PUBLIC

Market Manual

Market Manual 1: Connecting to Ontario's Power System

Part 1.7: Synchrophasor Data Requirements

Issue 2.1~~Issue 2.0~~

December 3, 2025

This document provides detailed procedures to be followed by connection applicants who wish to connect to the IESO-controlled grid.

MAN-131

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This *market manual* may contain a summary of a particular *market rule*. Where provided, the summary has been used because of the length of the *market rule* itself. The reader should be aware however, that where a *market rule* is applicable, the obligation that needs to be met is as stated in the *market rules*. To the extent of any discrepancy or inconsistency between the provisions of a particular *market rule* and the summary, the provision of the *market rule* shall govern.

Document Change History

Issue	Reason for Issue	Date
Refer to Issue 1.0 (PRO-723) for changes prior to Market Transition.		
1.0	Market transition	April 4, 2025
2.0	Issued for Baseline 54.1	December 3, 2025
2.1	Issued as part of Updates to IESO Monitoring Requirements	December 10, 2025

Related Documents

Document ID	Document Title
RUL-11	Market Rules Chapter 2: Grid Connection Requirements
RUL-12	Market Rules Chapter 2: Grid Connection Requirements – Appendices
RuL-24	Market Rules Chapter 11: Definitions

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Reference	Description of Change
Section 4	New section to outline requirements for electricity storage facilities
Section 6	New section to outline PMU connection process
Throughout	Reformatting to post-MRP template and conventions

Market Manuals

Market manuals set out procedural and administrative details with respect to *market rule* requirements. Where there is a conflict between the requirements described in a *market manual* or appended document, and those within the *market rules*, the *market rules* shall prevail.

Market Manual Conventions

The standard conventions followed for market manuals are as follows:

- The word 'shall' denotes a mandatory requirement;
- References to *market rule* sections and sub-sections may be abbreviated in accordance with the following representative format: '**MR Ch.1 ss.1.1-1.2'** (i.e. *market rules,* Chapter 1, sections 1.1 to 1.2).
- References to *market manual* sections and sub-sections may be abbreviated in accordance with the following representative format: '**MM 1.5 ss.1.1-1.2'** (i.e. *market manual* 1.5, sections 1.1 to 1.2).
- Internal references to sections and sub-sections within this manual take the representative format: 'sections 1.1 – 1.2'
- Terms and acronyms used in this *market manual* and its appended documents that are italicized have the meanings ascribed thereto in **MR Ch.11**;
- All user interface labels and options that appear on the IESO gateway and tools are formatted with the bold font style; and
- Data fields are identified in all capitals.

– End of Section –

~~Market Manuals~~

~~The *Market Manuals* consolidate the market procedures and associated forms, standards and policies that define the operation of the various areas within the *IESO-administered markets*. Market procedures provide more detailed descriptions of the requirements for various activities than are specified in the *Market Rules*. Where there is a discrepancy between the requirements in a document within a *Market Manual* and the *Market Rules*, the *Market Rules* shall prevail.~~

~~Standards and policies appended to, or referenced in, these procedures provide a supporting framework.~~

~~Market Procedures~~

~~"Connecting to Ontario's Power System" is Series 1 of the Market Manuals, where this document forms Part 1.7: Synchrophasor Data Requirements.~~

– End of Section –

1 Introduction

1.1 Purpose

This *market manual* elaborates on *synchrophasor* data requirements for:

1) ~~*Generators*~~ *Generation facilities* connected to the *IESO-controlled grid*, as documented in MR Ch.4 App. 4.15; ~~and~~
2) ~~*Transmitters*~~ *Transmission systems* connected to the *IESO-controlled grid*, as documented in MR Ch.4 App. 4.16; and
~~2)~~3) *Electricity storage facilities* connected to the *IESO-controlled grid*, as documented in MR Ch. App. 4.24.~~.~~

Sections 2, ~~and~~ 3, and 4 include technical specifications and guidelines for *generators*, ~~and~~ *transmitters*, and *electricity storage participants* for supplying *synchrophasor* data with the required attributes to the IESO for utilization in planning and operation of the *IESO-controlled grid*. Section ~~4~~5 and 6 includes the process of registering Phasor Measurement Units (*PMUs*) with the *IESO* before a connection can be established for the transmission of *synchrophasor* data and the process for connecting *PMUs*.

~~Section 5 includes background information on *PMU* technology and infrastructure, including where it fits with regards to conventional monitoring solutions.~~

1.2 Scope

This *market manual* supplements the following *market rules*:

- MR Ch.4 s.7.2: Provision of Connection-Related Information
- MR Ch. App. 4.15: IESO Monitoring Requirements: *Generators*
- MR Ch. App. 4.16: IESO Monitoring Requirements: *Transmitters*
- MR Ch. App. 4.24: IESO Monitoring Requirements: *Electricity storage participants*

~~The *s*~~*Synchrophasor* data ~~are~~ is ~~produced mainly by stand-alone devices~~primarily generated by dedicated devices ~~called Phasor Measurement Units (*PMU*)~~. However, ~~The~~ *synchrophasor* data can also be produced by other ~~dual~~multi-purpose devices that incporporate *synchrophasor* data ~~PMU~~ capabilities such as (1) modern Dynamic Disturbance Recorders ~~(DDRs)~~ or (2) Intelligent Electronic Devices ~~(IEDs)~~ used for protection. The technical requirements and functionalities of those devices are unique and ~~vastly~~ materially different to each other. The scope of this *market manual* does not include technical requirements of those devices but is instead focused on clarifying the technical requirements of the *synchrophasor* data that any of those devices, each

considered to be a *phasor measurement unit (PMU),* must produce to meet the *IESO*'s requirements.

The *synchrophasor* data from the *PMU* devices may be~~are~~ transmitted to the *IESO* via a processor called the Phasor Data Concentrator (PDC). The technical requirements of the PDC are also not in the scope of this *market manual*.

1.3 Contact Information

Changes to this *market manual* are managed via the IESO Change Management process. Stakeholders are encouraged to participate in the evolution of this *market manual* via this process. To contact the *IESO*, you can email IESO Customer Relations at customer.relations@ieso.ca or use telephone or mail. Telephone numbers and the mailing address can be found on the *IESO* website. IESO Customer Relations staff will respond as soon as possible.

– End of Section –

2 Requirements: Generators

2.1 Infrastructure Requirements for Generators

(MR Ch. 4 App.4.15)

~~*Generators* shall install and maintain at their expense, *synchrophasor* data generating devices and associated infrastructure including instrument transformers, communication channels and PDCs, and provide *synchrophasor* data as per below specifications (see **Section 2.22.2**) to the *IESO* on continuous basis.~~

~~Applicable *market* *Market* *participants*~~ are expected to follow NERC's IRO-010-3 standard as described in MM 11.1 s.7 when providing *synchrophasor* data to the *IESO* which will be used for situational awareness and planning analyses purposes. In cases where the *synchrophasor* data will be provided from devices already classified as a BES Cyber Asset then the data and its associated infrastructure must comply with *NERC* Critical Infrastructure Protection (CIP) program. ~~include *synchrophasor* data under their *NERC* Critical Infrastructure Protection (CIP) program. While the *IESO* will initially use the *synchrophasor* data for non-CIP related activities, *generators* are to consider CIP requirements when planning upgrades to their *facilities* so that they are in a position to meet CIP requirements when the IESO's *PMU* Integration Program advances to a point where CIP requirements will be needed. The *IESO* will engage with stakeholders to provide a reasonable timeline for the implementation of any specific CIP requirements.~~

Transmission of *synchrophasor* data to the *IESO* must occur over the internet using a secure IPsec site-to-site VPN connection with the following specifications:

~~1) Due to the higher bandwidth requirements associated with *synchrophasor* data, it should not be transmitted over existing dedicated communication links designed to transmit *SCADA* telemetry to the *IESO*. It it is recommended that this data instead be transmitted to the *IESO* over the internet via an IPsec site-to-site VPN connection. This connection must meet the following additional requirements:~~

~~2)~~1) Internet connection with bandwidth and latency specifications as per **Table 2-1**;

~~3)~~2) Public static IP address; and

~~4)~~3) Firewall device capable of creating IPsec site-to-site VPN tunnel with the following settings: IKEv2, AES-256 Encryption, SHA256 Data Integrity, 2048 bit DH group, PFS with 2048 bit DH group.

