3 Phase Utility Service and Metering Configurations

A review by Michael Klopfer, PhD

University of California, Irvine

California Plug Load Research Center (CalPlug)

California Institute of Telecommunications and Information Technology (Calit2)

Overview: Distribution of AC power from generation to consumption points often relies on conversion between polyphase (almost always 3-phase) and single phase AC. Three phase power in general allows more power to be delivered to loads with less wire cost as well as providing consistent instantaneous power across a single AC cycle. In this document we will briefly discuss service configurations and accepted metering strategies.

Utility Internal Service: 3-phase transmission and early distribution service is typically delta configured. Towards the final utility distribution transformer, the service is typically provided in either Wye (3 or 4 lines, typically 4 lines including each phase and an active neutral that may be used for power return), or Delta (3 phases and often a neutral that is not used for primary power return). For long stretches of transmission delta is preferred due to the lack of need for a power return neutral of sufficient carrying capacity

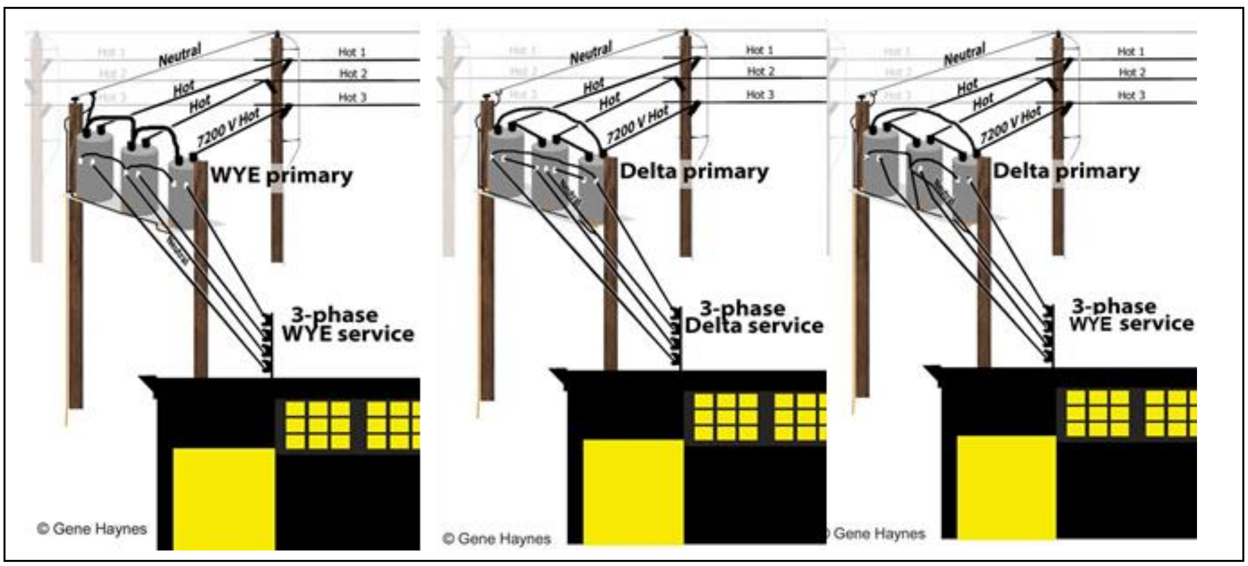


Figure 1: Transformer connections for final distribution to the customer with both Wye and Delta services to the customer. Image Source: Gene Hayes (http://waterheatertimer.org)

