Power System Generation, Transmission and Distribution

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Lecture No. # 26

Load Flow Studies

Today, we start our course ESN 718 generation, transmission, distribution of electric power. The topic I have selected is load flow studies. I am sure all of you must have been introduced to this topic, when you were doing your undergraduate studies, from wherever you have come from. Load flow study, in fact is a bread and butter for any power system engineer or electric energy system engineer. In fact, it gives you the pulse of the system, what is happening in a system that is given by load flow studies.

And it is a prerequisite for whatever you do in power systems, whether you do power studies, you do stability studies, you do economic operation, the load flow study is an important prerequisite, without solving this you cannot do any other study.

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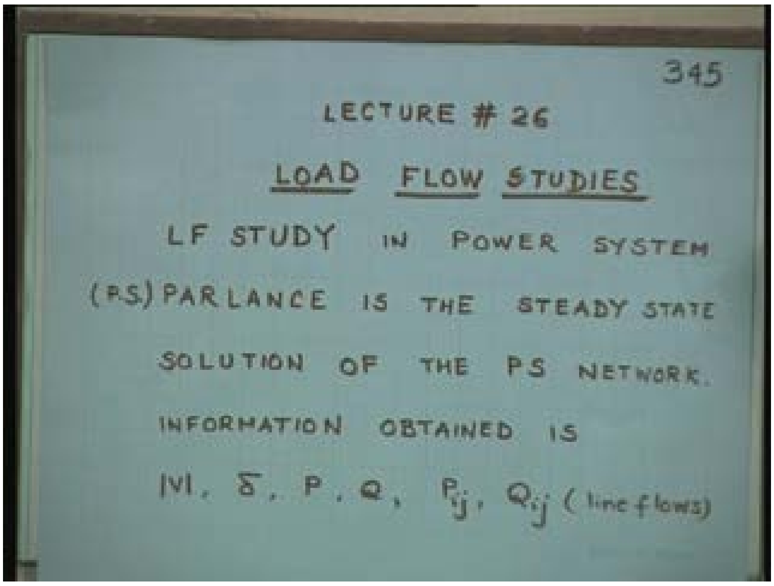

In a power system parlance, it is the steady state solution of the power system network. What do you obtain from the study? The information obtained is the voltage magnitude, the voltage angle, real power and reactive power, also line flows P i j Q i j. Finally, you also get losses, if you add all the line flows, strictly speaking, ideally speaking should be 0, but it will not be 0, because we have losses in the system. And there is no system, practical system, in which there is no losses, there is no will practical system in which there are no leakages, so that is a part of the life.

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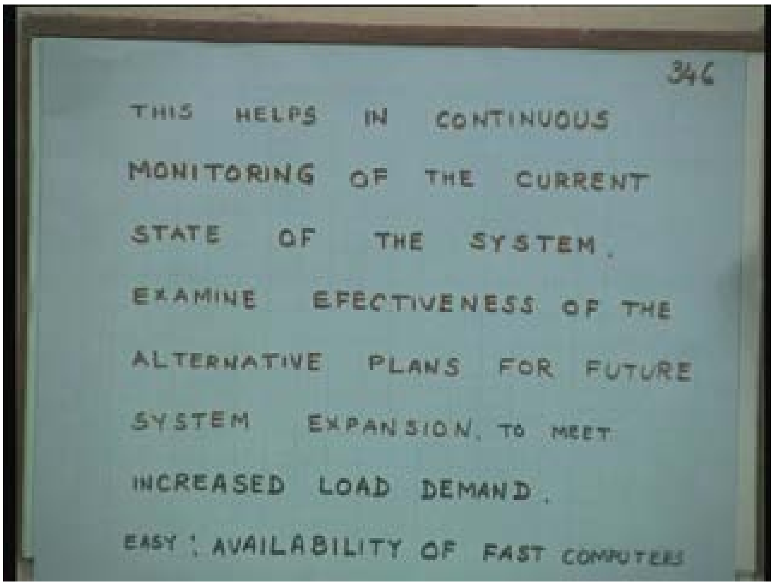

The load flow also helps in continuous monitoring of the current state of the system. I am sure all of you are aware of load dispatch centers, they are also called energy control centers, and they are also called power system control centers. In fact, the whole country has one national load dispatch center in this Katwaria Sarai, and you can go and have a look at it, you can even walk, there is no need of any vehicle. Then the whole country is divided into 5 zones, NREB, SREB, eastern regional electricity board, western regional electricity board and northern eastern region electricity board, north east, because of its strategic importance, they have created a separate regional board for north east region.

Now, each region is further divided into as many states at their state electricity boards, right and so, the information flows in a hierarchical way, in a multi level way. The nation load dispatch centers can conduct regional load dispatch centers, or regional can also talk to national load dispatch center. It is is not the one way traffic, it is on interactive mode, they can say out this something is going to be wrong, it is all automatic, it is all computer control. And similarly, then regional electricity board talking to the state electric board, state electricity board in turn can talk to further lower stations, and that is how you can get to know what is happening in the whole country.