In certain circumstances, the *IESO* may permit the use of a private communication link instead of a public internet-based VPN connection. Approval for such arrangements can

be requested at the time of *PMU* registration via e-mail submissions at PMUregistration@ieso.ca. The *IESO* has the sole discretion in approving such arrangements and will evaluate each request on a case-by-case basis.

~~There is no requirement for redundancy in *synchrophasor* data communication links between *generators* to the *IESO* currently.~~

2.2 Phasor Data Requirements for Generators

(MR Ch. 4 App.4.15)

~~Specifications noted as "required" must be satisfied, specifications noted as "preferred" are not required but add additional operational value and should be satisfied wherever practical.~~

~~Note that t~~The *IESO* may, at ~~their~~its ~~own~~ discretion, require ~~*generation facilities*~~*generators* to provide *synchrophasor* data for reliability and system awareness purposes. Such need will be informed by considerations such as proximity to other *synchrophasor* measurement units, criticality of the *facility* from system stability perspective, etc. If the *IESO* determines that *synchrophasor* data is required from a *generation facility* for reliability and system awareness purposes, the *IESO* shall notify the *market participant* of such requirement.

If a *market participant* is required to provide *syncrophasoer* data to the *IESO* in respect of multiple *facilities* commencing in the same calendar year, such *market participant* can email IESOCustomerRelations@ieso.ca to request a staged implementation plan. The *IESO* may permit a staged implementation plan, the specific terms of which will be ~~, at its sole discretion,~~ subject to mutual agreement.~~, permit a staged implementation plan.~~

Table 2-1 sets forth the *synchrophaseor* data requirements relating to a *generation facility.*

Table 2-~~-~~1: Requirements for Generators[1]

Attribute	Status	Requirement
Measurement Point	Required	Requirements (1) and (2) pertain to *generation facilities* that are directly *connected* to a Bulk Power System (BPS) Station OR have a *connection point* voltage greater than 200 kV. (1) For any single *generation unit* rated equal to or greater than 100 MVA name-plate rating, provide *synchrophasor* data measured at generator terminal (i.e. low side of the generator output transformer). ~~Existing *g*~~*G*~~*eneration facilities*~~ in operation prior to December 31, 2024 that have disturbance monitoring equipment on the high side

[1] Specifications noted as "required" must be satisfied, specifications noted as "preferred" are not required but add additional operational value and should be satisfied wherever practical.

Attribute	Status	Requirement
		of the *generator* output transformer may provide *synchrophasor* data from those existing measuring locations. See configuration 1 of **Figure 2-1**. (2) Multiple *generation units* ~~with~~ that have an aggregate name-plate rating that is ~~-~~equal to or greater than 100 MVA~~- name-plate rating~~, must provide *synchrophasor* data measured at the *generation facility* side of each point of connection to the *IESO-controlled grid*. See configurations 2, 3, 4 of **Figure 2-1**. Alternatively, other measuring locations of *synchrophasor* data inside the *generation facility* can be provided if they allow for calculating the aggregated *synchrophasor* data at the *generation facility* side of each point of connection. See configurations 2, 3, 4 of **Figure 2-1**~~-~~. ~~(3) G*eneration units*, regardless of rated size, whose output power flow is a part of an Interconnection Reliability Operating Limit (IROL) definition[2] must provide positive sequence voltage phasor, positive sequence current phasor and frequency at the terminals defining the IROL.~~ (3) ~~G~~Eligible ~~*g*~~*eneration facilities* subject to (1) and (2) above will not be required to provide the *synchrophasor* data if the *IESO* determines, in its sole discretion,~~-~~ that they meet one of the following criteria~~ and provides written confirmation to the generator *generator* that the *IESO* is exercising its discretion not to require the data~~: (a) The *generation facility* is expected to be deregistered ~~within a period of 5 years from date of implementation of market rules~~by December 31, 2029; or~~.~~ (b) The annual gross capacity factor of the *generation facility* meets the requirements as stipulated in ~~is significantly low as stated in the process covered in~~ **Section 2.5**.

~~[2] *Market Participants* should contact the *IESO* if they need assistance determining whether their plant is part of an IROL.~~

Attribute	Status	Requirement
		If the *IESO* determines that a *generation facility* meets such criteria, it shall notify the *generator* of such determination and such determination remains subject to ~~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 factor ~~respectively, on a case-by-case basis~~ and can be revoked at the *IESO's* discretion by providing the *generator* with notice of such new determination. If ~~at any time the *IESO* determines that criteria (a) no longer applies,~~ the *IESO* ~~may~~ revokes its ~~confirmation by providing written notice~~determination, and subject to the possibility of an *IESO*-approved staged implementation plan in accordance with section 2.2, ~~and~~the *generation* ~~*facilities*~~ *facility* will be required to provide the *synchrophasor* data within 3 years from the notification date. ~~For *market participants* that have~~with multiple ~~*facilities* affected by criteria (a) and/or (b) no longer applicable in a given year, *synchrophasor* data may be provided via a mutually agreed staged implementation plan.~~ ~~For a~~All *generation units* whose output power flow contributes to an Interconnection Reliability Operating Limit (IROL) definition[3], regardless of rated size, must provide voltage and current phasor for all three phases and frequency at the terminals defining the IROL.
Measurement Point	Preferred	Provide additional *synchrophasor* data from a ~~*generator*~~ *generation facility* for specific *reliability* needs (e.g. *generation facility* with history of oscillatory events or to achieve sufficient observability over the *IESO-controlled grid*).
Measured Quantities	~~Preferred~~ Required	Provide the following for all 3 phases the voltage magnitude (Volts or kV) and voltage phasor angle (degrees), for all 3

[3] *Market Participants* should contact the *IESO* if they need assistance determining whether their plant is part of an IROL.

Attribute	Status	Requirement
		phases the current phasor magnitude (Amperes or kA), and current phasor angle (degrees), frequency (Hz) and rate of change of frequency (ROCOF).~~All three phases of the voltage and current phasor measurements and frequency data~~~~Provide 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 magnitudes must be in SI units.
System Frequency	Required	Provide phasor data continuously at frequency between 57 Hz and 62 Hz.
Reporting Rate	~~Preferred~~ Required	Provide *synchrophasor* data at least once in every one sixtieth of a second (i.e. 60 samples per second).~~Note: Typical mid-term dynamic analysis tools provide 240 data point sets per second. Dynamic model validation using *synchrophasor* data can be improved if reporting rate is increased to 60 samples per second.~~
Time-Tag Format and Accuracy	Required	All *synchrophasor* data shall be reported in Coordinated Universal Time (UTC time) with zero offset. For each phasor measurement, data shall include a time tag traceable to UTC clock that includes the time and time quality at the time of measurement. The time tag shall accurately resolve time of measurement to at least 1μs within a specified 100-year period.
Data Format and	Required	Data provided to the *IESO* shall comply with the IEEE Std 60255-118-1-2018. Notwithstanding the foregoing, ~~For~~ *market participants* connected to the *IESO-controlled grid*

