Power Quality Improvement Technique
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Lecture – 01
Introduction

Welcome to our Power Quality Improvement Technique. We are going to have a 20 hours course on it. So, this is the introductory class and we shall discuss the scope of the power electronics and its definitions and its application and merits and demerits and who own the responsibility and who have been blamed every issue. These are techno-commercial aspect we required to look after for better understanding of this paper.

Apart from these introduction class, we will again review the two-pulse and the six-pulse converter and their performance with the inductive and the capacitor loading.

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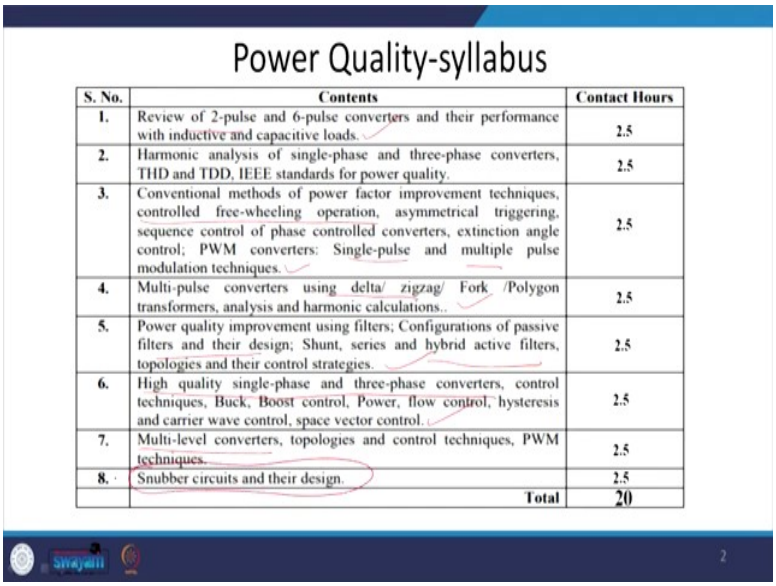

Thereafter harmonic analysis of single phase and the 3-phase converter, THD, TDD and IEEE standard for the power quality will be discussed.

Thereafter we shall discuss the different conventional methods of power factor correction technique, controlled free-wheeling operation, asymmetrical triggering, sequence triggering, thereafter sequence control phase control converter, extinction angle control, PWM converters, single pulse multi pulse modulation technique. Thereafter we shall go for high

value converter that is multi pulse converter using delta zigzag polygon transformer, analysis and harmonic calculations. Then power quality improvement technique using passive filter and their design. Thereafter we shall switch this over to the shunt and series hybrid filters, topologies and their control strategies and there after it is again AC to DC conversion.

And while referring to the AC to DC conversion, power quality will be an issue, high quality single phase and 3-phase power converter that is active rectifier, control technique of buck boost control, power flow control, hysteresis carrier control and the space vector modulation will also be dealt with. Consideration of the filters and we also required to search a suitable topology for it.

For this reason, we will again talk about the multilevel inverter and the topologies of the control technique of the PWM technique and then we shall see that snubber design. This will be something new and would also help to mitigate the power quality problem. This we will try to cover in 20 hours. Me and my TAs have a very aspirational level to complete the syllabus because this is our 40 hours syllabus mostly in IIT Roorkee, we have cut short few things.

So, let us talk about the problem of power quality. So, we want the quality power.

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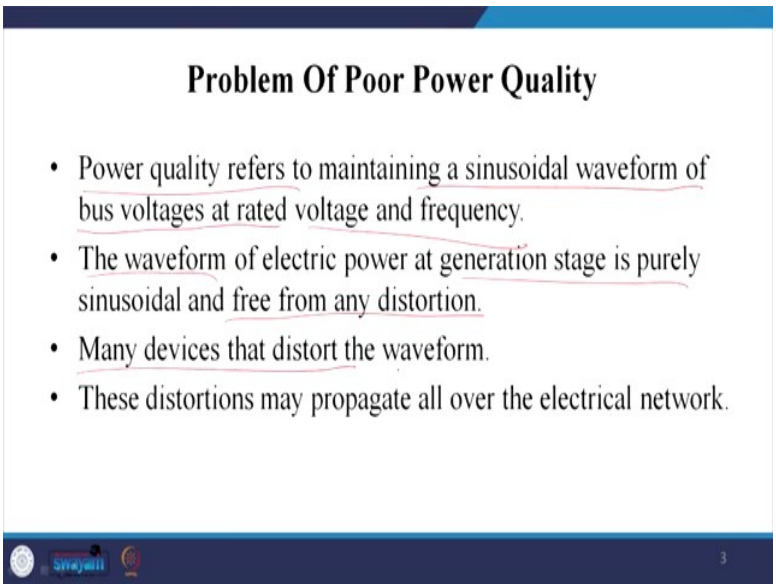

Thus, power quality refers to maintain a sinusoidal waveform of bus voltages at bus voltages at rated voltage and frequency. You should have a constant frequency and proper sinusoidal

voltage and current with constant magnitude and then only you say that, you are getting a good quality of power. The waveform of electric power at generation stage is purely sinusoidal, apart from their diagnostic and generally if you find that issues like some broken rotor or so are coming then generally those are being replaced and repaired.

So, mostly we can consider the generation stages are purely sinusoidal and free for any distortion, but in between when the power reaches to me, there are many source of contamination and thus, many devices that distort the waveforms which are the reason why we are getting a contaminated power. This distortion may propagate all over the electric network or it may be restricted or bypass or segregated. If this propagates then it is called as hazards to another person.

