# Draft Synchrophasor Data Requirements

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# 1. Introduction

## 1.1 Purpose

The primary objective of the Synchrophasor Data Requirements manual is to provide Market Participants with technical specifications and guidelines ~~for Market Participants to~~ for supplying synchrophasor data with ~~correct~~ the required attributes to the IESO for ~~its~~ utilizations 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~~ certain transmitters and generators connected to the IESO-controlled grid ~~and the transmitters~~.

The synchrophasor data are generated mainly by ~~a~~ stand-alone devices called Phasor Measurement Units (PMU). The synchrophasor data can also be generated by other dual-purpose devices such as (1) modern ~~Digital~~ Dynamic Disturbance Reorders[1] (DDR) ~~which is used for intermittent data recording,~~ or (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 is instead focused on clarifying ~~limited to~~ the technical requirements of the synchrophasor data ~~those~~ any of those devices must generate in order to meet the IESO's requirements. ~~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 a 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 the 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 registration and connection assessment ~~entry as well as interconnection~~ processes. The applicable market participants will need to comply with NERC Crtitical Infrastructure Protection (CIP) requirements.

## 1.3 Real-Time Monitoring Devices

[1] Newer versions of DDRs with PMU capabilities

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

The devices that generate synchrophasor data offer the following benefits compared to previous monitoring standards ~~as synchrophasor data contains~~:

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

(2) phase angles.

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

(4) continuous real-time measurements.

The data from SCADA, PSDR, DFR and DDR have ~~limited benefits~~limitations compared to synchrophasor data, including:

- ~~The~~ SCADA provides real-time measurements continuously but at a much slower ~~sampling~~ reporting rate (2 - 4 samples per second), does not measure phase angle and data contains no universal time stamp.
- ~~The d~~Data from PSDR, traditional DFR, and traditional DDR have similar or higher ~~sampling~~ reporting rate compared to synchrophasor data, provide phase angles, data contains universal time stamp, however ~~they are recording~~ these devices are only for recording (i.e. not real-time)
- Data recording in DFR is 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 s~~Synchrophasor data requirements 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 on those requirements ~~stated in Market Rules with more detailed specifications~~.

## 1.5 Phasor Measurement Unit (PMU)

The PMU is a device that generates synchrophasor 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 synchrophasor 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 as shown in **Figure 2**. 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 allows those synchronized 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 synchronized 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. They then and feed to various synchrophasor data based computer applications such as Network Monitoring Systems and State Estimators (SE) or are storageds at local in local control centers. From multiple mid-level PDCs, often synchrophasor data proceeds to a high level PDC which is usually regionally based and performs similar functions as mid-level PDCs at a large scale such as Wide-Area Monitoring System (WAMS).

The number and the hierarchy of different PDCs in a synchrophasor measurement system vary with the size of the power grid, monitoring extent and visibility requirements, ownership of synchrophasor data, capacity of each PDC, communication network, etc. The PDCs may be consideredrecognized as an administrative function rather than an electrical device or hardware/software package. A structured hierarchy of PDCs can be formed to serve a large power grid constituting multiple substations, utilities, control areas, reliability coordinators and interconnections and synchrophasor data is streaming thru them via a large network of communication links as data quality checks and applications take place at different points. For the reference of Market Participants should refer to, the latest IEEE standards applicable to PDC requirements is C37.247-2019.

