Case Study - Consolidating Monitoring with Protection

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1. Introduction

Today's disturbance monitoring and reporting requirements provided by FERC, NERC, or individual regional reliability organizations are typically defined by PRC-002-2 for bulk electric system (BES). Similarly, PRC-028-1 defines monitoring and reporting requirements for invertor-based resources. This paper will discuss the similarities and differences between PRC-002-2 and PRC-028-1. With advancements in todays' technology, one can argue the benefits of consolidating monitoring and protection to be able to meet the above monitoring and reporting requirements. This paper will discuss a case study of including monitoring within protection and control devices to meet these requirements. These requirements include minimum sampling rate, fault and disturbance record lengths, sequence of event record lengths, time sync and continuous record length.

2. Establishing Requirements for Disturbance Monitoring

It was August 14th, 2003, just after 4pm in midtown Manhattan in New York City when a voltage dip was observed by protection and control engineers at Consolidated Edison of NYC. Multiple heads popped out of their cubicles and speculated that there was probably a transient fault on the overhead transmission system followed by an auto reclose operation. Subsequently the entire office went dark and more conjecture about what happened ensued, maybe it was local network outage. As more and more reports came in that the outage was widespread in NYC and beyond, it became evident that the North American power grid had experienced its largest blackout ever affecting parts of New York, New Jersey, Connecticut, Pennsylvania, Massachusetts, Vermont, Ohio, Michigan and the Canadian provinces of Ontario and Quebec.

Figure 1[8] - 2003 North East Backout Outage Map

Approximately 50 million people affected/61,800 MW
Took up to 4 days to restore power to some parts

The North American Electric Reliability Corporation (NERC) established a task force to investigate the 2003 backout. Along with determining the root cause and establishing recommendations for preventing future outages, the task force acknowledged the importance of having time-synchronized disturbance recorders. "NERC investigators labored over thousands of data items to synchronize the sequence of events, much like putting together small pieces of a very large puzzle. That process would have been significantly improved and sped up if there had been enough synchronized data recording devices." [1]

It was recommended to install additional time-synchronized recording devices to ensure sufficient data is available to analyze disturbances in the Bulk Electric System (BES). NERC standard PRC-002/018 was then established to require operators of the BES to meet several criteria for disturbance monitoring and reporting. PRC-002 focused on the what of data needs to be recorded and PRC-018 on the reporting and retention requirements. PRC-002 also established requirements on how the data should be captured and stored. PRC-002-1 (revision 1) was revised and PRC-002-2 (revision) was published in 2011. The revision was primarily to merge with PRC-018, establishing an all-encompassing standard. It should be noted that PRC-002 being a NERC standard is enforceable by the Federal Energy Regulatory Commission (FERC) and hence is a requirement for all BES operators. PRC-002 is not an IEEE standard, but it does reference IEEE standards in its requirements such as for data formatting.

In summary PRC-002 establishes requirements on where and what on the power system should be monitored and the technical requirement on how and for how long the data should be stored. The discussion in this paper will primarily focus on the later as it establishes the minimum technical requirements or specifications of the recording device.

3. Disturbance Monitoring Requirements

PRC-002 requires three basic recording functions, each having its own requirements:

1. Sequence of Events (SOE) recording:

   Time stamped chronological status changes of significant events including breaker and protective relay operations per requirement R1 in the Requirements and Measures section.