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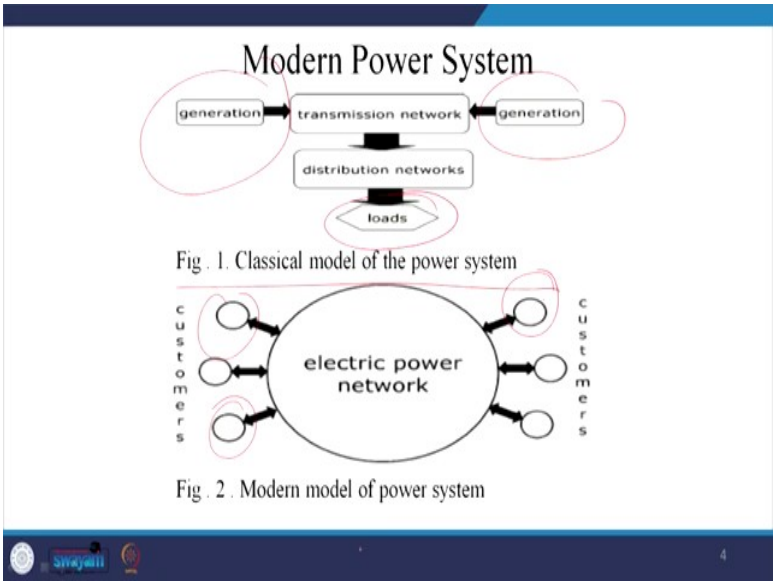

So, this model can be like this. This is a classical model of the power system. You have two generations because you may have a load that required to be feed from a different bus. So, this is the transmission network, they are distribution network and they are the loads. Now with the penetration of renewable energy even loads become a distributor source of generation. So, you can have an electric power network and here this is considered to be a ring structures, where all the customers are connected. If one of the customer polluting, then all will be affected, so this is something like this.

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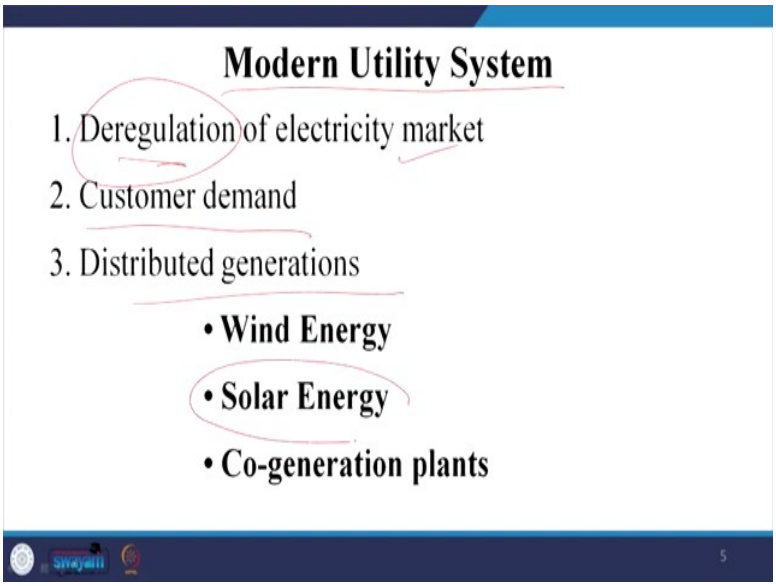

Now with the penetrations of the modern system, we have seen a commercialization aspect and for this reason deregulation of the electric market took place. What does it mean by that? You generate power and you go to the power market and say that I am selling at 5 rupees and someone else generates power and sells at 4.3 rupees. Of course, I am being a purchaser of the power, we will have a reverse bidding and we will take the power associated with least cost

This method of deregulation started in the European Union because of the nuclear power plant. Power in France is quite cheap and ultimately, it sells power to the all the countries and Switzerland. Because of Switzerland's ecosystem, they do not want to put neither nuclear nor the thermal power plant, hence their power was costly and as a consequence they were the net buyer of the power.

In that way this kind of regulated market started. Now here also, India now we have a deregulation in the electric market. In the month of August we have Ganesh Chaturthi in Mumbai. So, Mumbai will have a huge consumption of power, again just one month later Kolkata will celebrate Durga Puja and so it will be needing huge amount of power and as a result of deregulated market, Kolkata or West Bengal electricity board will be selling power to the deregulation and will have account field. And once West Bengal requires power, they will get this power credited to their account. It is something like this. Customer demand

profile also changes which is also an important issue and this has a seasonal pattern and it is increasing at some percentage. So, it should be taken care off.

Now with the penetrations of the distributed generations, we can see that mainly solar is fitted into the distribution system. We have a huge rooftop power system installation which you considered to be the load, but now it is also becoming a source of generation. The co-generation power plant, wind generation are also part of our modern utility system. What is the power quality problem?

