DISCUSSION OF TWO-ELEMENT METERS

The use of two-element watt-hour meters is quite general in the Southern California Edison Company. For all general purposes, the two-element meter is just as accurate as a three-element meter and is more economical. The proof of its accuracy is mathematically possible, as shown below:

Consider the following hypothetical distribution system:

The bank is connected star on the load side, and the load is connected phase to ground. We will consider the load to be balanced. The voltages and currents are indicated on Figure 1.

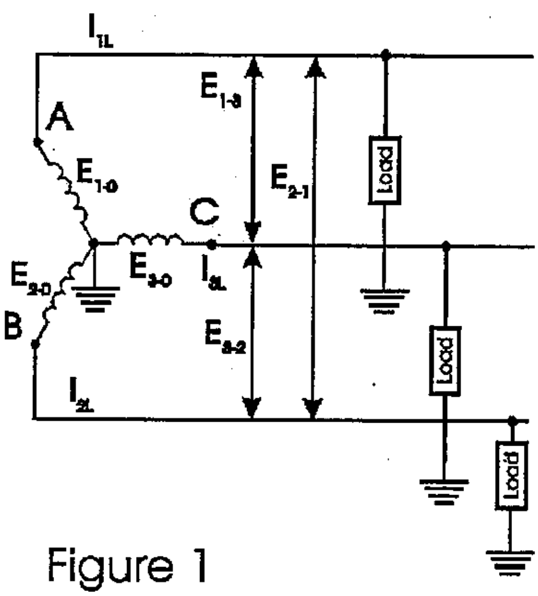

Figure 1

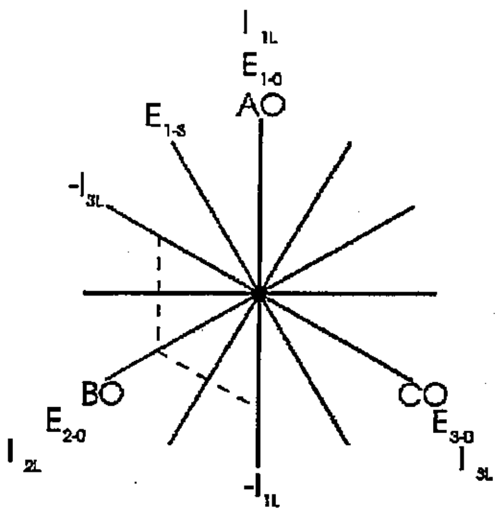

Figure 2

The total power on this system is:

$$P = E_{1\text{-}0} \times I_{1L} + E_{2\text{-}0} \times I_{2L} + E_{3\text{-}0} \times I_{3L}$$

We also know that in a balanced circuit, at any instant:

$$I_{1L} + I_{2L} + I_{3L} = 0 \text{ (phasorially added)}$$

If this is true, we may rearrange the equation so that:

$$I_{2L} = -I_{1L} - I_{3L} \text{ (see Figure 2)}$$

The value of I_{2L} may be substituted in the original power formula:

$$P = E_{1\text{-}0} \times I_{1L} + E_{2\text{-}0}(-I_{1L} - I_{3L}) + E_{3\text{-}0} \times I_{3L}$$

$$= E_{1\text{-}0} \times I_{1L} - E_{2\text{-}0} \times I_{1L} - E_{2\text{-}0} \times I_{3L} + E_{3\text{-}0} \times I_{3L}$$

$$= I_{1L}(E_{1\text{-}0} - E_{2\text{-}0}) + I_{3L}(E_{3\text{-}0} - E_{2\text{-}0})$$

And since $E_{1\text{-}0} - E_{2\text{-}0} = E_{1\text{-}2}$ (see Figure 3)

and $E_{3\text{-}0} - E_{2\text{-}0} = E_{3\text{-}2}$

we have $P = \underline{I_{1L} \times E_{1\text{-}2} + I_{3L} \times E_{3\text{-}2}}$

This proves that we could meter power using a two element meter by computing line to line voltage and line current on each of the elements providing we use the correct current and voltage pairs.

Diagram at right shows the current potential relationship for each element of the two element meter.

