Power System Operations and Control

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Module - 02
Lecture - 01

Welcome to module number two, and in this first lecture, I will discuss some of the introductory power of the equipment and their stability constraints in the power system operation. The various issues that will be discussed in this module is your capability and constraints of generators, exciters, governors as well as the network element constraints that is basically your transmissions line as well as the transformers. And also constraints related to the energy supply system, load characteristics and the introduction to angle and voltage stability phenomena's, and what are the various stability constraints will be discussed in detail.

This equipment and stability constraints, your power system is operating with the various equipments in the system. So, the constraints related to the equipments are also equally important and here equipment constraints may be of two types.

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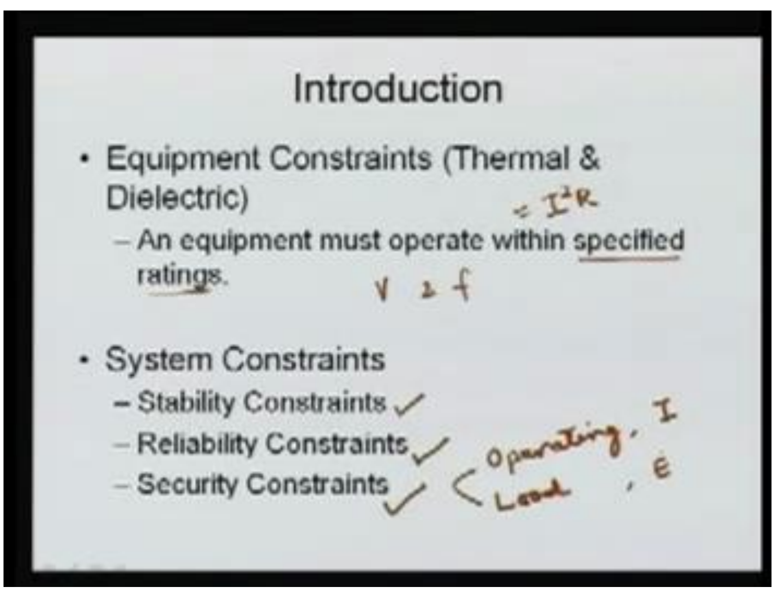

It may be thermal constraints or it may be the dielectric constraints. So, all the equipments those are in the power system, they must operate within the specified ratings; rating in terms of the voltage and the frequency. So, your supply system should also have the standard rated voltage, frequency, so that we can give this supply to the various operators in the power system. In these equipments constraints as I said, the thermal constraint is one of the very very important; that once your equipment is operating with some electricity supply system. Means there some current will be flowing in some of the conductors in that instruments.

And once they have some currents in the various part of the system, so there will be some losses as well and that may be your real and reactive power losses. But we are concerned much about the real power losses. The real power loss is nothing but we know it very well that is the current which is flowing in the system that is I the square of this and the resistance of that element where the current is flowing. So, this creates the loss, and if this loss is not dissipated outside, then there will be constant increase in the temperature, and that may lead to your thermal constraints, and there may be breakdown.

This it may be heated; it may be burnt some time. So, we have to see what is the equipment constraints in terms of thermal. In the dielectric constraints as we know, if current is flowing at the certain voltage, then there is some neutral or ground potential and the current which is flowing in that any part of the system that will have some potential. So, there should be some insulation, so that there should not be a short circuit. So, this insulation is providing from the current voltage that is where the current is flowing this electricity current as well as your zero potential, ground potential or you can say neutral potential. So, we have to provide some insulation and that is called the dielectric.

Now only there is different type of dielectric we know; it may be your solid dielectric, may be your gaseous dielectric, may be your liquid dielectric, but it depends upon system to system. Most of the operators that is the utilization or you can say end users equipments; they use normally your solid dielectrics. So, whenever there is some change in the voltage, there may be some overstress; your dielectric may over state or, it may get ruptured. And there may be a short circuit; there is a fault. So, the rating of equipments basically decided by thermal rating as well as the dielectric rating; so, the operating as I said the equipment must operate within the specified ratings in terms of voltage and it is in terms of your frequency.

If there is your supply system is not providing the balance sinusoidal wave or current in terms of current and voltages, what will happen? Then there may be more losses. So, your equipment must sustain those losses and we have to do something. For that, we can take those losses; that is the loss once it will be created in terms of heat i square r and that must be taken out, so that we can maintain the temperature, we can reduce. We should not increase the temperature that may lead to the damage of that equipment.

Another constraint in the whole system is your system constraints. One is related to equipment, and we know there are various equipments in the power system. And if we will take the combined considerations, so there are various constraints, system constraints are also arising. Those constraints I can enumerate that is your stability constraints; means we must operate our power system in stable fashion. Means whole synchronous operation means we have to operate system stably without loosing the synchronism.

Our system must be reliable, so that we have to operate system in terms of the reliability constraints as well, and another is your security constraints. I said the security constraints that we have to operate our power system operating constraints that is here the two constraints here your operating constraints, and another is called your load constraints. So, these two constraints must be satisfied; also we call this operating constraints as in previous lectures, I mentioned this is also called inequality constraints I and it is here your equality constraints E.

So, these two constraints must be satisfied and operating constraints we know that the line loading must be less than its maximum rated capacity. At the same time, the voltage limits must also well within its minimum and the maximum value to operate the system in the reliable and the secure fashion, so that we can achieve higher efficiency of the system. The stability constraints, there is various type of stability.

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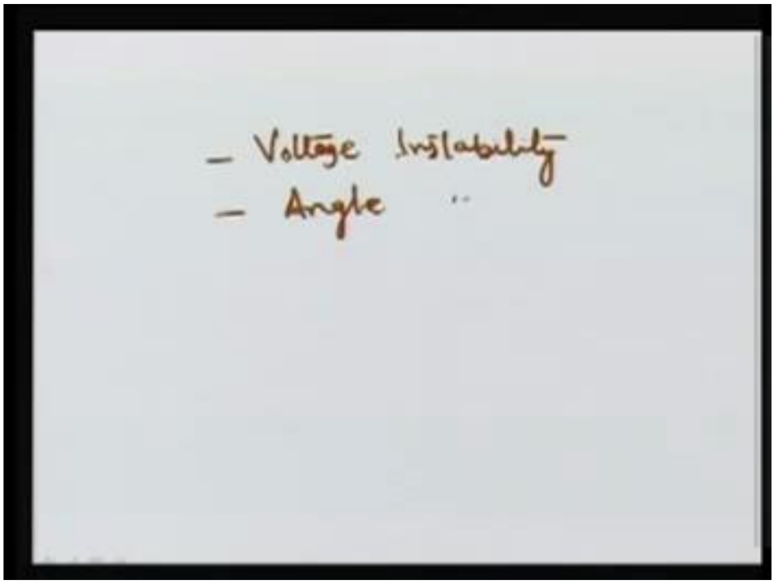

Normally, we call here either it is a voltage instability. This is voltage instability; I will discuss in detail, and another is your angle instability. So, we will discuss much in detail about these two instabilities in the later lectures of this module. To go for all these analyses, it is very very important. Let us review that what are the various relations in terms of power system; that is in terms of voltage, current, power and impedance, and also how we are going to represent to get the solutions.