2. Transient Fault Recording (TFR) or Fault Recording (FR):

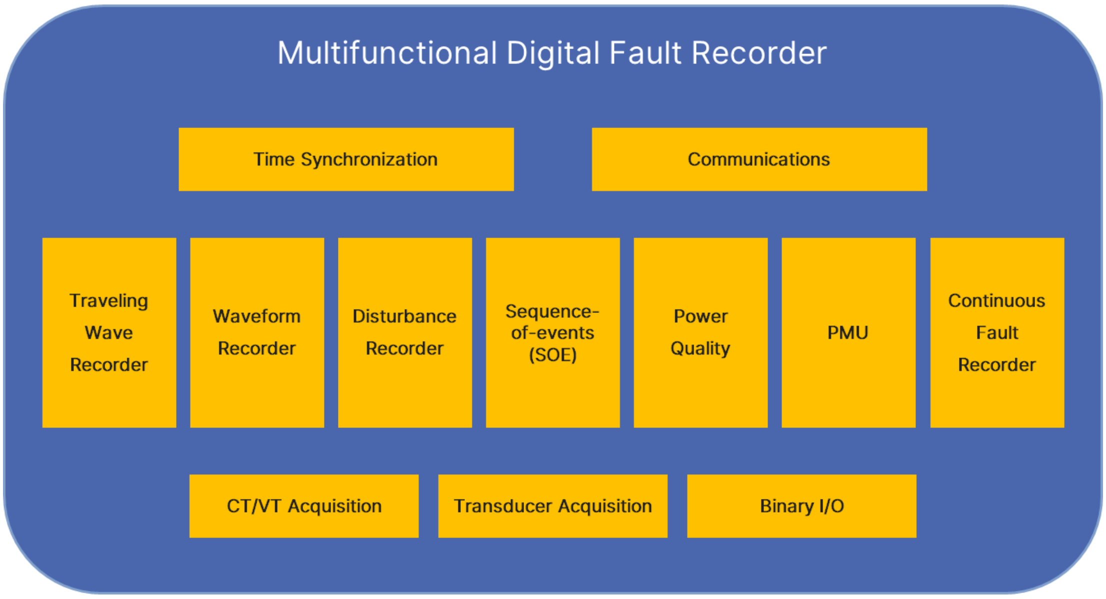
   Time stamped triggered power system waveform recording of at least 16 samples per cycle including post and pre fault data per requirement R1 in the Requirements and Measures section. Digital Fault Recorder (DFR) were initially TFRs which added sequence of event capabilities during the move to microprocessor-based hardware. The triggering event is typically a protective relay operation.

3. Dynamic Disturbance Recording (DDR):

   Untriggered (continuous) time stamped capture of all system disturbances for a 10-day period per requirement R5 in the Requirements and Measures section. During certain power system disturbances there might not be any event such as breaker opening or protective relay operation, stable power swing for example. While SOE and TFR have been widely available, DDR is a relatively new functionality and more resource demanding. Because of this, there is an exception in R8 of the Requirements and Measures section that states if the equipment was installed prior to the standard's effective date then triggered records of at least three (3) minutes will meet the requirement.

DDR is available in most modern multifunction recorders referred to as a Dynamic Monitoring Equipment (DME) to distinguish them from the legacy DFR name. The typical full featured modern multifunctional digital fault recorder is shown in Figure 2. The time stamp needs to be synchronized to the coordinated universal time (UTC) with an accuracy of within +/- 2ms with or without daylight savings offset, per requirement R10 in the Requirements and Measures section. Most operators prefer to use the daylight savings offset as it helps them with analysis of local disturbances but will need to clearly communicate the offset when reporting data. This often requires installation or use of GPS/GNSS receiver and distribution clock. The time distribution medium is typically IRIG-B over coax or over an Ethernet network. Network Time Protocol or Simple Network Time Protocol (NTP/SNTP) might not meet the accuracy requirements. Use of IEEE 1588 Precision Time Protocol (PTP) provides nanosecond accuracy and meet the accuracy requirements.

Figure 2 – Modern Disturbance Monitoring Equipment (DME)



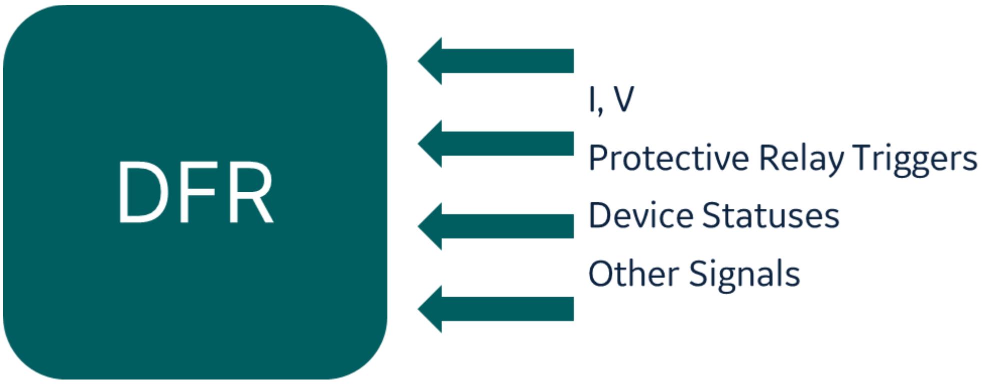
4. Managing Requirements

Managing the requirements present challenges in the complexity and cost of installation. Several disturbance monitoring architectures have been developed and used over the years to meet these requirements.

4.1. Centralized

As shown in Figure 3, all analog and digital signals (typically breaker statuses, CT/VT analog signals, protective relay trips, etc.) are wired directly to the DME requiring extensive amounts of copper wires. This requires considerable design, construction and commissioning to implement and maintain. An advantage is all data is captured simultaneously and stored in a common platform. This architecture can be suitable for small to medium sites but becomes complicated for larger sites. The architecture can be broken out into smaller individual monitoring zones in large sites, for example each bay being a monitored zone requiring multiple DMEs.

