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Guide for Application of Disturbance Recording Equipment

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Note:

Terms in bold typeface are defined in the *NPCC Glossary of Terms* (Document A-7)

1.0 INTRODUCTION

The power system is routinely subjected to faults or disturbances which can range from transient faults on transmission lines to system-wide disturbances involving many states or countries. Investigation of each incident is critical in optimizing the performance of protection systems with the goal of preventing future incidents from becoming wide-area disturbances. The tools required to perform post-incident analyses include Disturbance Recording Equipment (DRE) which can capture pre-event, event, and post-event conditions with a high degree of accuracy.

As technology has advanced, the capabilities and options available in modern recording equipment have improved dramatically. With these advancements comes the challenge of understanding how to configure them to maximize the benefits of recorded data. This guide provides the users of recording equipment within NPCC with many of the recommendations (or requirements) which should be considered in application of various disturbance recording equipment.

There are many names given to these devices in the industry, but essentially the recorders can be classified into 3 categories:

- DFR (Digital Fault Recorder)
- DSR (Dynamic Swing Recorder)
- SER (Sequence Event Recorder)

A DFR is generally used to record faults on the power system. The sampling rate is high (many samples per cycle) to provide the resolution required, but the length of the record is short (a few seconds at most), limited to immediate pre-fault, fault, and post-fault conditions.

A DSR is used to record power swings on the system. The sampling rate is lower (one sample every 1-10 cycles) but the length of the record is longer to capture a long, low frequency power swing. Some DSRs are capable of continuous recording.

A SER captures the sequence of events for monitored changes of state occurring in substations or power plants. It is used in conjunction with records from DFRs or DSRs to complete post-event analyses. For non-fault conditions, the SER record may be the only recorded data available.

Modern recording equipment often has the capability to perform more than one of the three functional categories discussed above.

This guide also provides the user with recommendations regarding deployment, trace assignments, record lengths, use of triggers, sampling rates, record retention, data format, maintenance, power sources, monitoring, and communication.

2.0 DFRs

2.1 Deployment

DFRs are required to be installed to the extent required to satisfy NPCC Criteria A-5 and A-2. This requirement considers the probability that during a system disturbance, one or more DFRs in a given area may be out of service or fail to trigger. The objective of providing this level of coverage is to assure the ability to identify the current-zero time for loss of BPS transmission elements.

2.2 Trace Assignments

2.2.1 Analog Channels

To facilitate fault analysis and review of protection system operations, all BPS circuits within a station should be monitored (it is acceptable to monitor currents from each line and voltages from a common set of instrument transformers). At minimum, two-phases of a delta connection and three phases of a wye connection (or two phases and a neutral) need to be monitored for analog current and voltage. This allows one to use symmetrical component calculations to calculate the value of the channel not being monitored. However, it is advisable that all current and voltage phases be monitored (if possible) to check the health of the current and voltage sources.

2.2.2 Digital Channels

Digital inputs to a DFR should include circuit breaker auxiliary contacts if they are not already being monitored by a SER (see section 4.2 for guidance on the use of interposing relays for breaker position indication). Additional digital inputs should be used to allow for the evaluation of protection system performance, particularly where other forms of SER capability do not exist. Such inputs could include trip bus operation, pilot channel start/stop functions, reclosing functions, transfer trip send/receive, breaker failure operation, etc.

2.3 Record length

The record should contain enough pre-trigger, trigger (fault), and post-fault information to evaluate protection system performance. The number of cycles of pre-trigger information should be sufficient to allow for the replication of pre-fault values if a dynamic simulation of a protection system operation is warranted (e.g., 10-cycles of pre-trigger). The user should consider the following when setting up a DFR:

- DFR characteristics (sampling rate, memory, number of channels, etc.)
- Minimum record required to capture a time stamp
- Requirements of local relays for reproducing events in the relays
- Expected local clearing time for most faults

In the absence of these considerations, a minimum of 1.0 second should be considered for the recommended record length.

