4kV METERING

The metering of 4kV power is somewhat more difficult to understand than the metering of 12kV power. On the Edison system, the 4kV power banks are connected star on the load side and the distribution transformers are connected phase to ground. We might meter this load the same way that we meter our 12kV load if we could be assured that load would be evenly balanced. However, we know that we cannot depend on having evenly balanced load so it becomes evident that the normal two element metering connection cannot be used, since the current in one phase would not be reflected in the watt meter.

A method is used which does "see" the current in all three phases, and this involves using three line CT's connected in delta. In addition to giving us a reflection of the current in all three of the phases, however, this gives us a current which is $\sqrt{3}$ times the required current in the meter element. To compensate for this, we connect our potential element to a potential which is equivalent to the expected voltage divided by $\sqrt{3}$. The total torque will then be correct. This works out since our normal station light & power transformers are connected phase to ground on the high side (see Figure 2).

The remaining problem is to connect the current and potential in the correct relationship.

The potentials on the low side of the 4kv pots will be in phase with the high side phase to ground voltages; however, we label them to correspond to our standard potential labeling. This calls for the 120 volt potentials to be in phase with the 12kV phase to phase voltages (Fig. 2). Also, we stipulate for metering that we use only real voltages. The voltage across the open end of the transformers is not to be used. The phasor diagram, Figure 1, shows the current voltage relationships that we use.

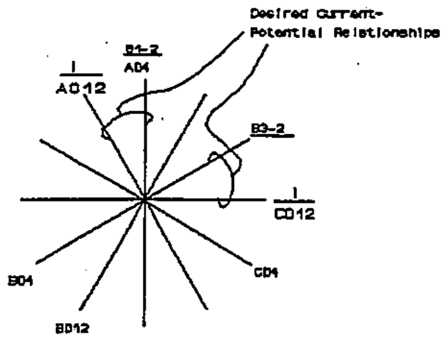

Figure 1

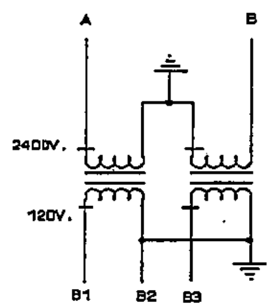

Figure 2

Notice that the desired current position does not correspond to any current provided. The phasor diagram in Figure 3 shows how we add currents to obtain the desired current-potential relationship.

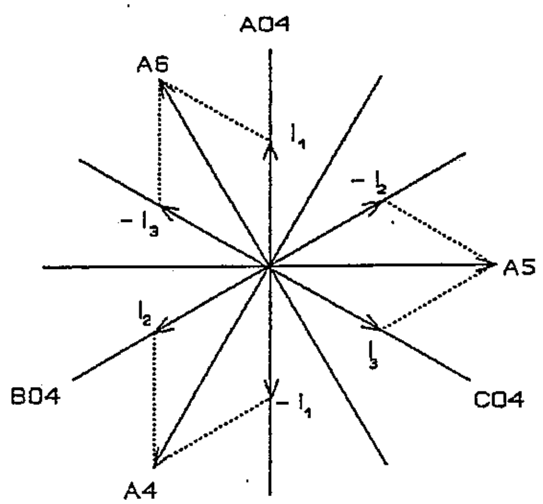

Figure 3

The delta wiring connection to obtain this current relationship is shown in Figure 4. The labeling A5, A6, and A4 is determined from the labeling of the ends of the CT secondaries. Note that the end of the CT from which the secondary current emerges is considered the positive current end, and the opposit end is considered the negative current end. (This is, of course, with primary current feeding toward the load.