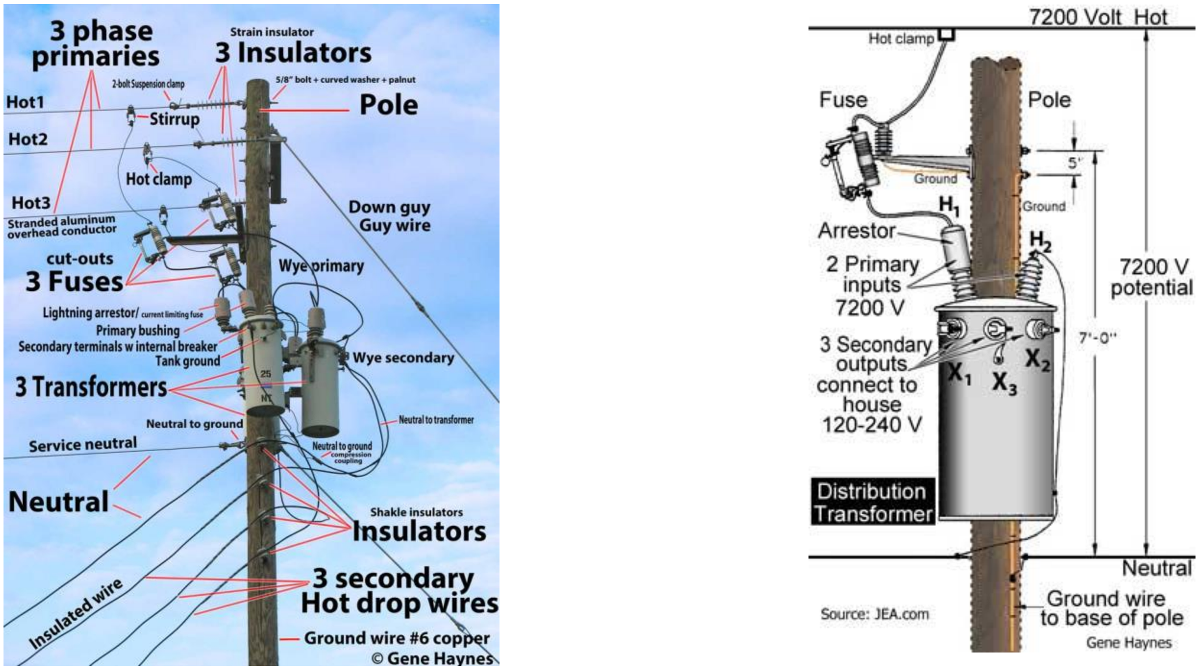


Figure 2(a,b): In end-pint distribution networks, a Wye- Wye configurations are common either multiple (a) primaries or a singular primary to neutral (b) can be provided to the transformer prior to the customer. Image Source: Gene Hayes (http://waterheatertimer.org)

Typically large-scale utility connections are delta configured. A neutral may be carried along that is grounded at multiple points but it is not used for active intended power carrying in delta configuration. Closer to distribution endpoints utility configuration typically remains as delta up to the final distribution transformer, but in some cases it may enter Wye configuration prior to distribution. In general, closed Delta configurations use less wire (typically expensive copper) in use and balance voltage that the expense of current. Delta systems are used for transmission even with current being potentially higher . High leg delta is a configuration to provide a neutral. Ground faults are difficult to detect, hard to hunt down ground faults on delta systems.

Utility to customer service: At the transition point where power is provided to the customer, the service is often provided as Delta (for major loads such as large motors or lighting services), Wye (general purpose loads, lighting, and loads requiring neutrals), or Split Phase (provided to residences). Service to most commercial buildings is 208V (phase to phase) 3-phase (Wye) or 480V (phase to phase) 3-phase (Wye), this configuration provides a neutral.

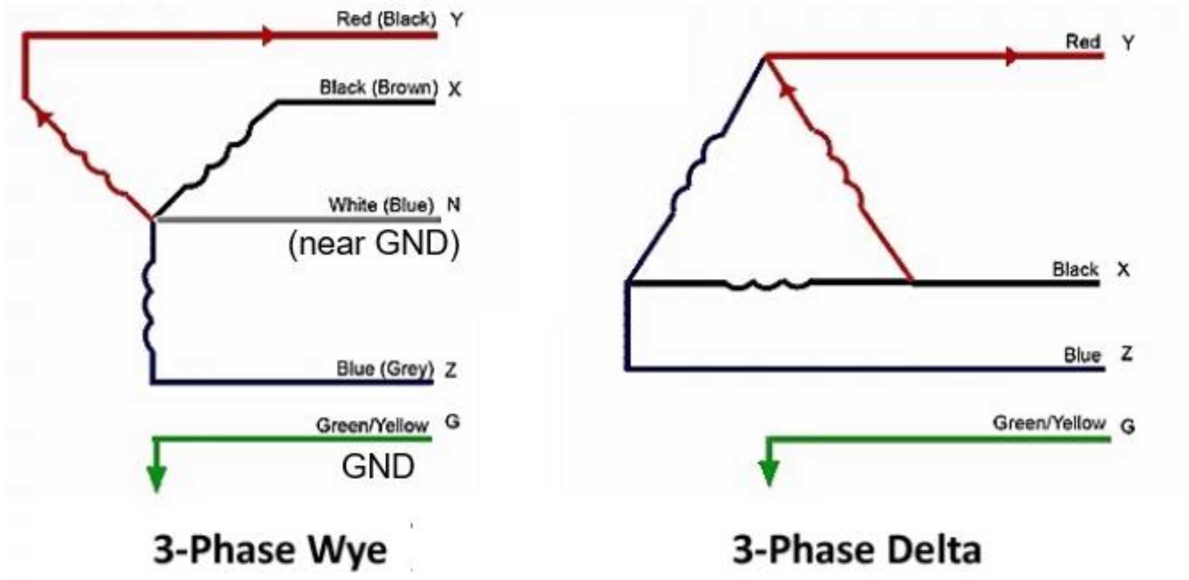


Figure 3: Conventional wiring for Delta and Wye distribution service within a facility.