So, monitoring of the current state of the system is the very important aspect, unless until you monitor, you cannot control anything. If you go to a doctor, what does he do? He monitors your state of your health, he takes your blood pressure, he takes your temperature if needed, he sees your pulse, and he sees your heart beat, this is the monitory. After getting the results, if this is not enough, then he prescribes certain test to be performed in the pathological laboratory, or some x rays, or (()) or CT scan and so on depending on what is the problem.

So, similarly here, once you monitor the current state of the system, then you can control. Suppose, it gives you a particular bus, the voltage is low, let say 0.85 per unit or 0.75 per unit, then the control will be either you put in SVS system inter place or use HVDC or some sort of compensation series, shunt series and shunt both or facts controllers, the flexible AC transmission. So, you can have UPFC, you can have so many, you know this carries the limit of controllers, that is the control action, like a doctor will prescribe medicines or tablets or injections or may be in an in extreme case, you will go for surgery, depending on what is the problem.

So, here also similar thing, the so called doctor, means the electric system expert will prescribe the remedies. Examining the effectiveness of the alternative plans, so future systems expansion, if you need to expand all the time future, the load is increasing exponentially in India right. So, in exponentially increasing load, you have to plan for a matching generation facilities. For example, when we got freedom our total install capacity was just 30 100 60 mega watts, 1360 in 1947. Today, the total install capacity is more than 100000 mega watt; in fact it is 100 and 10000 mega watt. So, where is 1360 and where is 100 and 10000 mega watt? Yet there are short it is, yet there are black outs, yet there are load sheddings, why? The load has gone further beyond is 100 and 10000 mega watts.

So, whenever your expenses are more than your earning, you have to borrow money, you have to take a loan, nobody takes loan with placer, it is a requirement, some sickness in the family, some emergency in the family, then only you go for a loan; may be student is admitted in private engineering colleges, the parents have to take a loan, however soft loan it may be.

So, similarly here, when you have to examine the effectiveness of alternative plan, should we have a generator in Delhi, should we have a generator in Panipat or Arwadi or Ghaziabad, all this alternative plans can be examined by running load flow program to meet the increased load demand. Now, it is easy, there was a time the whole electrical engineering story (( )) 116 year old, the first bulb was light by Edison in 1886. So, it is hardly not more than 120 years old, by up to 1920 it was all DC, it was all isolated power systems, then came AC, thanks to the invention of a transformer. And up to 1950, there was a hardly any indicated operation, the first operation start it the optimal operation started with using straight rules, then came AC calculating board, and then came a digital computer, first computer was made in Umist, Manchester, UK in 1948, and that computer was invented by three scientists or engineers and it was called baby computer.

And you know, how much space did it occupy? It occupied space of this hall, this studio and yet it was called baby computer. Luckily, I was presented in golden jubilee was celebrated in 1998, I was there in Umist, I saw that computer is still working. And now, we have come from that era to Pentium 4, Pentium executive, laptop, palmtop and so on. So, it is becoming small and smaller and smaller, and more and more powerful. So, with because of the easy availability of fast, modern, ultra modern computers carrying out load flow study is the child’s play, it is no more a problematic problem. Let the system be a 1000 bus, it does not worry me any more, there was the time when you to solve even 14 bus system, I have to go to the mainframe computer and type the program on cards, olden days and put it I use to get my output next day and there is the syntax error again, I have to correct that comma is missing, again go to next step and so on. Now, with in fraction of second, you get the answer.

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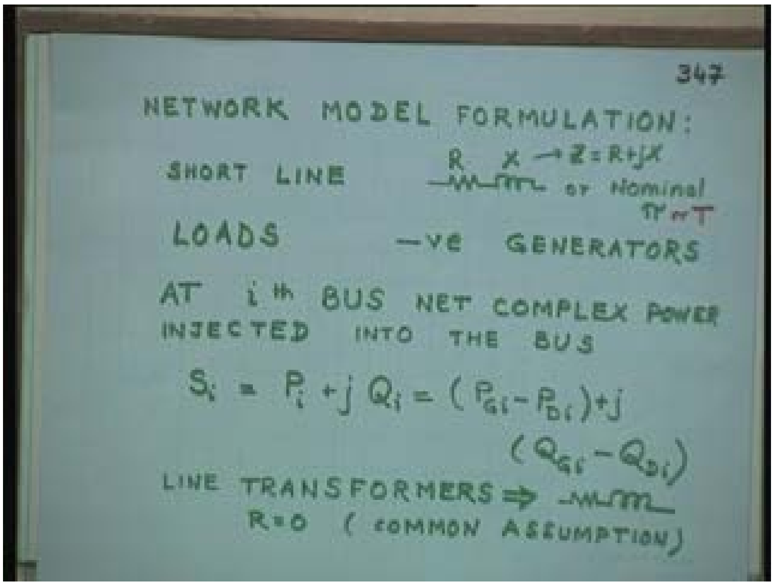

To solve out few problem, we have to do network modeling, because after all a power system is a network, there are generators, there are transformers, circuit breakers transmission lines, loads, these are the individual power system component right and you have to model them, because you cannot go to the real life power system, so big, so huge. So, you have to model it and carry out the simulation to find out the various answers, short line if it all it is there, it can be model by a just an impedance R and X which is nothing but z is equal to R plus j X. But if you are not satisfied, it is not a short line, it is not below 100 kilometers, it is something between 100 and 250 kilometers, that is called medium line.

