

# Technical Rationale for Reliability Standard

## PRC-028-1

August 2023

### **PRC-028-1 – Disturbance Monitoring and Reporting Requirements for Inverter Based Resources**

The recent disturbance reports (e.g., Blue Cut Fire, Canyon 2 Fire, Odessa disturbances) have identified a need for disturbance monitoring for inverter-based resources (IBRs) to aid with event analysis, performance monitoring, and disturbance-based IBR generating facility model validation. These disturbance reports recommended to install disturbance monitoring equipment (DME) at wind and solar photovoltaic (PV) resources to ensure adequate data is available for event analysis, performance monitoring, and validating IBR generating facility models. The recommendation included plant-level high resolution oscillography data, plant SCADA data with a resolution of one second, sequence of events recording for all IBR units<sup>1</sup> that include all fault codes, and at least one IBR unit on each collector feeder configured to capture high resolution oscillography data within the IBR unit.

The purpose of Reliability Standard PRC-002 is to capture event data to understand large scale system disturbances occurring on the Bulk Electric System (BES). Even with changing resource mix, the Reliability Standard PRC-002 serves the purpose. The recent disturbance analyses of events involving IBRs (e.g., Blue Cut Fire, Canyon 2 Fire, Odessa disturbances) have demonstrated that IBR's response to a normally cleared few cycle fault is undesirable and poses risk to system reliability. All these disturbance analyses have identified that IBRs involved did not have sufficient monitoring data to understand the plants' responses. The initiating event, e.g., a normally cleared transmission fault, was not a large-scale system disturbance; however, IBR plant's undesirable response due to a system fault resulted in a larger system disturbance. Adequate monitoring data is required to understand IBR plant's performance. Most of the IBRs involved in these disturbances did not have and were not required to have adequate disturbance monitoring data. The lack of disturbance monitoring data available from these facilities led to difficulty in adequately assessing the events. Introducing IBR monitoring requirements to Reliability Standard PRC-002 may create unintended consequences to purpose of Reliability Standard PRC-002 and may lead to industry confusion. Hence, to address needs identified in the Standard Authorization Request (SAR) submitted by the Inverter-Based Resource Performance Task Force (IRPTF), a new standard for monitoring requirements for IBRs is created instead of revising the Reliability Standard PRC-002.

The Transmission Owners and Generator Owners, as applicable, will have the responsibility for ensuring that adequate data is available for applicable Elements at the applicable IBR generating facilities. This

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<sup>1</sup> IBR unit includes the inverter, wind turbine generator etc.

standard requires that sequence of events recording (SER), fault recording (FR), and dynamic disturbance recording (DDR) data is available from the applicable IBR generating facilities.

## **Rationale for Applicability Section**

### **Functional Entities**

The two functional entities that are responsible for implementing disturbance monitoring equipment and collecting recording data are: Generator Owner and Transmission Owner. The standard is only applicable to Transmission Owner in case where Transmission Owner owns equipment within the IBR Plant.

### **Applicable Facilities**

The following facilities from the BES definition are in the scope of this standard:

- Inverter-based portion of generating plant/Facility meeting the criterion set by Inclusion I2, part (b)
- Generating plant/Facility meeting the criteria set by Inclusion I4

The following Elements associated with BES generating plants noted above are in the scope of this standard:

- Circuit breaker(s)
- Main power transformer(s)
- Collector bus
- Shunt static or dynamic reactive device(s)
- At least one IBR unit connected to last 10% of each collector feeder length (i.e., furthest from the collector bus)

The following examples are provided to clarify applicability of the PRC-028 standard.

### **Example 1: Applicability of PRC-028**

Figure 1 shows a typical single line diagram of an IBR generating facility. The IBR generating facility is connected to the transmission system via a short tie-line. The length of collector feeder #1, #2, and #3 is 3000 ft, 2500 ft, and 2800 ft respectively. IBR units #6 and #7 are connected to collector feeder #1 at 2800 ft and 3000 ft distance from the collector bus respectively. In other words, these IBR units are connected to last 10% of the collector feeder #1. This IBR generating facility is equipped with a dynamic reactive device (e.g., synchronous condenser, static VAR compensator etc.) connected to the collector bus.

