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1. Introduction

Disturbance recorders are used to monitor and record (i) analogue data (voltages and currents) and (ii) digital data from power system protection equipment (relays/IEDs and high voltage (HV) switching equipment), during faults or disturbances on the system. These records are used for post-fault analysis to determine important information relating to the fault, to evaluate the performance of the protection equipment and to study abnormal system conditions.

In Eskom Transmission, the terms 'disturbance recorder' and 'digital fault recorder (DFR)' are both used to refer to the same device and have therefore been used interchangeably in this document.

2. Supporting clauses

2.1 Scope

This document describes the philosophies for the application and design of disturbance recorders for use in the Eskom Transmission network. It also discusses the rationale for these philosophies and identifies any specific design criteria to be used for the implementation of these philosophies.

2.1.1 Purpose

The document aims to guide the business with respect to the philosophy for application of disturbance recording equipment in the Transmission network and to also guide the development and implementation of design solutions for disturbance recorder technologies.

2.1.2 Applicability

This document shall apply to Eskom Transmission.

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 9001, Quality Management Systems.

2.2.2 Informative

[2] The South African Grid Code – The Network Code (Version 10.1)

[3] 342-73 Digital Fault Recorder Setting Philosophy Guideline (Revision 1)

2.3 Definitions

2.3.1 General

Definition	Description
Disturbance	Any perturbation to the electric system.
Intelligent electronic device (IED)	A microprocessor-based device that encompasses all or some of the following functionalities: protection, control and automation, metering, telecontrol, substation DC and auxiliary supply systems, quality of supply monitoring, and disturbance and event recording.

Definition	Description
Scheme	A set of components that work together in order to execute a specific behaviour under predefined power system conditions sensed through the scheme interface (Cigré Working Group B5.27). 'Scheme' is most commonly applied in the context of power system protection equipment where it historically applied to the secondary plant components associated with the protection and control of a specific primary bay.

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
AFAS	Automatic Fault Analysis System
ARC	Auto Reclose
BB	Busbar
COMTRADE	Common format for Transient Data Exchange
CT	Current Transformer
CTTB	Current Transformer Test Block
DC	Direct Current
DDR	Dynamic Disturbance Recorder
DFR	Digital Fault Recorder
DSR	Dynamic Swing Recorder
EADS	Engineering and Data Server
EHV	Extra High Voltage
ET	Eskom Telecommunications
FIFO	First In, First Out
GOOSE	Generic Object Oriented Substation Event
GPS	Global Positioning System
HV	High Voltage
IDF	Intermediate Distribution Frame
IEC	International Electrotechnical Committee
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
IRIG-B	Inter-Range Instrumentation Group – time code B
kHz	kilohertz
kV	kilovolt

Abbreviation	Description
mm^2	square millimetre
MMI	Man Machine Interface
MMS	Manufacturing Message Specification
ms	millisecond
MV	Medium Voltage
NTP	Network Time Protocol
OT	Operational Technology
PC	Personal Computer
ppm	pulse per minute
pps	pulse per second
PTP	Precision Time Protocol
R,W,B	Red, White, Blue *(phases)*
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SNTP	Simple Network Time Protocol
UTC	Coordinated Universal Time
VDC	Volts Direct Current
VT	Voltage Transformer

2.5 Roles and responsibilities

Planning and project support personnel shall use this document as a guide to decide on disturbance recorder application requirements.

The technology custodian for disturbance recorders shall use the information provided in this document to guide the development of any design solutions for disturbance recorder technologies.

2.6 Process for monitoring

Not applicable.

2.7 Related/supporting documents

Not applicable.

3. Disturbance Recorder Philosophy

3.1 Scope of Application

3.1.1 Philosophy

Disturbance recorders shall be installed at all substations in the Eskom Transmission network for the following applications:

- for all extra high voltage (EHV)) lines (i.e. 220kV and above)

- for all transformers connected to busbars using the breaker-and-a-half configuration
- for all line reactors and busbar reactors at substations using the breaker-and-a-half busbar configuration
- for specific sub-Transmission lines (i.e. 132 kV and below) that are deemed critical by System Operator and the Transmission Grid. *(Note: This application may necessitate the implementation of an EHV feeder protection scheme.)*

3.1.2 Rationale

As per the South African Grid Code, the 'Transmission Network Service Provider' is required to "install disturbance recorders at locations in the network that shall enable the System Operator to adequately analyse system disturbances".