And the model you must have studied in undergraduate is nominal pi or nominal T, and it has being told to you by your teachers or various books that you might have read, that pi is preferred over T for several reasons. What are the reasons? The reasons are in pi, what is lamp is the series branch, the impedance branch, the impedance branch is and then at the co ordinates are two capacitance, this is the pi model, where as in T model, impedance is divided in to two parts and what is lump is the central shunt branch. Now, these loads can be merged with these branches, shunt branches, it can be merged with the loads.

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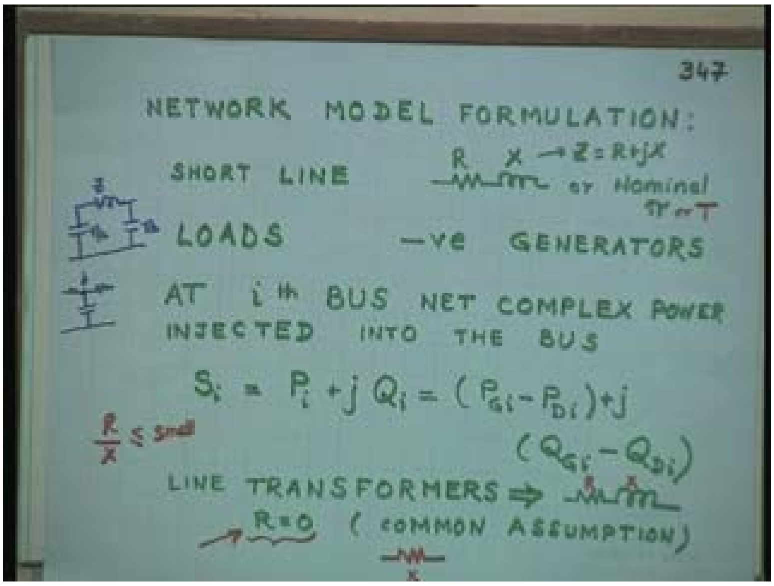

So, it can be reduced to a just short line model, which is not possible here. Secondly, we have an extra node here, this is an extra node, it increases the dimension of the system, the order of the system whereas the whole idea is, whole attempt should be, and whole effort should be in direction of reducing the order of the system. Man by nature wants simplicity, he wants to do minimum work, you can see any organization, whether government or private, people want to do minimum sort of work with maximum benefits, that is a human nature, and same nature gets reflected reflect in science and engineering. So, here also, we want to reduce our work and how work can be reduced, by reducing the model of the system.

So, here is an extra node is unnecessary where as in pi, this node is not there. And hence, pi is preferred over T, please remember, these are not equivalent. If you want to prove that, you can use star delta combination or transformation or convergence and show that this is not quite the same as this, this is not equivalent in that sense, loads; how do you model loads as a negative generator. See, if you want to give somebody 10 rupees, it is like minus income, but if you get 10 rupees, that is an income, positive income. But if to give 10 rupees to somebody, it is a negative income. What is the loan? Loan is nothing but in you have to pay it back, it is not the income, you are loosing that much money because you have already taken.

So, load is nothing but indicating generations at i th bus, net complex power injected into the bus is denoted as as S i is equal to P i plus j Q i. Now, what is P i? P i is the real injected power. What is Q i? It is an imaginary or reactive power injected at i th bus. Naturally, how to what power do you inject into the network, whatever is extra. Suppose, I ask you, please give you rupees 10, you will only give me if the rupees 10 is extra with you. If you need it, you will say, sorry sir I need it, may be tomorrow if I have anything extra, I will consider giving you, that there also you will not promise.

Here, suppose you have a Badarpur, as the power station and you are generating 100 mega watt and if dally needs that 100 mega watt, Badarpur will not give the power to either UP or Haryana or any neighboring state, why? You yourself need it at your home. That is the whole problem with the water, the disputes, Punjab, Haryana, Karnataka, Madras. When Karnataka says I need water, how can I give it to you? Similar problem is there in Punjab, Haryana or Delhi, the same problem here you will only inject power into the network, only if you have an extra power, how do you find out that? That you find out by subtracting local load at i th bus from local generation. P G i is the local generation real power generation at i th bus minus the demand at that bus, then whatever is extra, surplus, that you can inject into the network.

