Power System Analysis

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Lecture - 15
Load Model

Welcome to lesson 15 on Power System Analysis. In this lesson, we will discuss Load Model. Till now, we have discussed models for different components of power system. We started with the model for transmission line, then we discussed the model for the transformers and then, synchronous machines. In this lesson, we will take up the models for loads. Basically, the loads are consisting of number of different kinds of components.

They can be your household fans, lights, heating, air conditioning or industrial loads as induction machines, pumping loads in agriculture. So, we have different kinds of loads in the system. And as for power system analysis, we need to model these loads properly to get the proper and accurate analysis of the system, under different conditions.

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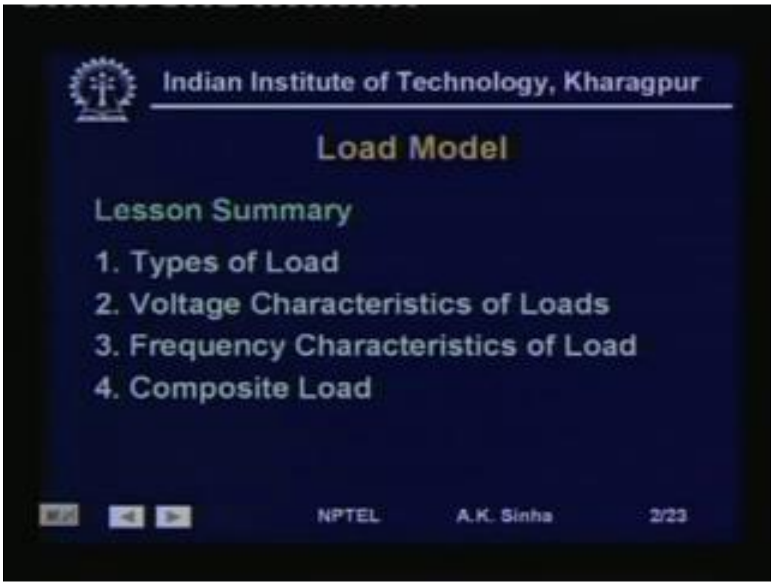

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Load Model

Lesson Summary

1. Types of Load
2. Voltage Characteristics of Loads
3. Frequency Characteristics of Load
4. Composite Load

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So, here we will take up different types of loads. So, we will talk about what are the different types of loads, that we have. Then, we will talk about the voltage characteristics of different loads, frequency characteristics of loads. That is when voltage and frequency in the system changes, how these loads are going to behave. And we will also talk about the composite load, because actually when we are modeling these loads, we are modeling them at the substation level. So, there are very large number of loads, all these have to be aggregated and put as a composite model for the power system analysis.

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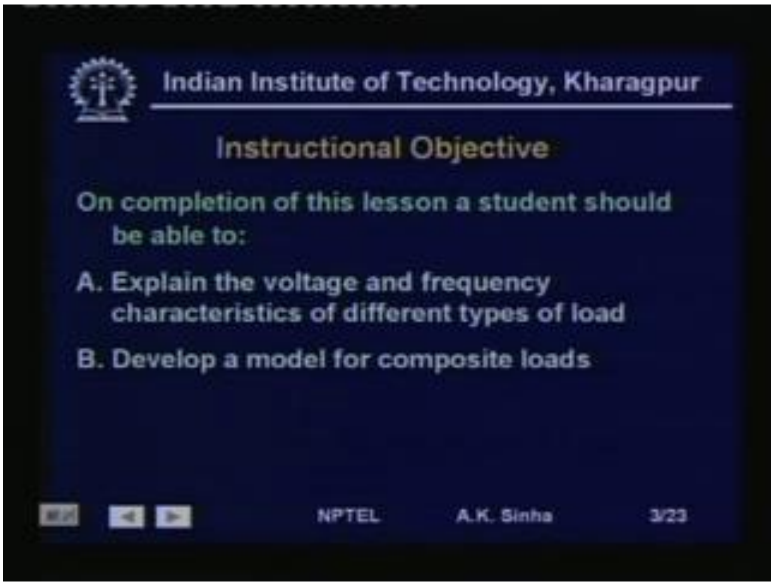

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Instructional Objective

On completion of this lesson a student should be able to:

A. Explain the voltage and frequency characteristics of different types of load

B. Develop a model for composite loads

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So, the basic instruction or instructional objective for this lesson will be, that on completion of this lesson. You should be able to explain the voltage and frequency characteristics of different types of load. And you would be able to develop a model for composite loads.

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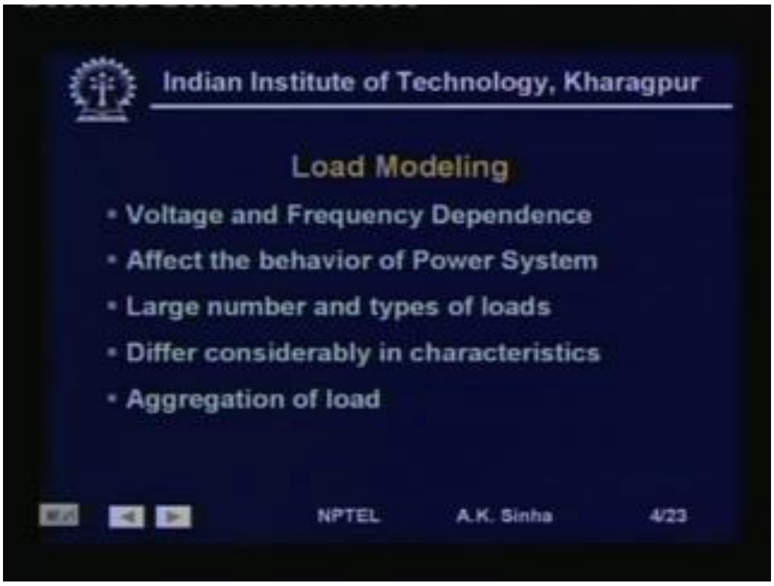

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Load Modeling

- Voltage and Frequency Dependence
- Affect the behavior of Power System
- Large number and types of loads
- Differ considerably in characteristics
- Aggregation of load

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Now, first thing that we are going to discuss is why we need modeling of the load. Well, we know that with the change in voltage and frequency, the active and reactive power drawn by different types of loads vary in a different manner. That is different loads have different voltage and frequency dependence characteristics. That is whenever a voltage or frequency changes, the load also changes along with it.

So, voltage and frequency dependence of load, then these loads affect the behavior of the power system. Because, if the loads suddenly increase or decrease with change in voltage and or frequency, then the response of the power system also will have to be taken into account to cater to these changes. We have very large number of different types of loads. So, when we are fine to model this we need to take that into consideration, that is how we are modeling.

Whether, we need to model each component, each load separately which in most of the cases is impossible. Because, at a substation, distribution substation level also you will have 1000's of various loads. Because, it caters to a number of residential complexes, may be it will be catering to certain industries in that area, commercial, establishments in that area. And all these will have large number of loads.

So, if you are thinking in terms of modeling all the loads separately. Then, at every substation you may have to have model more than 1000's of these loads, which is a very very difficult thing for any analysis to be carried out. Now, these as said earlier these loads also differ in their characteristics. So, whereas an induction machine load will have a different characteristics with variation in voltage or an frequency lighting load, or say incandescent bulb will have the entirely different characteristics.

If the frequency changes the incandescent bulb, it does not effect at all. Whereas, it does effect the loading on a induction machine. Similarly, if the voltage changes the loading for a lighting load will depend on the. since it depends on the square of the voltage. So, there is going to be variation in the load. if the voltage goes down the power drawn by the bulbs will reduce, of course will get less light.

If the voltage goes up, then the power drawn by the load increases considerably, and the lamps glow much brighter, but of course it also reduces the life of the lamps. Now, as I said, since we have very large number of loads connected at any substation, we need to aggregate these loads and build a composite model for the loads. So, we are going to discuss these factors in this lesson.

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Types of Load

1. Lighting
2. Heating
3. Induction Motor
4. Synchronous Motor

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Now, we will talk about different types of load. I have shown here 4 different types of loads. There may be many more, but these are the general types of load that we have. We have lighting load which consists of incandescent lamps, fluorescent lamps, may be discharged lamps. That is those light bulbs that we have incandescent bulbs, then we have fluorescent tubes or compact fluorescent lamps.