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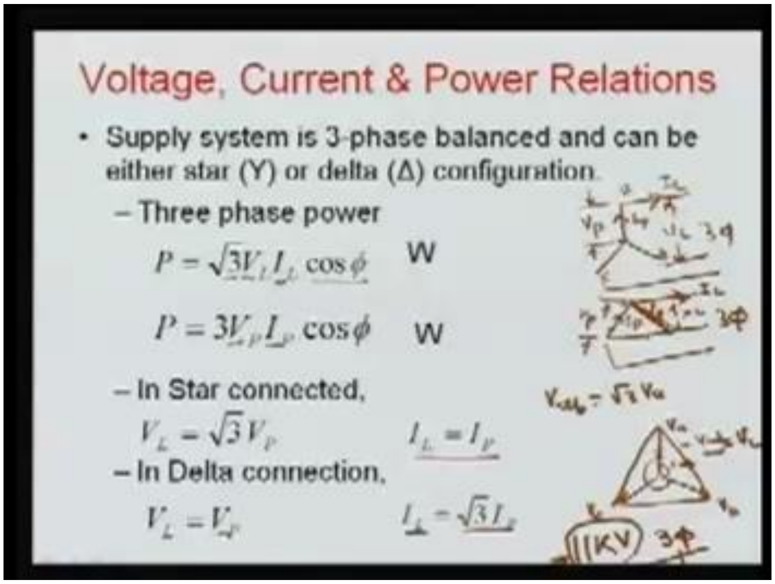

So, here the various relations that are normally we know the supply system is our three phase balance supply system. And it can be either in star connected or in delta connected. You know it very well that the star connected here, this is your star connection, and this is your delta connection. From these, we can get the three phase supply here, and this is also giving you a three phase supply system. Now the quantities which are very much used those are your power, voltage, current and the impedance. First, we will see the power that is the three phase power.

It is nothing but the power $P = \sqrt{3} V_L I_L \cos \emptyset$. This VL is line to line; here this voltage is your VL that is between two phases. So, it is called line to line VL. And the current that is flowing in line here, it is your IL. So, the power which is under root times voltage that is line to line; sometimes, it is also called phase to phase voltage multiplied by your current that is line current, and that is multiplied by your power factor that is power factor here cosine of the phi. And this phi is the angle between voltage and current at any particular point.

If you want to represent these quantities means that is your power in terms of phase quantity, we can write $P = 3 V_P I_P \cos \emptyset$ that is three times of the phase voltage as well as the phase current. What is the phase voltage here? The voltage here that will be here VP that is your line to your neutral position; so, this is also sometime called VP is the phase to neutral voltage. So, the VP and the current here again it depends upon what is the phase current which is flowing here that is your IP. In this delta connection, you have the line current is this; that is your IL and your VL that is the line to line is this voltage.

But the phase voltage here, this voltage between this it is your VP, and the current which is flowing here it is your IP that is your phase current. So, whether it is a star connected or it is delta connected, you have the real power equation. It will be the same whether you are representing in terms of line to line current and voltages or in terms of phasor. So, here the real power in terms of line voltage as well as the line current, we are getting under root three times voltage multiplied by your line current and multiplied by that is the power factor cosine of the power factor angle.

If you are representing in this phasor phase voltage and phase current, so it is thrice of here the phase voltage multiplied by phase current multiplied by your power factor. What is happening here? You can see why it is thrice? Because we have the three phases, one phase, second phase and third phase here. So, the phase power here one, this and this all will be added together and this is the thrice. We are assuming the phase power here this is balanced. So, the power in one phase will be here in the same this phase second phase as well as in the third phase. Similarly, here also the voltage here VP multiplied by IP for one phase, for here another phase, here for this.

So, if it is A phase; this is your B phase, and this your C phase. So, the phase A power, phase B power, phase C power will be added together, and that will give you real power. But now let us see this relation; that is the voltage line to line voltage and the phase angle as well as the current relation for these two configurations. So, line voltage here you can say this is between the two phases. So, this VL , $V_L = \sqrt{3}V_P$, that will be under root three times of your phase voltage; why it is so? You can see if we will draw the phasor diagram; that is here three phase.

This is say let us suppose your V a; this is your V b, because we know all these phasor voltages, they are displaced by 120 degree. So, it is 120 degree and here also 120 degree, here also 120 degree. So, if you will see that resultant voltage means I want to write the voltage V ab; here this is your V ab means,$V_{ab} = V_a - V_b$ this voltage. So, this V ab will be your line to line; here what is that? I am writing this is your VL. So, we can very easily show that this magnitude this V ab will be means I can say this V ab will be under root three times of your V a; that is this magnitude.

So, we can say this line to line voltage will be under root three times your phase voltage, because this is your phase voltage; this is your phase voltage; this is phase voltage; this is your line voltage; this is line voltage; this is also a line voltage. So, the line voltage is related with under root three times of your phase voltage in the star connected. So, this is your star connected configuration and this line current. Now you can see here the line current in this configuration which is here line current that is equal to your phase current. So, whatever the current which is flowing in the phase A is your line current here. So, that is written here in the star connected this line current will be equal to your phase current.

Let us see in the delta connected. Now you can see the delta connected. What is happening here? This is your V p, and this is your V L. Now you can see here this voltage and this voltage again it is VL. Similarly, you can see this voltage, this phase voltage; this $V_P = V_L$. So, I have written the line voltage will be equal to your phase voltage. For the current, now it is reverse, because here it is a line current; here it is your phase current. So, there are some current; it is addition of the two currents which is flowing here; it is phase a, phase b. So, similarly, if these are the currents, then this line current will be three times of your phasor current.

So, these are the relations which are very widely used in the power system. We have seen that people get confused with this line voltage, phase voltage and this and that. Normally, some students they ask that if the system which is retained that it is 11 KV three phase system. So, this voltage whether it is a phase voltage or line to line voltage. So, if nothing is mentioned. So, this voltage is always line to line voltage. So, there should not be any confusion that the voltage which is mentioned here, it is always line to line voltage rather than it is a phase neutral voltage if it is a three phase supply system is there.

In the single phase supply system, there is no concept of line to line and the phase, because always it is your phase. We always measure the single phase to neutral voltage. So, here this is your line to line voltage unless until it is stated. If it is said this 11 KV, it is a phase to neutral voltage or phase voltage, then it will be phase voltage. So, this is basically the relation between voltage, current and the power. Now in the power system if we will see, normally the various equipments those are having with the different voltage rating, different power ratings and especially we have the transformers and the generators.

In the power system, the generators are of different; they are generating at the different frequency not frequency. They generated at the same frequency if it is an interconnected system, but it may be rated at the different voltage. They may be generating different magnitude of power and the transformers those are interconnecting the generating stations as well as the various transmission lines and may have the different primary and secondary voltages.

