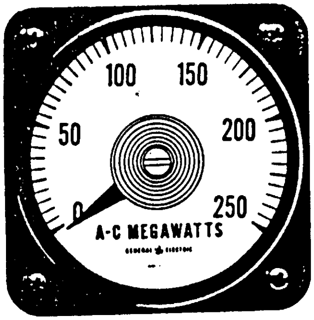


# WATTMETERS: THEIR CONNECTION AND CALIBRATION

Recommended connections for indicating and recording wattmeters on single- and polyphase circuits are normally well understood. Generally, the best practice is to adhere to these standard methods to obtain best possible accuracy. According to Blondel's rule, any polyphase circuit may be metered accurately by N-1 measuring elements where N is the number of wires in the system.

Quite frequently it is impossible to follow this rule without obtaining special instruments at considerable additional cost. Economic considerations may dictate a reduction in the number of expensive high-voltage current and potential transformers with some sacrifice in accuracy; or advantages of more economical or convenient wiring may justify the reduced accuracy.

These considerations suggest that the plant or utility engineer familiarize himself with not only the standard recommended connections, but also many of the "short cuts" and variations possible. The diagrams indicate type of circuit and instrument transformer combinations used, the type of wattmeter required, any necessary special features, and limiting assumptions with sources of error. Lettered arrows on the circuit leads indicate current or potential terminal designations on the wattmeter proper to which connections are made. These markings are symbolic since terminal marking systems are many and varied.

Vector diagrams indicate phase relations at both unity and 0.5 power factor lagging, and may assist in "phasing out" a circuit to check proper connections.

Equations for power indicate how the correct (or approximately correct) measurements of watts are obtained.

As for wattmeter calibration, we have an area in which there seems to be considerable mystery. However, the terms are quite easy to understand and the data straightforward in application and computation.

### Calibrating Watts

First, what is this elusive quantity designated as "CALIBRATING WATTS?" To answer this question, it must be understood first that the scale value of a wattmeter may have no direct relation to its current and potential ratings. For example, a single-phase wattmeter rated 5 amperes and 120 volts does not necessarily have a 600-watt scale. It might conceivably have a 1000-watt scale to indicate brief overloads, or, if used on a low power factor circuit, the scale might be as low as 200 watts. Current and potential transformers are installed in generating or industrial plants in accordance with certain standardized values with safety factors and growth allowances; so their ratings may exceed the maximum expected values.

On the other hand, the user or contractor may dictate a scale range consistent with the power of the generator or other equipment to which the wattmeter is connected. This value may differ considerably from that obtained by computation from maximum current and voltage circuit ratings. Thus, in order to calibrate or check a wattmeter, the relations of scale, potential transformer ratios, and current transformer ratios must be established.

Secondly, it must be made clear that practically all wattmeters, whether single phase or polyphase, are calibrated on single-phase circuits. The term "Calibrating Watts" then is an abbreviated form of "single-phase watts in calibration" and represents the single-phase power which must be applied to any wattmeter or varmeter having all current coils in series and all potential coils in multiple to obtain full-scale ratings.

$$\text{Calibrating Watts} = \frac{\text{Scale in Watts}}{\text{PT Ratio} \times \text{CT Ratio} \times K}$$

Where K = 1 for standard single-phase wattmeters; K = 2 for 2-element, 3-phase, 3-wire wattmeters used in the normal manner; and K = 4 for 3-current coil – 2-potential coil wattmeters used on 4-wire, 3-phase circuits. Note also that the factor K will vary for special applications to take into account unusual phase relations, multiplying factors, etc, so that values on the diagrams must be followed carefully for unusual applications.

Perhaps the greatest "mystery" exists in 4-wire, 3-phase instruments of the 3-current coil construction. The question is often asked, "Why is the value of K equal to 4 rather than 3?" During single-phase calibration at unity power factor, the current in all coils is in phase with the voltage, while in the actual 4-wire, 3-phase application, the two crossed current coils in the number 2 phase each operate at one-half torque due to the 60-degree phase angle between this current and its two related potentials. Thus, the torque during single-phase calibration is actually 4/3 the normal value on the 4-wire, 3-phase circuit and accounts for the value of 4 in the formula.

SAME FOR TRANSDUCER

THIS IS WHY WE USE X.75 FOR 1PH CAL ON 3PH-4W SYSTEM.