We also use sodium vapor lamp or mercury vapor lamps. So, the lighting load consists of these kinds of lamps. And we will discuss about characteristics of these loads. Another loading which we have is heating loads, especially in colder regions we use heating of a space. As well as in industry we need lot of heating, so we have heating loads. And these heating loads are basically using resistors. And therefore, we have a different kind of a loading characteristics for these.

Then, a majority of loads in industry, as well as in agriculture sector are induction motor loads. Because, the induction motors are the work horse of the industry. They are used almost for all kinds of applications even in agriculture, we have all these pump sets which are basically operated by means of induction machines. So, we have large number of induction motors, we need to learn about how to analyze or this loads with induction machines.

So, we need to know what is the characteristics of these machines, when voltage or frequency changes. Synchronous machines very few of them are there, but we need to model them, because synchronous machines are mostly used as generators. But, in some places where we need very constant frequency drives, we do use synchronous machines. So, synchronous machines loads are also the loads which we need to discuss.

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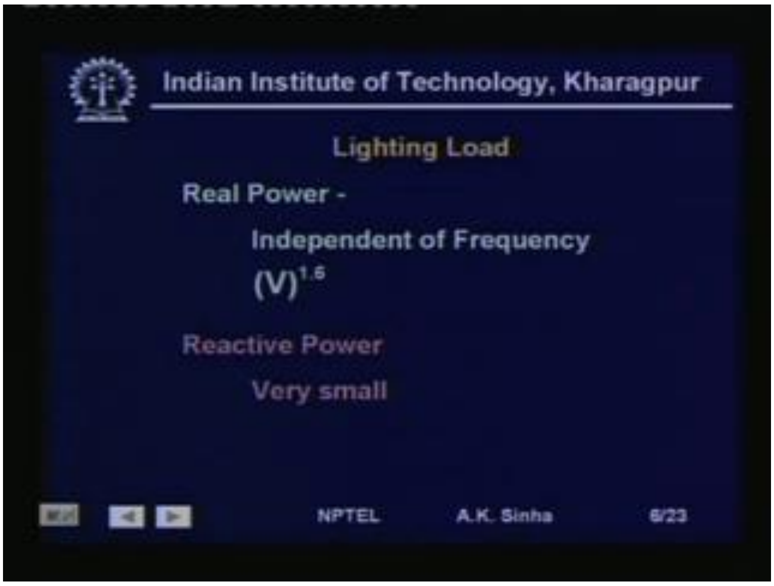
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Lighting Load

Real Power -

Independent of Frequency

$(V)^{1.6}$

Reactive Power

Very small

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Now, we will take up each of these types of load one by one. Now, if we look at the lighting load, the real power for these loads are basically independent of frequency. That is change in frequency does not affect the real power drawn by these loads, whereas a change in voltage does affect them considerably. In fact, if we have a incandescent bulb the resistance of this lamp is not a linear resistor, because the temperature of the filament goes to very high values.

So, we have a non-linear resistor, in their and therefore, the load is not exactly varying as per the square of the voltage. But, it varies with some factor which is near to the square of the voltage. And we have other loads like fluorescent tubes, we have compact fluorescent lamps, we have discharge lamps, like sodium vapor lamps or mercury vapor lamps.

All these form the lighting load and the characteristics of all these lamps with variation and voltage, can be seen as V to the power 1.6. That is it is not exactly V squared, but they can be model as varying with voltage. So, power is proportional to V to the power 1.6. So, if the voltage increases by 10 percent our power will increase much more, it is not a linear relationship, but the radiation is V to the power 1.6.

The reactive power drawn by these loads are generally very small, especially incandescent lamps they do not draw any reactive power at all, because they can be represented by a pure resistor, whereas for the CFL’s or fluorescent tubes and the discharge lamps, we do have a little bit of reactive power drawn by them. The fluorescent tubes of course, the older models which use normal choke, they have low power factor.

But, most of the model chokes that we have electronic chokes, the power factor is quite high. Even with those older chokes they are now providing some capacitance, to compensate for the low power factor. And therefore, the reactive power drawn by these loads are very small. And therefore, the variation of reactive power with the variation and voltage is most of the time neglected.

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Heating Load

Real Power -

Independent of Frequency

$(V)^2$

Reactive Power

Zero

Load – Constant resistance

Next we will discuss the heating load. Now, for heating load are basically can be modeled as pure resistors. So, if we are modeling it as pure resistor, then the real power will be equal to V into i and i is equal to V by r. So, actually a real power will be proportional to V square by R, R being constant. So, real power is proportional to the square of the voltage.

Again here the frequency has no part to play, because the frequency, whether it is DC or AC at any frequency, except if we go to frequencies which are much higher, in terms of 100's of Hertz or kilo Hertz or mega Hertz. The skin effect their does come into picture and the R value or the resistance does change. But, at 50 Hertz it does not affect it much and therefore, the frequency has hardly any effect. And also the variation of frequency for our power supply is very small.

Because, the bank under which it operates is generally very small, it is less than 1 percent or 2 percent plus minus 1 percent or 2 percent. So, these loads are independent of frequency variation.

We can consider them to be completely in independent of frequency variation. That is real power does not change with frequency. But, with voltage it changes considerably, because real power is proportional to V square. Now, reactive power since these are basically resistive loads, reactive power for these cases will be 0. And therefore, these loads most of the time can be represented by a pure resistance only. So, a constant resistance representation is good enough for most of the heating loads.

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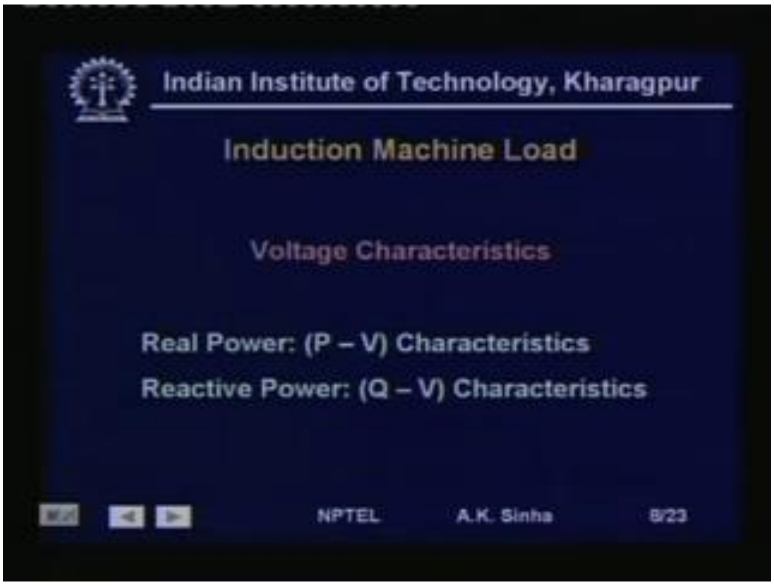

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Induction Machine Load

Voltage Characteristics

Real Power: (P – V) Characteristics

Reactive Power: (Q – V) Characteristics

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Next, we will discuss induction machine load or the induction motor load. Now, we will consider the voltage characteristics of these induction motors. I will not go into the theory of induction machine, because you would have done that, in the course on induction machine or in the course of machines. And therefore, I will take it for granted that you already know, the basic theory of induction machine. And from there, we will build the characteristics and the models for the induction machine. So, here we will talk about the real power versus voltage characteristics and reactive power versus voltage characteristics of induction machines.

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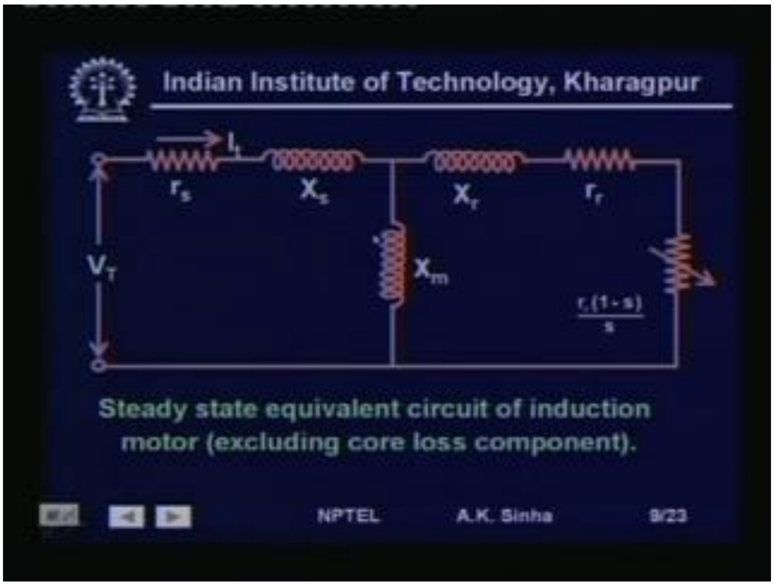

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Steady state equivalent circuit of induction motor (excluding core loss component).