Similarly, I do want to repeat whatever a story have told of real power, same thing happens for reactive power like somebody wants sugar in neighboring you know, now there is no in the neighborly relation will have it, in olden days, there must be you know, exchange of sugar, salt, atta whatever. So, they used to go each other, only if there is an extra, if there is only one sort of kilo atta, then that family also needs it. So, same thing happens to reactive power, line transfer (( )) you must have studied transformers in your machines course in under graduate, and all of you know the transformer can be modeled by a real circuit, ideal circuit and ultimately you boil it to just again a resistance and inductance, here we will be go one step further, even ignore resistance and it is only left has a reactors.

So, final model is just a reactance X, whether you solve short circuit studies, stability studies, load flow studies or economic operation, transformer is normally represented by just a reactor, reactance. It is the common assumption, but in power system, we almost always neglect resistance, because resistance is suppose to be very very small, r by x ratio is very small, say it is small, very small. So, 1 is to 10, if 1 is resistance, reactance is

10. If it becomes large, then that is not a normal power system, we call it ill condition power system. Somebody ask in interview, if you appear for engineering services or higher or NTPC or whatever, after your M.Tech, even lecturers, they will ask you define ill condition power systems. So, one basic requirement of ill condition power system is r by x ratio becomes comparable.

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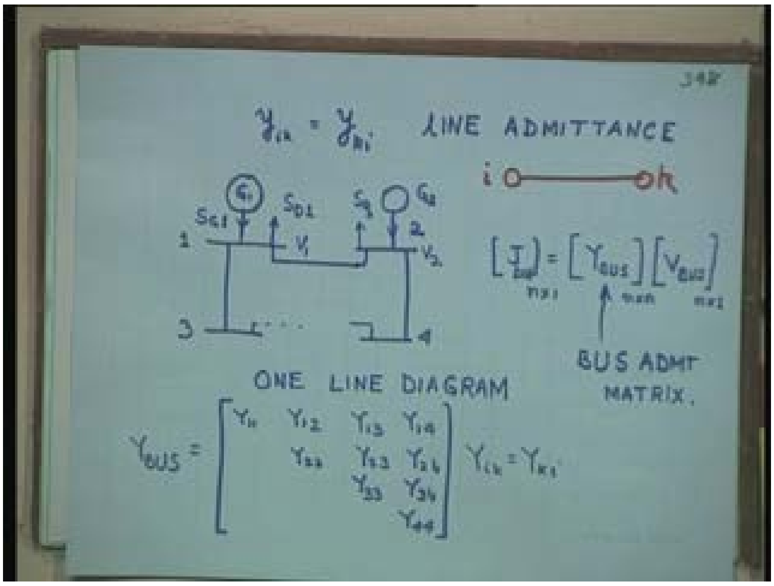

What is line admittance? If there is a line joining two nodes, this is i, this is k, this is the line, call it a (( )) line, call it anything, it is connecting two generators, two nodes, they need not be generators, just two nodes. So, this line has an admittance or impedance same thing, we are reciprocal of each other, z is equal to one part y, y is equal to one a part z. So, this admittance is denoted as small Y i k which is equal to Y k i, whether you go from here to here or here to here, the distance remain 10 kilometer, whether you go from Delhi to madras or madras to Delhi or Chennai, whatever it is, the distance remain same 3000 kilo meters, whatever it is.

So, similarly the admittance Y i k is equal to Y k I, now please consider this diagram. I have drawn this diagram as four bus system, 1 2 3 4. The minimum interconnected system is two bus system, one bus is not in interconnected system, it is called isolated system, there is the generator, that is the load, something like what you have in industry, (( )) power plant, you have a generator like Hindalco, the aluminum company has the kept power planted Renukoot in UP. Now, that power plant is exclusively generating power to cater to the needs of Hindalco, the aluminum factory, Bella aluminum factory. So, that is not an indicated power system, that sends oscillated power system captive power plant, but if there is the interconnected power system, the minimum condition is there has to be two power, two power plants which are interconnecting.

So, here we have considering four buses, please understand it is not necessary that all buses will have generators attached to it. In fact, only 15 percent buses will have generators attached to it, because it is costly, generation of a 1 mega watt needs 40 crores, 40 million, 1 million dollar, 40 million rupees and that is why, the power station generation power is a highly capital intensive business, and that is why, we do not have money being a poor country and that is why, this is the shortages and so, we request for in direct investment. But since Indians are not in habit of paying money for whatever they use, the foreign investment started and stopped with another one, no other company has visited Indian shores after (( )) had left, had a sad story like Devadas.

So, they do not want to have another Devadas. So, now, what we are going, we were asking our NRI's, non resident Indians, but they also complain, they tell us that you are treating us as a not required Indians or the non resident Indians. So, they also do not want to spend money here, though only send to their relations and friends or if you go there, they will entertain you; just you take a food etcetera and go back. So, we have to generate our own resources to fulfill the local demand, and there is no money, and that is why there are problems.