**Figure 1 | Components of PMU**

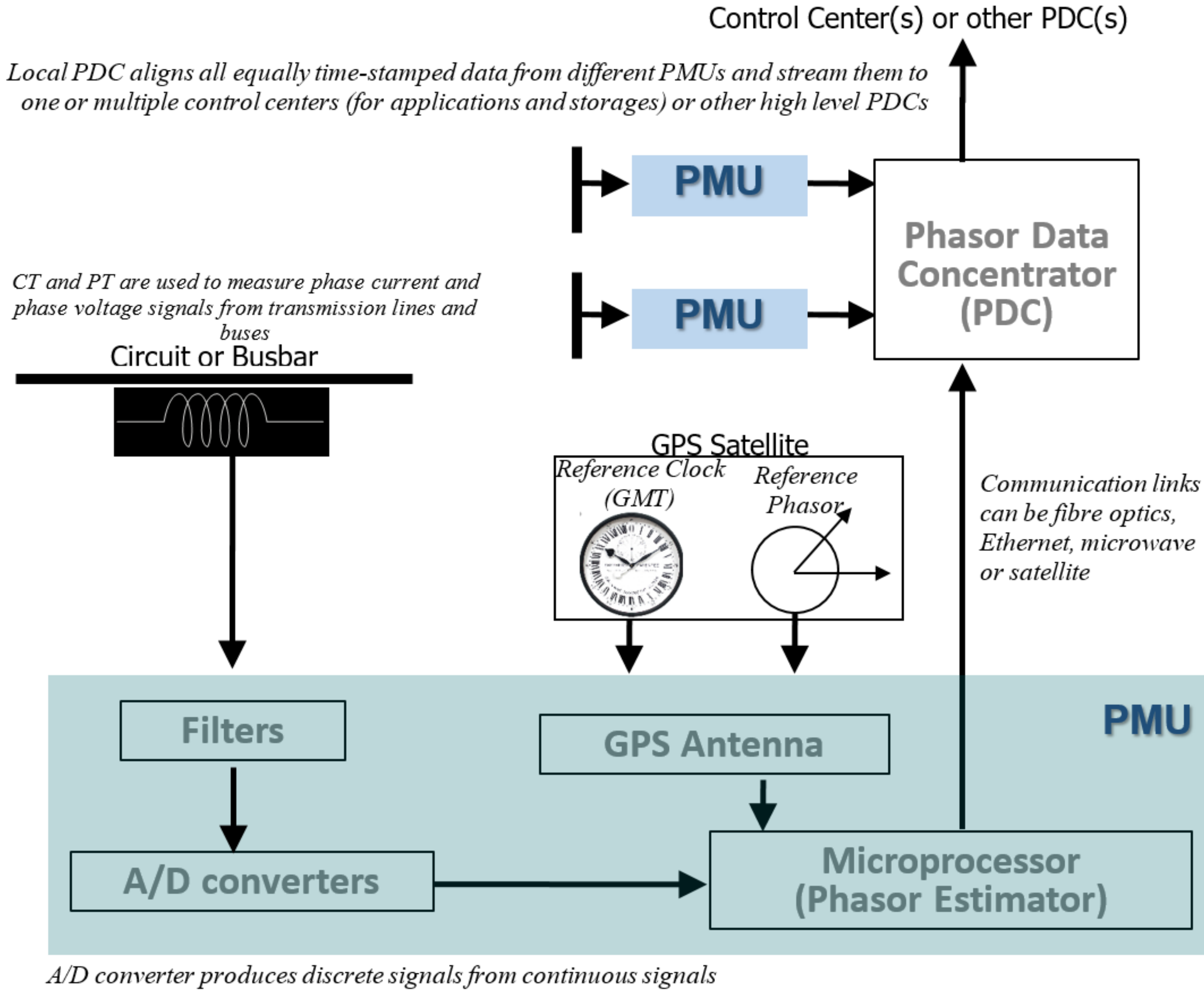
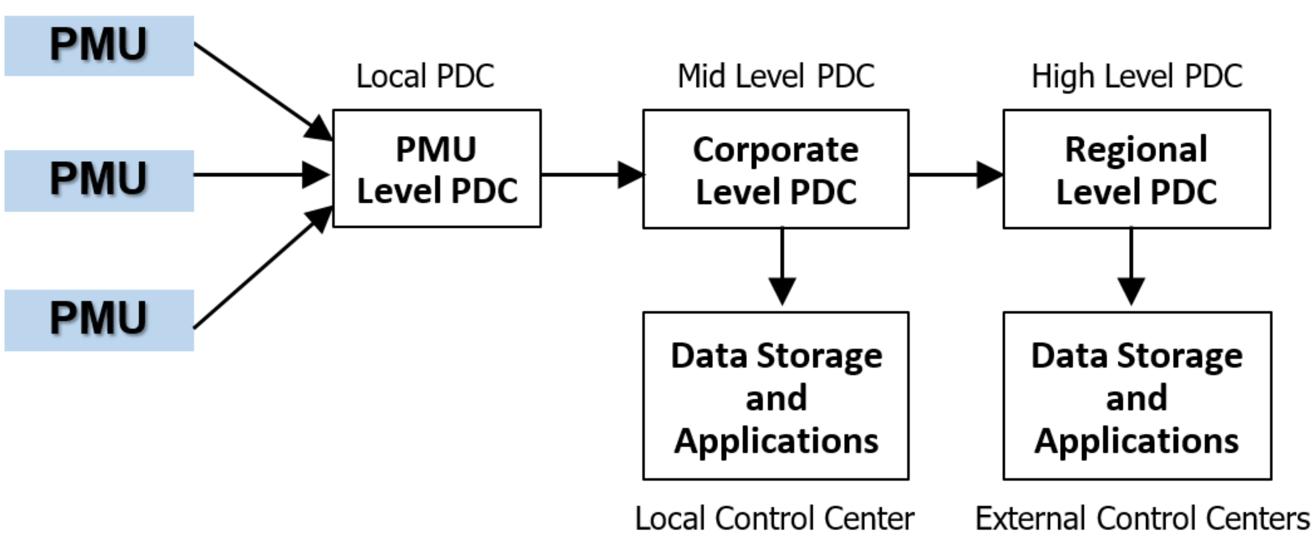


