Company Directive

STANDARD TECHNIQUE: TP6F/1

Power Measurement Conventions

Summary

This document specifies the conventions that are used for the direction of Power Flow within Western Power Distribution's Network.

Author: Andy Hood

Implementation Date: July 2017

Approved by

Policy Manager

Date: 13 July 2017

All references to Western Power Distribution or WPD must be read as National Grid Electricity Distribution or NGED

IMPLEMENTATION PLAN

Introduction

This document specifies the conventions for the direction of power flow within Western power Distribution's network.

Main Changes

Section 2.1 has been modified to allow greater flexibility regarding the convention for the direction of power flow.

Impact of Changes

The changes will have minimal impact.

Implementation

Managers shall ensure all relevant staff are familiar with and comply with the requirements of this document.

In accordance with the original issue of the document, retrospective action is required to:

- Check the calibration and directionality of active power and reactive power measurements in PowerOn.
- Add dynamic arrows to PowerOn indicating the direction of active power and reactive power and also a static arrow that specifies the direction of positive power flow.

Implementation Timescale

This document shall be implemented on issue.

Checks on existing active / reactive power transducers, power factor transducers, and power meters shall be carried out as part of the next protection maintenance. The person carrying out these checks shall send their results to the PowerOn Team who will update PowerOn, adding dynamic and static arrows. This work shall be completed by the end of February 2020 (in accordance with the requirements of the original issue of this document).

REVISION HISTORY

DOCUMENT REVISION & REVIEW TABLE		
Date	**Comments**	**Author**
July 2017	• Section 2.1 has been modified to allow additional flexibility regarding the convention for power flow direction. • A reference to ENA TS 41-15, Standard Schematic Diagrams for Equipment in 132kV Substations, has been added.	Andy Hood
February 2016	• New Document	Andy Hood

1.0 INTRODUCTION

With increasing levels of generation connected to Western Power Distribution's networks it is essential that the magnitude and direction of power flow within Western Power Distribution's networks is measured accurately and displayed in a consistent manner in PowerOn. This document specifies the conventions that are used for these measurements.
Where any difficulty is encountered in the application of this document the author should be contacted who will determine whether a variation is appropriate.

2.0 REQUIREMENTS

2.1 Power Flow Conventions

2.1.1 Analogue measurements such as current, voltage, active power and reactive power are either provided by meters, transducers or by protection / tap-change control relays. Going forward it is expected that the majority of analogue readings will be derived from protection relays. Given this, the convention for the direction of active power and reactive power must align with convention used for protection relays.

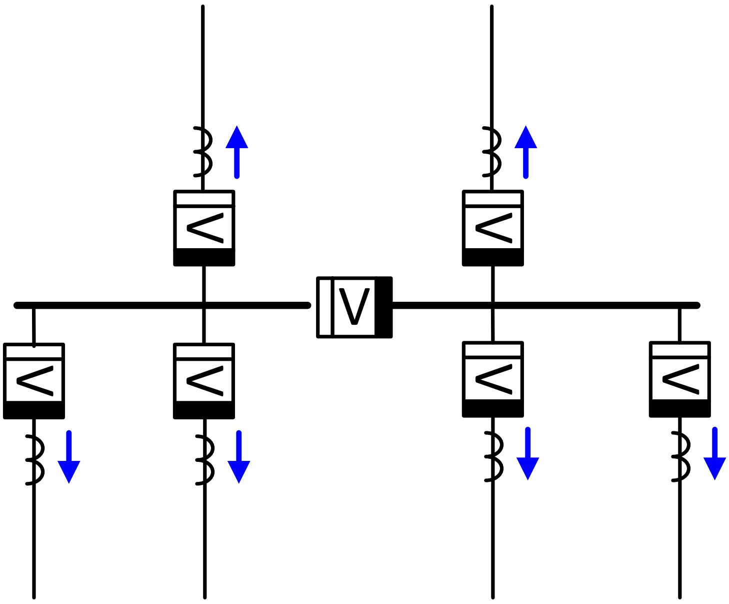
2.1.2 These meters, transducers and relays measure phase to phase voltage (via VTs) and line current (via CTs) and use this data to determine the active power and reactive power.