Most faults in the Transmission network occur on lines – typically 500 to 1000 line faults occur per annum on the Transmission system, which is significantly higher than faults on any other type of plant in the network. As such and due to the criticality of Transmission lines with regard to system integrity, DFRs are installed for all EHV lines. [3]

The decision to install DFRs to monitor transformers and line/busbar reactors at substations using the breaker-and-a-half busbar configuration was taken at the time of introduction of this type of busbar configuration into the Eskom network. This was predominantly due to the fact that this was a new and unfamiliar application at the time. Even though the occurrence of faults on transformers and reactors is not as common as on lines, it has been observed that the availability of fault records from DFRs adds value. Since ARC (autoreclosing) is not implemented on transformers and reactors, the timeous retrieval and analysis of DFR records to determine the cause of the fault can aid in quicker restoration of the plant.

Certain lines at sub-Transmission level are deemed critical due to their strategic importance or based on the customers they are servicing (e.g. lines directly feeding large/critical customers and/or international lines). The decision with regard to application of DFR devices for such lines is to be made in consultation with the System Operator as well as the relevant Transmission Grid to decide if there are considerable benefits in implementing this non-standard application.

3.1.3 Design Requirements

The DFR scheme design shall allow for the flexibility to allow different combinations of monitored plant/bays within a single scheme, as opposed to having separate scheme designs for each plant/bay type. For example, in a substation where there is a requirement to monitor 2 x lines, 1 x transformer and 1 x busbar reactor, these plant/bays shall be monitored by a single, common DFR scheme. However, separate scheme designs may be developed to optimise double busbar and breaker-and-a-half applications due to the differing analogue input requirements.

3.2 Dedicated vs Integrated Solution

3.2.1 Philosophy

Dedicated disturbance recorder schemes shall be used for all Transmission applications.

3.2.2 Rationale

Most modern (microprocessor-based) protection relays and Intelligent Electronic Devices (IEDs) offer fault recording functionality as a standard integrated function. Apart from the financial benefits of using this solution to achieve fault recording functionality, there are also other advantages such as minimal to no additional maintenance, skills and spares holding requirements.

However, the following disadvantages associated with the use of an integrated fault recording function within protection relays/IEDs, as opposed to a dedicated DFR solution, outweigh the advantages:

1) The motivation for use of an independent device to monitor the performance of protection devices. Incorrect parameterization of common inputs, incorrect data processing or malfunctioning/failure of common components (single point of failure) will result in corrupted or lost records i.e. there is no check point. (The probability of incorrectly parameterizing both the protection relay/IED and a dedicated DFR or of the malfunctioning/failure of both systems simultaneously is minimal – fault data from either one is expected to be available and correct.)

2) Security concerns regarding the provision of direct remote access to protection devices. The provision of remote access allows for the prompt retrieval and analysis of fault records. However, since the unwanted operation of protection IEDs can result in the interruption of power supply – affecting both the safety and reliability of the power system – it is not preferable to allow remote access directly to these devices as this makes them more susceptible to cyber threats such as hacking. (Allowing direct remote access to dedicated DFRs can result in fault records being corrupted or deleted but will not directly affect the operation of the power system.)

3) Given that there are multiple protection technologies from different vendors installed across the Transmission network, this would cause issues relating to misalignment of fault data due to differences in time synchronisation, sampling rates, trigger methods, record lengths, etc. and would also necessitate the use of multiple vendor software for retrieval of fault records. (Dedicated DFRs are capable of monitoring and recording data from multiple protection devices concurrently. A central fault recording solution allows for consistent parameterization and time referencing for all monitored protection devices.)

4) Low sampling rate of protection relays/IEDs. Most protection relays/IEDs currently used in the Transmission network only cater for sampling rates below the minimum required rate of 2.5 kHz. High sampling rates allow for the accurate monitoring of high frequency oscillations of analogue signals due to fast transient phenomena such as faults, lightning strikes and switching operations (e.g. circuit breaker re-strike). (Dedicated DFRs inherently offer relatively high sampling rates – with some currently used in Transmission offering up to 25.6 kHz).

