Economic Operation and Control of Power System

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Week - 03

Lecture – 15

Very good morning, welcome you all to this NPTEL course on Economic Operation and Control of Power System. And lecture 15, we will be talking about Calculation of Transmission Losses. We stopped in midway during the previous lecture where we learned how the transmission losses can impact not only your optimal solution, but also will provide you an idea and insight how the generation need to be scheduled accommodating those transmission losses of the network. This is a very, very important topic. In the previous section what we have discussed, the transmission loss calculation could be a physical number with historical data and could be a value that can come out from your Newton-Raphson load flow algorithms or could be a function which is dependent on the generation outputs. Now, the B loss coefficient which is a very important term or a concept through which the loss coefficients can be determined and hence the loss function can be prepared and those loss functions can be substituted in my Lagrangian equations to obtain the optimal values of P1, P2 up to Pn.

So with this, let us start how to obtain those B coefficients of the loss formula. So let us first derive the transmission loss formula. So an accurate method of obtaining general loss coefficients has been presented by Kroc. The method is also elaborate and a simpler approach is possible by making the following assumptions.

So first of all, we need to consider all load currents have the same phase angle with respect to a common reference which is not practically true but we have to assume it. Second the ratio x upon R is same for all the network branches. So with these two assumptions probably we will be in a position to derive the expressions of B coefficient of a transmission loss formula. Now to derive, consider the simple case of two generating plants connected to an arbitrary number of loads through a transmission network. As you could see the left side of the diagram 15.1, there are many generators connected. So here we have considered only two generators and connected to n number of loads. The second and third, B and C diagram very clearly says that everything is being provided by the generator 1 and third case everything is provided by the generator 2. So we disconnect generation 2 in the second case and generation 1 in the third case. So let us assume that the total load is supplied by only one generator based on the figure or diagram given in 15.1 B. Let the current through the branch K in the network be IK1 and NK1 which is nothing but IK1 upon ID. It is to be noted that IG1 equal to ID. In this case similarly with only plant 2 supplying the load current ID S1 and figure for 15.1C, we define NK2 which is the IK2 upon ID. Now NK1 and NK2 are called current distribution factors and their values depends on the impedance of the line and the network connections.

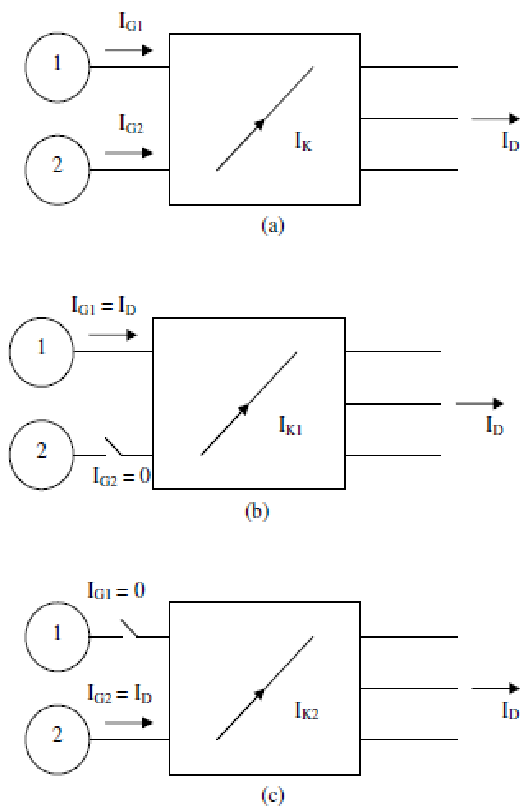

Fig. 15.1

So what we are claiming here, there is a strong relationship between the input current and output current and probably whatever the current being generated or coming out of a generator and the current which is injected to my load and that depends on my transmission parameter. So NK1 and NK2 are called current distribution factors. I am reiterating again and their values depends on the impedances of the lines and the network connections. They are independent of ID. When both generators are supplying the load, then based on the principle of superposition, one can say IK which is N times IG1 plus NK2 times IG2 through a superposition.

