Synchrophasor Data Requirements

Draft for Discussion

1. Introduction

1.1 Purpose

The primary object of the Synchrophasor Data Requirements manual is to provide technical speifications and guidelines for Market Participants to supply *synchrophasor* data with correct attributes to the IESO for its utilisations in planning and operational processes of the IESO-controlled grid.

1.2 Scope

The scope of this manual comprises technical requirements of the *synchrophasor* data to be provided to the IESO by the *generators* connected to the *IESO-controlled grid* and the *transmitters*.

The *synchrophasor* data are generated mainly by a stand-alone device called Phasor Measurement Unit (PMU). The *synchrophasor* data can also be generated by other dual-purpose devices such as (1) modern Digital Disturbance Reorders (DDR) which is used for intermittent data recording (2) Intelligent Electronic Device (IED) of relays which is used for protection. The technical requirements and functionalities of those three devices are unique and vastly different to each other. The scope of this manual does not include technical requirements of those devices, but limited to the technical requirements of the s*ynchrophaor* data those devices generate. The technical requirements of *synchrophasor* data generating devices are immaterial to the IESO as long as the *synchrophasor* data adheres to the requirements specified in this manual.

The *synchrophasor* data from the generating device are transmitted to the IESO via a processor called Phasor Data Concentrator (PDC). The technical requirements of the PDC are also not in the scope of this manual. The technical requirements of the PDC are immaterial to the IESO as long as the *synchrophasor* data adheres to the technical requirements specified in this manual.

The technical requirements presented here are to aid generation and transmission facilities already in-service as well as those facilities approved to be connected to the *IESO-controlled grid*. In latter case, the requirements specified in this manual can be used as a guide to make initial plans on designing synchrophasor measurement systems which should then be shared with and reviewed by the IESO during the market entry as well as interconnection process.

1.3 Real-Time Monitoring Devices

There are several tools such as SCADA, Phasor Measurement Units, Power System Data Recorders (PSDR), Dynamic Fault Recorders (DFR) and Digital Disturbance Recorders (DDR) conventionally used for the purpose of real-time power system monitoring for various degrees.

The devices that generate *synchrophasor* data offer following benefits as *synchrophasor* data contains

(1) a time-stamp as per Coordinated Universal Time (UTC).

(2) phase angles.

(3) higher data sampling rate (i.e. 30 - 120 samples per second).

(4) continuous real-time measurements.

The data from SCADA, PSDR, DFR and DDR have limited benefits compared to *synchrophasor* data.

- The SCADA provides real-time measurements continuously but at a much slower sampling rate (2 - 4 samples per second), does not measure phase angle and data contains no universal time stamp.
- The data from PSDR, traditional DFR and DDR have similar or higher sampling rate compared to *synchrophasor* data, provide phase angles, data contains universal time stamp, however they recording devices (i.e. not real-time), non-continuous and triggered by certain variables such as voltage or frequency exceeding certain thresholds or abnormal levels.

1.4 Overview of Synchrophasor Data Requirements

The requirements on synchrophasor data are documented in Market Rules Chapter 4, Appendix 4.15 on compliance obligations for generators connected to the IESO-controlled grid and Market Rules Chapter 4, Appendix 4.16 on compliance obligations for transmitters as part of real-time monitoring. This document elaborates those requirements stated in Market Rules with more detailed specifications.

1.5 Phasor Measurement Unit (PMU)

The PMU is a device that generates *synchrophsaor* data by estimating the magnitude and phase angle of voltage and current waveforms and stamping them with time of measurement from a time source provided by the Global Positioning System (GPS). The resulting data are known as *synchrophasors* since each data regardless of the type, originating location or equipment is stamped with the time of measurement as per Coordinated Universal Time (UTC) which is typically the Greenwich Mean Time (GMT), hence subsequently the measurements can be precisely synchronized.

The infrastructure required for providing *synchrophasor* data using PMU includes the PMUs, Phasor Data Concentrators (PDCs), GPS antenna, local clock, communication network and data storage. An overview of their connectivity is shown in Figure 1.

