Electricity Distribution

nationalgrid

Company Directive

STANDARD TECHNIQUE: TP6F/2

Power Measurement and Phase Angle Conventions

Summary

This document specifies the conventions that are used for phase angle and the direction of power flow within National Grid Electricity Distribution's (NGED's) Network. It is essential that the magnitude and direction of power flow within the network is measured accurately and displayed in a consistent manner in PowerOn.

Author: **Andy Hood**

Implementation Date: **October 2022**

Approved by

Carl Ketley-Lowe
Engineering Policy Manager

Date: **5th October 2022**

Target Staff Group	**Staff involved with the installation, commissioning, maintenance, design, analysis, operation and control of NGED's network including those involved with PowerOn**
Impact of Change	**Amber – The changes include useful background information for staff involved with testing / maintaining phase angle transducers and those who interpret their output**
Planned Assurance checks	**Engineering Policy will audit PowerOn in 2022 and 2023 to check that dynamic and static power flow arrows have been to PowerOn in accordance with this ST.**

IMPLEMENTATION PLAN

Introduction

This document specifies the conventions for the direction of power flow and for phase angle within NGED's.

Main Changes

Phase angle conventions and diagrams for phase angle transducers have been added to the document.

Impact of Changes

Target Staff Group	**Staff involved with the installation, commissioning, maintenance, design, analysis, operation and control of NGED's network including those involved with PowerOn**
Impact of Change	**Amber – The changes include useful background information for staff involved with testing / maintaining phase angle transducers and those who interpret their output**

Implementation Actions

Managers shall ensure all relevant staff are familiar with and comply with the requirements of this document. In accordance with the previous issue of this standard technique[1] 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.

An audit shall be carried out in 2022 to check that these active power and reactive power arrows have been added to PowerOn.

A presentation video that provides further information on the main changes is available here:

[ST: TP6F Briefing]

Implementation Timescale

This document shall be implemented on issue.

Where active power and reactive power analogues are provided in PowerOn and the associated dynamic and static arrows are found to missing directional checks shall be completed on site and the required arrows added to PowerOn within 12 months of the issue being discovered and reported.

Note [1] ST: TP6F/1 required these checks and PowerOn changes to be completed by February 2020.

REVISION HISTORY

DOCUMENT REVISION & REVIEW TABLE		
Date	**Comments**	**Author**
October 2022	• Implementation - An audit of PowerOn active power and reactive power arrows shall be completed in 2022 and issues addressed within 12 months of their discovery. • 1.0 – this section has been expanded • in 2.2.3 – The convention for phase angles provided in PowerOn has been clarified. • 3.1 – A definition for phase angle θ has been added. • 3.2.3 – Clause added to explain how the leading/lagging power factor is assigned. • 3.2.5 – Descriptions of I1, I2, I3 and I4 have been modified. • Angles displayed in Figure 7 have been modified. • Figure 8 and 9 have been amended / corrected. • 3.4 – new section added o phase angle transducer conventions.	Andy Hood
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

Contents

1.0 INTRODUCTION

With increasing levels of generation connected to NGED's network it is essential that the magnitude and direction of power flow is measured accurately and displayed in a consistent manner in PowerOn. This information is used by:

- Control for operational purposes
- Primary System Design and by Planners for network design studies
- Network Strategy for network assessments and reviews
- Active Network Management and other Flexible Design schemes used to automatically manage/control load (i.e. demand and generation) on the network
- Independent Distribution Network Operators, Independent Connection Providers and other third parties

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 NGED'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.