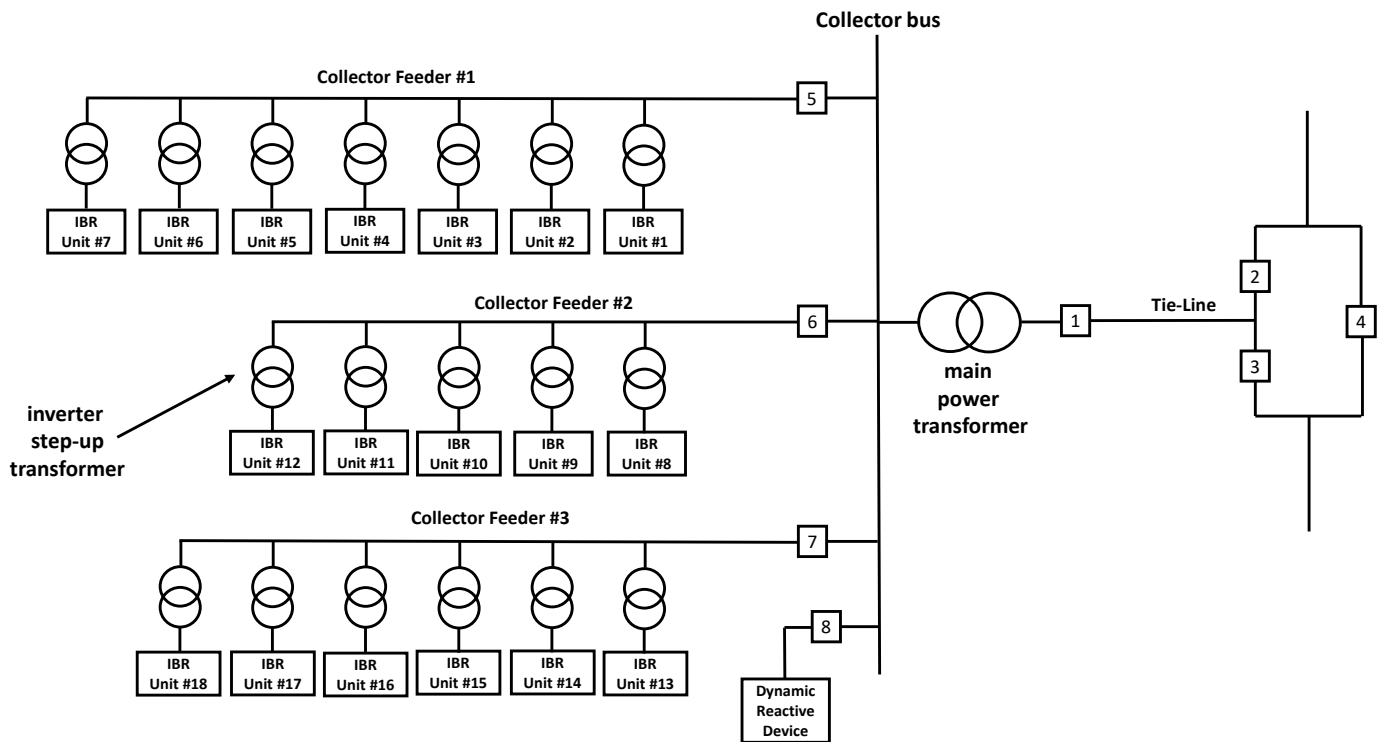


Figure 1: Typical IBR Generating Facility Single Line Diagram

**SER Data:** The SER data is required for circuit breakers 1, 5, 6, 7, and 8. Circuit breaker 1 is associated with the main power transformer. Circuit breakers 5, 6, 7, and 8 are associated with the collector bus. The SER data for either IBR unit #6 or #7 is required as both are connected to last 10% of the collector feeder #1 length. Similarly, at least one IBR unit connected to last 10% of collector feeder #2 and #3 is also required to have SER data.

**FR Data:** The FR data is required from high side terminals of the main power transformer. In this example, the IBR plant consists of only one main power transformer. If the IBR plant consists of more than one main power transformer, then FR data for each main power transformer is required. The FR data for either IBR unit #6 or #7 is required as both are connected to last 10% of the collector feeder #1 length. Similarly, at least one IBR unit connected to last 10% of collector feeder #2 and #3 is also required to have FR data. As the IBR plant is equipped with the dynamic reactive device, the FR data for it also required.

**DDR Data:** The DDR data is required from high side terminals of the main power transformer. If the IBR plant consists of more than one main power transformer, then DDR data for each main power transformer is required. The DDR data from individual IBR units is not required.