2.1.3 The convention for the direction of directional protection relays and hence the convention for analogue measurements shall be in accordance with Western Power Distribution's protection standards and standard schematics. These in turn are based upon ENA EREC S15 and ENA TS 41-15.

2.1.4 In general for circuits (both incoming and outgoing) the positive direction is away from the busbars and towards the circuit / equipment to be protected. Typical examples are given in Figure 1 to 3, below.

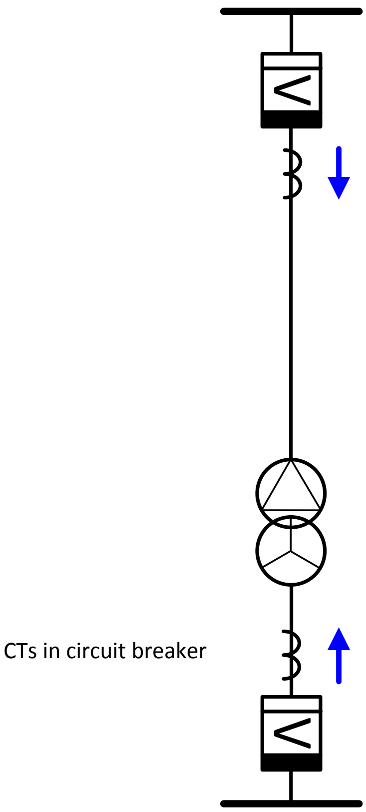
2.1.5 For other applications the positive direction will depend on site specific requirements.

2.1.6 Where guidance is needed for new installations this is provided by Engineering Design. For existing installations, the asset owner should be able to determine the existing CT / VT connections, check any relay / transducer settings and, where necessary carry out on load checks to determine the positive direction.