2.4 Triggers

Analog and digital triggers should be used to optimize the recording of system faults, protective relaying performance, and abnormal system conditions. Settings of trigger values in a DFR may vary by location, and evaluation of triggers should be done periodically after the initial commissioning of a recorder with adjustments made as necessary to reflect operating experience and changes in system conditions.

It is important to understand the operating characteristic of each manufacturer's digital fault recorder to ensure that it is configured to capture all desired system events. In some DFRs the operation limit of a trigger is settable. Incorrect application of these limiters could prevent the DFR from recording critical information.

There are a variety of other trigger settings available that may be considered for use in a DFR depending on need. Some of the triggers available are:

- Overcurrent
- Under/Over Voltage
- Positive Rate-of-Change of current, voltage, or frequency
- Negative Rate-of-Change of current, voltage, or frequency
- Total Harmonic Distortion Trigger (Current or Voltage)
- Positive Sequence (requires 3-phases of current or voltage)
- Negative Sequence (requires 3-phases of current or voltage)
- Zero Sequence (requires 3-phases of current or voltage)
- Impedance

- Frequency Deviation (over/under from nominal)
- Delta Frequency (step change in frequency)
- Frequency Rate-of-Change (relative to a setpoint for rate-of-change)
- Tripping relay operation or breaker operation

When selecting a frequency deviation trigger for transient recording, the trigger should be set higher than normal deviations for load changes in an area.

2.5 Sampling Rates

The DFR sampling frequency must be high enough to enable use of the records to verify system models. The sampling frequency also must be sufficient to allow capture of harmonics related to transient conditions such as breaker re-strikes. It is recommended that a DFR have a minimum sampling frequency of 3840 Hz (64 Samples/Cycle).

3.0 DSRs

3.1 Phasor Measurement Units (PMUs)

Phasor Measurement Units (PMUs), and particularly the transmission and storage of continuous phasor data, are considered a development project and are outside the scope of this guideline. Some NPCC members are participating in the Eastern Interconnection Phasor Project (EIPP). Information regarding this is available at phasors.pnl.gov. Although not within the scope of this guideline, it is important to note that the EIPP is presently recording DSR-type data on a continuous basis from many stations in the Eastern Interconnection.

Even after the EIPP matures, independent DSR installations will be important to supplement and to back up the EIPP. In fact, there are some PMUs which have local storage and can function as independently triggered DSRs--this class of PMU devices comes under the scope of this guideline.

3.2 Deployment

DSRs are distributed throughout NPCC systems at various key stations. There are at this time roughly 40 DSRs deployed in the NPCC region. Recently it has become possible to purchase a DFR which includes DSR features. This adds very little to the overall installed cost, and the use of such features should be considered in consultation with the **Area** Reliability Coordinator since it increases the probability of having a record from within any islands that may form. In deploying DSRs, the probability that one or more DSRs in a given area

may be out of service or may fail to trigger during a system disturbance should be considered.

3.3 Trace Assignments

Ideally, all BPS circuits within a station should be monitored. Single phase current monitoring may be employed with DSRs, although 3 phase current monitoring is more desirable. Ideally, at least two independent potentials (for example, bus potentials from two separate busses) should be connected and recorded at every installation. Frequency and rms voltage magnitude should be recorded for both potentials. There exist several locations in NPCC where DSRs are connected to potentials only, partly as an outgrowth of a past NPCC frequency monitoring project. These locations are set up to monitor frequency and rms voltage magnitude from one or more potential sources. These installations have been very valuable, but it is desirable to include significant currents in most future installations, particularly as this becomes economical with the advent of combination DFR – DSR equipment.

3.4 Record length

DSR records should contain enough pre-trigger, trigger (fault), and post-trigger information to enable evaluation of system performance and disturbances. For instruments accessible using dial-up lines, the record lengths have been held to 60 or 90 seconds to keep the record download times reasonable. Thirty seconds pre-trigger and 60 seconds post-trigger are suggested as a minimum in such situations. DSRs which can be accessed using network means should employ longer record lengths. DSRs records should always “auto-extend” when additional triggers occur during the recording period.