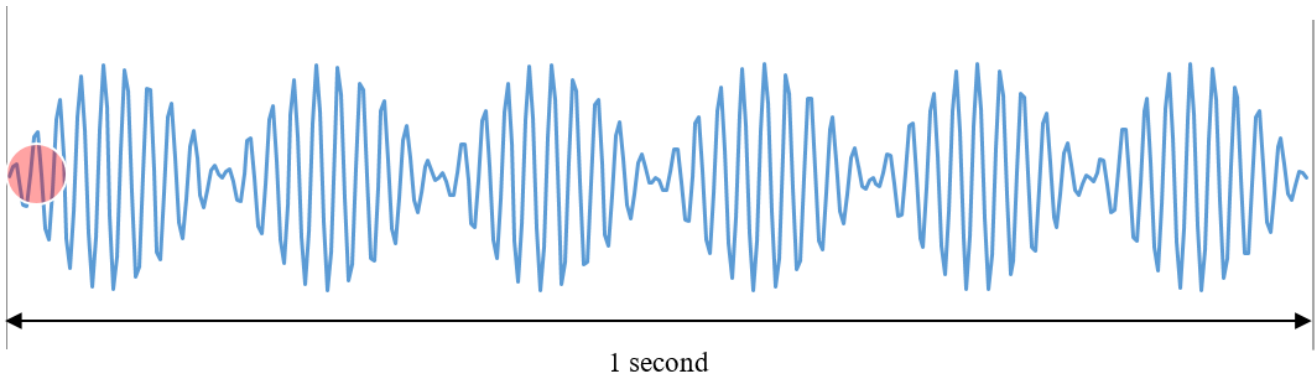

**Figure 2 | PMU and Phasor Data Concentrators**



## 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**




The Analog to Digital (A/D) converter built into the PMU does followings on the continuous phase voltage and phase current waveforms where the values are measured by potential transformers (PTs) and current transformers (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~~ reporting 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 $A_1$ and $B_1$ correspond to the term $A_1 \cos \omega t + B_1 \sin \omega t$ of each current phase and voltage phase.

(4) Convert each $A_1 \cos \omega t + B_1 \sin \omega t$ to the form of $C \sin(\omega t + \alpha)$.

(5) Compare each $C \sin(\omega t + \alpha)$ to the common reference phasor $\sin(\omega t + \beta)$ from the GPS.

(6) Assign rms magnitude $C/\sqrt{2}$ and angle $(\alpha - \beta)$ 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 channels 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 currently required but add additional operational value and should be satisfied wherever ~~possible~~ practical and may become "required" in future if needed for any reliability purposes.