= Convention for positive active power and reactive power

Figure 1 Typical Power Flow Convention for Switchboards



= Convention for positive active power and reactive power

Figure 2 Typical Power Flow Convention for Transformers

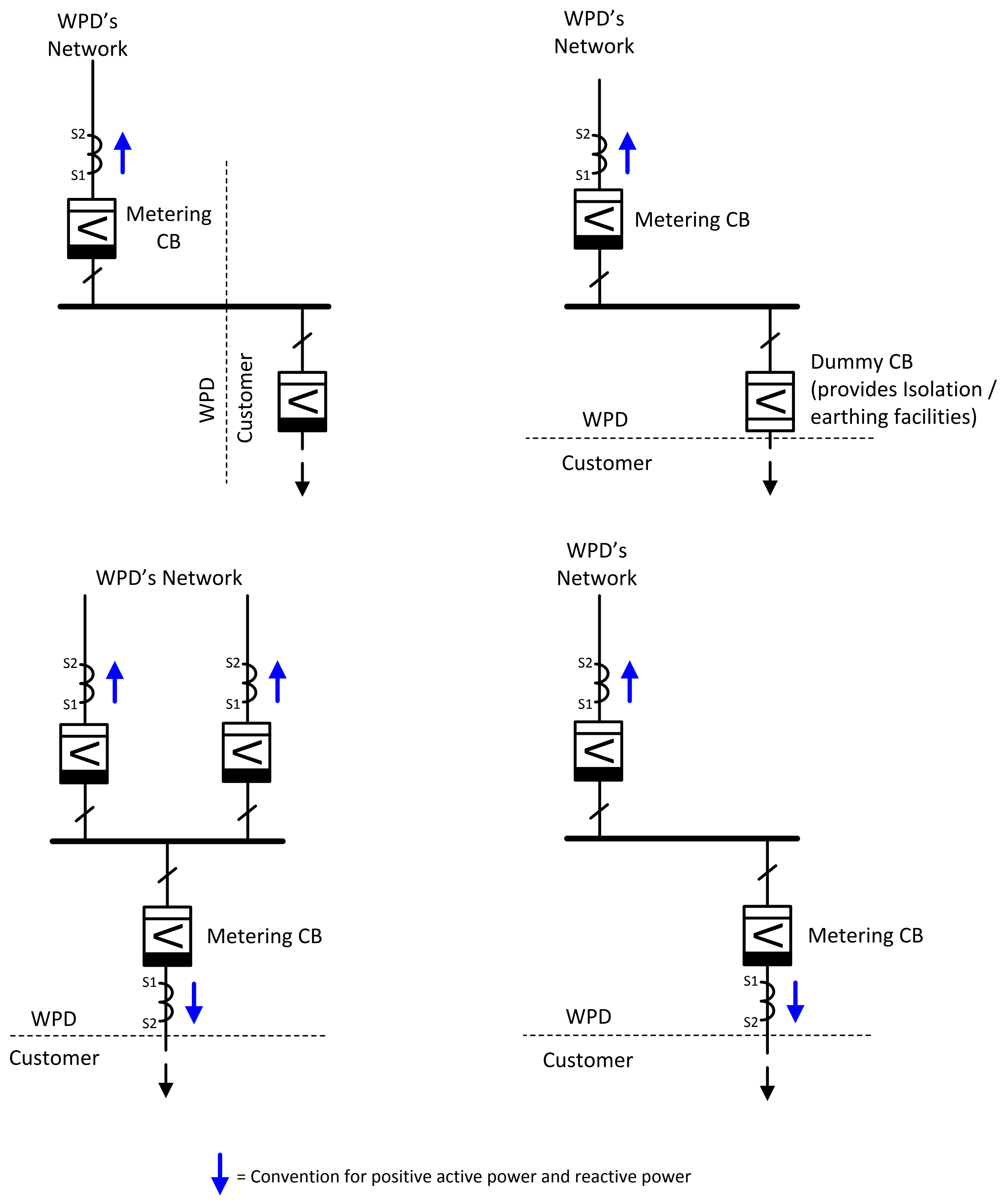


Figure 3 Typical Power Flow Convention for Metering Arrangements

2.2 PowerOn Fusion Facilities

2.2.1 Where power measurements are available in PowerOn the direction of active power and reactive power shall be displayed by dynamic arrows on the screen (one arrow for active power and one arrow for reactive power). In addition, when the user zooms in closely to the associated plant the convention for positive power flow shall be indicated by a static arrow.

2.2.2 It should be noted that voltage (V), current (A) and apparent power (VA) do not have a direction.

2.3 Data Logger

2.3.1 Data Logger shall provide positive and negative values of Active Power and Reactive Power. The convention for power flow direction shall be in accordance with the static arrow displayed in PowerOn.

2.4 Commissioning Requirements

2.4.1 Requirements for commissioning protection equipment are defined in the TP10 series of documents. Transducers and their associated CTs and VT circuits shall be commissioned using the same techniques applied to protection relays and systems. The calibration and directional sensing of relays, meters and power transducers are critical to their operation and therefore the commissioning tests must verify these aspects. The following checks and tests are applicable:

- Inspection of secondary wiring and equipment.
- Insulation resistance (IR) tests on secondary wiring.
- Resistance tests.
- CT Tests.
- VT Tests.
- Auxiliary supply tests (where applicable).
- Calibration tests.
- On load checks / tests to verify the correct magnitude of current, voltage, active power and reactive power etc. and also the directionality of active power and reactive power.

3.0 BACKGROUND

3.1 Types of Power Measurement

Three different types of Power are applicable to A.C. systems, Apparent Power, Active Power and Reactive Power.

(a) Apparent Power = Voltage x Current and has units of Volt-Amperes (e.g. VA, kVA or MVA).

(b) Active Power = Voltage x Current x COS Θ, where Θ is the angle between the Voltage and Current waveforms. Active Power is expressed in Watts (e.g. W, kW or MW).

