**Computer Aided Power System Analysis**
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**Lecture - 02**
**Modeling of Power System Components (Contd.)**

Welcome to this second lecture of this first module. In the last module, we have talked about the models of various power system components. We have discussed about the models of generators followed by transmission lines as well as the transformers. We are almost at the end of our modelling approach but before we end this we need to essentially discuss one or two minor points. So let us go.

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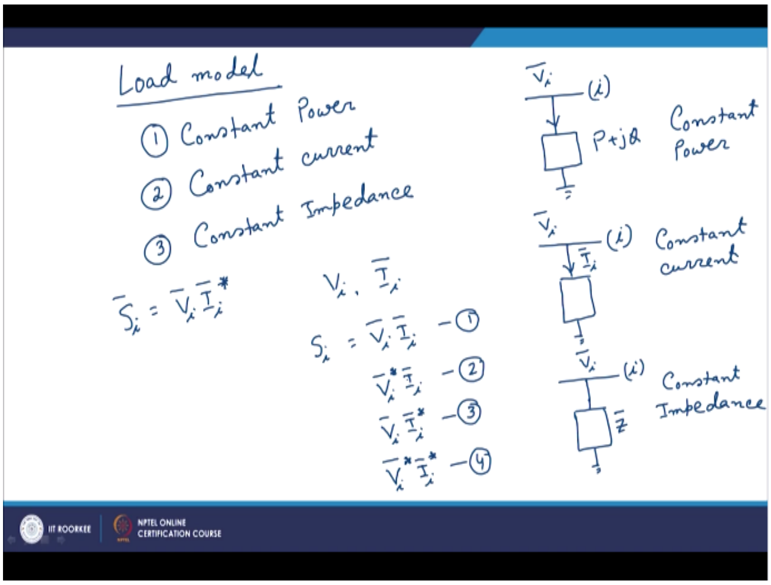


Now we have to talk about load model. Now we know that loads can be of 3 types; one is constant power, one is constant current and third is constant impedance. Constant power load means that if I have a bus let us say bus i and some constant power load is connected, we say that it is taking P+jQ or this is taking some constant value of P and constant value of Q, it means that irrespective of the voltage at this bus, this load will adjust the current drawn by it such that that this value of P and Q would remain constant.

That means if this voltage magnitude increases, so then in that case this load will adjust itself in such a way that it draws less amount of current. So that P and Q remain constant. On the other hand, if this voltage at bus i decreases so then in that case this load will adjust its internal impedance in such a way that it draws an higher amount of current so as to make this P and Q constant.

So it is basically nonlinear in nature. In the case of constant current, it is very simple that if I have bus i and if I have a load connected to it, we say that it is drawing some Ii current, this is Vi. So therefore in this case also if this voltage increases so in that case this load also increases its impedance in such a way that the current drawn by it remains constant. Similarly, if this voltage decreases so in that case this load also reduces its own internal impedance such that this current remains constant.

So it is also a kind of a variable impedance load and the constant impedance is the easiest to understand. So this is constant power, so this is constant current and constant impedance is the simple to understand, it is just a constant impedance z, its impedance is z, this is bus i, this is Vi constant. So then therefore in this case, if this Vi increases so then obviously current drawn by the load also increases.

And if this voltage decreases so then the current drawn by the load also reduces. Now out of these 3, we usually rather we generally use constant power loads for our analysis because the results given by constant power loads are the most pessimistic in nature. So then therefore if you are able to ensure that the performance of our system is within acceptable bounds while considering the loads to be constant power only.

So then in that case we would be able to ensure that for all practical loads also the performance of the system will always remain within the specified bounds. In actual reality no load is either pure constant power or constant impedance or constant current. Every load is actually in some fashion, some combination of these 3 basic types but for our analysis as you have just now mentioned we would be considering all loads to be constant power.

Because it gives the most pessimistic results, pessimistic means that if this voltage is reduced so then for constant power load this voltage would be reduced maximum and also if this voltage is increased, so then therefore for constant power loads this voltage is increased maximum. So then therefore if we are able to ensure that my voltage, etc are within limits while considering all loads to be constant power.

