devices, like active shunt filter, active series filter, etc. Most of the big manufacturer like ABB, Toshiba, and Siemens develop these active series filter or shunt filters or hybrid of them.

This is a DSTATCOM which is distribution static compensator can be used for reactive power compensation, negative sequence compensation, neutral current compensation. Also, if required then it can provide even harmonic compensation.

But, certainly if harmonic compensation along with above mentioned three compensations are performed then the rating is increased.

Similarly, there is a series compensation device called dynamic voltage restorer which is responsible for regulating the voltage across the load. The supply voltage might be having sag, swell, unbalance, and distortions. These power quality problems are mitigated through series compensation devices.amental voltage also. Thus, it provides the sinusoidal voltage across the load by injecting distorted or unbalanced voltage in series.

And, a unified power quality conditioner, we call it UPQC in short which are responsible for mitigating the current power quality problem as well as voltage power quality problem.

The third category, we can call it the power quality improvement equipment based on modification of input stage with power factor correction converter known as improved quality ac – dc converters, as maybe like a multipulse converter, matrix converter or ac – dc converter or ac – ac conversion.

So, in case of variable frequency drive like an induction motor at front-end might be using a simple diode rectifier which injects harmonics into the grid. So, it can be replaced by a power factor correction converter like a voltage source converter at the supply side to improve power quality. Similar is the case in single phase loads like LED lighting, permanent brushless dc fan or air conditioner with adjustability speed drive

So, in place of that you can use the power factor correction converter at the input stage and harmonics can be mitigated and most of the load whether it is a computer power supplies, I mean you can say today present the load whatever power is consumed in the either domestic sector or your you can call it commercial sector this is going to be all through power electronic converter.

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Well, we will like to talk about state of art power quality problems.

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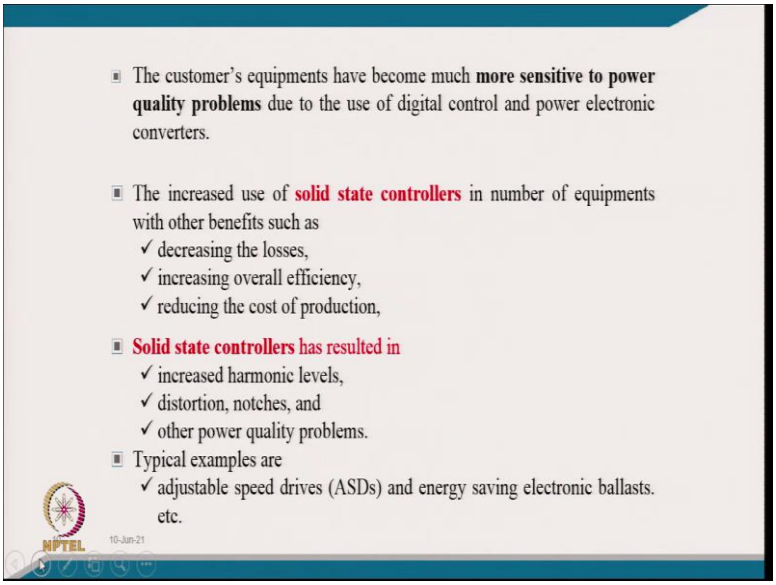

Why do we need power quality mitigation? One of the major reasons is that the customer equipment has become much more sensitive to power quality problems due to the use of digital control and power electronics converters. They are very sensitive equipment.

And, another is the increased use of solid state controllers for decreasing the losses in the system. And, you can think about if you are using a like a single phase induction motor fan

which consumes like a 70 to 80 watt, but if you have a BLDC fan which only consumes around 35 watt 30 to 35 watt. So, the power consumption reduce to less than half. So, you cannot deny the technology. But the BLDC fan injects harmonics in diode bridge rectifier is in front-end. Sometimes THD goes as high as might be more than 70 – 80 percent.

Another reason is the increasing overall efficiency of the system and that because the power consumption is reduced and reduces the cost of production. And, tonce it goes into mass production the cost also reduces.

If the power quality problem is diverted to distribution system, the utility company are not going to afford either the additional losses or additional cost for installing the higher size of equipment.

So, they are going to directly or indirectly penalise

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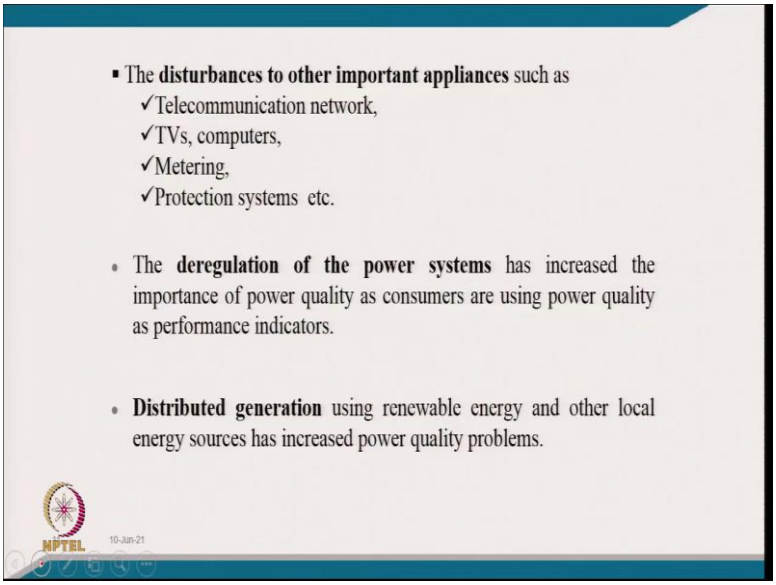

The disturbances to other important appliances such as telecommunication networks, TV, computers, metering, and protection system. Some of the equipment draws the nonsinusoidal current or harmonic current. These currents distort the voltage at the point of common coupling. It happens because of the source impedance of the distribution network. When these harmonics currents flow through the source impedance, the voltage distorts and affects the neighboring consumers or neighboring equipment.

As the deregulation of the power system has increased the importance of power quality as consumers are using power quality and performance indicators.

The another major reason behind the power quality problems is the distributed generation using renewable energy sources and other local energy sources. They have increased the power quality problem in the distribution network. A typical example we can consider is the distribution generation using solar energy. We cannot deny the technology as it provides cheap power. Even in India, we have a 2 rupee per unit per kilowatt-hours, and in many countries, it has already gone to 1 rupee per kilowatt-hour. So, if we have a cost of electricity only 1 rupee or 2 per unit and at the moment utility is giving 10 rupees per unit, we cannot deny the technology to generate the electricity from the solar energy. At the present, the Central Government of India has decided to go 100 gigawatts by 2022. Typically which is supposed to be like 33 percent, which is the total generation of India 5 years back.

Not only in India, but most of the country has gone the penetration of renewable energy. At the moment around 24%, -25% of renewable energy generation is either by solar or by wind or typically another source like biogas. In all these resources, we talk about solar generation as it produces DC output. So, to convert this DC into AC and to inject this generated power into the grid, power converters are used. These power converters have harmonic problems and other power quality problems. But major power quality problem comes because of the intermittent nature of the solar. As solar energy changes all day, the PV generation for a 500 kW system can vary from 50 kW to 500 kW.

So, when such a fast-changing generation is connected to the supply system, it certainly affects voltage and other parameters. A similar kind of problem is also faced with wind generation. Wind generation was quite popular even from 1970 to 2000. During the 90s, a squirrel cage induction generator was used which was operated by a simple wind turbine. When the speed goes above the synchronous speed, it starts generating power. It is a very simple kind of generation without using any power converter.