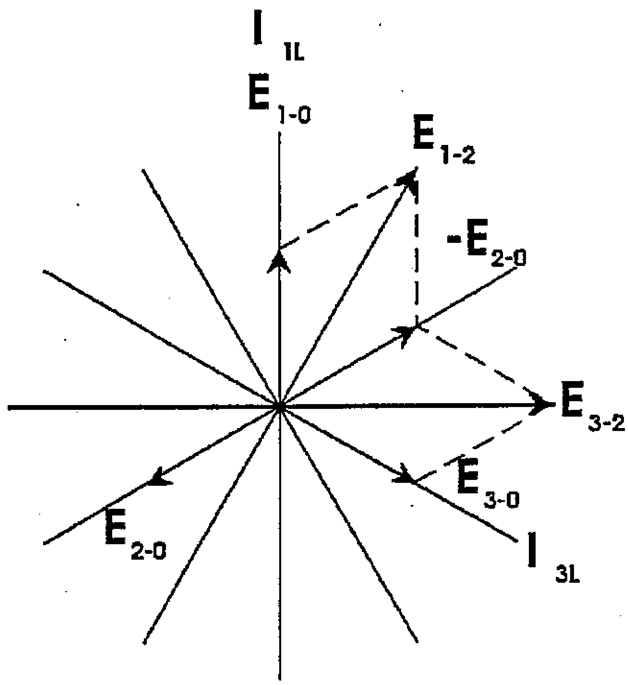

Figure 3

It is important to recognize that the equation for power is not an algebraic equation, but phasor equation. Also, currents and potentials are not in phase as connected to the elements. (Even at unity P.F.) This is shown clearly in Figure 3. Therefore, if it were desired to calculate power form this formula, one would have to find the in-phase component of voltage with current on each element. This will be discussed later in this write-up.

We will now consider the condition of load that is connected phase to phase.

Proof of 2-element metering for load connected phase to phase.

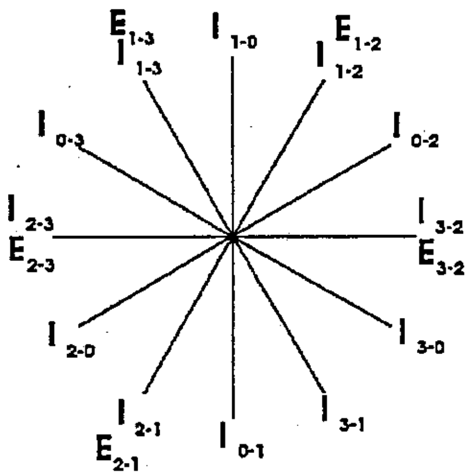

Figure 4

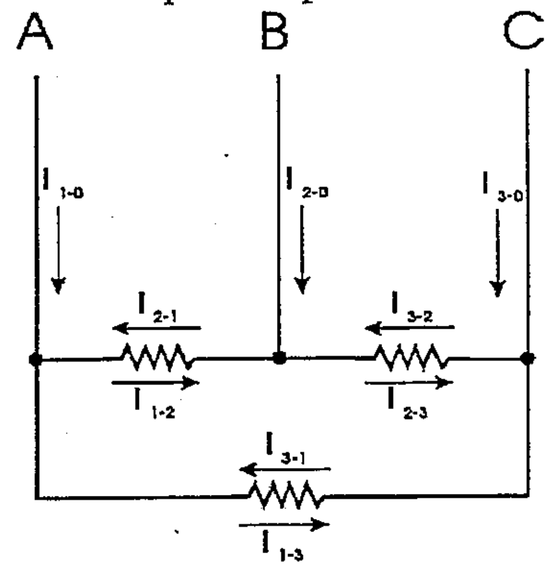

Figure 5

The current in AØ (or I_{1-0}) is the sum of currents I_{1-2} and I_{1-3} phasorially added. This is shown above in the phasor diagram and in Figure 4.

BØ current I_{2-0} is the sum of currents I_{2-1} and I_{2-3}

CØ current I_{3-0} is the sum of currents I_{3-1} and I_{3-2}

Total power in the circuit, Figure 5:

$P = I_{1-2} \times E_{1-2} + I_{3-2} \times E_{3-2} + I_{1-3} \times E_{1-3}$ = the sum of the power consumed in the individual loads.

This is the same as the two element watt meter method:

$$P \quad = (I_{1-0} \times E_{1-2}) + (I_{3-0} \times E_{3-2}) = (I_{1-2} + I_{1-3}) \times E_{1-2} + (I_{3-2} + I_{3-1}) \times E_{3-2}$$

$$= I_{1-2} \times E_{1-2} + I_{1-3} \times E_{1-2} + I_{3-2} \times E_{3-2} + I_{3-1} \times E_{3-2}$$

$$= I_{1-2} \times I_{1-2} + I_{3-2} \times E_{3-2} + (I_{1-3} \times E_{1-2} + I_{3-1} \times E_{3-2})$$