**Table 1 | Requirements for Generators**

| **Attribute** | **Status** | **Requirement** |
|---|---|---|
| Measurement Point | Required | (1) If a single generating unit is rated equal to or greater than 100 MVA (name-plate rating) 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 4.<br>(2) If a generator facility has multiple generator units and aggregate equal to or greater than 100 MVA (aggregate name-plate rating) and connected to the IESO-controlled grid, provide aggregated synchrophasor data measured at the generator facility side of each point of connection to the IESO-controlled grid. See configurations 2, 3, 4 of **Figure 4**. Alternatively, other measuring locations of synchrophasor data inside the facility can be provided if they allow for calculating the aggregated synchrophasor data at the generator facility side of each point of connection. See configurations 2, 3, 4 of **Figure 4**.<br>Eligible generation facilities in (1) and (2) are not required to provide the synchrophasor data if they meet the following criterion:<br>• The generation facility is not directly connected to a Bulk Power System (BPS) Station or has no connection point voltage greater than 200 kV.<br>Eligible generation facilities in (1) and (2) may not be required to provide the synchrophasor data if they meet one of the following criteria: |

| Attribute | Status | Requirement |
|---|---|---|
| | | a. The generation facility will be deregistered within a period of 5 years from date of implementation of market rules.<br>b. The annual gross capacity factor of the generation facility is significantly low.<br><br>The applicability of criteria (a) and (b) above are subject to the IESO's periodic review and assessment of the decommissioning plan and evaluation of capacity factors respectively, per mutual agreement on a case-by-case basis. |
| Measurement Point | Required | For generation units, regardless of rated size, whose output power flow is a part of an Interconnection Reliability Operating Limit (IROL) definition, provide positive sequence voltage phasor, positive sequence current phasor and frequency at the terminals defining the IROL. This requirement will take precedence even if a facility meets any of the applicability criteria (a) and (b) listed above. |
| Measurement Point | Preferred | Provide additional synchrophasor data from a generator facility for specific reliability needs (e.g. generation facility with history of oscillatory events or to achieve sufficient observability over the IESO controlled grid). |
| ~~Measurement Point~~ | ~~Preferred~~ | ~~Provide additional synchrophasor data measured as shown in **Figure 4**.~~ |
| Measured Quantities and Units | Required | Provide frequency (Hz), positive sequence voltage magnitude (Volts or kV), positive sequence voltage phasor angle (degrees), ~~and~~ positive sequence current phasor magnitude (Amperes or kA), and positive sequence current phasor angle (degrees). Actual measurement of all three phases is required for calculation of above phasors. It is not mandatory to have dedicated measuring devices to provide required measured quantities. |
| Measured Quantities | Preferred | Provide rate of change of frequency, individual RYB phase current and RYB phase voltage phasors.<br><br>If providing aggregated positive sequence phasors requires installing instrument transformers to individual generators, provide phasor data from individual generators. |