(c) Reactive Power = Voltage x Current x SIN Θ, where Θ is the angle between the Voltage and Current waveforms. Reactive Power is expressed in VARs (e.g. VAr, kVAr or MVAr)

Note, COS Θ is known as the Power Factor

3.2 Direction of Power Flow

AC current, voltage and apparent power are, by themselves, non-directional quantities and are therefore not assigned a direction. The direction of active and reactive power flow depends on the relationship (angle) between the voltage waveform and the current waveform. This relationship can be shown in two ways, as a diagram of voltage and current by angular displacement (as shown in Figure 4) or as a vector diagram (as shown in Figure 5).

3.2.1 <u>Active Power</u>

If the current lags or leads the voltage by 90^{o} or less the active power is positive. If the current lags or leads the voltage by more than 90^{o} the flow of active power is negative.

3.2.2 <u>Reactive Power</u>

If the current lags the voltage by less than 180^{o} the reactive power is positive. If the current leads the voltage by less than 180^{o} the flow of reactive power is negative.

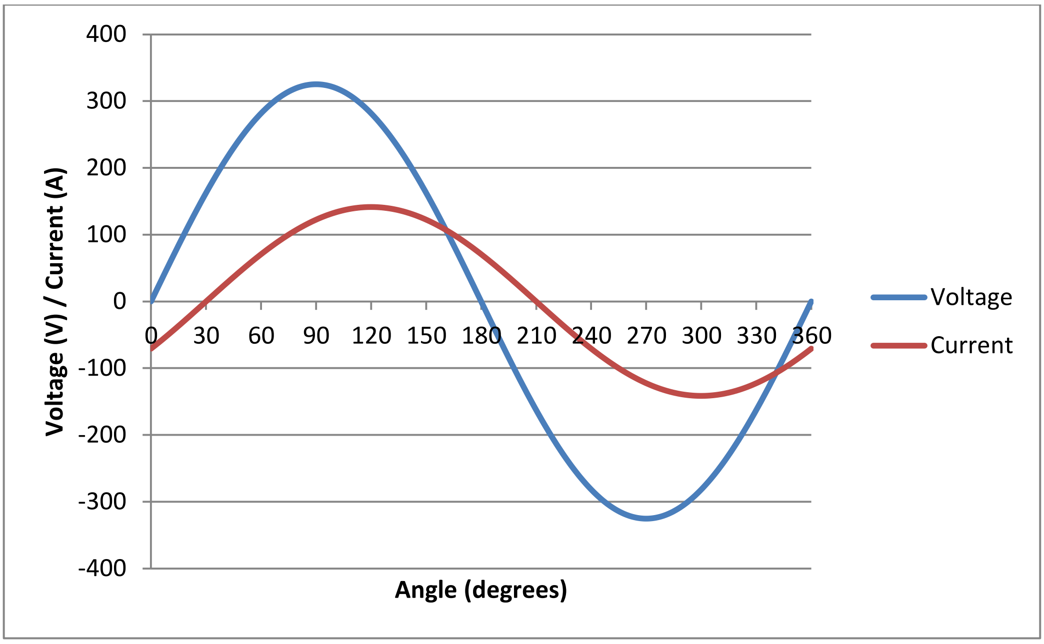


Figure 4 **Current & Voltage V Waveforms - Current lagging Voltage by 30°**

Note, A compete cycle (i.e. 360°) has a duration of 20ms where the frequency is 50Hz.