X.86 FOR 3 WIRE

## Circuit Connections

Correct circuit connections are extremely important, especially in the case of polyphase wattmeters. It has been determined that a standard two-element wattmeter connected on a 3-wire, 3-phase circuit can have 30 possible connections of which only one is correct. The diagrams presented here are necessarily schematic and may not represent the actual location or arrangement of terminals. It is important, therefore, to carefully follow the instruction book or diagrams normally furnished with these devices.

Phase-angle meters may be of invaluable aid in checking connections where circuit markings are questionable or non-existent.

Various methods of checking connections have been described in electrical metering texts and published articles. Two deserve consideration:

1. The Kouwenhoven Check. This check applies to a standard two-element wattmeter on a 3-wire, 3-phase circuit with approximately balanced loads at any power factor. The two potential leads connected to the lines from which current is supplied to the current coils (normally lines 1 and 3) are interchanged, and under this condition the instrument should read close to zero if the remaining connections are correct.

2. The Ackerman Check. This is used on a two-element, polyphase wattmeter connected to a 3-wire, 3-phase circuit having a common connection to 2 potential coils under condition of loads which are not unbalanced by more than 25 percent. Here, the line connection to the common lead is removed, leaving the two potential coils connected in series across the third phase (normally line 1 to line 3). If the connections are incorrect, the instrument will have reversed deflection (assuming that it read up-scale initially and that the proper voltage and current sources are connected to each element).

When considering connections other than those recommended, study the limitations carefully with the following questions in mind:

1. What unusual sources of error are present?
2. Does the application justify readings of reduced accuracy?
3. Are the frequently made assumptions of balanced currents and voltages valid?
4. Will the application require instruments of special construction or calibration?
5. How will unusual current transformer connections affect relaying and other instrumentation?

When ordering instruments for any special application or unusual connection, give full details to the instrument manufacturer with a schematic connection diagram, since considerable confusion can exist in this area.

With these considerations in mind, it is possible to obtain, connect, and to check indicating or recording wattmeters with confidence.

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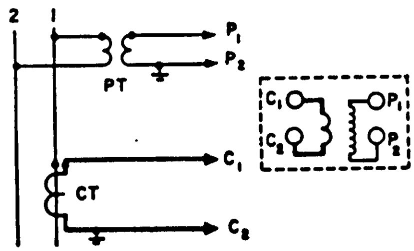
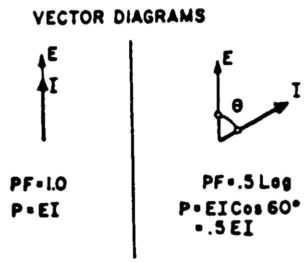
1. Metering:
Watts on single-phase, two-wire circuit
Transformers:
1 potential, 1 current trans.
Instrument:
Single-element wattmeter
Special Features:
None
Limitations:
None. Standard connection
Cal. Watts = Scale in watts / P.T. Ratio × C.T. Ratio

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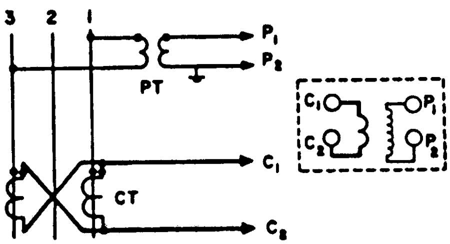
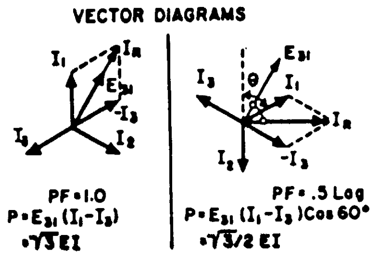
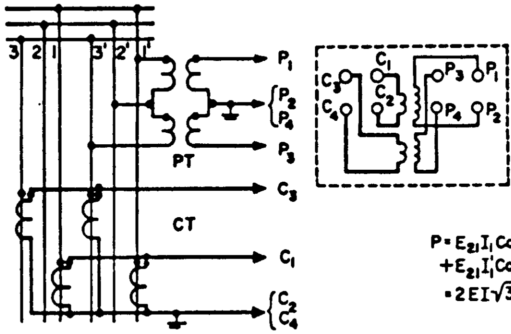
2. Metering:
Watts on 3-phase, 3-wire circuit
Transformers:
1 potential, 2 current trans.
Instrument:
Single-element wattmeter
Special Features:
8.66 ampere current coil
Limitations:
Balanced Currents and voltages
Cal. Watts = Scale in watts / P.T. Ratio × C.T. Ratio