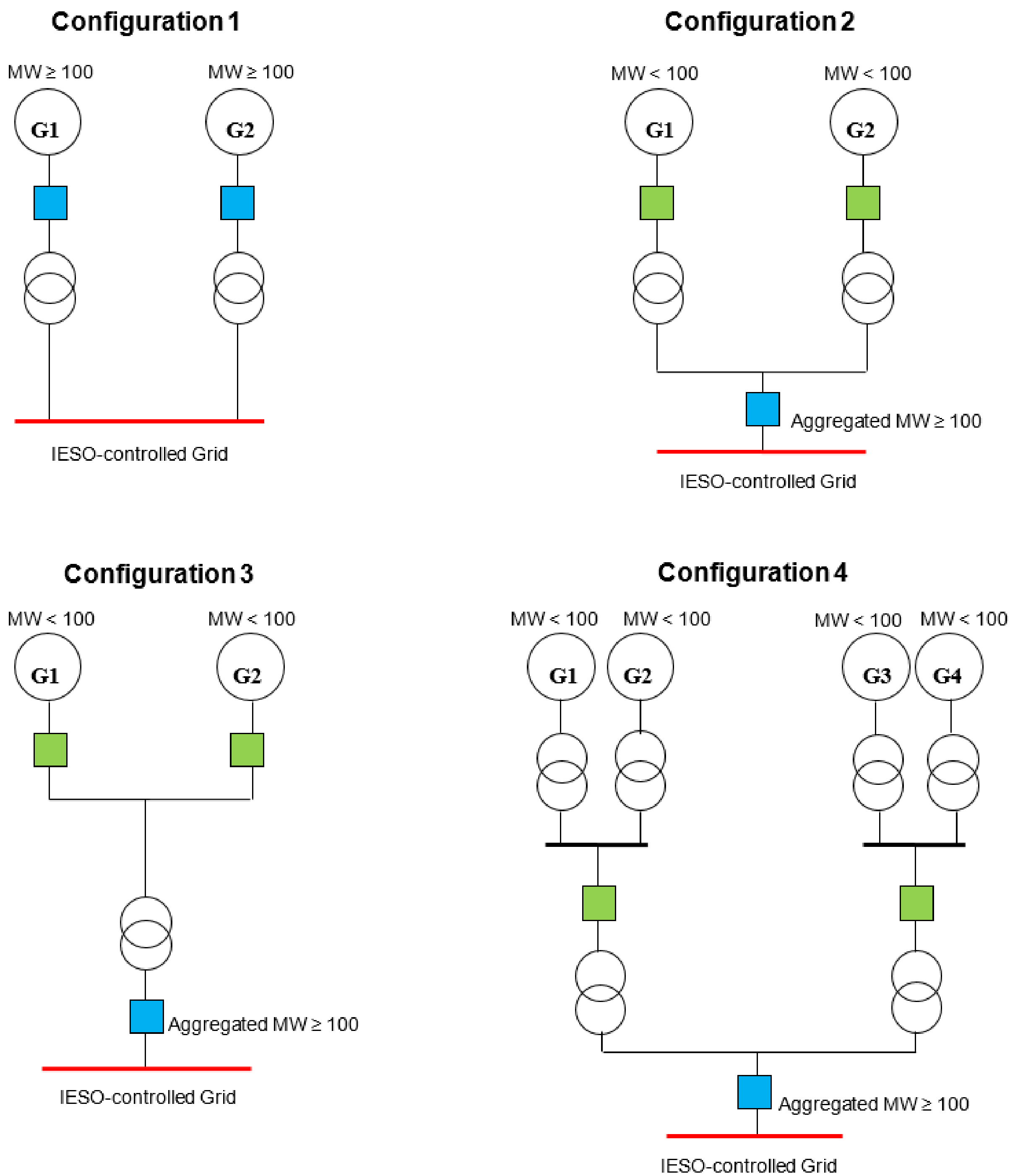
| Attribute | Status | Requirement |
|---|---|---|
| | | Note: Individual phase voltage and current phasor data are valuable for analyzing phase imbalance problems. |
| Coordinates | Required | Provide phasor data in polar coordinates where angles must be in degrees in the range 0 to 360 and magnitudes must be in SI units. |
| System Frequency | Required | Provide phasor data continuously at frequency between 57 Hz and 62 Hz. |
| ~~Scan~~ Reporting Rate | Required | Provide synchrophasor data at least once in every one thirtieth of a second (i.e. 30 samples per second). |
| ~~Scan~~ Reporting 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 reporting rate of 10, 30, 25, 50, 60 samples per second~~.<br><br>Note: Typical mid-term dynamic analysis tools provide 240 data point sets per second. Dynamic model validation using synchrophasor data can be improved if ~~sample~~ reporting 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.<br><br>Provide phasors data in UTC with zero offset.<br><br>Notes:<br><br>(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).<br><br>(2) A time error of 1 microsecond corresponds to a phasor error of 0.022 degrees for a 60 Hz system. |

| Attribute | Status | Requirement |
|---|---|---|
| Data Format | Required | Provide phasor data in the IEEE C37.118data format. The accuracy shall be as per the corresponding IEEE C37.118-2005 standards 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.<br><br>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 utilized in IESO real-time applications.<br><br>Note: Total latency depends on sampling reporting 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. |

| Attribute | Status | Requirement |
|---|---|---|
| Latency | Preferred | Provide total latency for phasor data from PMU to the IESO control center or IESO owned PDC 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.<br><br>~~Provide total latency for phasor data from PMU to the IESO control center or IESO owned PDC no more than 1 sec if that data is to be used only for visualization for situational awareness.~~ |
| Bandwidth | Required | Provide communication channels with bandwidth adequate to transmit the volume of phasor data at selected ~~sample~~ reporting rate.<br><br>Note: The required bandwidth varies with the number of phasor data and ~~sample~~ reporting rate. Thus, the size of bandwidth required depends on ~~sample~~ the reporting 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 | Examples for synchrophasor data measurement locations ~~Phasor Requirements~~ for different generator connection configurations**




*Locations from where synchrophasor data are required*

*Possible alternate ~~Additional~~ locations from where synchrophasor data are ~~preferred~~ required*

# 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 channels 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 currently required but add additional operational value and should be satisfied wherever ~~possible~~ practical and may become "required" in future if needed for any reliability purposes.