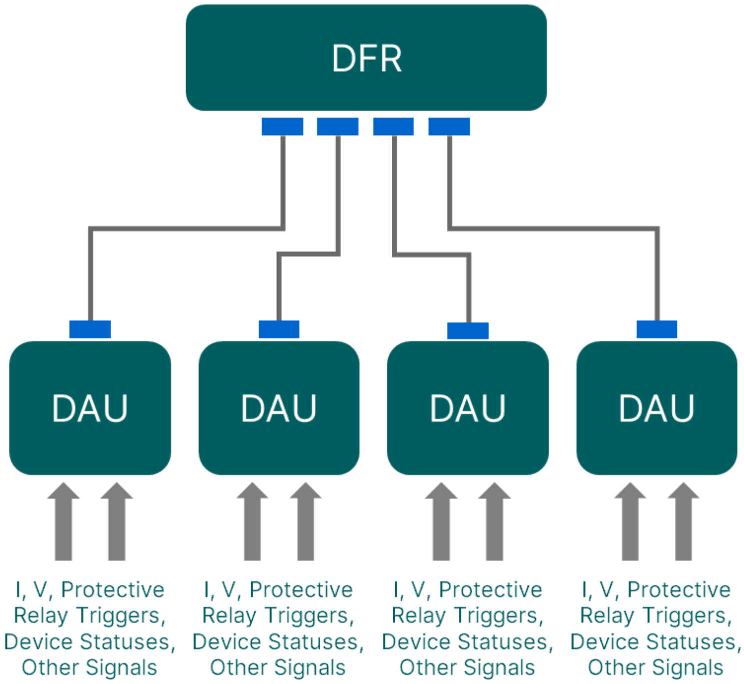
Figure 3 – Centralized DME



4.2. De-centralized

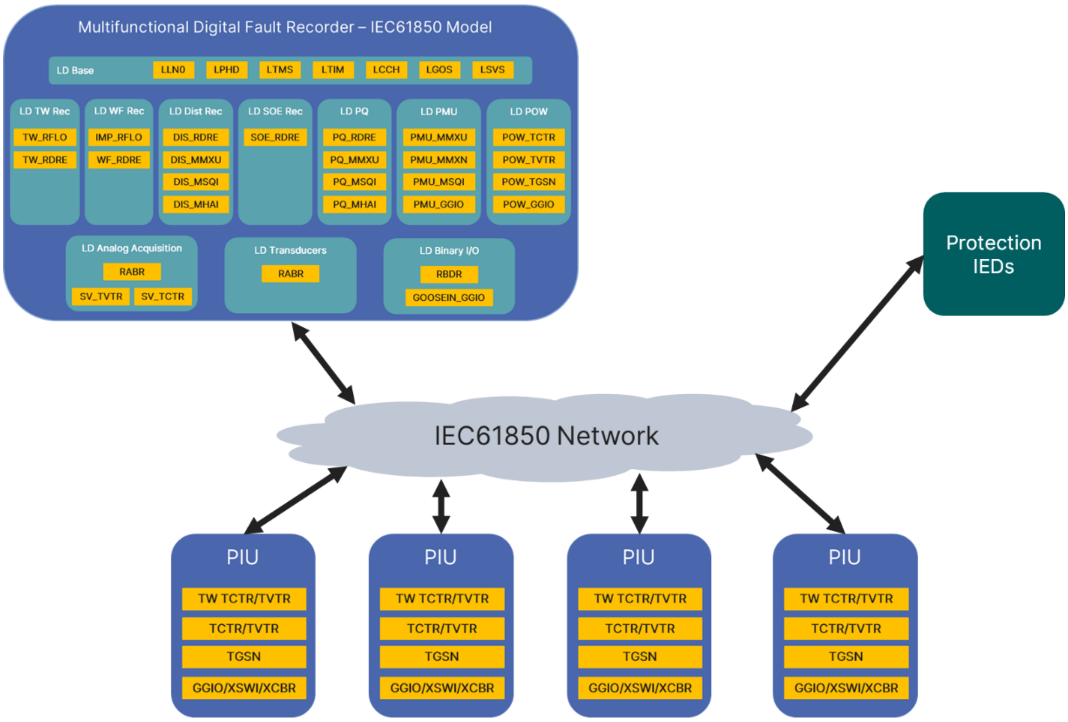
Conversely to the centralized approach, all the analog and digital signals are installed closer to the source of the signals using a data acquisition unit (DAU) to convert the signals to a digital format, whose format can be proprietary. Each acquisition unit is then be wired back to a central processing device via some form of communications, typically using direct fiber as the medium as shown in Figure 4.

