Power System Operations and Control
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Module - 01
Lecture - 02

Welcome to lecture number two of module one. We have seen in the previous lecture that is lecture number one that our power system that is present day power system is highly interconnected, and it is highly complex power system. So, our main motto to operate the power system in a certain sufficient way that we should supply power in uninterruptible way to our customers; there should not be any blackout, although, blackout is there that must be as minimum as possible.

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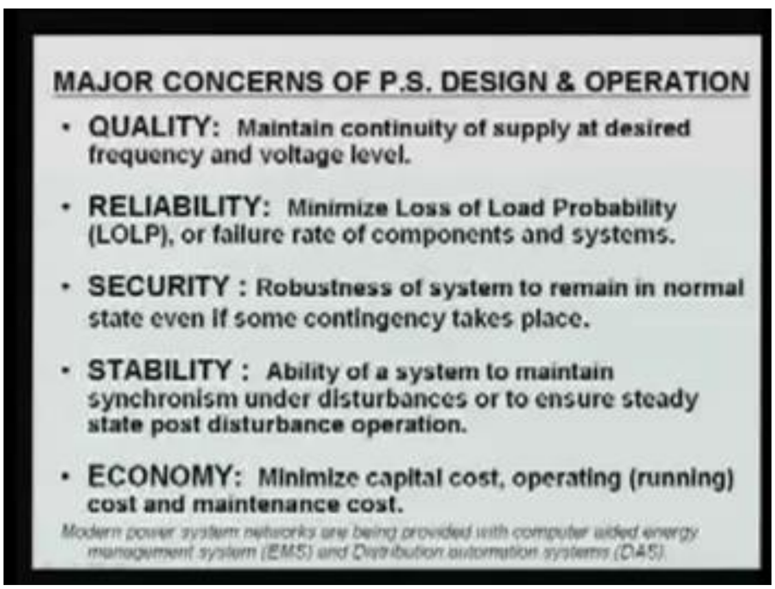

So, our basic concerns that is we can say major concerns of power system design and operation or basically the power quality; that is one of the very raising issues nowadays. We should have the reliable power system; that is we can say the reliability and we can have the secure power system means power system security is another concern in the designing of power system as well as the operation of the power system. And also our power system should be stable, so that our system should be stable as well.

And last but not least, we must supply the electricity to our customers at the cheap rate means we should operate our power system in the most economical way. The power quality here this is known as basically it is defined already now this IEEE has given some definition the power quality is to maintain the continuity of supply at desired frequency and the voltage level. I will discuss more detail about the power quality issues, but we can see other issue that is reliability. Reliability of a power system is related to basically to minimize loss of load probability that is called LOLP or failure rate of components and the systems.

We have to design our power system means the elements should have the least probable for the failure means we should have the minimum failure in the equipment damage or equipment failure in the system. So, we can say our system is reliable like a transmission line; let us suppose there is a possibility of breaking of the conductor is least, then I can say our transmission line has the least loss of load probability. Similarly, for the transformer; if the transformer outage or failure of the transformer is minimum, so it is just basically we can say the reliability we are improving.

Another term is known as the security means we should design our power system; we should operate our power system that our system must be secure. Security is related to the robustness of the system to maintain in the normal state even if some contingency takes place. Contingency are nothing but outages; it may be outages of generating stations or outage of power plants. Normally, it is two types of contingencies are in the power system. One is called the branch outage and another is known as power outage. Power outage means the outage of generators, outage of compensating devices, outage of some SVC static VAR compensators.

So, these are the power outage whether it is a real power outage or reactive power outage; both are coming into the power outage contingencies. In the branch outage, normally the outage of transmission lines, outage of your transformers is coming to that category. So, that is normally people get confused in the reliability and the security. The security is related to this robustness of the system to maintain in the normal state. What are the normal state means our operating limits of your power system that is the line flow limits, voltages limits, generators limits, etc, tap limits; if all are well within limit, we can say our power system is secure.

So, the security if right now there your system is operating in this well secured manner means in normal states there is no violation of the power system states, but if there is any contingency which is going to come into the near feature, what will be the state of your power system if you are planning in such a fashion that the effect of that contingency will not lead to a power system in abnormal condition, then we can say our power system is secured one. However, the reliability is related to the probability of outage of equipment; like equipment again I can tell you, it is equipment corresponding to branches, your power outages, etc.

The fourth concern for the power system design and operation is your stability. So, as you know the stability is one of the big concerns in AC power system. So, it is ability of a system to maintain in synchronism under the disturbance or to ensure the steady state post disturbances operations; it means we have to operate our power system in your secure, reliable and also as well as the stable manner. To several equipments, several generators are connected in the AC power system. They must operate in the same frequency; we cannot have the different frequency means they are operating in the synchronism.

So, the stability is one of the concern already we have seen in our previous lecture that the stability in the AC power system is one of the major concern. We will see much detail about the stability in the later lectures, and we will find what are the various stability criteria’s, how we can improve it, what are the other related issues in the stability of the power system. There is last that is economy means our main emphasis of the power system engineers to operate their system in a least economical way; it means always we have to reduce the cost of capital cost means we have to operate our power system with the minimum capital cost, minimum operating or you can say sometimes known as the running cost.

And at the same time, we should invest minimum on the maintenance of the whole power system operation. So, the economy is also one of the major concerns and if you are operating your power system in economical way; it means that you are providing electricity at the cheap rate to your customer's. Modern power system networks are being provided with the computer added energy in management system. Normally, it is known as EMS and in the distribution side because energy management system is related to your supply side; that is we have to operate our generating stations in such a fashion that the cost of production is as minimum as possible.

Similarly, in the distribution side, we can also automate; we can also operate our distribution system in automatic way, so that we can minimize the fault; we can minimize the losses, and finally, we can give the better service to our customers. That is one of the main mottos of whole electricity business. Now let us come to this your power quality. Here this power quality as I said, the continuity of the supply at the desired frequency and the voltage level.

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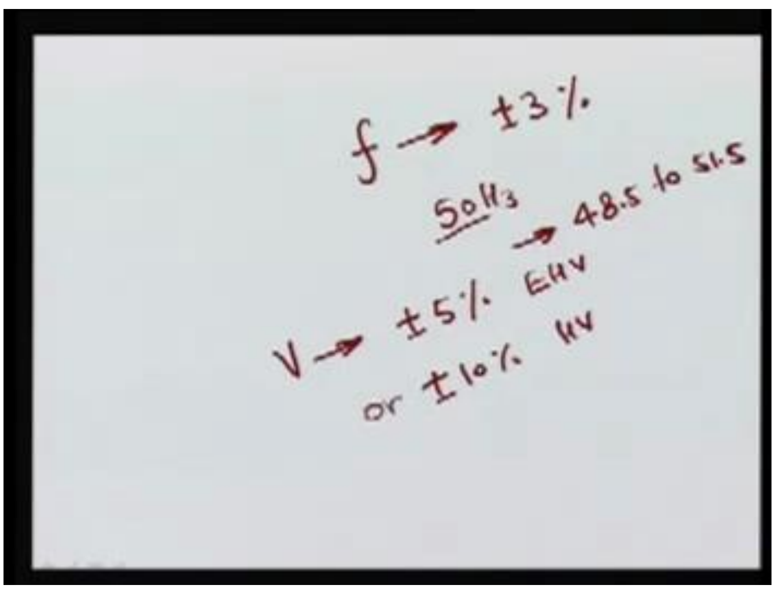

Normally, here the power quality if you achieve in terms of frequency variation, here your frequency of the power system always we operate in the plus minus three percent of the normal rated. So, if we are operating at the 50 hertz here 50 hertz cycle as you know in Asian European country, we operate our power system at the 50 hertz, whereas the USA and the Canada, they operate at the 60 hertz. So, if your frequency of operation is $50 \pm 3\%$ gives you that you must operate your power system with the 48.8 hertz to your 51.5 hertz.