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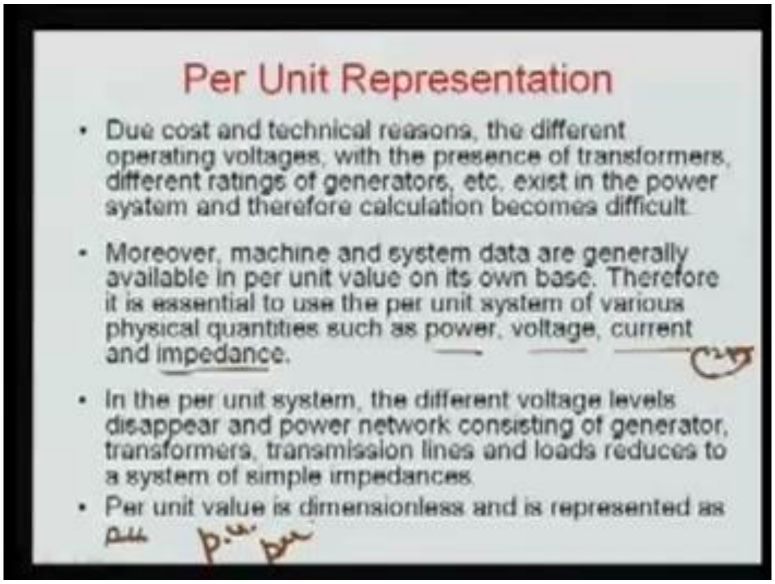

So, due to cost and technical reasons especially, the different operating voltages represent the transformers, different rating of generators, etcetera exist in the power system, and therefore, the calculation become very very difficult. So, if you want to use the actual value calculation, so always you should be very much aware about this the change in the voltage and also in terms of connection. Sometimes, a star connected and delta connected that creates lot of confusion in calculating the voltage; whether you are calculating the phasor voltage, whether you are calculating the line to line voltage.

So, it is always convenient that we can use the per unit system. In the per unit system, we will see the various advantages and another you can see most of the machine data's, they are normally available in the per unit system of it their own bases. Means machines and the systems data are generally available in per unit values on its own base; therefore, it is essential to use the per unit system of various physical quantities; what are that physical quantities? We have only four physical quantities that is your power, voltage here and current as well as your impedance.

These are the various four power system quantities, and these four quantities must be represented into the per unit system, and the common base that is also very important. No doubt all the elements are having the per unit system on their own base, but we have to represent power system quantities; if you want to solve, you want to use them for various calculation, etcetera, then you have to take the common base for all these values, and then you have to convert it back. Suppose, our machine is written here 0.2 per unit and its base is the different, then you have to change this impedance at the different base which is you can say system base.

In the per unit system, the different voltage levels disappears as I said using the per unit system the voltage level concept. Means whether there is an 11 KV to 132 KV and so on, so forth, there will be no voltage variation. So, it is disappeared and also the power network consisting of generators, transformers, transmission lines and the load reduces to our system of simple impedances. Means we can remove; let us suppose we want to represent a transformer. So, the transformer will be represented simply by its impedance and then we calculate again this impedance in per unit.

So, we can calculate the currents as well as the voltages, and later, we can get it back to actual voltage and the current. The per unit system as it is a dimensionless system, it has no dimension, and it is represented as per unit. Some people write here it is p.u., some people write p u simply, so it is up to you. So, it is per unit means p u we represent this. So, per unit is defined.

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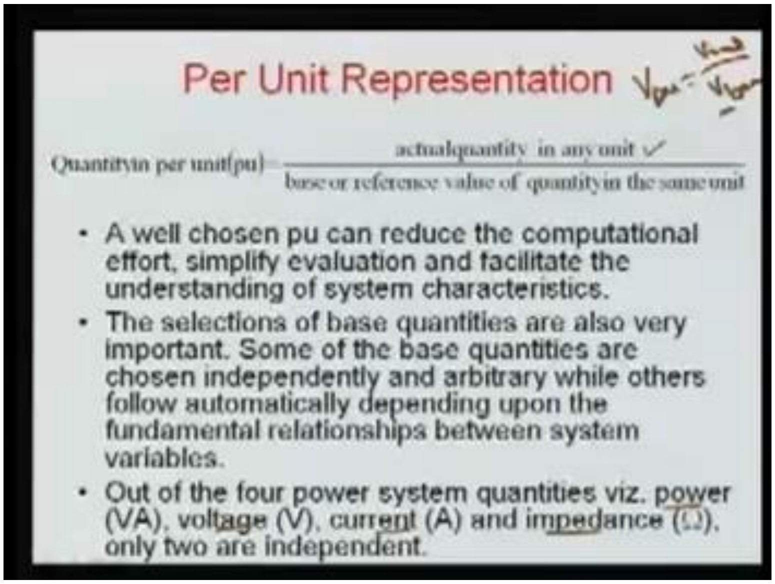

The quantity in per unit that is p u is defined at the ratio of actual quantity in any unit here divided by the base or reference value of the quantity in the same unit. Why it is same unit? Suppose you want to write the per unit for your voltage. So, the voltage here p u will be the actual V actual divided by V the voltage of the base. So, let us suppose actual it is in kilovolt. So, your base must also be in the kilovolt; it is not in volt, so, that we will get the different value. So, that is why here the quantity in per unit is defined at the ratio of actual quantity in any unit. If you are using voltage, so it will be here it will be in the same voltage; if you are using kilovolt, it should be in the same kilovolt.

So, base or reference value of quantity in the same unit that is the per unit definition. We know that a well chosen per unit can reduce the computational effort, simplify evaluation, and facilitate the understanding of the system characteristic; this is one of the advantage. The selection of base quantities is also very important. Some of the base quantities are chosen independently and arbitrary, while other follows the automatically depending upon the fundamental relationship between the system variables. Because in the power system, I said there are various elements including transformers, transmission lines, generators and they are of different rating.

So, you have to start by taking one base for one element, and then you have to follow with the various element which are keep on transforming the voltage; therefore, the bases will be also changed. I will come to that point later. So, out of four power system quantities that is the voltage, power, current and the impedance; only two are independent. Means here we have the power, voltage, current and the impedance; only the two are independents. So, we have to take the only two bases, and other two bases, we calculate by knowing this one.

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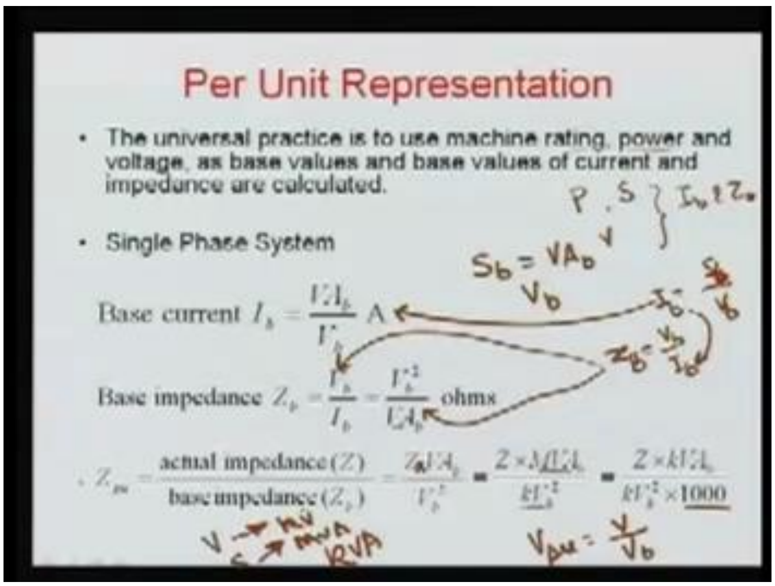

So, what we did? The universal practice is to use machine rating, power and basically, using the machine rating; that is your power and the voltage at the base values. Means we are using the power; again here the real power, or you are using complex power that is apparent power here not complex power. And the voltage, they are taken as base quantities and other base values; means from these, we can calculate the current base and your impedance base can be calculated. Now let us see as we know in power system, mostly the power supply system is three phase, but in the distribution areas, another sometimes in generation area also it is not conventional, then we can go for the single phase.