Now, if you recall the induction machine equivalent circuit is shown here. Now, in this the terminal voltage V T is applied to the induction machine the stator winding of the induction machine has resistors r s and an reactance X s. The magnetizing part is represented by a reactance X m, of course we are neglecting the core loss part. So, therefore, this resistance normally which we put in parallel with X m is neglected, because that part is much smaller.

And therefore, this representation of X m for magnetizing part is good enough. Now, the rotor circuit has reactance X r and resistance r r. And the load is represented here as r r into 1 minus s by s. This is standard equivalent circuit for an induction motor. So, steady state equivalence circuit of an induction motor excluding core loss component can be seen as the circuit. I t is the current which is flowing into the induction machine.

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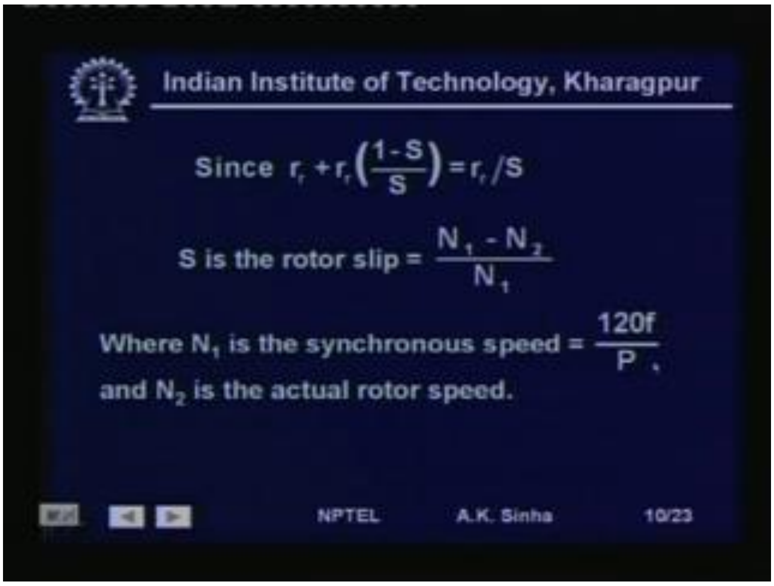

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Since $r_r + r_r\left(\frac{1-S}{S}\right) = r_r/S$

S is the rotor slip = $\frac{N_1 - N_2}{N_1}$

Where N_1 is the synchronous speed = $\frac{120f}{P}$,
and N_2 is the actual rotor speed.

Now, we know that r r plus r r into 1 minus S by S is equal to like that, if we add these two resistances here r r and r r into 1 minus S by S. Then we have this equal to r r by S, where S is the rotor slip and this is equal to N 1 minus N 2 by N 1. Where, N 1 is the synchronous speed given by 120 f by P, where f is the frequency in Hertz and P is the number of poles. So, this we had seen when we discussed the synchronous machine. So, synchronous speed is 120 f by P and N 2 is the actual speed of the rotor.

So, it is N 1 which is the synchronous speed minus N 2 the actual speed divided by the synchronous speed, this is how we define the slip. That is how much the rotor is slipping with respect to the synchronous speed. So, because the air gap flux the three phase winding on the stator, produces field which is rotating in the air gap at synchronous speed. And the rotor if it is rotating at a speed N 2, then it is slipping with respect to the rotating magnetic field in the air gap.

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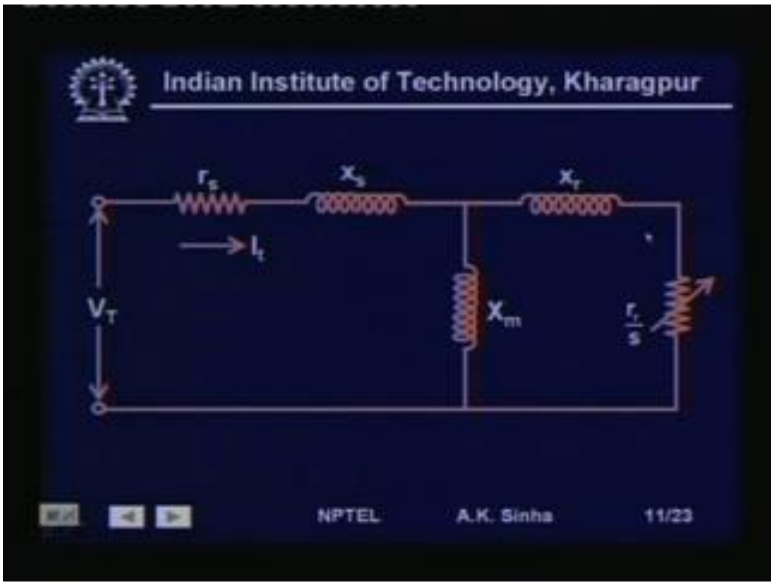

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So, this is how we define the slip, therefore if we add these the rotor resistances and the load part. Then, we are going to get the equivalent circuit as, this is the stator part, this is the magnetizing part, this is X r the reactance of the rotor circuit. And the rotor resistance as well as the load part is represented here, so we have this as r r by s. Now, when s is equal to 0, then what we have is this resistance is infinite, which means it is open circuit.

And which simply says, that no load can be served, because no current will be flowing in this part of the circuit. And the machine, therefore cannot operate at synchronous speed, because whenever it rotates there is going to be some loses in friction and wind age. Those mechanical losses have to be supplied and if it rotates at synchronous speed, there will be no current which can flow in the rotor circuit. Because, there is no flux which can be cut by the rotor conductor and therefore, no torque can be developed.

When the rotor is standstill, then r r is giving the resistance of the rotor. That is when the machine is at standstill, then we have the resistance of the rotor here. And since, this resistance will be much less, so much smaller, therefore you will have a very large current flowing through this. As the rotor picks up speed the value of s will keep on reducing.

And that means, this r r by s will keep on increasing, because s is equal to 1 is standstill. And as the rotor starts rotating s becomes less than 1 and it keeps on increasing till it reaches very near to the synchronous speed, then this s is very near to the synchronous speed. Normally these induction machines will be working at around slip off around 0.4, 0.5 like that, that is at 4 percent, 5 percent slip.

Therefore, this value will be very large. But, when we switch on the machine, that is when we apply the voltage across the machine, when it is at standstill this resistance, this s will be equal to 1. So, this is only r r coming into picture and that is why you get a very large current flowing. So, starting current of induction machine is generally very large. So, this effect has to be taken into account, when we are trying to analyze the machine. So, if we have an induction machine node, then we have to consider all this. And that is why this circuit provides us that kind of a representation, where we can model this machine properly.

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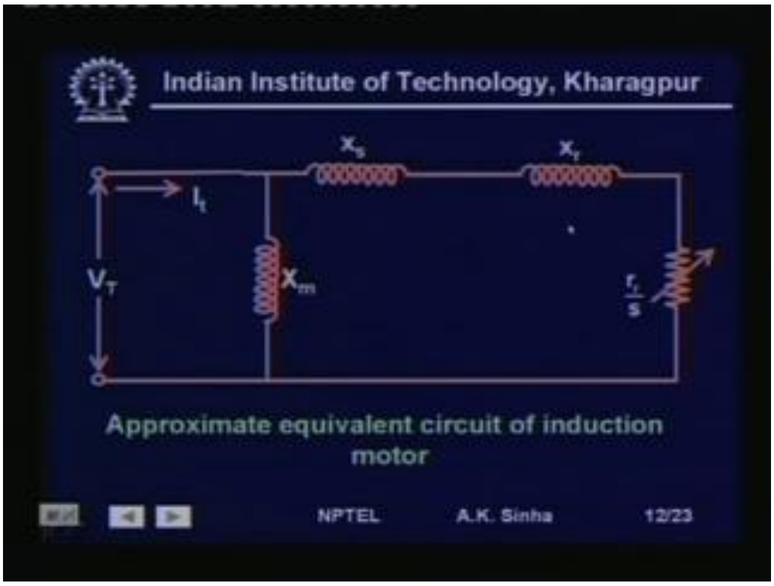

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Approximate equivalent circuit of induction motor

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Now, if we see here ((Refer Time: 23:51)) this magnetizing part is drawing some current here. Now, this current will be very much out of phase or almost at 90 degrees with this current, because this will have a large resistance initially, so a small resistance. And therefore, we will have here, what we will get is this current being very small, because this impedance is going to be very large, it is only the magnetizing current.

