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Referring to your slide (pg 6) where it indicates the equation for Real & Reactive power. My queries,

1) $P = |V|\,|I|\cos\theta_1 = (|I|\,|Z|)\,|I|\cos\theta_1 = \ldots$

2) $P = |V^2| / |Z| \cos\theta_2\ldots$

For 1, the θ is referring to the current angle.

Yes, it is the angle between the voltage and current vectors.

But for 2, are we supposed to use the current angle or the impedance angle?

θ_2 is not the same θ_1. Equation (1) is used when you have R and X in a series branch while equation (2) is used when you have R and X in a parallel branch (Please see p42 of our EE3015 notes). The two equations are different in nature. I do not quite agree that in (2) you use the same Z symbol as in (1). If you need to make the two equations the same, both theta and Z could not be the same. For parallel branches, I would prefer that you use the P equation in p42. Because the R and X in p6 are assumed to be in series, it is not advisable to talk about angle in (2) where the impedance is arranged in parallel.

Sir, I have the following query, which I hope you can enlighten me to find complex power, there are 2 formulae:

a) $S = VI^*$

This formula is the complex power $S = P + jQ = VI^*$. It is expressed in complex number and is meant for single-phase complex power in per-unit or actual quantities. The formula can also be used as three-phase power provided it is expressed in per-unit quantities. The above cannot be used for three-phase power expressed in actual quantities.

b) $S = (\text{root } 3)\, VI$

I have read through the earlier part of your notes, as well as EE3010's notes. However, I am quite confused with the use of these 2 formulas, which are always alternately used in EE3015 tutorials.

This formula is the three-phase apparent power (Magnitude of complex power, $|S|$) in actual quantities without considering the phase angle. When the formula is expressed in this way, it means that V is the line-to-line voltage and I is the line current. Both quantities are magnitudes only expressed in actual quantities. This formula cannot be used as a three-phase power expressed in per-unit quantities because in the per-unit system, the three-phase power cannot have root 3. If you need to express the three-phase power in per-unit quantities then you have to drop the root 3 and expressed it as $S = VI$ (Magnitudes only). You could also use the earlier formula in (a). In (a), you are interested in both the real and imaginary power.

Keep in mind that it is incorrect to write $S = (\text{root } 3)\, VI^*$ with the conjugate symbol next to the I variable. The reason is because this gives the reader an impression that the phase angle is between the line current and line voltage phasors. In reality, the phase angle, i.e. the power factor angle, is the difference between the phase voltage and phase current (or line current for Y).

If you wish to write three-phase power formula, the following three-phase complex power formula is normally used:

$S_{3\phi} = \sqrt{3}V_L I_L \cos\theta_\phi + j\sqrt{3}V_L I_L \sin\theta_\phi$

If you prefer a more compact form, you could use the following formula
$S_{3\phi} = 3V_\phi I_\phi^*$

The conjugate symbol is allowed in phase quantities as it will not cause ambiguities in the definition of the power factor angle. We need to ensure that the angle difference of V and I is between the phase voltage and phase current and this aligns with the definition of the power factor angle.

Kindly advise the difference between the 2 (Like for instance, for finding base current, which do we use? etc...)
Since I_b is normally expressed in actual quantities and by definition of the per-unit system I_b is the line current, we could use formula (b) that you listed to compute the base current.

With regard to pg 20 of the slide in the notes, may I ask the point stated in the notes below:
"per unit values if Z, R, X & I are the same on either side of the transformer, but the actual values are not!"
Do you mean that the Z pu,pri = Z pu,sec ?
Yes. The example in page 24 reflects this concept. X pri = 0.06. My hand-written notes next to X pri, X sec = 0.06. This confirms the concept learned.

In Tut 1 Q1, what's the physical difference between the single-phase unit and 3-phase unit stated in question b?
A three-phase transformer can be formed by a three-phase unit in which all the windings for the three phases are wound on the same iron core or a three separate single-phase transformers. In the latter case, the windings for each phase are wound on a separate iron core and you would need three separate iron cores to form a three-phase transformer.

13.8Δ/120Y kV,
What kind of physical meaning can be derived from the above?
The above tells us that the 13.8-kV (line to line) side is connected in delta and the 120-kV (line to line) side is connected in Y. Please keep in mind that a transformer can be energized from either side. This means that the 13.8-kV side can be the primary or secondary winding. The same can be side about the 120-kV side.

