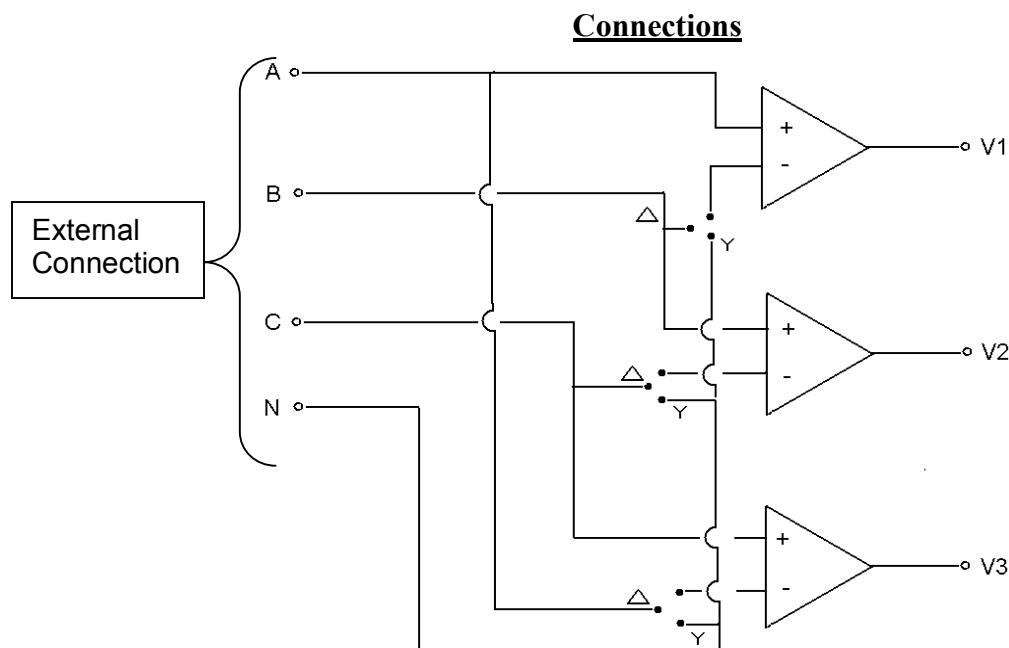# Megger ®

APPLICATION BULLETIN

Using the PMM-1 Power Multi-Meter
For Delta Power Measurements

Electrical energy is the same regardless of the system configuration in which it is measured. In other words, 500 watts is 500 watts regardless of whether it is distributed throughout a 3 phase wye (Y) system or a delta (Δ) configured system. Blondel's Theorem suggests that the number of watt meters required to accurately measure energy within a circuit is one less than the number of conductors in that circuit. In keeping with Blondel's energy measurement philosophy, it becomes necessary to employ a minimum of two watt meters to measure energy in a delta system, whether it be an open or closed system. Due to the fact that the PMM-1 does not have a specific preset measurement mode for performing power measurements using a two watt meter method, the following procedure is set forth for that purpose.

Before going too far into an explanation of how these measurements are made, let's take a look at a diagram representing PMM-1 internal connections.

Connections

Y Configuration

$V_1 = V_{AN} = V_A - V_N$
$V_2 = V_{BN} = V_B - V_N$
$V_3 = V_{CN} = V_C - V_N$

Δ Configuration

$V_1 = V_{AB} = V_A - V_B$
$V_2 = V_{BC} = V_B - V_C$
$V_3 = V_{CA} = V_C - V_A$

If we choose to use the 3 phase delta measurement mode on the PMM-1, we should assume that it will use three watt meters in the measurement process. Unfortunately, when quantities are limited such that only two watt meters are utilized, this measurement mode will display incorrect power quantities.

By selecting the C phase voltage as the reference, and tying it to the neutral binding post of the PMM-1, a 3 phase wye (ie. line to neutral) measurement mode can effectively be reconfigured for line to line measurements. Line to line voltage measurements can now be obtained using the 3 phase wye mode of measurment. The connection diagram in this case would be as follows.
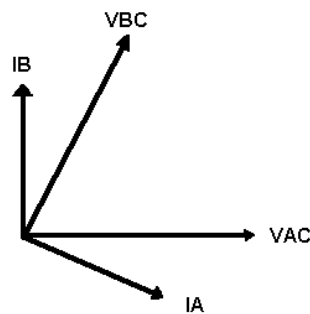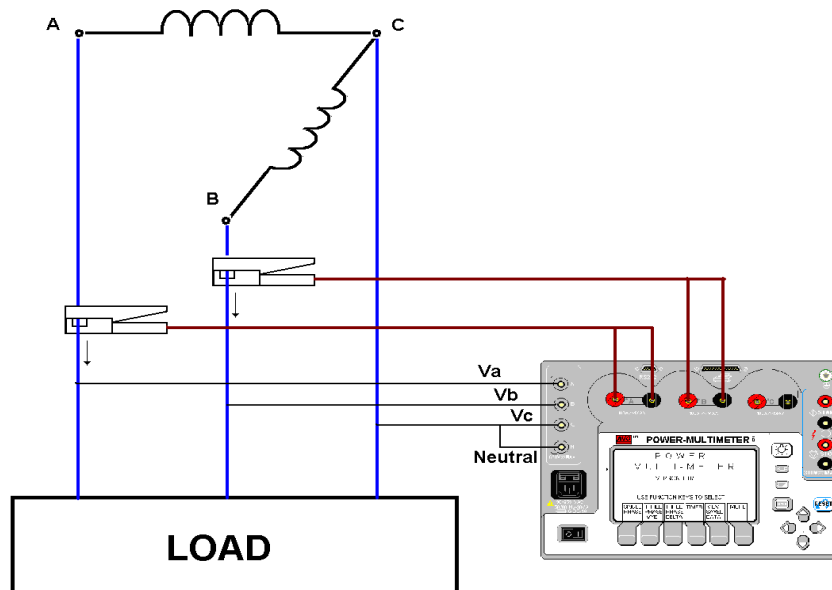
Therefore the anticipated results of such a power measurement would be:

Phase A   =▶ $(V_A - V_C) I_A = V_{AC} \times I_A$
Phase B   =▶ $(V_B - V_C) I_B = V_{BC} \times I_B$
Phase C   =▶ $(V_C - V_A) 0 = 0$

The following mathematical exercises are for the purpose of coming to a better understanding of how we might accurately account for power measurements when monitoring a system of this sort.

Δ Configuration

If we were to assume a balanced load in a closed delta circuit, then we could also assume certain equalities within the circuit. For the sake of simplicity we will assume the following values and equalities to use in our calculations.

$E_{AB}=E_{BC}=E_{CA}=$ 100 Volts
$I_A=I_B=I_C=$ 1 Amps
$θ=0°$, **Power Factor** = Cos θ = 1
Where θ represents the phase angle relationship between voltage and current.

For this to be true, the voltage and current of each leg must be in phase with one another. Then single phase power could be calculated as follows.

$$\text{Watts} = \text{Voltage x Current x Power Factor}$$
$$= 100 \text{ x } 1 \text{ x } 1$$
$$= 100 \text{ watts}$$

Total Load Power would equal to the single phase power multiplied by the number of phases.

$$\text{Total Load Power} = \text{# of phases } \textbf{x} \text{ phase voltage } \textbf{x} \text{ phase current } \textbf{x} \text{ Cos θ}$$
$$= 3 \textbf{(100)}$$
$$= 300 \text{ watts}$$

However, when using the two watt meter measurement method, Ø will become 30 degrees as a result of using the C phase voltage for our reference in making line to line measurements. Now there are only two legs that can have current flow in them, according to the above diagram. Power in a delta system will now have to be based on the voltages and currents in the remaining 2 legs. We will refer to these as $\textbf{P}_{AC}$ and $\textbf{P}_{BC}$. The power in each of the two remaining legs can be calculated using the following formula.

$P_{AC} = P_{BC} = E \text{ x } I \text{ x } \sqrt{3} \text{ x Power Factor}$
Where: $θ = 30°$, Power Factor = Cos 30° = $\sqrt{3}/2$ = .866

Total Power Measured = $\textbf{P}_{AC}$ **+** $\textbf{P}_{BC}$ **=** $(E_{AC} \textbf{ x } I_{AC} \sqrt{3} \textbf{ x Cos θ)} \textbf{ + } (E_{BC} \textbf{ x } I_{BC} \sqrt{3} \textbf{ x Cos θ)}$
                       = 2 **x** 150
                       = 300 watts

Where we had previously used **Cos θ** to represent power factor, **θ** can now be represented in terms of it's components. When adding the power factor values for each of the two legs of the circuit being measured, the sum must be divided by $\sqrt{3}$. The PMM-1 only displays the individual power factor values for each individual voltage and current being measured. Therefore, a system power factor can be calculated by adding the power factors for each of the two legs in the system and then dividing their sum by $\sqrt{3}$

For example: If the power factor of each of the two legs were Cos 30˚, then:

$PF_{AC} = \sqrt{3}/2 = 0.866$
$PF_{BC} = \sqrt{3}/2 = 0.866$

Load Power Factor can now be represented in terms of these two components

Load PF = $\dfrac{PF_{AC} + PF_{BC}}{\sqrt{3}}$ = $\dfrac{0.866 + 0.866}{1.732}$ = 1 = Cos θ (30˚)

%PF = PF(100) = 100%

The following chart is provided as an example of the equality shown in the above equation. Power Factor may be represented in terms of Cos θ or in terms of the summed power factors from each leg of the circuit divided by the √**3.**

Ø	Load Cos Ø	PF_{AC} Cos (30˚+Ø)	PF_{BC} Cos (30˚-Ø)	$\dfrac{PF_{AC}+ PF_{BC}}{\sqrt{3}}$	Total Power
-90˚	0	1/2	-1/2	0	0P
-60˚	½	√3/2	0	1/2	1/2P
-30˚	√3/2	1	1/2	√3/2	√3/2P
0˚	1	√3/2	√3/2	1	P
30˚	√3/2	1/2	1	√3/2	√3/2P
60˚	½	0	√3/2	1/2	1/2P
90˚	0	-1/2	1/2	0	0P

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