**Example 2: Applicability of PRC-002 versus PRC-028**

Figure 2 shows an example of IBR interconnection to the transmission system via Line 34. The BES bus in substation Wu is the identified BES bus per methodology in Attachment 1 of the Reliability Standard PRC-002. The SER and FR data requirements for the identified BES bus are per the requirements in the Reliability

Standard PRC-002. The IBR generating facility in this example meets the criteria set by inclusion I2 of the BES definition. Hence, the Reliability Standard PRC-028 is applicable to the IBR generating facility.

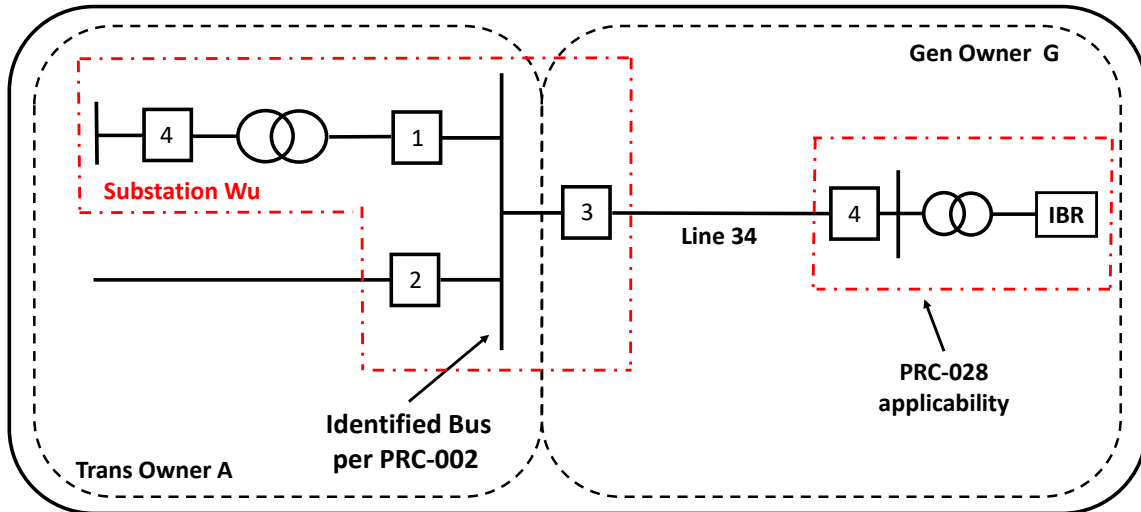


Figure 2: IBR Interconnection – Applicability of PRC-002 versus PRC-028

**Example 3: Transmission Owner owned Equipment within the IBR generating facility**

Figure 3 shows an example of an IBR interconnection where Transmission Owner A owns circuit breaker 3 associated with an IBR generating facility. In this case, Transmission Owner A is responsible for SER data for circuit breaker 3. It is not common for Transmission Owner to own the main power transformer and/or portions of collector system associated with an IBR generating facility. However, in cases where this is true, Transmission Owner is responsible for SER, FR, and DDR data, as applicable, required by the Reliability Standard PRC-028.