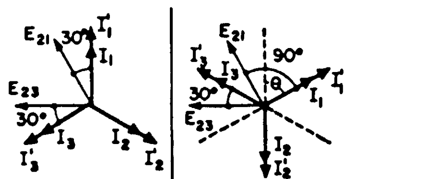



11. **Metering:**
Total watts on 3-phase, 3-wire double circuit
**Transformers:**
2 potential, 4 current trans.
**Instrument:**
2-Element wattmeter
**Special Features:**
10 ampere current coils (or aux. current trans.)
**Limitations:**
Common potential source
Combined trans. ratios alike

$$\text{Cal. Watts} = \frac{\text{Scale in watts}}{\text{P.T. ratio} \times \text{C.T. ratio} \times 2}$$




VECTOR DIAGRAMS




PF=1.0

$P = E_{21}I_1\cos 30° + E_{23}I_3\cos 30° + E_{21}I_1'\cos 30° + E_{23}I_3'\cos 30° = 2EI\sqrt{3}$ for Bal. Circuits

PF=.5 Lag

$P = E_{21}I_1\cos 90° + E_{23}I_3\cos 30° + E_{21}I_1'\cos 90° + E_{23}I_3'\cos 30° = EI\sqrt{3}$ for Bal. Circuits

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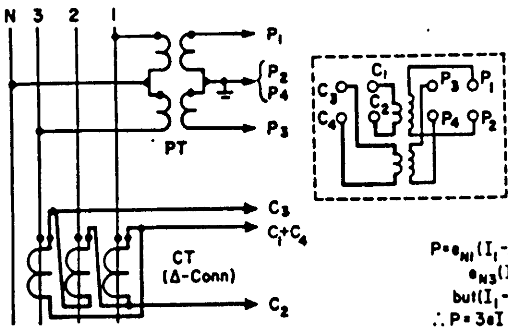
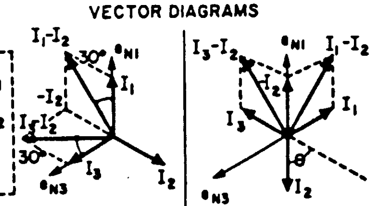
12. **Metering:**
Watts on 3 phase 4 wire
**Transformers:**
2 potential, 3 current trans.
**Instrument:**
2-Element wattmeter
**Special Features:**
Preferably 8.66 ampere coils
**Limitations:**
Balanced voltages

$$\text{Cal. Watts} = \frac{\text{Scale in watts}}{\text{P.T. ratio} \times \text{C.T. ratio} \times 2}$$




VECTOR DIAGRAMS




PF=1.0

$P = e_{N1}(I_1 - I_2)\cos 30° + e_{N3}(I_3 - I_2)\cos 30°$ but $(I_1 - I_2)$ and $(I_3 - I_2) = \sqrt{3}\,I$ $\therefore P = 3eI$

PF=.5 Lag

$P = e_{N1}(I_1 - I_2)\cos 30° + e_{N3}(I_3 - I_2)\cos 90° = 3eI/2$

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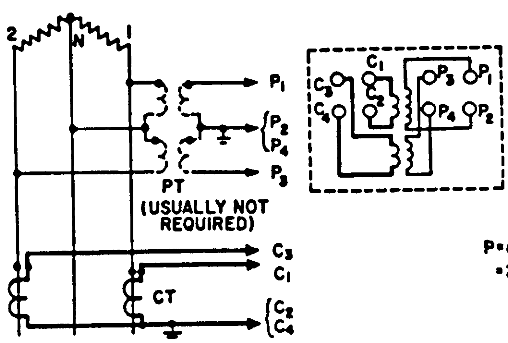
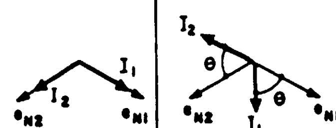
13. **Metering:**
Watts on 3 wire 120 degrees (from 3 phase 4 wire)
**Transformers:**
2 potential, 2 current trans.
**Instrument:**
2-Element wattmeter
**Special Features:**
None
**Limitations:**
None. Standard connection

$$\text{Cal. Watts} = \frac{\text{Scale in watts}}{\text{P.T. ratio} \times \text{C.T. ratio} \times 2}$$