**Table 2 | Requirements for Transmitters**

| Attribute | Status | Requirement |
|---|---|---|
| Measurement Points and quantities | Required | • Two separate 500 kV buses in 500 kV stations, two separate BPS-classified buses in BPS stations, two separate buses in stations that are required to restore the grid from black-start units. Provide positive sequence voltage phasor~~s~~ magnitude, positive sequence voltage phasor angle, and frequency.<br>• Terminals of circuits defining Interconnection Reliability Operating Limits (IROL) and Interties. Provide positive sequence current phasor~~s~~ magnitude, positive sequence current phasor angle, positive sequence voltage phasor~~s~~ magnitude, positive sequence voltage phasor angle, and frequency.<br>• Terminal bus of Static Var Compensators (SVC), synchronous condensers and static synchronous compensators (STATCOM). Provide positive sequence current phasor~~s~~ magnitude, positive sequence current phasor angle, positive sequence voltage phasor~~s~~ magnitude, positive sequence voltage phasor angle, and frequency. |

| Attribute | Status | Requirement |
|---|---|---|
| Measurement Points and quantities | Preferred | Provide positive sequence current phasor magnitude and positive sequence current phasor angle from one circuit terminal for circuits required to restore the grid from black-start units.<br><br>Provide rate of change of frequency, individual RYB phase current and RYB phase voltage phasors.<br><br>Positive sequence current phasors and positive sequence voltage phasors from high-side and low-side of auto-transformers.<br><br>Notes:<br><br>(1) Individual phase voltage and phase current phasor data are useful in analyzing phase imbalance problems.<br><br>(2) With both low-side and high-side phasor data from auto-transformers, the impact of Geo-Magnetically Induced (GIC) currents can be monitored. |
| Units of Measured Quantities | Required | Provide frequency (Hz), positive sequence voltage magnitude (Volts or kV), positive sequence voltage phasor angle (degrees), positive sequence current phasor magnitude (Amperes or kA), and positive sequence current phasor angle (degrees). Actual measurement of all three phases is required for calculation of above phasors. It is not mandatory to have dedicated measuring devices to provide required measured quantities. |
| 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~~ Reporting Rate | Required | Provide synchrophasor data at least once in every one thirtieth of a second (i.e. 30 samples per second). |

| Attribute | Status | Requirement |
|---|---|---|
| ~~Scan~~ Reporting 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 reporting rate of 10, 30, 25, 50, 60 samples per second~~.<br><br>Note: Typical mid-term dynamic analysis tools provide 240 data point sets per second. Dynamic model validation using synchrophasor data can be improved if ~~sample~~ reporting 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.<br><br>Provide phasors data in UTC with zero offset.<br><br>Notes:<br><br>(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).<br><br>(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 the IEEE ~~C37.118~~data format. ~~The accuracy shall be as per the corresponding IEEE C37.118-2005 standards level 1 where Total Vector Error (TVE) shall be less than 1%~~. |

| Attribute | Status | Requirement |
| --- | --- | --- |
| 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.<br><br>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 utilized in IESO real-time applications.<br><br>Note: Total latency depends on sample reporting 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 or IESO owned PDC 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.<br><br>Provide total latency for phasor data from PMU to the IESO control center or IESO owned PDC no more than 1 sec if that data is to be used only for visualization for situational awareness. |

| Attribute | Status | Requirement |
|---|---|---|
| Bandwidth | Required | Provide communication channels with bandwidth adequate to transmit the volume of phasor data at selected ~~sample~~ reporting rate.<br><br>Note: The required bandwidth varies with the number of phasor data and the ~~sample~~ reporting rate. Thus, the size of bandwidth required depends on ~~sample~~ reporting 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. |

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