Attribute	Status	Requirement
Accuracy Standard		with *synchrophasor* data measurement infrastructure meeting IEEE Std C37.118 (2005, 2011, or 2014) and ~~existing before~~ operating as part of the *IESO-administered markets* prior to ~~the implementation date,~~ December 31 2024, ~~of the *synchrophasor* data Market Rules requirements,~~ the ~~*IESO* will accept utilization of such measurement infrastructure~~ the *market participant* may use such existing measurement infrastructure for the remainder of its expected useful life. ~~The *IESO* will work with these *market participants* to assess the need for any future upgrades in their *synchrophasor* data measurement infrastructure, and if necessary, develop a staged implementation plan.~~
Network Protocol	Required	Provide *synchrophasor* data via a site-to-site VPN with the *IESO*. A public static IP address is required.
Instrumentation Channel	Required	Provide instrument transformers and its corresponding instrumentation channel components with accuracy high enough to be appropriately utilized in *IESO* real-time applications[4].
Latency	Required	Provide total latency for ~~phasor~~ *synchrophasor* data from *PMU* to the *IESO* control center or *IESO* owned PDC no more than 500 ms. The *market participant* shall be required to provide latency of no more than a 100 ms if informed by the *IESO* that its *synchrophasor* data is to be used in a Linear State Estimator as part of a Transient Stability program.
Latency	Preferred	Provide total latency for ~~phasor~~ *synchrophasor* data from *PMU* to the *IESO* control center or *IESO* owned PDC no more

[4] This requirement intends to provide flexibility to *market participants* to utilize their current Instrumentation Channel infrastructure with minimum accuracy equal or better than those used for *SCADA* measurements. ~~Should Instrumentation Channel specifications be prescribed in the future, the *IESO* will stakeholder them with *market participants* in advance and support reasonable staged implementation plans to deploy any resulting required equipment upgrades to comply with such specifications.~~

Attribute	Status	Requirement
		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.~~
Bandwidth	Required	Provide communication channels with bandwidth adequate to reliably transmit the volume of *PMU* data at ~~selected~~ the required reporting rate. ~~Note: The required bandwidth varies with the number of phasor data and reporting rate. Thus, the size of bandwidth required depends on 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).~~ For most *generation facilities* a bandwidth of 1 Mbps per transmitting *PMU* device will be sufficient. ~~This could be lower for configurations wherein multiple *PMU* devices are aggregated at a local PDC before being transmitted to the *IESO*.~~
Bandwidth	Preferred	Provide dedicated communication channels.~~Note: Dedicated communication channels avoid potential data transmission interruption and fluctuations in latency.~~
Critical Infrastructure Protection (CIP)	Preferred	*Market participants* to include *synchrophasor* data under their *NERC* Critical Infrastructure Protection (CIP) program.
Redundancy	Required	Provide primary communication path for *synchrophasor* data to the *IESO*. The *market participant* shall be required to provide primary and secondary communication paths for *synchrophasor* data if informed by the *IESO* that its data is to be used in a Linear State Estimator as part of a Transient Stability program.

Attribute	Status	Requirement
Redundancy	Preferred	Provide primary and secondary communication paths f~~or~~ *synchrophasor* data to the *IESO*, ~~if that data is to be used in a Linear State Estimator whose output is to be used in on-line Transient Stability program.~~
CVT/PT Selection	Preferred	Provide Metering Class Bus CVT or PT measurements where possible or Metering Class Transmission line or feeder CVT/PT measurements for better accuracy.
CT Selection	Preferred	Provide Protection Class CTs measurements where possible to capture the dynamic and fault conditions.

2.3 Applicable Generator Connection Configurations

(MR Ch.4 s.7.2)

Figure 2-1 illustrates ~~required~~ measurement points for applicable *generation facilities*.

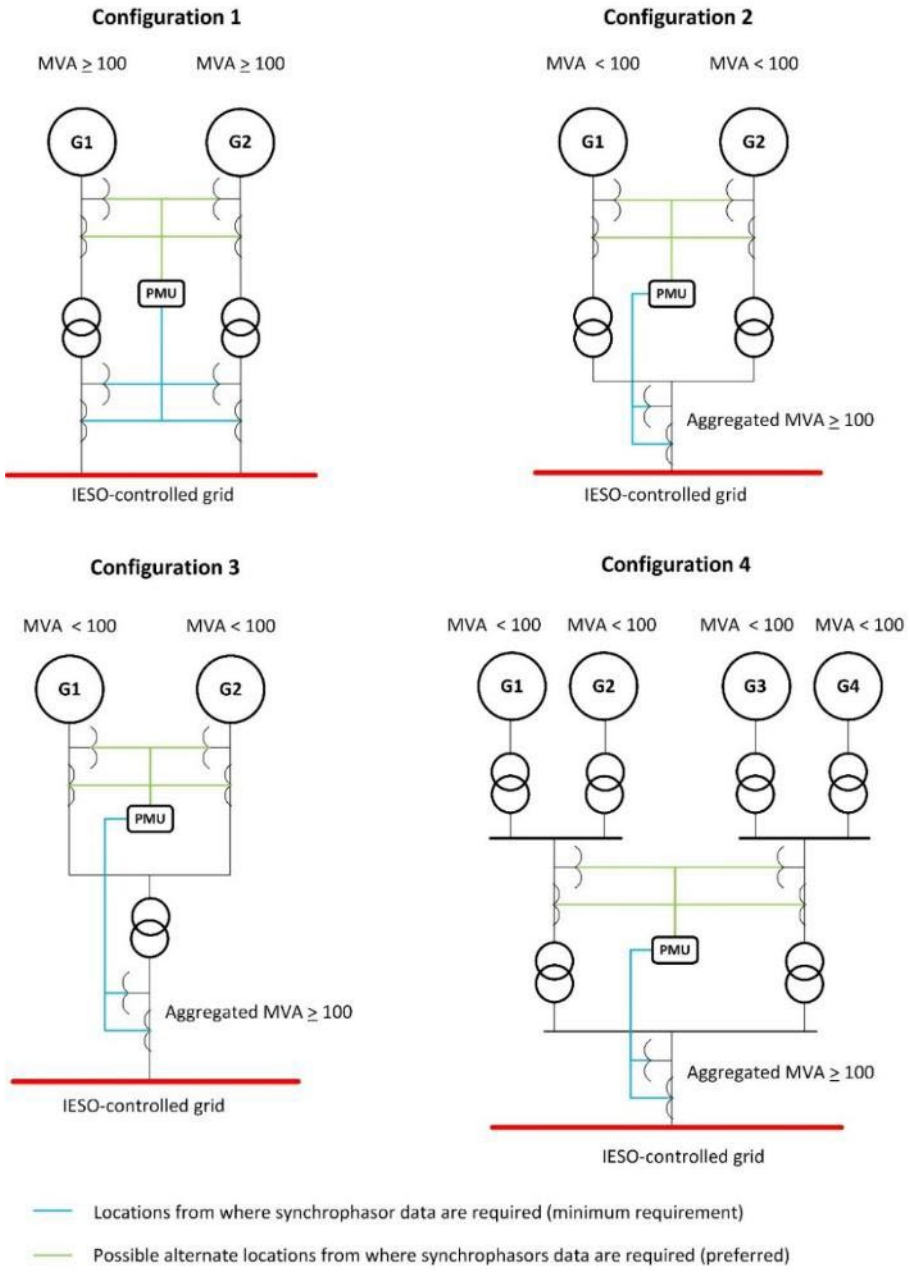


Figure 2-12 1: Examples for synchrophasor data measurement locations for different generator connection configurations.

2.4 Reliability, Maintenance and Repair

(MR Ch.4 s.7.7)

MR Ch. 4, Sec. 7.7, is applicable to installed *synchrophasor* data devices and associated required infrastructure including instrument transformers, communication channels and PDCs.

2.5 Low Capacity Factor

MR Ch. 4 App.4.15)

This section explains the process for identifying *generation units* that are ~~not required to~~excluded from ~~*provide*~~ *synchrophasor* data requirements ~~because of their~~due to a ~~low~~ Capacity Factor (CF) below 10%. When the *IESO* determines that a *generation unit* has a CF ~~greater~~less than ~~or equal to~~ 10% ~~CF, as determined by the *IESO,*~~ such *generation unit* will not be required to provide the *IESO* with *synchrophasor* data until otherwise directed by the *IESO*.