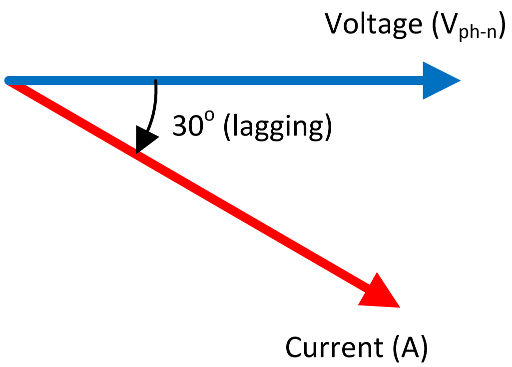


Figure 5 **Vector Diagram – Current Lagging Voltage by 30°**

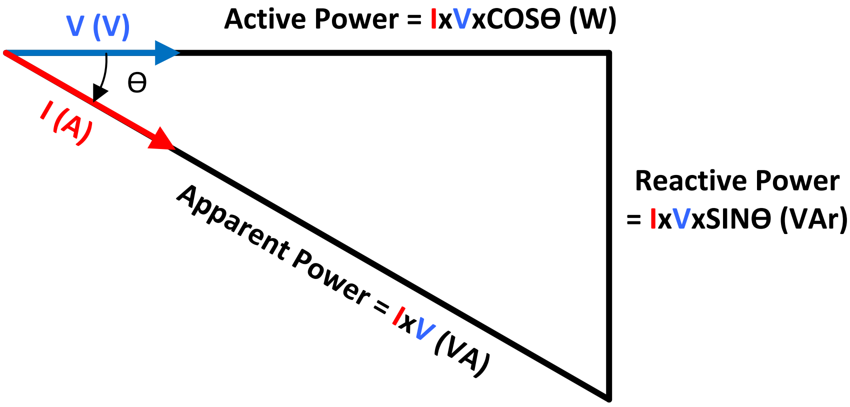


Figure 6 Apparent Power, Active Power and Reactive Power

3.2.3 Figure 6 shows the relationship between apparent power, active power and reactive power. In this case both active power and reactive power are positive since the current is lagging the voltage by less than 90^o.

3.2.4 Figure 7 shows how the direction of power flow changes as the angle between the current and voltage varies. Four examples are provided:

- I1 lags the voltage by approximately 20^o and, in this case, the Active Power and Reactive Power are both positive.
- I2 leads the voltage by approximately 20^o and in this case the Active Power is positive and the Reactive Power is negative.
- I3 lags the voltage by approximately 160^o and so in this case the Active Power is negative and the Reactive Power is positive.
- I4 leads the voltage by approximately 160^o and so in this case both the Active Power and the Reactive Power are negative.