But, if we look into the last couple of decades, a lot of power converters come into the wind renewable generation, whether we used the wound field induction machine or the salient pole synchronous generator, or any other kind of electrical generator. But, all these wind renewable generations has typically 2-stage of power conversion.

This 2-stage conversion is adopted for the variable speed wind generation. Variable speed wind generation gives us around 50 percent more energy by using this advanced technology or sophisticated technology. This extra generation easily compensates for the cost of these additional power converters and their cost can be recovered within a few months

So, this distributed generation cannot be avoided as they provide cheap electricity and they are the natural energy resources, which are locally available. But distributed generation also causes the power quality problem. So, we have to find out the solution for such power quality problems..

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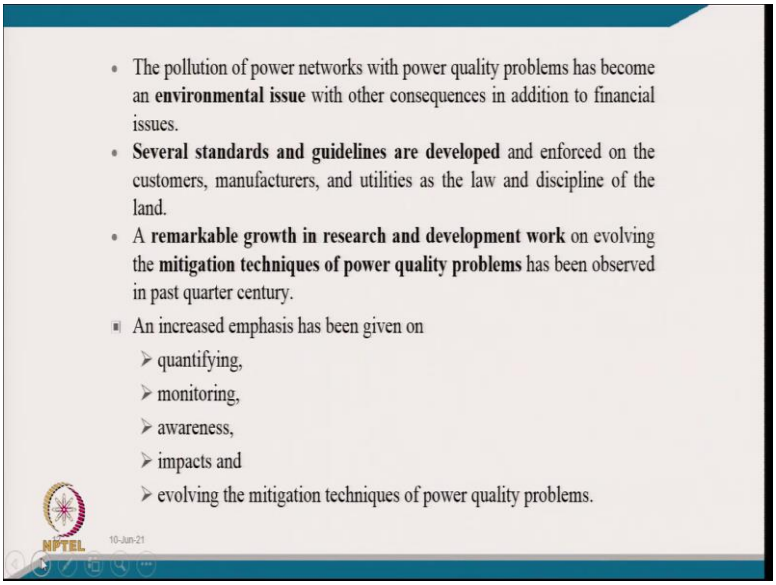

Well, the pollution of power networks with power quality problems has become an environmental issue with other consequences in addition to the financial issue.

And, several standard guidelines are developed and enforced on the customer, manufacture, and utility as the law or discipline of the land.

A remarkable growth in the research and development work on evolving the mitigation technique of power quality problems has have been observed in the first quarter-century. And, an increased emphasis has been given on quantifying the power quality problems, monitoring the power quality problem, awareness of these power quality problems because of which we people are suffering, impact and evolving the mitigation technique of power quality problem.

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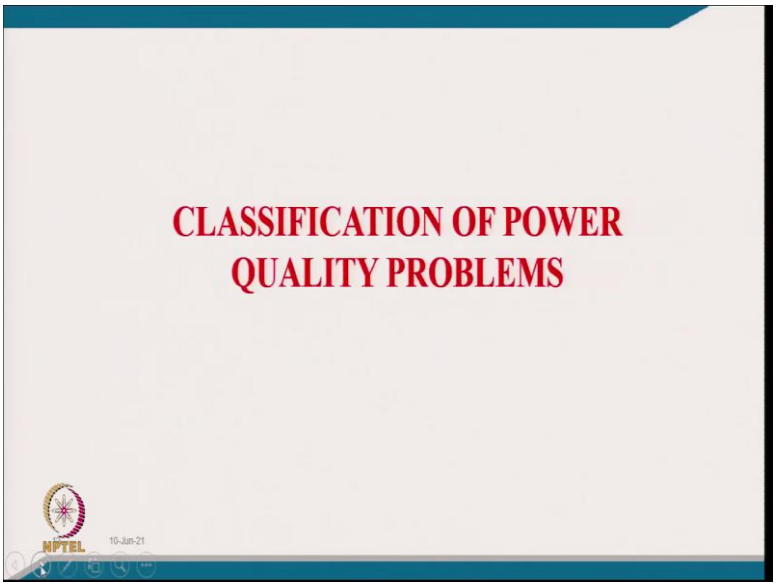

So, we like to classify these power quality problems.

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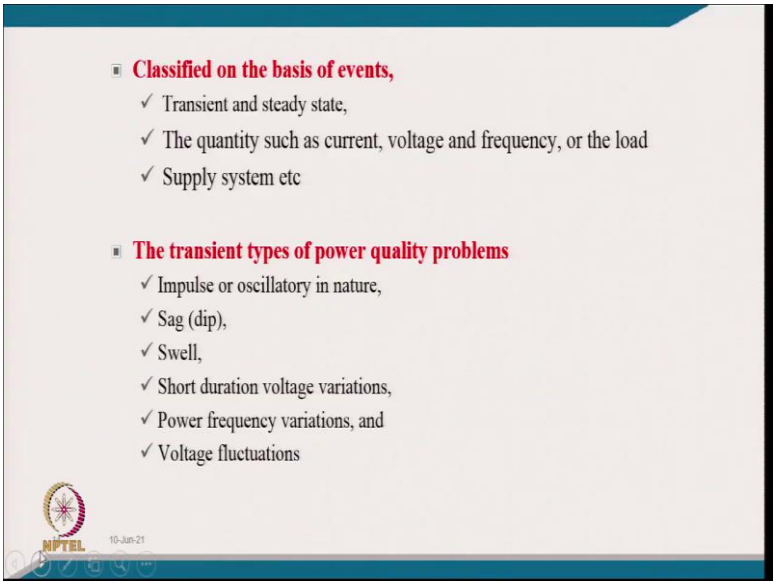

These quality power problems quality is typically classified one on the basis of the event like it can be transient or it can be a steady state or it can be quantity such as current, voltage and frequency or the load.

In the sense of current-based power quality problems, the load might be drawing the reactive current or harmonic current, negative sequence current, neutral current. So, we quantify these

harmonics or the reactive power, reactive current, or harmonics in the current. All these are the power quality problem in the current.

Similarly, we have power quality problems in the voltage also like the distorted voltage, unbalanced voltage, fluctuating voltage, the voltage with the sag, swell unbalanced surges, spike, notches all these are the power quality problem in the voltage.

The frequency may vary over a wide range. Earlier it varied in a very wide range, but now the variation is limited like plus-minus 3 percent. A lot of equipment is affected by the large frequency variation.

Like, if we think about even a 1 Hertz reduction in frequency (from 50 Hertz to 49 Hertz), the speed of the motors will reduce, and maybe the motors or the core of the generator will saturate because of over fluxing. So, the flux will increase by typically by a few percent like 2 to 3% which cause increasing magnetizing current or exciting current, especially for the ferromagnetic core of the transformer or the motor or generator.

Another classification is a transient type of power quality problem. It can be like an impulse in nature or oscillatory in nature, it can be voltage sag or it can be voltage swell and short duration voltage variations or power frequency variation and typically the voltage fluctuations.