So, what we can do is, we can shift this on this side. And therefore, we can make our model something like this, where we have also neglected the stator resistance, which is much smaller compared to the stator reactance. So, approximate model which makes our analysis much simpler, can be seen as this circuit model. So, this is the approximate equivalent circuit model for an induction machine.

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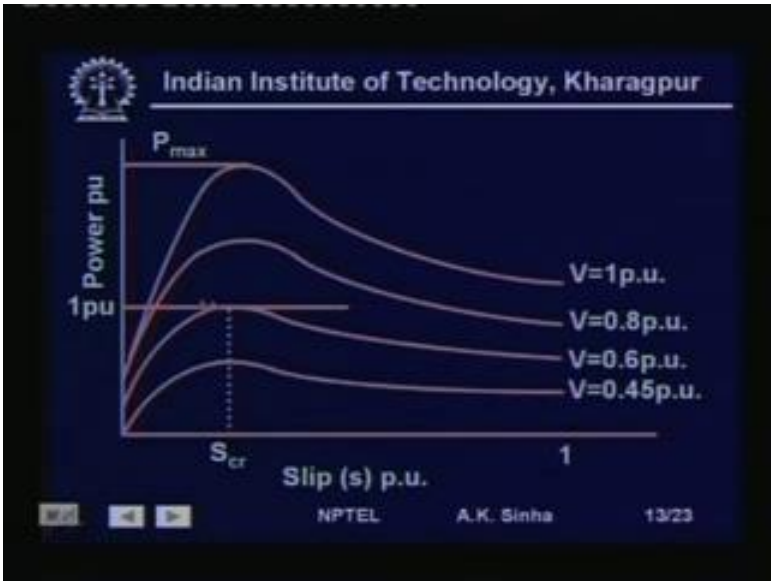
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Now, using this model if we want, we can plot the power versus voltage characteristics at different voltages for the machine. That is if we have applied 1 per unit voltage, then what we will get is a characteristics like this. If we have reduced the voltage to 0.8, then the operating characteristics will be following this curve and so on. If 0.6 there then it will be following this curve and if it is 0.45, it will be following this curve.

That is at different values of voltage applied to the terminal of the machine. We can plot the power versus voltage characteristics of the machine, it is very similar to the torque speed characteristics or torque slip characteristics. So, when we apply these voltages, we can find out how the power versus slip of these machines change. So, slip is equal to 1 basically means that, this is the standstill position and slip is equal to 0 is this position where the power output is going to be 0.

All these machines will work only in this portion, that is this is the stable portion on the left of this line. We have got the stable portion, this is this part is stable, this part is stable and so on. This part which is on the right of this line is the unstable part, that is the machine would not be working in this part at all. So, when you apply the voltage it goes up like this and it will be working on this portion somewhere.

Now, suppose the load the mechanical load or machine is 1 per unit. Then what we find is if we have applied a voltage of 1 per unit, the operating point will be this point. If we had applied a voltage of 0.8 per unit operating point will be here. Suppose, if we reduce the voltage to 0.6 what we find is, this will be the operating point. And if we reduce the voltage further what do we find is that, there is no operating point available.

So, what is going to happen if the voltage goes below 0.6 per unit, for this machine when the load remains at 1 per unit. Then, in that case we find that there is no point of intersection between a constant power load. And constant power 1 per unit load and the power speed characteristics of the machine. So, this simply means that, this machine will stall or it will stop, it will not be able to generate torque to take care of this power or the mechanical load of the machine.

So, electrical torque is going to be much less than the mechanical load on the machine. And therefore, the machine will start slowing down and will finally stop, this is called stalling of the machine. Now, if this kind of a situation can happen, if we have a short circuit occurring very near to the machine terminal, or the substation at which this machine is connected. There, then the voltage at the machine terminals can go to very low value.

Because, if this short circuit is occurring at a nearby substation, then the voltage at the substation can go very low during the period of short circuit. And if this happens, then some of the machines induction machines if the voltage goes below this point will start. And this point is the maximum power that can be generated by this machine, is called the P max for the machine. And the slip at which this can be generated is called the critical slip.

And the voltage at which the maximum power is equal to the load is called the critical voltage. So, in this case we find that V is equal 0.6 per unit is the critical voltage for this machine. Because, below that the machine is going to start, that is it is going to come a stop. And the slip at which this occurs is the critical slip. Now, if this happens that the machine stops, then if the short circuit is removed, again it will the voltage will be restored and the machine will start.

Now, if it starts from a stand still position or at a very low speed, it is going to draw very large current. Because, we have seen from this characteristics that (Refer Time: 31:09), this s will be coming near to one. So, this resistances is very small, so the current drawn by this machine will increase considerably. Therefore, this situation needs to be analyzed properly if we are doing an accurate, we are going to do an accurate analysis of a power system under such situations. Similarly, if we want to keep the torque on the machine constant and vary the voltage, then we get different characteristics.

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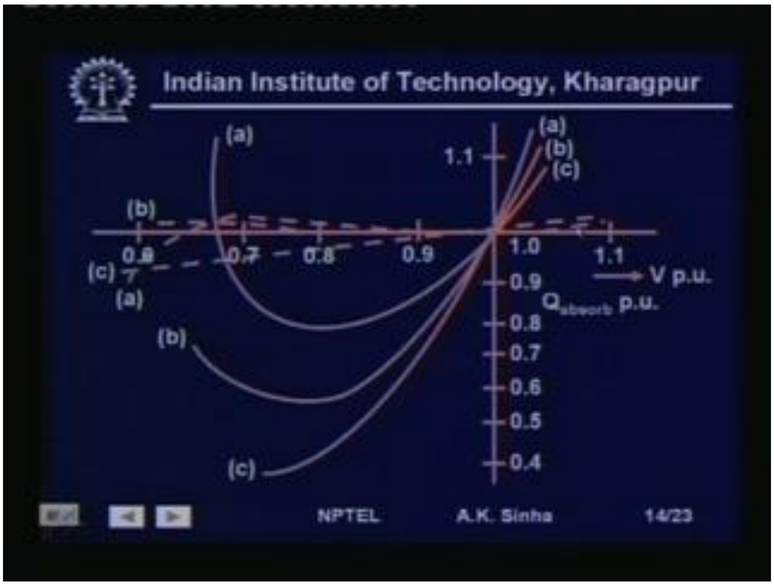
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If the torque is constant say at 1 per unit, then we have this characteristics a which shows how the real power is going to vary. This dotted line for this characteristics a is telling us, how the real power is going to vary, when the voltage is varied. That is if it increases beyond 1 per unit, then the real power which will be developed by the machine will also be more than 1 per unit. Otherwise, we are finding that this will be near to 1 per unit and at very low voltages it does rise a little bit and then, falls off considerably.

Of course, beyond 0.6, we find that this is going to fall down and you will have a stalling of the machine. The characteristics b is for 0.75 per unit torque and it is characteristics c is for 0.5 per unit torque. Now, the real power changes are not really very much except that, beyond the critical voltage you are going to get no power at all. But below this the variation is not very large may be around 10 percent or so whereas the variation in the reactive power is considerable.

If you see, if we are keeping the torque at 1 per unit and change the voltage, then the reactive power which is absorbed by the machine is like this, whereas on this side of course, the reactive power increases considerably. So, below a certain voltage, the absorption of reactive power by the machines becomes very, very large. Same thing is seen by this curve b, which is for 0.75 percent of the full load torque and c which is at 0.5 or 50 percent of the full load torque.

So, these show the characteristics of the real power and the reactive power drawn by the machine, under different voltage conditions. Now, this is mostly telling us about the steady state operation of the machine. That is if we keep the voltage at 0.9 per unit, then this is what is going to happen. That is the real power will be this much, the reactive power drawn by the machine will be this much and so on.