As stated in the notes, the base voltages ratio is related to the turn-ratio of the transformer. Explain why there is no need to multiply120 by the square root of 3 before taking the ratio?
There is no need to multiply 120 kV by SQRT(3) because 120 kV is already a line-to-line quantity. This is because by default all voltage ratings of transformers are expressed in line-to-line quantities. Our base voltage, Vb, is always a line-to-line quantity. Since Vb is always expressed in line-to-line, we just need to use the ratio of the voltage ratings. If the transformer is given in single phase (as in 1.1 (b) (ii)), then you need to adjust the its voltage ratings to line voltage ratings based on the transformer connection (delta/wye as given in the first line of Q1.1) before you do the calculation.

When do you need to multiply by square root of 3?
If the voltage ratings are given as phase quantities as in single phase transformers, then you may need to adjust the voltage ratio. For example, if the three single-phase units of 1.1 (b) (ii) are connected as delta/wye, then the wye side of the transformer will have SQRT(3) x 69 kV. Hence, the ratio is now 13.8/SQRT(3)x69. No adjustment is required for the delta side since the line voltage is the same as the phase voltage.

In Tutorial 2.1, the transformer is labelled as for example 70/120 kV. Do these two values tell the terminal voltage of the transformer at the primary and secondary side?
These two values tell you the rated voltages of the transformer as given by the transformer manufacturer. They may not be the actual operating voltages. A transformer can be energized from either side.

And these values are always treated the Vb,old (old base voltage). Am I right to say so?
Yes. I assume that you have new base values.

We always take the per-unit of the load voltage as the reference and calculate the per-unit terminal voltage of each point in the system. Is it Ok if we start from the generator and treat the generator Vt as a reference? I don't think it is correct but can I know why?
Yes, it is possible especially when the generator terminal voltage is given and the load voltage is not given. Please see page 38 of our lecture notes.

In Tut 2 Q1, to calculate the X of T4, we have the voltage of L3 as new base voltage of 140 kV and the transformer old base voltage as 138kV. However, here why not multiply 138 kV by the square root of 3 since it's connected in wye?
By default, all transformer ratings are assumed to be line to line if the question did not say so. The 138-kV value is already a line to line quantity. Hence, there is no need for you to multiply it by SQRT(3).

Lecture notes Review Exercise 5: I am not sure how to find the Z p.u for Tr 2. I used the equation (1+j7) * (200/345)(square) * (100/30) = 1.1202, but your answer is 0.0112. So,

I would like to know where I went wrong. I wonder whether for the Wye-Delta connection in Tr 2, we should use the 20kV of the transformer or 200kV.
First you need to convert % to per-unit by dividing the given value by 100, i.e. $(1+j7)/100 = 0.01 + j0.07$

Next, the given Tr 2 data are in single-phase quantities. This means that you must adjust them to three-phase quantities. For example, 30 MVA becomes 3 x 30 = 90 MVA. This is the old MVA base for your conversion. Also, the primary side of Tr 2 is connected in Y and the given primary voltage of the single-phase transformer is 200 kV. You need to adjust it to a line voltage, i.e. SQRT(3) x 200 kV.

Finally, combining all the above using our old to new impedance conversion formula, the new value is

(0.01 + j0.07) x [SQRT(3)x200/345]**2 x100/90.

On page 26 of the notes, how do we calculate the value of $Z_T = (0.2723 + j0.726)$ ohm referred to HV side. I tried to calculate by referring from LV side by "a^2", but I could not get the value of $Z_T = (0.2723 + j0.726)$ ohm. Hope you will assist me with how is being calculated.
The Z_T value is already given at the HV side of the transformer as $Z_T = (0.2723 + j0.726)$ in the one-line diagram. There is no need for you to compute Z_T at the HV side.

We were not given any Z_T value at the LV side. Hence there is no way that you can refer your LV impedance value by multiplying it by a^2. You could refer the Z_T at the HV side to the LV side by dividing the given value by a^2.

I have some questions on Review Exercise on Lecture Notes, P 43., Qn 6.
How do I calculate the V for Load in p.u form? Is it 0.58 p.u?
However it is shown as 1.004 p.u in the answer. Please advice.
V = 1.004 is correct.
It is obtained from 20/Vb. Vb = 345 x 20/[SQRT(3) x 200]

For the notes on review exercises Qn7(b), do you calculate the load p.u. impedance first, then divide the Bus1 voltage by the total impedances to get the load current in p.u.. Next use IxZ to calculate Vload? My answer is a bit different from the given answer (mine is 11.302kv). Am I correct?
Yes, this is the calculation technique that you should use. The difference between your answer and mine is a bit too big for round-off errors. Please check your intermediate steps and values. Your Bus 1 voltage should be $11/11 = 1\angle 0°$ pu. Your total impedances should 4.2691 pu (magnitude) and your load impedance should be 3.6596 pu (magnitude).

For the same question, the load is fixed but the load voltage is different. Is it b'coz in order to maintain Bus1 at 11kv, the load current changes, so Vload changes?
Yes, what you said is essentially correct. I offer another explanation which complements your explanation.