Now question why we want in the narrow band? There are so many reasons for that. It has a lot of advantages if you are operating your power system near to the 50 hertz, because your equipments are giving satisfactory performance at the standard that is the normal frequency. So, if you are operating beyond this limit, it is not desirable, and it leads your system is a power system which power you are supplying it is not good in the quality.

Similarly, in terms of voltage, normally voltage for the EHV system, we have to go for only plus minus five percent for EHV system that is extra high voltage that is more than 220 KV system. It can be also $\pm 10\%$ for the lower distribution system; it means HV system and the medium voltage system. So, these are already the standards, because if you are operating beyond this, there are so many possibilities that your system will not be stable and reliable. So, in terms of frequency and the voltage and these are the steady state value; it means your frequency is plus minus three percent in the steady state.

Similarly, your voltage is also plus minus five percent or here plus minus ten percent in steady state, but there are so many chances that your voltage is something different in the fraction of second, so that here let us again go for this more detail about the power quality issues.

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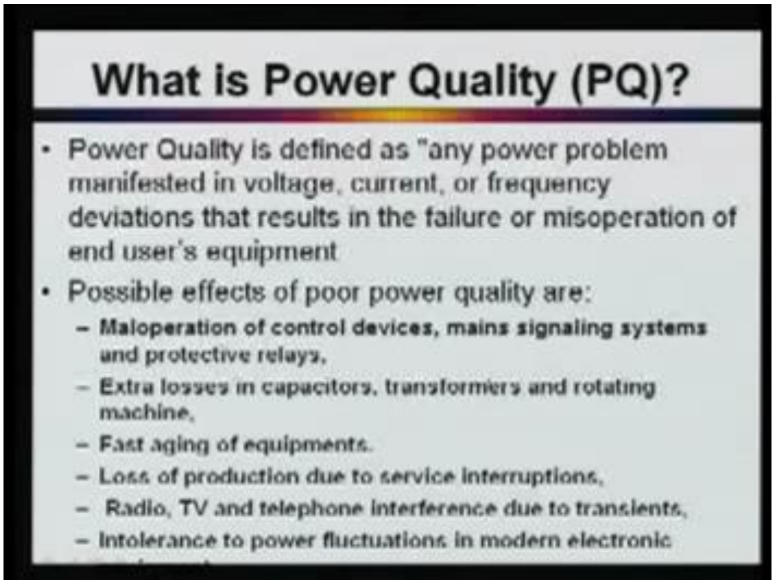

The question arise what is power quality? Power quality as per definition; power quality is defined as any problem manifested in the voltage, here the voltage, current or frequency or combination of any deviations that results in the failure or mis operation of end user equipments. So, always we must try that we must provide the electricity at the standard voltage current and the frequency. The possible effects of poor power qualities are that mal operation of control devices; you know there is lot of these machines. They are very much sensitive to the change in the frequency.

We are using lot of control devices. They are directly related with the frequency of the supply system. If your supply system changes, what will happen? Then these control devices may operate in different fashion, and that may lead to huge production loss, and sometimes, it may lead to your production loss as well as equipment itself may not operate in satisfactory manner. It may also affect, sorry, signal means signal systems and also the protective relays. So, a poor quality may lead to your mal operation of control devices, mains signaling systems and also the protective relays as well.

This may also lead to the extra loss in the capacitor, in the transformer and in the rotating machine. Normally, if your power quality is not good, let us suppose your supply you are supplying to your customers, it is rich of harmonics; it means you have frequencies other than 50 hertz your normal frequency. So, what will happen? There will be huge loss in the core; that is core loss other than your I^2R loss. So, it will lead extra loss. And it means if extra loss is there means efficiency of the system is not good; it means you are operating in inefficient way.

Another problem of the poor quality is the fast aging of equipments; you have the equipment that equipment may be very costly. So, it always better that we must supply in the better quality way, so that aging of the equipment can be minimized. Some of the harmonics as well as the transients and other disturbances may create lot of problems to your equipments, and that may lead to the aging of the equipments in terms of your insulation failure, in terms of other failure, etc. Another concern here is loss of production due to service interruption, because interruption is one of the PQ problem.

Again interruption I will come to later stage that interruption may be of different kind. It may be momentarily, it may be instantaneous, it may be for long duration**.** If any interruption is there, certainly, that will lead to your loss of production; at the same time, it may give you some of the loss of waste material. For example, you can assume that if any production unit is running and there is a certain interruption in the supply, what will happen? All these material which were passing, they will be standard style and your output will not be the perfect which we want.

So, therefore, the loss of production and also that is lot of waste will be generated if there is any interruption in this one. This power quality will also lead in terms of radio, television and the telephone interference due to the transients. If the transients you have supplied is having lot of transients, so always we will face this type of interference in terms of telephone, radio as well as the TV receptions. Intolerance to the power fluctuations in the modern electronics equipments; most of the modern power electronics equipments, they are very much sensitive to this power quality issues.

If your power is fluctuating, then they will not operate satisfactory. No doubt, these power electronic devices are the major source of the pollution of the electricity supply that they are creating the power quality problems. But at the same time, they are very much proved if the power quality is not good, they will not operate in the satisfactory manner. So, what are these various PQ disturbances?

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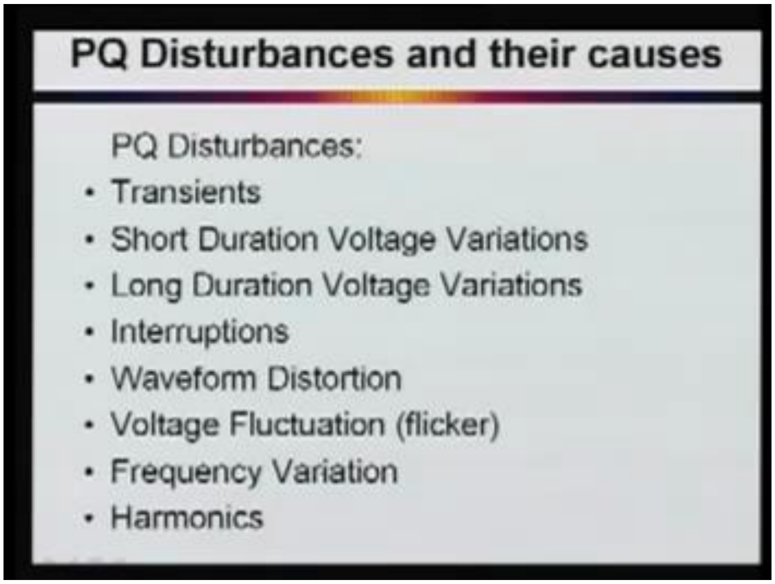

The various PQ disturbances can be categorized in the eight different disturbances. First one is your transients. It may be your short duration voltage variations, your long duration voltages variations, interruptions, waveform distortions, voltage fluctuation; that is also known as the voltage flicker, frequency variation and the harmonics.