At least once a year the *IESO* will calculate the annual average CF using historical data for the last 3 years or since the in-service date, whichever is less, only for *generation units* that had CF ~~<~~ below 10% in all prior assessments. ~~The list of *generation units* excluded from *synchrophasor* requirements will be developed by the *IESO* and shared with the *facility* owners. The IESO will continue with calculating annually the moving average for CF of excluded generation units only.~~ Upon performing the annual assessment, if the CF for a *generation unit* ~~≥~~ is greater than or equal ~~than~~to 10%, the *IESO* will notify the *facility* owner that:

- The exclusion from *synchrophasor* requirements is no longer valid
- The *generation unit* will no longer be included for future annual CF assessments
- *Synchrophasor* data must be provided to the *IESO* within 3 years from the notification date. *Market participants* having multiple *facilities* whose CF becomes greater than or equal to 10% in the same year, may provide *synchrophasor* data via mutually agreed staged implementation plan, if required.

Future generation projects will be assessed during the connection approval process to determine if they qualify for exclusion from the *synchrophasor* requirements.

– End of Section –

3 Requirements: Transmitters

3.1 Infrastructure Requirements for Transmitters

(MR Ch. 4 App.4.16)

~~*Transmitters* shall install and maintain at their expense, *synchrophasor* data generating devices and associated infrastructure including instrument transformers, communication channels and PDCs, and provide *synchrophasor* data as per below specifications (see Section 3.2) to the *IESO* on continuous basis. See Section 3.2 for data requirements.~~

Market participants are expected to follow NERC's IRO-010-3 standard as described in MM 11.1 s.7 when providing *synchrophasor* data to the IESO which will be used for situational awareness and planning analyses purposes. In cases where the *synchrophasor* data will be provided from devices already classified as a BES Cyber Asset then the data and its associated infrastructure must comply with *NERC* Critical Infrastructure Protection (CIP) program.

~~Applicable *transmitters* are expected to include synchrophasor data under their NERC Critical Infrastructure Protection (CIP) program. While the IESO will initially use the synchrophasor data for non-CIP related activities, transmitters are to consider CIP requirements when planning upgrades to their facilities to be in position to meet CIP requirements when the IESO's PMU Integration Program advances to a point where CIP requirements will be needed. The IESO will engage with stakeholders to provide reasonable timeline for the implementation of any specific CIP requirements.~~

Transmission of *synchrophasor* data to the *IESO* must occur over the internet using a secure IPsec site-to-site VPN connection with the following specifications:

1) Internet connection with bandwidth and latency specifications as per **Table 2-1**;
2) Public static IP address; and
3) Firewall device capable of creating IPsec site-to-site VPN tunnel with the following settings: IKEv2, AES-256 Encryption, SHA256 Data Integrity, 2048 bit DH group, PFS with 2048 bit DH group.

In certain circumstances, the IESO may permit the use of a private communication link instead of a public internet-based VPN connection. Approval for such arrangements can be requested at the time of PMU registration via e-mail submissions at PMUregistration@ieso.ca. IESO has the sole discretion in approving such arrangements and will evaluate each request on a case-by-case basis.

3.2 Phasor Data Requirements for Transmitters

(MR Ch. 4 App.4.16)

~~Specifications noted as "required" must be satisfied, specifications noted as "preferred" are not required but add additional operational value and should be satisfied wherever practical.~~

The *IESO* may, at its discretion, require *transmitters* to provide *synchrophasor* data for reliability and system awareness purposes. Such need will be informed by considerations such as proximity to other *synchrophasor* measurement units, criticality of the *facility* from system stability perspective, etc. If the *IESO* determines a transmission *facility* is required to provide *synchrophasor* data for reliability and system awareness purposes, the *IESO* shall notify the *market participant* of such requirement.

If a *market participant* is required to provide *syncrophasor* data to the *IESO* in respect of multiple *facilities* commencing in the same calendar year, such *market participant* can email IESOCustomerRelations@ieso.ca to request a staged implementation plan. The *IESO* may permit a staged implementation plan, the specific terms of which will be ~~, at its sole discretion,~~ subject to mutual agreement.

Table 3-1 sets forth the *synchrophasoer data* requirements relating to transmission *facilities.*

Table 3-1: Requirements for Transmitters[5]

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

[5] Specifications noted as "required" must be satisfied, specifications noted as "preferred" are not required but add additional operational value and should be satisfied wherever practical.

Attribute	Status	Requirement
		voltage phasor magnitude, positive sequence voltage phasor angle, and frequency. Terminals of circuits defining Interconnection Reliability Operating Limits (IROL) and Interties. Provide positive sequence current phasor magnitude, positive sequence current phasor angle, positive sequence voltage phasor magnitude, positive sequence voltage phasor angle, and frequency. Terminal bus of Static Var Compensators (SVC), synchronous condensers and static synchronous compensators (STATCOM). Provide positive sequence current phasor magnitude, positive sequence current phasor angle, positive sequence voltage phasor magnitude, positive sequence voltage phasor angle, and frequency.
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. 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 phasor data from auto-transformers, the impact of Geo-Magnetically Induced (GIC) currents can be monitored.~~

Attribute	Status	Requirement
Measured Quantities and Units	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 magnitudes must be in SI units.
System Frequency	Required	Provide phasor data continuously at frequency between 57 Hz and 62 Hz.
Reporting Rate	~~Preferred~~Required	Provide *synchrophasor* data at least once in every one sixtieth of a second (i.e. 60 samples per second). ~~Note: Typical mid-term dynamic analysis tools provide 240 data point sets per second. Dynamic model validation using *synchrophasor* data can be improved if reporting rate is increased to 60 samples per second.~~
Time-Tag Format and Accuracy	Required	All *synchrophasor* data shall be reported in Coordinated Universal Time (UTC time) with zero offset. For each phasor measurement, data shall include a time tag traceable to UTC clock that includes the time and time quality at the time of measurement. The time tag shall accurately resolve time of measurement to at least 1 microsecond within a specified 100-year period.

Attribute	Status	Requirement
Data Format and Accuracy Standard	Required	Data provided to the *IESO* shall comply with the IEEE Std 60255-118-1-2018. Notwithstanding the foregoing, ~~For~~ *market participants* connected to the *IESO-controlled grid* with *synchrophasor* data measurement infrastructure meeting IEEE Std C37.118 (2005, 2011, or 2014) and operating as part of the IESO-administered market prior to December 31, 2024 ~~existing before the implementation date, December 31 2024,~~the *market participant* may use such existing measurement infrastructure for the remainder of its expected useful life. ~~of the *synchrophasor* data Market Rules requirements, the *IESO* will accept utilization of such measurement infrastructure~~. ~~The *IESO* will work with these *market participants* to assess the need for any future upgrades in their *synchrophasor* data measurement infrastructure, and if necessary, develop a staged implementation plan.~~
Network Protocol	Required	Provide *synchrophasor* data via a site-to-site VPN with the *IESO*. A public static IP address is required. ~~Provide phasor data via a network that comply with TCP/IP or UDP/IP protocol.~~
Instrumentation Channel	Required	Provide instrument transformers and its corresponding instrumentation channel components with accuracy high enough to be appropriately utilized in *IESO* real-time applications[6].

[6] This requirement intends to provide flexibility to *market participants* to utilize their current Instrumentation Channel infrastructure with minimum accuracy equal or better than those used for *SCADA* measurements. ~~Should Instrumentation Channel specifications be prescribed in the future, the IESO will stakeholder them with *market participants* in advance and support reasonable staged implementation plans to deploy any resulting required equipment upgrades to comply with such specifications.~~

Attribute	Status	Requirement
Latency	Required	Provide total latency for *synchrophasor* ~~phasor~~ data from *PMU* to the *IESO* control center or *IESO* owned PDC no more than 500 ms. The *market participant* shall be required to provide latency of no more than a 100 ms if informed by the *IESO* that its *synchrophasor* data is to be used in a Linear State Estimator as part of a Transient Stability program.
Latency	Preferred	Provide total latency for ~~phasor~~ *synchrophasor* 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.~~
Bandwidth	Required	Provide communication channels with bandwidth adequate to reliably transmit the volume of *PMU* data at ~~selected~~ the required reporting rate. For most transmission *facilities* a bandwidth of 1 Mbps per transmitting *PMU* device will be sufficient. ~~Note: The required bandwidth varies with the number of phasor data and the reporting rate. Thus, the size of bandwidth required depends on 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.