NOTE: $I_{3-1} = -I_{1-3}$

$$P \quad = I_{1-2} \times E_{1-2} + I_{3-2} \times E_{3-2} + (I_{1-3} \times E_{1-2} - I_{1-3} \times E_{3-2})$$

$$= I_{1-2} \times E_{1-2} + I_{3-2} \times E_{3-2} + I_{1-3} \times (E_{1-2} - E_{3-2})$$

$E_{1-2} - E_{3-2} = E_{1-3}$, Therefore

$$P \quad = I_{1-2} \times E_{1-2} + I_{3-2} \times E_{3-2} + I_{1-3} \times E_{1-3}$$

Now look at a problem somewhat graphically (see Figure 6). Let us assume a three phase load at unity power factor. To find 3Ø watts by the 1Ø method:

3Ø Watts = 3 x 100 x 10 = 3000 Watts.

Using 100 volts Ø to N and 10 amps, the Watts for one phase will be 1000. For three phases then, it will be 3000.

Using a two element meter requires the use of line current and line voltage and hooking it up in the configuration at right. The line voltage will be 100 x $\sqrt{3}$ or 173.2 volts and will be 30 degrees out of phase with the currents. The watts acting upon each element will be equal to the voltage times the current times the cosine of 30 degrees, or:

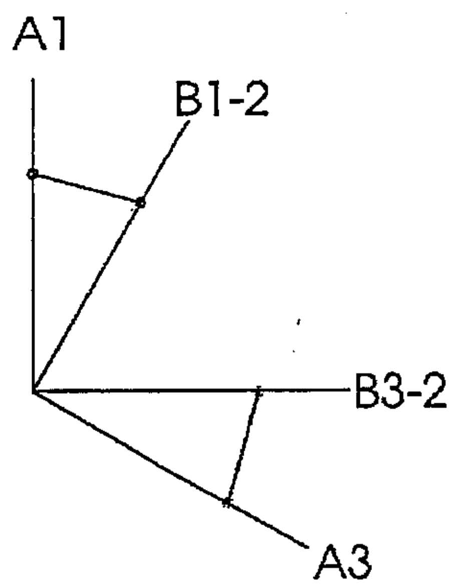

Figure 6

173.2 x 10 x .866 = 1500 Watts

Total Watts = 2 x 1500 = 3000 since there are two elements.

This same analogy can be used with a system having a power factor of 30 degrees lag. Let us first calculate by the single phase method what the 3Ø watts will be.

$$3\varnothing \text{ Watts} = 3 \times 100 \times 10 \times \cos 30 \text{ degrees} = 2598$$

Referring to Figure 7, see that the voltage and current in the A1 element are in phase, while the current in the A3 phase lags the voltage by 60 degrees.

The A1 Watts = 173.2 x 10 x cos 0 degrees = 1732 Watts

The A3 Watts = 173.2 x 10 x cos 60 degrees = 866 Watts

3Ø Watts = 1732 + 866 = 2598, which is the same as that which was figured by the single phase method.

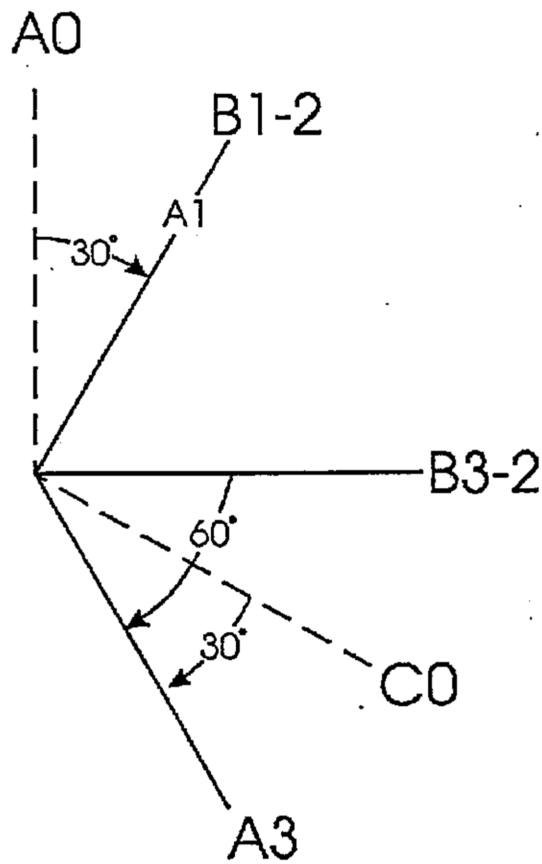

Figure 7