So, let us see what are the various base quantities those are calculated with the help of knowing the two our power as well as our voltage base; if your power base that is S I can say b; b denotes your base, it is unit is your V a. It is sometimes also written as V a base; since, it is apparent power. So, V a base if it is given to you and you know this voltage base; so we, know this relation that current is always your S that is here divided by V. Here we are talking the magnitude. So, here the I base will be your power base; sorry, this is b and this is your V a.

So, knowing these two bases, we can calculate the current base. So, that is written here you can here this is written. So, the current base $I_b = \frac{VA_b}{V_b}$, and its units will be ampere. Here if you are using volt as ampere volt ampere here you are using voltage; so, it will be ampere. So, always you must be very careful what you are going to use; means whether you are using kilo, then you have to change accordingly. So, your impedance base are now similarly we know this z will be sorry $Z = \frac{V}{I}$; we know it very well.

Because impedance is ratio of voltage to current; so, the z base similarly here $Z_b = \frac{V_b}{I_b}$. So, here I have written this. So, we can calculate the z base. We can also substitute the value of I base; from here if you put this value, then we will get this relationship that is your $Z_b = \frac{V_b^2}{VA_b}$, and it will be in ohms. So, the z per unit suppose you want to calculate in the power system, we want to calculate all the quantities especially impedance in the per unit. Because now knowing the voltage base is known to you, actual value you can simply you can divide. Means your voltage per unit here is, $V_{pu} = \frac{V}{V_b}$ that is actual voltage divided by voltage base.

But this z per unit is defined at actual impedance z of any element; element in the power system is the broadly the three elements; that is your branch includes your transformer and transmission line and it can be your generator and some other devices like reactors, capacitors, etc. So, the actual impedance z per unit is equal to $Z_{pu} = \frac{Z}{Z_b}$; this base impedance we calculated from the previous equations. So, I can write here this $Z_{pu} = \frac{Z\,VA_B}{V_b^2}$. Normally, in the power system, your voltage is here.

It is given into the kilovolt; the unit is not volt. It is in terms of kilo and your power that is your S; it is given in your MVA. So, we know this is the M is the megavolt ampere, and it is a kilovolt ampere. So, we can write here the Z multiplied by MVA base divided by KV base means the voltage base in term of kilo and here in terms of mega, or if you are using the power base in terms of here in KVA, it will be z multiplied by KVA divided by kilovolt; that is the base in terms of kilo square multiplied by here 1000.

So, knowing all these base value, whether we are knowing in the voltage or in kilovolt and power base in terms of actual VA or KVA or MVA, we can calculate the z power unit for the single phase system. Let us see now the three phase system. Three phase system is slightly different because single phase system is very simple. In the three phase system, now we have to calculate this base current.

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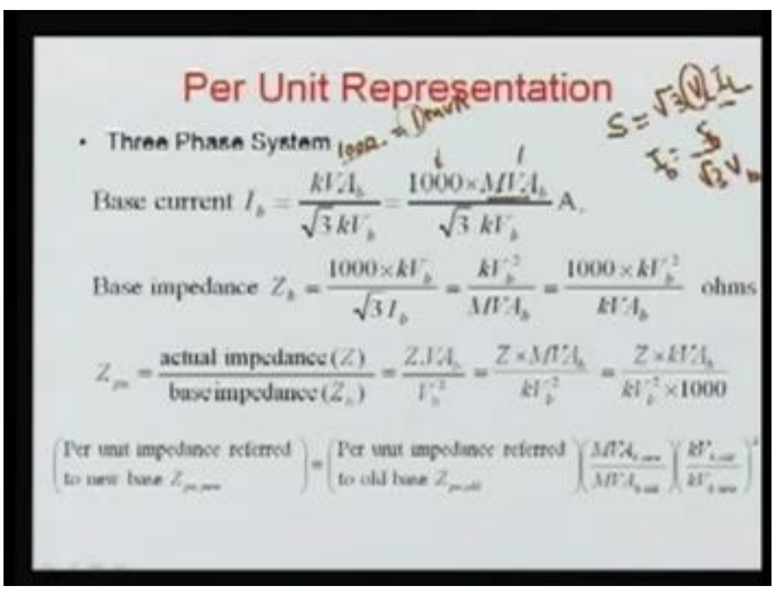

Here also we know this power S is nothing but, $S = \sqrt{3}V_L I_L$. So, this voltage this VL, we take this line to line voltage as the base value. So, we can write this I, $I_b = \frac{KVA_b}{KV_b}$; means here I will be your S over under root 3 V. So, this I b will be here b power base divided by under root three times voltage base. So, this voltage base is line to line; it is not phase. So, we take the line to line voltage at base, then it will be your current base will be power. And here it is in kilo, so it will be in kilo, because all these ten power three will be canceled, and we get the previous here like this.

But again most of the since we are operating the high power that is in terms of megawatt, MVA, MVAR and so on, so forth. So, the power base is normally it is represented into the MVA. So, what we do here? If we are going for here smaller unit, you have to here multiply by this smaller unit because here earlier the kilo. Now we are going for mega. So, here already you have included ten power three, so that should come out. So, that we can here unit is reduced.

Means here let us suppose you are using 1000 KVA; what does it mean? It means it is equal to 1 MVA. So, the unit here it is reduced. So, here we are writing only one. So, this thousand should come here. So, we are multiplying by thousand that is the kilowatt and then this MVA divided by under root three KVA and that is your MVA. Our base impedance z base can be written with this expression. Now this is you can understand why we have written like this that can be explained.