VECTOR DIAGRAMS




PF=1.0

$P = e_{N1}I_1 + e_{N2}I_2 = 2eI$ for Bal. Circuit

PF=.5 Lag

$P = e_{N1}I_1\cos 60° + e_{N2}I_2\cos 60° = .5e_{N1}I_1 + .5e_{N2}I_2 = eI$ for Bal. Circuit

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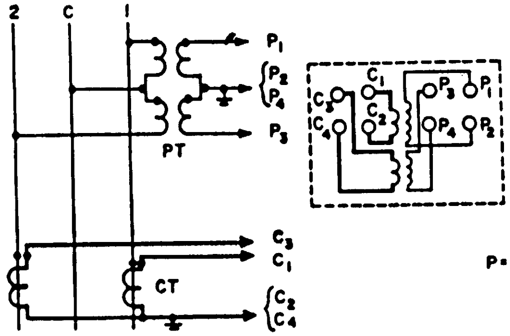
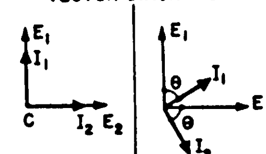
14. **Metering:**
Watts on 2 phase 3 wire
**Transformers:**
2 potential, 2 current trans.
**Instrument:**
2-Element wattmeter
**Special Features:**
None
**Limitations:**
None. Standard connection

$$\text{Cal. Watts} = \frac{\text{Scale in watts}}{\text{P.T. ratio} \times \text{C.T. ratio} \times 2}$$




VECTOR DIAGRAMS




PF=1.0

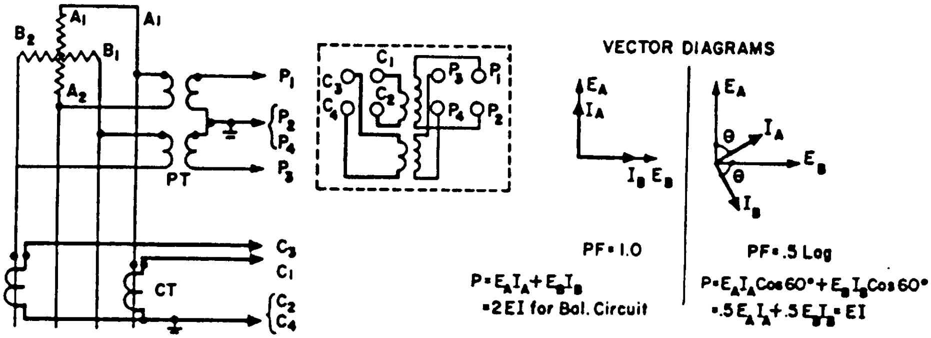
$P = E_1I_1 + E_2I_2 = 2EI$

PF=.5 Lag

$P = E_1I_1\cos 60° + E_2I_2\cos 60° = .5E_1I_1 + .5E_2I_2 = EI$

15. Metering:
Watts on 2 phase 4 wire
Transformers:
2 potential, 2 current trans.
Instrument:
2-Element wattmeter
Special Features:
None
Limitations:
None. Standard connection

$$\text{Cal. Watts} = \frac{\text{Scale in watts}}{\text{P.T. ratio} \times \text{C.T. ratio} \times 2}$$

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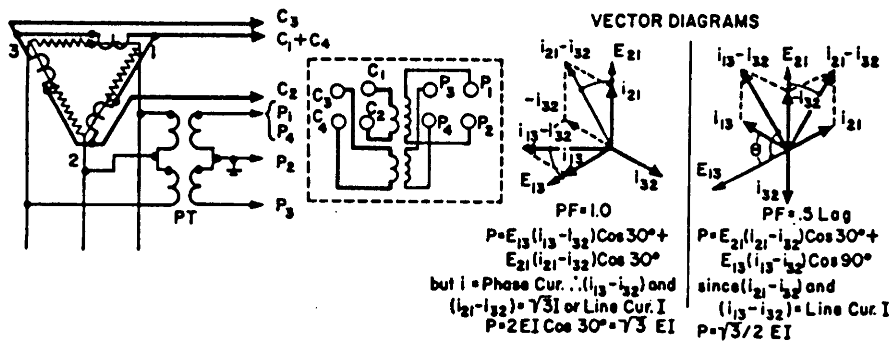
16. Metering:
Watts on 3 phase 3 wire delta
with C.T. inside delta
Transformers:
2 potential, 3 current trans.
Instrument:
2-Element wattmeter
Special Features:
Preferably 8.66 amp. current
coils
Limitations:
Balanced voltages

$$\text{Cal. Watts} = \frac{\text{Scale in watts}}{\text{P.T. ratio} \times \text{C.T. ratio} \times 2}$$