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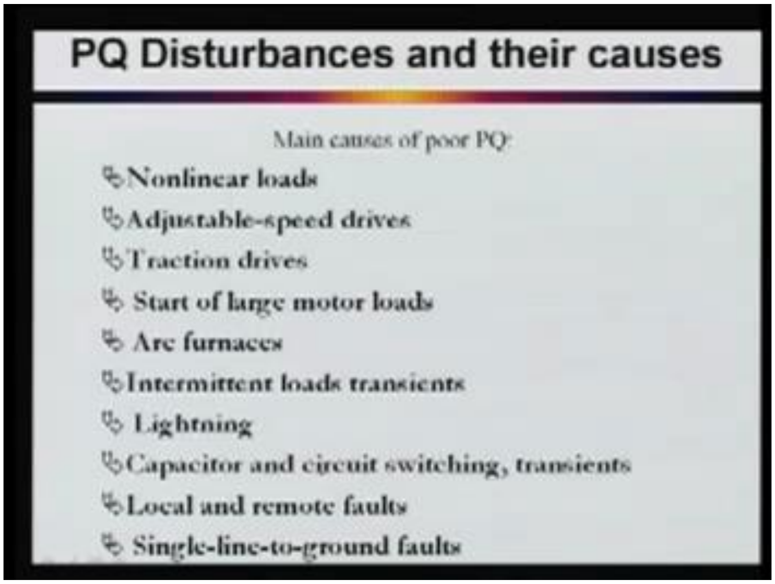

Here, let us see the major causes; we will come later about the various disturbances, and I will explain one by one. But what are the major causes of the poor quality? First one is the nonlinear loads; now what are the nonlinear loads? All the power electronics driven loads, they are connected either all the power electronics like converter if your load is fed through the converters or any other like arc furnace, etcetera. They are the nonlinear loads, and these nonlinear loads create lot of problem to the power quality. So, the nonlinear loads are one of the major causes, other is the adjustable speed drive.

Nowadays, we are using the AC drive with the power electronics controls AC drive, and we call it adjustable speed drive. They create this lot of problem in terms of harmonic generations; they generate harmonics. And those harmonics again we use some filters to filter out all these harmonics, but still they are not enough. The tracks and drive, the tracks and you know in railway, we use the DC generators for moving the trains. Earlier, we were using DC generator, but nowadays, we are using induction motors. And they are basically used with some power electronics devices, and they are also single phase. So, these power electronics devices once they are used in the system, they pollute much to your power quality your supply system.

If you are starting large motor, what will happen? They require huge inrush current that is rich of harmonics, and therefore, if sudden huge current is flowing so that create lot of power quality problem in your supply system. Arc furnaces also they introduce power quality problem, intermittent load transients. If there is some intermittent loads, they create transients, and that is also one sort of major cause of poor quality lightening. Lightening means if the lightning is strokes, those are coming from our sky, and they may create a lot of power quality issues.

Capacitors and the circuit switching transients, if your capacitors is switched, normally they are in the distribution system; if you are switching, you know the switching instant is very very important and you do not know at which instant you are going to switch. So, they may create because they store energy; we have the interrupter in the circuit. So, there may be RLC resonance and other things. So, switching up your capacitor and the circuit; circuit means if a line, etcetera, if you are switching in and out that will create some power quality disturbances, and they normally leads through the transients, the faults.

You know the power system; there is lot possibility of the faults, because we have the overhead conductors those are going from the generating station to your customers. And there may be some local faults, there may be some remote faults, and again the fault will be of different kind. It may be single line to ground fall or it may be this LLL; that is the three phase fault. They create lot of problem that may be in terms of dead short circuit, may have the low voltage, may have some transient. So, here the faults are also one of the main causes.

So, most of the our bare conductors transmission line towers as well as the conductors, they are open to the sky and any disturbances falling the tree, birds, etcetera; that may create some faults, and therefore, that may be one of the concern for the poor quality. That is why here I mention the single line to ground faults means here the LG fault that is line to ground faults is also one of the major cause of the poor power quality.

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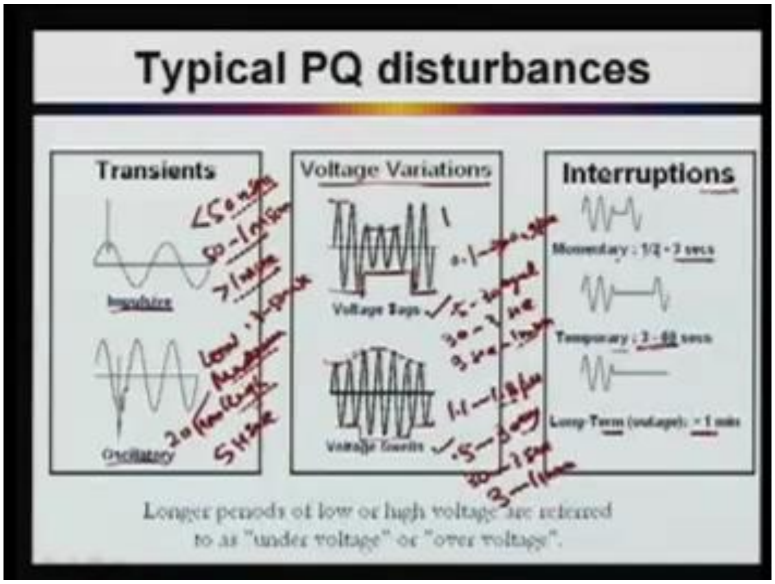

Now let us see the various power quality disturbances. The typical power quality disturbances, first one is transient. You can see here the transient may be of two types. One is your impulsive transient, another it is your oscillatory transients. Here it is known as impulsive, because you can see this is a perfect sinusoidal wave shape; it may be your voltage or current. And if there is some impulses here, it is known as the impulsive transient. And if it is oscillating in nature, you can see here it is oscillating; so, it is a oscillatory transient. The transient again can be of the different magnitude in terms of time; it is called the impulsive, may be your nanosecond, microsecond, or it is called the millisecond.

If your impulsive transient here it is less than this 50 nanosecond, then it is called nanosecond impulsive transient; if it is from 50 to 1 millisecond, then it is called your microsecond impulsive transient, and if it is your more than 1 millisecond, then it is known as your millisecond impulsive transient. Similarly, for the oscillatory, here it can be classified in terms of three terms. That is your low frequency oscillatory, medium frequency and it is your high frequency. So, if your frequency here it is 0.3 to 50 millisecond, then it is known as your low frequency oscillatory transient.

