Return of the dedicated DFR: how IEC 61850 process bus simplifies DFR installation

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Abstract: The advantages of a dedicated, standalone DFR are well known: natively synchronised fault records, large record storage capabilities, high sampling rates, numerous types of triggers, and large numbers of analogue and digital recording channels. The main disadvantage to the dedicated DFR is cost: a dedicated DFR must be directly wired to every current, voltage, and status point, resulting in an installed project cost easily ten times the material cost of the DFR itself. However, IEC 61850 process bus makes dedicated DFRs affordable again, by eliminating all field wiring necessary for installing a DFR.

1 Introduction

The term ‘DFR’ or a ‘transient fault recorder’ is a word that is substitution for an application requirement: the desire to make specific types of time coordinated non-operational data available to understand how power system equipment responds to specific conditions. This non-operational data includes fault recording or oscillography, capturing the behaviour of the power system current and voltage waveforms at a high resolution [1]. The sequence of events recording documents the operation of power system equipment [2]. Disturbance recording shows the general behaviour of the power system during all conditions. This non-operational data can be used to:

• Understand and document how secondary equipment and primary equipment respond to abnormal events such as short circuits
• Document, verify, and analyse the performance of primary equipment to enable better maintenance practices
• Verify power system models and short circuit calculations
• Identify power quality disturbances and provide for event analysis
• Detect incipient failure of primary equipment such as bushings and instrument transformers
• Understand wide-area power system disturbances, including power system oscillations
• Provide data for power system planning models

Transient recorders were created specifically to provide this data when no device existed that could do this. As a result, the tendency is to conflate the application with the device: a DFR is needed to provide the recording data, when the discussion should be around the best method to capture the required non-operational data.

2 Review of DFR installations

DFRs and transient recording describe a set of application requirements [3]. Specific devices have been designed, or adapted, to meet these requirements. The use of these devices leads to several general architectures to accomplish recording.

2.1 Centralised DFR

The first DFRs or transient recorders were centralised devices, and many modern DFRs are still centralised devices. All data is analogue data, directly wired between the primary and secondary equipment sources of the data, and the DFR itself. Every recording channel therefore requires a pair of copper wires, connected from the primary equipment. These wires to collect raw data are installed in parallel to, or as an extension of, wiring already installed for protection and control systems, metering, and other similar types. A pair of wires is therefore required for every input channel to the DFR (see Fig. 1).

A centralised DFR captures recordings based on triggers asserted on changes of state of the input channels. These can be triggers on analogue measurements, such as overcurrent conditions, or the assertion or deassertion of a binary input channel, such as a protective relaying trip indication. The general goal is to have the trigger be independent of the performance of other secondary equipment, such as protective relay element operation.

One key benefit of a centralised DFR is that it records and captures all channels simultaneously, in a common format, with a common sampling rate. Therefore, a coherent record is achieved: all data are natively coordinated to each other, and records are captured with a record-based time stamp.

The biggest concern of a centralised DFR is the cost of installation. Every input channel involves a pair of copper wires. A typical 36 analogue channel, 64 digital channel DFR requires 200 copper wires, and a minimum of 400 wiring terminations, installed between the DFR, relay panels, and primary equipment. The total project cost of installing a DFR can easily be ten times the material cost of the DFR itself. Also, the DFR becomes a separate device that must be configured and maintained.

2.2 Distributed data acquisition units (DAUs)

One industry solution to address the installation costs of a DFR is the use of DAUs. Instead of wiring every analogue signal directly to the DFR, a DAU is installed closer to the source of the signals, and sends data back to the main DFR through some form of communications. The intent is for the DAU to be dumb, distributed I/O for the DFR system (see Fig. 2).

DAUs may be installed anywhere, but are most typically installed in protective relay panels, because most signals are already wired to these relay panels. The communications between the DAUs and the DFR may take any form: analogue signals, serial communications, or digital communications. The communications method and protocol is normally proprietary to the equipment vendor, with DAUs and the DFR acting as a closed system.

The advantage of using DAUs is in installation cost. Though every channel requires a pair of copper wires to the DAU, these wires will be local to the DAU. DAUs may be installed when relay panels are built, transferring the main work of wiring to panel builders. The only on-site wiring and commissioning required is connecting the DAUs to the main DFR unit.
The downside is that there is still a significant installation cost to the DFR, as the DAUs still must be wired in parallel to other secondary devices. The communications method is typically proprietary, limiting flexibility.

2.3 Distributed DFRs

Another industry solution to the challenge of installation costs is the concept of a distributed DFR. This extends the concept of the DAU, to turn the DAU into an individual DFR, with a DFR installed in every relay panel. A DFR data concentrator is then used to collect and synchronise the records from individual DFRs, and for bulk record storage. This concept, at heart, is intelligent DAUs.