Table 1 shows common US and international service configurations. Some atypical services include low service capacity high-leg deltas which provide a 120/240 split-phase in addition to a 3 phase delta service which may find service in applications such as small apartment buildings using 3 phase elevators or HVAC units along with conventional 120/240V service. Figure 3 shows the typical layout for both Delta and Wye configurations.

Table 1: Common international power service configurations: an (*) is used to denote common US light industrial/commercial configurations. Figure Source: CCS, LLC (https://ctlsys.com/support/electrical_service_types_and_voltages/)

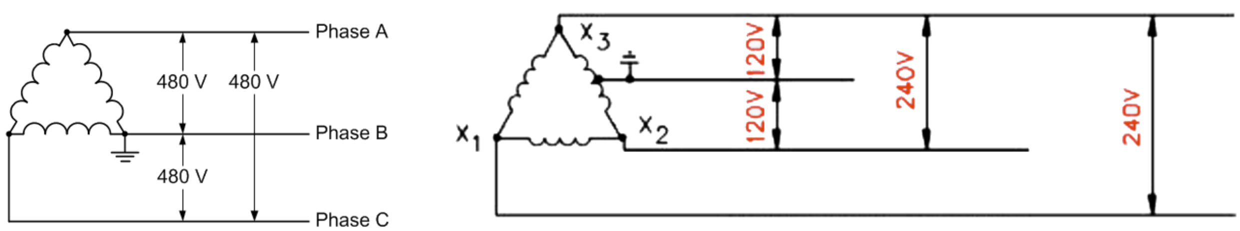
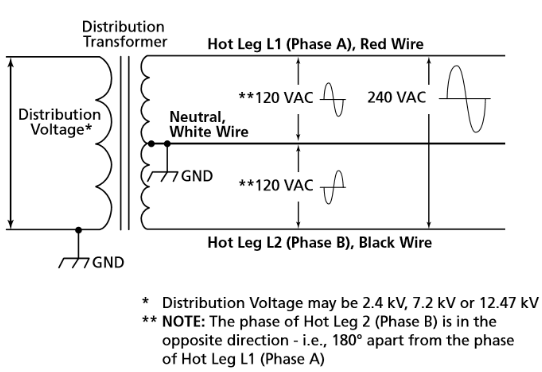


Figure 4(A,B): Uncommon Delta configurations (A) high-leg Delta and (B) corner-grounded Delta.

Description	L–N Vac	L–L Vac	Countries	WattNode Models (Wye or Delta–Voltage)
* 1-Phase, 2-Wire 120 V with neutral	120	–	US	3Y-208
1-Phase, 2-Wire 230 V with neutral	230	–	EU, Others	3Y-400
* 1-Phase, 2-Wire 208 V (No neutral)	–	208	US	3D-240
* 1-Phase, 2-Wire 240 V (No neutral)	–	240	US	3D-240
* 1-Phase, 3-Wire 120/240 V	120	240	US	3Y-208
* 3-Phase, 3-Wire 208 V Delta (No neutral)	–	208	US	3D-240
3-Phase, 3-Wire 230 V Delta (No neutral)	–	230	Norway	3D-240
3-Phase, 3-Wire 400 V Delta (No neutral)	–	400	EU, Others	3D-400
* 3-Phase, 3-Wire 480 V Delta (No neutral)	–	480	US	3D-480
3-Phase, 3-Wire 600 V Delta (No neutral)	–	600	US, Canada	none[1]
* 3-Phase, 4-Wire 208Y/120 V	120	208	US	3Y-208, 3D-240
3-Phase, 4-Wire 400Y/230 V	230	400	EU, Others	3Y-400, 3D-400
3-Phase, 4-Wire 415Y/240 V	240	415	Australia	3Y-400, 3D-400
* 3-Phase, 4-Wire 480Y/277 V	277	480	US	3Y-480, 3D-480
3-Phase, 4-Wire 600Y/347 V	347	600	US, Canada	3Y-600
3-Phase 4-Wire Delta 120/208/240 Wild Phase	120, 208	240	US	3D-240
3-Phase 4-Wire Delta 240/415/480 Wild Phase	240, 415	480	US	3D-480
3-Phase Corner-Grounded Delta 208/240	–	240	US	3D-240
3-Phase Corner-Grounded Delta 415/480	–	480	US	3D-480

An example of split phase distribution setup is shown in Figure 5. In this configuration a single phase that is 180 degrees out of phase provides 240V service while each phase to neutral provides 120V service.