So then we would be able to make sure that for all other types of loads that is constant current or constant impedance this voltage is also would be remaining within their bounds and of course for all practical types of loads in which these loads are nothing but the combination of these 3 basic types, obviously these voltages will remain within the bounds. Now before I process further, one simple concept need to be probably recollected.

If you remember in the last module, we have defined that this complex power Si is given by Vi*Ii star. Now the question is that why are you taking the complex conjugate of Ii only? That is after all this Vi and Ii, both are complex quantity, so then therefore between these two, there can be 4 different combinations to express Vi. One could be Vi*Ii, remember dimensionally this is also denoting complex power. This is the first option, option 1. Second option is Vi star*Ii this is option 2.

Third option is Vi*Ii star option 3 and the fourth option is Vi star*Ii star. Please note all these 4 combinations dimensionally denote complex power. All these 4 combinations are nothing but the product of voltage and current which dimensionally denote power but out of these 4 we only choose option 3. What is the reason? Why do not we choose option 1, 2 and 4? We need to little bit recollect it or rather understand it.

Because this is this central expression which would be using throughout the course in fact for any power system analysis, this is the starting point of defining the complex power that Si is=V*I star. So to understand little more detail why we take V*I star? Now this is basically due to the convention we take. I mean this as per se does not have anything to do with it, technical reason but it is actually due to some convention.

Now what is mean by that, by convention in power system analysis by convention we say or rather we considered that all inductive loads or rather the power drawn by and inductive load considered to be positive, so what does it mean?

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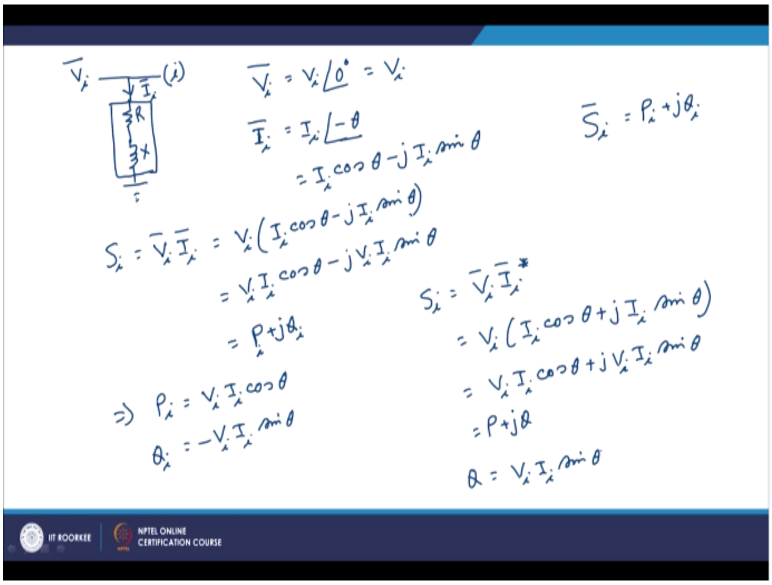


So let us say that I do have a bus i which has got a voltage Vi and in that bus i there is one load connected which is a combination of series r and l. so then therefore if the current drawn by this current is Ii so then therefore this Ii will lag this voltage Vi by some angle depending upon the value of this r and x, so this is resistance, this is reactance. So depending upon the value of r and x, the magnitude as well as the angle of Ii will change.

So if I take that Vi to be the reference quantity so then this we take Vi angle 0 and Ii would be lagging so Ii would be given by magnitude angle –theta. So it will have Ii cos theta-j Ii sin theta. So now if we compute the power Si drawn by the load and if I do Vi*Ii so what we will get? We will get Vi angle 0 is nothing but Vi so it is Vi*Ii cos theta-jIi sin theta.  Remember here this j is nothing but the complex operator.

So it is Vi*Ii cos theta- jVi*Ii sin theta and if I say denote that it is P+jQ that is if I say that Si just Pi, i stands for. So if I say that Si is given by Pi+jQi after all it is a complex quantity so then therefore from this identity we get Pi is=Vi Ii cos theta and Qi is=-Vi Ii sin theta. So we can see if we take only Ii so then Qi becomes a negative quantity which is in contrast to our convention.