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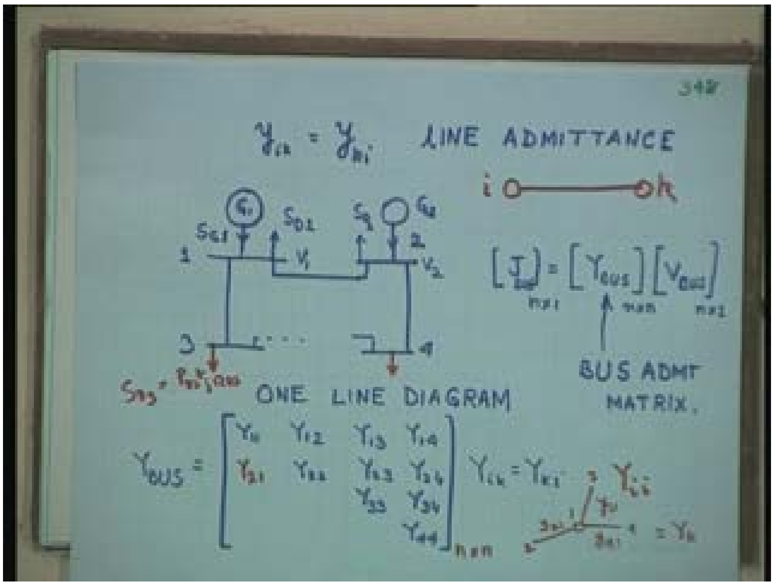

So, not all buses will have a generators attached to them, at G 1 generates both real as well as reactive power, that is why I am denoting it by S G i, complex power generated at first bus is S G i, complex demand at bus one is called S D i and what is the injected is S G 1 minus S D 1, that is total complex generation minus total complex power is the complex power injected in to the network, sense story holds good for second generator third and forth and more generator, then you have load, which you can called P D 3 plus J Q D 3 which is nothing but S D 3.

Now, this is the model which I am looking for this particular network. What is the model? J bus is equal to Y bus in to V bus, this is the injected source current is equal to bus admittance matrix into bus voltage matrix, even a column vector is also a matrix, it is a column matrix, the order here is n in to 1, n in to n and n in to 1, this is the n bus system where n can have any value 1000, 2, 2 to 1000. A bus admittance matrix model is preferred in a load flow study, why? I will it after 5 to 10 minutes, let us first find out how to built this Y bus which is our network model, which is also called bus admittance matrix.

Now, the diagonal terms are Y i i, this is the diagonal terms, the naturally n in number for n by n matrix. These are called driving point admittances or they are also called self admittances. How do you compute them? Summation of all the admittances coming to that node, if here is a node and these are the various lines, you sum it, this is the first node. So, Y 2 1 Y 3 1 Y 4 1, add and that becomes Y 1 1. So, this Y 1 1 is nothing but small y 1 2 plus small y 1 3 plus small y 1 4, summation of all the admittances of the lines coming to that particular node, that is the formula for obtaining diagonal nodes. Now, what is the formula for obtaining of time (( ))? They are called transfer admittances, the formula is very simple, luckily they are same Y 1 2 is same as Y 2 1 because it is a symmetric matrix, as I told you whatever distance you travel from Madras to Delhi is same as Delhi to Madras.

So, if there is a transmission line from Delhi to Panipat or Panipat to Delhi, the admittance of that line will remain same and hence it is symmetric. So, we do not have to evaluate all n by n terms, it only evaluate n n plus 1 by 2; that means, if it is the 2 by 2, then we are to evaluate only three elements, forth one is already same as the 1 2 element Y 1 1 Y 1 2 Y 2 1 Y 2 2 Y 1 2 is equal to Y 2 1.

So, we have to evaluate only Y 1 1 Y 1 2 and Y 2 2. So, we are saving one, the higher this size of the matrix higher will be the savings. Now, how do you compute transparent admittance? How do you compute? It is the sum of all the admittances between the two nodes change the sign, minus of sum of all the admittances between two nodes, normally that is only one, so minus Y i j.

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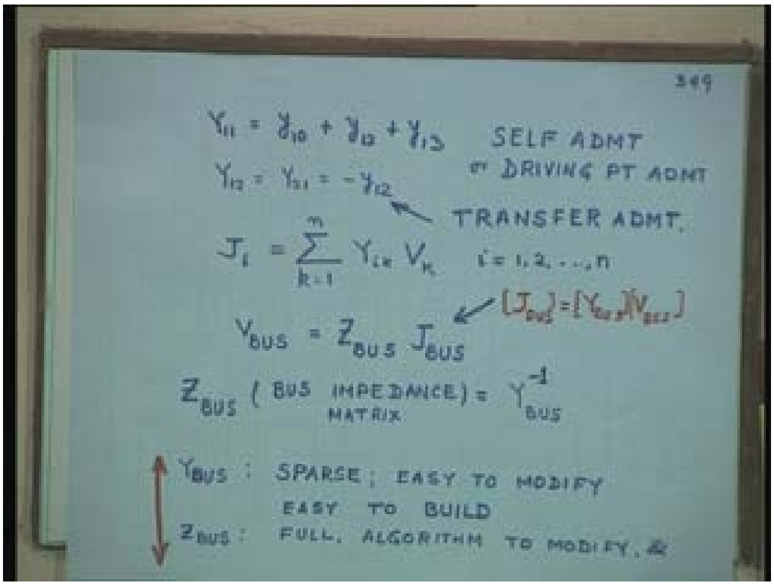