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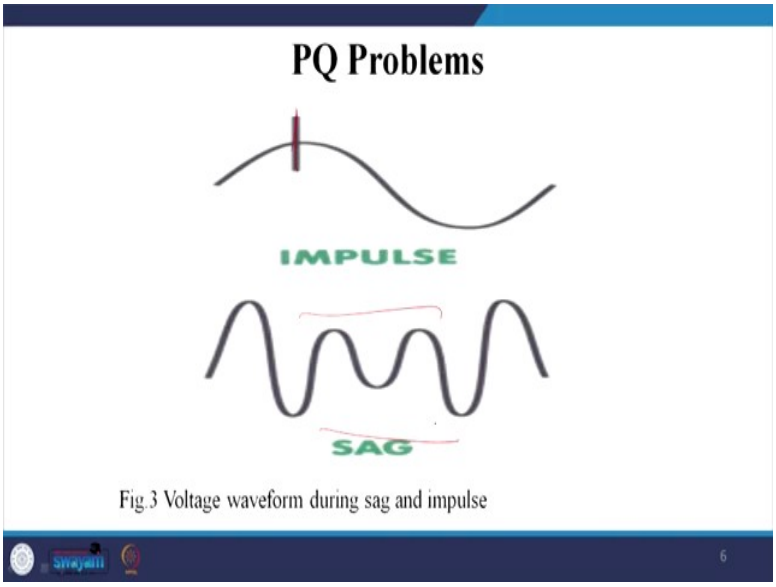

I am giving you one example here. So, all of a sudden there is a spike and this is called impulse and of a sudden we have a sag.

So, this is also a power quality problem.

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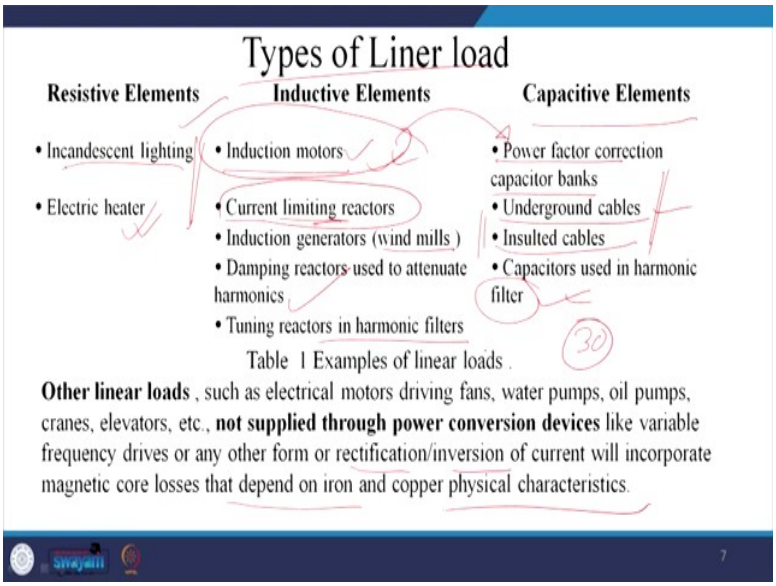

Now, first of all what kind of load we generally see? In our power system we have resistive element like incandescent lighting, so your 10 rupees electric bulb is nothing, but an incandescent lighting. There after electric heater and these are the resistive element although mostly this does not dominate nowadays. But induction motor consumes huge amount of power and deteriorates power quality because, it takes huge amount of the reactive power and also current limiting reactor.

You have seen that in a dual converter and in all such power electronics entity and you have a current limiting reactor and that is the inductor element. Induction generations for example, windmills we have damping reactor to attenuate harmonics. In a most of the power electronics converters because solar inverter and other we have to we have a PWM technique and we require to mitigate the harmonics and damping reactors are used. Tuning reactor in harmonic filters and thereafter it can have a capacitor element, mostly this power is consumed in induction motor drive and thus to mitigate this we have a solution that is power factor correction capacitor bank but that itself is nasty.

We will discuss it to the effect of the capacitor in a one chapter itself. Then underground cable because these are maybe in different potential, due to that, the distance between the soil acts as a dielectric. So, ultimately silting cable also comes into the pictures. This cable itself also behaves like a capacitive element. Insulated cable same way behaves like a capacitor

element and the capacitor used in harmonic filters. So, that also we can use very intentionally use for that reason these two comes into the picture because its inherited property.

So, other linear loads such as electric motor driving fans and water pumps, oil pumps, cranes, elevator, et cetera not supplied through the power conversion devices like adjustable speed drive or variable frequency drive or any other rectification inversion of the current will incorporate magnetic core loss that depend on iron and the copper physical characteristics. So, these constitutes our linear load and now we can say that 30 percent of the power is generally consumed into the daily unload because we are moving more towards rectification inversion and the adjustable speed drive and huge amount of power is being consumed there.

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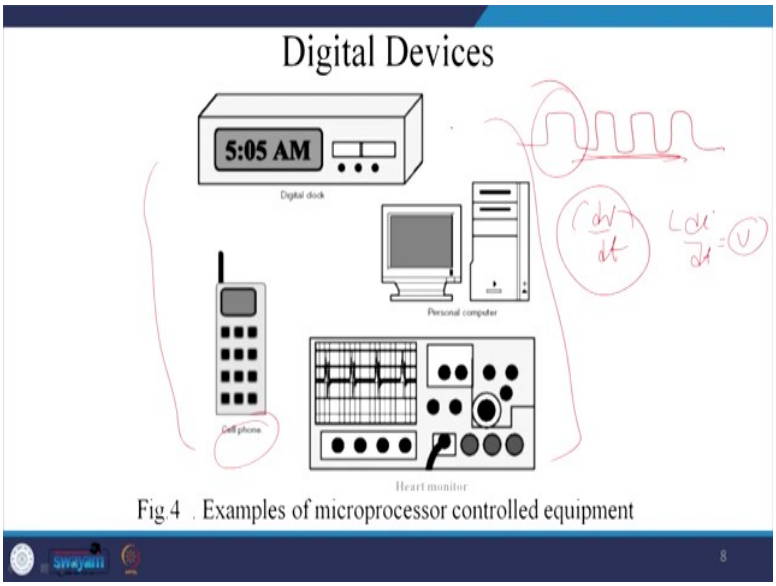

Now digital devices: though it takes small amount of power, but these are all quiet nasty elements. What happened you know, digital devices works on a clock pulses. The moment you have a very high clock pulses, and $C\frac{dv}{dt}=i$ and $L\frac{di}{dt}=v$ with that it interacts and it generates EMI EMC problem. So, these are the other issues here that has to localized here.