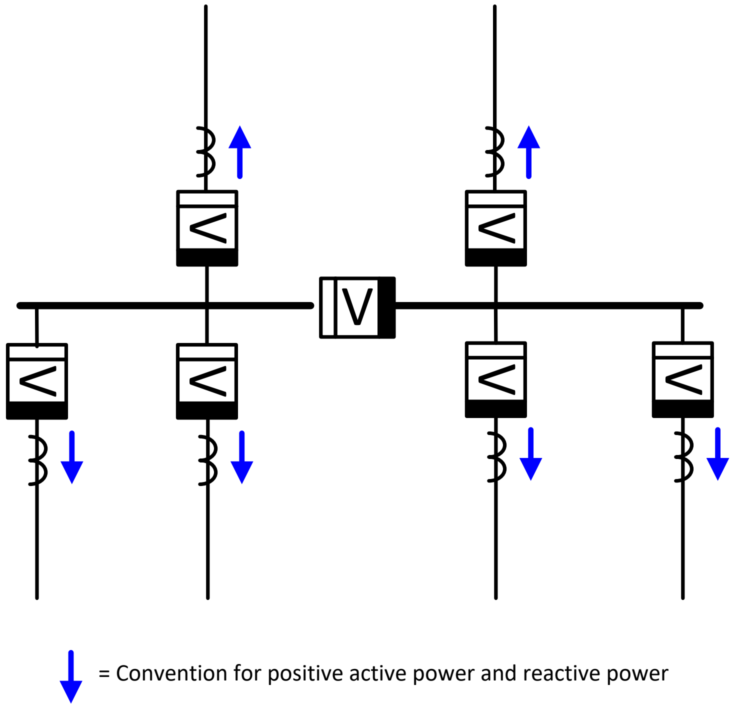

Figure 1 Typical Power Flow Convention for Switchboards

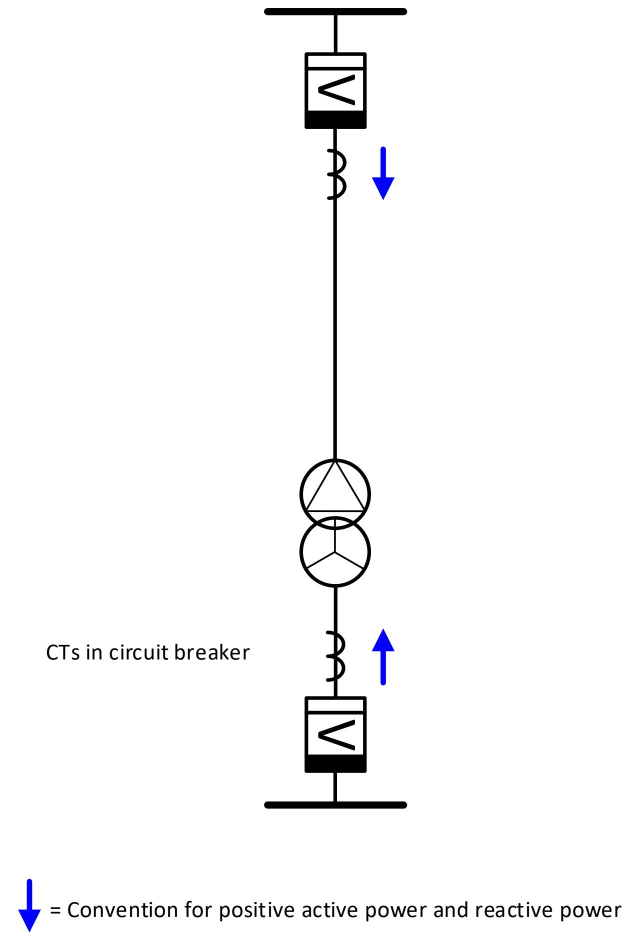

Figure 2 Typical Power Flow Convention for Transformers

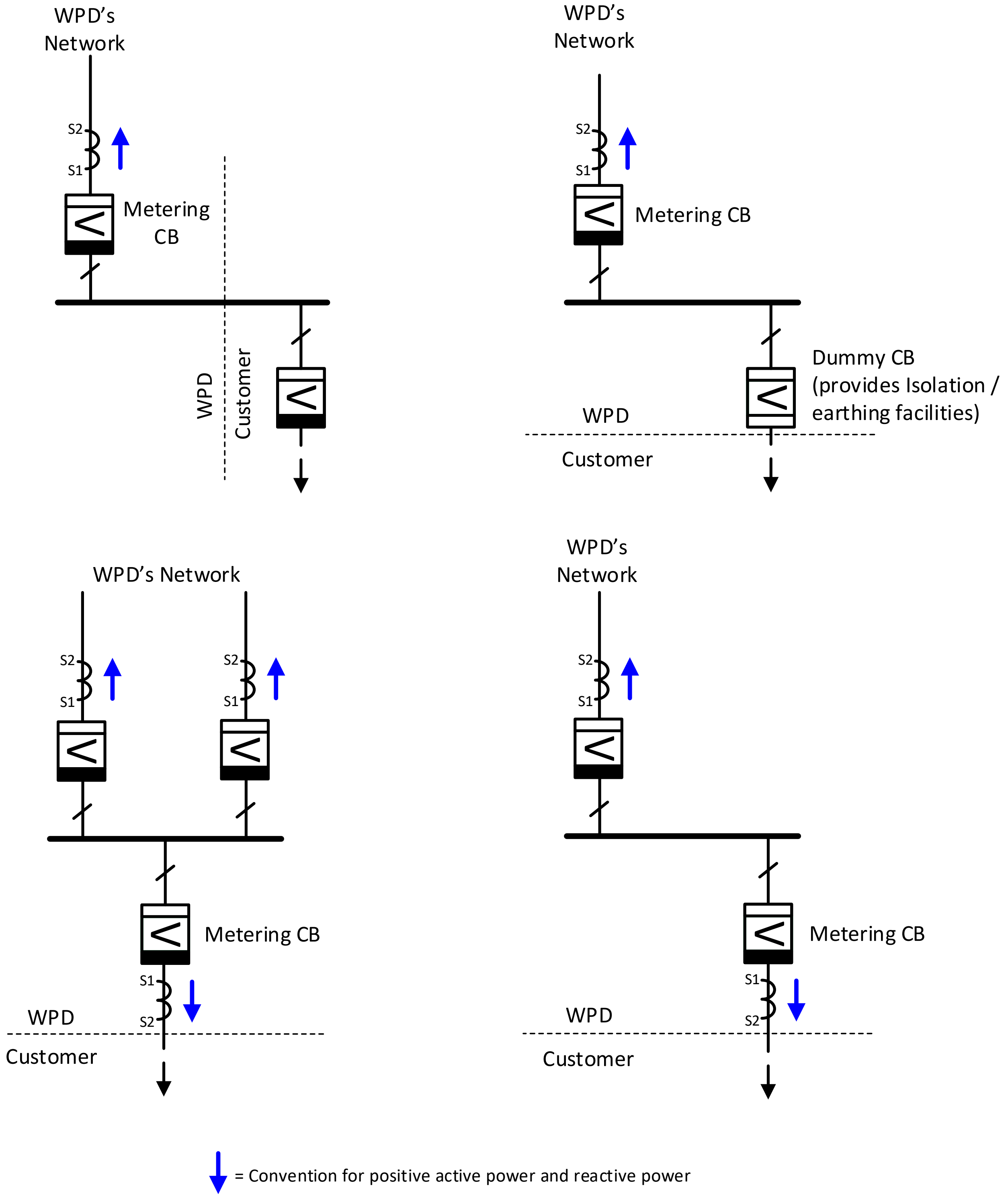

Figure 3 **Typical Power Flow Convention for Metering Arrangements**

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 Voltage (V), current (A) and apparent power (VA) do not have a direction.

2.2.3 Power system phase angle, i.e. the angle of phase current with respect to the associated phase to neutral voltage, is expressed as a value from 0^o to 360^o.

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)

ϴ (theta) is the angle in degrees by which the phase current lags the associated phase to neutral voltage.