Same thing I have written here, Y 1 1 is equal to y 1 0 y 1 2 y 1 3 Y 1 2 is equal to Y 2 1 is equal to minus y 1 2, this is called transfer admittance and this is called driving point admittance or self admittance. Now, we want to write that matrix equation which we wrote in it different form, and that is called index notation to J i is equal to summation of sigma k 1 to n Y i k V k, this is same thing as writing J bus is equal to Y bus in to V bus, some people write this bracket, some people do not, now in books show them in bold phase, but on a board or on a paper, you have to write them in a same way, at them also you can write it two three times, that is to look it bolder, but then you will loose time in exam, if you go on making it bolder and bolder. So, it is understood, but this is a, this equation rather can be written like this or it can be written like this, one may is to write them in an expanded form, what is that expanded form? If it is a 2 by 2, so then we can write in we have lonely speak you can write J 1 J 2 is equal to Y 1 1 Y 1 2 Y 2 1 Y 2 2 and V 1 V 2, this is expanded here, this is index and this is the matrix notation, all three are same.

We are describing the same network by writing them in three alternative ways, now if you inward this, I get this matrix and this is V bus is equal to Z bus is equal to J bus where Z bus is equal to bus impedance matrix equals inverse of Y bus. So, Y bus and Z bus are inverse of each other, invert one you get another, invert that you get back the original. So, essentially this is the same equation is this, only thing the model selected in these equations is bus impedance matrix rather than bus admittance matrix that is all. Otherwise, these two equations are same, you may ask the next question, if they are same then why you are preferring this and not this, let me say we prefer this for load flow state and not this, the answer to this is line here in the last two lines given on this line, Y bus is parse, what is parse? The Y bus is not a full matrix, that means, there are many zeroes.

For example, if we look to the Haryana not is it is connected with each other city, Panipat may not be connected with Ambala, it may be connected to Karnal, the Karnal is connected to Ambala. So, Ambala to Panipat there is no rule zero. So, this will have remaining zeroes and hence it is a parse matrix, this class is a parse class, there are so many chairs vacant, it is a post graduate class. So, there are only 12 students, let it to be in (( )) class the whole studio would have been full, that is Z bus.

So, UG class is the Z bus, a PG class is is Y bus, there are certain PG courses we are get also become Z bus because it is a huge big, huge class, some even there are now PG classes of 16 students, it is easy to modify and easy to built first letter stock of easy to build, I have given you to golden rules to build Y bus, the diagonal element can be obtained by summation of all the admittances coming to that node and off diagonal is minus of summation of all the admittances in between these two nodes, very easy to build, a child's play, any child can do that. But to build Z bus in (( )) go to them, that will go to them you must have dot, otherwise you can see in appendix in the book which gives you how to get Z bus, Z bus is full, UG class this is no zero, few may be few, but hardly a new and to modify Y bus is very easy, you remove that particular element which you have added in a transfer admittance, here to modify you need another algorithm, you have to add a node, you have to add a link, that is the graph theoretic approach. It is called Z bus building algorithm which is given all the books, you can seat you can revise it in case you are forgotten it.

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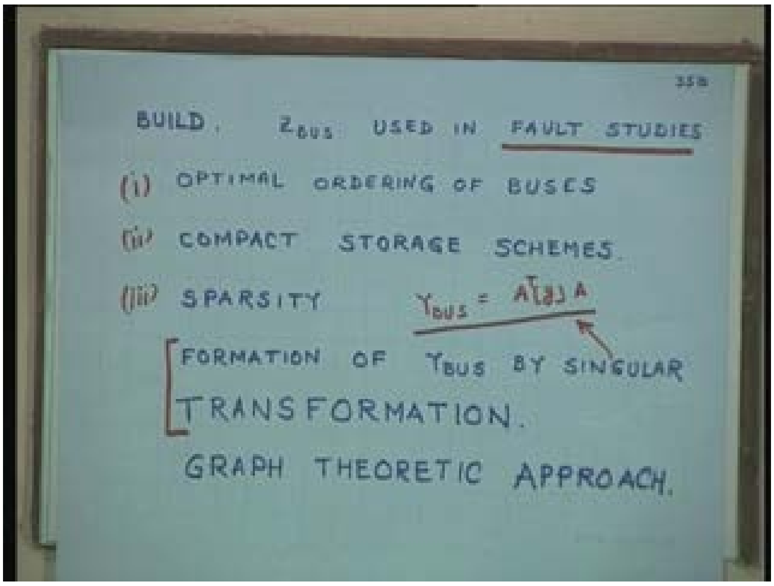