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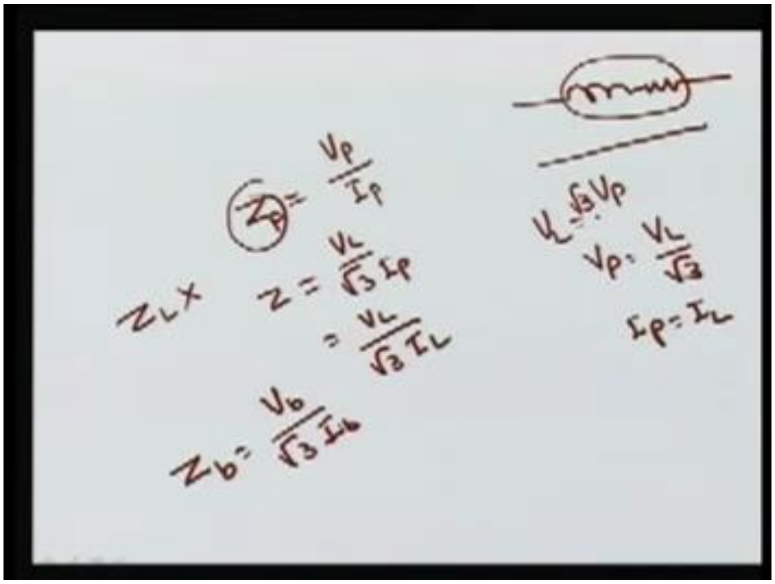

Here this z we know; this z is your $Z_p = \frac{V_p}{I_p}$ because the z is always there is no concept of z line to line. So, z is always for let us suppose this is a transmission line; this is your inductance resistance. So, this value is for phase value. So, this z is always z phase; there is no concept of Z L it is no. So, this z phase will be equal to V phase divided by current phase. Since, our base here V base was your V L and we know this VL is your V P under root three means your V phase is nothing but V L over under root three. So, here I can write this Z will be $Z = \frac{V_L}{\sqrt{3}I_p}$.

So, the current here it was your phasor in the star connected if you are using this. So, in this case, this is equal to the phase current will be equal to line current. So, using this, we can write here $Z = \frac{V_L}{\sqrt{3}I_L}$. So, now already we have calculated means z base will be your V base; that is line to line divided by under root three your I base. So, this expression is used previously here if we will see; here I am using this. Here this thousand is multiplied due to the units that I have used the KV; means KV if you are not using K, then this thousand, this K will be canceled because this unit is reduced by k.

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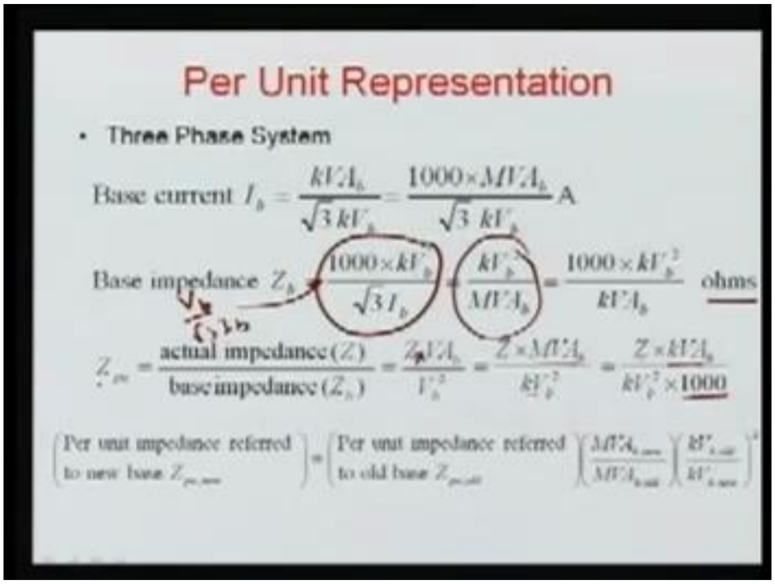

So, it is nothing but your this value is your V base divided by under root three I base or we can write this one. Again we know this is our power system quantities. We do not want to represent the current anything in the current value. We always try to represent in terms of the two bases; that is your voltage base as well as the power base. So, this current base can be replaced from the previous equation, and then if we reuse this, then we can go for we can get this here this voltage base in the kilo square divided by the power base in the mega will be your z base, and this unit will be your ohms.

If you are using this power in terms of kilo, then we can write 1000 will be going up, and then finally, we are going to get this one. So, the z per unit will be your actual impedance z divided by as usual the base impedance, and then we can write here z multiplied by here your VA divided by voltage base square. And for the various different power and the voltage levels or you can say unit in terms of kilo or voltage, we can represent in this either z multiplied by the MVA base divided by the voltage base square in terms of kilovolt.

Here we can write again the z base z per unit will be your $Z_{pu} = \frac{Z\ KVA_B}{KV_b^2 1000}$ that is actual z multiplied by your power base in kilo divided by the voltage square in terms of kilo multiplied by 1000. So, this is your z per unit. Now it is very much usual to represent all the quantities on the common base. As I said even though in the very beginning here these bases suppose your system your transformer or your generator.

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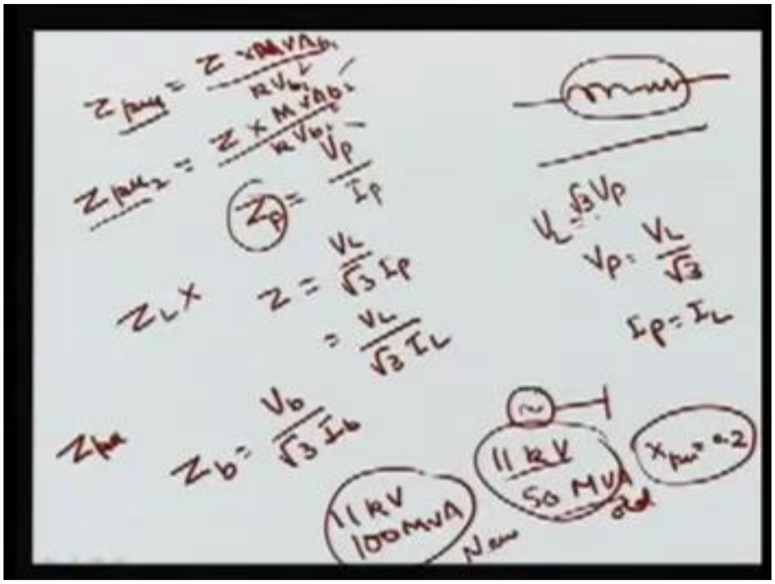

Here this generator is rated at 11 KV, and its power is your 50 MVA or you can say megawatt, whatever you say. Power normally here whether it is megawatt or MVA, we take the same value. So, here and this x is given in the per unit is let us suppose is 0.2. Now I want to write this x per unit on the different base; I want to get here in the 11 kV and let us suppose 100 MVA base. So, we have to change this x per unit, because this value is on this base and in this base. So, we have to change it back to our base here this is called the new base, and this is called your old base.

To know this here, what I can do? We know this z per unit; whether it is old or new, it is equal to your various quantities in terms of power and this one. And this value is nothing but here you can see this value is your z MVA divided by KV square. So, it is your z that is your actual value multiplied by here KV that was your here this is MVA divided by KV. So, it is your MVA base divided your KV base square. So, if this is your for one base; let us suppose this per unit on your base one. So, I can say it is one, here it is one; means here this is your old is equal to your first base.

Similarly, I can write this z per unit on another base that is then it will be z per unit at the base two quantities. Here the actual will not change multiplied by your MVA base two divided by your KV base two square. So, we want that z per unit, it is given you. These bases are also known to you; this is given. I want to calculate this z per unit on the new base; this is the new base; this is your new base. And then what I can do? This now your z per unit two will be we can simply divide this equation here. So, I can write here as the simplified equation.