But, if we want to do a dynamic analysis, that is how this machine is going to behave when these values are changing rapidly. So, how the machine, because what is going to happen is, the speed of the machine will also change, the voltage and current drawn by the machine will also vary. So, if we want to study the dynamic or do a dynamic simulation of the machine, then we need a little different circuit for that.

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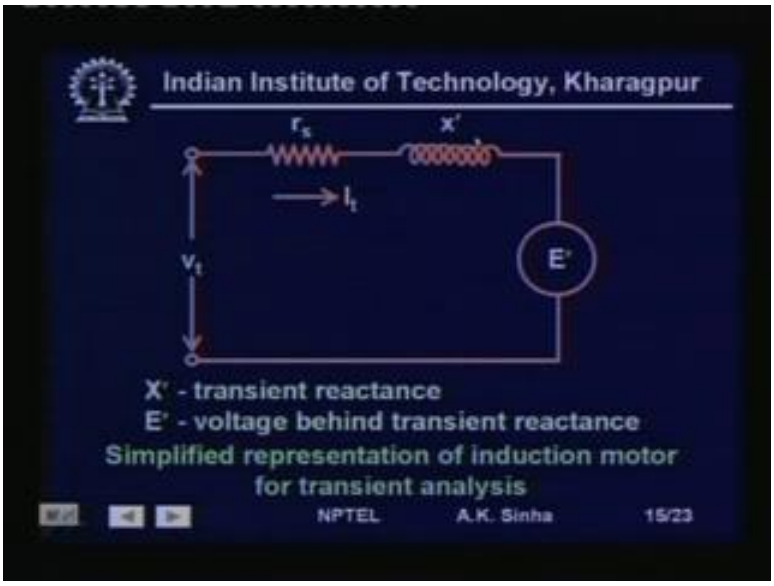

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X' - transient reactance
E' - voltage behind transient reactance

Simplified representation of induction motor for transient analysis

Now, what we do for dynamic simulation is, we use a circuit where we have the resistance of the stator given here as r s. X dash is the transient reactance of the machine. Now, transient reactance of a induction machine is very much same as the block rotor reactance of the induction machine. And this voltage E dash is the voltage behind the reactance of the machine, which is basically what we can call as the voltage generated by this machine or the air gap voltage. So, X dash is the transient reactance, E dash is the voltage behind the transient reactance. This is a simplified representation of the induction machine for transient or dynamic analysis.

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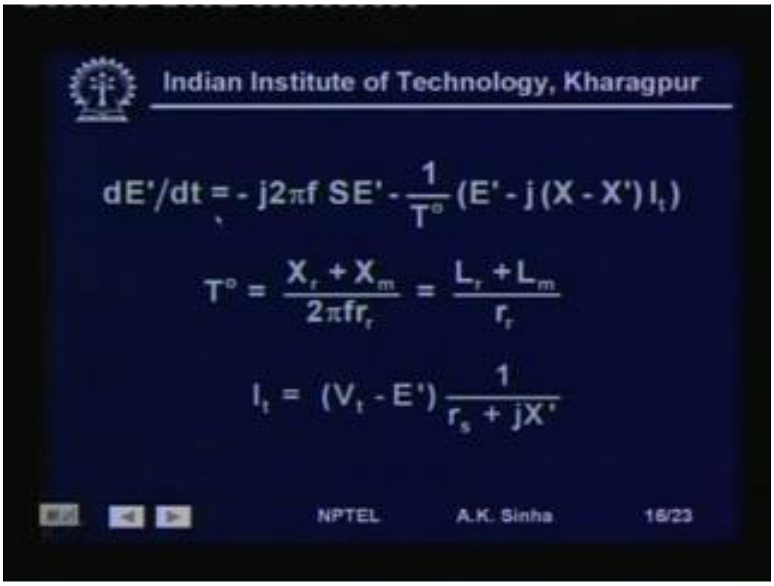

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$$dE'/dt = -j2\pi f\, SE' - \frac{1}{T^{o}}\left(E' - j(X - X')I_t\right)$$

$$T^{o} = \frac{X_r + X_m}{2\pi f r_r} = \frac{L_r + L_m}{r_r}$$

$$I_t = (V_t - E')\frac{1}{r_s + jX'}$$

So, with this model, if we want we can find out how the voltage is going to change with time for this machine. So, that is we can find out the slope of the rate of change of voltage with time. So, d E dash by d t will be in this case given by omega f, that is twice pi f, so this is omega. So, j omega S is the slip into E dash minus 1 by T 0, which is I can write this is as tau 0 into E dash minus j X minus X dash into I t, where tau 0 is the time constant and this is given by X r plus X m by omega into r r.

That is twice pi f into r r, which can also be written as L r plus L m by r r, where L r is the inductance of the rotor winding. L m is the inductance representing the magnetizing part, r r is the rotor resistance. And I t the terminal current into the motor is given by V t minus E dash into 1 by r s plus j X s. That is what we see from this circuit I t will be V t minus E dash divide by r s plus j X s.

So, this equation differential equation governs the dynamics of the voltage of the induction machine. So, when we are doing the dynamic analysis, we use this kind of a representation. If we want even more detailed analysis then of course, we can also introduce the rotor dynamics, that is the mechanical dynamics of the induction machine. However, most of the time that is not required and we do not go in for such complex representation, unless we are analyzing a single very large induction machine in the system.

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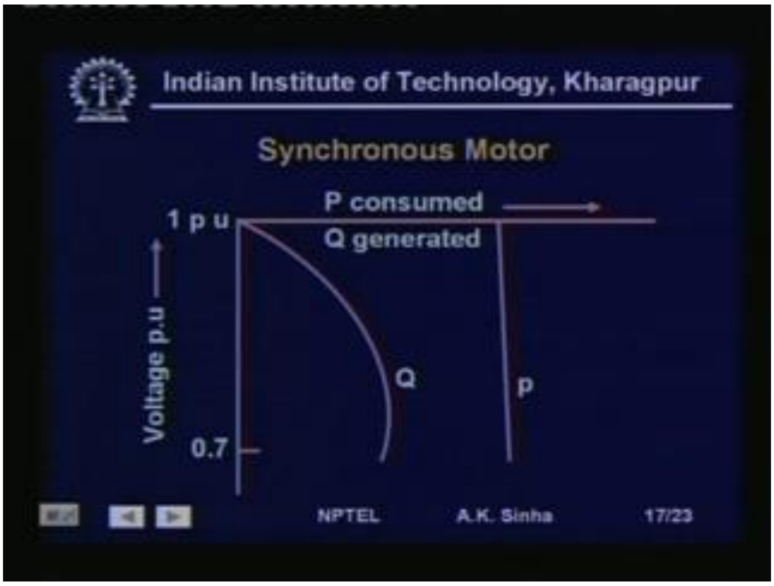

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Synchronous Motor

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Next is synchronous motors. The synchronous motors are very rarely used as such most of their application have been, either as a synchronous condenses, where we want to use these machines for providing the reactive power. Or in some applications where we need very constant speed, which is not possible by a induction motor, because where change in load the induction machine power or the torque changes, so speed also changes.

So, if you change power the speed will change, whereas for a synchronous machine the speed will remain constant whatever may be the power. So, synchronous machine characteristics as the voltage changes can also be shown here. We see that with change in voltage the change in power is hardly there, whereas the change in reactive power is considerable. Because, we would like to keep as the voltage reduces our reactive power demand, or the reactive power which is generated by this synchronous generator by fixing x excitation to keep the E dash constant is going to be much larger.

So, the Q generated is much larger as the voltage goes below the rated value. So, this is about the synchronous motor.

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Categories of Load

- Residential
- Industrial
- Commercial

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Next, we will talk about the different categories of load. In fact, as we said earlier in at a substation, we have large number of loads which are connected. Now, these loads can be categorized as loads in residential buildings, loads in industrial sector or in different industries and loads in commercial and business establishments. Now, these loads in these different establishments have some kind of different break ups and different characteristics.

So, what we can do is categorize the loads into different segments, like residential industrial and commercial. And for each one of these categories, we can find out what is the percentage of various kinds of loads various types of loads, which are there in these different categories. And once we have this, then knowing the total load on these categories, we can form or a composite model or aggregate all the loads. And make a model of the complete load as a single load on the substation or the busbar of the power system.