COS ϴ is known as the Power Factor and is expressed as a leading power factor or lagging power factor, depending on the angle ϴ.

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 Active Power

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 Reactive Power

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.

3.2.3 Power Factor

If the polarity of both the active power and reactive power are the same, i.e. both are positive or both negative then the power factor is deemed to be lagging. If the polarity of the active power is different to the polarity of the reactive power then the power factor is deemed to be leading. This is shown in Figure 7.

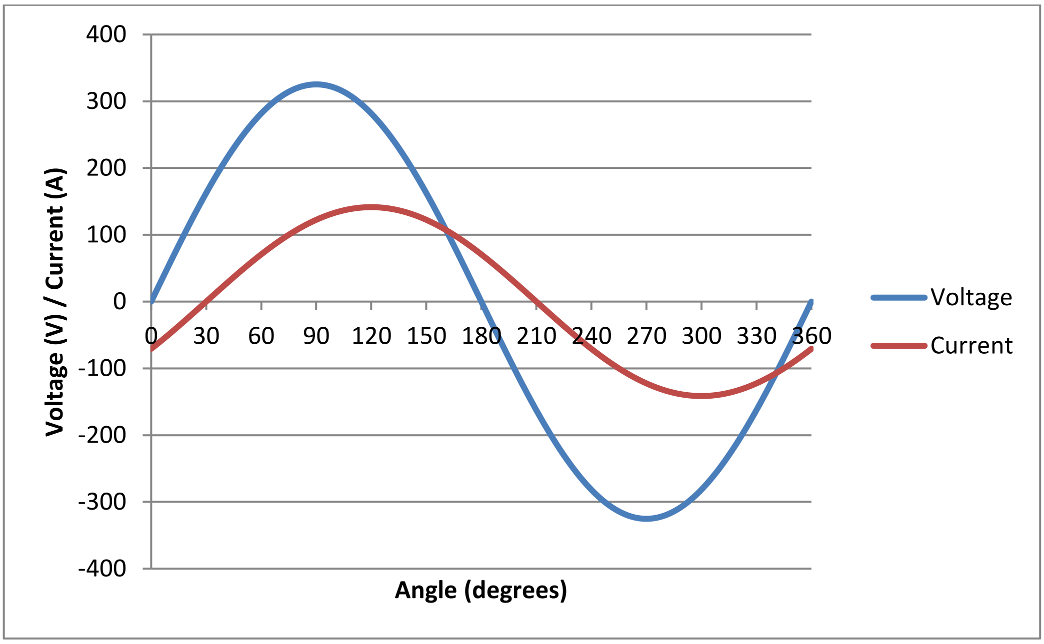

Figure 4 Current & Voltage V Waveforms - Current lagging Voltage by 30°

Note [1] A compete cycle (i.e. 360°) has a duration of 20ms where the frequency is 50Hz.

