Power Network Analysis

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Lecture-42

Hello everyone, welcome to Lecture 2 of Week 9 of the course Power Network Analysis. This discussion is going to be the last discussion of Module 7, which is Power Flow Analysis. In the previous lectures related to this module, we have extensively talked about or discussed the essence or reason behind solving or understanding power flow analysis, why we need to solve power flow equations, and we have extensively talked about solving these equations for steady state analysis of the typical transmission network, which is meshed and has a low r by x ratio, and the assumptions behind power flow analysis that the network is balanced can be represented in a single line diagram on a per unit basis. All those with the assumptions we have discussed about the techniques involved in solving power flow equations for transmission networks. In today's discussion, we will exclusively talk about a technique that serves the purpose of solving the same set of power flow equations, but for low voltage or medium voltage distribution networks. The question is why we need to have a separate technique.

One of the techniques that we will discuss is the backward-forward technique, although there could be several other techniques that can be used, and they are present in the literature. One of those techniques that is popular is this backward-forward technique, which we will discuss in today's discussion. So the question that arises is: why do we need separate techniques? Why can't the same Newton-Raphson, Gauss-Seidel method, fast decoupled method, or DC power flow model, which we discussed in the previous lecture, be used for the distribution networks as well? So, typical conventional power flow methods that we have learned for transmission networks cannot usually be used for power flow analysis of distribution networks. The first reason for not being applicable is that distribution networks are usually unbalanced networks.

The transmission networks tend to be balanced networks, whereas distribution networks are usually unbalanced. Transmission networks remain balanced because one of the reasons for their balance is the transposition of transmission lines, where R, L, and C values appear more or less in similar quantities across all three phases. The secondary reason is that, through proper switching, operation, or shifting of loads, the transmission network per phase load or source level remains more or less balanced. In distribution networks, however, the story becomes completely different in the sense that the loads themselves need not remain balanced across all three phases. By balanced, I mean all three phases for a typical three-phase network have the same quantum of load or source connected to them.

That means if there is a three-phase distribution line, then each of the three phases of the line carries the same quantum of power and the same quantum of current; the magnitude can be the same, but the phase angles may differ by 120 degrees, which we will again see in detail in the next module on fault analysis. So distribution networks, this sort of assumption is usually not at all applicable because the distribution network tends to serve low voltage consumers, customers wherein each section of the three-phase line need not have all three phases present in it. Some of those sections may only have one-phase or two-phase lines, and hence the three-phase representation is essential, as is the single line diagram assumption we had for power flow analysis, which does not hold true; that is the primary reason. The unbalanced distribution network is due to the nature of the loads being served by it. Also, the R by X ratio of the associated overhead lines or underground cables in the distribution network tends to be higher.

It is not that the different types of conductors-obviously, the conductor types are different- but the conductor material used in distribution lines and transmission lines remains more or less the same. The number of cross-section windings and the number of coupled composite conductors may differ for different networks. So, in distribution systems, the conductor type remains more or less the same as the transmission network. So, the question arises: since the conductor type remains the same, why is this R by X ratio different? It is low in transmission and high in distribution. The reason for this aspect is that distribution networks are typically low voltage or medium voltage networks, where the typical operating voltage does not exist, at least in the Indian domain, beyond 11 kV ; beyond 33 kV , they come into the transmission or sub-transmission domain.

So, compared to a low-voltage operation, 11 kV is, in fact, a higher voltage distribution system. A typical distribution system, from a residential perspective, operates at 415 or 440 volts three-phase, or 230 or 220 volts singlephase. Under such low operating voltages compared to high voltages, where transmission networks typically operate at a few hundred kVs , hundreds of kVs . The corresponding electromagnetic induction phenomena, which are responsible for the flow of power from the source to the load at low voltages, are the electromagnetic phenomena that we have discussed briefly during the traveling waves discussion. This phenomenon becomes weaker under low voltages, and that is the reason why the corresponding line reactance or capacitance values also tend to go down.
So, it is not that the value of R is changing; the value of R more or less remains the same under low voltages when this electromagnetic phenomenon effect is lower because of the low operating voltage. The corresponding X value tends to go down in the distribution

network, and that's the reason why the R by X ratio tends to be higher. The resistance value remains more or less the same. It's not significantly different whether we talk about a crosssection of a transmission conductor and a distribution conductor. It's the value of X that is being significantly impacted or lowered in the distribution network due to low operating voltage, and that's the reason why the R by X ratio tends to be higher.