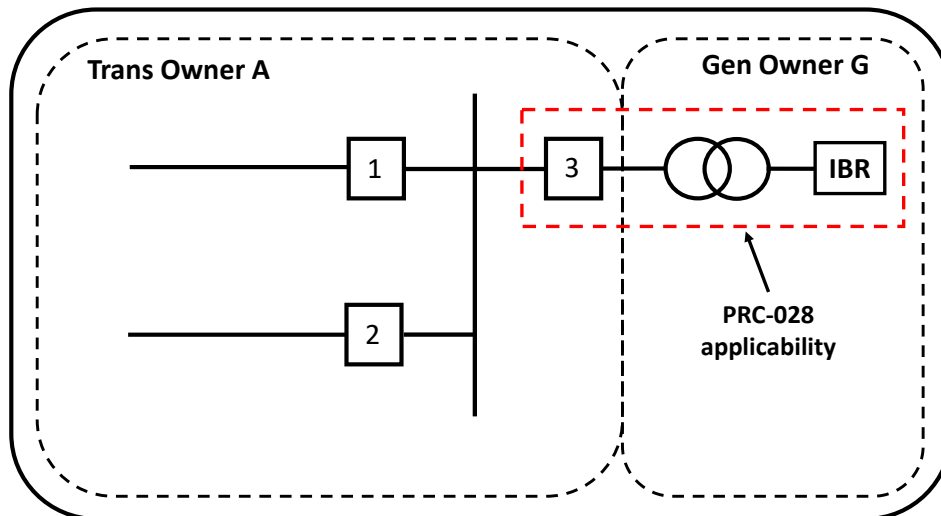


Figure 3: Transmission Owner owned Equipment within an IBR Plant

**Example 4: Hybrid Plant (synchronous machine + IBR)**

Figure 4 shows an example of a hybrid plant, i.e., synchronous machine + IBR, interconnecting to the transmission system via Line 34. The aggregate nameplate rating of this hybrid generating facility is greater than 75 MVA and meets the criteria set by inclusion I2, part (b) of the BES definition. The SER, FR, and DDR data for inverter-based portion of this hybrid generating facility is required.

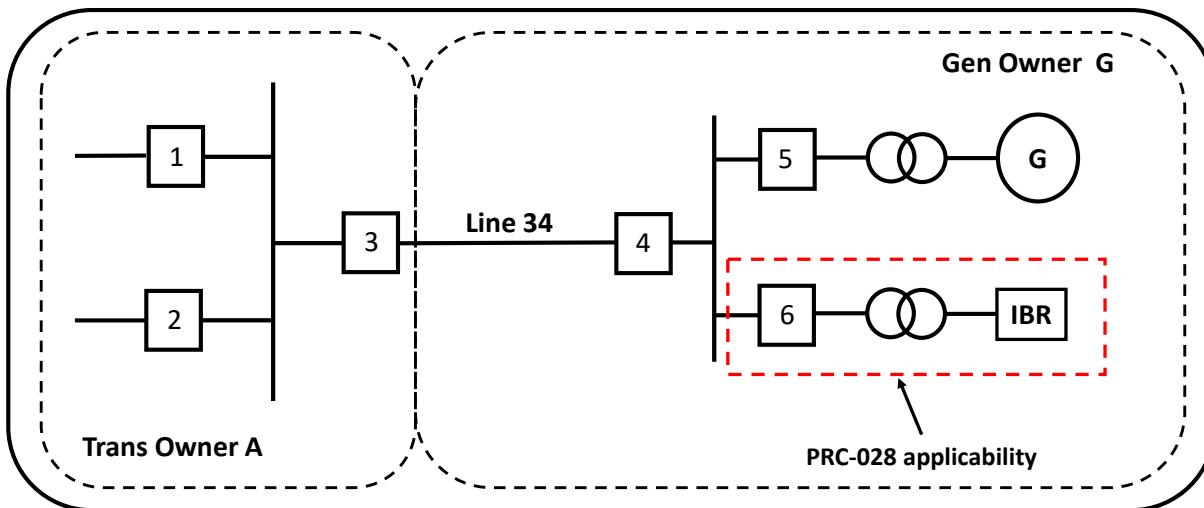


Figure 4: Hybrid Generating Facility

**Rationale for Requirement R1**

The standard requires to capture SER data from circuit breakers and IBR units within the IBR generating facility. At least one IBR unit connected to last 10% of each collector feeder length must have the data specified in R1, Part 1.2.1 through 1.2.6

Change of state of circuit breaker position and IBR unit data, time stamped according to Requirement R7 to a time synchronized clock, provides the basis for assembling the detailed sequence of events timeline of IBR generating facility’s response during a power System disturbance. Analyses of system disturbances often begin by evaluation of SERs to help determine the initiating event(s) and follow the disturbance propagation. Recording of breaker operations helps determine the interruption of flows during the disturbances. Recording of at least one IBR unit connected to last 10% of each collector feeder length helps analysis of IBR unit performance during BES disturbances that do not operate the interconnecting circuit breaker. One IBR unit in the last 10% of the collector feeder length is specified because it may be the most challenging location for IBR units to continue to ride-through during BES disturbance.

**Rationale for Requirement R2**

The intent is to capture sufficient FR data for Elements at each IBR generating facility to analyze the overall response of the IBR generating facility to a system disturbance. Analyses of disturbances involving widespread reduction of power output from IBRs in recent years has shown that expansion of monitoring at IBR sites is necessary. The required electrical quantities may either be directly measured or determinable if sufficient FR data is captured (e.g. residual or neutral current if the phase currents are directly measured).