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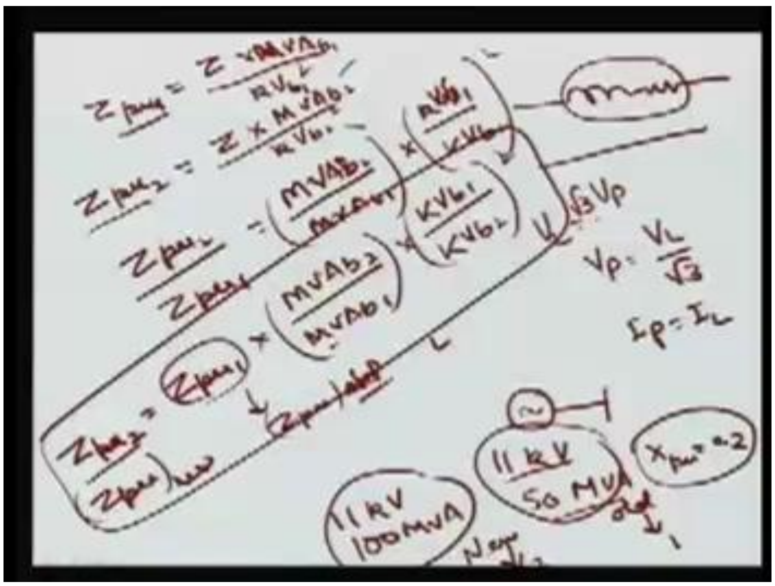

This your z per unit two divided by your z per unit one will be here now this actual quantity will vanish. So, in this, we do not know the actual quantity; all even we can calculate it, but there is no need to this. So, if you are dividing this z per unit here, what we again getting here MVA b 2 divided by here MVA b 1; this quantity divided by this. Now multiplied by here this quantity since you are dividing, it will be coming here two and this will be going up. So, we are getting KV base 1 here KV base 2, and this is your square term.

Now I can say this z per unit two will be this multiplied by this unit. So, $Z_{pu2} = Z_{pu1}\left(\frac{MVA_{b2}}{MVA_{b1}}\right)\left(\frac{KV_{b1}^2}{KV_{b2}^2}\right)$. So, what we can say? At the new base, here this new base I represented at 2; old base I have represented as 1. So, I can write here this value is the z per unit at the new base and this z per unit I can say z per unit at the old base. So, this equation can be again written here. If we will see, this per unit impedance referred to the new base; that is z per unit new will be equal to z per unit old multiplied by your MVA base new that is two to MVA base to old value.

And multiplication here of the voltage base of old divided by voltage base new, and then it is the square value. So, it is always easy, and this formula is used very widely. Means whatever the per unit quantity you are knowing, have the different base you have to calculate all the quantities of the power system on the single base for your calculation purpose. So, this equation is very widely used. So, you are knowing the new base, you are knowing the old bases; knowing the old per unit quantity, you can calculate on the new per unit. So, this equation is very widely used. Now let us see the various advantages we have explained this.

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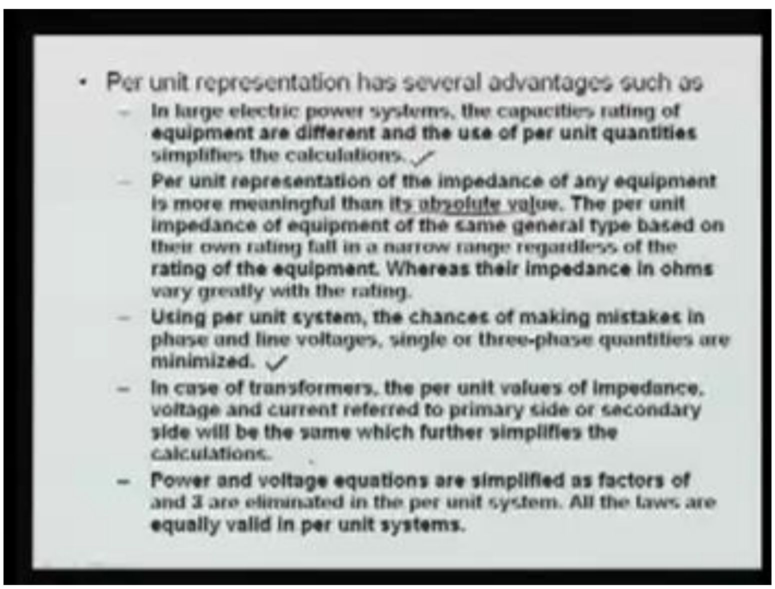

The various advantages of using the per unit is in large electric power systems, the capacities, rating of equipments are different and the use of per unit quantity simplifies the calculation as mentioned earlier. So, it is basically recap of the per unit representation advantages. The per unit representation of the impedance of any equipment is more meaningful than its absolute value, why? Knowing the absolute value, let us suppose the impedance of a transformer is known to you or machine it is known to you two ohms. And if it is known in the 0.1 per unit, why this absolute value is not so meaningful than the per unit; that can be understood.

By the per unit impedance of equipments of the same general type based on their own rating fall in a narrow range regardless of the rating of equipments, whereas their impedance in ohms vary greatly with the rating to rating. So, using per unit system, the chances of making mistakes in phase and the line voltages, single or three phase quantities are minimized as we saw the phase and the your line to line voltages. So, the various advantages of per unit representation just as I mentioned using per unit system, the chances of making calculations in terms of phase to line, line to line phase and also three phase or single phase, it is greatly minimized.

Already, I have shown that how this line to line and per unit phase quantities are related, but in the per unit, this is per unit whether you are line or base, it is a constant. So, there is no confusion in the phase; that is always base value per unit quantities. So, it has no line to line or phase to phase calculation; also in the single phase and the three phases, this calculation becomes very simple. In case of transformers, this is the great advantage of per unit system. In case of transformer, the per unit values of impedance voltage current refer to the primary side or secondary side will be the same which further simplify the calculation.