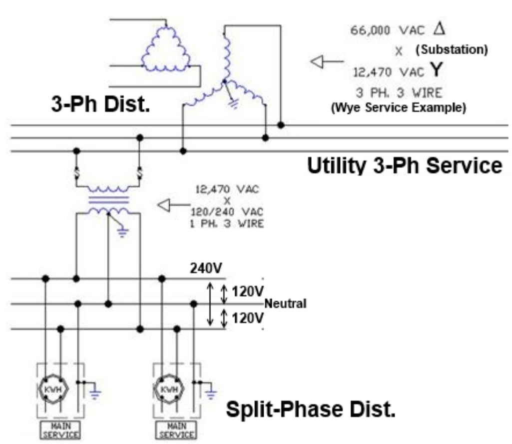
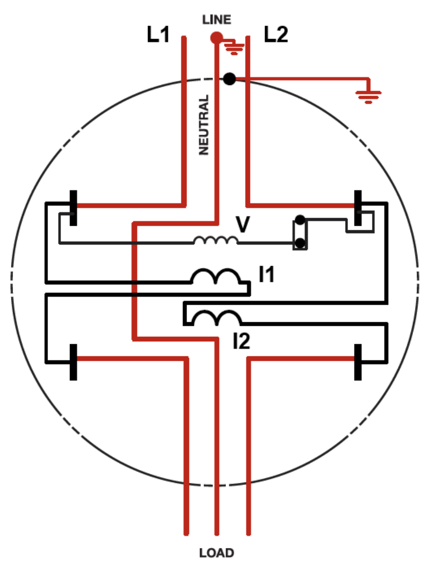


Figure 5: Example split phase configuration for distribution to residences in the US.

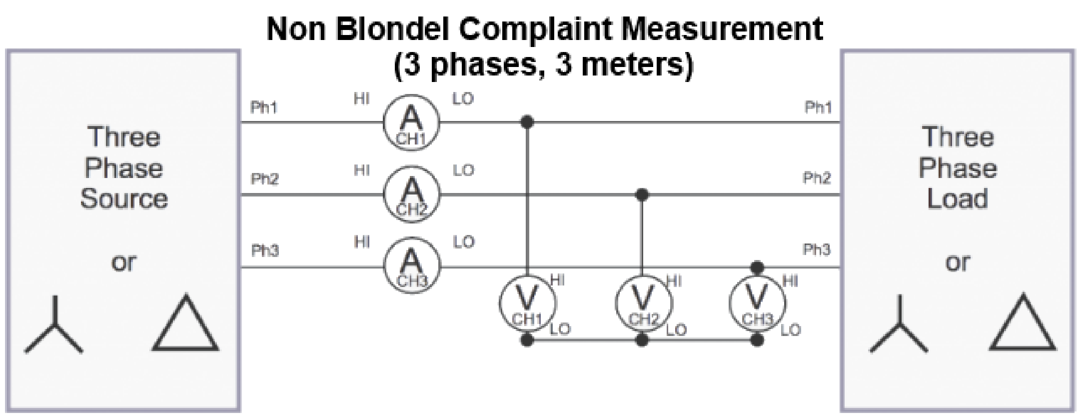
Measurement of Power in Split Phase and 3 Phase Service:

Blondel's theorem indicates in multiple measurement cases n-1 total phases is the required meters needed to know total energy consumption. Underdefended systems can occur when neutrals are in use and in which case explicit metering on each pathway is required. Shows are several split and 3 phase configurations that are commonly metered.

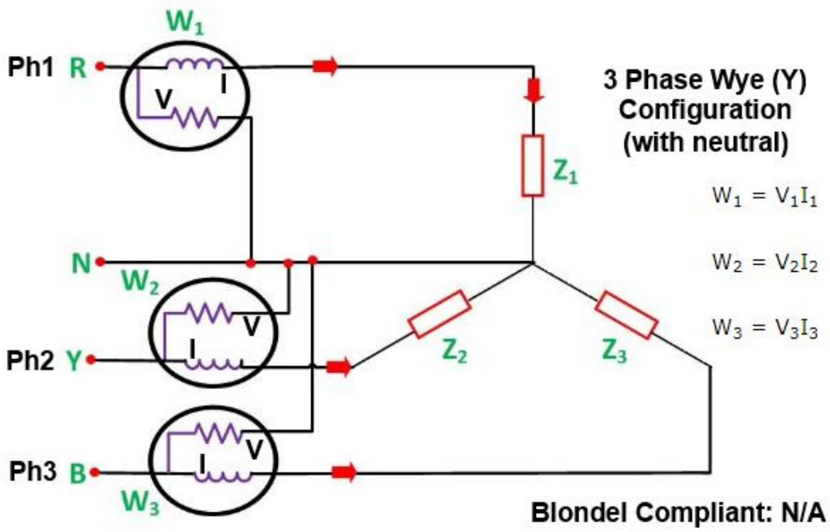
Case 0: Split phase AC distribution using a "Form2S" type meter. Form 3S meters use external current transformers for measuring large loads. The sum of the power calculated on each of the split phases is total power consumption.