The advantage of distributed DFRs, once again, is in installation cost. Each DFR will be installed in relay panels, and the work of installation may be transferred to panel builder OEMs. Also, zone-specific recordings are triggered and captured, which may allow more precise information to be collected (see Fig. 3).

The drawback of distributed DFRs is that this solution is still expensive, and may be more expensive in terms of material cost than the centralised DFR or distributed DAUs. The DFRs are more complex devices to maintain. The communications are still typically proprietary in format, limiting the flexibility of application.

2.4 Distributed recording, or the virtual DFR

An obvious response to the challenges of DFR installation costs is to use the recording capabilities of other devices. Microprocessor-based protective relays include the ability to capture waveforms and sequence of events logs, and may include the ability to capture disturbance data. Distributed recording then uses individual protective relays and recording metres to trigger and capture recordings. A centralised device or software then retrieves these recordings, coordinates and synchronises recordings captured for the same power system event, and stores the data. In essence, this becomes a virtual DFR (see Fig. 4).

The big advantage of distributed recording is that all the devices used for this already exist in the substation. Relays are installed for protection purposes; data concentrators are installed for substation automation and operation needs. The communications between relays and the data concentrator may be serial or digital communications, and normally use open protocols for the communications. The only tool that needs to be added is software that can collect the records from individual devices, and can combine and coordinate these records into a common format to make a station-wide recording.

However, the virtual DFR is a tradeoff between the application requirements for recording, and installation costs. Triggering is normally limited to protection element operation, and not generic analogue quantities. Sampling rates in devices may be too low for good resolution, and the sampling rates of records may be different in different devices. Records are timestamped in each device, and the timestamping method may be different, resulting in difficulties in coordinating data. Some devices will use raw data for oscillography, while others may use filtered data. The collecting and coordinating data into one station-wide coherent view of an event may therefore take significant manual effort. Also, if no microprocessor-based relay exists for specific protection zones, these relays must be installed simply for recording purposes, forgoing some of the installation cost advantages.

2.5 Comparison of DFR types

Table 1 generally compares the capabilities of each type of DFR installation in terms of recording capabilities and installation costs and requirements [3]. It is obvious that all types of installations meet the general requirements for recording. A dedicated DFR system will be better at recording than a virtual DFR system, but a virtual DFR system has a better installed cost.

The utility industry is split between the use of a dedicated DFR versus a virtual DFR system. There have been detailed discussions as to the benefits of each type [1]. At heart, this is a philosophical choice. The companies using a dedicated DFR have decided that they want an independent DFR, providing high-quality data, using coordinated records, without being limited to the protection...
element triggers. These companies are willing to accept the extra cost for the use of dedicated DFRs.

Companies using virtual DFRs have decided that lower installation and maintenance costs are more important, and are willing to accept lower quality data, and the limitations of relying on multipurpose devices for recording. In truth, every company that uses dedicated DFRs still take advantage of the records contained in protective relays as part of event analysis. However, the choice of a dedicated DFR versus a virtual DFR is nothing more than a discussion on managing analogue signals: what is the best way to wire analogue signals and capture the data. The focus is on the device as much as the application of recording. But this is the wrong focus. The focus should be on: how do I meet my requirements for recording data such that I can improve the operation of the power system?

3 IEC 61850 and functional modelling

IEC 61850 is an international standard focusing on communications networks and systems inside of substation [4]. 61850 relies on functional modelling of the power system, and is a possible way to provide all the requirements of a DFR application, while minimising the installation costs of having a dedicated DFR [5].

### 3.1 Sharing information under IEC 61850

IEC 61850 describes two basic methods for sharing information between devices: the publish/subscribe model and the client/server model. Publish/subscribe uses multicast transmission over Ethernet. A source device publishes data to the network using a multicast Ethernet frame. Any other device on the network may subscribe to this data, and use the data. This is best used for ‘right now’ data: data that end devices need to make immediate use of. There is no handshaking, or direct acknowledgement of reception, between publishing and subscribing devices. Since these are standard Ethernet frames, everything takes place at the media layer of a network, and publishing uses MAC (media access control) addresses.

Client/server uses a two-party association model of transmission. Essentially, a client (the user of data) establishes a point-to-point connection through the network to the server (a source of data). This connection remains in place until released by either the client or the server. This is best used for ‘must trust’ type communications, such as control services to operate circuit breakers. The client and server do establish a connection, and do acknowledge the receipt of information between the two.

### 3.2 IEC 61850 modelling example

Fig. 5 is a simple DFR arrangement. Currents, voltages, and circuit breaker status are wired to both the protective relay for the zone, and a DFR. In addition, protection element trips are wired to the DFR as well.

Fig. 6 illustrates this same arrangement under the functional modelling of logical nodes under IEC 61850.

