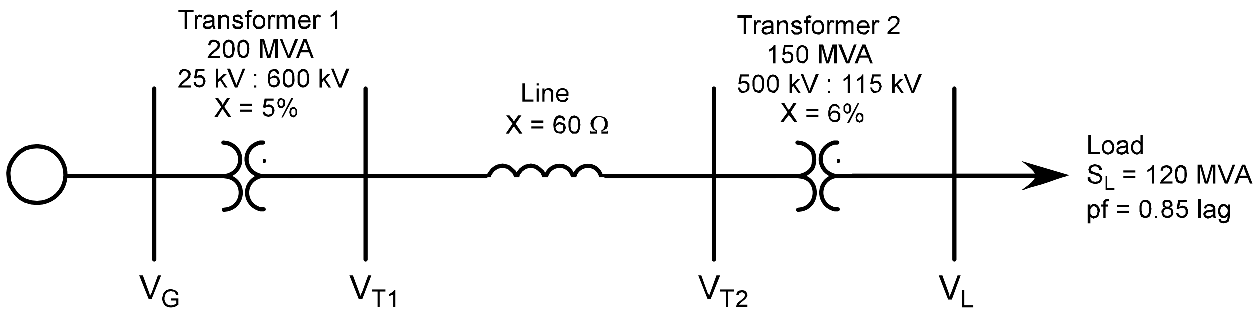
EXAMPLE 18.6

In the system shown below, the generator is ideal ($X_S = 0$) and the magnitude of the load bus voltage, V_L is to be held at 110 kV. Working on a system base of 100 MVA and a base voltage of 115 kV in the load circuit:

a) draw the single-phase equivalent pu reactance diagram, and

b) determine the necessary generator terminal voltage V_G (kV).



Solution

a) We must note that the presence of the transformers causes the base voltage to vary as we move back from the load toward the generator. We are given:

V_{Bload} = 115 kV, as the base voltage in the load circuit, while:

$V_{Bline} = 115 \text{ x } \dfrac{500}{115} = 500 \text{ kV}$, is the base voltage in the line circuit. Likewise:

$V_{Bgen} = 500 \text{ x } \dfrac{25}{600} = 20.83 \text{ kV}$, is the base voltage in the generator circuit.

Since transformers do not alter power, the base power remains at 100 MVA throughout the system.

We apply the per-unit notation by dividing actual quantities by the base quantity.

At the load: $\boldsymbol{V_L} = \dfrac{110}{115}\angle 0^0 = 0.9565\angle 0^0 \quad \textbf{\textit{pu}}$

$$\boldsymbol{S_L} = \frac{120}{100}\angle \cos^{-1} 0.85 = 1.2\angle 31.8^0 \quad \textbf{\textit{pu}}$$

$$\boldsymbol{I} = \left(\frac{\boldsymbol{S_L}}{\boldsymbol{V_L}}\right)^* = \frac{1.2\angle -31.8^0}{0.9565\angle 0^0} = 1.255\angle -31.8^0 \quad \textbf{\textit{pu}}$$

The per-unit value of the current is the same in all parts of the circuit since the transformers do not alter current in per-unit form.

The reactance of transformer 2 is given on a base of 115 kV, which is what we want, but the power rating is 150 MVA while 100 MVA is required. So the following change is needed:

$$X_{T2} = 0.06 \text{ x } \frac{(115)^2}{(115)^2}\frac{100}{150} = 0.04 \text{ pu}$$

It is concluded that 6% on a 150 MVA base is the same as 4% on a 100 MVA base, if the voltage base is unaltered.