3.5 Continuous Recording

Advances in storage have made it possible for DSRs to be equipped for continuous recording. A buffer of perhaps 30 days of data is available in such DSRs and a file can be requested that includes any selected time period within that past 30 day period (refer to Section 3.7 for recommended sampling rates). This is an important development; however, the use of event triggers is still important as a quick and convenient way to identify and examine typical disturbances. Triggered records have often called attention to events that otherwise would have been missed.

3.6 Triggers

Settings of trigger values in a DSR will vary by location, and evaluation of triggers should be done periodically after the initial commissioning of a recorder, with adjustments being made as necessary to reflect operating

experience and changes in system conditions. NPCC members have a long history triggering DSRs with delta frequency in the range of plus or minus 20 mHz. Delta frequency triggering was very successful during the August 2003 blackout. Members of the TFSP can be consulted as to the trigger levels being used with various manufacturer's DSRs. Often triggers with similar names actually use quite different algorithms.

- Positive Rate-of-Change of current, voltage, or frequency
- Negative Rate-of-Change of current, voltage, or frequency
- Total Harmonic Distortion Trigger (Current or Voltage)
- Apparent Impedance
- Frequency Deviation (over/under from nominal)
- Delta Frequency (step change in frequency)
- Frequency Rate-of-Change (relative to a set point for rate-of-change)
- Tripping relay operation or breaker operation

3.7 Sampling Rates

DSR data rates must be high enough to observe the active power system oscillation modes, which have been observed to be in the range of 0.20 to 1.0 Hz. As discussed above in connection with record lengths, the download time using dial-up access has been a limiting factor in selecting sampling rates. Installations operating at a 6 Hz or 10 Hz data sampling rate have proven to be adequate to observe the active oscillation modes in the NPCC Region. Data rates should be several multiples of the highest frequency to be observed. When DSRs are accessed using network means, the sampling frequency can easily be higher, such as 30 Hz or 60 Hz. Experience indicates that it is not actually necessary to sample at such a high rate, but the technology makes it relatively easy to do.

3.8 Filtering

Users should be aware that analog and digital filtering leads to internal delays in DSRs and the magnitude of the delays are not generally known. That is, a particular event observed in a DSR record actually occurred some finite time before it is shown. This is equipment specific, and manufacturers should be consulted for information.

4.0 SERs

4.1 Point Assignments

Sequence of Events Recorders (SERs) are intended to monitor the change-of-state of devices and control signals in a station. Essential to this application is the monitoring of circuit breaker and circuit switcher positions. Additional information in analyzing an event can be gained from monitoring other significant data points in the station, including:

- Breaker trip coil energization
- Output contacts of protective relays
- Teleprotection key and receive functions
- Selected control relays (voltage, reclosing, etc.)
- Disconnect switch positions
- Significant alarm points
- Security systems events

4.2 Interposing Relays

The intent of a SER is to capture an accurate sequence of the high speed operations of various devices in a station. This enables the user of the data to identify the conditions that existed prior to each step in the sequence and to understand the nature of the subsequent operations. The objective is to determine if the operations were correct and to correlate the system data at each step with that which would be expected based on system design and modeling. In order to satisfy this objective, it is critical to be able to establish the time of an event as precisely as possible. In so doing, the user must be aware of any time delay inherent in the contact inputs being recorded. Even circuit breaker auxiliary switches or other direct contacts may introduce a time delay—in fact, the opening of a breaker's auxiliary contacts would not likely correspond to the true current-zero arc interruption of the breaker's primary contacts.

Interposing relays are often used to facilitate connection of control points to SERs. This practice is sometimes necessary due to the unavailability of contacts on monitored devices. However, conventional interposing relays would add delay to the recording of events at the SER. For this reason, conventional interposing relays should not be used where the device being monitored may be critical to establishing the time of an event. Special utility-grade event recorder relays are available which provide a deterministic high speed interface (typically under 2 ms with 0.5 ms repeatability) as well as the diode blocking components required for direct insertion of the package into relay trip schemes and circuits. If an interposing relay is required, care should be taken to assure the fastest and most repeatable possible operating time of the relay (pickup and dropout). Any data provided for analysis should identify which points are monitored using interposing relays as well as an estimate of the operating times of the interposing relays.