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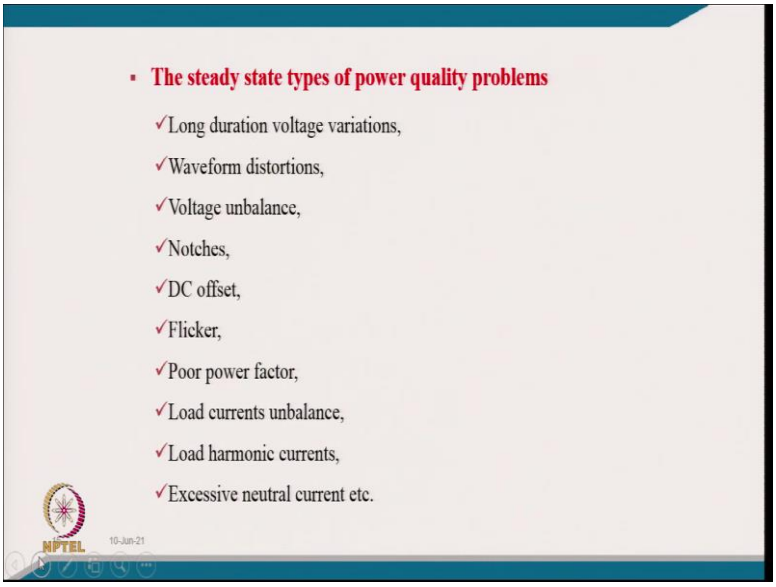

The steady state type of power quality problem is classified as a long-duration voltage variation. It is like a voltage has depressed for a long period or you might have seen some time

maybe in the evening when there is an overload, the voltage gets depressed low and that is why you are not able to operate the fan at proper speed as well as typically, you are not able to have a light also sometimes. Typically, the lighting system also even not function earlier when you have a fluorescent lamp or so.

Or we can have a voltage waveform distortion that really might have seen when the electricity goes and inverter starts feeding the home loads. So, you might be seeing the noise coming out from the fan because of the torque pulses.

Voltage imbalance: As already mentioned about the like induction motor or many loads which causes increased heating because of the increased losses due to the unbalanced voltage. Then we have typically the notches in the voltage, DC offset because some load might be drawing DC current, flicker, poor power factor, load current unbalance which causes typically the unbalanced voltage at the point of common coupling if you are drawing the unbalanced current in the 3-phase system, harmonic currents or excessive neutral current.

If you have a balanced sinusoidal current in a 3-phase system, the neutral current should be 0, but if all three phases are drawing the balanced square wave current, we will find that the neutral current is also the same as the phase current. In some situations such as load diode rectifier with the capacitor filter (60-degree conduction), in that case, you may find the neutral current can go root 3 times of the phase current. And that is the reason in most of the new buildings like hospitals and other buildings where a lot of equipment includes a lot of solid-state controllers, the neutral conductor cross-section area double compared to the phase conductor cross-section area.

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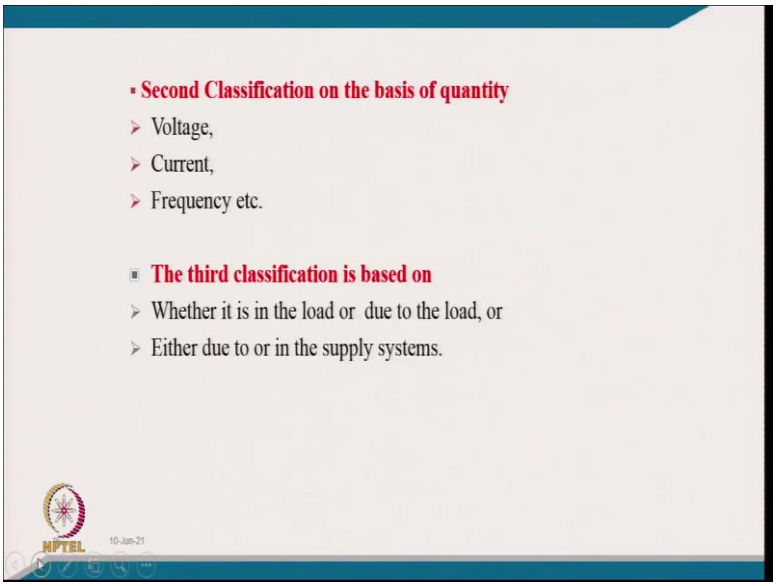

Well, the second classification of these power quality problems on the basis of voltage, current, and frequency as already mentioned it can be a power quality problem in the voltage or in current or in frequency.

And, the third classification can be based on whether it is in the load or due to the load. Whether the load is creating power quality problems or it is in the load itself or either due to or to the supply system either increasing the supply system or it is because of the supply system.

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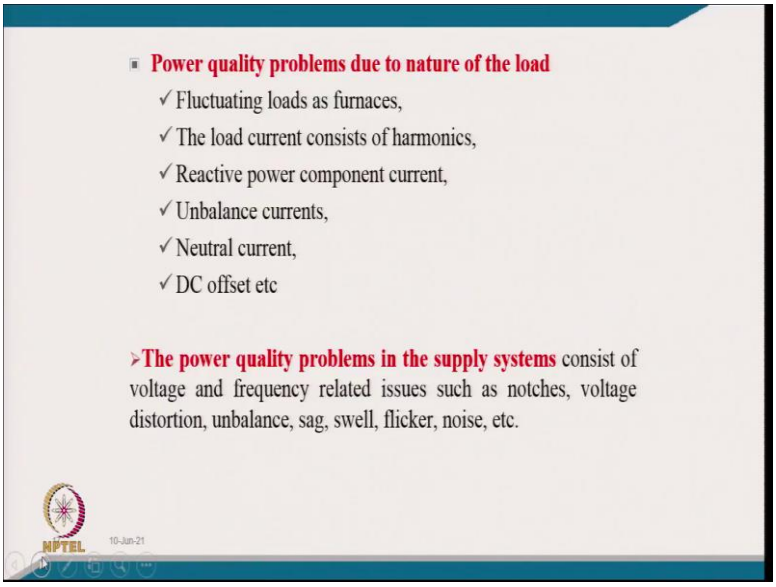

The power quality problem is due to the nature of the load which we mentioning it can be like fluctuating loads as furnaces like, the load current can consist of harmonics, reactive power current component, unbalanced current, neutral current and DC offset current. All these problems are because of the nature of the load.

The power quality problem can be in the supply system which consists of voltage or frequency-related issues such as notches, voltage distortion, unbalance sag, swell, flicker, noise etc.

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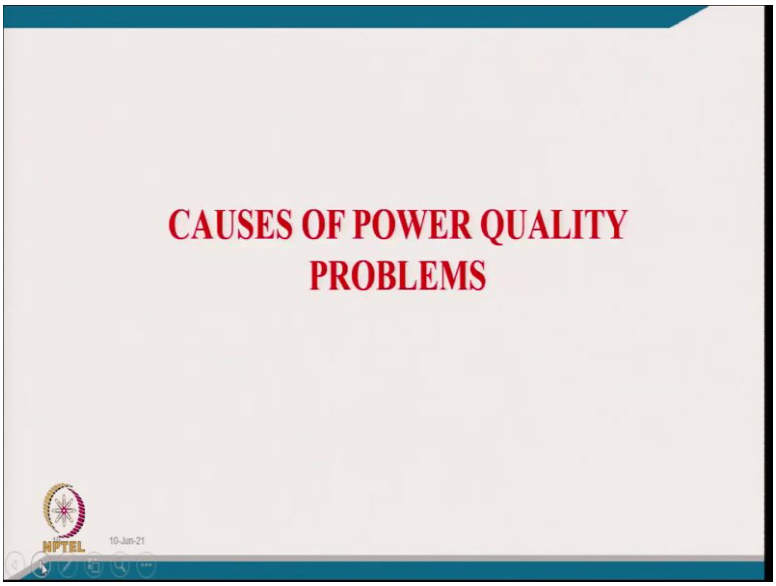

Well, we like to discuss the causes of power quality problems.