Because our convention says that for an inductive load here our load is inductive because it is nothing but r and x. So for an inductive load, the reactive power drawn by an inductive power should be considered to be positive but here if you do not do anything if you just go by this simple principle we end up in getting the expression of Q that is the reactive power drawn by the load which is nothing but the negative.

So it is going against our convention, so we have to do something to make this positive. To make it positive, we now define Si is=Vi*Ii star complex conjugate. So if I do that so we can easily see that it will simply reduce to Ii cos theta+jIi sin theta, so it is now you know Vi Ii cos theta+j Vi Ii sin theta. So then therefore this is P+jQ so P remains same and Q now becomes Vi Ii sin theta which is now positive and which is in tune with the convention.

So this is due to this reason to honor the convention we take this complex conjugate of the current to define complex power. So now you are done with the modeling of the individual components. Now let us see just taken very simple example that how this individual models are connected together to form a circuit.

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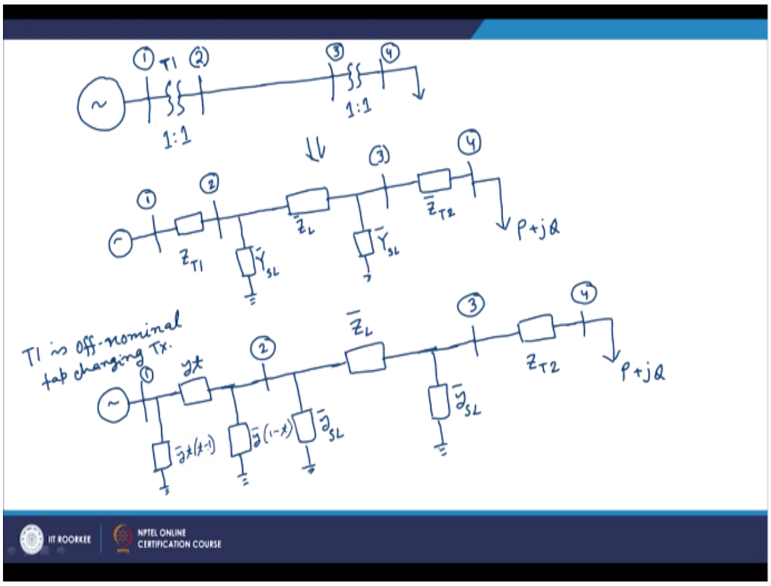


So let us take a very simple circuit so let us I do have a generator, this generator is connected at bus 1, then from bus 1 and 2 there is a transformer. This transformer let say that this is 1:1. Then, from bus 2 and 3 there is one transmission line; this is a medium length transmission line. Then, between bus 3 and 4 there is another transformers let say this is also 1:1 transformer and then there is some load.

See so if I draw this equivalent circuit of this what I will get? So I have got a source here. This is the source, so this is bus 1. Then, I am putting the equivalent circuit of the transformer, so let us say this is z T1. Please note that for an nominal tap changing transformer 1:1 the equivalent circuit of any nominal tap changing transformer is nothing but a series impedance only.

So this is bus 1 and 2 and then from bus 2 and 3 there is a medium length transmission line, so then therefore I would be representing it by a pi model. So this is a pi model bus 3 and this at the so this is nothing but the z line and this is the y shunt line, this is also y shunt line. Then, again between 3 and 4 bus 3 and 4 I do have another transformer so because this is also a nominal tap changing transformer.

So it will also be represented as by impedance z T2 and then I do have a constant power load let say some constant power load this is P+jQ, this is bus 4. So our simple power system now being reduced to an equivalent circuit. Of course, if this transformer instead of being let say 1:1 if this transformer is now off-nominal tap changing transformer let say 1:t, so then instead of this series connection of j T1 we would have another pi model.

So that is very trivial so we are not really discussing it or rather say if this is 1:t okay let us draw it just for the sake of convenience. So the second case at T1 is off-nominal. So in that case, this would be so it is yt and then there would be some shunt branches here. Then, there is also another shunt branches here and then of course so this is bus 1, this is bus 2 and then we have this line zL, then we have got y SL, then I have got y SL.