Figure 4 – De-centralized DME



This architecture is more easily installed, not requiring extensive wiring and pulling of copper cables, while having the advantage of all data being captured and stored in a common platform. The data acquisition synchronization across all the remote units is an additional requirement as well as cross triggering, each individual remote unit should be able to trigger acquisition across the other units connected to the central device. In digital substations, the acquisition devices can be the merging units (MU) or process interface units (PIU) streaming sample values and GOOSE messages to the central device as shown in Figure 5, making the scheme non-proprietary.

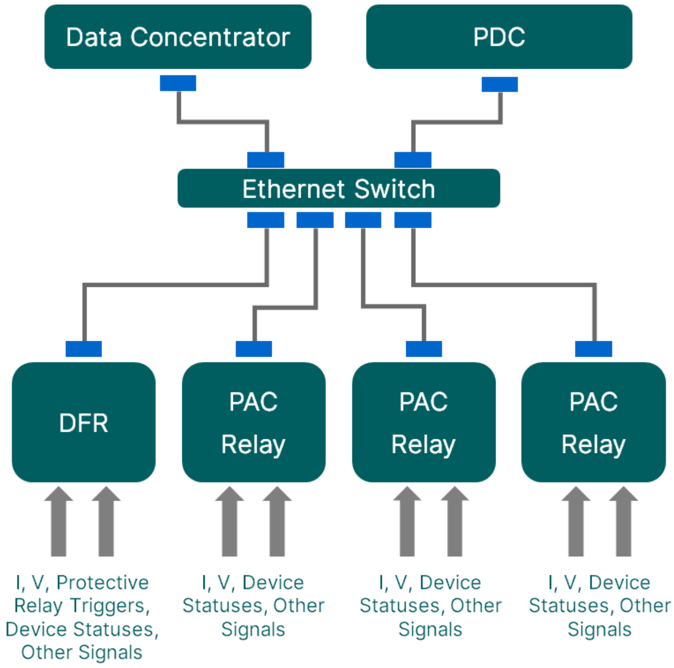
Figure 5 – De-centralized DME in a Digital Substation



4.3. Distributed

A distributed architecture is like the de-centralized approach but using various individual devices like protective relays and recording meters to trigger and capture recordings. These modern microprocessor-based devices include the ability to capture waveforms and sequence of events logs. A centralized device or software then retrieves these recordings, coordinates and synchronizes the recording logs and stores the data. This is the most cost-effective method to provide recording in substations from purely a DFR perspective, no DDR requirements. These devices however do not provide full DME functionality, storage being the most limiting factor where only finite number records can be captured and stored locally. DDR recording problematic, capabilities for continuous recording storage is limited or non-existent. Typically, this architecture will need to be supplemented to meet some of the requirements including DDR. This can be done by introducing phasor measurement unit (PMU) stream(s) from the devices to a local or remote phasor data concentrator (PDC), increasing the complexity and cost of the scheme. The frequency tracking nature of these devices is also a concern as well as sampling rate. Hence, meeting the DDR requirements using this approach can defeat the cost-effectiveness when compared at a de-centralized DME.

Figure 6 – Distributed DME



5. Monitoring Evolution

It has been recognized that with evolvement of the bulk power system the existing PRC-002 standard might not cover all monitoring requirements and hence itself should be an evolving standard. NERC Project 2021-04 was created for this purpose to evaluate and modify PRC-002 with two (2) Standard Authorization Requests (SARs) being accepted in early 2022. The project expectations were to be completed in two (2) phases.

5.1. Phase I

Phase one (1) addressed notifications to the sequence of events recording (SER) and fault recording (FR) data and identify BES element owners needing this data. The latter was to address a request to review the standard from Glencoe Light and Power and modify it to address clarity around stations that have multiple owners of BES equipment. Specifically, clarity on requirement R1 and R5 were enhanced addressing notifications of DME requirements of other owners of BES elements on busses that have multiple owners. An update in the fault current level criteria effectively would require changing/adding SER/FR data recording locations. New requirement R13 was included to address timeline of three (3) years to install DME equipment after notification, offering some flexibility for small transmission entities. This revision, PRC-002-4, was adopted in early 2023.