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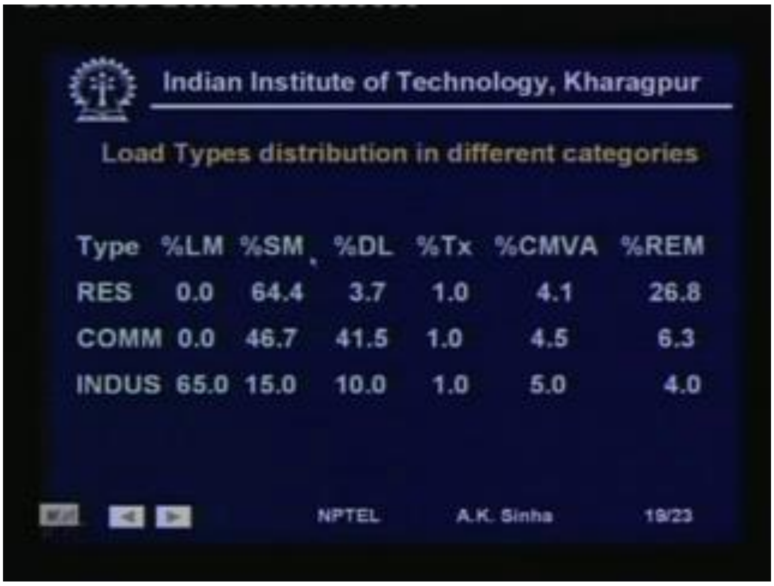

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Load Types distribution in different categories

Type	%LM	%SM	%DL	%Tx	%CMVA	%REM
RES	0.0	64.4	3.7	1.0	4.1	26.8
COMM	0.0	46.7	41.5	1.0	4.5	6.3
INDUS	65.0	15.0	10.0	1.0	5.0	4.0

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So, here I have given just some typical values of different kinds of loads, in these different sectors. This is LM represents large motors, large induction motors, SM represents small induction motors. DL represents the lighting loads, T x represents transformer kind of load, CMVA means constant MVA load. And rest is all mixed up kind of loading for which it is difficult to identify exactly.

So, if you look at residential sector the very few or in fact, no large induction motors, small induction motors are there for running of water pumps. Your fans, may be air coolers, may be air conditioners and so on. So, you have a large percentage of loading which is there for this small motors kind. Now, for lighting load you have some power drawn by the lighting load.

If you are using fluorescent tubes, CFLs and others this is much smaller. Transformer loading very few, so around only percent constant and VA load, very few around 4.1 percent. This is a typical value and this will change from various substation, this is for some particular substation, where this analysis was carried out. And remaining different kinds of load are shown here as 26.8 percent and so on.

Commercial establishment 0 percent of large motors, large percentage of small motors, again fans, air conditioning and other things. Lighting load there is much more in commercial establishments, specially shops and other things, you have all kinds of advertising boards, you have very large lighting very bright lights there. So, you have large amount of lighting load, transformer loading is hardly there, constant MVA loading is also very little remaining type of loads also are somewhat less. Say around 6.3 percent in this particular case.

For industrial sector we have large motors, which form the major portion of the load that is around 65 percent of the total load is will be large motors. 15 percent of the load is small motors, around 10 percent is for lighting load, 1 percent is for transformer kind of load. 5 percent constant MVA load and 4 percent remaining different kinds of loads that we have. So, this is showing that we have some kind of a division of different types of load for different sectors.

These may not be exactly same, but will be following similar kind of trends at various substations. So, if we know out of the total load at the substation say 30 percent load is for residential, 40 percent load is for commercial sector and 30 percent of the load is for the industrial sector. Then, using this division of different types of loading, we can form a composite percentage of different types of loads. And using this we can make a composite model for the load at the busbar or at the substation. So, this is what we call aggregation of the load.

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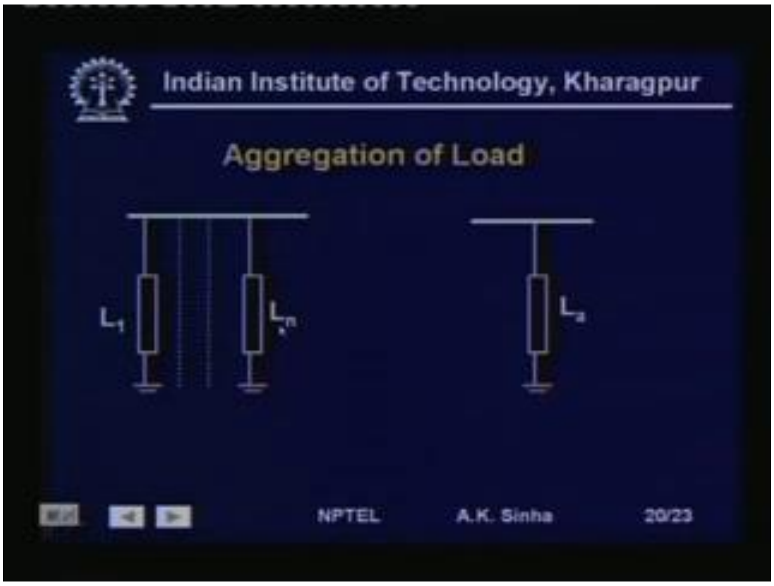

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Aggregation of Load

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That is at a substation you have large number of loads. These each of this individual loads will have different characteristics. Now, what we need to do is aggregate all of them into one load on the substation. Now, if you want to do that, then we have to again as I said earlier, know different percentage of various categories of loads that we have. And we know the division of various types of loads in these categories. So, we can form a percentage of different types of load on the substation. And then, based on these voltage and frequency characteristics of these loads, we can build a composite model for the load. So, next we will talk about the composite load model.

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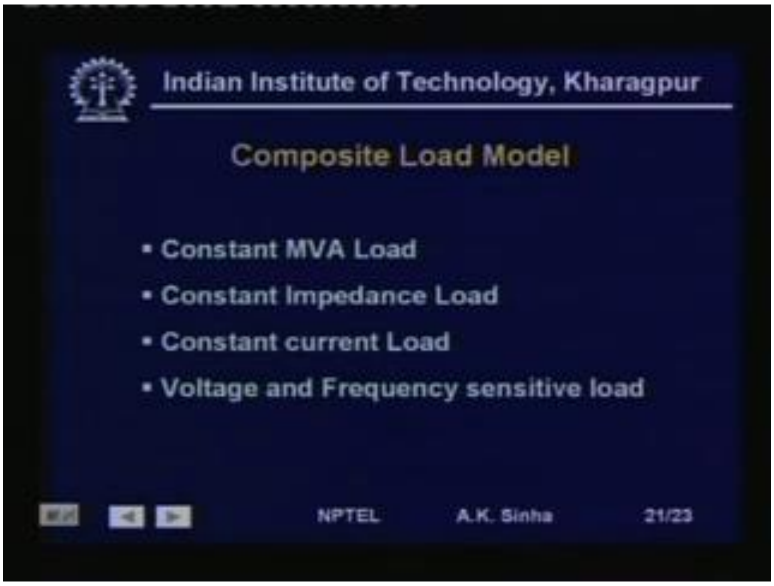

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Composite Load Model

- Constant MVA Load
- Constant Impedance Load
- Constant current Load
- Voltage and Frequency sensitive load

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Now, for most of the system analysis that we do, specially the steady state analysis. That is the load flow analysis that we carry out for power systems, there we have to model these loads. Either as a constant power loads that is P and Q remain constant, at that point or we can call it as a constant MVA load. We can for many of the transient stability analysis, we model the loads as constant impedance load, that is we assume the loads to remain as a constant impedance connected at the bus.

So, with change in voltage the power drawn by the load, changes also with the change in frequency, the power drawn by the load changes, because the impedance will also change. Then, we can many times for this transient stability analysis, the induction machine loads are specially a small motors are modeled as constant current loads. Finally, if we see the composite load, that is if we add up all kinds of load what we have is loads which are sensitive to both voltage and frequency.

And therefore, if we want we can create a general model for the load as shown here.