4.3 Use of RTUs for Sequence of Events Recording

Many new SCADA RTUs have the ability to provide SER functionality. These RTUs can accept GPS time synchronization signals and can time stamp inputs to the nearest millisecond. In order to take advantage of this feature, it is necessary to have a means to bring the data back from the RTU to the individuals performing the data analysis. Protocols are now available that support transfer of the data, complete with time stamp, to the SCADA Master. At that point, the data can be accessed for analysis. In providing this feature via the RTU, it is important that the communication bandwidth be sufficient to simultaneously support all normal SCADA functions without compromise.

5.0 COMMON ISSUES

5.1 Record retention

Critical data should be retrieved from the recording devices on a regular basis to prevent records from being overwritten. The server or hard drive should be backed up periodically to prevent records from being lost. Records may be requested by the **Area** or by NPCC and should be capable of being located and provided upon request. Retrieved records should be maintained for two years; however, trigger events not related to actual system disturbances need not be retained. Recorded data relating to an event which was the subject of an NPCC event investigation shall be retained for at least three years. However, if records of a particular system disturbance might be used for other purposes, a company should maintain a separate archive of these events for future reference. Transients in these files may be used for dynamic simulations and/or the evaluation of protective relay performance.

5.2 Data format

Disturbance records should be stored in the native file format. When sharing files the records shall be converted to ASCII COMTRADE. However, it must be noted that not all COMTRADE conversion utilities function in the same way and information contained in the native file format may not be carried into the new file.

When naming a file for sharing or archiving, the date and time of the event trigger should be contained in the file name. It is recommended that files be named in accordance with the latest version of IEEE document "File Naming Convention for Time Sequence Data - Final Report of IEEE Power System Relaying Committee Working Group H8" (COMNAMES).

5.3 Maintenance

Periodic maintenance should be performed on all DRE to assure accuracy and availability, with the understanding that regular use and checking of synchronization and calibration constitutes periodic maintenance. The communication channels used for accessing records remotely and time synchronization should be verified monthly. It is normally not necessary to check calibration on a frequent basis, but a check of the calibration settings in the software should be done every two years to assure that the settings have not been corrupted through routine software evolutions. Event records from DRE may also be used to check calibration. If DRE is found defective, repairs should be performed on a priority basis to identify the problem and recommend parts replacement or field repair.

5.4 Power Supply

The power supplies of all substation equipment covered by this document should be supplied from a station battery and qualified for utility grade substation service. This includes the GPS receiver/clock, the SCADA/EMS RTU, the Disturbance Recording Equipment, modems, and any equipment supplying signals to the DRE. Modems may be powered from AC station service provided sufficient storage capacity exists within the recorder to cover the time required to re-establish station service if interrupted. Consideration should be given to powering master station computers and support equipment from a UPS and/or emergency generator at the control center or engineering offices such that automatic record retrieval is not interrupted and event analysis can proceed before normal power is restored. Consideration should also be given to the end-to-end communications channels, which may involve computer networking equipment and switches, etc.

5.5 Monitoring

DRE should be monitored by SCADA or some other alarming method for equipment failure, loss of power, or shortage of storage capacity. GPS receivers/clocks and any associated IRIG-B distribution equipment should similarly be monitored for equipment failure, loss of power, or loss of synchronization. Loss of synchronization may also be recorded within the DRE record.

5.6 Communication

Communication between the master station and DRE should be reliable, even during system disturbances, and should meet cyber security standards where warranted. Communication should be sufficiently fast and over a sufficient number of channels to permit retrieval of records in a timely manner to support

system operations and restoration. Consideration should be given to a prioritization scheme to allow records with the most important information on a disturbance to be retrieved first. This may be based upon proximity to the disturbance and capability of the DRE.

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References: *NPCC Glossary of Terms* (Document A-7)
SP-6 Report