If it is of medium is known as 20 microsecond, then it is known as the medium frequency and your high if it is 5 microsecond. So, here the transients again can be categorized of different category as I said it is an impulsive or it may be oscillatory. Same time this impulsive can be categorized in the three; that is your nanosecond impulsive, your millisecond impulsive and your microsecond. So, this is your nano, this is your micro millisecond, and this is your millisecond.

Similarly, this oscillatory transient can be of as I said the three types. It may be low frequency oscillatory transient, medium frequency and also it is the high frequency oscillatory transient. Another PQ disturbance is your voltage variations. Again your voltage variation can be divided at the two that is it may be of voltage sag or voltage swell. Voltage sag as a sag means there is a reduction in the voltage; there is a voltage dip. This is also known as the voltage dip or voltage sag, and another is voltage swell. You can see from this figure, here you have described your voltage is more at the particular here; till here it is okay, and suddenly, this voltage magnitude is increased and then it is reduced here.

Let us come to the first voltage sag here. Similarly, here the voltages or this magnitude in the steady state, and suddenly, the voltage is reduced, and then it is again falling at the normal voltage. So, this is known as the voltage dip. Again this voltage dip is categorized in the three categories. One is your instantaneous that is called instantaneous; another is your momentarily, and third one is your temporary voltage dip. Here the voltage dip, this magnitude how much dip? If it is less than 0.1 to 0.9 per unit if your voltage dip here this voltage is between 0.1 to 0.9 per unit, then it is called voltage dip.

Here why it is 0.1? If this is less than 0.1, then it is called as interruption because sudden short circuit as the voltage is almost zero; 0.9 here just we have mentioned because 0.9 more than voltage of 0.9 per unit, it is known as the normal voltage sometimes. So, this voltage here instantaneous voltage sag is again if your duration is 0.5 to 30 cycles, then it is called instantaneous. Here if it is momentarily means from 30 to 3 seconds here 30 cycles to 3 second, and your temporary voltage dip, it is from 3 seconds to 1 minute. So, here your voltage dip if it is up to 1 minute, then it is called voltage sag.

There is always possibility that your power system can operate especially in our country. This is the continuous voltage dip means voltage dip for the longer duration; it may go for even the hours, especially due to the heavily loaded; that is not your power quality problem. That is a different type of power quality. Another is your swell here if your voltage is between 0.1 to 1.8 per unit means your voltage increase from 1.1 to 1.8 per unit; it is known as your voltage dwell means voltage increase.

Again this is classified into three categories. One is your instantaneous; instantaneous here again it is from 0.5 to 30 cycle. It is also momentarily if we will define if your duration is from 30 cycle to 3 second, then it is called momentarily voltage swell. And here if it is from your 3 second to 1 minute, then it is called temporary voltage swell. Now let us come to your interruptions. Interruptions here, normally these interruptions are also known as the long duration variations voltage basically variations. Here the interruptions can be also classified into three categories. One is your momentarily, another is your temporary, and third one is your long term.

The interruption if it is for 1.2 means half cycle to three second, then it is called momentarily. It is from 3 second to 30 second here, then it is called temporary interruptions, and if it is more than 1 minute, then it is called long term or basically normally finally it is known as the outages. So, this is your interruptions.

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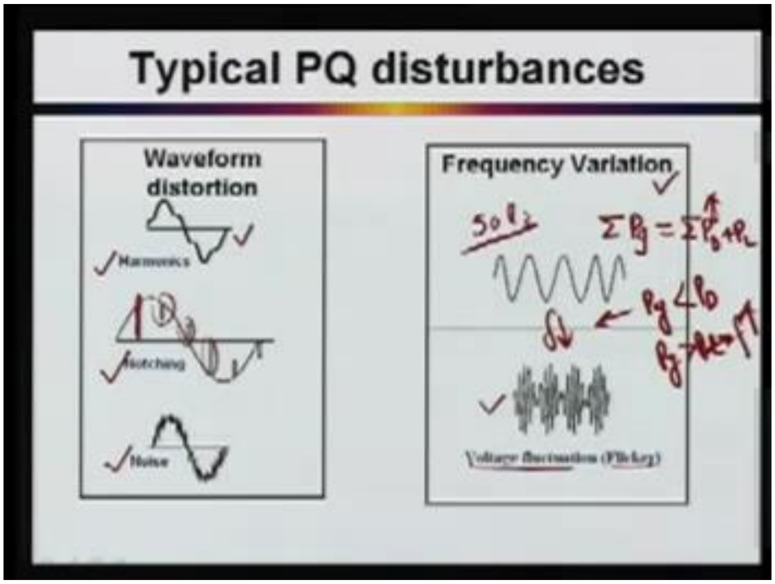

Now another here that is your waveform distortion; in the waveform distortion that can be classified into again three categories. One is your harmonics; second one is notching, and third is your noise. Here as you know the waveform distortion, we must supply our power at the perfect sinusoidal your AC that is the AC voltage as well as the current should have the perfect sinusoidal curve. But if there is any deviation in those variations in terms of voltage and frequency, then it is known as the waveform distortion. First one is your harmonics. Due to the harmonics because we know we are supplying our power at the 50 hertz cycle.

So, your sinusoidal should follow the 50 hertz in terms of current as well as the voltage. Any other frequency components if they are there, then what will happen? That is your frequency here, your variation of sinusoidal voltage will be distorted. So, in presence of harmonics, your waveform will be distorted, and it will be looking like this figure. Here we have some harmonics; those are added with your fundamental component. Fundamental means here the 50 hertz supply. If there are some notches here, you can see this is a perfect sinusoidal, but there are certain here notches.

There is some sudden dip like here you can see here you can see. So, these are basically called the notches, and those are also not required. Third type of waveform distortion if your supply is with the noise; again noise may be white noise. It means your mean will be zero. It is basically superimposed on your sinusoidal here this curve, and this curve you can see here. This is some noise are coming and then it is called noise, and we do not want this one, because these noises create some sort of extra losses, and also they may create interference with other neighboring circuit and so on, so forth.

Another type of PQ disturbances is your frequency variation. Here as I said our nominal frequency is 50 hertz, then we should have the 50 hertz supply throughout the day throughout the hours, but there may be possibility. Your frequency is somewhere less, somewhere more; again it depends upon the power system loading. If your power system is highly loaded, then what will happen? Then there may be possibility the frequency of the system may fall; why it will fall? The question arise; normally you know this always whatever we are generating power that must be utilized at the same time

But if your power normally that is called the power here that is the summation of power generation that must be equal to your summation of your demand plus some losses in the system. But if any quantity here let us suppose your demand is more than your generation, what will happen? Then we have to use this we are consuming means we are consuming more power from the system; it means whatever the energy we have in terms of store energy that is the speed rotating mass is there.

So, it has the kinetic energy; that energy can be utilized for delivering this power, and if this is utilized, then there will be fall in the rotating mass, and therefore fall in the frequency. So, the frequency here if your generation is less than your demand, the frequency will be your fall. And opposite to that if your generation is more than your demand, then your frequency here will arise. So, we want that a continuous frequency because the frequency is very very important especially in the some of the control devices. They use this frequency if there will be some change, then it may lead to a lot of production loss, and sometime it will lead to the mall operation of the several control devices.