The reactance of transformer 1 is given on a base of 25 kV, however, we need to use a base of 20.83 kV and the power rating is 200 MVA while 100 MVA is required. So the following change is needed:

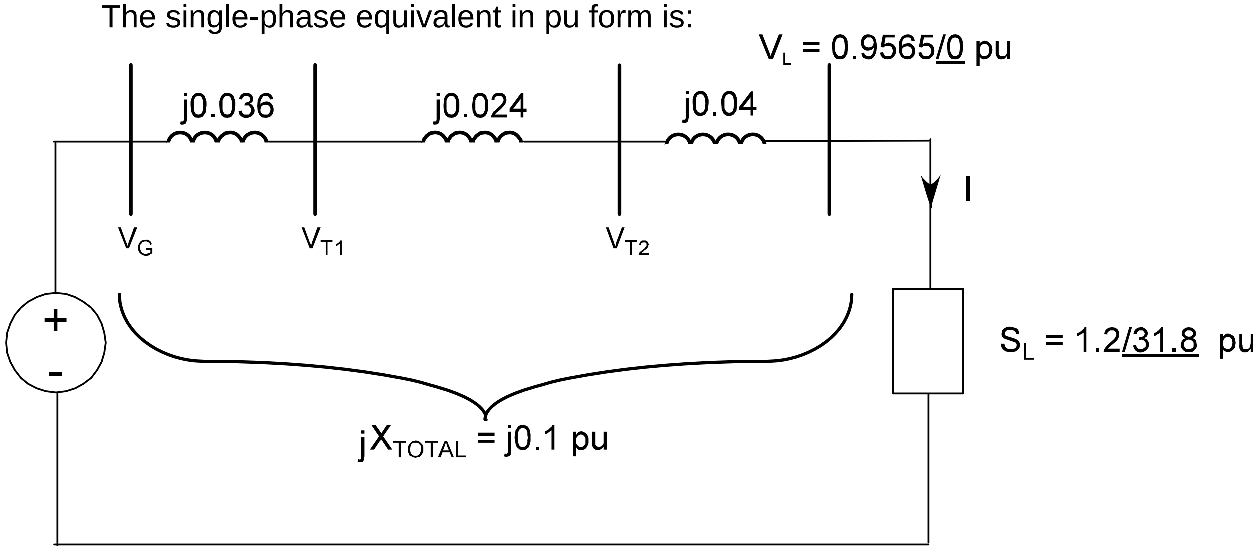
$$X_{T1} = 0.05 \text{ x } \frac{(25)^2}{(20.83)^2}\frac{100}{200} = 0.036 \text{ pu}$$

The reactance of the line is given in ohms, so we need to determine the base reactance, i.e.

$$X_B = \frac{(V_{BL})^2}{S_B} = \frac{(500)^2}{100} = 2500\ \Omega$$

$$\therefore \quad X_{line} = \frac{60}{2500} = 0.024 \text{ pu}$$

The single-phase equivalent in pu form is:



b)

$$\boldsymbol{V_G} = \boldsymbol{V_L} + jX_{TOTAL} \text{ x } \boldsymbol{I}$$

$$\boldsymbol{V_G} = 0.9565\underline{/0} + j0.1 \text{ x } 1.255\underline{/-31.8} = 1.028\underline{/6^0} \text{ pu}$$

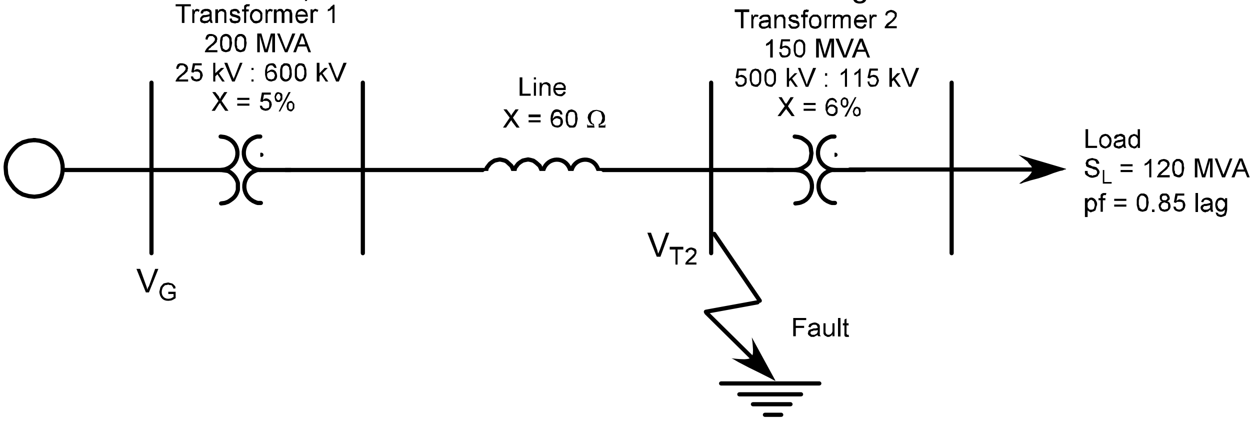
The 6^0 angle can be neglected when converting the magnitude back from per-unit, i.e.