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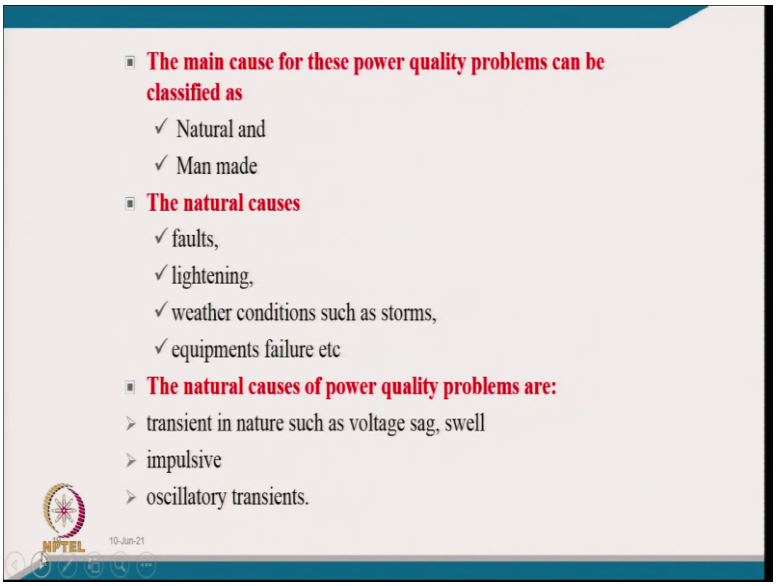

The main cause of this power quality problem can be classified typically the natural or manmade. The natural power quality problems are thereby natural causes. It can be like a fault in the system or it can be lightning or thunderstorm, weather conditions such as storms, or equipment failure.

The storms can be of different varieties. It can be related to air blow or can be a winter storm. So, these are the natural causes of power quality problems that are transient in nature, such as sag, swell, impulsive or oscillatory in nature. The man made causes of power quality problems are due to the loads.

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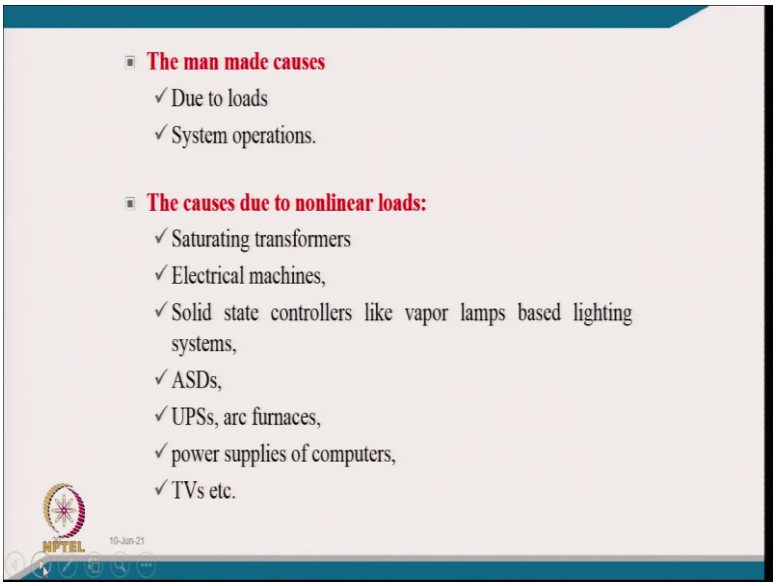

The non-linear loads which cause power quality problems, mainly consist of a saturating transformer or electrical machines, solid state control like vapour lamp based lighting systems, adjustable speed drives, uninterrupted power supply, arc furnaces, computer power supplies also know as sigmoid power supply and televisions sets.

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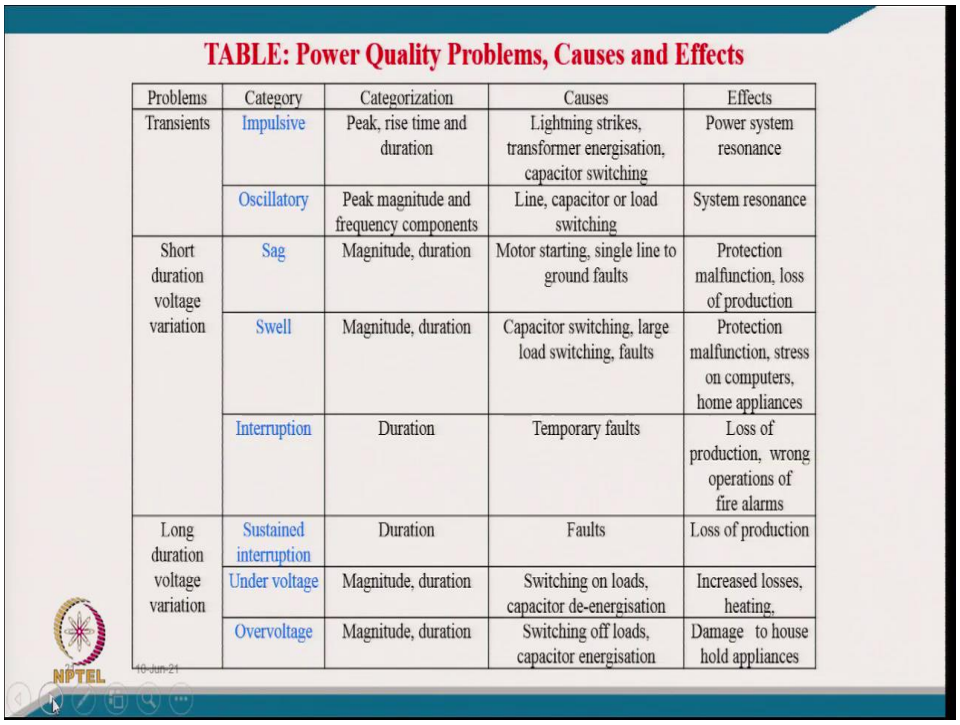

Problems	Category	Categorization	Causes	Effects
Transients	Impulsive	Peak, rise time and duration	Lightning strikes, transformer energisation, capacitor switching	Power system resonance
	Oscillatory	Peak magnitude and frequency components	Line, capacitor or load switching	System resonance
Short duration voltage variation	Sag	Magnitude, duration	Motor starting, single line to ground faults	Protection malfunction, loss of production
	Swell	Magnitude, duration	Capacitor switching, large load switching, faults	Protection malfunction, stress on computers, home appliances
	Interruption	Duration	Temporary faults	Loss of production, wrong operations of fire alarms
Long duration voltage variation	Sustained interruption	Duration	Faults	Loss of production
	Under voltage	Magnitude, duration	Switching on loads, capacitor de-energisation	Increased losses, heating,
	Overvoltage	Magnitude, duration	Switching off loads, capacitor energisation	Damage to house hold appliances

The table consists of power quality problems, causes and effects. The transient category can be impulsive or oscillatory in nature. The transients are quantified in terms of peak rise, and it appears because of lightning stroke, transformer energisation, and capacitor bank switching. Further, it causes a power system resonance.

Similarly, oscillatory nature, it really can be quantified in terms of peak magnitude and frequency components and it affects, caused by line switching or capacitor switching or load switching. Certainly, it causes the system to resonate.

Similarly, short duration voltage variation can be in terms of sag, swell or interruption. These can be quantified in terms of magnitude and duration. These are mainly caused due to large rating motor starting, and single phase line to ground fault. And further effects the protection circuitry and creates loss of production.