The plant level FR measurements, i.e., measured on high-side terminals of the main power transformer, specified in Requirement R2, Part 2.1 provide data at the IBR generating facility interconnection to the bulk power system. To cover all possible fault types, phase-to-neutral voltage recording for each phase is required to be determinable. Each phase current and residual current are required to distinguish between phase faults and ground faults. This data also facilitates determination of the fault location and cause of relay operation. The measurements of active and reactive power provide data on the overall generating facility's response to the system disturbance.

Analyses of system disturbances involving widespread reduction of real power output from IBRs in recent years have shown that all individual IBR units within the IBR generating facility do not react to the disturbance identically because of their wide geographic distribution. The choice of at least one IBR unit connected to the last 10% of each collector feeder length in Requirement R2, Part 2.2 requires monitoring on a selection from some of the most geographically remote IBR units at each site, ensuring that FR data is available to analyze individual IBR unit response. It may be challenging to record/determine specified electrical quantities from IBR unit terminals for existing installations. As such, the standard allows for recording/determining specified electrical quantities on high-side of IBR unit transformer.

In some cases, the dynamic reactive device is used within the IBR generating facility and often connected to medium voltage collector bus. Regardless of where dynamic reactive device is connected, the output of it during system disturbances is important to understand overall performance of the plant during a disturbance. The measured or determined electrical quantities for dynamic reactive device are same as those specified to be measured/determined from high-side of main power transformer.

### Recording of Electrical Quantities

For effective fault analysis, it is necessary to know values of all phase and neutral currents and all phase-to-neutral voltages. Based on such FR data, it is possible to determine all fault types. FR data also augments SERs in evaluating circuit breaker operation. FR also shows generator output response to a system disturbance.

### Current Recordings

The required electrical quantities are normally directly measured. Certain quantities can be derived if sufficient data is measured, for example residual or neutral currents. Since a Transmission System is generally well balanced, with phase currents having essentially similar magnitudes and phase angle differences of 120 degrees, during normal conditions there is negligible neutral (residual) current. In case of a ground fault, the resulting phase current imbalance produces residual current that can be either measured or calculated.

Neutral current, also known as ground or residual current  $I_r$ , is calculated as a sum of vectors of three phase currents:

$$I_r = 3 \cdot I_0 = I_A + I_B + I_C$$

$I_0$  - Zero-sequence current

$I_A, I_B, I_C$  - Phase current (vectors)

### Voltage Recordings

Voltages are to be recorded or accurately determined at applicable Elements as outlined in Requirement R2.

### **Rationale for Requirement R3**

Time stamped pre- and post-trigger FR data aid in the analysis of power system operations and determination if operations were as intended.

The “Odessa Disturbance” report from September 2021 recommended high resolution oscillography data at the point of interconnection and on individual IBR units. The minimum recording rate of 128 samples per cycle is specified recognizing state-of-the-art for DME including storage any storage capability limitations and provides sufficient data to recreate accurate response of the IBR generating facility to system disturbances. This higher sampling rate is particularly important for capturing transient events at the individual IBR units.

Pre- and post-trigger fault data along with the SER data, all time stamped to a common clock, aid in the analysis of Protection System operations after a fault to determine if a Protection System operated as designed. Additionally, IBR units employ fast acting control systems (with built in protection functions) dictating IBR generating facility’s response to system disturbance. The FR data from IBR units time stamped to a common clock is necessary to analyze IBR unit and generating facilities response to system disturbances. Generally speaking, BES faults persist for a very short time period, approximately 1 to 30 cycles. To capture the full response of IBR generating facility spread over a large geographic area, a two-second total minimum record length synchronized to a common clock is necessary for FR data. Multiple records allow for legacy microprocessor relays which, when time synchronized to a common clock, can provide adequate fault data but are not capable of providing fault data in a single record with 120 contiguous cycles total.

FR triggers can be set so that when the monitored value on the recording device goes above or below the trigger value, data is recorded. Requirement R3, Part 3.1.3.1 specifies a neutral (residual) overcurrent trigger for ground faults. Requirement R3, sub-Part 3.1.3.2 specifies a phase overvoltage or undervoltage trigger during voltage ride-through events. For IBR unit FR data triggers, Requirement R3, Part 3.2.3.1 specifies a phase overvoltage and undervoltage. Requirement R3, Part 3.2.3.2 specifies a trigger for DC overvoltage, DC overcurrent, and DC reverse overcurrent to monitor for abnormal DC quantities at the IBR unit resulting from system disturbances. Requirement R3, sub-Part 3.2.3.3 specifies a trigger for overfrequency and underfrequency to record response during frequency ride-through events.