- **TVTR and TCTR** are logical nodes that model the function of instrument transformers. In this case, they provide data in the form of ‘sampled values’ (SVs), instantaneous digital samples of voltage (TVTR) and current (TCTR) waveforms.
- **XCBR** is a logical node that models the circuit breaker, including the position of the circuit breaker.
- **PTRC** is a logical node that models protection trip processing: essentially the output of every protection element in the relay.
- **RDRE** is the disturbance recording logical node, modelling all recording functions, including triggering, recording length among other attributes. Disturbance recording under IEC 61850 means all types of recording: fault recording (waveforms), sequence of events, and phasor data [1, 2, 6, 7].

### 3.3 Recording under IEC 61850

IEC 61850 includes a robust recording model that fully models the functions typically included in a DFR (see Fig. 7). The inputs to the RDRE logical node are two different logical nodes that...
represent analogue and binary inputs channels. RADR is for analogue input channels, and RBDR is for binary input channels.

A DFR is modelled as in Fig. 8. Analogue inputs, such as the SVs of TVTR and TCTR are mapped to RADR. Binary inputs, such as circuit breaker position and protection trips, are mapped to RBDR. There is an instance of RADR and RBDR for every input channel into the RDRE disturbance recording logical node.

4.1 Dedicated DFR under IEC 61850

IEC 61850 is a powerful concept: the focus is on defining needed functionality, as opposed to thinking in terms of devices. The challenge is that 61850 functionality is device dependent: how the function is actually implemented is determined by the manufacturer of a specific device. There is still the concern about how to trigger, how long a record is available, what type of records and data is available, and data storage requirements. Therefore, the distributed DFR under IEC 61850 is no different in terms of performance than the distributed DFR before 61850, other than the advantage of timestamped data.

However, IEC 61850 does provide an advantage to the dedicated DFR. Physical installation cost of a dedicated, centralised DFR is basically only the material cost of the DFR, and the cost to configure. There is no wiring cost, as the installation is simply to mount the DFR in a cabinet, connect power, and connect to the network to start acquiring data. A dedicated DFR system using process bus is illustrated in Fig. 8.

The dedicated DFR in this case is a true DFR implementing 61850. Source data comes from SV [8] and GOOSE messages [9] published by MUs, RIOs, PIUs, and other devices like relays. The DFR includes all the capabilities of a modern DFR, like freely assignable analogue channel triggers, configurable record length, long records, records with large number of channels, massive data storage, and the like.

Note that this DFR could be a multipurpose data concentrator that implements all the recording functions and triggers as in a regular DFR, because the device is potentially free of hardwired inputs for data acquisition. However, in the near future, it is likely to remain a dedicated recording device.

4.1 Practical installations

There have been several actual installations of dedicated DFR units using process bus. In both cases, the DFR acquired data from SV messages and GOOSE messages over process bus, and also from traditional DAUs hardwired to instrument transformers and primary equipment.

The first project is at Palhoça Substation, a 138 kV substation operated by Electrosul in Brazil. This project is a pilot project for process bus and IEC 61850 in general. The goal of this project is to prove the concept of process bus, including tripping time of protection, performance of the virtual DFR using SVs, and improved safety for protective relaying installations. The project scope was simply one line bay, and a complete process bus network. The general concept of the installation is shown in Fig. 9.

The second project is at Embu-Guaça Substation, operated by CTEEPI in Brazil. This is also a pilot project for process bus, applied on a 13.8 kV distribution feeder. The goals of this project are similar to that of the Palhoça project, including verifying performance and measurement of analogue signals by traditional methods and by SVs. This project is a dedicated pilot project that involved mounting a PIU and traditional DAU in switchyard kiosk, and building a dedicated equipment panel, as shown in the one line of Fig. 10.

One of the key learning goals of this project is to prove that SV measurements and traditional analogue measurements can co-exist in the same device. This goal has been proven during field experience of this project. Fig. 11 is an example capture of data, showing the identical performance of the SV and conventional (DAU acquired) data.

5 Conclusions

The need for DFRs, or more correctly, DFR data, is well understood. Fault recordings, sequence of event logs, and disturbance recording can help understand how the power system, along with the primary and secondary equipment that make up the power system, actually operates. The role of the DFR is to make this non-operational data available as data files to various groups...
inside the utility. The DFR is therefore a useful diagnostic tool for utilities.

The cost of installation has driven utilities to move away from a dedicated DFR to a virtual DFR using microprocessor-based protective relays as the source for DFR data. This reduces the quality of DFR data, slightly, to improve installation costs.

However, the introduction of process bus for data acquisition through IEC 61850 changes the calculations. A dedicated DFR that accepts SVs and GOOSE messages from process bus as inputs can be the best of both worlds. A quality, mission-specific recording device with a very limited cost of installation is proposed. This can bring about the return of the dedicated DFR.

6 References

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