So, we want that frequency should be constant to its rated value, and that is why it is called frequency deviation. Always there is another some sort of PQ disturbances is called the voltage fluctuation, and it is also known as the flicker. Here it is always oscillating you can say this is here you can see this curve. This is some sort of voltage flicker, and these are basically the major PQ disturbances. So, let us see the power quality problems and their effect.

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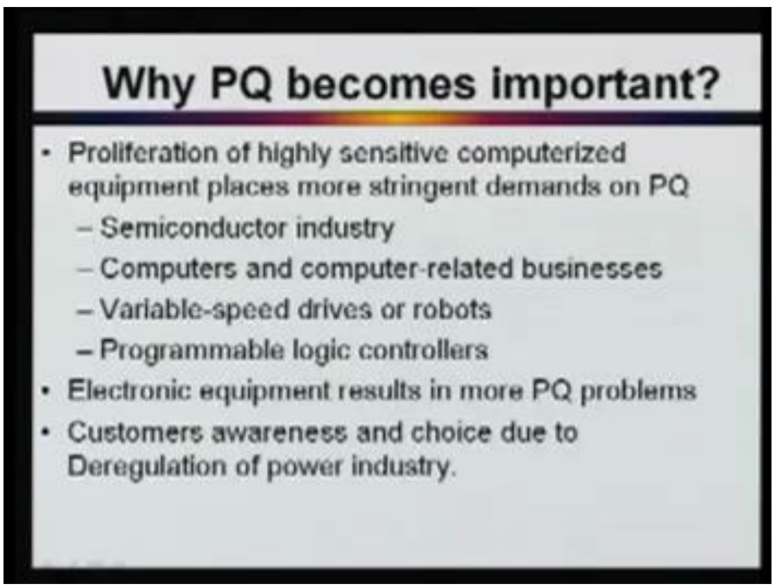

Already, we have seen the various power quality disturbances that were your voltage dip; first it was voltage swell, phase angle displacement, may be your transient, harmonics and electrical noises. Now the effect of voltage dip is the mall operation of power down sensing circuitry in computers and control. The variable is we drive and the computers trip out. Sometimes, your variable speed drive controller if there is a voltage dip, it may not work properly, because they sense the voltage, and that voltage is used for firing circuit utilization. So, your voltage dip is basically mal operation of your sensing circuitry in computers, in your variable speed drives and the computers, etcetera.

The voltage swell if voltage is more than your normal one per unit voltage as I said the voltage swell if it is 1.1 per unit to 1.8 per unit for certain duration if it is less than one minute, it may damage the insulation. Because you know high voltage may cause some damage of insulation, and therefore it is a permanent factor; we have to replace insulator and the instrument must be of that equipment must be replaced. Similarly, if the phase angle displacement is there is excess in heating of the three phase devices such as motor or the three phase rectifier.

If transients are there in the power system, then it may cause the tripping, component failure, damage to electronics equipments, insulations breakdown of the transformer and the motor loads. So the transient can have the lot of effects and again it depends upon its duration, it depends upon its magnitude, it depends upon frequency, etcetera. So, the transient is very very common in the power system; at the same time, they are very dangerous to the power system equipments and also very dangerous to the insulation failure.

Harmonics as I said harmonics are another some sort of PQ problems; harmonics may be of different order. It may be of lower order harmonics or it may be higher order harmonics, and that may cause transformer and the natural conductor heating leading to the reduce equipment life span, audio hums, power supply failures, the overheating of motor loads, mal operation of relays and the insulation breakdown. If you are having higher harmonics, one is obvious that the core loss will be more because the frequency is more than your normal supply frequency, and that is added on your fundamental components. Then it will lead to more loss, and there will be more heating, and also at the same time more heating may reduce the life span of your equipments.

Electrical noises are also one of the power quality disturbance, and that may lead to the mal operation of the microprocessor based equipment, and also sometimes, they may create some RI interference that is radio interference or TV reception to your system. Now question why PQ becomes important? The proliferation of highly sensitive computerized equipment plays more stringent demand on the power quality. Nowadays, you can say in each and every device, normally we are adding some power electronics instruments or power electronics devices. Power electronic devices may be your diodes, thyristors or it may be your IGBTs, and then any sort of power electronic devices.

If you are putting those, they are very very sensitive to the power quality issues, power quality problem, and at the same time, they normally generate the power quality problems. So, normally in the semiconductor industry is one of the major concerns, because this industry is booming, and there is a lot of advances in that one. Now even the people are talking that we can go for the transformer without any winding; it means we can realize the transformer with the help of power electronic devices. So, these devices normally are increasing in the number, in size, in the rating, and they are creating lot of power quality problem as well.

Computers, you know the computers, we are using the DC power inter computer circuitry, and we are having SMPS, the switch more supply system, and they create lot of harmonics in the system. We have major this harmonics in our IDK network, and it is very near to the computer center where we have a large Ups, and it has large of harmonics, and that is why your voltage waveform is highly distorted. So, your computers as well as the computer related business are creating the power quality problems very well. Another is the variable speed drive or robots. We use the variable speed drives, because the control in the AC is very very difficult.

So, we use the power electronic devices to control the motors in terms of torque, speed and other related quantities, and therefore these control circuitry, they use power electronics. And finally, they are introducing power quality problem in the supply system. The PLC, the programmable logic controllers, they are also one of the major concern for this your power quality. Electronic equipment results in the more PQ problems electronics equipments; all the electronics equipment including not here the power converters or rectifiers but the other electronic equipments also, because they normally use the DC supply. And that DC supply if it is coming from AC supply means we are having some interface of the power electronics devices.

And these devices basically convert from AC to DC, and finally, that DC is generating some sort of harmonics to the AC system. Another issue that is very important in the power quality that the power system restructuring that is deregulation of the power system. Now our electric power system in most of the developed country, it is operating in the deregulated mode means the competitive power mode. It means the price at each hour or each half an hour in several countries, it is varying so that people are at the same time, they are cautious to the price of electricity and as well as what quality they are going to receive.

It means we have the customers are having choice to change their suppliers, and that is why they demand more power quality, and therefore, the suppliers are willing to provide the better quality supply so that they can attract their customers. So, in this deregulated regime, the power quality issue becomes more and more relevant, and that is why the customers are more aware. And so that if you are not supplying the good quality of the supply, they may change, and that may affect your business as well. So, we have seen the various causes, various effects and various types of power quality disturbances and their related effects. Now it is obvious that these problems are not good, and we have to rectify them.