So, all those digital equipments are essentially required to convert AC to DC, there after it have to be a chopped DC. Once you convert AC to DC since it is a non-linear conversion you have problem with the harmonic and you thereafter make a pulsation kind of entities and that leads to the more EMI EMC noise.

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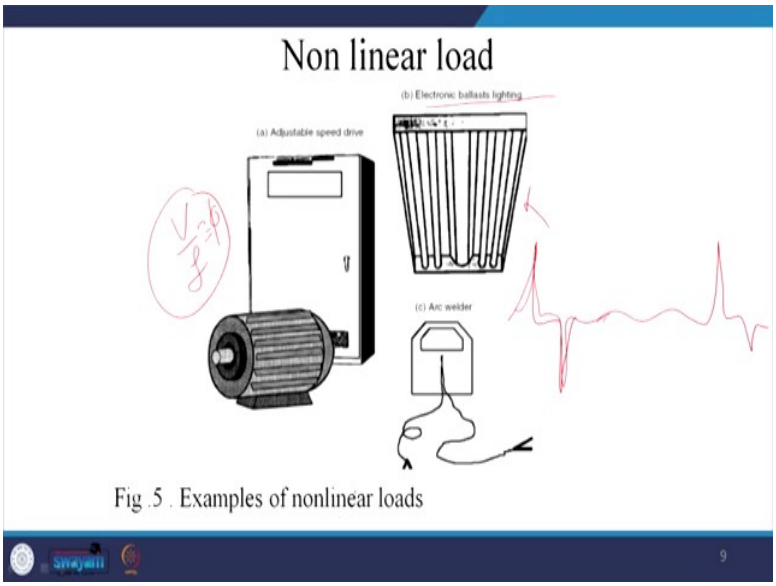

And this is an example of the non-linear load. This is the adjustable speed drive. So, it may have a $\frac{V}{f}$ control. Once you control $\frac{V}{f}$, your flux remains constant. So, thus your torque will be proportional to the current. If you keep the current constant then your torque will constant.

You can get a smooth variable speed in a $\frac{V}{f}$ control and this is an example of the electronic flash lighting. So, this will also non-linear devices here the arc comes and goes comes and goes. So, once arc comes as a picky notch and like this and there after very small amount of current will flow. All of a sudden there will be a notch these will be the current profile for this.

Similarly arc welder, once it gets short circuited, then only arc will be there and once arc is there you are trying to use the arc. So, this will have this kind of picky nature. All of a sudden there will be a sudden jump in the current. So, these are the few application where we use these non-linear loads frequently and thus the power quality deteriorates.

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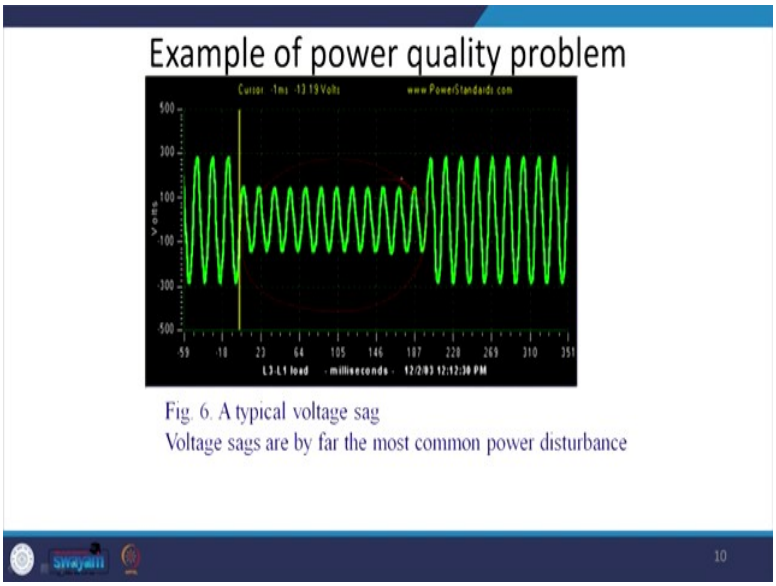

So, I am giving you one example from our data. So, look this is an example of the power quality problem. So, this is example of sag, all of a sudden sag comes, it may be that a branch of the t is touching. So, here the scale is in lower range anyway.

So, scale is touching the t and here it comes down, but it is for the high voltage that will be in a level of the kVA and it may be so, that some kind of voltage sag has occurred and so we will define what is sag an all in a subsequent classes. So, this is the example of the sag and this is also a problem.