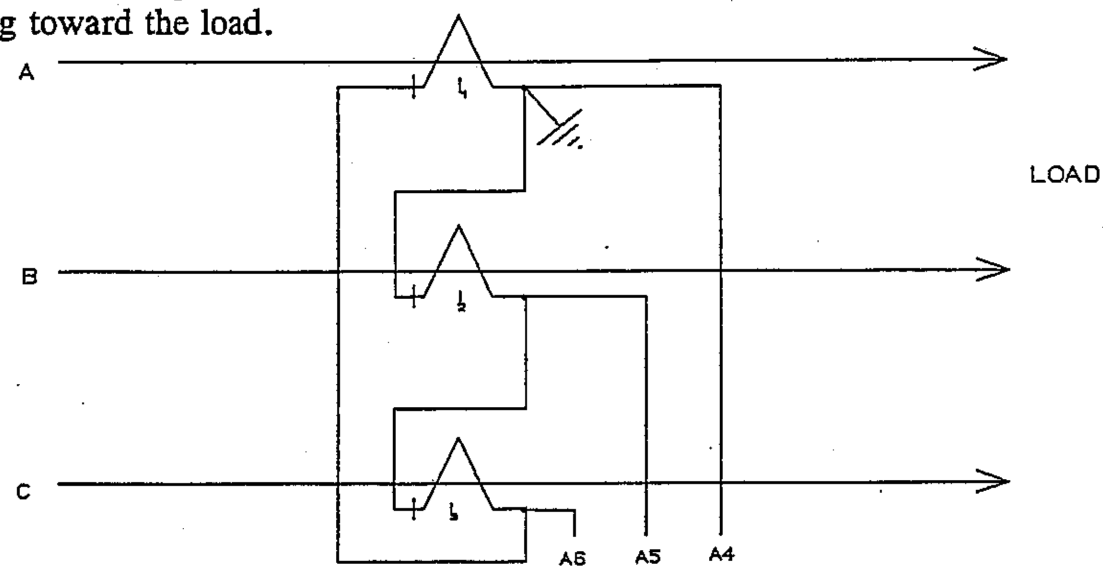

Figure 4

Generally we find the metering CT's connected in the neutral leads of the transformer bank, if it is connected star on the load side, which would subject the CT's to considerably less voltage. The diagram in Figure 5 shows how the CT's would be connected in the neutral leads of a delta-star bank. This diagram is a complete schematic, but is should be understood that the CT delta will be made up inside the station in order to indiacte three-phase bank amperes. For a typical wiring diagram for 4kV metering, see drawing number 116202-3 (9A1 TM #1).

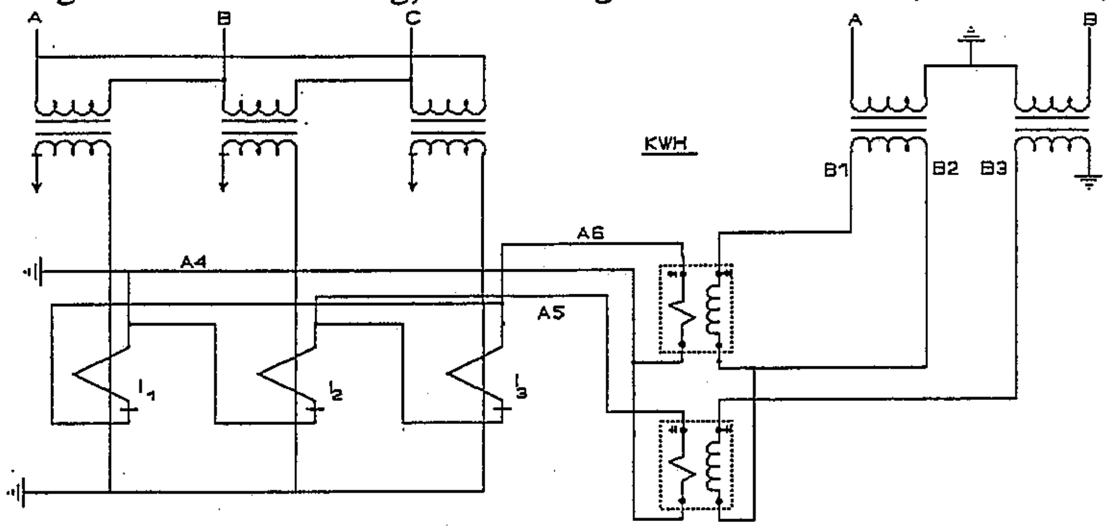

Figure 5

Proving that the power metered is correct with this metering scheme is not difficult, providing that the three phase load is balanced and the computation of a balanced load is shown in Figure 6. The watt load is figured single-phase-wire first and then as a two element watt-meter would compute it. For ease of computation, low voltages, 1/1 CT's and unity power factor is used.

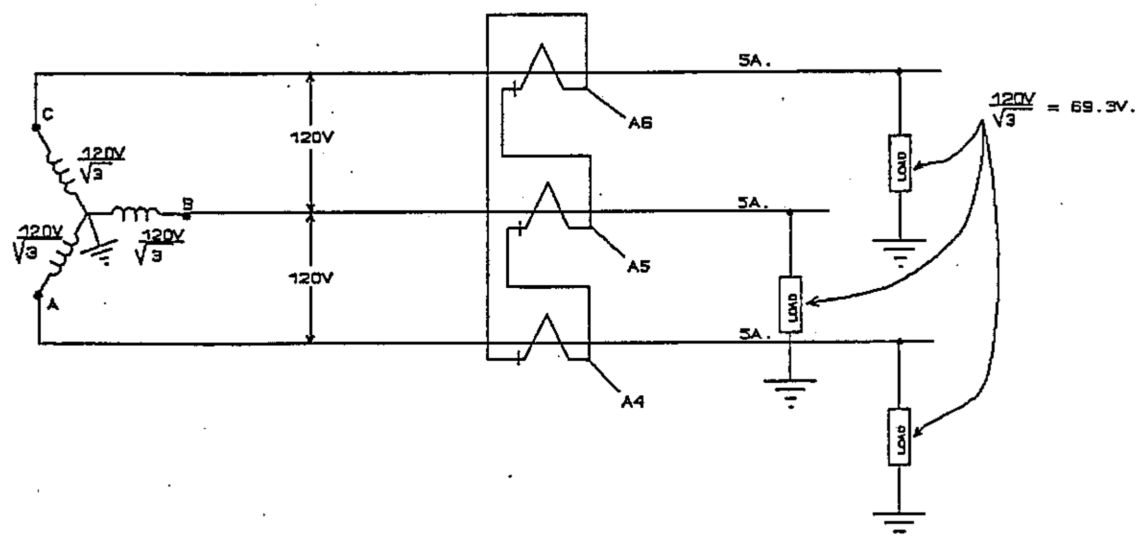

Figure 6

Figuring the power on a single phase basis:

Total Power = 5 x 69.3 + 5 x 69.3 + 5 x 69.3 = <u>1039</u> watts

Figuring the power as the meter computes it:

Power = $A5 \times B_{3\text{-}2} + A6 \times B_{1\text{-}2}$.

(Remember that this is a phasor equation since the currents and potentials are not in phase.)

$B_{3\text{-}2}$ and $B_{1\text{-}2}$ represent the voltages which are in phase with A and B phase to ground voltages. (69.3 volts)

$A5 = I_3 - I_2$

$= \sqrt{5^2 + 5^2 + 2 \times 5 \times 5 \times \cos 60^\circ}$

$A5 = 8.66$

$A6 = I_1 - I_3$

$= \sqrt{5^2 + 5^2 + 2 \times 5 \times 5 \times \cos 60^\circ}$

$A6 = 8.66$

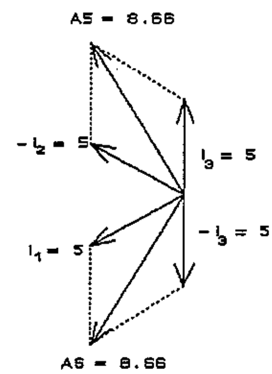

Figure 7

Since the potentials and currents are 30° out of phase, it is necessary to find the component of voltage that is in phase with the current (or vice-versa). (see Figure 8)

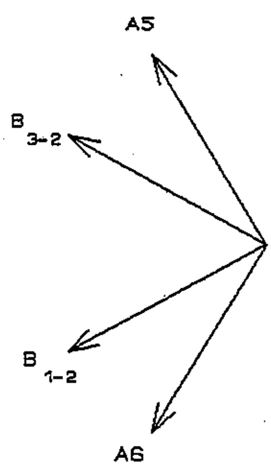

Figure 8

The in-phase component of the A5 current with $B_{3\text{-}2}$ is:

8.66 x Cos 30° = 7.5 Amp.

The in-phase component of the A6 current with $B_{1\text{-}2}$ is:

8.66 x Cos 30° = 7.5 Amp.

P = 7.5 x 69.3 + 7.5 x 69.3

= <u>1039</u> watts

The computation becomes more complex when the load is unbalanced since the vector sum of I_3 - I_2 and I_1 - I_3, produce A5 and A6 currents which are no longer exactly 30 degrees out of phase with the B_{3-2} and B_{1-2} potentials. The new phase angle between currents and potentials must be calculated as well as their magnitudes.

Consider a problem similar to the previous one, but with loads as follows: A phase equals 5 amps, B phase equals 7 amps, and C phase equals 9 amps.

Figured on single phase basis:

$$P = 5 \times 69.3 + 7 \times 69.3 + 9 \times 69.3$$

$$= \underline{1455} \text{ watts}$$

Figured as the meter computes it:

The cosine of the angle between A5 and B_{3-2} (which is the angle between A5 and $-I_2$) can be figured from the Law of Cosines.

$$a^2 = b^2 + c^2 - 2bc \cos a, \quad \cos a = a^2 - b^2 - c^2 / -2bc$$
$$= b^2 + c^2 - a^2 / 2bc$$

$$= \frac{49 + (13.892)^2 - 9^2}{2 \times 7 \times 13.892}$$

$$= .828$$

$$A5 = I_3 - I_2$$
$$= \sqrt{7^2 + 9^2 + 2 \times 7 \times 9 \times \cos 60°}$$
$$= 13.892 \text{ amps}$$

$$A6 = I_1 - I_3$$
$$= \sqrt{5^2 + 9^2 + 2 \times 5 \times 9 \times \cos 60°}$$
$$= 12.288 \text{ amps}$$

The cosine of the angle between A6 and B_{1-2} (which is the angle between A6 and I_1):

$$\cos a' = \frac{5^2 + (12.288)^2 - 9^2}{2 \times 5 \times 12.288}$$

$$= .774$$

The component of A5 current in phase with B_{3-2} is:

13.892 x Cos a = 13.892 x .828 = 11.5

The component of A6 current in phase with B_{1-2} is:

12.288 x Cos a' = 12.288 x .744 = 9.5

P = 11.5 x 69.3 + 9.5 x 69.3 = <u>1455 Watts</u>