The triggers specified in Requirement R3, Part 3.3 for dynamic reactive device FR data are similar to ones specified in Requirement R3, Part 3.1 for plant level FR data measured or determined on high-side of the main power transformer.

### **Rationale for Requirement R4**

Large scale system disturbances generally are an evolving sequence of events that occur over an extended period of time, making DDR data essential for event analysis. Data available pre- and post-contingency helps



identify the causes and IBR generating facility's response to large scale system disturbances. Therefore, continuous recording and storage are necessary to ensure sufficient data is available for the entire event. The state-of-the-art DDR equipment is capable of continuous recording.

DDR data contains the dynamic response of the IBR generating facility to a system disturbance and is used for analyzing complex power system events. This recording is typically used to capture short-term and long-term disturbances. Since the data of interest is changing over time, DDR data is normally stored in the form of RMS values or phasor values, as opposed to directly sampled data as found in FR data.

DDR is used to measure transient response to system disturbances during a relatively balanced post-fault condition. Therefore, it is sufficient to provide a single phase-to-neutral voltage or positive sequence voltage and current from the same phase or positive sequence for each applicable main power transformer for analysis. It is also sufficient to provide a single frequency for any of the provided voltages since all main power transformers within a IBR generating facility are at the same frequency. Recording of all three phases of voltage/current is not required, although this may be used to compute and record the positive sequence value(s). The electrical quantities for Real Power and Reactive Power on a three-phase basis can be measured/recorded or determined (calculated, derived, etc.).

The data requirements for PRC-028-1 are based on a system configuration assuming all normally closed circuit breakers on a BES bus are closed.

A crucial part of disturbance analysis is understanding the dynamic response of generating resources. Therefore, it is necessary to have DDR on high-side of the main power transformer(s) measuring the specified electrical quantities to adequately capture IBR generating facility's response.

The Requirement R4, Part 4.1 requires either one phase-to-neutral or positive sequence voltage. However, the phase-to-phase voltage recording is acceptable. Since the BES operates under a relatively balanced operating condition and, if needed, phase-to-neutral quantities can be derived from phase-to-phase quantities.

#### **Rationale for Requirement R5**

An input sampling rate of at least 960 samples per second, which corresponds to 16 samples per cycle on the input side of the DDR equipment, ensures adequate accuracy for calculation of recorded measurements such as complex voltages and frequency. The input sampling rate specified is same as one specified in the Reliability Standard PRC-002.

An output recording rate of electrical quantities of at least 60 times per second refers to the recording rate of the device. Recorded measurements of at least 60 times per second provide adequate recording speed to monitor the IBR generating facility's response during power system disturbances. Since control system associated with IBRs is fast acting, higher frequency recording is necessary to accurately reconstruct events. An output recording rate of 60 times per second provides this higher frequency recording while not greatly increasing data storage requirements.



### **Rationale for Requirement R6**

Time synchronization of disturbance monitoring data is essential for time alignment of large volumes of geographically dispersed records from diverse recording sources. Coordinated Universal Time (UTC) is a recognized time standard that utilizes atomic clocks for generating precision time measurements. All data must be provided in UTC formatted time either with or without the local time offset, expressed as a negative number (the difference between UTC and the local time zone where the measurements are recorded).

Accuracy of time synchronization applies only to the clock used for synchronizing the monitoring equipment. The equipment used to measure the electrical quantities must be time synchronized to  $\pm 100$  microsecond accuracy; however, accuracy of the application of this time stamp and therefore, the accuracy of the data itself is not mandated. This is because of inherent delays associated with measuring the electrical quantities and events such as breaker closing, measurement transport delays, algorithm and measurement calculation techniques, etc.

Ensuring that the monitoring devices internal clocks are within  $\pm 100$  microsecond accuracy will suffice with respect to providing time synchronized data. Accuracy of time synchronization applies only to the clock used for synchronizing the monitoring equipment. Note that the recently published IEEE Std 2800 requires the DME recording plant level data be synchronized to the clock with accuracy of  $\pm 1$  microsecond accuracy; however, the accuracy requirement is set to  $\pm 100$  microsecond to strike a balance between need of accuracy and practical limitations of equipment necessary to achieve the stated accuracy.