Now, when the R by X ratio tends to be higher, what we can understand or analyze from the perspective of the Y bus is that when we evaluate the Y bus for a network whose lines have a high R by X ratio, the corresponding real part of the Y bus, which is the G matrix. It will be significantly dominant compared to the imaginary part of Y-bus. Unlike in the transmission network where B was more and G was less, in the distribution network the value of G would be more and the value of B elements would be lesser. Now, when the resistive component of the network tends to be dominant compared to the reactive component, the corresponding Jacobian matrices that we tend to evaluate for the transmission network have diagonal entries that are mostly significantly dependent upon the values of B and not so much on the value of G, because the differences in cosine and sine phase angles are more or less similar to the phase angle difference; the quantums remain the same. So, there in the Jacobian matrix also starts to have some sort of deformity or an ill-conditioning nature that is not just one of the reasons why the Jacobian tends to become significantly ill-conditioned.

The first reason, obviously, is that the Jacobian is dependent upon the Ybus matrix. Jacobin also starts to become ill-conditioned because of the nature of the distribution network, which is that the distribution networks are mostly radial in structure. They have either one single feed or one source system for conventional passive distribution networks. With multiple sources present in the network, we would still have one slack bus or one angle reference bus with several thousand PQ buses and very few or no PV buses present in case it is a passive distribution network. So this radiality of the network structure also affects the Jacobian matrix to some extent.

In fact, that's one of the primary reasons why it affects the Jacobian significantly. The Jacobian in the distribution network for the Newton-Raphson technique, the pass decoupling technique, or the DC power flow technique tends to become ill-conditioned. And once this becomes ill-conditioned, its factorization cannot be done, and then a solution cannot be obtained properly. For the fast decoupled technique, the decoupling aspect we consider is that P is mostly dependent on phase angle, while reactive power Q is mostly dependent on voltage magnitude. So the decoupling aspect is no longer valid.

R value has gone up; X value has gone down in terms of the distribution network line parameters. So the Jacobian value becomes highly illconditioned or rank deficient. Typically, in a distribution network, the way distribution lines are modeled is unlike in a transmission network, where we had node j and node i , or maybe I'll use a different notation, not node j , let's say node m and node n. If there's a line connected to buses m and n, then we would have assumed the corresponding nominal pie model for the line. where the half-line susceptances were present, which are Ysh, Ysh, and then here we had the corresponding series line impedance.

This was on a single-phase equivalent representation since, in the distribution network, this line itself need not have all three phases a, b, and c. So it becomes even more important to represent each phase of the line present in the distribution network. That is point number one. And that's where you would find Zaa, Zbb, and Zcc, the series line impedances. And the lines are also mutually coupled.

In fact, the mutual coupling effect, due to the closer vicinity in distribution networks, increases the impact. So Zab, Zbc, and Zac represent the mutually coupled impedances between the phases and the corresponding admittances in the half-line part they present on either side. This is for the typical distribution line network models. Similarly, for the load model, all three phases have to be considered together in order to represent the corresponding load behavior. It may happen that one of these load values may not be present at all; it may be that there is just a single-phase or two-phase load, or just a single-phase load, which is a typical residential load.

So, depending on the type of load that is present, all three phases need to be considered together; the single-phase equivalent representation of the network will no longer be valid. So, what do we do? That is where one of the most popular techniques, the backward-forward technique, comes in. We will focus on a much simpler version of a typical distribution network or feeder. Where in the numbers or the numbers which are sort of present inside these rectangular boxes, they would represent the node numbers or bus numbers, whereas the numbers which are present within these simple brackets would refer to the line number or the branch number. So, in this typical distribution network or feeder, there are 10 nodes present and 10 buses because the last rectangular box has the number 10 present in it, and all these 10 buses are mostly radially structured, and so one would wonder what I mean by a non-radial structure or a mesh structure.

The mesh structure would occur when I have some circulating paths present in this distribution; for example, if bus 2 and bus 7 are connected by a branch and bus 8 or bus 7 are connected by another branch, I would have two circulating paths. In case one path in this particular circulating branch is unavailable, the distribution loads will still have alternative routes to receive their power feed from. The typical radial structure means that if one branch or one path is disturbed, perturbed, or experiencing a fault, causing this line to become non-operational, the entire network loads will have no other path to get their source supply from. So that's the essence, reason, or explanation behind the radial network.