Similarly, for swell, it is a magnitude you can quantify in terms of magnitude, and duration. It can be because of capacitor switching or sudden switching of large loads. It again affects the protection system and puts extra stress on computers, home appliances.

Similarly, the interruptions are quantified as, how long it can be there, as it may be a temporary fault or permanent failure. It can cause loss of production or can cause wrong operations of fire alarms.

The long duration voltage variation can be categorized into sustained interruption, which further quantifies in terms of duration. So, it is mainly caused due to fault and can create the loss of production.

Similarly, under voltage can be quantified like a magnitude and duration. It may be because of switching on load or due to capacitor de-energization, which further increase the losses and cause heating problems. Similarly, the overvoltage can be quantified in terms of magnitude or duration and caused due to the switching off load, or capacitor energisation. This can damage the household load appliances.

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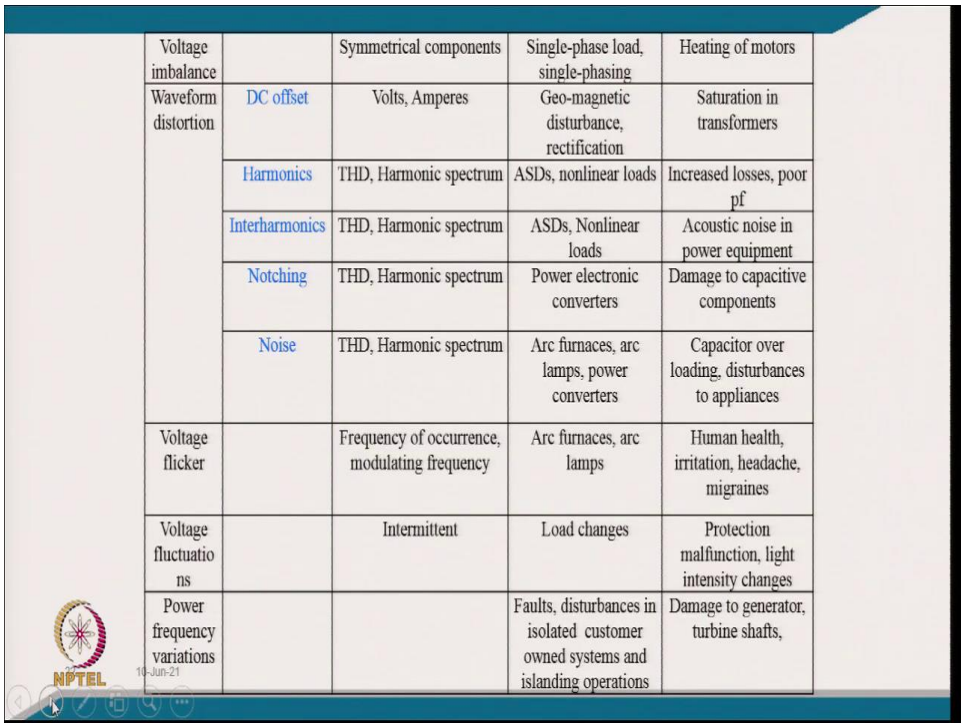

Voltage imbalance		Symmetrical components	Single-phase load, single-phasing	Heating of motors
Waveform distortion	DC offset	Volts, Amperes	Geo-magnetic disturbance, rectification	Saturation in transformers
	Harmonics	THD, Harmonic spectrum	ASDs, nonlinear loads	Increased losses, poor pf
	Interharmonics	THD, Harmonic spectrum	ASDs, Nonlinear loads	Acoustic noise in power equipment
	Notching	THD, Harmonic spectrum	Power electronic converters	Damage to capacitive components
	Noise	THD, Harmonic spectrum	Arc furnaces, arc lamps, power converters	Capacitor over loading, disturbances to appliances
Voltage flicker		Frequency of occurrence, modulating frequency	Arc furnaces, arc lamps	Human health, irritation, headache, migraines
Voltage fluctuations		Intermittent	Load changes	Protection malfunction, light intensity changes
Power frequency variations			Faults, disturbances in isolated customer owned systems and islanding operations	Damage to generator, turbine shafts,

Well, the voltage imbalance can be defined in terms of symmetrical components and can occur because of single phase load or single phasing; and further cause the motor heating. Similarly, waveform distortions; like, DC offset, is defined in terms of voltage and current. It can be caused due to geomagnetic disturbance or rectification; and remains a major cause of transformer and inductor saturation.

Further, harmonics, interharmonics, notching and noise can be quantified in terms of total harmonic distortions and harmonic spectrum, and caused due to adjustable speed drive, non-linear load, power electronics converters, harmonic arc furnaces, and arc lamp power. These further increase the losses, cause poor power factor, increase acoustic noise in the power equipment, damage the capacitive component or capacitor bank, and cause the capacitor overloading.

Similarly, voltage flicker can be caused by arc furnaces and lamps and affect human life, human health, irritation, headache and typically migraine. The voltage fluctuations again can be intermittent in nature and caused due to load changes and affect the protection circuits.

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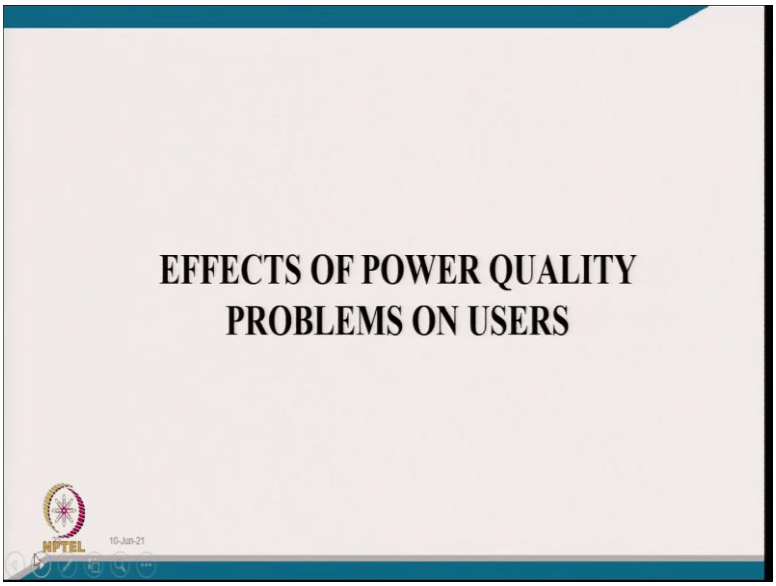

Now, we will look into the effects of these power quality problems on the users. Like, what are the effects and how they affect.

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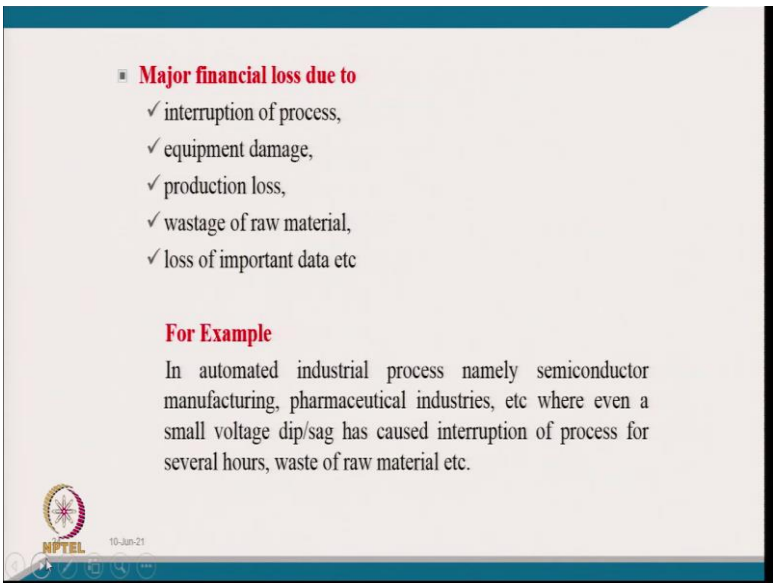

Financial loss is a major effect of the interruption of the process. For example, in the semiconductor manufacturing and pharmaceutical industries; if the equipment is a chain of the process and suddenly interruption occurs in the process, then a small interruption can cause loss of production and loss of raw material. Further, the interruptions may cause equipment damage and loss of important data, typically in a banking system.