1.6 Phasor Data Concentrator (PDC)

The PDC works as a node in a communication network where synchrophasor data are processed and fed out as a single stream to higher level PDCs or control center applications. There are multi levels of PDCs (i.e., local, mid level and high level) performing different roles. The local PDC is owned by the generator or the transmitter and located at close vicinity of the generator or transmitter facility. The local PDC aggregates and aligns all phasor data reaching it from different synchrophasor data generating devices based on the UTC time-stamp regardless of their arrival order or time and then allow those synchronised phasors to proceed to mid level PDCs. This compacting of synchrophasor data before they are sent on to the mid-level PDC minimizes the communication bandwidth between local and mid-level PDC and also creates a synchronised measurement set for the local system.

Mid level PDCs which are typically owned by same entity as the local PDC collect synchrophasor data from multiple local PDCs, conduct data quality checks and re-align all inputs based on UTC time-stamp and feed to various synchrophasor data based computer applications such as Network Monitoring Systems and State Estimators (SE) or storages at local control center. From multiple mid level PDCs, often synchrophaor data proceeds to a high level PDC which usually a regional based and perform similar functions as mid-level PDCs at a large scale such as Wide-Area Monitoring System (WAMS).

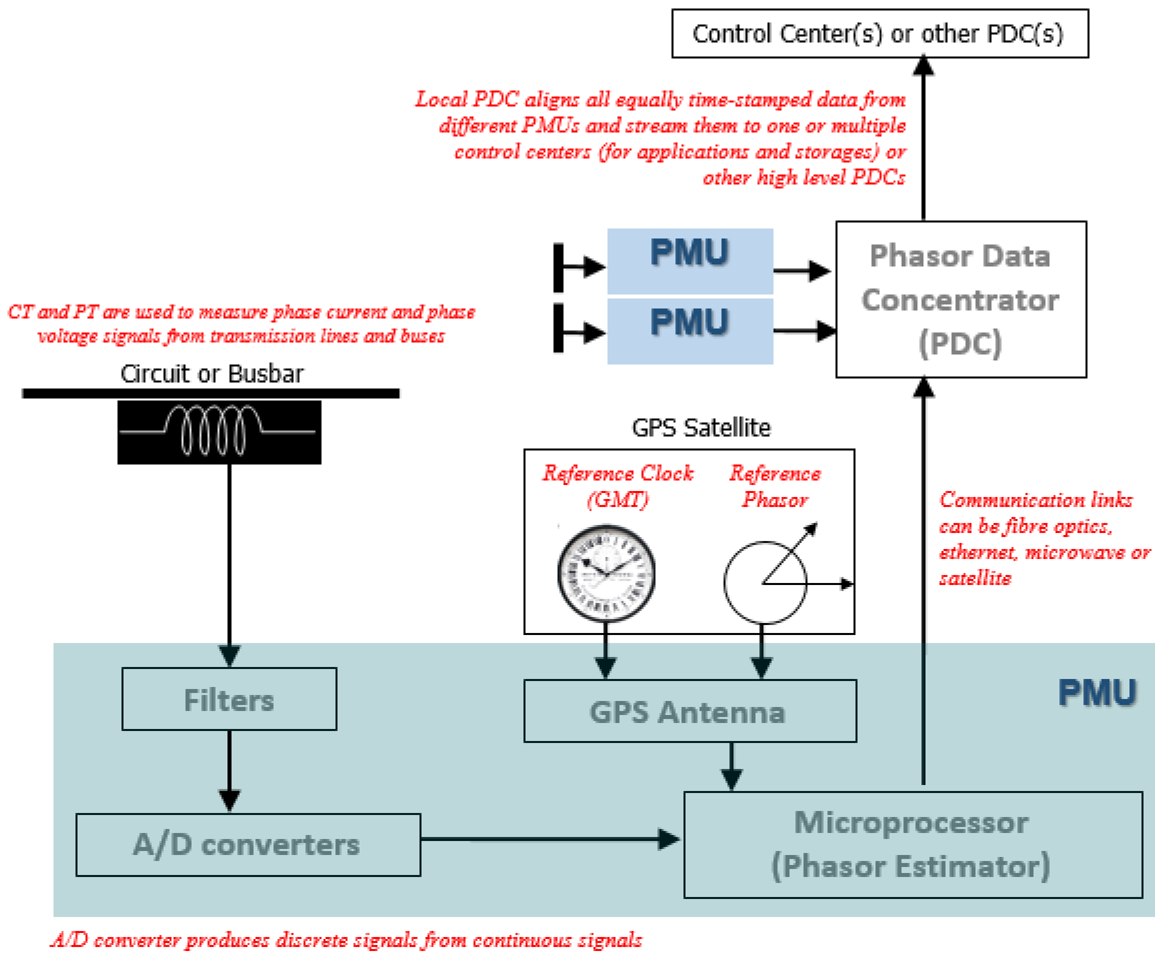

Figure 1 – Components of PMU

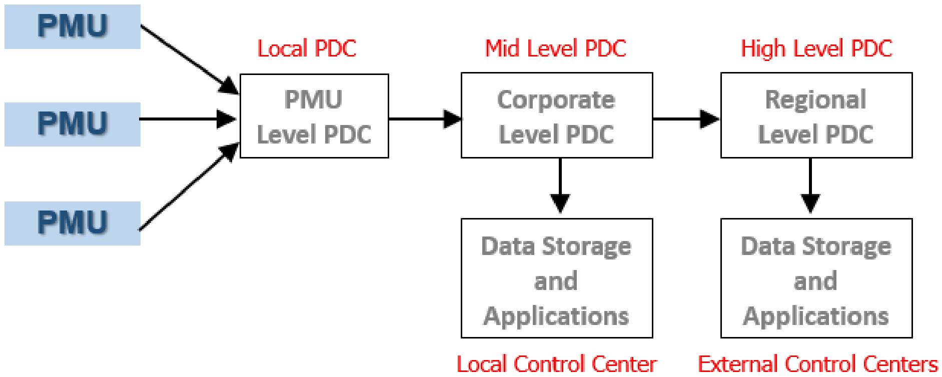

Figure 2 – PMU and Phasor Data Concentrators

1.7 Phasor Estimator

AC waveforms typically oscillate at or close to 60 Hz frequency (i.e. 60 cycles take place in 1 second). It could be perfectly sinusoidal during steady-state or distorted during dynamics as the example shown in Figure 3 which depicts as 0.1 Hz oscillations in the power system.

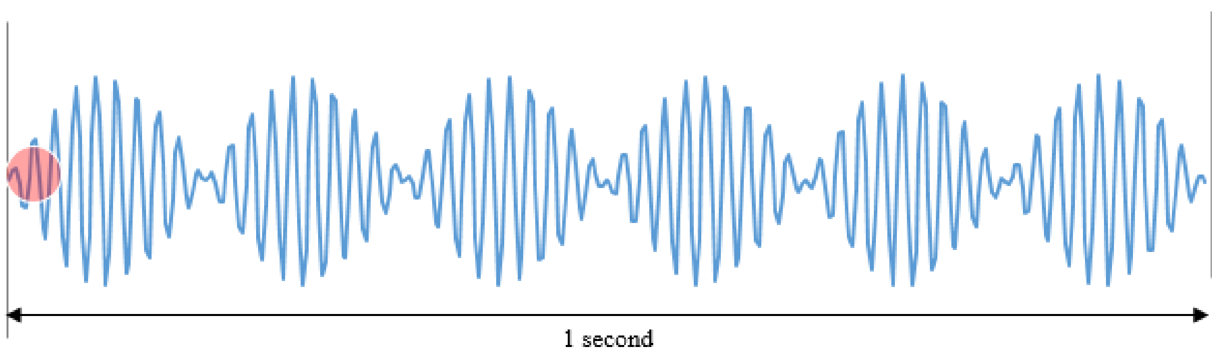

Figure 3 – AC waveform during dynamics

AC waveforms typically oscillate at or close to 60 Hz frequency (i.e. 60 cycles take place in 1 second). It could be perfectly sinusoidal during steady-state or distorted during dynamics as the example shown in Figure 3 which depicts as 0.1 Hz oscillations in the power system.