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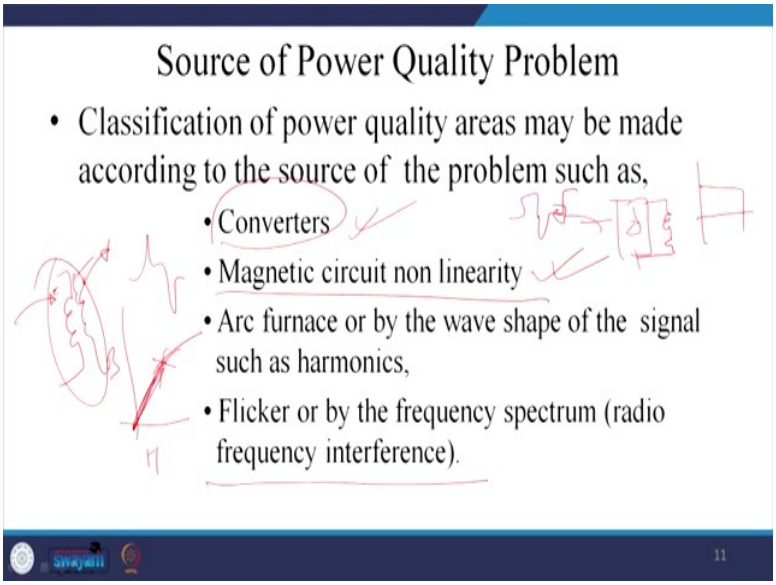

So, classification of the power quality areas may be made according to the source of problem such as converter. Once you convert AC to DC and you have, let say a diode bridge rectifier and your inductor is quite high then your load current is continuous. Thus, your source current will be a square wave.

So, you can do the fourier series analysis and find out what are the harmonic content. So, this is the case and depending on the capacitor depending on this RL, RC and different combinations, the input current profile will be distorted. Magnetic circuit non-linearity: transformer works on the principle of the demagnetizing of the flux. If current enters this point, then current will leave from this point, if load is very high then in the B-H curve, it will be close to the saturation. Once it is close to the saturation then as this region is linear region of the B-H curve, there after it goes to the saturation.

So, if it is unloaded, current you will find a little picky because so that demagnetization does not occurs. And this is the problem of the magnetic transformer, as transformer goes into the saturation mode. There also arc furnace or by the web shape of the signal such as harmonics. Arc furnace also will have a same problem. “Flicker”, we shall define all those entities by the frequency spectrum, radio frequency interference. So, flicker is above the audio frequency and hemce will cause many problems in the communication network.

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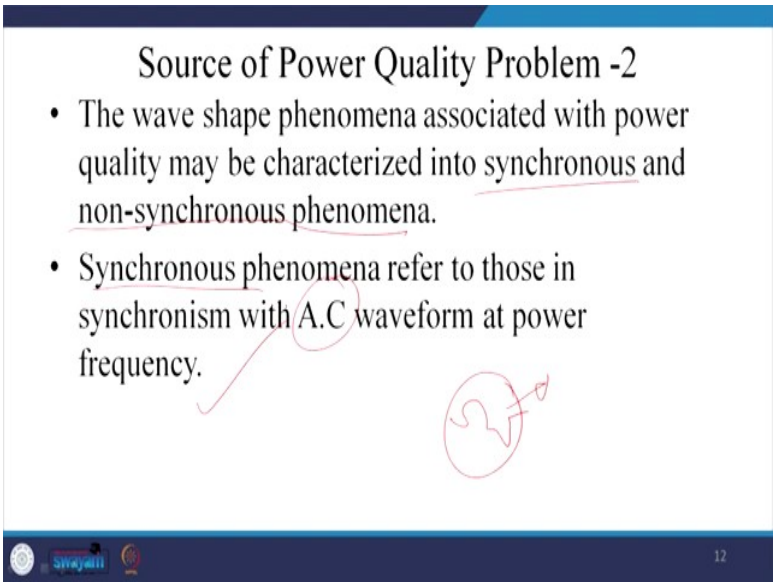

Now, source of power quality problem which may be more, that the wave shape phenomenon associated with the power quality may be characterized into two broad categories. One is

synchronous that is a 50 hertz problem and its harmonics and non-synchronous phenomena like lightning strikes and all those issues.

So, once you know that it is a synchronous phenomenon, you know how to mitigate it properly, you calculate and mitigate the harmonics which is required to be injected. Like as you know that in a square wave consisting of this kind of waveform you can do the spectrum analysis and this is repeated. So, it is a synchronous problem and once it is a synchronous problem you can apply a particular correction technique and get rectified, that you can do in a shunt active power filter. But if let's say thunder strikes, lightning strikes, then is a asynchronous phenomenon. You does never know that when it will strike.

So, for this reason eliminating the synchronous phenomena is easier. We can say that synchronous phenomena referred to those in synchronism with AC wave form at power frequency.

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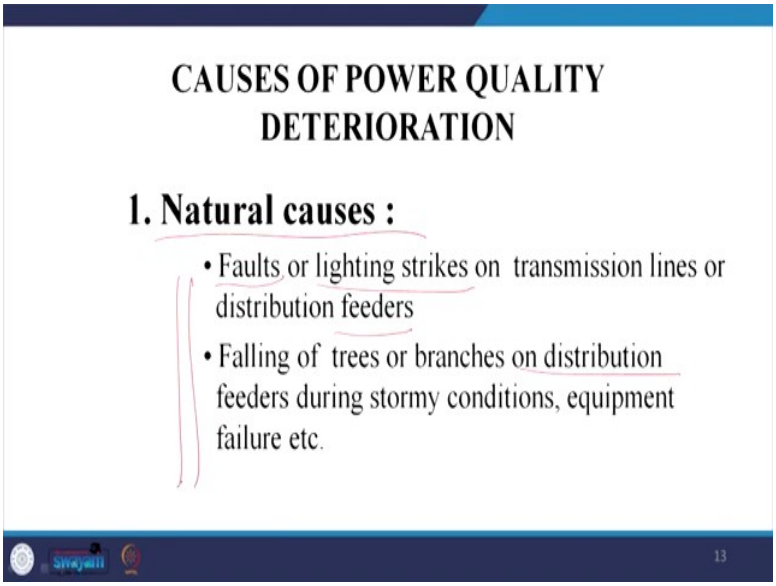