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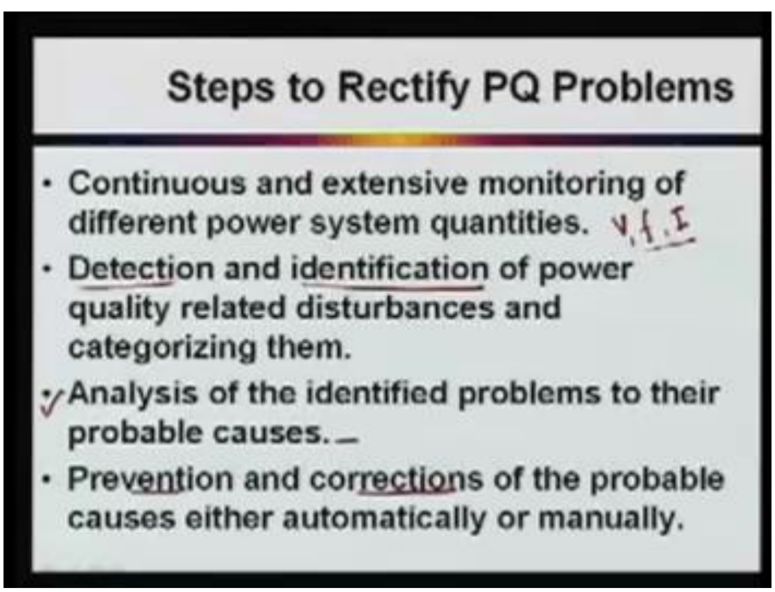

So, the steps to rectify the power quality problems; first one is the continuous and extensive monitoring of the different power system quantities. We can only monitor this unless until we measure this, and the measurement in terms of voltage, frequency and as well as the current. So, by extensive monitoring, then we can know that whether which type of problem is occurring, whether it is voltage sags, because these voltage sags swells transient; they are not continuous phenomena. They may occur in whole day once, they may occur in years also.

So, it is a continuous and extensive monitoring of the PQ power system quantities are required. Now once you have monitors, you have collected the information for these power system quantities; that is in terms of your voltage, frequency and the current if you are measuring. So, these three quantities can give information about all your PQ problems or you can say disturbances. Once you have measured this, now it is our duty to detect which type of power quality problem is occurred. So, the detection and the identification of the power system quality related disturbances and categorizing them; it means we can measure the frequency, voltage and current, then we can detect whether it is a voltage sag, voltage swells, interruption, transients, harmonics, notches, flickering, or it is a noise some sort of that.

So, once you are detecting it, then you have to identify which type of power quality related problem is there. Then you have to analyze, and that is known as the analysis of identified problems to their probable cause. Let us suppose you have identified that it is a voltage swells; after extensive monitoring of the voltage frequency and the current, it is identified that problem is voltage sag. Now then you have to analyze your system that what was the probable cause for that. It was the single cause or so many causes, so then we can analyze the identified problem to their probable causes.

Once you have analyzed, then you can have some preventive or your corrective measures. It can be done automatically; it can be done manually, but no doubt the manual correction as well the prevention is very very difficult, because these things as I said already I have showed you, it is very fraction of seconds or minutes. So, manually it is not possible. So, normally these corrections are done automatically in the power system. So, this we have seen the power quality issues and the related problems, the probable cause. Another concern of the power system design and operation is your power system security.

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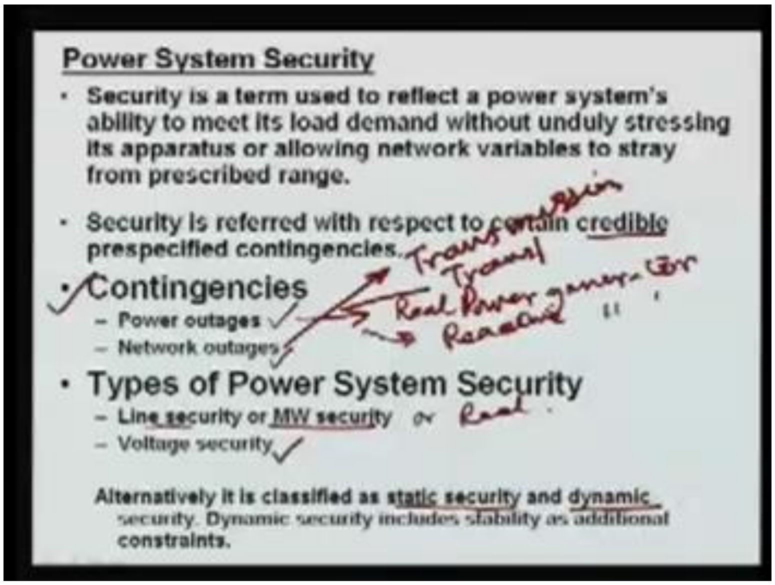

The security is a term used to reflect a power system ability to meet its low demand without unduly stressing its apparatus or allowing network variables to stay from prescribed range. Basically, the security is referred with respect to certain credible prescribed contingencies. Again the contingencies can be of different kind, contingencies can be you're here it can be your power outages or it may be network outages. Power outages are nothing but your outage of real power generators, any reactive power sources. These are coming into the power outages. In your network outages, it is nothing but your transmission line, and it may be your transformers.

So, these are the basically the contingencies; as you know in the power system if it is having thousands of buses, there may be more than several thousand element in the power system including your transmission line, your transformers, your generators. So, the number of contingencies are in any power system are very very high. So, for which contingencies, we are talking about; it is one contingencies, it is two contingencies, or it may be several. Normally, we have to go for that is why here it is called the credible prescribed contingencies; it means the possibility of those contingencies are very very high, at the same time they are very very critical.

Again this power system security can be classified into the two categories. One is your line security or it is called the megawatt security. Megawatt sometime it is also called the real power security. Another is your voltage security. In the line power security or line security or megawatt security or you can say real power security; normally we deal with the power flow of the transmission lines and the transformers. If there are some violations in the loading of the transformers or the transmission lines, then we can say it is related with the line security. So, normally it is megawatt means real power security related.

If there is we are only talking about the voltage of the power system and then we are monitoring the operating limits of the voltage, then it is called voltage security. This power system security can be also classified into the two terms to different broad categories. One is called the static security and another is called dynamic security. The dynamic security basically includes the stability as the additional constraints. In this static security, we only go for the steady state constraints, and constraints are nothing but your equality constraints as well as inequality constraints.

It means constraints related to the voltage limit that is also known as the operating limits. In terms of line flow limits, they must be well within limit, and other is your inequality constraints; it means that is related to your operating limits of the system; here we can see this, yeah.

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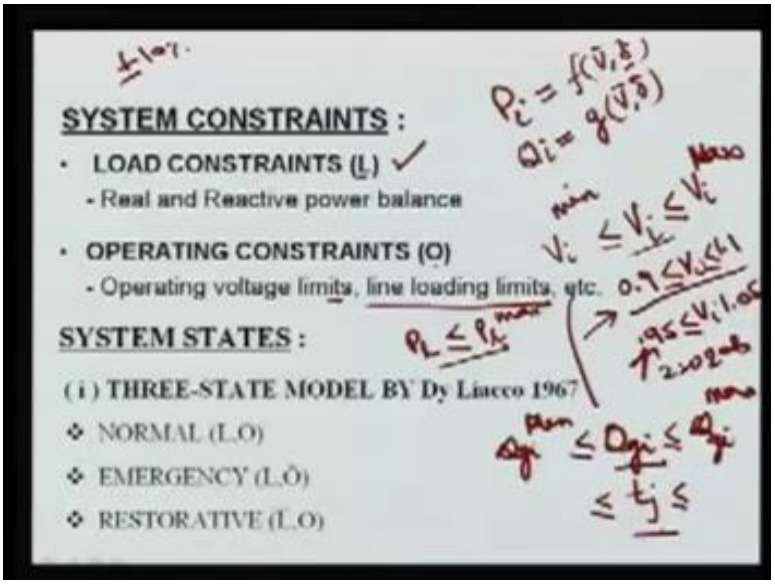

System constraints, system constraints here that we can classify it at the load constraints; this is nothing but your real power as well as the reactive power balance equations. At each node, we can write like here the p injection at any i th bus, we can write it is a function of your voltages and the deltas of all the buses, $P_i = f(\bar{V}, \delta)$. So, this is your power balance equation. Similarly, we can write the reactive power injection will be equal to another function; I can say it is g, and it is another equation in terms of voltage and angles, $Q_i = g(\bar{V}, \delta)$. So, these are your power balance equations, and it is two in number, and it is for all the buses.