So we reach bus 3 and then bus 4 is still a 1:1 transformer so it is z T2 bus 4 and then P+jQ. So this is yt and this is y*1-t and this is y*t*1-t so anyway we have already discussed this. so that is how the equivalent circuit of any power system network can be built. So of course if there is any power system network which has got 100 machines, 200 transformers, 1000 lines, 5,000 loads, etc we cannot hope to draw its equivalent circuit on pen and paper and then do the analysis.

So we have to devise some algorithm through which we can do this analysis right. So for that so to derive that algorithm or rather to develop that algorithm we now need to consider a very important concept or rather it is essentially the central concept of the power system analysis which is called this injected power rather injected.

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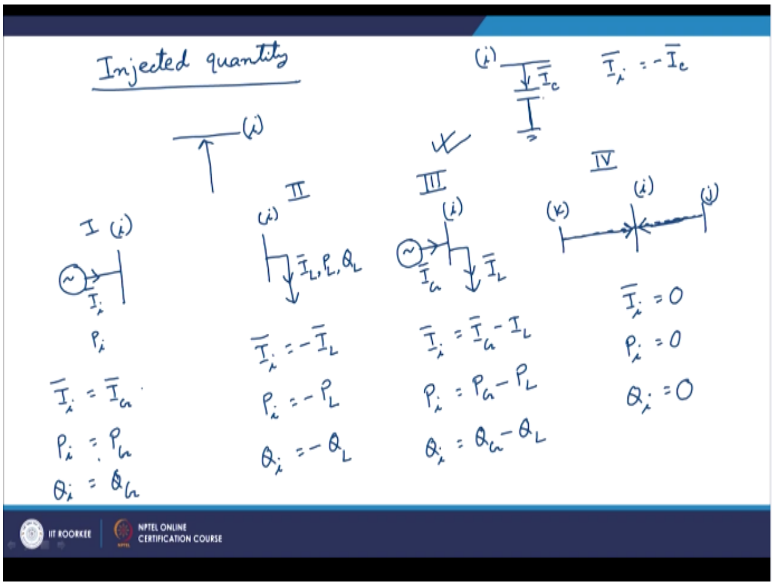


So what is our objective? Objective is very simple that we would like to analyze any general power system network involving any number of loads, any number of generators, any number of bus, any number of transformer, any number of lines and as we could see right now that as the number of components in power system increases, it is just not possible to draw their equivalent circuit on pen and paper.

So then therefore we have to devise some automatic computer based algorithm to do the analysis. Now for developing any algorithm to do this analysis, the first essential concept which is essential is the injected quantity. So let us understand what is mean by injected quantity. So when we talk about injected quantity, this injected quantity is defined at a particular bus.

So then therefore if I have bus let say i, we talk about injected quantity at bus i, now this injected quantity is actually in shunt that means there is some quantity, some electrical quantity which is being injected into that bus from shunt. For example, now depending upon the components which is connected at a bus there can be 3 cases. Now suppose I do have a bus, bus i, one case could be that there is a generator connected to it, this is case I.

Case II could be that at bus i, there is a load connected to it but no generators connected so this is case II and case III sorry there can be case sorry there can be 4 cases. Case III is that at this bus both are generator and a load are connected. Remember when we are talking about a generator and load are connected essentially they are connected in shunt to the bus and in case IV there is nothing connected to this bus in shunt remember.

But this bus can be connected to let say bus i, let say bus j here. This bus also can be connected to bus k here right. This connection is possible but when we are saying that there is nothing connected at bus i that means we are saying that there is nothing connected bus i in shunt, neither a generator nor a load. Now for case I what happens, if there is a generator so that means it is actually supplying current and power physically current and power is actually entering into the bus.

So then therefore physically if this current and power are entering into the bus so we say that in this case this injected power or current is nothing but the power or current supplied by the generator. So that in this case, the injected current Ii is given by IG, G stands for the generator that is the current supplied by the generator and Pi should be=PG, PG stands for the real power supplied by the generator.

Similarly, Qi that is the reactive power supplied by the generator also would be equal to the injected reactive power to the bus because physically all these are being supplied or injected to the bus. Now in the second case, when there is a load connected, now physically a load actually draws current or power both real and reactive power out of this bus so then physically the direction of flow of this current or real power or reactive power is actually away from the bus.