Attribute	Status	Requirement
Circuit Breaker Status	Preferred	Provide Circuit Breaker Status (Digital Channels) of all transmission lines or feeders for Linear State Estimator Estimation, and for Single Line Diagram topological display purposes This may become a requirement in the future as the *IESO* deploys *PMU*s into real-time operations. Note that this data supports industry best practice to collect this data directly from *PMU*s to reduce dependencies and provide a solution for state estimation when *SCADA* is not available.
Isolator Status	Preferred	Provide Isolator Status (Digital Channels) of all transmission lines or feeders for Linear State Estimator Estimation, and for Single Line Diagram topological display purposes. This may become required in the future as the *IESO* deploys *PMU*s into real-time operations. Note that this data supports industry best practice to collect this data directly from *PMU*s to reduce dependencies and provide a solution for state estimation when *SCADA* is not available.
CVT/PT Selection	Preferred	Provide Metering Class Bus CVT or PT measurements where possible or Metering Class Transmission line or feeder CVT/PT measurements for better accuracy.
CT Selection	Preferred	Provide Protection Class CTs measurements where possible to capture the dynamic and fault conditions.

3.3 Reliability, Maintenance and Repair

(MR Ch.4 s.7.7)

MR Ch. 4, Sec. 7.7, is applicable to installed *synchrophasor* data devices and associated required infrastructure including instrument transformers, communication channels and PDCs.

– End of Section –

4 Requirements: Electricity Storage Participants

4.1 Infrastructure Requirements for Electricity Storage Participants

(MR Ch. 4 App.4.24)

Market participants are expected to follow NERC's IRO-010-3 standard as described in MM 11.1 s.7 when providing *synchrophasor* data to the *IESO* which will be used for situational awareness and planning analyses purposes. In cases where the *synchrophasor* data will be provided from devices already classified as a BES Cyber Asset then the data and its associated infrastructure must comply with *NERC* Critical Infrastructure Protection (CIP) program.

Transmission of *synchrophasor* data to the *IESO* must occur over the internet using a secure IPsec site-to-site VPN connection with the following specifications:

1) Internet connection with bandwidth and latency specifications as per **Table 2-1**;
2) Public static IP address; and
3) Firewall device capable of creating IPsec site-to-site VPN tunnel with the following settings: IKEv2, AES-256 Encryption, SHA256 Data Integrity, 2048 bit DH group, PFS with 2048 bit DH group.

In certain circumstances, the *IESO* may permit the use of a private communication link instead of a public internet-based VPN connection. Approval for such arrangements can be requested at the time of PMU registration via e-mail submissions at PMUregistration@ieso.ca. The *IESO* has the sole discretion in approving such arrangements and will evaluate each request on a case-by-case basis.

4.2 Phasor Data Requirements for Electricity Storage Participants

(MR Ch. 4 App.4.24)

The *IESO* may, at its discretion, require *electricity storage ~~units~~ participants* to provide *synchrophasor* data for reliability and system awareness purposes. Such need will be informed by considerations such as proximity to other *synchrophasor* measurement units, criticality of the *facility* from system stability perspective, etc. If the *IESO* determines an *electricity storage facility* is required to provide *synchrophasor* data for reliability and system awareness purposes, the *IESO* shall notify the *market participant* of such requirement.

Table 4-1 sets forth the synchrophasor data requirements relating to an *electricity storage facility.*

Table 4-1: Requirements for Electricity Storage Units[7]

Attribute	Status	Requirement
Measurement Point	Required	Requirements (1) and (2) pertain to *electricity storage units* that are directly *connected* to a Bulk Power System (BPS) Station OR have a *connection point* voltage greater than 200 kV. (1) For any single *electricity storage unit* rated equal to or greater than 20 MVA name-plate rating, provide *synchrophasor* data measured at electricity storage units terminal (i.e. low side of the generator output transformer). See configuration 1 of **Figure 4-1**. (2) Multiple *electricity storage units* that in aggregate equal to or greater than 20 MVA name-plate rating, must provide *synchrophasor* data measured at the *electricity storage unit's facility* side of each point of connection to the *IESO-controlled grid*. See configuration 2 **Figure 4-1**. Alternatively, other measuring locations of *synchrophasor*

[7] Specifications noted as "required" must be satisfied, specifications noted as "preferred" are not required but add additional operational value and should be satisfied wherever practical.

		data inside the *facility* can be provided if they allow for calculating the aggregated *synchrophasor* data at the *electricity storage unit's facility* side of each point of connection. See configurations of **Figure 4-1**. For all *electricity storage units* whose output power flow contributes to an Interconnection Reliability Operating Limit (IROL) definition, regardless of rated size, must provide voltage and current phasor for all three phases and frequency at the terminals defining the IROL.
Measurement Point	Preferred	Provide additional *synchrophasor* data from an *electricity storage –facility* for specific *reliability* needs (e.g. *electricity storage facility* with history of oscillatory events or to achieve sufficient observability over the *IESO-controlled grid*).
Measured Quantities and Units	Required	Provide the following for all 3 phases the voltage magnitude (Volts or kV) and voltage phasor angle (degrees), for all 3 phases the current phasor magnitude (Amperes or kA), and current phasor angle (degrees), frequency (Hz) and rate of change of frequency (ROCOF).
Coordinates	Required	Provide phasor data in polar coordinates where magnitudes must be in SI units.
System Frequency	Required	Provide phasor data continuously at frequency between 57 Hz and 62 Hz.
Reporting Rate	Required	Provide *synchrophasor* data at least once in every one sixtieth of a second (i.e. 60 samples per second).
Time-Tag Format and Accuracy	Required	All *synchrophasor* data shall be reported in Coordinated Universal Time (UTC time) with zero offset. For each phasor measurement, data shall include a time tag traceable to UTC clock that includes the time and time quality at the time of measurement. The time tag shall accurately

		resolve time of measurement to at least 1µs within a specified 100-year period.
Data Format and Accuracy Standard	Required	Data provided to the *IESO* shall comply with the IEEE Std 60255-118-1-2018.
Network Protocol	Required	Provide *synchrophasor* data via a site-to-site VPN with the *IESO*. A public static IP address is required.
Instrumentation Channel	Required	Provide instrument transformer~~s~~ and its corresponding instrumentation channel components with accuracy high enough to be appropriately utilized in *IESO* real-time applications[8].
Latency	Required	Provide total latency for *synchrophasor* data from *PMU* to the *IESO* control center or *IESO* owned PDC no more than 500 ms. The *market participant* shall be required to provide latency of no more than a 100 ms if informed by the *IESO* that its *synchropashor* data is to be used in a Linear State Estimator as part of a Transient Stability program.
Latency	Preferred	Provide total latency for *synchrophasor* data from *PMU* to the *IESO* control center or *IESO* owned PDC no more than 100 ms.
Bandwidth	Required	Provide communication channels with bandwidth adequate to reliably transmit the volume of *PMU* data at selected reporting rate. ~~amount~~For most *electricity storage -facilities* a bandwidth of 1 Mbps per transmitting *PMU* device will be sufficient.

[8] This requirement intends to provide flexibility to *market participants* to utilize their current Instrumentation Channel infrastructure with minimum accuracy equal or better than those used for *SCADA* measurements.