Why should we then study Z bus if it is so useless? No, it may be useless for load flow study, but for the fault studies, you have to use Z bus, because it gives you quick answers, fault have taken place 29 th bus, just look at the 29 th element of Z bus, inverse it you get the fault current, when a point Z ij is fault current that is so easy there. So, one particular medicine may not useful to particular problem, but it can solve some other problem very effectively. So, you do not show that medicine, depends on the problem if you are having a Diarrhea, you do not take a medicine of getting more stools, and you take the reverse medicine, but that is you will through it you may be you need it some other day.

Now, these are the four important operations required for load flow study, one is optimal ordering of buses, what you mean by when I say optimal ordering of buses, say for example, let us take a whole country India, if you want to write a Y bus for India, Delhi Bombay, Chennai, Kolkata and so on. These are all major stations, now whether you should say Delhi is number one bus Bombay is number one bus or Kolkata is number one bus that is the ordering, it is totally arbitrary, the seating arrangement here is totally arbitrary as an when you come and you sit here, this is not a cinema hall or this is not a Rajathani express, where you have booking and you have fix seat or aero plane you come and sit anywhere.

So, similarly the ordering of numbers of buses in a network is totally arbitrary as it is done normally, but there is a method in Magnus, you have certain algorithms of level, if you order your buses according to that, you are lightly to get less numerical storage requirement, numerical operations requirement and it will be easy to solve load flow study the Y bus is likely to be more parts, if you number in a particular fashion. In our book, three such ordering schemes are given, though they are not optimal, they are sub optimal, because optimal needs lot of effort, sometimes you have to see cost benefit, see it may be very comfortful or easy or convenient to go from here to a not place by helicopter, but I am sure none of us sitting here can offered, that the politician can because somebody else place for him.

So, what we will do, we rather go by 620 or we go by auto or we go by at the most by cab. So, even if optimal ordering of buses is desirable, but if you do not have that much effort or money to do that, why do it. So, there are sub optimal three schemes given in literature which have listed in this book, you can go and have a go at it, at your rooms. Second is compact storage schemes, this schemes were developed in 60’s and 70’s when storage was the problem, with modern day computers storage is no problem, you have almost any amount of storage you want, but then just for you know, knowledge sake or fundamental sake, you must know how in olden days, we used to solve load flow problem with less storage. And these are solve by using compact storage scheme, how use to store these elements wipers, etcetera etcetera, that is the really wonderful though it is not needed any more, it is like small parts medicine is no more needed or because it is not there, it is totally eradicated, but same thing is not true for polio.

So, hence still we celebrate those days or the year mark certain days your polio vaccine is given to small children, it's sparsity, sparsity technique exit itself is a big topic, how to exploit, use, exploit in a positive sense, the sparsity, the sparse matric that use to be techniques books have written in chapter on this, how to exploit, how to use to your benefit, the property of sparsity. Well Still we need sparsity, because it is there and, but then is not necessary that an normally we use such techniques and we have we can afford, specially the system is small say up to 100 18 bus we can go without sparsity.

Formation of Y bus by singular transformation, I will given you those golden rules for building Y bus fine, but there are cases when those golden rules are not adequate, there not enough, specially if you have a mutual coupling, or you have a phase shifting transformers, which makes your Y bus non symmetry, then you use graph theoretic approach to find out Y bus by singular transformation, and the whole article is given in the book and I will request you to read it, this is the formula for building a Y bus using singular transformation, this capital A is a matrix call is bus incidence matrix and a small y is called primitive admittance matrix and the sixth chapter gives, how to use this singular transformation to obtain Y bus.

This is most general way of obtaining Y bus with any type of network, let it have mutual coupling, let it have phase shifting transformer, it does not worry me, what I do I draw a graph and there is a bus is a matrix is a formulate, and this is to be given in much detail in a book called (( )) I do not know whether you have are read that book, that is in 1970 book. So, that will give you a good account of how to formulate Y bus using singular transformations.

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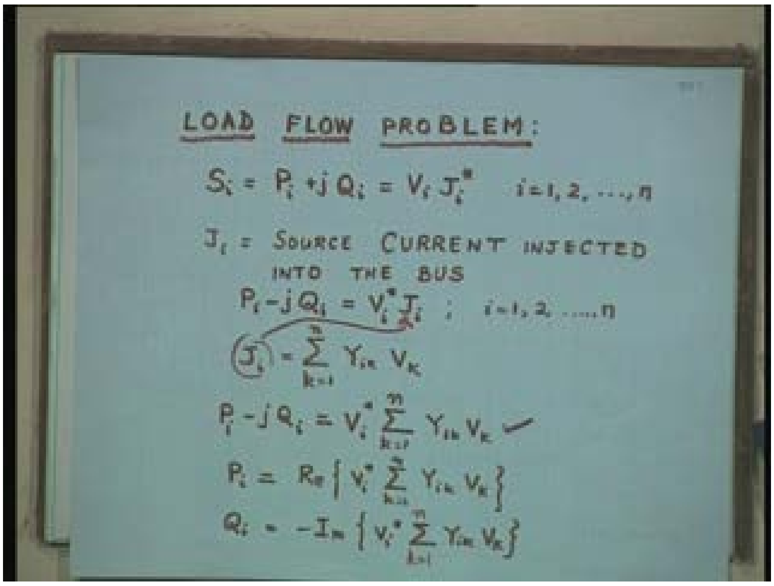