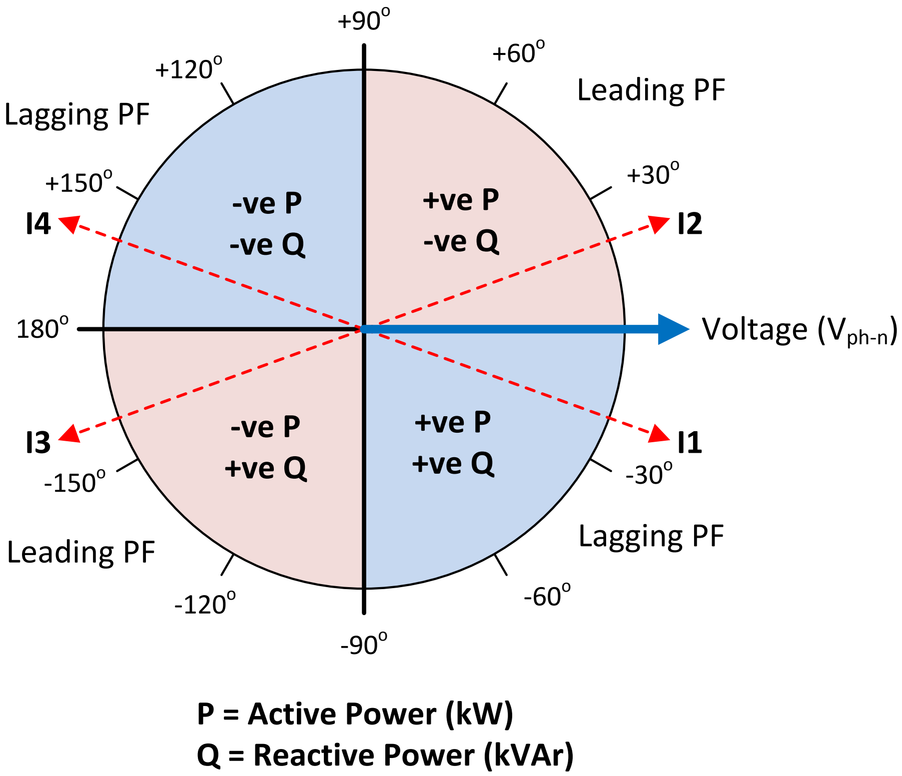


Figure 7 Four Quadrant Diagram - Direction of Power Flow

3.3 Power Transducer Requirements

3.3.1 Transducers shall satisfy the requirements of the relevant WPD switchgear and protection panel specifications, for example EE SPEC: 3 and EE SPEC: 87.

3.3.2 Figure 8 and 9 show the AC connection requirements for standard Power transducers and the direction of positive power that results from these connections.

3.3.3 At the time of writing, power transducers are connected using the 3 x voltage, 1 x current arrangement, shown in Figure 8, which is suitable for balanced three wire networks. Going forward, specifications and standard drawings will be modified so that transducers are connected using the 3 x voltage, 3 x current arrangement shown in Figure 9. This will allow additional data, including all three current values to be made available if the transducer is connected to the RTU by a communication interface (e.g. Modbus, DNP3.0 or IEC61850 protocol).

3.3.4 Where the transducer DC milliamp outputs are hardwired to an RTU the following parameters shall be monitored:

- 1 x line Current
- 1 x voltage (phase-phase)
- Active power (total)
- Reactive power (total)

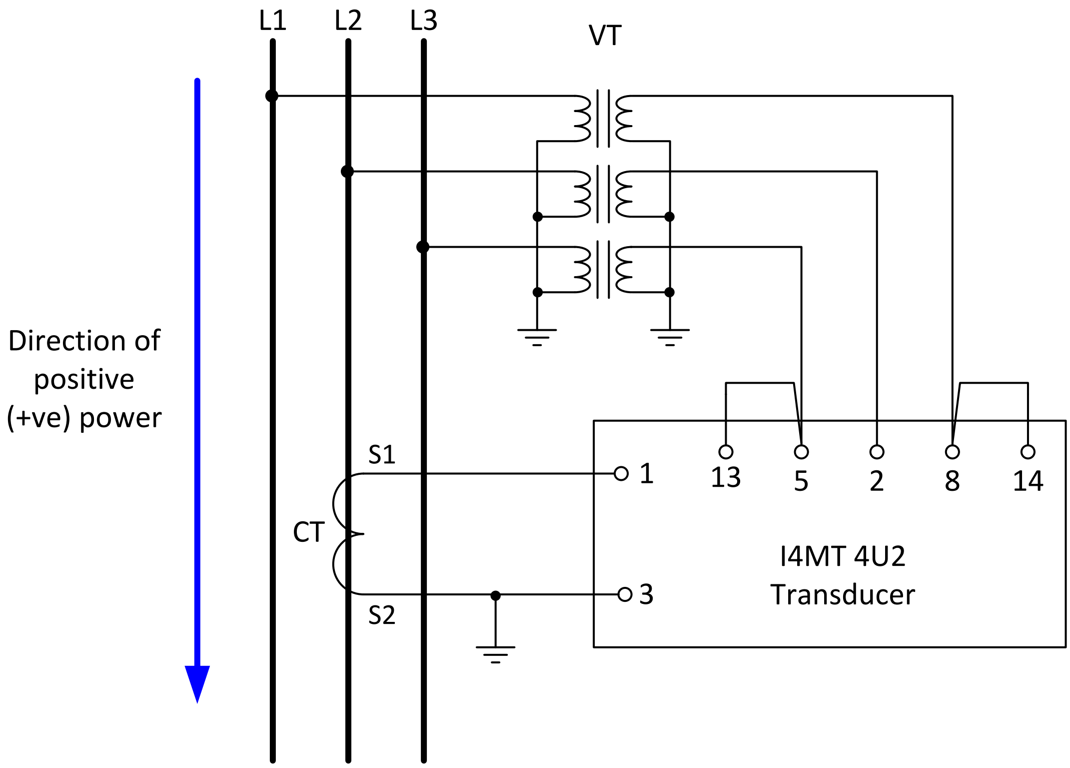


Figure 8 Standard Transducer Connections (1 Current, 3 Voltage Arrangement)