So, load constraints are related with this that will be satisfied. Another is your operating constraints, and we can denote as O. And here the load constraints we can denote as the L, and that here this O includes your operating voltage limits. That is the voltage limit at each bus means we have your voltage at bus i it should be well within limit means less than or equal to its i th bus limit that is your maximum value, $V_i^{min} \leq V_i \leq V_i^{max}$. Similarly, at i th bus it should be the minimum value. So, this is your limit on the voltage at each and every bus. And already, in the power quality issues, I explained that we should maximum we can go for the ten percent of the voltage violation. So, this voltage normally we take at 0.9 per unit again v i to 1.1 per unit.

So, this is your operating voltage limit. Again this voltage limit is not 0.9 and 1.1 for all the buses. Some, the buses they are especially EHV transmission line wherein the voltages at the buses of the high voltage buses. It may be less than that, and it can be here 0.95 to here 1.05 per unit. So, those are voltages normally 220, and above, we have to go for this voltage limit. However, for the lower voltage, we can go for here 0.9 per unit to 1.1 per unit.

Another limit is your line loading limit. We know that we cannot operate our power system continuously beyond that the limit of transmission lines. So, we must operate our power system well within the loading of those transmission lines as well as the transformer limits. So, here if any line here the loading of that line should be less than or equal to the loading here that is maximum is permissible. So, it should be always less than its rated value; otherwise, what will happen? There may be possibility of the cascade tripping, and that is why we cannot get the reliable and the secure operation of all the system.

So, other limits are also related that we can have the limits on the real power generation $P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max}$; we can have the limits on the reactive power sources. That we can say here the reactive power source is generated at any i th bus. We should be well within limit here Qgi limit that is minimum value here, and it should be less than Qgi at that bus. Here it is the maximum value, $Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}$. So, here the reactive power generation should also well within limit; we can also go for the tapping at any bus; let us do the transformer is there, so it should be less than that the transformer tap limits.

So, these are the various limits, and these are here related like the voltage your line flow or you can say branch flow, reactive power generation and the transformer tapping are basically coming into the operating constraints of the power system well. The power system states actually there is we go for this security. Power system security is defined in terms of the system states; same times, we can say the power system states. Both are totally different.

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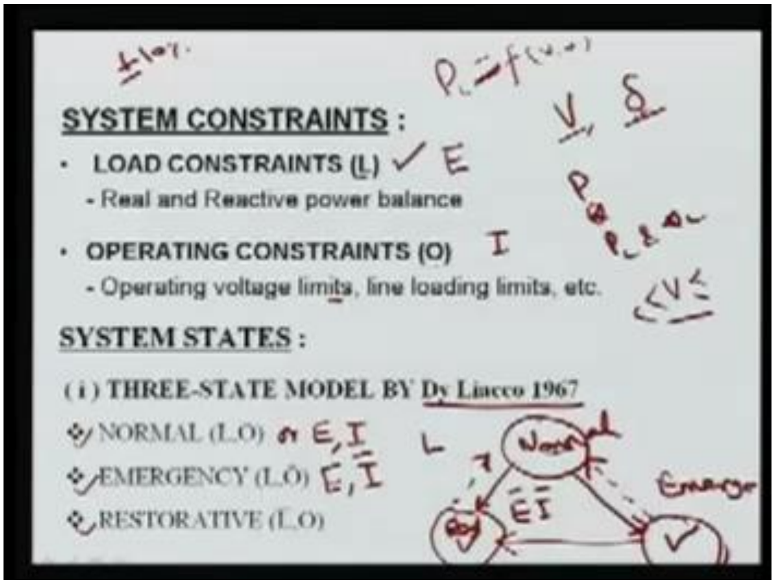

Power system states are nothing but your voltage and your angle at each and every bus. Why it is called power system states that with the help of these voltages and their angles, this is nothing but you have voltage magnitude, and the delta is your voltage angle. With the help of these two quantities and knowing your network topology, we can calculate all your here the real power, reactive power and the losses both losses that is real and reactive power, we can calculate. So, this voltage and angles that is the phase angle of the voltage here; we can determine all the information of the power system.

So, that is known as the states of the power system means voltage and angle is the states of the power system, but the system states are the different. Those are defined in terms of whether they are normal states, they are in emergency states or they are in the restorative state. So, this Dy Liacco in 1967, he gave the three state model of the power system, and based on that, he defined that the power system can have the three states. One is your normal, another your emergency and it may be your restorative state. This power system states or even you can say power system security is not very old.

This basically concept arise after the blackout of the northeast USA in 1965. After that then Liacco who gave the first model of the power system state and then he defined the power system security based on these three states; that is whether your system is in normal state or your emergency state or it is in restorative state. He gave three states model, and these three states are your normal. Normal is known if your load constraints as well as your operating constraints are satisfying the limits here your O; that is why I have written O and L means here it is your normal state.

And then if there is any contingency, then your system can come to here; that is emergency state. And there is a possibility here it is your restorative state; here the system come in the restorative state or even from here we can reach the restorative state. Means in the normal state your load constraints, they are also known as the equality constraints; here we can say it is an equality constraints as well, here it is inequality constraints you can see here. Because here I wrote this P i is equal to the function of voltage and delta; it means here is the equality. However, in these constraints, it was less than or equal to these are the inequality constraints.

So, here I can say the normal state is E means equality constraints as well as your inequality constraints, both are satisfying, then it is called normal states. Now the question arise if your system is operating well within limits, there is no violation; there is no problem with the load constraints. It means your loads are satisfied, then we can say right now we are in normal state. Now if your system is leading or moving in a different way; it means suppose there is one contingency; that is a critical contingency. There are possibilities that your system after that outage, the system may go in the emergency state or it may go in the restorative state.

Means your load constraints or your equality constraints here are satisfying but inequality constraints are not satisfying; it means there are violations of your operating constraints. So, thus if it is happening so, then it is known as emergency state. Even though there is another outage may lead your power system to restorative state, where your equality constraints and inequality constraints are not satisfied; bar means it is opposite to equality means violation here.