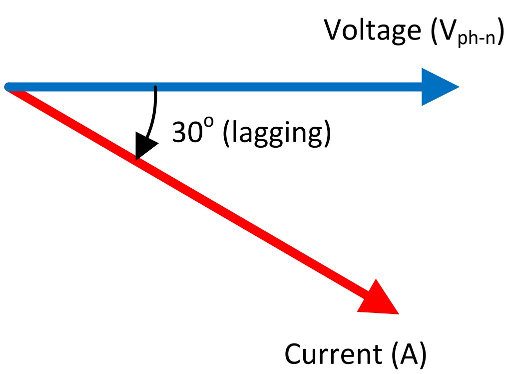

Figure 5 Vector Diagram – Current Lagging Voltage by 30°

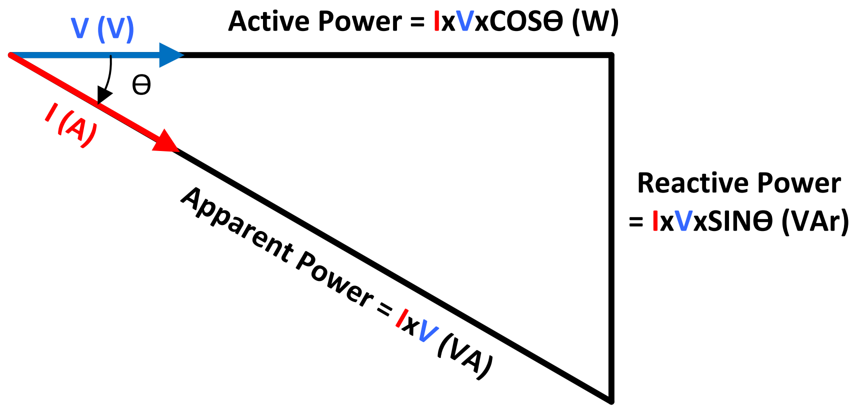

Figure 6 Apparent Power, Active Power and Reactive Power

3.2.4 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.

3.2.5 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 therefore the power factor is deemed to be lagging. In this case, the Active Power and Reactive Power are both positive.

- I2 leads the voltage by approximately 20^o (i.e. the power system angle is 360^o – 20^o = 340^o) and therefore the power factor is deemed to be leading. In this case the Active Power is positive and the Reactive Power is negative.

- I3 lags the voltage by approximately 160^o and therefore the power factor is deemed to be leading. In this case the Active Power is negative and the Reactive Power is positive.

- I4 leads the voltage by approximately 160^o (i.e. the power system angle is 360^o – 160^o = 200^o) and therefore the power factor is deemed to be lagging. In this case both the Active Power and the Reactive Power are negative.

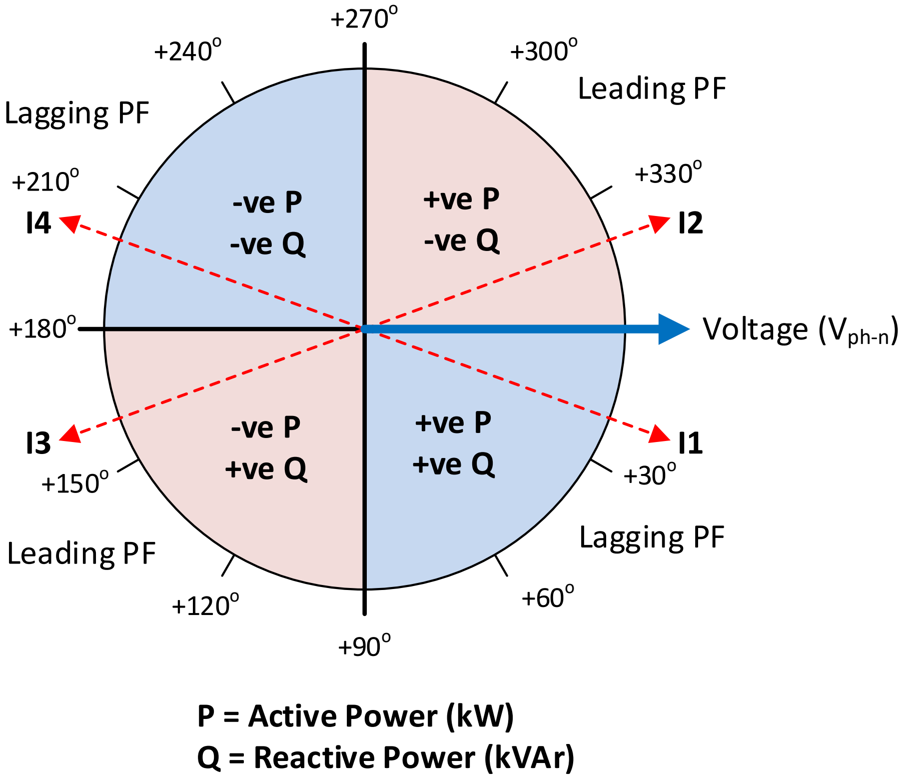

Figure 7 Four Quadrant Diagram - Direction of Power Flow

3.3 **<u>Power Transducer Requirements</u>**

3.3.1 Transducers shall satisfy the requirements of the relevant NGED 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)