The A/D converter built into the PMU does followings on the continuous phase voltage and phase current waveforms where the values are measured by PTs and CTs.

(1) Select preceding 60/N cycle segments in last 1/30 sec of waveforms from A, B, C phase voltages and A, B, C phase currents (N = sampling rate).

(2) Discretize each selected continuous waveform segment to a large number of separate data points.

The phasor estimator is a mini-computer built into the *synchrophasor* data generating device that performs following calculations on the discretized waveform segments in order to derive the phasors.

(3) Use Discrete Fourier Transformation (DFT) algorithm in the mini-computer to calculate $\mathbf{A_1}$ and $\mathbf{B_1}$ correspond to the term $\mathbf{A_1 \, Cos \, \omega t + B_1 \, Sin \, \omega t}$ of each current phase and voltage phase.

(4) Convert each $\mathbf{A_1 \, Cos \, \omega t + B_1 \, Sin \, \omega t}$ to the form of $\mathbf{C \, Sin \, (\omega t + \alpha)}$.

(5) Compare each $\mathbf{C \, Sin \, (\omega t + \alpha)}$ to the common reference phasor $\mathbf{Sin \, (\omega t + \beta)}$ from the GPS.

(6) Assign rms magnitude $\mathbf{C/\sqrt{2}}$ and angle $\mathbf{(\alpha - \beta)}$ to the corresponding waveform segment of each phase voltage and phase current.

(7) Assign UTC corresponds to the mid-point of the waveform segment to each magnitude and angle calculated in (6).

(8) Repeat (1) – (7) for next 60/N cycle segments of waveforms.

In addition to above, following optional calculations are available in the mini-computer.

- Compute positive, negative, zero sequence magnitudes and angles of phase voltages and currents.
- Compute 3-phase active power and reactive power.
- Compute frequency.
- Compute rate of change of frequency.

2. Monitoring Requirements: Generators

2.1 Phasor Data Requirements for Generators

Generators shall install and maintain at its expense, synchrophasor data generating devices and required infrastructure including instrument transformers, communication chaneles and PDCs if total generation facility is rated equal to or greater than 100 MVA and provide synchrophasor data as per below specifications to the IESO on continuous basis.

Specifications noted as “required” must be satisfied, specifications noted as “preferred” are not required but add additional operational value and should be satisfied wherever possible.

Table 1 – Requirements for Generators

Attribute	Status	Requirement
Measurement Point	Required	If a single generating unit is rated equal to or greater than 100 MVA and directly connected to the IESO-controlled grid, provide synchrophasor data measured at generator terminal (i.e. low side of the generator output transformer). See configuration 1 of Figure 3. If a generator facility has multiple generator units and aggregate equal to or greater than 100 MVA and connected to the IESO-controlled grid, provide aggregated synchrophasor data measured at generator facility side of each point of connection to the IESO-controlled grid. See configurations 2, 3, 4 of Figure 3.
Measurement Point	Preferred	Provide additional synchrophasor data measured as shown in Figure 3.
Measured Quantities	Required	Provide frequency, positive sequence voltage phasor and positive sequence current phasor. Actual measurement of all three phases is required for calculation of above phasors.