We have a simple 10 -bus distribution network that is connected by nine branches or nine lines, and for explaining the backward-forward technique, I will keep the discussion limited and make the assumption that The network is a single-phase network; although the discussion that we would have can still be applied to a three-phase network, please be patient; we will come to a three-phase network discussion in a moment, so what we do is the technique, as it says, the backward and forward method.

So there are certain steps in which the calculations are done in a backward manner. And then the second part of the technique requires certain calculations, which we would call forward calculations. So, backward and forward terms come in from the perspective of these calculations. To give you a brief essence of what I specifically mean by backward calculation, it is all to do with the bus number where I am currently present while applying the backward-forward technique. If I am present or if my calculations are evolved around bus 10 and I do certain calculations that would shift these numbers or calculations closer to the source end, starting from the far end node, if I do certain numbers, if I do certain evaluations, and those numbers try to bring me close to the source node, which is bus number one here, then that calculation or phase would be called the backward phase.

In the next phase, if I perform a certain evaluation, let's say I have reached source number one in backward mode, and now I want to go back to the last end node. So, if I do certain calculations that would move my numbers or calculations away from the source node to these far-off nodes, then that phase is called the forward mode. That's the basic essence of what these backward and forward steps involve, so we choose our bus one to be the angle reference bus, whose voltage magnitude is usually known; it would depend mostly on the transformer tap. which depends on the tap position of the distribution transformer or substation transformer that is present, connecting this distribution network with the sub-transmission or medium voltage distribution grid. So we are not considering the impact or presence of whatever tap position has been set.

According to that, the voltage magnitude has been set here, and we are coincidentally choosing the same voltage magnitude as the base voltage. So our voltage magnitude has a value of 1 pu . For angle reference, we are choosing 0 degrees or 0 radians for convenience as a reference. Also, this number could be different from 0 degrees or 0 radians. And the way we chose an initial flat start for all other voltages, we choose a similar, preferably flat start voltage.

Based on this flat start voltage, we try to do our first step, which is the backward step that is based on this initial choice of voltages. In the backward phase, we start from the far end or tail end nodes and try to evaluate the corresponding line currents that satisfy the KCL, or basically the KCL at this node. We apply KCL at each node. Where loads or sources might be present, and based on this KCL, if there is a current being drawn from this node, then this current essentially has to come from branch number 9, which is connecting 6 and 10 . So, based on the KCL application, we find these branch currents.

Once we find the upper branch current, we try to apply KCL again at node number 6 to find the next branch current, which is between 4 and 6 , and that is how we can get the current from the source end, which is the current being drawn from the substation end. In the next phase, which is the forward phase, having obtained all these currents, we try to update the voltages at each of these nodes by applying KVL; so basically, KCL is all about the backward phase, whereas KVL is all about the forward phase. Based on the latest currents in the branches, we update those voltages, and this sort of backward-forward process continues until the voltages don't change significantly or the line currents don't change significantly. So what do we do? We start with the farthest nodes possible since the backward phase is the first phase. The farthest nodes from the source end are nodes number 7, 8, 9, 10, and 3.

So we focus on node number 10; I guess the box is mistakenly present here. It's actually the box present over line number 9 that is connecting bus 6 to N 6 to 6 to 6 to 10 . The same logic, however, could be applied to this box as well. So, on bus number 10, we might have a load whose complex conjugate complex power is given; Sd 10 represents the bus number. The bus may also have a source connected to it in case it is the active distribution network.

So, generated power is also known as Sg. So, essentially, the net power being drawn from bus 10 is Sd_10 minus Sg_10. If the demand is less and generation is more, the value of S would automatically be negative; if the demand is more and generation is less, the corresponding S would be positive. Either in the real or imaginary domain, if this is the complex power being drawn from the bus, then this complex power essentially should come from this line itself; there is no other path for this line to have power from. Therefore, this S has to flow from this current line in order for that line to carry this power.