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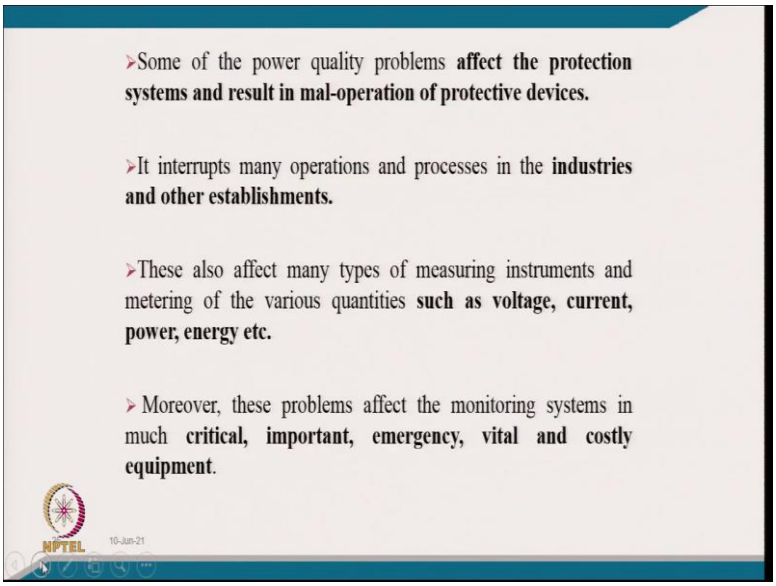

Some of the power quality problems affect the protection system and result in mal-operation of protective devices. It interrupts many operations processes in the industry and other establishments. This also affects many types of measuring instruments and metering of various quantities such as voltage, current, power, and energy. Moreover, these problems affect the monitoring system in much critical, important, emergency, vital and costly equipment.

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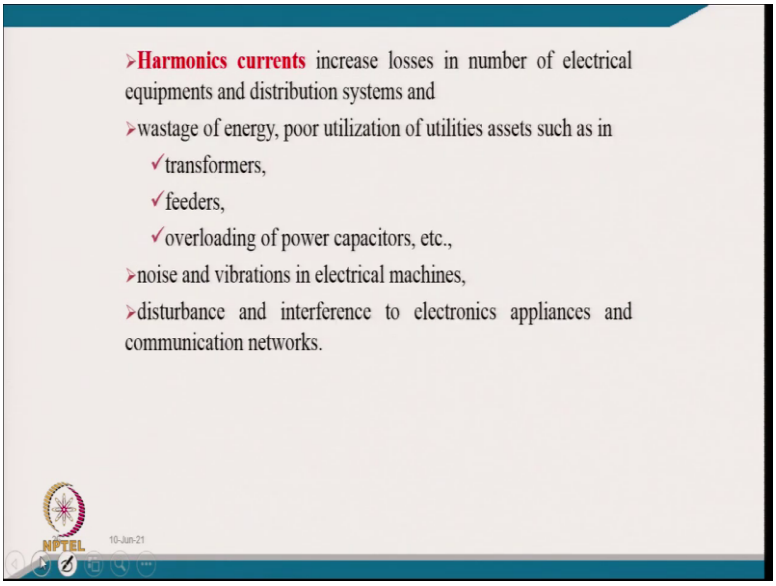

Well, the harmonic currents increase the losses in the number of equipment and distribution systems, cause the wastage of energy, and poor utilization of utility assets such as transformers,

feeders, overheating, and overloading of the power capacitors. Further, the harmonic currents create noise and vibration in electrical machines and generate disturbances and interference to electronics appliances and communication networks.

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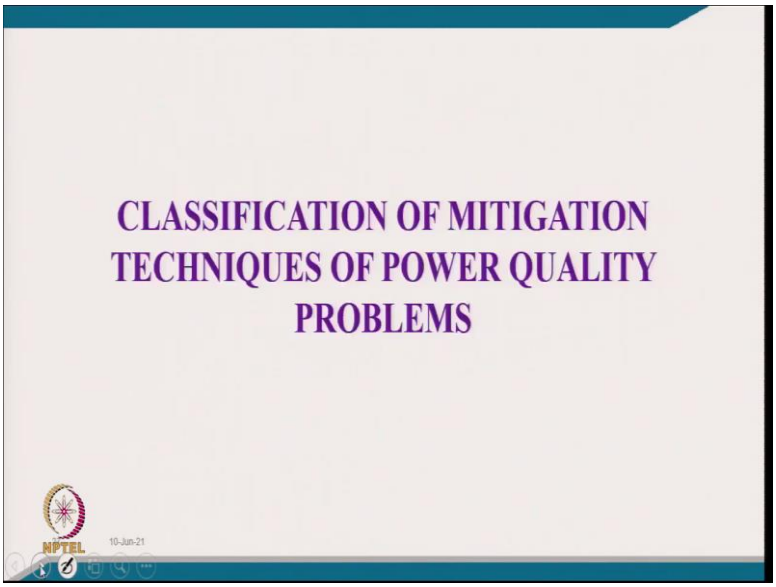

Now, we will like to give a classification of mitigation techniques on power quality problems.

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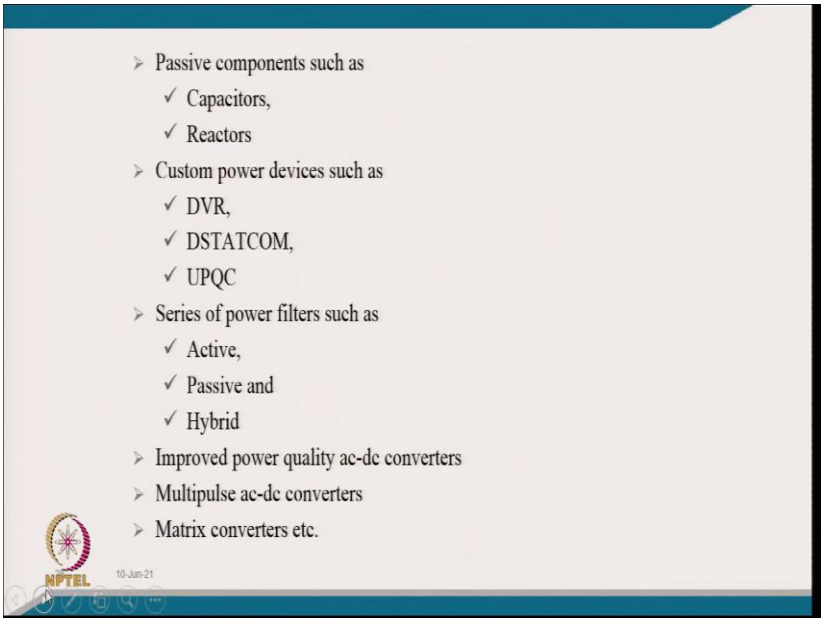

Well, we have a mitigation means like earlier we are using a passive component such as, capacitor and reactors, for the purpose of compensating the reactive power as well as providing

the compensation for negative sequence current. The passive component normally used in developing countries and developed countries because these are cheaper in manufacturing.