They are actually away but when you are talking about this injected quantity we define something which is injected which is going into the bus. So then therefore mathematically if I should change this notation little bit should say this is IL, L stands for load, PL L stands for load and QL L stands for load. So physically IL, PL and QL they are moving away from the bus, they are being taken away from the bus.

But when you are defining injected quantity is something which is being injected into the bus so that therefore injected quantity at bus i for a load bus, load bus means when there is only a load connected should be equal to the negative of the current which is being drawn by the load. Similarly, Pi should be equal to negative of this load power, Qi should be negative of this load power.

In the third case, when both generator and load are connected, so this is this generator is supplying a current of IG and this load is taking a current of IL, physically the direction of current of IG is moving into the bus and physically the direction of current IL is away from the bus so then therefore net amount of current which is being moving into the bus that is the injected quantity Ii would be nothing but IG-IL.

Similarly, Pi that is the injected real power to the bus would be PG-PL, Qi would be QG-QL and in the fourth case when there is neither load or neither generator connected so then therefore there is no shunt quantity, so then therefore neither any quantity or electrical quantity being physically injected to it neither any electrical quantity being physically taken away from it so then therefore there is no injected quantity so then therefore Ii would be 0, Pi would be 0, Qi would be 0.

Remember again I repeat these quantities are nothing but which is being injected to the bus in shunt. Now this expression for bus 3 or rather case III is the most general expression. This covers everything. For example, if I have only a generator connected that is case I but not load connected, so then therefore IL would be 0.

So then therefore following this expression if IL is=0, Ii would be is=IG, Pi would be=PG and Qi would be QG which is nothing but exactly what we have already understood from the physical interpretation of case I when there is only generator connected. If on the other hand if in this case if IG is=0 that is if there is no generator connected at this bus so then therefore IG is 0, PG is 0, QG is 0.

So then therefore from this expression Ii would be=-IL, Pi would be=-Pl, Qi would be=-QL which is exactly the same expression of case II which we have understood or derived from the physical understanding. So on the other hand, if there is neither a load, nor a generator connected at any bus so when therefore both IG and IL is 0 so then therefore Ii would be 0-0 that is 0, Pi would be PG-PL that is 0-0 would be 0, Qi also would be=0-0 that is 0.

So then therefore this expression this third one is the most general expression and we define that Ii so then therefore we define the injected quantity is nothing but the electrical quantity supplied by the generator-the electrical quantity rather the same electrical quantity drawn by the load. So then therefore this is nothing but the difference between the generator quantity and the load quantity.

Sometimes, students make confusion that here in this case if there is a line connected between bus k and i and bus j and i and also power is coming from bus k and i, so then this power is coming here and from here also power is coming here. Sometimes some students think that this and this are the injected quantity at bus i. This is absolutely not correct. Whenever you are talking about an injected quantity that injected quantity is basically would be contributed by the shunt connected elements which is connected at the bus.

And the shunt connected elements which is connected at this bus is nothing but either generator or load. Now when we are talking about a load, now suppose for example if I have a bus and there is no load connected but let say that there is a shunt capacitor connected so in that case how would you represent this capacitor current. In that case, the current drawn by this capacitor if this current is Ic so this c stands for capacitor current.

If this current drawn by this capacitor which is moving away from bus i is Ic we say that this injected current at bus i would be= -Ic given by this capacitor is connected in shunt with the bus. Similarly, if instead of a capacitor there is a inductor connected at this bus and this inductor is drawing a current of IL so in that case also Ii would be= -IL. So then therefore the central point which needs to be remembered is that the injected quantity is nothing.

But the current or power which is being injected to the bus in shunt from the shunt connected elements not the current or power which is coming to any bus through the transmission line or the transformer. So in this lecture, we have continued with the power system model. We have continued with the modeling of the power system components. We have first looked into the models of the loads and then we have recollected our concept of the complex power expression.

And subsequently we have discussed about the concept about this injected quantity which is nothing but a very central concept for the computer aided power system analysis. In fact, if we do understand injected quantity well, this injected quantity will help us to develop our computer based algorithms. We will continue with this module with these lectures. Thank you.