V_G = 1.028 x 20.83 = 21.4 2 kV .

The per-unit system is also useful for calculating fault levels on a power system. This is very important when deciding how large a circuit breaker has to be and the trip level of its associated relay. For *balanced faults* (all three phases shorted) this is modeled by connecting the phase conductor to the system neutral in the single-phase equivalent.

EXAMPLE 18.7

Refer to example 18.6 and determine the fault level (kA) at the bus whose voltage is labeled V_{T2}. Note that the fault level is the current that will flow into a fault at the position stated. Assume that the load does not contain any components that will feed current into the faults, so that all fault current flows from the generator.



Solution

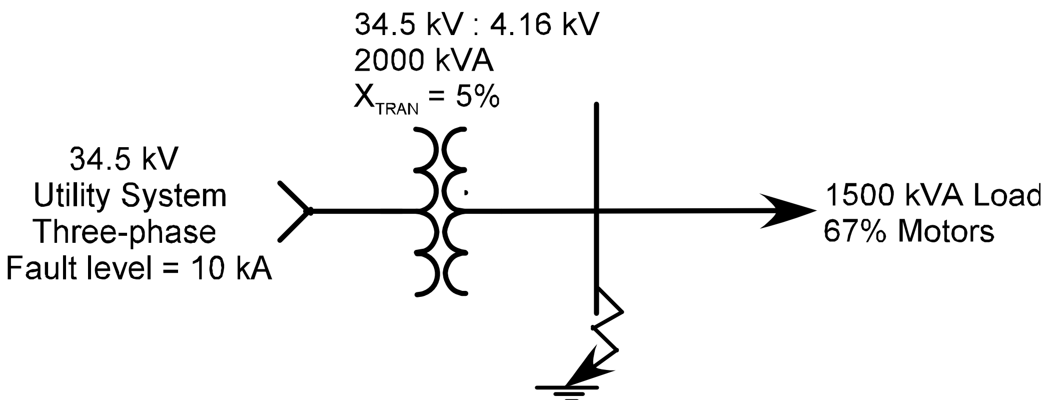
If this was the largest fault current that would flow through the associated circuit breakers then it would be used to determine the rating (size) of the breakers. If, on the other hand, it was the smallest fault current then it would be used to set the relay that would send the signal to trip the breaker and interrupt the fault.

It is important to note that motors are the largest component of power system loads and that they will *feed current into* faults for a few cycles i.e. they become generators and cause fault levels to be higher. They briefly become generators because voltage levels collapse during faults and the stored mechanical (kinetic) energy flows out of the motor in the form of electricity. Precise fault calculations with motors are very complex, but a simple *rule of thumb* states that 400% of the full-load running current (FLA) of the motor will flow in to the fault. This models the motor as a constant current source feeding into the fault and is sufficiently accurate for our purposes.

When fault levels are known at a supply bus the bulk power system can be replaced by its Thevenin equivalent, to allow downstream fault levels to be calculated, as shown in the following example.

EXAMPLE 18.8

For the system shown below, determine the balanced, bolted three-phase fault level at the 4.16 kV bus.



Solution