Later on, in the other category, the power quality improvement devices are dynamic voltage restorer (DVR), DSTATCOM, and UPQC, which are explained earlier. Furthermore, in another series of power filters, include active filters, passive filters, and hybrid filters. In hybrid filters, hybrid can be of active-active passive-passive or active-passive.

Further, at low power levels, improved power quality ac-dc converters can be utilized. Whereas, for the large rating like in case of a multi megawatt power drive, the multipulse ac-dc converter can be employed at the input.

So, these are the power quality mitigation equipment under different situations.

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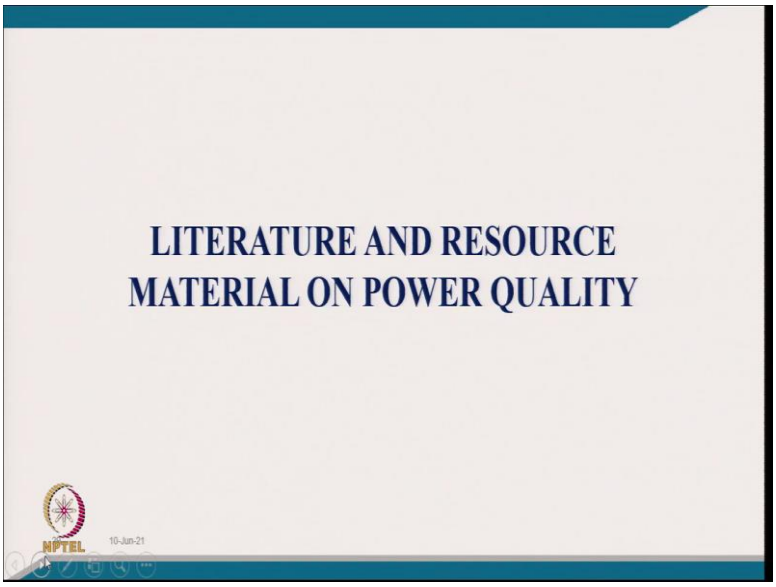

Well, we like to talk about the literature and resource material on power quality problems.

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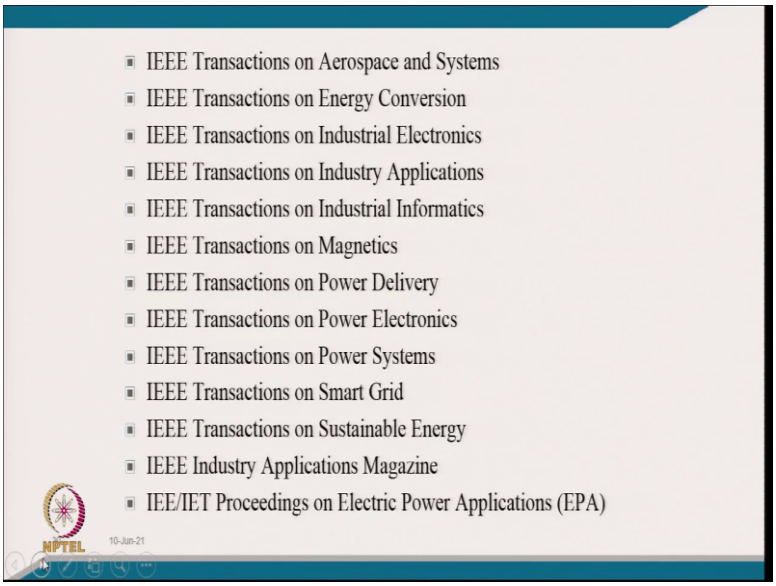

So, these are some of IEEE transactions, journals in which a lot of literature is published related to power quality mitigation techniques and mitigating equipment, under different situations.

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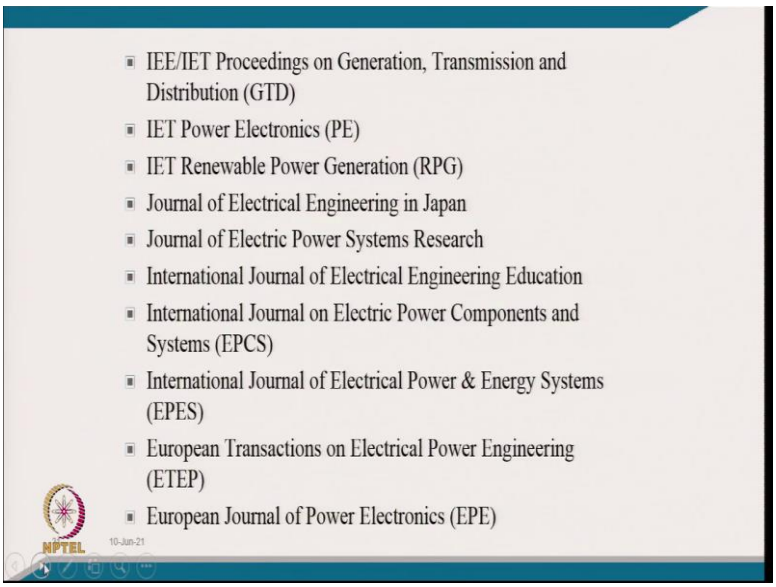

So, all these are the typical journals and there are a lot of conferences which are organized yearly by IEEE or many such organizations like IET or even other professional societies around the world.

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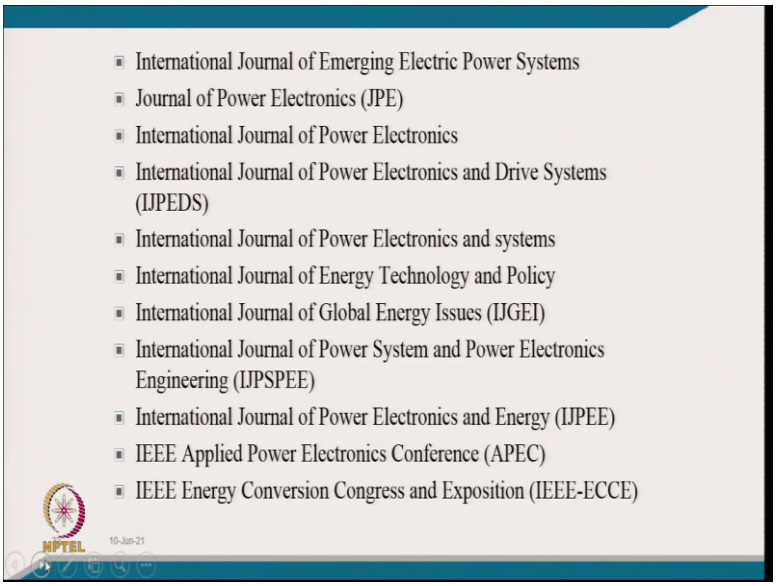