The IBRs, which are not affected by inertial time constants, make changes in power production very rapidly. To understand and analyze control decisions during system disturbances and the reasons behind them over dozens of plants with possibly 100's of IBR units requires a high level of accurate time synchronization. Following provide some examples of IBR's fast response:

- Typical 90% response to a three-phase fault is <40 ms.
- Central power plant controllers issue updated commands in as little as 40 ms upon detection of change in system conditions.
- Standard closed loop voltage control response can be <200 ms.
- Instantaneous Inverter protective trip decisions such as AC or DC overvoltage or reverse DC current can be made in less than 10 ms.

### **Rationale for Requirement R7**

Requirement R7, Part 7.1 specifies a minimum time period of 30 calendar days inclusive of the day the data was recorded for which the data to be retrievable. Data hold requests are usually initiated the same or next day following a major event, however, it takes a longer time to determine which data from which generating facility needs to be retrieved for event analysis. A 30 calendar day time period provides enough time for communication between various Entities regarding the event and need for data retrieval from DME at various generating facilities. The requestor of data has to be aware of 30 calendar day retrievability limit to ensure timely data hold requests. Requiring data retention for a longer period of time is expensive and unnecessary.

With the state-of-the-art equipment, having the data retrievable for the 30 calendar days is realistic and doable. It is important to note that applicable entities should account for any expected delays in retrieving data and this may require devices to have data available for more than 30 days. To clarify the 30 calendar day time frame, let's assume that event occurs on Day 1. If a request for data is made on Day 6, then that data has to be provided to the requestor within 30 calendar days after a request or a granted time extension. However, if a request for the data is made on Day 31, that is outside the 30 calendar days specified in the requirement, and an entity would not be out of compliance if it did not have the data.

This requirement directs the applicable entities, upon requests from the Reliability Coordinator, Regional Entity or NERC, to provide SER, FR and DDR data for generating facilities as per the applicability. To facilitate the analysis of system disturbances, it is important that the data is provided to the requestor within a reasonable time. Providing the data within 30 calendar days (or the granted extension time), subject to Requirement R7, Part 7.2, allows for reasonable time to collect the data and perform any necessary computations or formatting. An entity may request an extension of the 30 calendar days submission requirement. If granted by the requestor, the entity must submit the data within the approved extended time.

Disturbance analysis includes reviewing data recording from many devices and entities. Standardized formatting and naming conventions of these files significantly improves timely analysis. The formatting and naming convention requirements for SER, FR, and DDR are consistent with same requirements in the Reliability Standard PRC-002.

**SER data:** Requirement R7, Part 7.3 specifies a simple ASCII Comma Separated Value (CSV) format according to Attachment 1. It is necessary to establish a standard format as it allows data submitted by one entity or facility to be incorporated with same data provided by other entities or facilities to develop a detailed sequence of events timeline of a power system disturbance.

**FR and DDR data:** Requirement R7, Part 7.4 specifies the IEEE C37.111 Standard for Common Format for Transient Data Exchange (COMTRADE) format for the FR and DDR data. The IEEE C37.111 is well established in the industry. It is necessary to specify a standard format as multiple submissions of data from many sources is typically incorporated to provide a detailed analysis of a power system disturbance. The 2013 revision of the IEEE C37.111 includes an annex describing the application of the COMTRADE standard to synchrophasor data.

Requirement R7, Part 7.5 specifies the IEEE C37.232 Standard for Common Format for Naming Time Sequence Data Files (COMNAME) format for naming the SER, FR and DDR data files. The lack of a common naming practice seriously hinders the event analysis and investigation process.

### **Rationale for Requirement R8**

The standard requires that Entity restore the recording capability for SER, FR, or DDR data within 90 calendar days of the discovery of a failure. The 90 calendar day time period permitted in this requirement strikes a balance between reasonable time needed to restore capability while ensuring that recording capability is not out of service for an extended duration. If the recording capability cannot be restored

within 90 calendar days due to limitations such as budget cycle, service crews, vendors, needed outages, etc., the entity is required to submit a Corrective Action Plan for restoring the recording capability to the Regional Entity and implement it. It is treated as a failure if the recording capability is out of service for maintenance and/or testing for greater than 90 calendar days. An outage of the monitored Element does not constitute a failure of the disturbance monitoring capability.