Topic : Constant KVA Loads and Power Factor Correction

Key Ideas:

1. Power System Loads appear to be constant KVA at some power factor—more precisely over a short period of time even if voltage changes a little, the load impedance adjusts(changes) so that the load draws the power(energy) needed.
2. Notice that the statement in HW problems will start changing. Loads will be given in terms of KVA and power factor
3. In power system design and analysis we begin with a knowledge of how much load (KVA, pf) we want to serve.
4. A fundamental analysis problem in power is to determine how much voltage and power to generate, given that we want to supply a specific voltage to our loads.
5. See posted example "Constant KVA Load". Note the two ways to solve the problem. The easy way is to use Complex power and Voltage to find current. Then do KVL
6. The example shows that with inductive line impedance and lagging load we need to start with a higher voltage magnitude at the generator. The generator voltage also has a higher phase angle than the load. The generator must produce a complex power equal to load plus loss in the transmission line. If the load is leading power factor then the generator voltage magnitude is lower than load voltage magnitude. We used phasor diagrams to show this.
7. Ideally we would want loads to have unity power factor. POWER FACTOR CORRECTION refers to connecting a capacitor in parallel with the load (shunt) to compensate for the lagging reactive power in the load. The capacitor 'supplies' the load reactive power. Benefits are
   a. Lower current / Smaller conductors
   b. Reduced voltage requirement at generator
   c. Reduced loss

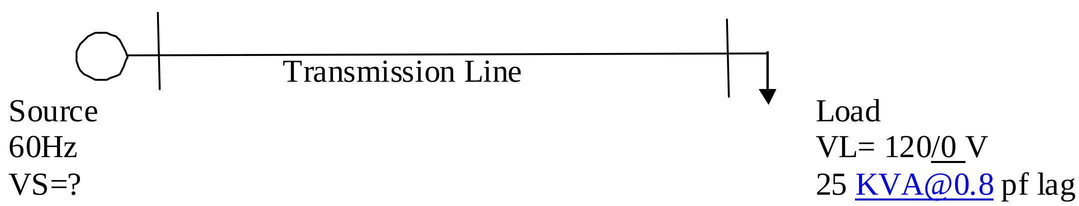
   One has to trade these benefits off against capacitor cost.

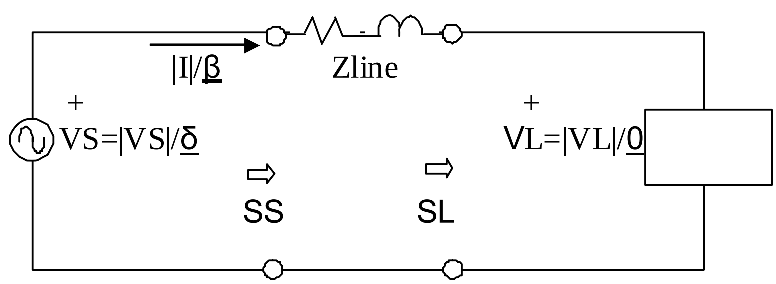
Constant KVA load

A unique feature of power systems is that the 'loads' appear to demand a 'constant' KVA at some power factor. More precisely, we say that the power consumed by loads remains constant even under small(5%) variations in voltage. For this reason power system calculations are posed as in the problem below.

Example 1
A single phase 60 Hz source supplies a 25 KVA, 0.8 pf lagging load through a transmission line of impedance 0.031+j0.029 ohm. Determine the source voltage needed to obtain 120 V at the load. Also calculate the complex power supplied by the source and the power loss. Show a phasor diagram relating source voltage, load voltage and voltage drop phasors.

The zero'th law of circuit theory states, "..don't you ever work a circuits problem without sketching the circuit!!!..." SO shown below is a conceptual "One Line Diagram" as well as the electric circuit corresponding to the problem statement.





Notation

VS Source voltage phasor, rms V
VL Load Voltage Phasor, rms V
SS Complex power delivered by Source
SL Complex power delivered to Load
Zline the inductive impedance(series R-L) of the transmission line at 60 Hz
I phasor current, rms A

Given

Line Impedance $\quad Zline := 0.1 + j \cdot 0.1$ ohms at 60 Hz

Load complex power:
We are given the magnitude of load complex power as 25 KVA.