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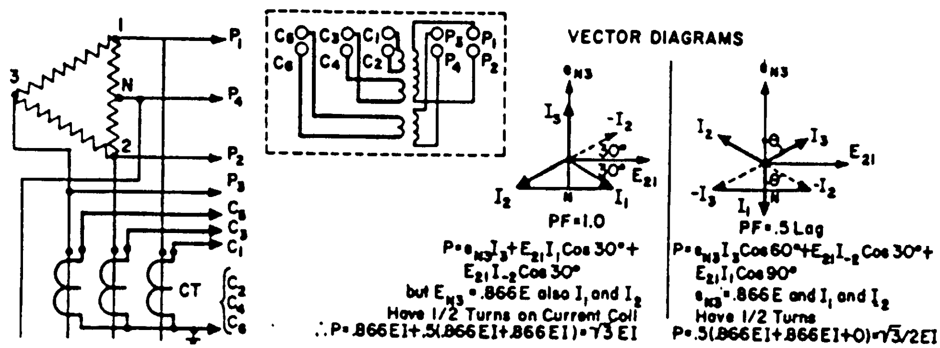
17. Metering:
Watts on 3 phase 4 wire delta
Transformers:
3 current transformers
Instrument:
Special 3-current, 2-potential
wattmeter
Special Features:
2 current coils in 1 element
Limitations:
Balanced center-tap voltages

$$\text{Cal. Watts} = \frac{\text{Scale in watts}}{\text{C.T. ratio} \times 2}$$

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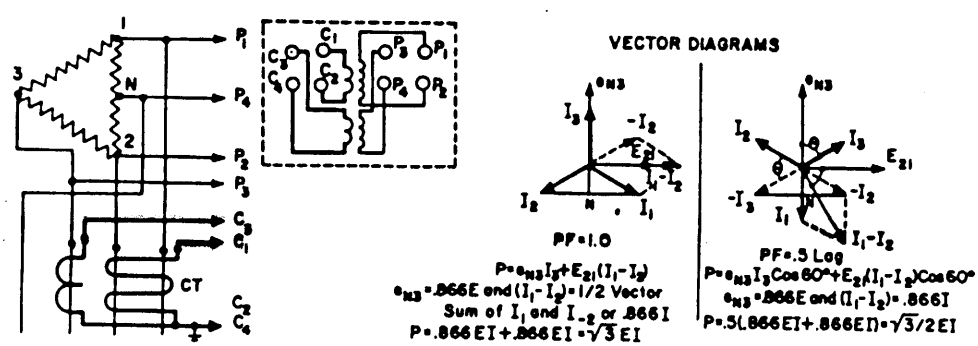
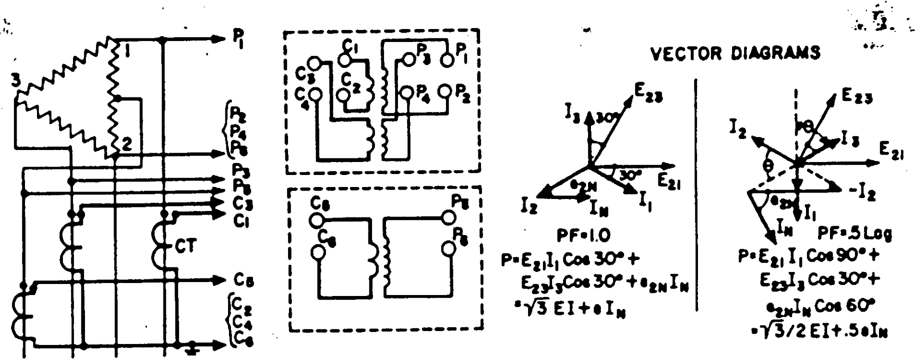
18. Metering:
Watts on 3 phase 4 wire delta
Transformers:
2 current transformers
(1 double primary)
Instrument:
2-Element wattmeter
Special Features:
None
Limitations:
Balanced center-tap voltages