The load impedance is fixed in 7(a) because the question asked us to represent the load by constant series impedance. In 7(b), we assume the same constant series impedance. Since the operating condition changes (11 kV at Bus 1 and this may not imply 13.2 kV at the load side), we need to re-compute the load voltage.

T2 Q1: The transformer T4 is rated as 12/138kV. Since that's the case, the base voltage at bus E (load side), I thought, it should be 140 kV * 138/12 = 1610 kV as opposed to what you have said in the tutorial. Am I right to say that?
It should be 140*12/138=12.1739.

May I know why? I have thought about this for quite a long time. The load side is supposed to be connected on the High Voltage side of the transformer. Thus, the base voltage should be raised accordingly. Correct me if I am wrong.
A transformer can be energized from either side. It does not make sense to connect the 12-kV side of T4 to a 140-kV transmission line system. If we connect this way, the transformer T4 will blow. We should not take the order of T4 voltage ratings (12/138 kV) as the order of the connection.

In a generation transmission/distribution system such as the one in Problem 2.1, G1 and G2 represent the generation systems, L1 and L2 form the transmission system with T1 as a step up transformer and T4 as a step down transformer.

T2 Q1: From the tutorial, can I conclude that for 3-phase transformer, start-delta transformer, the higher turn ratio is always referred to as the star side (high votage side is always on the star-side). If this is the case, can you explain why? Else how to tell the turn ratio is referred to which side from the question?
Transformer can be energized from either side. Hence, you should not say that the HV side is always the STAR side. We normally determine the voltage rating of the transformer side by examining the apparatus/component rating that we connect to. For example, if you connect a 12 kV generator/load to a transformer, then that side of the transformer should be around 12 kV (+/- 5 to 10%) line-to-line.

T2 Q1: I notice that TR1, 3, 4 are connected Delta-Wye, and TR2 is connected Wye-Wye. What effect does these two different methods of wiring up the transformer affects the electrical circuit? Does it make a difference on the voltages and the currents? Thanks for your time!!
Generally, the delta-wye connection is used for stepping up voltage and wye-delta connection is used for stepping down voltage. The reason is obvious since the line-to-line voltage of the Y connection is SQRT(3) times the phase voltage. There is also a 30

degrees phase shift (HV to LV or LV to HV) involved for these two connections. This may create problems if you try to connect two transformers of different configuration in parallel operation. Other than these, the line and phase currents of a delta-connected side observe the SQRT(3) factor and 30-degree phase shift relationship. Similarly the line and phase voltages of a wye-connected side also observe similar relationship.

The wye-wye connection does not introduce phase shift from LV to HV or HV to LV. However, the usual line and phase voltage relationship still holds. In general, the wye-wye transformer connection is seldom used in operation. The reason is because it has a serious problem with third-harmonic voltages which make the operating voltage non-sinusoidal.

T2 Q3: I realised that the ratings on the transformer on T1 is 220/22 kV and T2 is 11/220 kV. But when I do the calculations for X T1 PU, I need to use 22 kV (referred to primary side) in order to get my answer. So my guess is that at T1, the voltage needs to be stepped up in order to transmit the current, that's why I need to use 22kV referred to primary side? The opposite goes for T2, that is why I need to use 220 kV referred to primary side for the calculation.

Transformers can be energized from either side. Do not connect the generator according to the voltage rating order given in T1 (220/22 kV). Since the generator is rated 22 kV, it only makes sense to connect the generator to the 22 kV side of T1. The same applies to T2. You can only connect the 11 kV side of T2 to the motor rated at 10.45 kV. Hence L1 can only be energized at 220 kV where the remaining 220 kV side of T1 and T2 are connected.

I have read through the written notes and have doubts on the issues of Sb = Pb = Qb, is it always the same throughout all kinds of questions or only on the specified case.

Sb = Pb = Qb is true all the time for all per-unit problems. It is the same concept used in Zb. When you are given the actual X value, to convert X into Xpu you simply divide Xactual by Zb. Indirectly, you assume Xb = Zb. Hence, if you are given Sb = 0 + j10 = jQ, to find the Qpu, you divide either side of the above equation by Sb, i.e. you divide Q by Sb. Doing this way, you indirectly accept that Qb = Sb. Likewise, we can say the same for Sb = Pb or Zb = Rb. This is how the per-unit system works.

Keep in mind that Sb, Qb and Pb are not the actual MW and/or MVar the generator produces. They are base values to facilitate per-unit conversion in our calculation. We are not saying that S = P = Q in actual operation but rather we are saying these bases are equal. In actual operation, formulae such as S = P + jQ = |S| cos thetha + j |S| sin theta is still valid.