5) Data storage limitations of protection relays/IEDs. Most protection relays/IEDs used in the Transmission network have limited non-volatile memory for storage of fault records – therefore the length(duration) and number of fault records stored is limited by the available memory and could result in records being lost or overwritten. (Dedicated DFRs have ample memory for storage of fault records as this is their primary function.)

6) Relays are intrinsically set to operate for fault conditions and therefore will typically only record data regarding faults or other protection function events. DFRs can be used to monitor faults as well as other system disturbances and as such, record trigger settings can be set lower than applied for protection equipment, if required.

7) There is a significant number of protection relays currently installed in the Transmission network that don’t have integrated fault recording functionality (e.g. Phase 1 and Phase 2 schemes). If the existing dedicated DFR technologies monitoring plant protected by legacy protection devices were to fail – fault recording functionality would be unavailable for a significant amount of time until a replacement solution is implemented. (The existence of a supply contract for dedicated DFRs reduces the period of unavailability of fault recording functionality in such scenarios.)

An analysis of the benefits of each option indicates that the integrated fault recording functionality within protection relays/IEDs is currently inadequate for fault/disturbance recording requirements.

3.2.3 Design Requirements

None

3.3 Centralised vs Distributed System

3.3.1 Philosophy

A centralised DFR scheme shall be used at all Transmission substations, excluding kiosk-based substations. The scheme shall be applied at station or voltage level, as per the criteria identified below:

- Where a single control room exists housing protection schemes for various station voltage levels (e.g. 400kV and 275kV), a common digital fault recording scheme shall be used at station level, catering for monitoring of plant at all relevant voltage levels.
- Where protection schemes are housed in separate control rooms, segregated based on various station voltage levels (e.g a 765kV control room and a 400kV control room), separate digital fault recording schemes shall be used at control room level.

The disturbance recorder scheme shall be situated in a central position within the control room, as close as possible to the protection schemes it interfaces to.

Kiosks

Where protection schemes are housed in individual kiosks in close proximity to the primary plant, instead of in a centralised control room – disturbance recorder devices/schemes monitoring the individual bay are installed in the kiosks in a distributed system. For these types of non-standard applications, provision shall be made to send the recording information from each DFR to a data concentrator located at a central location within a substation control room.

3.3.2 Rationale

Housing a separate disturbance recorder device in each protection scheme (or at distributed locations in other secondary plant panels) is not recommended due to the following reasons:

- Typically, individual DFR devices are capable of monitoring between two to four feeder bays within a single 19-inch device chassis. The use of multiple distributed DFR devices configured for single-feeder applications is not a cost-effective solution.
- The availability of sufficient panel space in the protection scheme could be a constraint.
- Not all secondary plant supply contracts run in parallel. For example, the protection scheme contract period could be different to DFR contract period. This could lead to problems such as necessitating the requirement for modifications to the protection scheme designs (i.e. where a change in DFR technology is brought about by way of a new contract while the previous protection contract is still in place) or delays in finalising protection scheme designs (i.e. in the event that a new protection contract is finalised prior to the finalisation of a new DFR contract).

3.3.3 Design Requirements

None

3.4 Monitored Signals

3.4.1 Analogue Signals

3.4.1.1 Philosophy

The DFR device shall monitor the following analogue signals for each application type:

Table 1: Monitored Analogue Signals

	Application Type	**Monitored Signals**	**Source** *(See Note 1)*
1.	Line (Double Busbar)	3 x Phase-to-Neutral Voltages (R, W, B)	Line VT
		1 x Phase-to-Neutral or Phase-to-Phase Synchronising Voltage	Busbar 1 VT (fixed)
		3 x Phase Currents (R, W, B) 1 x Neutral Current	Line CT
2.	Line (Breaker-and-a-half Busbar)	3 x Phase-to-Neutral Voltages (R, W, B)	Line VT
		2 x Phase-to-Phase Synchronising Voltages	Busbar 1 and Busbar 2 VTs (fixed)
		3 x Bay Phase Currents (R, W, B) 1 x Bay Neutral Current	Bay CT
		3 x Tie Bay Phase Currents (R, W, B) 1 x Tie Bay Neutral Current	Tie Bay CT
3.	Transformer (Breaker-and-a-half Busbar)	3 x HV Phase-to-Neutral Voltages (R, W, B)	HV Connector VT
		3 x MV Phase-to-Neutral Voltages (R, W, B)	MV Connector VT or Transformer MV or Busbar 1 VT *(See Note 2)*
		3 x HV Bay Phase Currents (R, W, B) 1 x HV Bay Neutral Current	HV Bay CT
		3 x HV Tie Bay Phase Currents (R, W, B) 1 x HV Tie Bay Neutral Current	HV Tie Bay CT
		3 x MV Bay Phase Currents (R, W, B) 1 x MV Bay Neutral Current	MV Bay CT
		3 x MV Tie Bay Phase Currents (R, W, B) 1 x MV Tie Bay Neutral Current *(See Note 3)*	MV Tie Bay CT *(See Note 3)*
4.	Line/Busbar Reactor (Breaker-and-a-half Busbar)	3 x Phase-to-Neutral Voltages (R, W, B)	Connector VT
		3 x Phase Currents (R, W, B) 1 x Neutral Current	Reactor CT

Notes:

1) If a dedicated VT or CT core is available for fault recording functionality, then the DFR shall use VT and CT inputs from this core. If no dedicated VT or CT core is available, the DFR shall share the VT or CT core used for one of the main protection systems. VT and CT cores dedicated for DFR functionality shall be of the same protection class as the VT and CT cores used for the main protection systems.

2) For breaker-and-a-half transformer applications, the MV phase voltage inputs shall be connected from the:

   a) MV Connector VT - where the transformer MV side is also connected to a breaker-and-a-half busbar configuration

   b) Transformer MV or Busbar 1 VT - where the transformer MV side is connected to a double busbar configuration

3) For breaker-and-a-half transformer applications where the transformer MV side is connected to a double busbar configuration, the current inputs from the MV Tie Bay CT are not applicable.

3.4.1.2 Rationale

All available analogue data from the plant being monitored is recorded to provide a holistic view of the system conditions.

Analogue data provides a snapshot of the system shortly before, during and after the fault or disturbance, against which the performance of the protection equipment is analysed. Information such as the fault type, fault duration and magnitudes of fault currents and voltages is also deduced from the analogue data.

In addition to fault analysis, analogue data can also be used for the analysis of disturbances or abnormal conditions in the area of the recorder installation that are a result of faults or disruptions elsewhere on the power system (i.e. on interconnected networks or plant).

For breaker-and-a-half busbar configurations, there is no CT installed on the line or transformer bay/object. The current flowing through the bay/object is determined based on the sum of the currents seen by the relevant bay and tie bay CTs on the diameter – see figure 1 below.