Wer are told that the power factor(pf) is 0.8. Since power factor= cos(ϕ), the power factor angle is ϕ=acos(pf). Note we don't yet know if ϕ should be positive or negative.

We are also told that the power factor is lagging, i.e., load current lags load voltage. Thus the load consists of a resistor and an inductor. Since the power factor angle ϕ also equals the phase angle of voltage minus the phase angle of the current we use the positive answer from acos(pf). For a leading load, which would contain a capacitor, we would take the negative answr for ϕ.

Now we can use the euler notation to specify the complex power delivered to the load.

$$SL := 25000 \cdot e^{j \cdot acos(0.8)} \quad VA$$

Load Voltage: We are given the magnitude in rms volts. We are free to take the load voltage as our phasor reference. So we specify

$$VL := 120 \cdot e^{j \cdot 0} \quad V$$

Find

We want to calculate the source voltage VS, and the complex power delivered by the source SS

Approach

KVl, VS= VL+Zline I, comes to mind right away.

Unlike typical ac circuit problems however the load is a 'black box' whose impedance can vary but the complex power remains constant. But knowing the complex power and voltage we can calculate the current since S= VI* (Note: In mathcad the overbar represents complex conjugate).

Solution

So $\quad IL := \overline{\left(\frac{SL}{VL}\right)} \quad IL = 166.667 - 125i \quad |IL| = 208.333 \quad \beta := arg(IL) \quad \beta = -36.87\,deg$

Then $\quad VS := VL + Zline \cdot IL \quad |VS| = 149.225 \quad \delta := arg(VS) \quad \delta = 1.6\,deg$

Alternate approach

An alternate, but less preferred, way to work the problem is to first calculate the impedance of the load (Remember in a constant KVA load impedance varies with voltage). In this problem, though, we are given that VL=120V

$Z := \frac{(|VL|)^2}{\overline{SL}}$ $\quad Z = 0.461 + 0.346i$ ohms

$IL := \frac{VL}{Z}$ $\quad IL = 166.667 - 125i$

$|IL| = 208.333$ $\quad \beta := \arg(IL)$ $\quad \beta = -36.87\,deg$

Then $\quad VS := VL + Zline \cdot IL$ $\quad |VS| = 149.225$ $\quad \arg(VS) = 1.6\,deg$

Source Complex Power and Loss

Look at source power and losses

Load Power $\quad SL = 2 \times 10^4 + 1.5i \times 10^4$ VA

Source Power $\quad SS := VS \cdot \overline{IL}$ $\quad SS = 2.434 \times 10^4 + 1.934i \times 10^4$ VA

The difference between source and load power is the 'lost' in the line. The real power loss is power disspated in line resistance. The reactive power loss is not really a 'loss'- it is an oscillating power flow necessary to sustain the magnetic field of the line.

$Loss := SS - SL$ $\quad Loss = 4.34 \times 10^3 + 4.34i \times 10^3$ VA

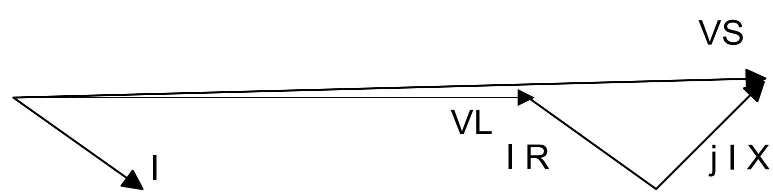
Can calculate Loss as follows

$Loss := (|IL|)^2 \cdot Zline$ $\quad Loss = 4.34 \times 10^3 + 4.34i \times 10^3$ VA

In the above example the transmission line (feeder) has an inductive impedance. The load is also inductive. In this case typically

Load Voltage magnitude< Source VOltage magnitude
Load voltage phase angle< Source voltage phase angle