The corresponding current it should carry is basically I_10 naught conjugate; the conjugate here is the conjugate value I conjugate, which we evaluated during power evaluation. So if this is the current at bus 10 and the only path for this current to flow is through the line, then we know what the line current is in the initial estimate; 0 here refers to the initial iteration, which I would say is a recursion; whether you call it a forward or backward recursion, 0 would refer to the initial recursion. So we now know what the current is in branch number 9 in the initial recursion.

$$I_{10}^{0*} = \frac{S_{10}^d - S_{10}^g}{V_{10}^0}$$
$$I_{(9)}^0 = I_{6-10}^0 = I_{10}^0$$
$$I_9^{0*} = \frac{S_9^d - S_9^g}{V_9^0}$$

Similarly, we can apply the same KCL or power evaluation for node number 9 , and we can get the current in branch number 8 . Once we know the currents in branch number 8 and 9 , the only path for these currents available is through branch number 7 .

$$I_{(8)}^0 = I_{6-9}^0 = I_9^0$$
$$I_{(7)}^0 = I_{4-6}^0 = I_6^0 + I_{(8)}^0 + I_{(9)}^0$$

So we get the current for branch number 7 while considering the injection at bus 6 , the power currents, and the currents in line numbers 8 and 9 . And this sort of current devaluation continues until we reach the current in branch number one; once we have arrived at the currents in branch number one and we also know the remaining branch currents, that completes one phase of the backward step in the forward step using the same currents.

$$I_{(4)}^0 = I_{4-5}^0 = I_5^0 + I_{(5)}^0 + I_{(6)}^0$$
$$I_{(3)}^0 = I_{2-4}^0 = I_4^0 + I_{(4)}^0 + I_{(7)}^0$$
$$I_{(2)}^0 = I_{2-3}^0 = I_3^0$$
$$I_{(1)}^0 = I_{1-2}^0 = I_2^0 + I_{(2)}^0 + I_{(3)}^0$$

So, in the backward step, we move from the far end to the source end; this is the backward phase in which the currents were evaluated by KCL application. In the forward phase, we would move from the source end to the far-off ends by applying KVL and updating the voltages. So, we start from the source end; the source end voltage cannot change because of the tap position or distribution transformer.

So, the voltage that can only update itself is the voltage of bus number 2; 1 here refers to the next update of voltages. So, that basically 0.5 step is recursion because of the backward phase, and 0.5 phase is because of the forward phase. By using these same currents, depending on the impedance present in these branches, we can find the corresponding voltages and repeat the same steps until we reach the far-end voltage nodes.

$$V_2^1 = V_1 - z_{(1)} I_{(1)}^0, \quad V_3^1 = V_2^1 - z_{(2)} I_{(2)}^0$$
$$V_4^1 = V_2^1 - z_{(3)} I_{(3)}^0, \quad V_5^1 = V_4^1 - z_{(4)} I_{(4)}^0$$
$$V_7^1 = V_5^1 - z_{(5)} I_{(5)}^0, \quad V_8^1 = V_5^1 - z_{(6)} I_{(6)}^0$$
$$V_6^1 = V_4^1 - z_{(7)} I_{(7)}^0, \quad V_9^1 = V_6^1 - z_{(8)} I_{(8)}^0$$
$$V_{10}^1 = V_6^1 - z_{(9)} I_{(9)}^0$$

This sort of process would continue until convergence happens; convergence might occur when voltages don't change, currents don't change, or power valuations don't change. This is all about the case when we have a singlephase distribution network, and as I mentioned, when you have a three-phase distribution network, all three phases have to be evaluated. So essentially, if I were to talk about one such backward phase equation, I had only one single-phase network, single-phase demand, and single-phase generation, so one single equation was sufficient. When I have a three-phase distribution network, I will have to evaluate these currents on a per-phase basis. And then, depending on these per-phase currents, once I get my backward step, in the forward step, the impedances have to be three-by-three matrices instead of one-by-one matrices.