Measured Quantities	Preferred	Provide rate of change of frequency, individual RYB phase current and RYB phase voltage phasors. If providing aggregated positive sequence phasors requires installing instrument transformers to individual generators, provide phasor data from individual generators. Note: Individual phase voltage and current phasor data are valuable for analyzing phase imbalance problems.
Coordinates	Required	Provide phasor data in polar coordinates where angles must be in degrees in the range 0 to 360 and magnitudes must be in SI units.
System Frequency	Required	Provide phasor data continuously at frequency between 57 Hz and 62 Hz.
Scan Rate	Required	Provide synchrophasor data at least once in every one thirtieth of a second (i.e. 30 samples per second).
Scan Rate	Preferred	Provide phasors data at least once in every one sixtieth of a second (i.e. 60 samples per second) or device shall be suitable for configuring the sample rate of 10, 25, 50, 60 samples per second. Note: Typical mid-term dynamic analysis tools provide 240 data point sets per second. Dynamic model validation using synchrophaor data can be improved if sample rate is increased to 60 samples per second.
DC Supply Variations	Required	Provide phasors data where station DC supply enables phasor measurement equipment on variations of +10% to -10% DC voltage.
Time-Tag Accuracy	Required	Provide phasor data with time-stamp equal or less than 1 microsecond accuracy from Coordinated Universal Time (UTC) clock. Provide phasors data in UTC with zero offset. Notes: (1) Time offset is an amount of time subtracted from or added to UTC to get the current civil time, whether it is standard time or daylight saving time (DST). (2) A time error of 1 microsecond corresponds to a phasor error of 0.022 degrees for a 60 Hz system.

Data Format	Required	Provide phasor data in IEEE C37.118 format. The accuracy shall be as per the IEEE C37.118-2005 standard level 1 where Total Vector Error (TVE) shall be less than 1%.
Data Format	Preferred	Provide phasor data in IEEE C37.118 format. The accuracy shall be as per the IEEE C37.118.2-2011 class M. Note: There is no direct translation between phasor data accuracy level 0 & 1 in 2005 standard and classes M & P in 2011 standard. P class includes accuracy requirements of level 0 whereas M class includes accuracy requirements of level 1. M class has more filters, provides more precise data, higher accuracy, slow (higher latency), used mostly for measurements, good for steady-state analysis. P class has less filters, provides less precise data, accuracy within acceptable limits, fast (low latency), used mostly for control and protection, good for dynamic analysis.
Network Protocol	Required	Provide phasor data via a network that comply with TCP/IP or UDP/IP protocol.
Data Storage	Required	Provide 90 days-worth of rolling storage for phasor data.
Data Storage	Preferred	Provide 180 days-worth of rolling storage for phasor data.
Instrument Transformers	Required	Provide instrument transformers with accuracy equal or better than those used for SCADA measurements.
Latency	Required	Provide total latency for phasor data low enough to be appropriately utilised in IESO real-time applications. Note: Total latency depends on sampling rate, PMU classification (M or P), PMU computation time, PDC time and communication time. Higher latency makes phasor data ineffective in real-time applications and low latency makes increased loss of phasor data at the PDC.
Latency	Preferred	Provide total latency for phasor data from PMU to the IESO control center no more than 100 ms if that data is to be used in a Linear State Estimator whose output is to be used in on-line Transient Stability program. Provide total latency for phasor data from PMU to the IESO control center no more than 1 sec if that data is to be used only for visualisation for situational awareness.

Bandwidth	Required	Provide communication channels with bandwidth adequate to transmit the volume of phasor data at selected sample rate. Note: The required bandwidth varies with the number of phasor data and sample rate. Thus, the size of bandwidth required depends on sample rate, the facility MVA size and configuration and the communication segment for which bandwidth is applicable (i.e. from PMU to local PDC, local PDC to mid-level, mid-level to high level).
Bandwidth	Preferred	Provide dedicated communication channels to avoid any data transmission interruption and excessive latency.