So, now let us come to the cause of the power quality deterioration. So, few are the natural causes. It is not human inflected. For example, faults of a line, L-G fault. As a result voltage sag will occur, unbalance will occur. Lightning strikes on the transmission line or the distribution feeder and it propagates since it is a surge. Falling of trees or the branches on the distribution feeder during the stormy conditions and equipment failure of the relay or any other entities.

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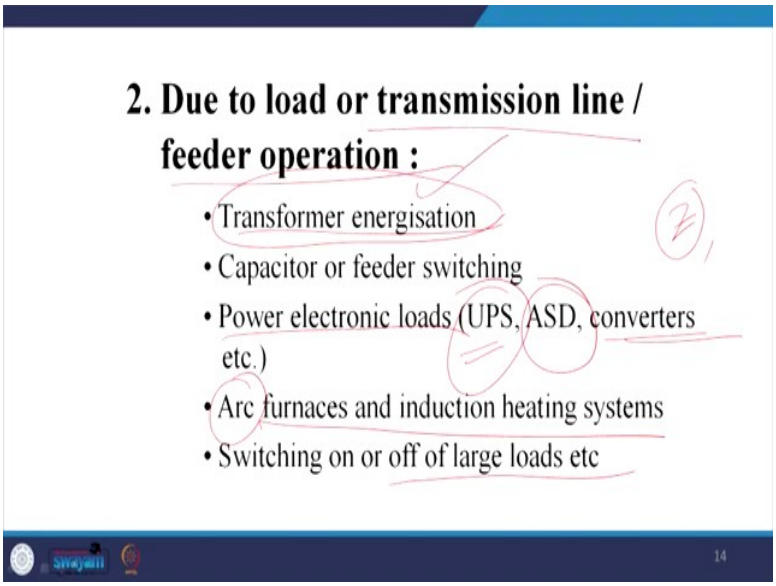

So, that leads to the natural cause and thereafter it may be due to the load or the transmission line feeder operation, transformer energization. So, once its energization in a transformer you excite the transformer, then it will have a high inrush current and the voltage will sag and this is a problem of a transformer energization. So, that also cause a sag in the voltage. Capacitor of the feeder switching: capacitor will charge very fast and thus it will cause a deep in a voltage initially and thereafter is an undamped circuit continue to oscillate. Then there are the power electronics loads. Power electronics loads mostly have a voltage source and these loads are generally constant impedance load and these can be constant power load.

So, if the voltage is low it will take more current and thus it has more problem from the stability point of view. It will take you to the more unstable region, that is another issue. So, it can be uninterrupted power supply, we generally very frequently use it in our desktop. So, there after we can have ASD that is called adjustable speed drive and different type of AC to DC converter et cetera. Thereafter we can have an arc furnace and induction heating system. So, that also cause a problem of the wave form. Switching off and switching on of large load that may also create disturbance to the power system network. So, this is due to the transmission line or the feeder operation.

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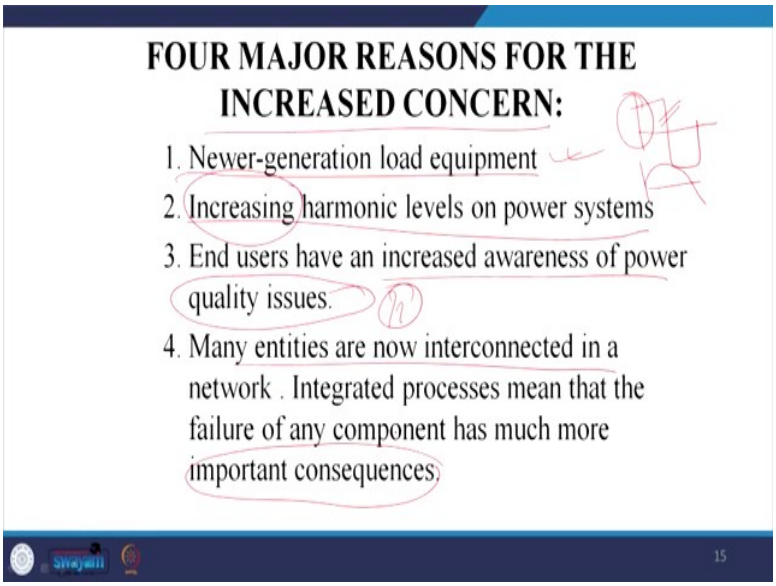

Four major reasons for the concern, is the newer generation load equipment which are very sensitive to the power quality. If it is not fitted with a good quality power, it's life will deteriorate. Why? It is very simple example you know, if you are feeding a square wave instead of the sine wave your sine wave you have, if you differentiate it, you get cos wave.