This is illustrated in the phasor diagram below



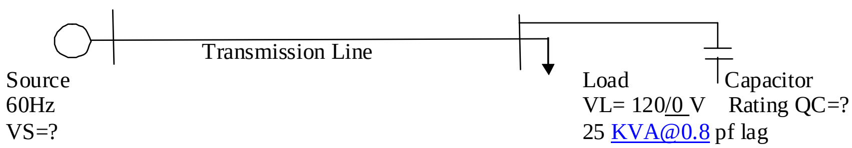
Power Factor correction

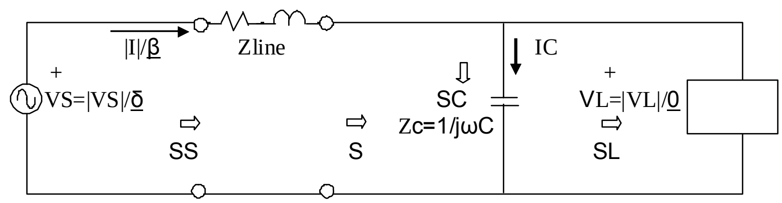
The load current is determined by both real and reactive power. Power system loads are typically inductive as are transmission line impedances. Thus a lagging power factor load presents the following problems:
- components must carry larger current
- voltage magnitude drops from source to load.
- losses are high

Power factor correction involves connecting a capacitor in parallel with the inductive load.

Example 2:

For the system in the previos example, correct the power factor to 0.95 lagging. Determine capacitor required, source voltage, and loss. Load voltage should be 120 V





Setting up the problem

The new on-line and circuit is shown above

Let Qc represent the reactive power SUPPLIED by the capacitor. This number is also called the RATING

Complex power delivered TO Capacitor is SC= - j QC

Let S represent load complex power after correction.

S = SL +SC = PL + j QL - jQC so QL-QC=0

Given

As before Load power and voltage are given

$SL = 2 \times 10^4 + 1.5i \times 10^4$ VA $\quad$ $VL = 120$ V

Find

We first need to find SC so that the the power factor of the combined load is 0.95 lagging
Then we repeat the calculations in example 1

Approach

Let ϕold represent the original power factor angle and ϕnew the desired one.

Then tan(ϕold) = QL/PL and tan(ϕnew)= (QL-QC)/PL

Note the real power must remain the same, while reactive power changes

Thus (QL-QC)/QL = tan(ϕnew)/tan(ϕold)

Thus QC= (QL-PL*tan(ϕnew)

Solution

In our case the desired power factor is .95 lag

$PL := Re(SL) \qquad QL := Im(SL) \qquad \phi new := acos(0.95)$

$PL = 2 \times 10^4$ W $\quad QL = 1.5 \times 10^4$ VAR

$QC := QL - PL \cdot \tan(\phi new) \qquad QC = 8.426 \times 10^3$ VAR capacitive

So we need a a capacitor that supplies 8 KVAR at 120 V

In order to calculate the capacitance in uF we first need the impedance. We can calculate that as shown below

Complex power supplied to the capacitor

$SC := -j \cdot QC$

So current $IC := \overline{\left(\frac{SC}{VL}\right)} \qquad IC = 70.219i$

Then Impedance $ZC := \frac{VL}{IC} \qquad ZC = -1.709i$ ohm $\quad XC := 33.036$ ohm

Since XC = 1/ωC $\qquad C := \frac{1}{377 \cdot XC} \qquad C = 8.029 \times 10^{-5}$ $\qquad$ 80.29 uF

Alternatively QC = |VL|^2/XC yields the same answers

What is the effect of Power Factor Correction?

$S := SL + SC$

So $IL := \overline{\left(\frac{S}{VL}\right)}$ $IL = 166.667 - 54.7$ $|IL| = 175.439$ $\arg(IL) = -18.195\,deg$

Then $VS := VL + Zline \cdot IL$ $|VS| = 142.584$ $\arg(VS) = 4.501\,de$

Load Power $SL = 2 \times 10^4 + 1.5i \times 10^4$

Source Power $SS := VS \cdot \overline{IL}$ $SS = 2.308 \times 10^4 + 9.652i \times 10^3$

Loss $Loss := SS - S$ $Loss = 3.078 \times 10^3 + 3.078i \times 10^3$

Note improvement in voltage, and reduction in current and loss g