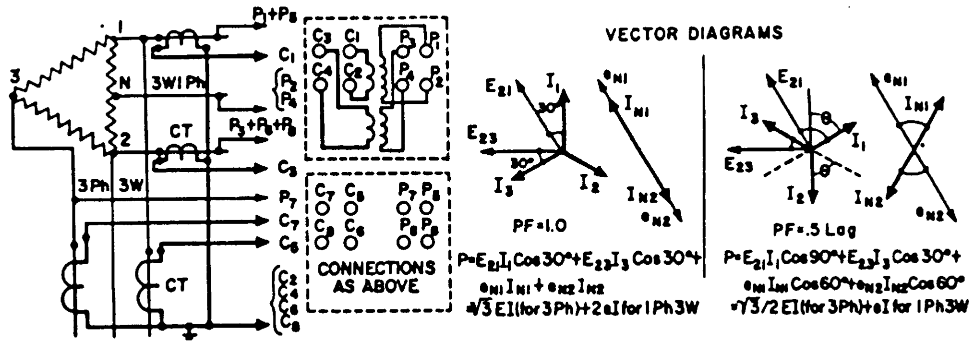
$$\text{Cal. Watts} = \frac{\text{Scale in watts}}{\text{C.T. ratio} \times 2}$$



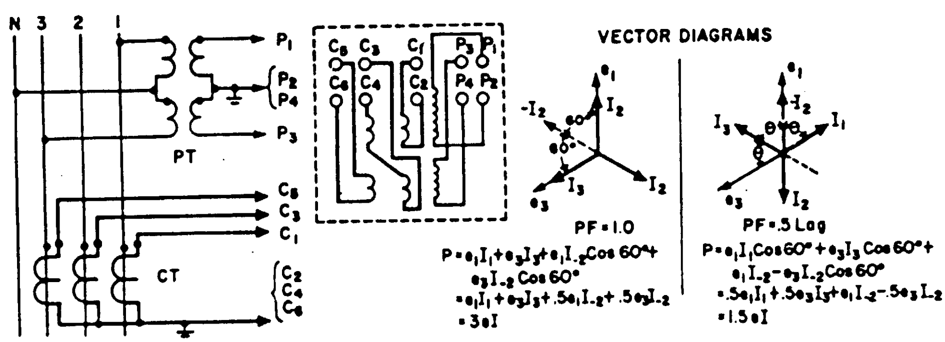
19. Metering:
Watts on 3 phase 4 wire delta
Transformers:
3 current transformers
Instrument:
Single element plus
2-Element wattmeter
Special Features:
None. Single phase = 120 v
3-phase = 240 v
Limitations:
Balanced center-tap voltages
on single-phase instrument.
Two-element meter is standard.
Cal. Watts (2-element) = $\frac{\text{Scale in watts}}{\text{C.T. ratio} \times 2}$
Cal. Watts (1-element) = $\frac{\text{Scale in watts}}{\text{C.T. ratio}}$




20. Metering:
Watts on 3 phase 4 wire delta
Transformers:
4 current transformers
Instrument:
Two 2-element wattmeters
Special Features:
None
Limitations:
Balanced center-tap voltages
Cal. Watts (both meters) = $\frac{\text{Scale in watts}}{\text{C.T. ratio} \times 2}$




21. Metering.
Watts on 3 phase 4 wire
Transformers:
2 potential, 3 current trans.
Instrument:
3-current, 2-potential watt-
meter
Special Features:
None
Limitations:
Balanced voltages (bal. error
small) Standard connection
Cal. Watts = $\frac{\text{Scale in watts}}{\text{P.T. ratio} \times \text{C.T. ratio} \times 4}$




22. Metering:
Watts on 3 phase 3 wire delta
Transformers:
2 potential transformers
3 current transformers inside
delta
Instrument:
3-current, 2-potential watt-
meter
Special Features:
None
Limitations:
Balanced voltages (bal. error
small)
Cal. Watts = $\frac{\text{Scale in watts}}{\text{P.T. ratio} \times \text{C.T. ratio} \times 4}$