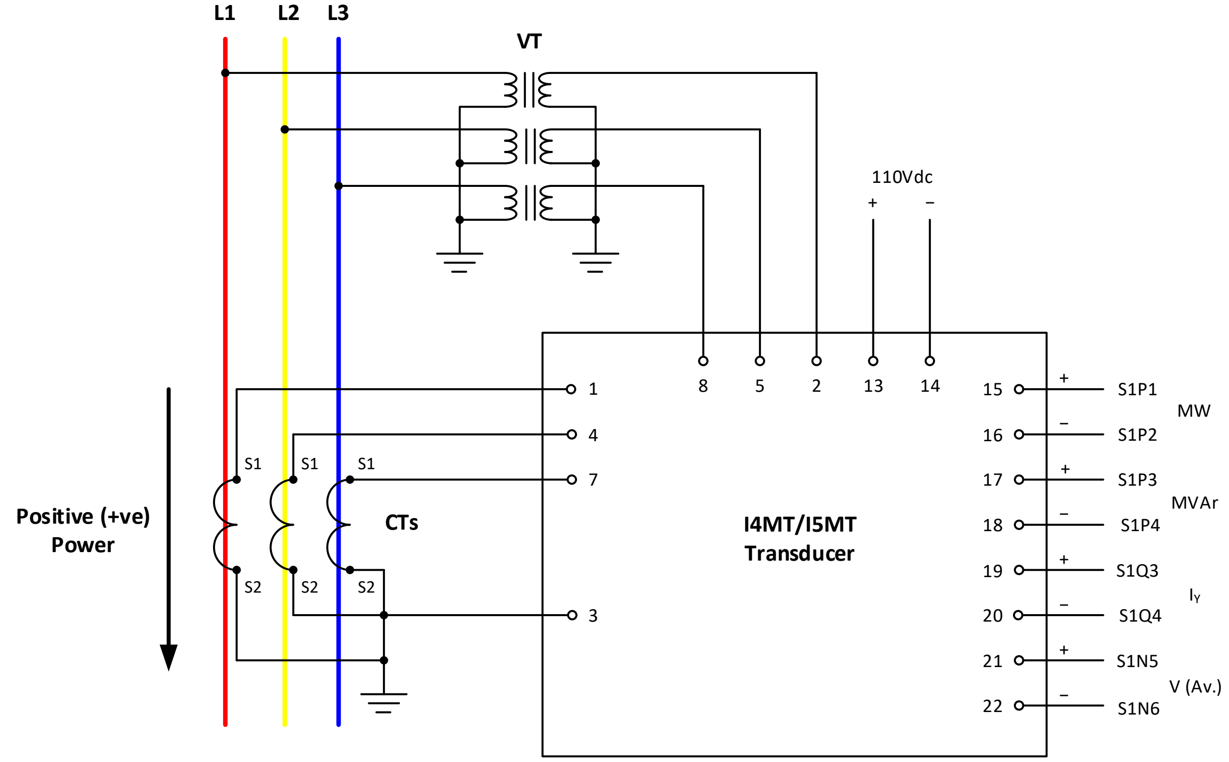

Figure 8 Standard Power Transducer Connections – I_Y, V_R, V_Y and V_B Inputs

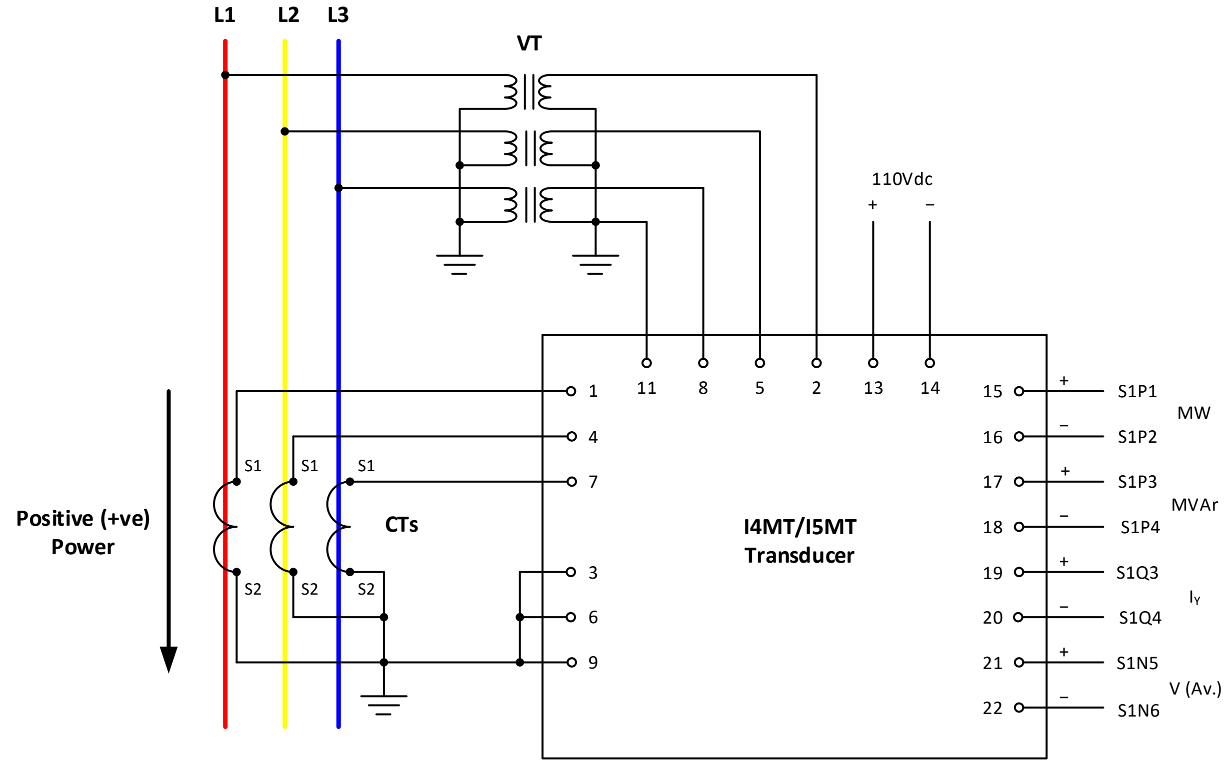

Figure 9 Standard Power Transducer Connections – I_R, I_Y, I_B, V_R, V_Y and V_B Inputs

3.4 <u>Phase Angle Transducer Requirements</u>

3.4.1 Although power factor transducers were historically installed within parts of NGED's network they are no longer purchased. Where existing phase angle transducers need to be replaced, for example, following failure multi-function power transducers should be used instead.

3.4.2 Figure 10, 11, 12 and 13 show standard connection arrangement for phase angle transducers. A <phase angle transducer guide> is also available which provides further information on the transducer connections and how the outputs are used by the RTU and by PowerOn to derive power system angle, active power (MW) and reactive power (MVAr).