Bandwidth	Preferred	Provide dedicated communication channels.
Critical Infrastructure Protection (CIP)	Preferred	*Market participants* to include *synchrophasor* data under their *NERC* Critical Infrastructure Protection (CIP) program.
Redundancy	Required	Provide primary communication path for *synchrophasor* data to the *IESO*. The *market participant* shall be required to provide primary and secondary communication paths for *synchrophasor* data if informed by the *IESO* that its data is to be used in a Linear State Estimator as part of a Transient Stability program.
Redundancy	Preferred	Provide primary and secondary communication paths for *synchrophasor* data to the *IESO.*
CVT/PT Selection	Preferred	Provide Metering Class Bus CVT or PT measurements where possible or Metering Class Transmission line or feeder CVT/PT measurements for better accuracy.
CT Selection	Preferred	Provide Protection Class CTs measurements where possible to capture the dynamic and fault conditions.

4.3 Applicable Electricity Storage Units Connection

(MR Ch. 4 s.7.2)

Figure 4-1 illustrates measurement points for applicable *electricity storage units*.

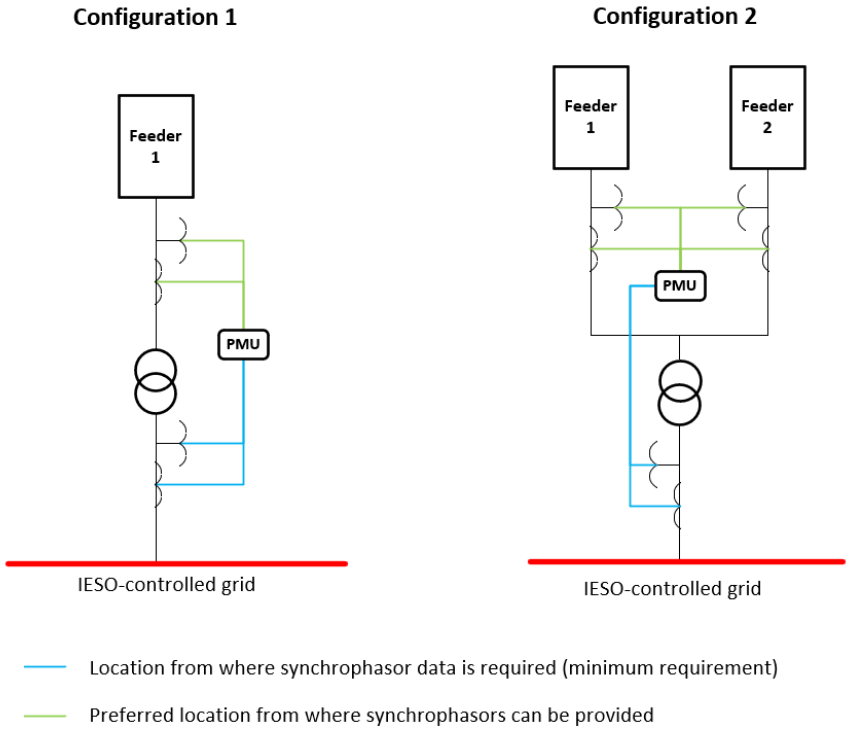


Figure 4-1: Examples of synchrophasor data measurement locations for different electricity storage facilities and PMU connection configurations

4.4 Reliability, Maintenance and Repair

(MR Ch.4 s.7.7)

MR Ch.4 s.7.7, is applicable to installed *synchrophasor* data devices and associated required infrastructure including instrument transformers, communication channels and PDCs.

– End of Section –

45 PMU Registration Process

(MR Ch.4 s.7.2)

This section describes the process of registering *PMU*s with the *IESO*. A *PMU* registration form must be completed for each *PMU* required to transmit data to the *IESO*. See **Figure 5-2**~~**Figure 4-2**~~.

In cases where data from *PMU*s will be sent via PDC, the registration information of that PDC is to be provided shown in **Figure 5-3**~~**Figure 4-3**~~.

The *IESO* will review the information provided and provide a response about any registration data that might need further clarification. The *PMU* registration information is required for *IESO* to deem that the *PMU* is ready to be connected, and the expected data will be transmitted. Upon completion of the review the *market participant's PMU*/PDC equipment will be entered into a queue for establishing a connection to the *IESO*. *Market participants* will be provided a timeframe for when it will be their turn to connect.

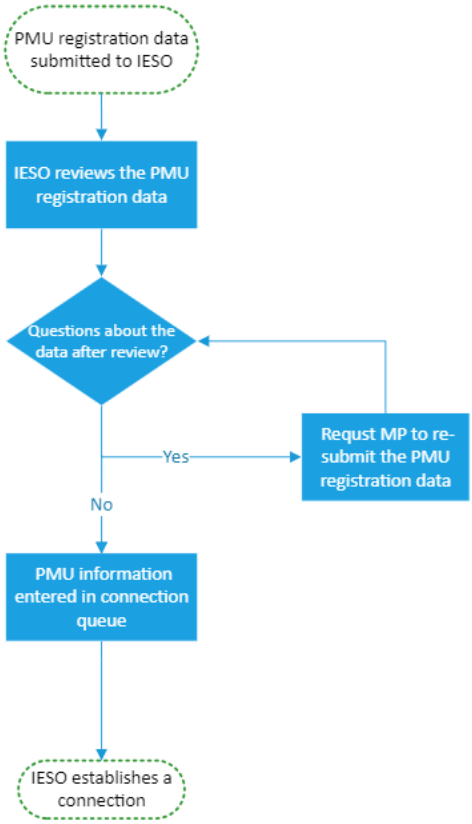


Figure 5-15-1: PMU Registration Process

Phasor Measurement Unit (PMU) Copy and fill out one form for each PMU. Fill in all applicable gray Value fields, and explain with the Comment field as required.				
	Entry Type	**Value**	**IESO Comment**	**TO/GO Comment**
Location	Company Name:		Maximum 50 Characters	
	Substation/Plant Name:		Maximum 50 Characters	
	Contact Information for Phasor Data:			
	o Name			
	o Phone			
	o Email			
Phasor Measurement Unit Information	PMU IDCODE		As per assigned IDs; see 'ID Code assignment' worksheet for the IDs available for your company's PMU/PDCs	
	PMU In Service Date		mm/dd/yyyy	
	STN		Maximum 16 Characters; As defined in 'Naming Conventions' work sheet in this excel file	
	PMU Manufacturer		Maximum 50 Characters	
	PMU Model (Name and Version)		Maximum 35 Characters	
	PMU Firmware Version		Maximum 15 Characters	
	PMU Class		'P' or 'M' (2011 std.) or '0' or '1' (2005 std.)	
	PMU Reporting Rate		Reporting Rate	
	PMU Operational Status		Free form For Example: In Service, On Outage, Not Connected to PDC, In Testing. Maximum 35 Characters	
	Time Synchronization Source (for the PMU):			
	o Manufacturer		Maximum 50 Characters	
	o Model (Name and/or Version)		Maximum 35 Characters	
	Data Sent to - from this PMU (To be repeated for each PDC):			
	o PDC (ID Code)		As per assigned IDs; see 'ID Code assignment' worksheet for the IDs available for your company's PMU/PDCs	
	o PDC Type		Substation or Regional or Central (Main)	
Voltage Phasor Measurements (To be repeated for each voltage phasor measurement)	CHNAM		Maximum 16 Characters; As defined in 'Naming Conventions' work sheet in this excel file	
	If Line Side Measurement:			
	o Line Identifier		Free form field. Could be a description or the ID used by the TO to identify the line when the voltage source is on the line side	
	Breaker #1 Identifier		Free form field. Could be a description or the ID used by the TO to identify the Breaker	
	Breaker #2 Identifier			
	If Bus Side Measurement:			
	o Bus Identifier		Free form field. Could be a description or the ID used by the TO to identify the Bus if the Voltage source is on the Bus side	
	Nominal Voltage		For Example: 115 KV or 230 KV or 500 KV	
	Instrument Transformer:			
	o Device Description			
	o Accuracy Class			
	o Ratio			
	Measurement adjustments required (external to PMU):			
	o Scaling Factors		Free Form Field: to identify if there are any scaling adjustments to be done to the measurements. In most cases this should be not applicable	
	o Phasor angle adjustment		Free Form Field: to identify if there are any phase angle adjustments to be done to the measurements. In most cases this should be not applicable	
Current Phasor Measurements (To be repeated for each current phasor measurement)	CHNAM		Maximum 16 Characters; As defined in 'Naming Conventions' work sheet in this excel file	
	Line Identifier		Free form field. Could be a description or the ID used by the TO to identify the line	
	Breaker #1 Identifier		Free form field. Could be a description or the ID used by the TO to identify the Breaker	
	Breaker #2 Identifier		Free form field. Could be a description or the ID used by the TO to identify the Breaker	
	Nominal Voltage		For Example: 115 KV or 230 KV or 500 KV	
	Instrument Transformers (Rows 49 to 51 shall be repeated for each transformer):			
	o Device Description			
	o Accuracy Class			
	o Ratio			
	Measurement adjustments required (external to PMU):			
	o Scaling Factors		Free Form Field: to identify if there are any scaling adjustments to be done to the measurements. In most cases this should be not applicable	
	o Phasor Angle Adjustment		Free Form Field: to identify if there are any phase angle adjustments to be done to the measurements. In most cases this should be not applicable	