IK = NK1 IG1 + NK2 IG2 …(15.3)

So you are getting NK1 IG1 when generator 1 is there, NK2 IG2 when generator 2 is there. When both of them are present, then my IK will be NK1 IG1 plus NK2 IG2. Where IG1 and IG2 are the current supplied by the plant 1 and 2 respectively, to meet the demand ID because of the assumption made IK1 and ID have same phase angle as do IK2 and ID do possess the same phase angle. Therefore, the current distribution factor are real rather than complex. So we can say IG1 which is IG1 angle sigma 1, IG2 is IG2 angle sigma 2 where sigma 1 and sigma 2 are the phase angles of IG1 and IG2 with respect to a common reference.

$$I_{G1} = |I_{G1}|\angle\sigma_1 and\ I_{G2} = |I_{G2}|\angle\sigma_2 \qquad \ldots(15.4)$$

Now based on this, we can rewrite IK square the equation number 15.5.

$$|I_K|^2 = (N_{K1}|I_{G1}|\ cos\ cos\ \sigma_1\ + N_{K2}|I_{G2}|\ cos\ cos\ \sigma_2\ )^2 + (N_{K1}|I_{G1}|\ sin\ sin\ \sigma_1\ + N_{K2}|I_{G2}|\ sin\ sin\ \sigma_2\ )^2$$

$$= {N_{K1}}^2|I_{G1}|^2[\sigma_1\ + \sigma_1\ ] + {N_{K2}}^2|I_{G2}|^2[\sigma_2\ + \sigma_2\ ] +$$

$$2[N_{K1}|I_{G1}|\ cos\ cos\ \sigma_1\ \ N_{K2}|I_{G2}|\ cos\ cos\ \sigma_2\ + N_{K1}|I_{G1}|\ sin\ sin\ \sigma_1\ \ N_{K2}|I_{G2}|\ sin\ sin\ \sigma_2\ ]$$

$$= {N_{K1}}^2|I_{G1}|^2 + {N_{K2}}^2|I_{G2}|^2 + 2\ N_{K1}\ N_{K2}\ |I_{G1}||I_{G2}|\ cos\ cos\ (\sigma_1 - \sigma_2) \qquad \ldots(15.5)$$

Now, $|I_{G1}| = \frac{P_{G1}}{\sqrt{3}|V_1| coscos\ \emptyset_1}\ and|I_{G2}| = \frac{P_{G2}}{\sqrt{3}|V_2| coscos\ \emptyset_2}$

But one thing please remember, the IG1 of the generator 1 is nothing but the power generator PG1 upon PG1 upon under root V1 cos phi 1. And similarly, we can also say that in case of IG2, it is PG2 upon under root 3 V2 cos phi 2. So if you consider IG1 and IG2 are PG1 upon root 3 V1 cos phi 1 based on my power equation.

IG2 which is PG2 upon root 3 V2 cos phi 2. And where PG1 and PG2 are the three phase real power output of plant 1 and 2 and V1, V2 are the line to line voltages and phi 1, phi 2 are the power factor angles. The total transmission loss in this case will be PL which is 3 times IK square RK. Now where the summation is taken all over the branches, the network and RK is the branch resistance considering one branch which is RK. So the P loss equation can be represented in this form.

So what you have to do in the previous case as you have seen that 3 IK square RK, if you substitute the value of IK square here, that means 15.5 will be substituted in 15.6 and then the equation will be similar to my 15.7.

$$P_L = \sum_K \quad 3|I_K|^2 \, R_K \quad \ldots(15.6)$$

$$P_L = \frac{P_{G1}^2}{|V_1^2|(cos\emptyset_1^2)} \sum_K \quad N_{K1}^2 R_K + \frac{2P_{G1}P_{G2}cos(\sigma_1-\sigma_2)}{|V_1||V_2|cos\emptyset_1 cos\emptyset_2} \sum_K \quad N_{k1}N_{k2}R_K + \frac{P_{G2}^2}{|V_2^2|(cos\emptyset_2^2)} \sum_K \quad N_{K1}^2 R_K$$

$$P_L = P_{G1}^2 B_{11} + 2\, P_{G1}P_{G2}\, B_{12} + P_{G2}^2 B_{22} \quad \ldots(15.7)$$