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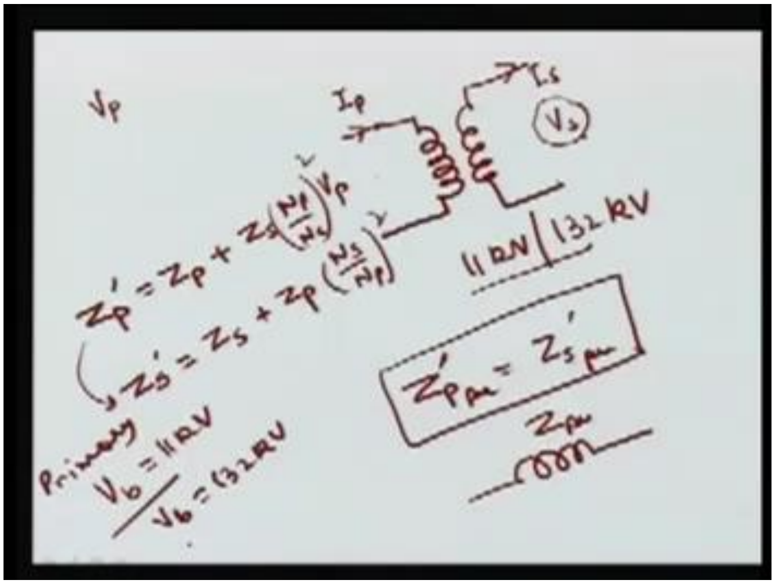

To understand this, here you can say this is a transformer. This is your transformer primary winding; this is your secondary transformer winding. Now the quantity which this side is going, it is called the v primary, I primary, and here your v secondary and the current here your secondary current. If this transformer is let us suppose is 11 KV to 132 KV, then the impedance which is referred this side will be certainly different than the impedance referred to the side. If this transformer is the z let us suppose z actual referred to the primary side that is here z p referred to the primary side, it will be $Z'_P = Z_P + Z_S \left(\frac{N_P}{N_S}\right)^2$. So, this quantity you have referred to the primary. In actual quantity, it will be different than this impedance referred to the secondary side. This will be your nothing but $Z'_S = Z_S + Z_P \left(\frac{N_S}{N_P}\right)^2$. So, these two impedances are different whether you are referring this side or that side, but in per unit system whether you are referring this side or that side; that will be same. Means your z per unit referred to the primary side in per unit will be equal to your z secondary per unit referred to this side.

So, whether it is referred to the secondary side per unit or it is referred to this primary side, in the per unit, both will be the same. So, it simplifies; means this transformer is simply represented by the impedance here z and it is in per unit. So, now it is irrespective or referred to the primary side and the secondary side. This is the great advantage of the per unit system but can be proved very easily. And you will find all these proofs in the various books. Here normally what we do? The base now, another important quantity here the base this primary side your here this V p will be the base; however, in the secondary side, this voltage will be this base.

For example, for this transformer, the voltage base in the primary side, it is 11 KV. However, in the secondary side, I can say primary side, and in the secondary side, it will be your v base. It will be 132. So, the base is also going to be changed. So, in the power system, here suppose we have a different transformer of different ratings in terms of power as well as the voltage rating, generators are also of the different voltage and the power ratings. So, all they are interconnected as we saw the various advantages of interconnection. So, we have the interconnected complex power system.

Then we have to the power base will be constant throughout the system. Let us go for the various advantages, then I will come back to that one. Here this other advantage is the power and the voltage equations are simplified as a factor of and the three are eliminated in the per unit system. Means here the three concept is basically eliminated means every time we can write in the per unit in the power your this voltage base as well as your current base that will give you the power base. So, this three phase, etcetera, it is eliminated, and it is very easy to calculate all the power system quantities in terms of your steady state as well as your dynamic quantities that can be calculated.

And also all loss are equally valid in the per unit system; that is very important. So, that you should not worry that whether Kirchhoff's current law and voltage law are valid in per unit system equally valid in that one. To understand this, let us see a power system here consist of transformers, generators and other systems. This is a system which I am representing; let us suppose we have a generator

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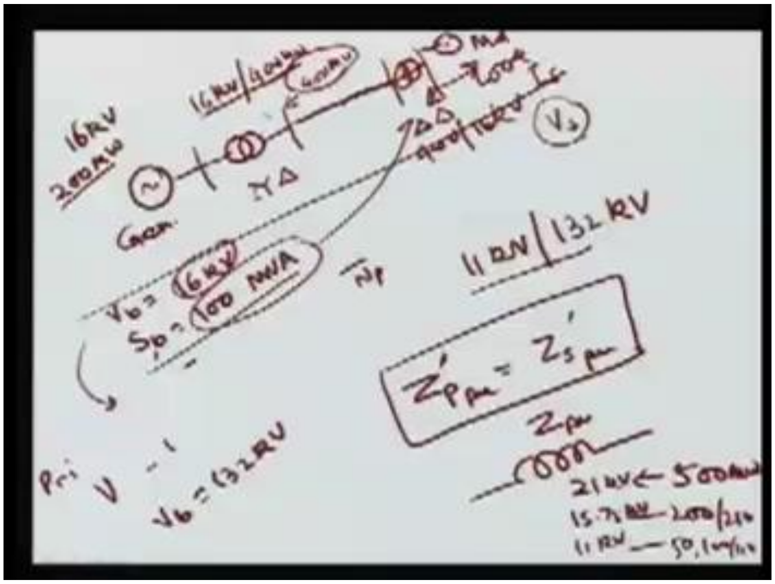

This is the connected with the transformer; here transformer I can represent like this. Here we have another bus; we have a transmission line, and we have the various load as well as we can have the motor loads. So, this is your generator; this is your motor load, and here this is any other static load. Now this transformer actually this generator is a three phase; transformer is also a three phase. Let us suppose this connection will be always not always it is a star and delta and this may be your grounded as well. Now the rating of this is let us suppose is 11 KV, and the power which is generating it is a 200 megawatt.

Basically, for the 200 megawatt units in our India, it is 16 KV normally. In India, we have the different rating generators. So, the generators which are rated at the 500 megawatt, they are basically operating at 21 KV. Those are 200 and 210 megawatt; they operate 15.75 kilowatt and others like 50, 100, 110, they operate 11 KV. So, let us suppose this is a 200 megawatt generator, and it is rated at 16 KV this per unit. Now this transformer is we have here 16 KV to 400 KV and then here we have another basically the transformer we have to use, because we cannot use the motor load at the 400 KV.

So, it is another transformer I can say it is your delta delta and it is 400 by 16 KV. So, now we have to take the common base for this complete system, and we have to start from one end and especially we start from the generating end. So, our voltage base if we start from this generator, let us suppose it is 16 KV. So, this is your V b; I said it is a three phase generator, and it sets in 16 KV voltage means it is line to line and that will be the base value. Now the power here it is even though shown at 200 megawatt, but normally, we take the power base in normal calculation it is 100 MVA.

So, this power base will continue, and it will be same throughout the system; however, the voltage base will keep on changing. Now you can see at here at the primary side of this transformer, the base will be your 16 kV; however, this side since we are transforming with this transformer, the voltage base at here, it will be 400 KV. So, the voltage base of this transmission line will be this is your voltage base and the power base will be your 100 MVA. Now again if you are going for again this transformer is used means again we are using 400 to 16 KV; means we are stepping down.

So, the voltage base at this bus, again it will become the 16 kilovolt and the power base as I said it will be continued throughout the system. So, what happens? Then you have to calculate, because this transformer is one element; this is one element; this is another element; this is another element, and this is also an element. So, we have to convert all the quantities on the single phase.