Because it's a three-phase network, three phases might have different impedances; these impedances might also be mutually coupled, and that is essentially what is shown here in terms of this 3 × 3Z matrix. The corresponding backward phase, which can be done on a per-phase basis, is also shown here. Essentially, in a single-phase network where we had one equation for one node and one branch, in a three-phase network we would have all three equations coupled together because of mutually coupled impedances, and the same convergence process would continue until we get the solution for the three-phase network.

$$I_{10}^{0*} = \begin{bmatrix} I_{10}^{a0} \\ I_{10}^{b0} \\ I_{10}^{c0} \end{bmatrix}^* = \begin{bmatrix} \left(S_{10}^{da} - S_{10}^{ga}\right)/V_{10}^{0a} \\ \left(S_{10}^{db} - S_{10}^{gb}\right)/V_{10}^{0b} \\ \left(S_{10}^{dc} - S_{10}^{gc}\right)/V_{10}^{0c} \end{bmatrix}$$
$$\begin{bmatrix} V_2^{a1} \\ V_2^{b1} \\ V_2^{c1} \end{bmatrix} = \begin{bmatrix} V_1^a \\ V_1^b \\ V_1^c \end{bmatrix} - \begin{bmatrix} z_{(1)}^{aa} & z_{(1)}^{ab} & z_{(1)}^{ac} \\ z_{(1)}^{ba} & z_{(1)}^{bb} & z_{(1)}^{bc} \\ z_{(1)}^{ca} & z_{(1)}^{cb} & z_{(1)}^{cc} \end{bmatrix} \begin{bmatrix} I_{(1)}^{a0} \\ I_{(1)}^{b0} \\ I_{(1)}^{c0} \end{bmatrix}$$

Although there are ways to make this process much faster, we are not going to discuss that for the sake of simplicity. I will conclude this discussion with a unique example wherein I have a three-phase radial distribution network, and I am calling it a distribution network because each line has an impedance z , where the value of R is much larger compared to the value of X .

Bus 1 is To be considered as the substation bus whose voltage magnitude and phase angle are already specified in the example. And each of these remaining buses, which are bus 2 and bus 3 connected through impedances z and z in between, we have considered two cases. In one case, this load, which is P plus j 0.5 P pu , basically the real power demand is P , and the reactive power demand at every such bus is 0.5 P ; that is the understanding behind this complex power being given for every bus.

We choose two scenarios: in one scenario, the load is 0.43388370 per unit, and in the second case, the load becomes 2 per unit; that is, I mean two values; that is the only difference. And through this example, I will try to explain why the Newton-Raphson technique has difficulty in getting the voltages of bus three and bus two for this simple radial three-bus distribution network. And on the other hand, how the forward-backward technique can still give a desirable solution - the same solution, in fact - with no convergence problem at all. Often in the backward-forward technique, the term "sweep" also comes in because the way backward-forward calculations are done in the backward phase is that you are sweeping from the tail end to the source end.

In the forward mode, you are sweeping from the source end to the tail end. So the sweep term refers to that. So for our first load case where P is 0.43388370 per unit, we evaluate the Y bus matrix and find the power flow equations you can apply: rectangular coordinate solution or polar coordinate solution. Either way, the application of the Newton-Raphson technique would remain the same.

And when we try to solve using the Newton-Raphson technique, the solution that we get takes about 35 iterations with initial flat start as the voltage values. There are no PV buses involved, only two PQ buses and one slack bus. And after 35 iterations, this is the final solution obtained in per unit. Please note that these angles are all in radians and not in degrees.

These are in radians, not degrees. This is the solution obtained for this three-phase radial distribution network using the Newton-Raphson technique. And you can imagine or wonder about the number of iterations involved. There are 35 in number, which is substantially higher even for such a small three-bus network, and this 35 iteration is based on the convergence check that was made on the mismatch vector equation used in the NewtonRaphson technique. What is that mismatch vector technique? So we will preferably come back to this in slide number 12. For the backward sweep technique, during the backward phase, we choose the initial voltages, perform a flat start, work with the currents I3_0, the injection current, find the corresponding branch current, which is I23_0, then find the corresponding injection at bus 2 , which is this current here, the one arrow shown over here, and eventually arrive at I12_0 by applying KCL.

$$I_3^0 = \frac{(P - j0.5P)}{V_3^{0*}} = 0.433837 - j0.21694185$$
$$I_{23}^0 = I_3^0 = 0.433837 - j0.21694185$$
$$I_2^0 = \frac{(P - j0.5P)}{V_2^{0*}} = 0.433837 - j0.21694185$$
$$I_{12}^0 = I_2^0 + I_{23}^0 = 0.866674 - j0.4338837$$

Once we know I12_0, we use the same currents to update our voltages, and these voltages have now been updated; they are not at one at an angle of 0 per unit. So, the equation values remain the same as shown here, and this completes one backward-forward sweep method.