Similarly, here L bar means there is your load constraints are not satisfied. So, if your outage occurs in the system, again it is not occurring; it is thought of that we are thinking if this contingency will occur if your system is still in the normal state means your both equality and inequality constraints are satisfied. Then we can say your system is secured; it is in normal state. Presently, in the normal state in event of any credible contingency and again your system is in your normal state, then we can say our power system is secured. But there may be possibility that after that contingency, your system may go into this emergency, then we have to have some emergency control so that we can bring back to the power system into the normal states.

Similarly, if your system is fallback in your restorative state, then we have to use some measures, and it may be your preventive or corrective measures, so that we can bring our system from restorative to the normal states. So, the Dy Liacco who gave the first concept of your power system state; after that, there were lot of researchers and here they give the five state model.

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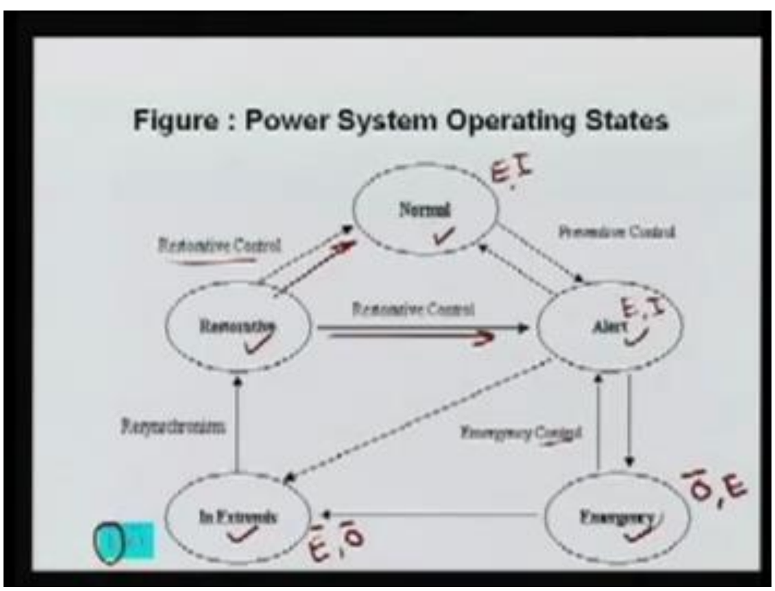

You can see here the normal state, alert state, your emergency, extremes and restorative. In the De Liacco model, this was the normal state and the restorative as well as the emergency states was there, but after that, the Fink and Carlson who gave this five state model. Now we can understand that here this is your normal state, again here normal state is your E and your I; that is your equality constraints and the inequality constraints are satisfying.

Now, if there will be any contingency, then there may be possibility that your system may go in the alert state. Here in this alert state is the state where your equality and inequalities are satisfying, but if there will be another contingency in the system, then your system will not be in the normal state. Then it will go to your extremis or it may go in the emergency case. So, this alert means it shows that a power system operator must be alert that in the event of next contingency, your system will be certainly going in the emergency or in other conditions which we do not want.

So, in normal state if your system is in alert state after any one contingency, then you must try that your system should go back to the normal state, because our main intention to operate power system in the secure manner. In the event if it is not possible, you are not taking any preventive control here that is going back, then what will happen; if there will be another contingency, then it may lead that your system will go in the emergency state where emergency state is again is the previous to this the emergency state where your operating constraints are not satisfying. It means here your operating constraints not satisfying where your equality that is load constraints are satisfying.

So, in the emergency contingency if you are landing up, then you have to use the emergency control to bring back to the alert system. And then finally, you can go to the normal system. There is a possibility that even though another contingency is occurring after that means there may not only one contingency will occur at a time; there may be several contingency if they are occurring, then your system will go in the extremis. Here your both equalities as well as your operating constraints or inequalities, they are not satisfying, and then it is your extremisms.

If your condition here you are landing this, here you have to go for the load shedding, because here load constraints are not satisfying; it means you have to change your loading and then the resynchronize is required for the remaining system. And then you can go in the restorative state, and you have to apply your restorative control, and then finally we are coming to the normal state, or we can come to the restorative control here in the alert state, and then we can go to the normal state. So, this is your five state model of power system state.

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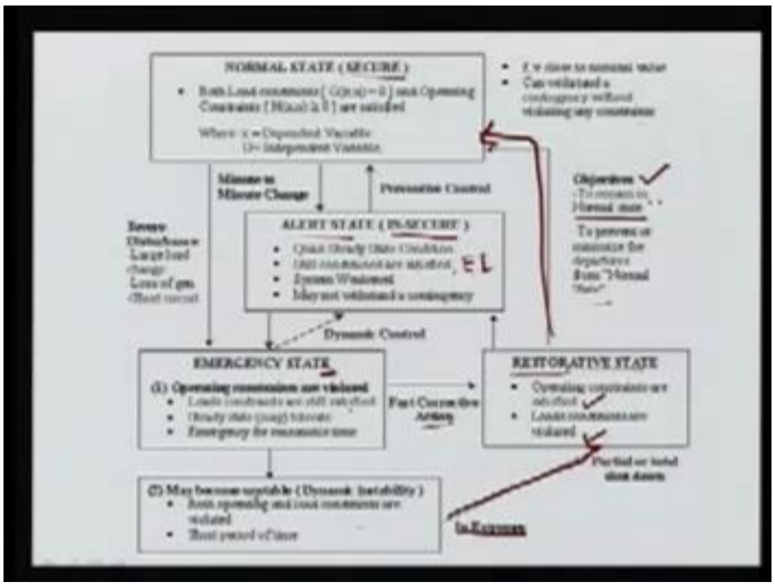

Later here Stuart Et al., they give here they categorize the states in the different fashion, and it is very elaborative in the sense that the normal state they call it the security state. Here they have the alert state; this is known as the insecure state, because after that if any contingency is occurring, then it will lead to your emergency state that we do not want that. So, here in the normal state which is known as the secure state the both load constraints as I said and the operating constraints are satisfied where x are the depended variable and u are the independent variable.

In this state, your voltage and frequency very close to the nominal value and can withstand a contingency without violating any constraints, then it is known as the secure state. In this alert state, it is a quasi steady state condition and still constraints are satisfied; it means both your E andI are satisfying, but system is very weak. Means if there is any other contingency that may not withstand and your system may come here in your emergency state; in this emergency, there is a two type of emergency here he has classified. Means that is your operating constraints are violated; it means your load constraints are still satisfied a steady state may tolerate but emergency for the reasonable time.

So, we require the fast corrective action and then we can come into the restorative state, and from this restorative state, we can come back to your normal state. In restorative state as I said operating constraints are satisfied but your load constraints are not satisfied, violated, then we have to go for the load synchronous. Means we have to synchronize our power system those are violating; it means we have to go for some load management as well here. Here again from here you can see may be unstable if suppose your dynamic instability is there, then this dynamic instability relate to your extremis, and then we have to go to the restorative state and finally again to the normal state.

So, with this, this is your five state model where it is very elaborative explanation is given. So, always our objective is to maintain in the normal state and to prevent or minimize the departure from the normal state. Means we must operate our power system, so that our power system must operate in the normal state as well as it should minimize that it should not depart from the normal state as minimum as possible, so that we can say our power system is secure.

Thank you.