Now with so much preparation, we have come to the stage when we can define what is load flow problem, all of you know the complex power S i is equal to P i plus j Q i can also be written as V i J i conjugate, V is the voltage, J is the current J is the source current injected in to the bus. And there are n buses and can be anything can be 2, can be 20 can be 100, can be 1000. I know that the P i j Q i is I know that P i j Q i is V i J i is cross, if I take the complex, I can I can replace this bus minus j Q i equal to V i star and J i complex conjugate, just change.

I can change both side is like multiplying by 2, both the side equation remains same thing and this equation and this equation are same, why I have done that, because I want get read of current ultimately. So, I must get current in to is original form, not in a conjugate form, this no secrete I can always share we this why we are done this, because I want this current in it is normal form, because I want to get rid of it, nobody cares for current in orders. And that is why I have done this step, otherwise it is not needed I know that Kirchhoff’s current law gives me the current this is nothing, but Kirchhoff’s current law current is nothing but a summation of all and voltage there is only one element, then no summation is require you can recognize this as i is is equal to y v or v is equal to z i which is nothing, but ohms law.

Here, we are writing that law in a generalized way current is equal to (( )) it is not sorry it is ohms, this is ohms law now using this substitute this into this, and this equation comes

P i minus j Q i is equal to V i star and substituting J i from here from this separating realign creative parts and real in imaginary parts I would do it in mathematics instead of in it thousand times doing your B.Tech, B.E, (( )) B.Sc, engineering and I get finally, these two equations P i is equal to real of v i star sigma y i v k Q i equal to minus imaginary of v I star sigma Y I k of course, here also you have to write q is equal to 1 2 and up to this point no problem we just separated real and real to parts or equations to go back home and do it again read it depending on the time you have that your comment right I can always express a (( )) is several ways one is the (( )) way magnitude into..

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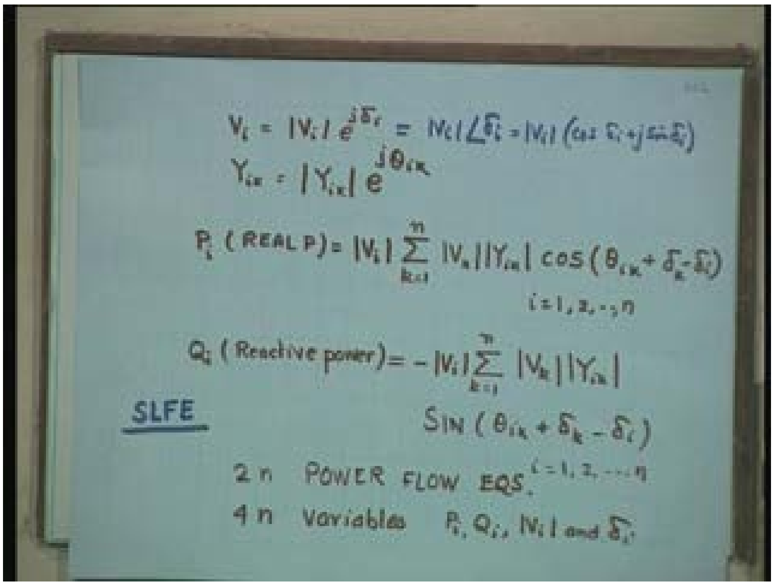

In fact, I can further express this as further I can express is an all are same all three ways are same this is the rectangular form this is the polar form this is an exponential form all mean in the same thing whether you call it Roti, Phulka, Chapatti, it means the same it only shows with region your coming from,, but all are same made of wheat and atta.

So, this is same Roti, chapatti, Phulka admittance can also be express as the magnitude and and if you substitute the in those two equations which where there in the last class you get finally, this two equations and these are very important equation you must c t m what is c t m coming to memory these two equation must be finger tips, if you are a power system engineer or if you are a electrical energy system engineer, this must be very close to your hard this is your (( )) in better and they are called in literature s l f e, what is the s l f e? static low flow equations how many are they they are few and powerful equations and this, and this you call it power flow or you call it low flow one in the same thing, but what is the problem there only 2 n in amber the variables are 4 n. So, you have to do something and what is that, we will do that, we will see on next Tuesday, we will leave it here this time.