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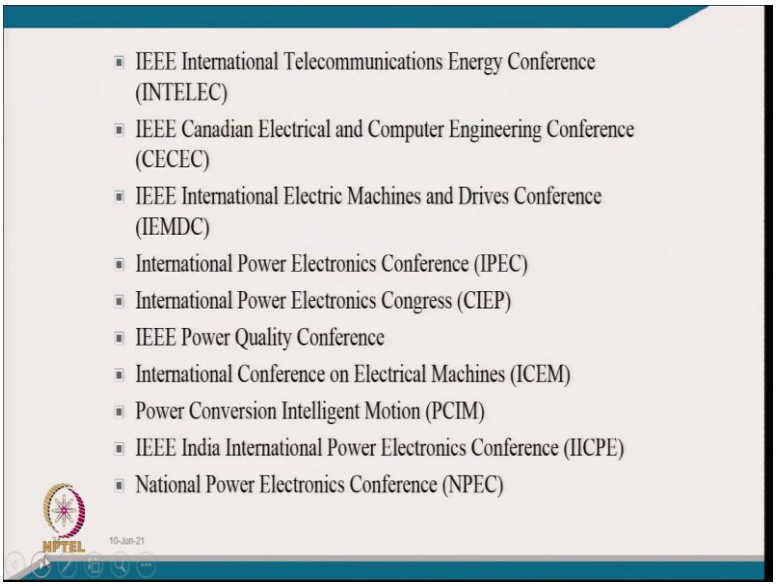

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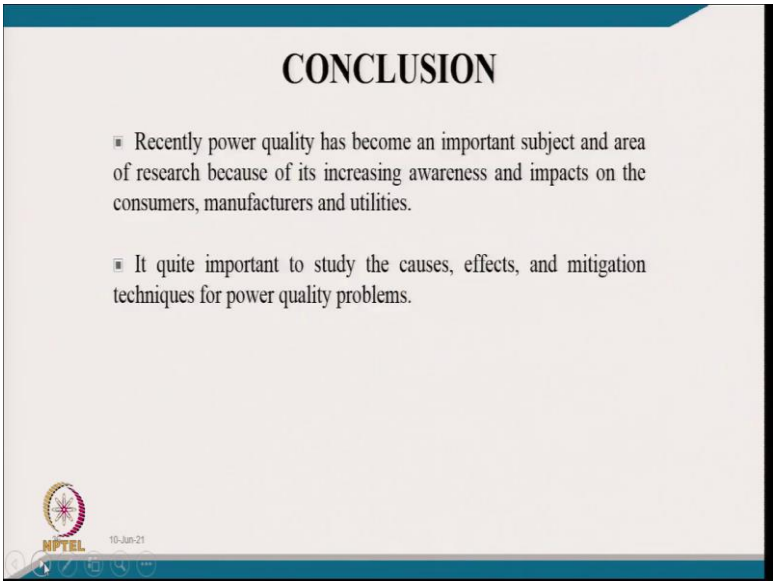

So, I will like to conclude with this. The recent power quality problem has become an important subject and area of research because of its increasing awareness and impact on the consumers' manufacture and utility. And, it is quite important to study the causes, effects and mitigation techniques for power quality problems.

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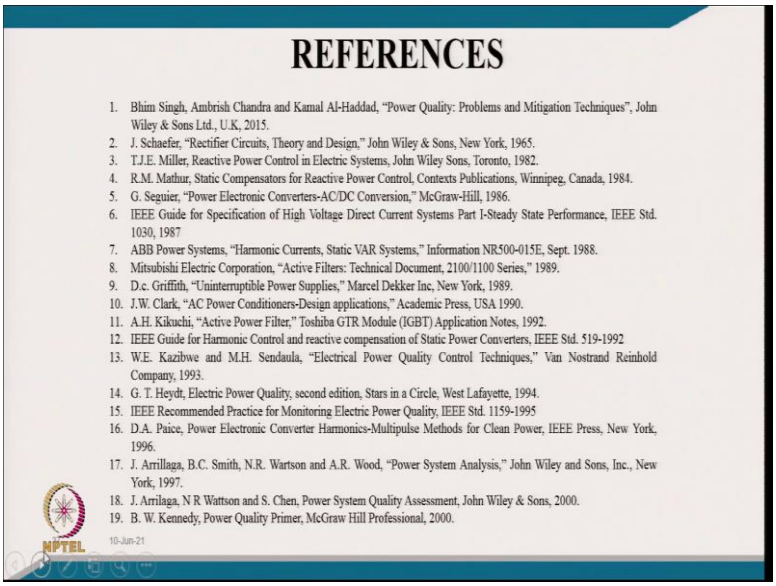

And, these are some of the references.

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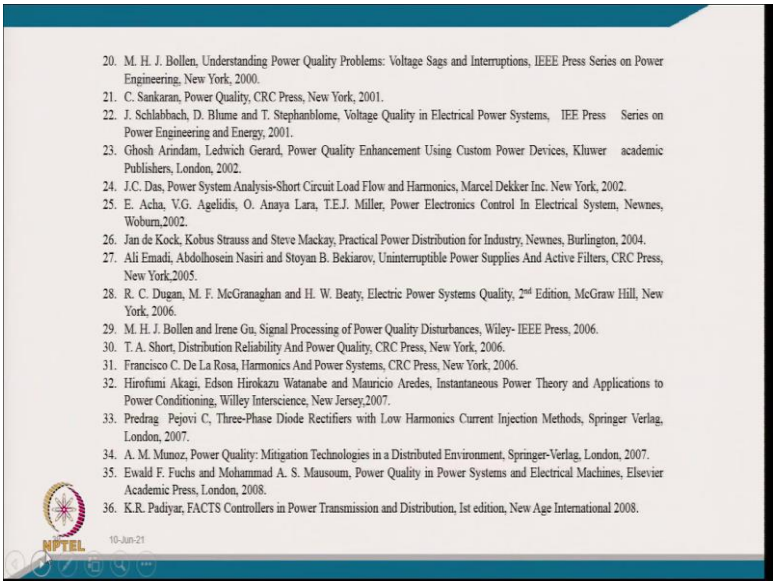

And, there are plenty of books on power quality which you can think about.

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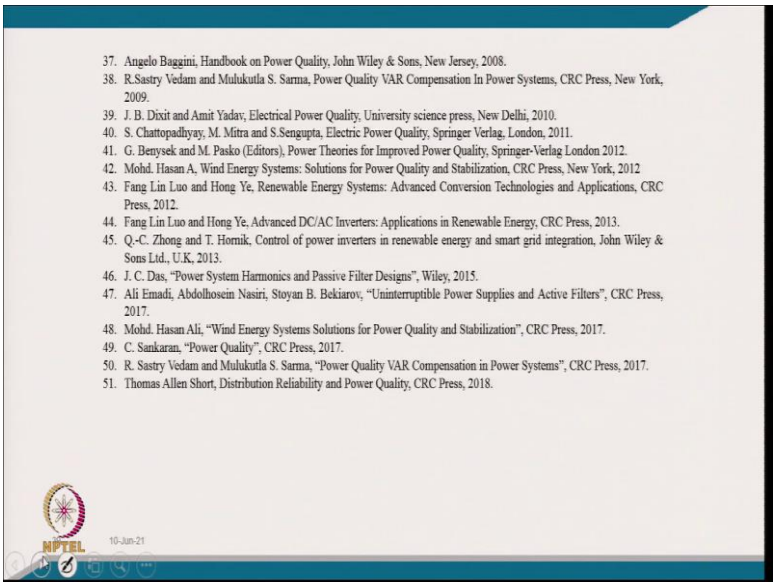

So, today, we have introduced this power quality course, by not only appreciating the power quality problems, but also talking about the why this power quality, what are the power quality problems, and how we can mitigate, what are the equipment for mitigating these problems.

At last, I would like to thank you.