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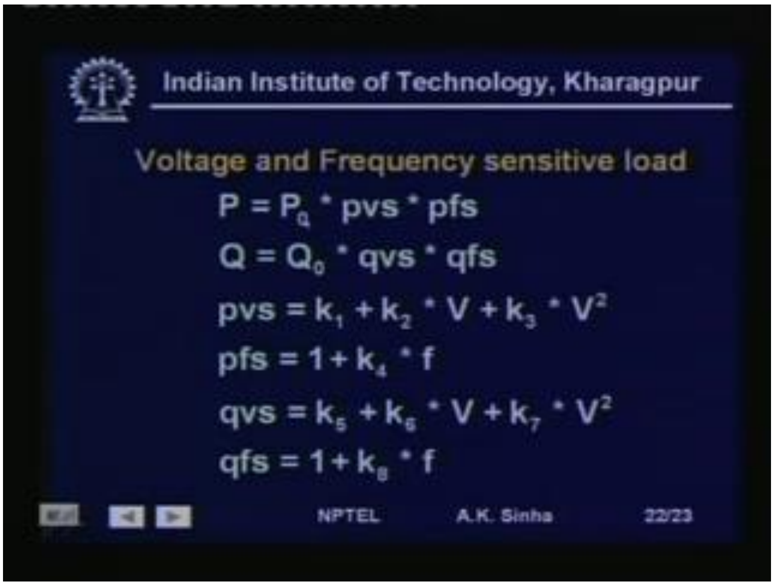

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Voltage and Frequency sensitive load

$$P = P_0 * pvs * pfs$$

$$Q = Q_0 * qvs * qfs$$

$$pvs = k_1 + k_2 * V + k_3 * V^2$$

$$pfs = 1 + k_4 * f$$

$$qvs = k_5 + k_6 * V + k_7 * V^2$$

$$qfs = 1 + k_8 * f$$

So, we have voltage and frequency sensitive load, where we write the load P at any voltage and frequency is equal to load P 0, which is the load at the rated voltage and rated frequency. So, P 0 is the load at rated voltage and rated frequency. This multiplied by a factor p v s and multiplied a factor p f s. Similarly, the reactive power load can also be modeled as the Q at any voltage and frequency will be equal Q 0 into, that is Q 0 is the reactive power of the load at rated voltage and frequency into q v s into q f s.

And these factors p v s p f s, q v s q f s. can be represented as p v s is the voltage sensitivity of the real power P. If this can be written as k 1 some constant k 1 plus a constant k 2 into voltage plus a constant k 3 into voltage square, because we have seen many loads, especially the constant impedance loads are where in the real power varies as per square of the voltage.

So, here we have p v s given by k 1 plus k 2 v plus k 3 v square. Similarly p f s the variation of real power with or the sensitivity of real power with frequency is give by this factor p f s, which we can represent as 1 plus k 4 into f. Now, here we do not use generally a higher order terms of frequency, because the band of frequency in which the frequency varies is generally very small.

It is say normally the frequency which is varying in India is around 49.5 to 50.5, so that is the band of plus minus 1 percent. In fact, in many developed countries this band is much, much smaller, the variation in the frequency is very, very small. So, frequency variation in most of the cases is generally neglected. But, even if we consider the variation in frequency, only the first order term should be good enough. So, p f s we write as 1 plus k 4 into f and q v s is the sensitivity of reactive power with v, that can be represented as k 5 plus k 6 into v plus k 7 into v square.

And similarly, the sensitivity of the reactive power with frequency can be written as 1 plus k 8 into frequency. So, we know that by choosing different values of this k 1, k 2, k 3, k 4 all these constants, we can model all kinds of combinations of load. So, once we know these, the percentage of various kinds of load on a substation, then we can obtain this coefficients k 1 to k 8. And we can model this the complete load on the substation by this kind of a generalized load model.

So, with this we end this lesson on modeling of loads. In this lesson, we started with the what are the various kinds of load. We talked about the voltage and frequency, sensitivity of load. We talked about how we aggregate these different types of loads and categories of load into a single load by a generalized load model. So, with this we end this lesson.

Thank you.

Preview of next lecture

Welcome to lesson 16 on Power System Analysis. In this lesson we will talk about the power flow problem.

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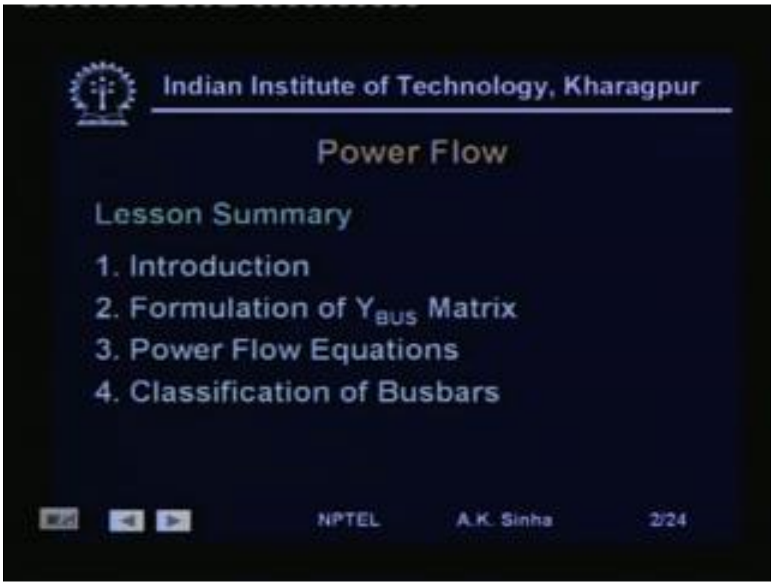

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Power Flow

Lesson Summary

1. Introduction
2. Formulation of Y_{BUS} Matrix
3. Power Flow Equations
4. Classification of Busbars

In this lesson, we will start with an introduction to power flow problem. Then, we will talk about how we formulate the Y Bus matrix, then we will derive the power flow equations. And finally, we will be talking about how we classify the busbars into different types for power flow problem.

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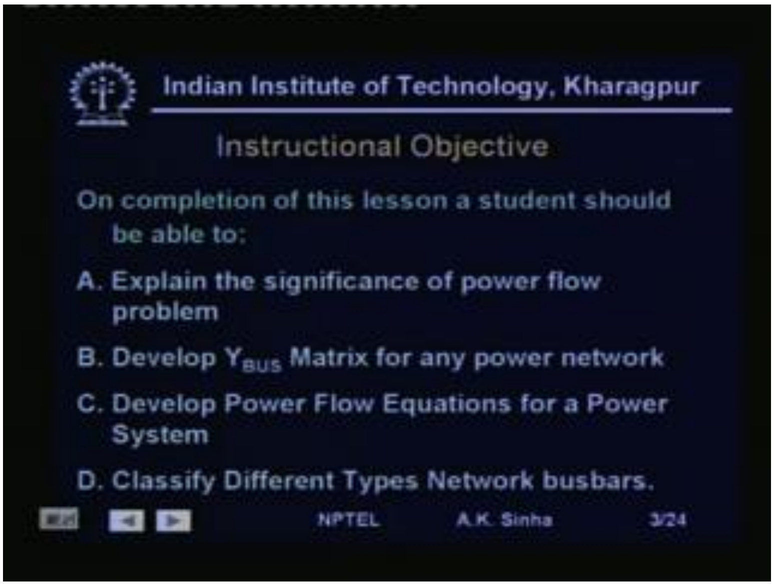

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Instructional Objective

On completion of this lesson a student should be able to:

A. Explain the significance of power flow problem
B. Develop Y_{BUS} Matrix for any power network
C. Develop Power Flow Equations for a Power System
D. Classify Different Types Network busbars.

Well, on completion of this lesson you should be able to explain the significance of power flow problem. Develop the Y bus matrix for any power network, develop power flow equations for a power system and classify different types of busbars.