2.2 Applicable Generator Connection Configurations

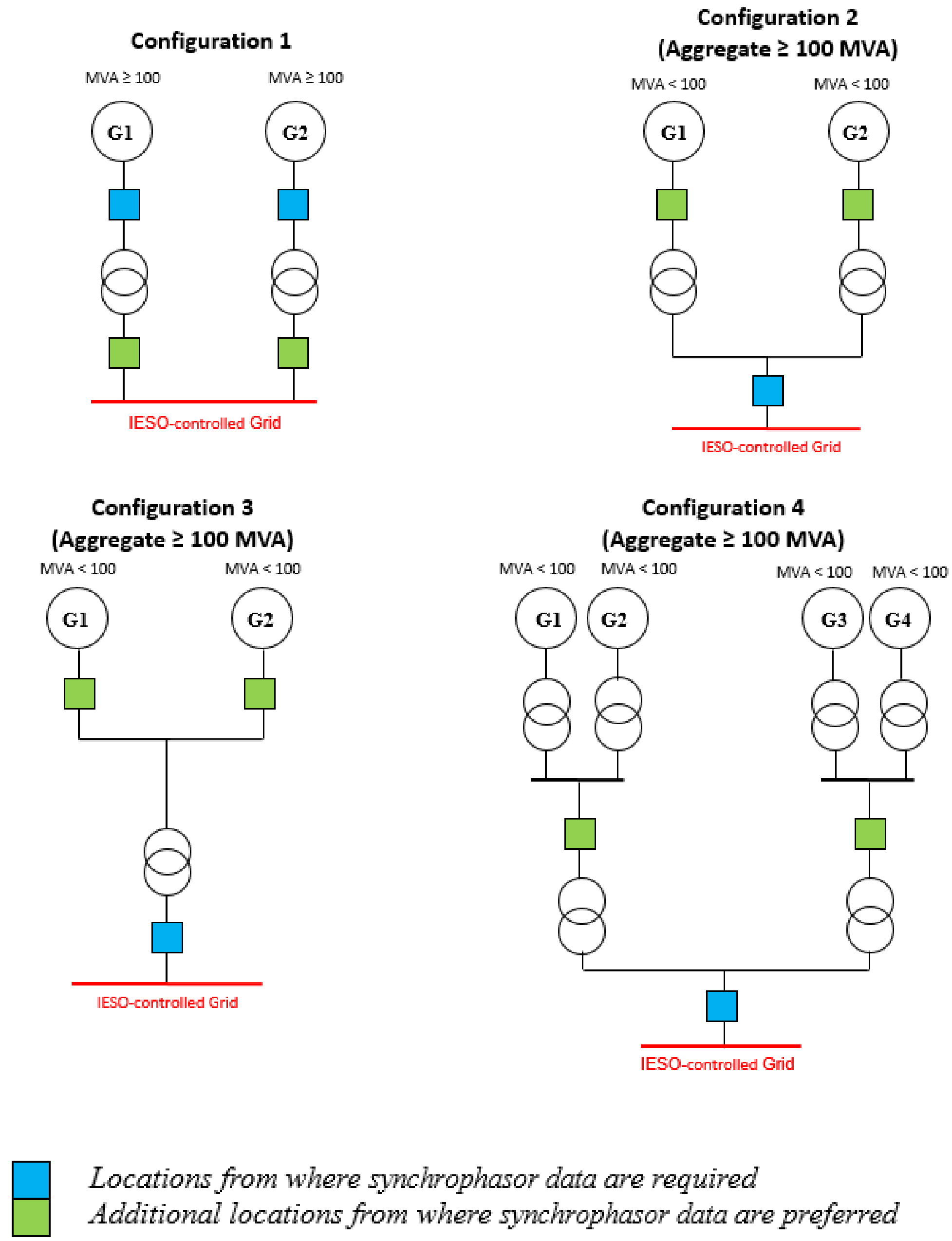

Figure 4 – Phasor Requirements for different generator connection configurations

3. Monitoring Requirements: Transmitters

3.1 Phasor Data Requirements for Transmitters

Transmitters shall install and maintain at its expense synchrophasor data generating devices and required infrastructure including instrument transformers, communication chaneles and PDCs and provide synchrophasor data as per below specifications to the IESO on continuous basis.

Specifications noted as “required” must be satisfied, specifications noted as “preferred” are not required but add additional operational value and should be satisfied wherever possible.