$$V_2^1 = V_1 - I_{12}^0 z = 0.8242771015 + j0.082437903$$
$$V_3^1 = V_2^1 - I_{23}^0 z = 0.7364156523 + j0.123656855$$

In terms of the convergence check, as I mentioned in slide number 10, we use the typical polar version of voltage coordinates and try to find the mismatch vector in the Newton-Raphson technique, as it was done in the Newton-Raphson analysis discussion, and the corresponding f of x, which I was referring to, refers to the real power equation of bus 2 , the real power equation of bus 3 , the reactive power equation at bus 2 , and the reactive power equation at bus 3 . So, this is the P P equation for buses 2 and 3 ; these are the Q Q equations for buses 2 and 3.

$$f(x) = \begin{bmatrix} |V_2|\left[2g|V_2| - (g\cos\,\theta_2 + b\sin\,\theta_2) + |V_3|\left[b\sin\,(\theta_3 - \theta_2) - g\cos\,(\theta_3 - \theta_2)\right)\right] + P \\ |V_3|\left[g|V_3| + |V_2|\left[b\sin\,(\theta_2 - \theta_3) - g\cos\,(\theta_2 - \theta_3)\right)\right] + P \\ -|V_2|\left[2b|V_2| + (g\sin\,\theta_2 - b\cos\,\theta_2) - |V_3|\left[g\sin\,(\theta_3 - \theta_2) + b\cos\,(\theta_3 - \theta_2)\right)\right] + 0.5P \\ |V_3|\left[-b|V_3| + |V_2|\left[g\sin\,(\theta_2 - \theta_3) + b\cos\,(\theta_2 - \theta_3)\right)\right] + 0.5P \end{bmatrix}$$

I have avoided explaining how these equations were obtained. You can refer to the discussions on the Newton-Raphson technique where the polar version of equation forms for P and Q or PQ buses was discussed, and from there you would definitely be able to find these numbers or forms. So basically, you have to find the Y bus for this three-bus network based on the impedance values or admittance values given here, and then when you plug in those corresponding admittance values, you would get this as the corresponding equation form. So, if we evaluate the mismatch vector, it is because we are trying to compare the Newton-Raphson technique with the backward-forward sweep technique. If we evaluate this mismatch vector at this latest voltage solution, then the corresponding f of x that we would get is of this particular order: it is a 4 cross 1 vector, and after 20 recursions, the maximum absolute value, or infinity norm, here is the maximum absolute value of this 4 cross 1 vector, which is a mismatch vector. This number turns out to be somewhere around 10 to the power of the order of 10 to the power of minus 3 or 4 .

Whereas after 220 recursions, the number is significantly lower, of the order of 10 to the power of minus 6 minus 7 , and the final solution that we get is more or less the same as the solution that we got for the NewtonRaphson technique, as shown in slide number 10. The numbers here are more or less similar; there are minor differences in the phase angles that we have obtained in terms of radians, but the voltage magnitudes and, in fact, the phase angles to the fourth or fifth decimal are more or less the same.

So the question now is whether the backward forward sweep technique is applicable; the observation is not the question; the observation is that there is no matrix factorization involved, and the effort required to solve either 20 recursions or 200 recursions is much smaller than the 35 Jacobians that were factorized in each of those 35 iterations of the Newton-Raphson technique for this particular value of P . The situation becomes trickier when we increase the load by a very insignificant quantum for P equal to 0.43388372 per unit instead of the previous value of P. The initial Newton-Raphson solution remains the same, but if we try to look for convergence of the NewtonRaphson technique with a similar convergence check that we have been using, the Newton-Raphson technique never converges nor diverges; it keeps on iterating, and the number of iterations, even if they are tending to infinity, will never match. Whereas for the same load, the forward-backward sweep technique takes the same number of recursions-20 recursions if we talk about minus 3 , minus 4 PU convergence, or 10 to the power of minus 6 convergence-for the forward-backward sweep technique, the same exact solution is obtained with minor differences because the load has now changed. The same solution is obtained in the backward-forward technique with not much difficulty at all. In the next lecture, we will start with our new module, which is fault analysis, and try to understand why faults are a problem in power networks, how our synchronous generators behave during this fault period, and whether this is where the parameter variation of synchronous generators and corresponding time constants come into the picture. Thank you.