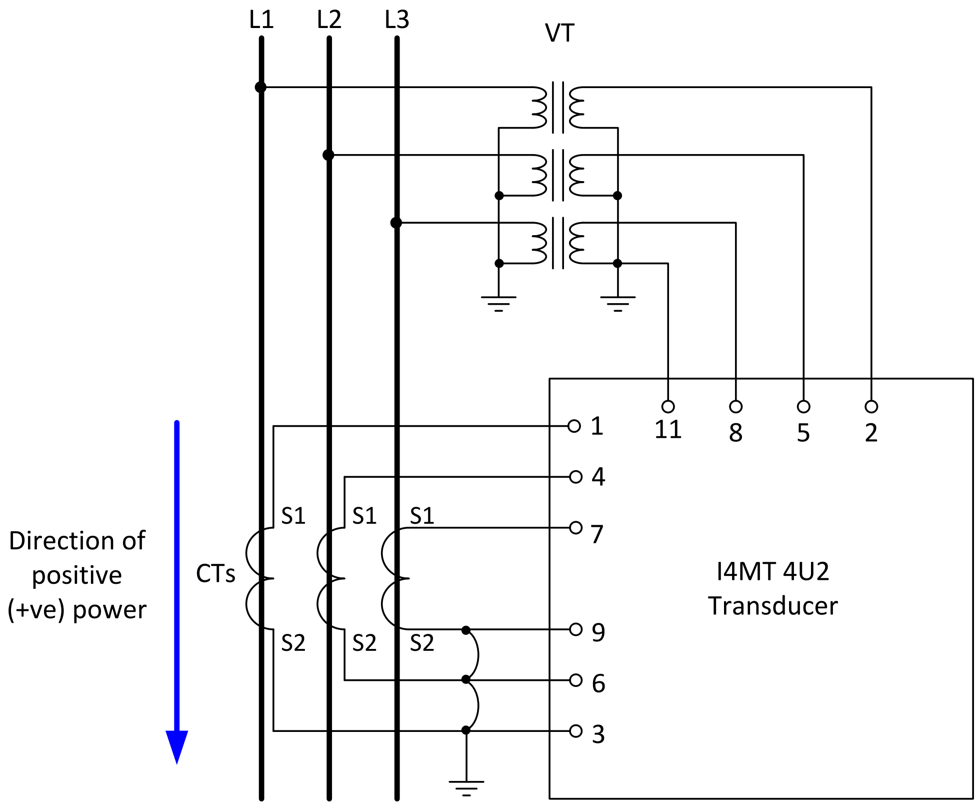


Figure 9 Standard Transducer Connections (3 Current, 3 Voltage Arrangement)

APPENDIX A

SUPERSEDED DOCUMENTATION

ST:TP6F dated February 2016

APPENDIX B

ANCILLARY DOCUMENTATION

EE SPEC: 3	12kV and 36kV Indoor Circuit Breakers including associated Protection and Ancillary Electrical Equipment
EE SPEC: 87	Protection and Control Cubicles for Outdoor 72kV and 36kV Circuit Breakers and Primary Substation Transformers
ENA EREC S15	Standard Schematic Diagrams
ENA EREC 41-15	Standard Schematic Diagrams for Equipment in 132kV Substations

APPENDIX C

KEY WORDS

Transducer, Power, Apparent Power, Active Power, Reactive Power, Power Factor, Current, Voltage, Protection, Direction, Measurement.