Figure 5-25-2: Sample PMU Registration Form to be completed. Download PMU

Registration Form from IESO website

Phasor Data Concentrator (PDC) Copy and fill out one form for each PDC. Fill in all applicable gray Value fields, and explain with the Comment field as required.				
	Entry Type	**Value**	**IESO Comment**	**TO Comment**
Location	Company Name:		Maximum 50 Characters	
	PDC Location (Substation/Plant Name for Substation PDC or Control Center Name for Central PDC):		Maximum 50 Characters	
	Substation/Plant location (if this is a Substation PDC): Latitude –		Maximum 15 Characters	
	Contact Information for PDC administrator:			
	o Name			
	o Phone			
	o Email			
Phasor Data Concentrator (PDC) Information	PDC IDCODE		As per assigned IDs; see 'ID Code assignment' worksheet for the IDs available for your company's PMU/PDCs	
	PDC Vendor		Maximum 50 Characters	
	PDC Firmware Version		Maximum 15 Characters	
	Time Synchronization Source (if used for PDC)			
	o Manufacturer		Maximum 50 Characters	
	o Model (Name and/or Version)		Maximum 35 Characters	
	o Firmware Version		Maximum 15 Characters	
	Data Sent to (To be repeated for each PDC):			
	o PDC (ID Code)		As per assigned IDs; see 'ID Code assignment' worksheet for the IDs available for your company's PMU/PDCs	
	o PDC Type		Substation or Regional or Central (Main)	
Archival Information	Archive Description		Free Form text	
	Archival Rate		Free Form text	
	Archival Format		Free Form text	
	Data Retention Period in days		Free Form text	

Figure 5-35-3: Sample PDC Registration Form to be completed. Download the PMU Registration Form from IESO website.

– End of Section –

~~5~~6 PMU Connection Process

(MR Ch.4 s.7.2)

This section defines the required steps for establishing a secure and reliable connection between the *market participant* and the *IESO* for the purpose of *synchrophasor* data being transmitted continuously to the *IESO*. The initiation for this process is the completion of the *PMU* registration process as outlined in the previous section.

For instances where a *market participant* has multiple devices capable of generating *synchrophasor data* at a given *facility* the recommended option is for a PDC to be utilized as it minimizes the amount of VPN connections required between the IESO and *market participant.* In addition, PDC helps with the transmission of *synchrophasor data* ensuring all of the data is time-aligned from the various devices at site and transmitting it in a more compact way to the *IESO*. The connection architecture will be discussed in the initial meeting that starts the Connection Process to ensure that the chosen architecture is easy to maintain and administer.

Table 6-1: Steps involved in establishing connection with the IESO for the transmission of *synchrophasor* data

Step	Description
6.1 Initial Design Discussion	*Market participant* and the *IESO* shall review the networking technical requirements via meeting
6.2 Exchange of VPN Form	*Market participant* shall complete and submit the VPN configuration form provided by the *IESO*
6.3 Network and/or Application Validation Meeting	*IESO* will implement VPN tunnel based on 6.2 above, and once ready initiate a meeting to validate the connection at the network and application levels
6.4 Final Confirmation	Following the application validation meeting, *market participant* commences transmission of the *synchophasor* data and the *IESO* confirms successful receipt of the data and the PMU connection process is complete.

In **Figure 6-1** the most common ways of transmitting *synchrophasor* data to the *IESO* are illustrated. During the initial design discussion the *market participant* and *IESO* will

determine the details in terms of establishing the connection required for the transmission to take place.

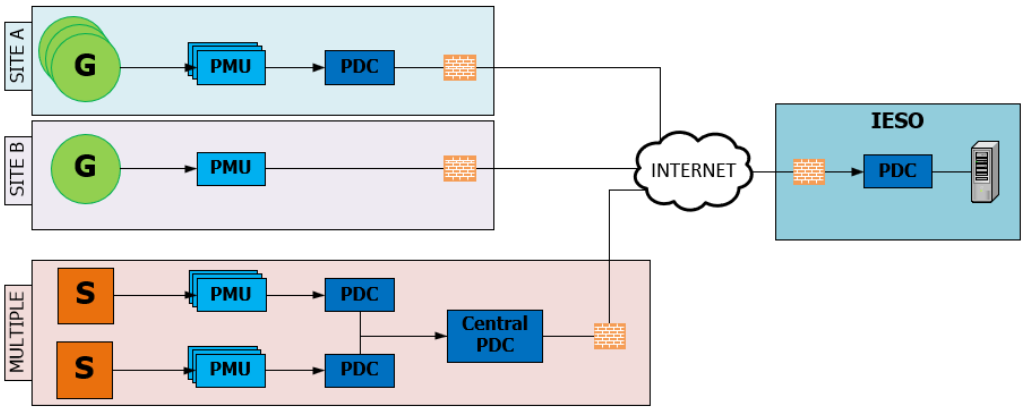


Figure 6-1: Typical *synchrophasor* data flow architecture based on number of PMUs at a given site and/or number of sites

– End of Section –

6 Background Information for Synchrophasors and Associated Infrastructure

This section is provided only for background information on *synchrophasor* monitoring devices and typical infrastructure and use-cases.

6.1 Real-Time Monitoring Devices

There are several tools such as *SCADA*, Phasor Measurement Units, Power System Data Recorders (PSDR), Digital Fault Recorders (DFR) and Dynamic Disturbance Recorders (DDRs) 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:

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

(2) phase angles.

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

(4) continuous real-time measurements.

The data from conventional telemetry, PSDR, DFR and DDR have limitations compared to *synchrophasor* data, including:

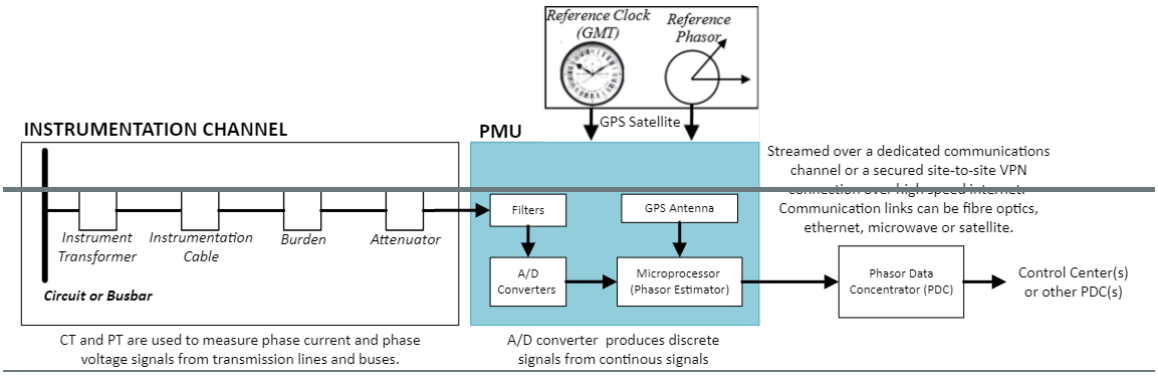
- *SCADA* (telemetry) provides real-time measurements continuously but at a much slower reporting rate (2 - 4 samples per second), does not measure phase angle and data contains no universal time stamp.
- Data from PSDR, traditional DFR, and traditional DDR provide phase angles, contain universal time stamps, and have similar or higher reporting rate compared to *synchrophasor* data, however 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.