Case 1 and Case 2: Either (1) Wye (no neutral) or (2) delta 3-phase service (non-Blondel compliant) using 3 meters to measure 3 phases.

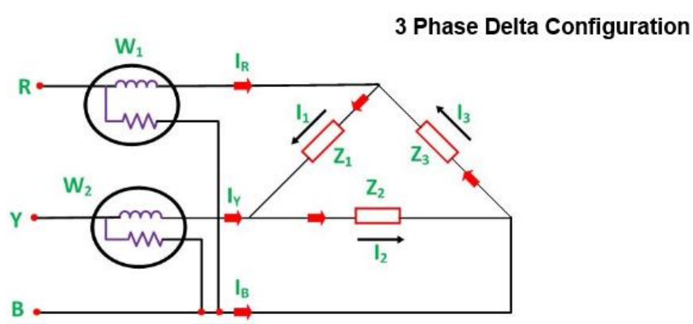


Case 3: Wye configuration with a neutral. This configuration is not Blondel compliant (or could be) because of the neutral. Each phase must be monitored and the power on the neutral is (typically) calculated by process of Kirchoff's laws. This configuration is typical for many commercial buildings because 208V phase-phase provides 120V phase to neutral for service outlets.



$$\text{Total power P} = W_1 + W_2 + W_3$$

Case 4: Delta service: This Blondel compliant approach uses two meters to measure power across 3 phases.



(Blondel Compliant)

$$W_1 + W_2 = e_{RB}(i_1 - i_3) + e_{YB}(i_2 - i_1)$$

$$W_1 + W_2 = i_1 e_{RB} + i_1 e_{YB} - i_3 e_{RB} - i_1 e_{YB}$$

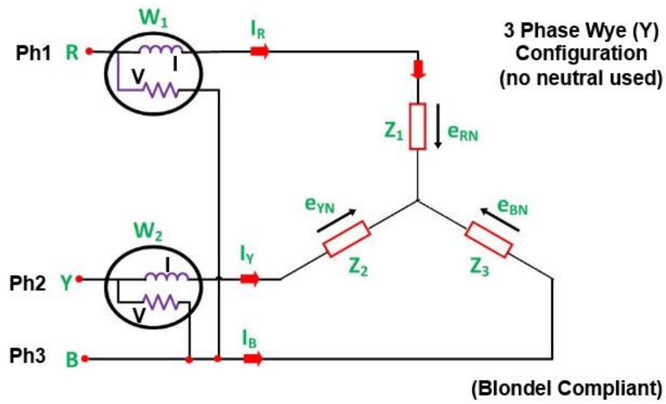
$$W_1 + W_2 = i_2 e_{YB} + i_3 e_{BR} - i_1(e_{YB} + e_{BR}) \quad (\text{i.e.} -e_{RB} = e_{RB})$$

$$W_1 + W_2 = i_1 e_{RY} + i_2 e_{YB} + i_3 e_{BR} \quad (\text{i.e } e_{RY} + e_{YB} + e_{BR} = 0)$$

$$W_1 + W_2 = P$$

Where P is the total power absorbed in the three loads at any instant.

Case 5: Wye service: This Blondel compliant approach uses two meters to measure power across 3 phases.



The total instantaneous power absorbed by the three loads Z_1, Z_2 and Z_3, are equal to the sum of the powers measured by the Two wattmeters, W_1 and W_2.

$$W_1 + W_2 = i_R\,(e_{RN} - e_{BN}) + i_Y\,(e_{YN} - e_{BN})$$

$$W_1 + W_2 = i_R e_{RN} + i_Y e_{YN} - e_{BN}\,(i_R + i_Y) \quad \text{or}$$

$$W_1 + W_2 = i_R e_{RN} + i_Y e_{YN} + i_B e_{BN} \quad (\text{i.e. } i_R + i_Y + i_B = 0)$$

$$W_1 + W_2 = P$$

Where P – the total power absorbed in the three loads at any instant.