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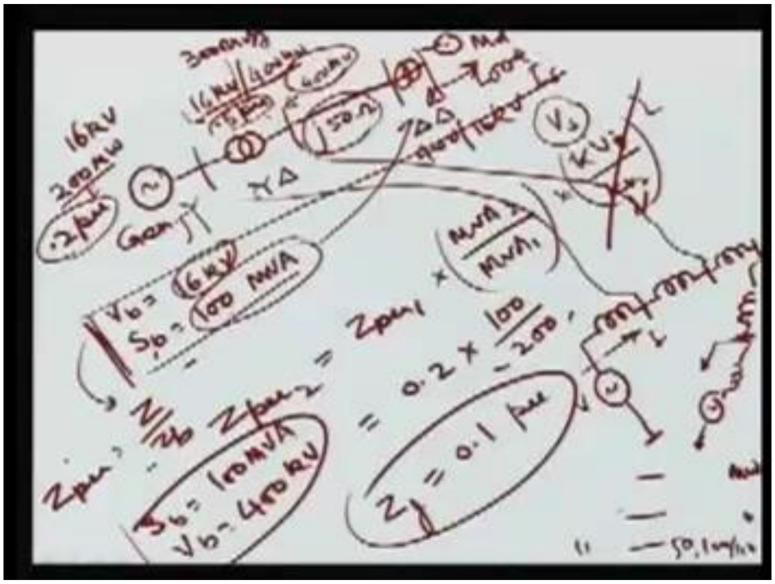

So, for example, if here we have given the per unit impedance of let us suppose this generator is given 0.2 per unit; for this transformer, it is written let us suppose 0.5 per unit, and again, here this is the voltage rating. And all that as I said all the elements, they will be rated with its maximum power that it can handle. And again it depends upon the constraints; how much power it can handle without excessively heating, and it should not burn means continuous rating of the operators. So, let us suppose it has your 300 MVA rating, and this line is there.

Let us suppose impedance is 50 ohm, and it is let us suppose only x is there, and then we have another transformer of the same rating, and then we have the motor load. Now what we have to do? We have to basically calculate the impedance of this on this base, because this value is given on its base. This value is given on this base and in this base. So, we have to change it; we have to change in this this value base, and so here we can as I said, I should z per unit at the new base will be equal to here $Z_{pu2} = Z_{pu1}\left(\frac{MVA_{b2}}{MVA_{b1}}\right)\left(\frac{KV_{b1}^2}{KV_{b2}^2}\right)$

So, we have to see the voltage is same, so there is no use of this and here 200 means now it will be your z per unit volt is two multiplied by MVA two is now your 100. New one is 100, and the old on which it is given it is 200. So, it is 200. So, now we are getting this one per unit. So, for the calculation on this base, now this impedance of this generator will be taken at here z per unit of this generator is this; here resistance is neglected basically. Similarly, we have to go for this one and then for the other element. Here for the transmission line, we have not written in the per unit, because the transmission line the voltage rating is very difficult to define.

It is very easy to calculate r, l and c as you know the elements parameters of that transmission line, we will see later also. And then, we have to calculate what will be the base. For this line, your power base will be again it is your 100 MVA; however, the voltage base will be your S will be your 400 KV. So, you have to calculate the z base, and then we can calculate the z per unit of this line will be z upon z base. And then whole this system will be represented by the impedance diagram, and that impedance diagram of this will be here this is your only generator is represented by its impedance, then this is this bus.

And since, it is the voltage source, here it is generating, and here there will be some ground; this is the star connected generator. Now for the transformer, transformer here we are simply representing as the impedance; this is another bus. So, this bus corresponds to this; this bus corresponds to this, and then we have this impedance of the transmission line, and then here we are having the impedance of again another transformer here. And then we have again at this bus, we have a load, and we have a motor, and this motor is again motor, then it is a grounded.

So, basically this is the impedance diagram, and based on that, now we can calculate this current knowing this voltage here, and we can calculate other quantity of the power system. So, this is whole duty of the per unit system; that is why I have reviewed, because all our calculations later on, we will go in the per unit calculation. Whether we are calculating our AGC that is the automatic load frequency control or automatic generation control; in that, I will be using the per unit system, also in the stability we will see the various here in the per unit system.

So, this is basically total about your per unit system representation. Now let us come to the various equipments of the power system and those are here the first one is that is called the generators. Generators are the source of a power system means they supply power to the grid to the system, and that power must carried by the transmission lines, transformers, distribution lines, and finally, it is reaching to the various customers.

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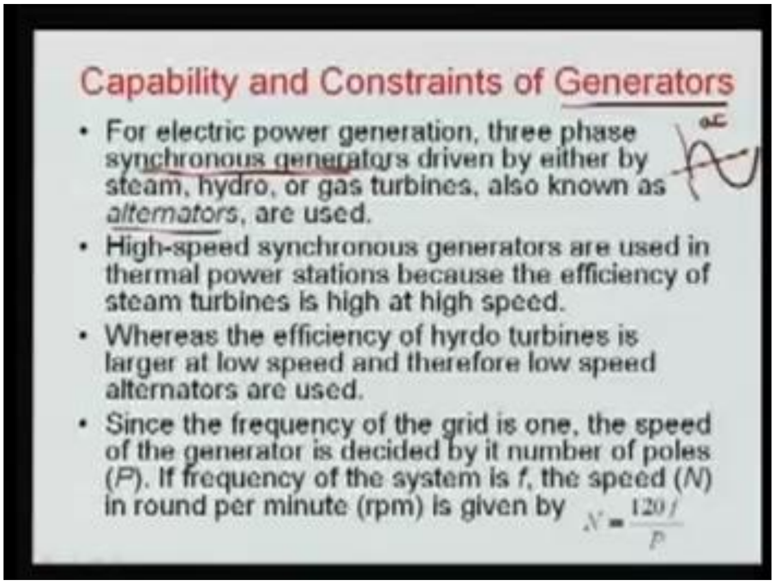

So, for the electric power generation, normally it is the three phase synchronous generators driven by either steam turbines, hydro turbines, or it is a gas turbine known as the alternator are used. Normally, these generators are also called the alternators. Why it is actually this is a very old term; alternator means they provide the alternating voltage that is here this voltage normally they are providing. So, it is alternators, and since, there is alternating current and you know they provide the ac current; this is alternating current. So, they are called the alternators as well. In other cases as I said, it is a synchronous generator.

We have the two types of generators, and broadly in the ac, we have two type of machines. We can say the synchronous, another is your induction. Induction generators are having inherent problem, and therefore, they are not widely used. They are only used for some specific purpose like a wind turbine where there is a variable speed is there and other related, but the synchronous alternators for all the conventional power system; that is your steam, hydro and the gas they are used. So, it is very very important to know about their limitations, their constraints, so that we can see and we can feel about the power system constraints.

So, the equipments constraints in terms of generators that is your alternator, and the alternator I am talking about only the conventional power generators; that is whether it is a cool base that is steam, hydro or it is a gas turbines. Basically, we have a four type of conventional; that is your steam, hydro, gas, diesel as well as the nuclear power station. So, we use the synchronous generator. So, we will see the limitations, and to know the limitations and the capabilities of the generators, we must see the various types of generators and how their phasor and other relations are derived, so that we can go for their capabilities limits.

So, in this lecture, now I can recap. We saw various constraints that is I briefly said that it is related to the system constraints or related to the equipments constraints. They are very very important, and then, we saw the per unit representation, their advantages, and those advantages are very very useful for the power system analysis. And also in this power system operation and control, we will use those quantities in the further lectures.

Thank you.