So, rate of change of voltage is quite low and since in this kind of nature it will break down the insulations of the winding. Thus, it degrades and deteriorates its performance, its life span also decrease and ultimately you put into the cost that also comes down as, instead of the 15 year, it will last 6 years and it's performance will also be less and consequently will end up increasing harmonic level on the power system. If you have more harmonic it will create more distortion into the system and for this reason THD is a measurement of the harmonic total harmonic distortion, total harmonic distortion required to be low as prescribed by the different standard that I have taken a separate class on the standard.

So, there I will discuss it in detail. End users have an increased awareness of the power quality issues because since they are giving money and they are not doing any charity, they have a right to get a good quality power to ensure that his equipment last long. So, we can also become more aware so, that quality power to be given. Many entities are now interconnected in a network, that means someone installing the solar rooftop system and they are giving you the energy guarantee to the system apart from the utility grid.

So, many entities are now interconnected in the network. Integrated process mean that failure of any component has much more important and consequences. So, for example, you know it happens to our institute that few days ago there was a power cut because of the feeder was removed as it was bad, but solar was generating power and ultimately, we failed to evacuate that power because of lack of power supply and for this reason we require to stop this inverters, solar inverters.

So, for this reason we have different entities they are linked together. So, it is not that the consumers do not get power, but also solar company fail to sell their power and they say that look I have an energy commitment of this much, I failed to deliver because of you and they can take a legal action. So, it is quite complex for this reason nowadays.

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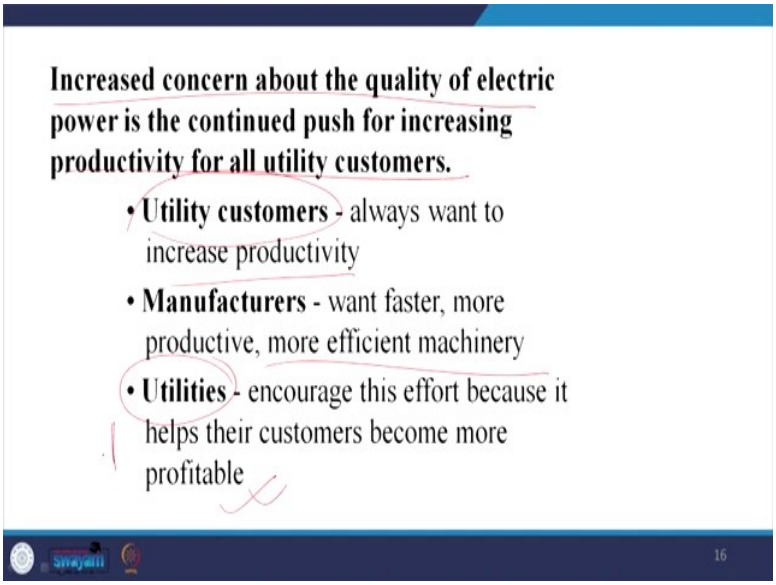

The increased concerned about the quality of the electric power is to be continued to push for increasing productivity for all the utility concern, because if you have a bad quality power your industrial production will go down, ultimately you will hamper your production cost and your labor cost will increase. So, ultimately there is a cascading effect to it.

Now, this utility customers always want increased productivity and definitely the manufacturer wants faster more productive more efficient machinery and utilities also has the philosophy that encourage this effort because it helps this customer become more profitable in that way, they can also sell the power at a good tariff.

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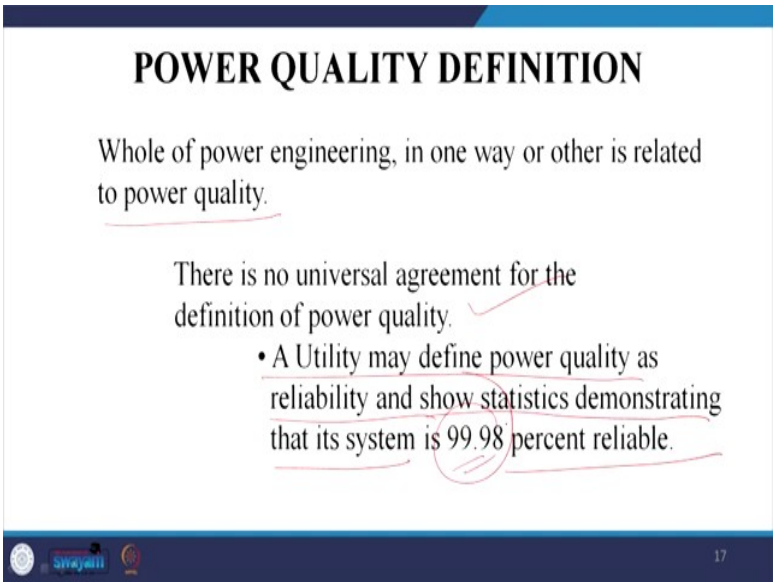

So, now let us come to the definition of the power quality, with different books write different definitions, whole of the power engineering in one way or other it is related to the power quality. There is also no universal agreement for the definition of the power quality. A power quality may be defined as power quality as reliability and like this 99.98 percent reliable.

So, why not 99.99? So, these are the tricky questions and hopefully you will understand after finishing of the course, why these definitions are being formed based on different standard and different requirement.