Table 2 – Requirements for Transmitters

Attribute	Status	Requirement
Measurement Points and quantities	Required	• Two separate buses in 500 kV stations, two separate buses in bulk power stations, two separate buses in stations that are required to restore the grid from black-start units. Provide positive sequence voltage phasors and frequency. • Terminals of circuits defining Interconnection Reliability Operating Limits (IROL) and Interties. Provide positive sequence current phasors, positive sequence voltage phasors and frequency. • Terminal bus of Static Var Compensators (SVC). Provide positive sequence current phasors, positive sequence voltage phasors and frequency.
Measurement Points and quantities	Preferred	Provide rate of change of frequency, individual RYB phase current and RYB phase voltage phasors. Positive sequence current phasors and positive sequence voltage phasors from high-side and low-side of auto-transformers. Notes: (1) Individual phase voltage and phase current phasor data are useful in analyzing phase imbalance problems. (2) With both low-side and high-side sphasor data from auto-transformers, the impact of Geo-Magnetically Induced (GIC) currents can be monitored.

Coordinates	Required	Provide phasor data in polar coordinates where angles must be in degrees in the range 0 to 360 and magnitudes must be in SI units.
System Frequency	Required	Provide phasor data continuously at frequency between 57 Hz and 62 Hz.
Scan Rate	Required	Provide synchrophasor data at least once in every one thirtieth of a second (i.e. 30 samples per second).
Scan Rate	Preferred	Provide phasors data at least once in every one sixtieth of a second (i.e. 60 samples per second) or device shall be suitable for configuring the sample rate of 10, 25, 50, 60 samples per second. Note: Typical mid-term dynamic analysis tools provide 240 data point sets per second. Dynamic model validation using synchrophaor data can be improved if sample rate is increased to 60 samples per second.
DC Supply Variations	Required	Provide phasors data where station DC supply enables phasor measurement equipment on variations of +10% to -10% DC voltage.
Time-Tag Accuracy	Required	Provide phasor data with time-stamp equal or less than 1 microsecond accuracy from Coordinated Universal Time (UTC) clock. Provide phasors data in UTC with zero offset. Notes: (1) Time offset is an amount of time subtracted from or added to UTC to get the current civil time, whether it is standard time or daylight saving time (DST). (2) A time error of 1 microsecond corresponds to a phasor error of 0.022 degrees for a 60 Hz system.
Data Format	Required	Provide phasor data in IEEE C37.118 format. The accuracy shall be as per the IEEE C37.118-2005 standard level 1 where Total Vector Error (TVE) shall be less than 1%.

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Network Protocol	Required	Provide phasor data via a network that comply with TCP/IP or UDP/IP protocol.
Data Storage	Required	Provide 90 days-worth of rolling storage for phasor data.
Data Storage	Preferred	Provide 180 days-worth of rolling storage for phasor data.
Instrument Transformers	Required	Provide instrument transformers with accuracy equal or better than those used for SCADA measurements.
Latency	Required	Provide total latency for phasor data low enough to be appropriately utilised in IESO real-time applications. Note: Total latency depends on sampling rate, PMU classification (M or P), PMU computation time, PDC time and communication time. Higher latency makes phasor data ineffective in real-time applications and low latency makes increased loss of phasor data at the PDC.
Latency	Preferred	Provide total latency for phasor data from PMU to the IESO control center no more than 100 ms if that data is to be used in a Linear State Estimator whose output is to be used in on-line Transient Stability program. Provide total latency for phasor data from PMU to the IESO control center no more than 1 sec if that data is to be used only for visualisation for situational awareness.

Bandwidth	Required	Provide communication channels with bandwidth adequate to transmit the volume of phasor data at selected sample rate. Note: The required bandwidth varies with the number of phasor data and the sample rate. Thus, the size of bandwidth required depends on sample rate, the facility MVA size and configuration and the communication segment for which bandwidth is applicable (i.e. from PMU to local PDC, local to mid-level, mid-level to high level).
Bandwidth	Preferred	Provide dedicated communication channels to avoid any data transmission interruption and excessive latency.