6.2 Typical Infrastructure for Providing Synchrophasor Data

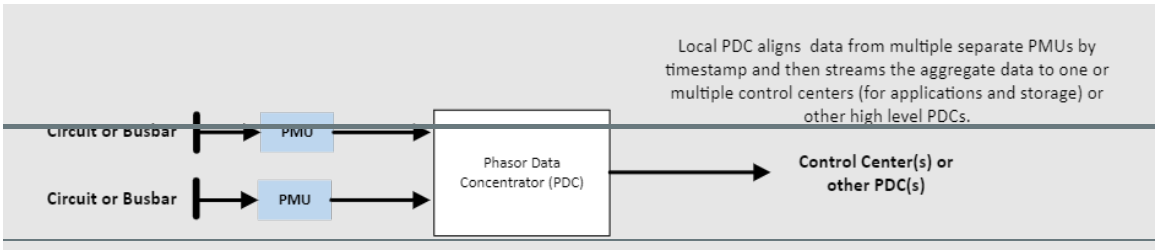
The *PMU* is a device that generates *synchrophasor* data by estimating the magnitude and phase angle of voltage and current waveforms and stamping them with time of

~~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.~~

~~Typical infrastructure required for providing *synchrophasor* data includes an Instrumentation Channel, the *PMUs*, Phasor Data Concentrators (PDCs), GPS antenna, local clock, and a communication network. A typical Instrumentation Channel consists of Instrument Transformers (ITs) and the physical components connecting the ITs to the *PMU* (such as control cables). An overview of their connectivity is shown in **Figure 6-1Figure 51** and **Figure 6-2Figure 52**.~~



~~**Figure 7-16-1: Typical infrastructure required for providing synchrophasor data (single PMU)**~~



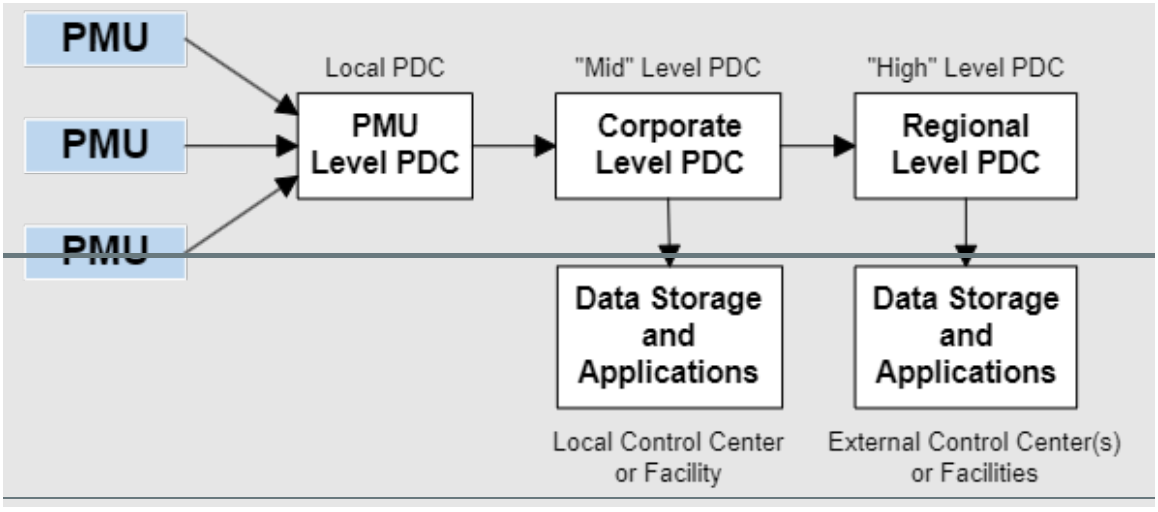
~~**Figure 7-26-2: Typical infrastructure for multiple PMUs**~~

~~A PDC works as a node in a communication network where *synchrophasor* data from one or multiple *synchrophasor* devices is processed and re-transmitted 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 6-3Figure 5-3**. 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 t 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 (i.e. *generator* or *transmitter*) 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 feed to various *synchrophasor* data based computer applications such as Network Monitoring Systems and State Estimators (SE) or are stored 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 considered 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; *Synchrophasor* data is streaming through them via a large network of communication links as data quality checks and applications take place at different points.~~



~~Figure 6-3: PMU and Phasor Data Concentrators~~

~~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 5-4** which depicts as 0.1 Hz oscillations in the power system.

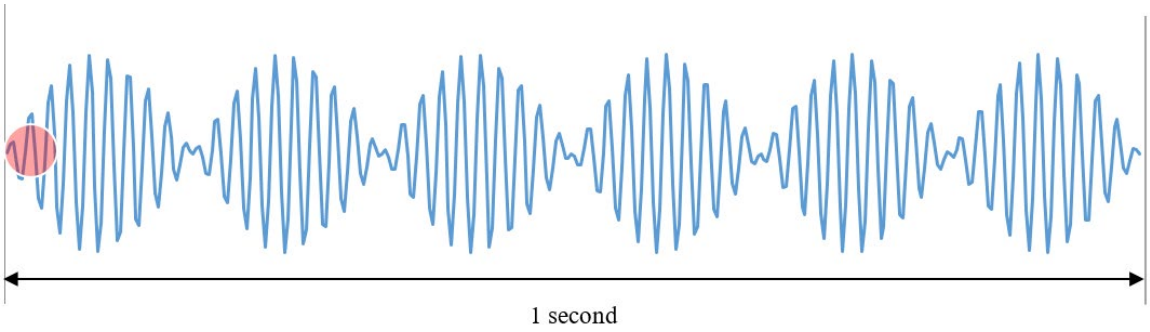


Figure 6-4: AC waveform during dynamics

The Analog to Digital (A/D) converter built into the *PMU* does the following 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 = 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 and correspond to the term $\boldsymbol{cos\,\omega t + sin\,\omega t}$ of each current phase and voltage phase.
(4) Convert each $\boldsymbol{cos\,\omega t + sin\,\omega t}$ to the form of $\boldsymbol{C\,sin\,(\omega t + \alpha)}$.
(5) Compare each $\boldsymbol{C\,sin\,(\omega t + \alpha)}$ to the common reference phasor $\boldsymbol{sin\,(\omega t + \beta)}$ from the GPS.
(6) Assign rms magnitude and angle $\boldsymbol{(\alpha - \beta)}$ 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.

Synchrophasor Network Data Quality

The quality of data consumed by applications that rely on *synchrophasor* data is crucial for accurate and reliable output.

Data quality issues may develop from issues such as:

- latency,
- repeated values,
- measurement bias,
- loss of GPS synchronization,
- incorrect signal metadata,
- outages,
- poor hardware performance,
- improper device configurations, and
- communication link issues.

The entire path from the *PMU* to the destination, including the *PMU* itself, communication networks, and datacenters, can impact overall data quality. Each stage, from signal origination at the *PMU* to use by applications, plays a role in ensuring the integrity of the data.

Data Availability %

Measures the reliability of a Phasor Data Concentrator setup and network integrity.

It is calculated by dividing the number of data frames received by the number of data frames expected, then multiplying by 100. It is the inverse of data dropout %.

Bad Data %

Quantifies the quality of the received data by calculating the percentage of data frames that contain errors.

This is determined by dividing the number of frames with status errors by the total number of frames received. According to the C37.118 standard, the main status errors that can render a data frame "bad" include Data Error, Sort-By-Arrival Error, *PMU* Error, and Sync Error. If any of these errors occur in a data frame, the entire frame is considered bad.

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