5.2. Phase II

Phase two (2) of Project 2021-4 will address gaps identified in the inverter-based resource (IBR) performance task force (IRPTF). The goal is to modify the requirements to ensure adequate data is available and periodically assessed to facilitate the analysis of the BES disturbances, including areas of the Bulk Power System that may not be covered by the existing requirements in PRC-002. Out of this work a new standard has been developed to cover the IRPTF scope, PRC-028 – Disturbance Monitoring and Reporting Requirements for Inverter Based Resources. The main concern was raised by IRPTF that the criteria used in PRC-002-2 for generating facilities is not adequate and many inverter-based resources will not fall under the scope of this requirement. It was decided to remove IBR requirements from PRC-002 with revision PRC-002-5 and create the new PRC-028 specifically for IBRs. Both standards, PRC-002-5 and PRC-028-1, went out for balloting in 2023 and were adopted in October 2023.

In summary, these new requirements and definitions may potentially increase the need for DMEs especially at locations connected to or near renewable resources. Hence meeting these requirements could place addition financial burdens on BES entities and owners.

6. Can Modern Protective Relays meet DME Requirements?

Today's generation of microprocessor relays can meet the requirements in PRC-002-5 of sampling rate, time stamping synchronization, accuracy, and SER/FR data. For SER and FR, the data retention length of 10 days can be problematic for relays but possible depending on the device's storage capability as this data is triggered by state changes only, for example breaker opening for SER and protection element operation for FR. A minority of protective relays on the market today included a couple of giga bytes of solid-state drive (SSD) storage for the purpose of storing recorded data. Storage requirements and hence data retention time is not an issue for a DME, as they contain large amounts of storage either on SSDs or mechanical drives. DMEs also use quantity-based, in addition to element-based triggering or in leu of. Most modern microprocessor protective relays include elements that can selected to be used for triggering purposes only and excluded from operating the main protection trip. Further, modern microprocessor protective relays include multiple instances of these elements, several stages of overcurrent protection for example, allowing for different trigger level settings. However, care should be taken by the setting engineer to not mistake monitoring triggering for protection trips. Today's protective relays use the common COMTRADE file format for data files but use a somewhat proprietary naming format for these files. PRC-002 requires data files to be named in conformance with C37.232, IEEE standard for common format for naming time sequence date files (COMNANE), revision C37.232-2011 or later. To meet this requirement the COMTRADE file would need to be converted or renamed offline. With the cost of data storage being reduced significantly over the past couple of decades, as much as ninety percent of the past two decades, the next generation of relays on the market can easily incorporate enough storage to meet and exceed the storage and data-retention requirements. As COMNAME is a relatively new standard, manufacturers have just not had to time to implement and hence it is just a matter of time before this becomes a common implementation in relays.

When it comes to the sampling requirement of 128 samples per cycle in PRC-028-1 for IBRs most modern protective relays do not comply. Standalone DMEs can have sampling rates of up to 256 samples per cycle. Continuous recording (DDR) requirements for up to 10 days is also an area where modern protective relays will not be able comply. There is an exception in the standard for legacy installed equipment, in leu of the continuous recording the device can comply if have triggered records of at least minutes at a minimum sampling of 16 samples per cycle. Even with using this exception, modern protective relays will not be able to comply. A limited number of relays on the market today already meet the sampling rate requirements hence the next generation protective relay systems (stand-alone or centralized digital substation versions) will be able to meet and exceed these sampling per cycle requirements. DDR recording and storage requirements will not be an issue for future generation of relays as previously discussed given the low cost and easy implementation of data storage as previously discussed.

It can then be concluded today's protective relays will not be able the meet all the requirements of PRC-002-5 and PRC-028-1. However, as mentioned when discussing the distributed architecture in section 4.3, if supplemented with data concentrator or PDC the data retention requirements can be met. However, there is still the gap of meeting the 128 sample per cycle requirement in PRC-028-1 for IBRs. Future generations of protective relay systems (stand-alone or centralized digital substation versions) however will be able to easily meet and exceed the requirements of PRC-002-5 and PRC-028-1.

7. Conclusions

Using protective relays to meet the requirements of PRC-002-5 and PRC-028-1 is advantageous for BES entities and owners. They will not incur any additional cost of around the design, installation and maintenance of a separate DME. This can also make the installation process easier and faster. This is especially beneficial to renewables as the quicker they can design, build and place into service the quicker they can start reaping the intended financial benefits.

Today's protective relay will not be able to meet these requirements without incurring additional cost. However, given the reduced cost of storage and availability of more powerful processors the next generation or iteration in design (stand-alone or centralized digital substation versions) can easily meet the requirements of sample rate and data storage. This is especially true with the move to virtualization or separation of processes, where the real time and non-real time functions can be run in separate processes eliminating setting mistakes as mentioned previously. It is just a matter of implementation.

8. References

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9. Biographies

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