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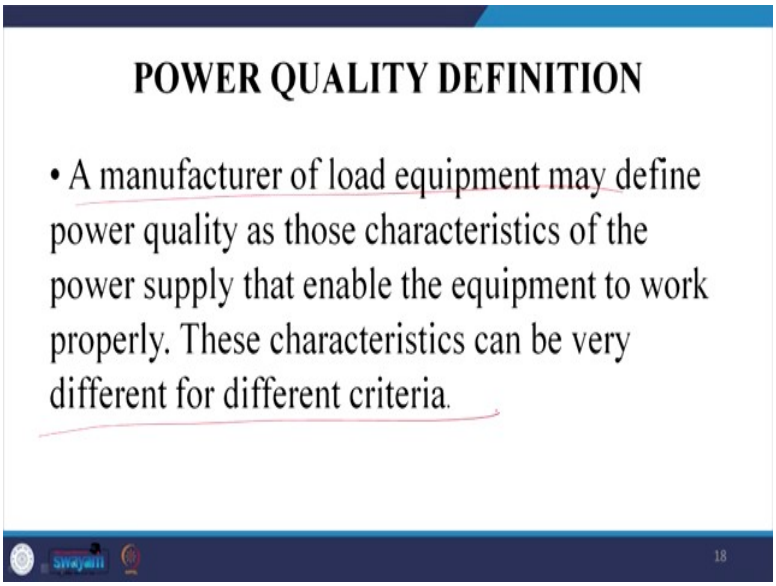

And also, from the manufactures point of view, a manufacturer of the load equipment may define the power quality as those characteristics of the power supply that enable equipment to work properly. This characteristic can vary different for different criteria. Power quality is ultimately a consumer driven issue.

I may require a particular power quality for a particular machine.

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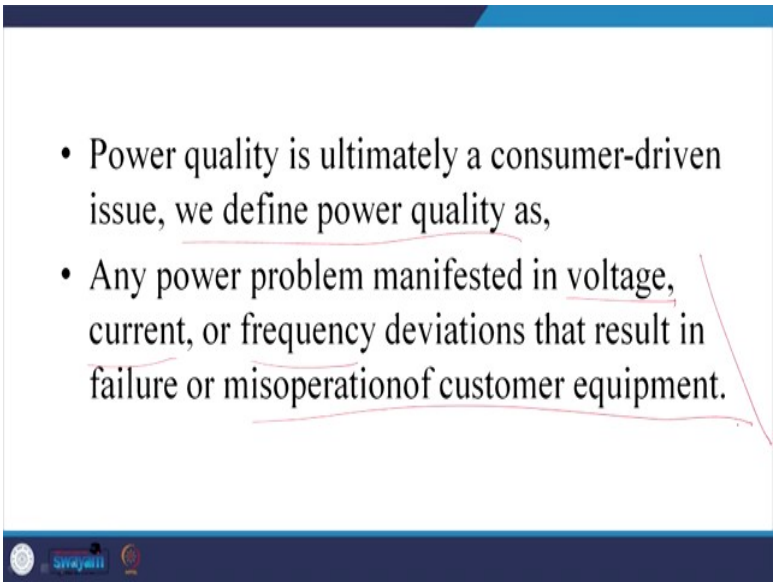

Thus, we define power quality as any power problem manifested in voltage, current or frequency deviation that results in failure or maloperation of the customer equipment. So, then we will say that we have a power quality problem.

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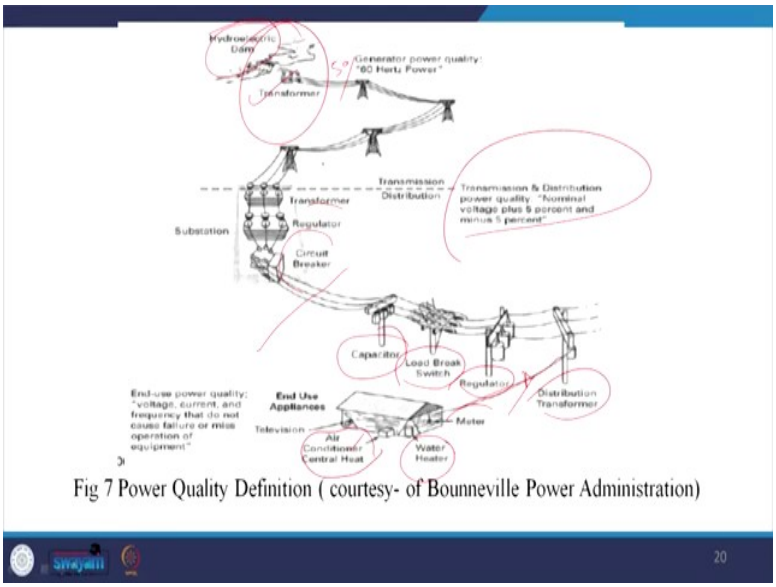

Fig 7 Power Quality Definition (courtesy- of Bounneville Power Administration)

So, this is the power quality definition and how power flows and how power get contaminated.

We have taken a hydel power example and there is a hydel power dam thereafter it can be 50 or 60 hertz and from a transformer it comes and then transmission distribution system here power quality nominal voltage plus 5 percent plus minus is available to you. Thereafter transformer, regulator, circuit breakers that you got a capacitor bank, you got a load switch, you got again regulator, there are your distinguisher meter.

Thereafter in your house, you got a television, you got water heater, you got a meter for billing. This is a way from here you get the power and in between generally here power is satisfactorily generated all are sinusoidal, but in between some way it been corrupted and what happened you know if you get a corrupted power then your equipment will not last long or malfunction. So, thus we required to ensure that from this point to this point power quality is been maintained, but mostly though it is restricted to the distribution system. So, transmission system does not have much problem on the power quality apart from the voltage sag.

Thank you for your attention. I will continue my discussion in my next class.