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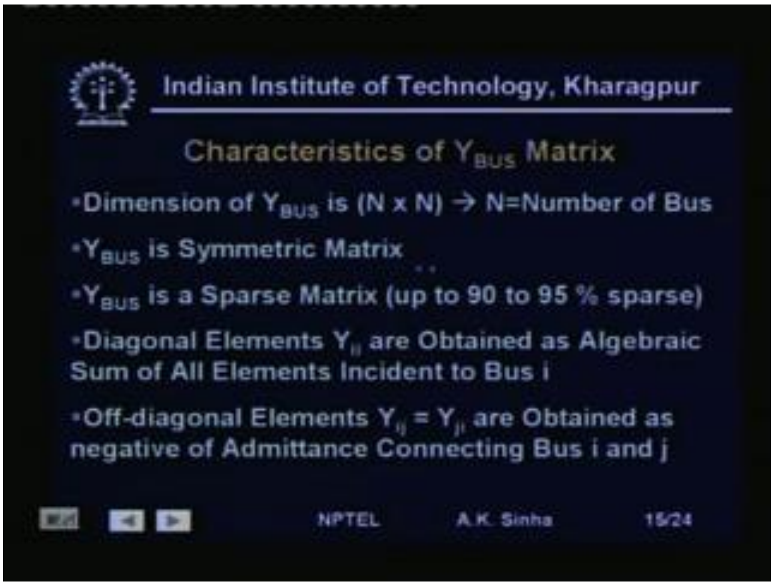

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Characteristics of Y_{BUS} Matrix

- Dimension of Y_{BUS} is (N x N) → N=Number of Bus
- Y_{BUS} is Symmetric Matrix
- Y_{BUS} is a Sparse Matrix (up to 90 to 95 % sparse)
- Diagonal Elements Y_{ii} are Obtained as Algebraic Sum of All Elements Incident to Bus i
- Off-diagonal Elements $Y_{ij} = Y_{ji}$ are Obtained as negative of Admittance Connecting Bus i and j

Characteristics that we see for this Y bus matrix is that it is a symmetric matrix.

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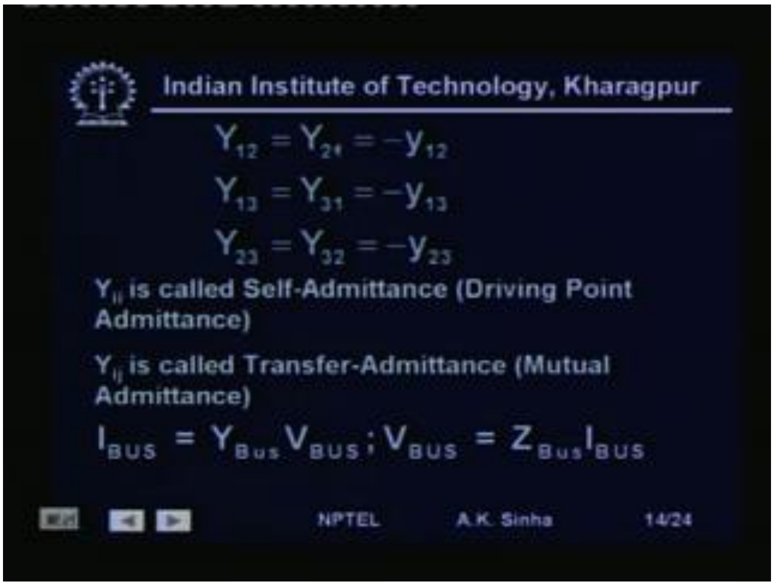

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$$Y_{12} = Y_{21} = -y_{12}$$
$$Y_{13} = Y_{31} = -y_{13}$$
$$Y_{23} = Y_{32} = -y_{23}$$

Y_{ii} is called Self-Admittance (Driving Point Admittance)

Y_{ij} is called Transfer-Admittance (Mutual Admittance)

$$I_{BUS} = Y_{Bus} V_{BUS} ; V_{BUS} = Z_{Bus} I_{BUS}$$

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That is what we are seeing here, is Y 1 2 is equal to Y 2 1 is equal to minus Y 1 2, that is minus small y 1 2. So, what we are saying Y 1 2 is equal to Y 2 1 Y 1 3 is equal to Y 3 1 Y 2 3 is equal to Y 3 2, that is we are seeing that the matrix is a symmetric matrix.

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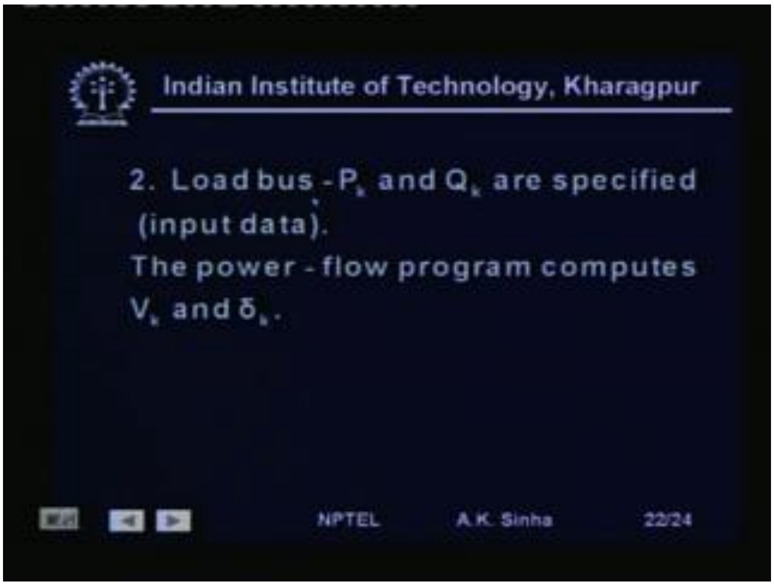

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2. Load bus - P_k and Q_k are specified (input data).
The power - flow program computes V_k and δ_k.

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Then, other type of busbar is a load busbar, where both real and reactive power are specified. At this busbar what we what are the unknowns, if we know V and delta at this busbar we have all the variables. So, here P and Q are specified, that is injection real and reactive power injection is specified. And the unknowns at this busbar are V and delta, voltage magnitude and its phase angle. We have a third type of busbar which we call as voltage control busbars.

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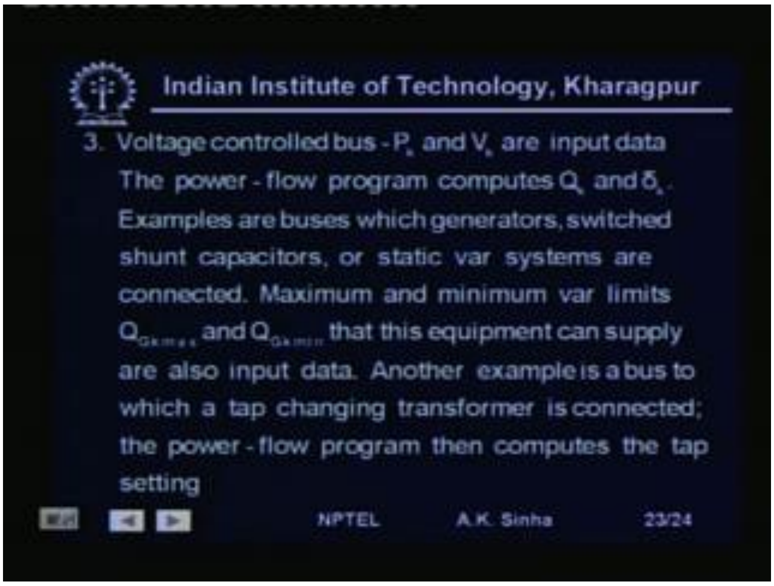

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3. Voltage controlled bus - P_k and V_k are input data The power - flow program computes Q_k and δ_k. Examples are buses which generators, switched shunt capacitors, or static var systems are connected. Maximum and minimum var limits Q_{Gkmax} and Q_{Gkmin} that this equipment can supply are also input data. Another example is a bus to which a tap changing transformer is connected; the power - flow program then computes the tap setting

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These are generally busbars where we have generation. At these busbars P k and V k are specified, that is the real power and the voltage magnitude is specified. And the power flow program or the solution of power flow will provide us the reactive power and the voltage phase angle. Now, these busbars as I said are generally the generator busbars or switched shunt capacitors or static var systems.

So, busbars which have these, they are generally P V bus or voltage controlled bus. The main reason for this is at these busbars, since we have reactive power control available. So, we try to keep the voltage controlled or the voltage magnitude at some specified value. And therefore, the voltage magnitude can be specified and there is since, these are also generator busbars or may be load busbars, the real power at these busbars are known.

So, once we have fixed this magnitude of voltage, once we calculate the delta angle for this voltage, then we can calculate Q for this voltage. So, Q and delta are the unknowns for this. Sometimes maximum and minimum var limits that is P G k max and P G k min for the equipment is also specified. And in case we find after the solution that, the value of the reactive power that is Q k is exceeding these limits.

Then we fix the value of Q k to these limits and consider this busbars as load busbars. Because, P and Q are now fixed at these busbars and V and delta need to be found out.

So, with this we come to a the end of today’s lesson, we will talk about the solution methods for power flow equation in the next lesson.

Thank you very much.