Where, $B_{11} = \frac{1}{|V_1|^2(cos\emptyset_1)^2} \sum_k \quad N_{k1}^2 R_K$, $B_{12} = \frac{COS(\sigma_1-\sigma_2)}{|V_1||V_2|cos\emptyset_1 cos\emptyset_2} \sum_k \quad N_{k1}N_{k2}\, R_K$

$$B_{22} = \frac{1}{|V_2|^2(cos\emptyset_2)^2} \sum_k \quad N_{k2}^2 R_K \quad \ldots(15.8)$$

And 15.7 very clearly says that PL, the loss formula which is a function of PG1 square, which is a function of actually PG1 and PG2 and which is also a function of PG2 square. So all the coefficients, that means PL can be now represented as PG1 square B11 where B11 is a coefficient plus 2 PG1 PG2 B12 where B12 is another coefficient and finally PG2 square B22 where B22 is another coefficient. So B11 and B12 and B122. A B11, B12, B21 and B22 can be determined based on the coefficients. So here I think I need your attention for some seconds.

What we need to do, once you calculate B11 of a network, if you can calculate B12, if you can calculate B22, that means the loss formula can be generated based on equation number 15.7. So once you have this loss equation, this can be substituted in my Lagrangian equation assuming the system do have losses included in my generation to get the loads. Now for a general system with n number of plants, now previously we considered two plants, now we can expand it to n number of plants, so you can get the equation 15.9, 10, 11 accordingly.

So we are the coefficients can be treated as constants over the load cycle by computing them at average operating conditions without significant loss of accuracy. So what we need to do, now today the load at a given point of time is something different compared to tomorrow, day after tomorrow, so around the year the load is keep on changing. When the load is keep on changing, the power flow is keep on changing and hence my coefficients are also being calculated on a particular day and time will keep on changing. So how do I claim my loss formula equal to some constant times B12, it is very difficult, so that constant will be obtained as an average of all the load profiles experienced around the year and then you can average it out to obtain all these B coefficients to be substituted in your loss formula. So this is one of the numerical example that you can check it up in 15.2, calculate the transmission loss coefficient in per unit per megawatt one on the base value of 50 mVA for the network, so you can calculate the network and calculate the impedances, the currents, once the currents are known to you, you can calculate NL1 and NL2 and finally for a different case study, you can calculate the value of actually current distribution which has been shown in the diagram which is given in the following figure where you could see the G1 which has been connected to many loads and many buses, so you can calculate the value if the total load is supplied only by the generator 1, then my I1 will be equal to IL and IL2 will be 0. Now you can take one more example where everything is supplied by generator number 2 where I2 equal to IL and I1 equal to 0 and finally you can have a combination of IG1 and IG2, so you can calculate what is V1, you can calculate what is V2 and then based on the current phase angles, you can calculate sigma 1, sigma 2 and then perfect angles like phi 1 and phi 2 and those values can be substituted in my V1 expression, V12 expressions and V22 expressions, so V11, V12, V22 become a function of your phi 1, V1 and resistances and NK1's, those parameters are being calculated for a given diagram and then you can obtain what is your V11. So, here as you could see my V11 is being calculated at 0.0677 per unit and similarly you can calculate V22 which is 0.112 10 to the power minus 2 and similarly you can calculate V12 which is close to 0.0078 times 10 to the power minus 2 and so once you get those values probably you can take different load profiles of the same network and you can average it out and then you can confidently create an empirical formula saying that the losses will be now x coefficient P1 square, y coefficient P1, P2, z coefficient P2 square, alright. So then you can perhaps do it. So this talk is mainly, it's a research topic to be very honest, most of the post-graduate students do it and solve the problem but this is to bring clarity on you that you should not feel surprised at how these loss equations are being generated. So for benefit of doubt and most of the textbooks do not cover this portion, so we thought that it is appropriate to be taught how those VmN coefficients are generated. They are not simply by guess but they are all numerical.

With this note, thank you very much and wish you all the best.Take care.