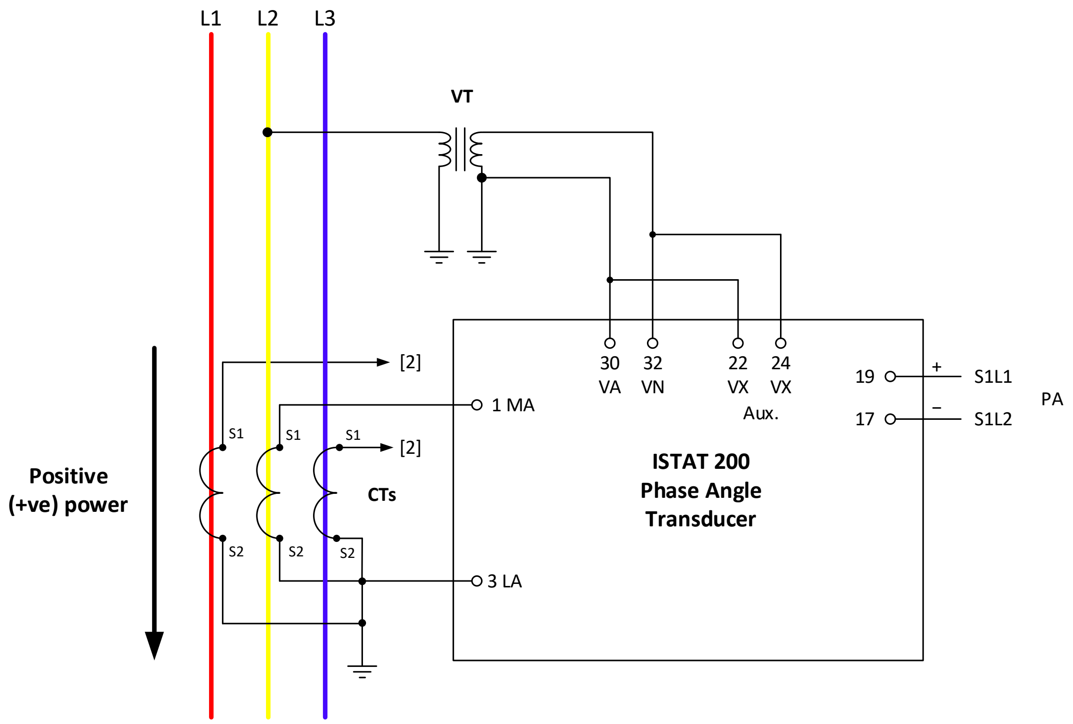

Figure 10 Standard ISTAT 200 Phase Angle Transducer Connections – I_Y and V_Y Inputs

Note [2] CT secondary wiring may also be connected to other equipment and <u>must not</u> be open circuited when the primary circuit is energised

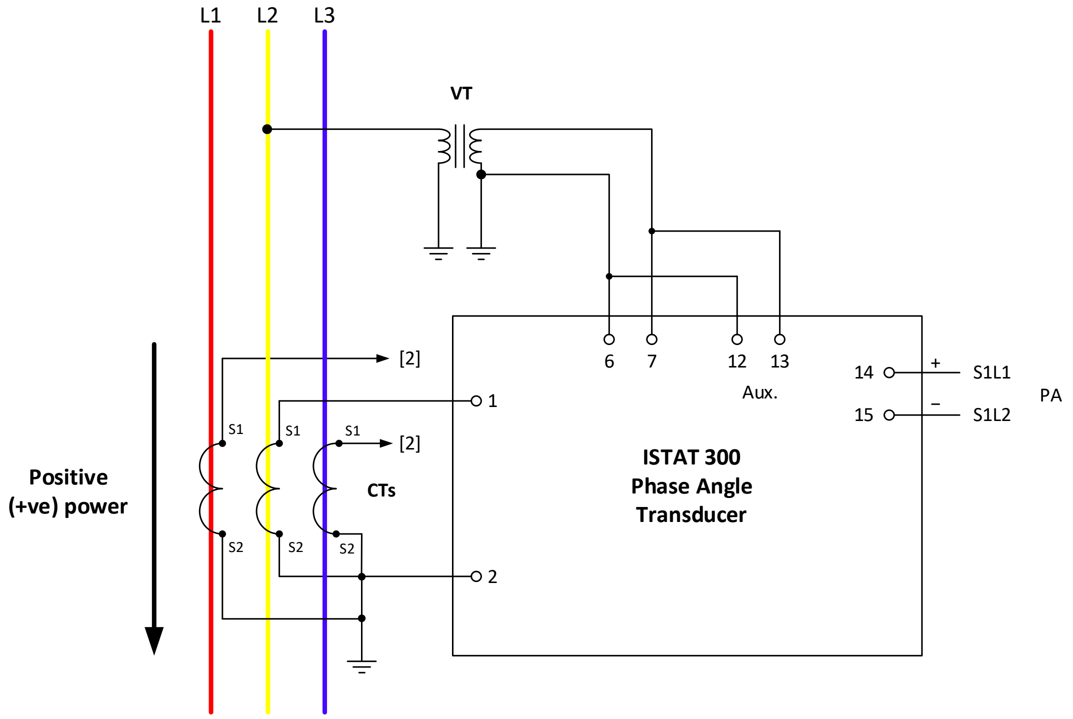

Figure 11 **Standard ISTAT 300 Phase Angle Transducer Connections – I_Y and V_Y Inputs**

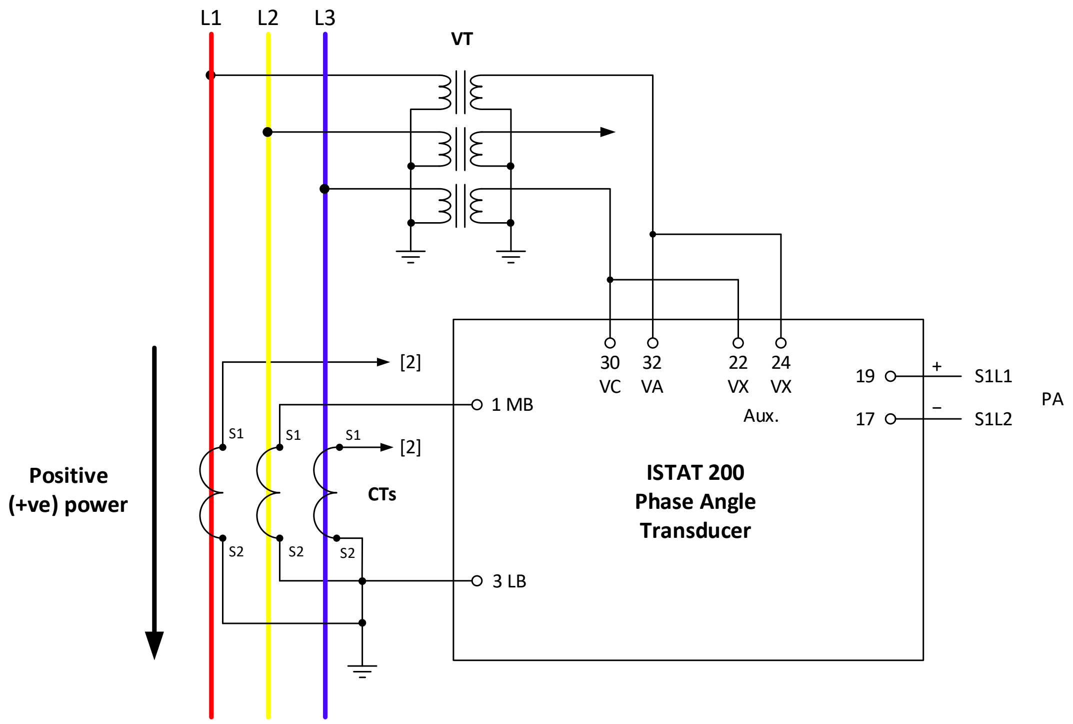

Figure 12 **Standard ISTAT 200 Phase Angle Transducer Connections – I_Y and $V_{R\text{-}B}$ Inputs**

Note [2] *CT secondary wiring may also be connected to other equipment and _must not_ be open circuited when the primary circuit is energised*

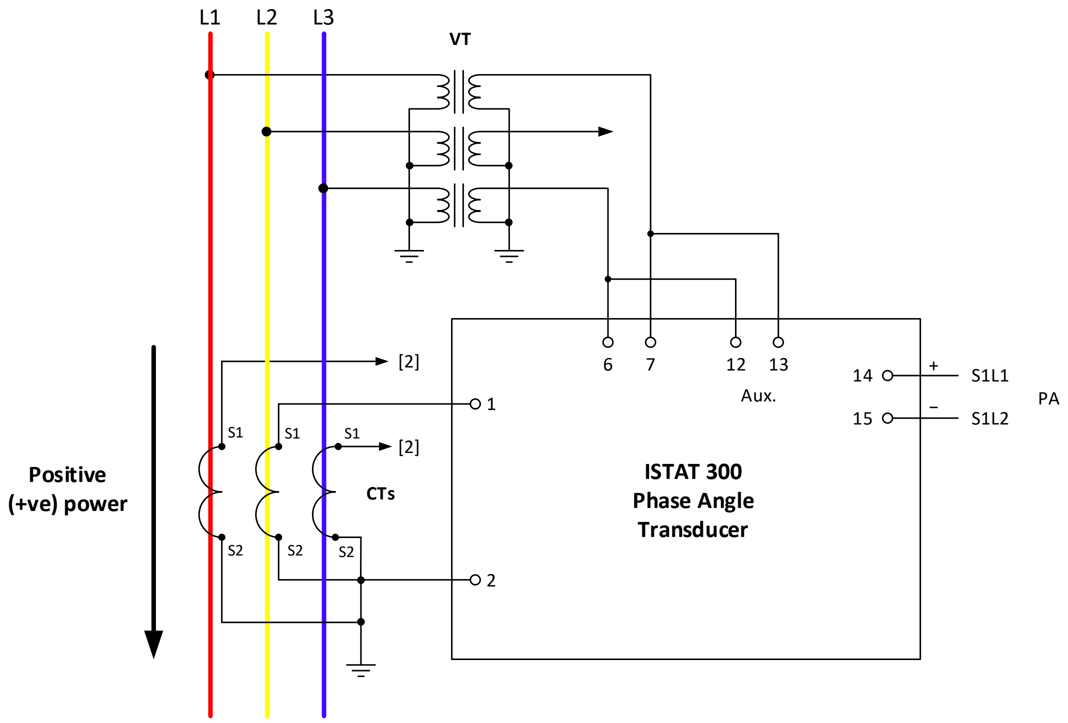

Figure 13 Standard ISTAT 300 Phase Angle Transducer Connections – I_Y and V_{R-B} Inputs

Note [2] CT secondary wiring may also be connected to other equipment and must not be open circuited when the primary circuit is energised

APPENDIX A

SUPERSEDED DOCUMENTATION

This document supersedes ST: TP6F/1 dated July 2017 which has now been withdrawn.

APPENDIX B

RECORD OF COMMENT DURING CONSULTATION

Comments – ST: TP6F/2

APPENDIX C

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 D

KEY WORDS

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