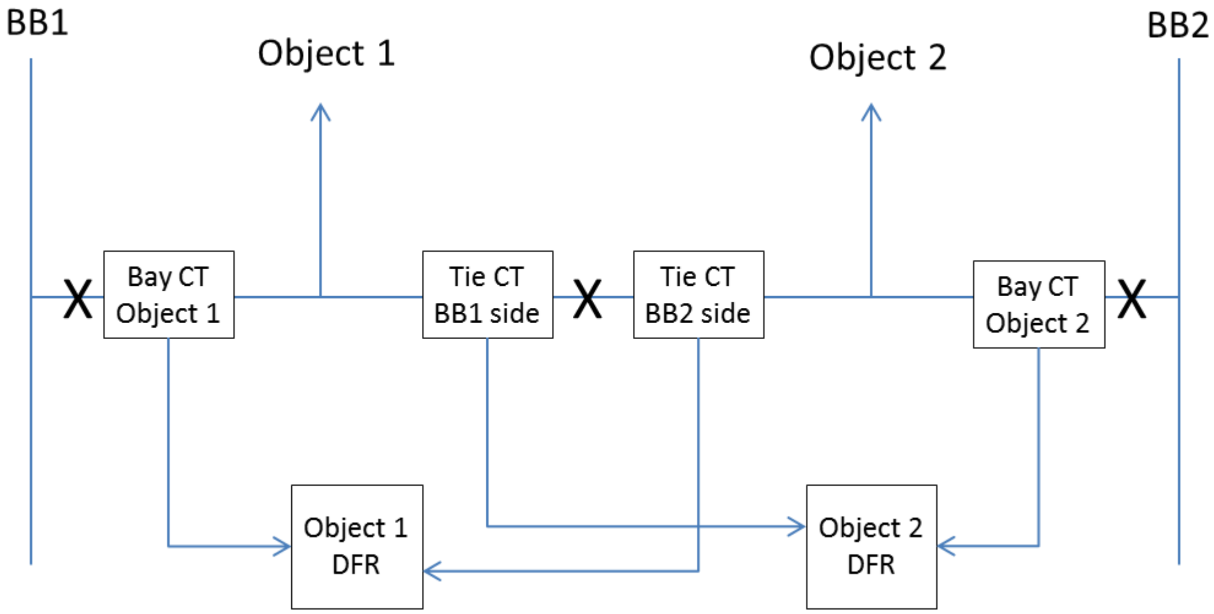

Figure 1: Simplified representation of a breaker-and-a-half diameter

3.4.1.3 Design Requirements

a) The DFR device shall make provision for the following number of analogue channels for each application type:

Table 2: Analogue Channel Requirements

	Application Type	**Number of Analogue Channels**
1.	Line (Double Busbar)	4 x voltage 4 x current
2.	Line (Breaker-and-a-half Busbar)	5 x voltage 8 x current
3.	Transformer (Breaker-and-a-half Busbar) with Auxiliary Transformer	6 x voltage 16 x current
4.	Line/Busbar Reactor (Breaker-and-a-half Busbar)	3 x voltage 4 x current

b) For breaker-and-a-half applications, the DFR shall allow the option for internal summation of CT inputs monitored separately from the relevant bay and tie bay CTs.

c) On the DFR scheme, current transformer test blocks (CTTBs) shall be provided for the following applications. CTTBs (for the disturbance recorder) shall be provided for on the protection schemes for the other applications. In future, CTTBs shall be provided for on the DFR scheme for all applications.

Table 3: CTTB Location

	Application	**CTTBs on DFR Scheme**	**CTTBs on Protection Scheme**
1.	Line (Double Busbar)		X
2.	Line (Breaker-and-a-half Busbar)	X	
3.	Transformer (Breaker-and-a-half Busbar) with Auxiliary Transformer	X	
4.	Line/Busbar Reactor (Breaker-and-a-half Busbar)		X

d) Sliding link terminals shall be provided for on the DFR scheme at the first point of connection of all VT circuits, for all applications.

3.4.2 Binary Signals

3.4.2.1 Philosophy

The DFR device shall monitor the following type of binary signals from the Main 1 and Main 2 (or Back-up) protection equipment/relay/IED:

- primary plant status signals (open/closed positions of circuit breakers and isolators)
- protection trip signals
- protection related signals (e.g. blocking and starter operation)
- teleprotection signals

The detail regarding the monitored binary signals will be specified in the individual standards for the various protection equipment for each application type.

Where both the protection equipment/relay/IED and the DFR support the IEC61850 standard for substation automation, the DFR shall record the binary signals as GOOSE messages. Where either the protection equipment/relay/IED or DFR (or both devices) do not support the IEC61850 standard, hardwired interfacing shall be used between the schemes for the monitoring of binary signals. For hardwired interfacing, the DFR scheme shall supply a 24VDC wetting supply to the protection scheme.

3.4.2.2 Rationale

Binary data is used to analyse the performance of protection equipment during fault conditions, to determine if the equipment operated according to the operational philosophy.

The move towards the use of the IEC61850 standard for substation automation has multiple advantages including savings in terms of cabling and commissioning costs, increased data monitoring capabilities and interoperability between various substation devices from different vendors, to name a few.

Potential free (dry) contacts are provided within the protection schemes for the purpose of interfacing to the DFRs. The wetting supply from the DFR scheme is required to detect a change in state of these dry contacts and activate the binary inputs on the DFR. The reasons for the selection of a 24VDC wetting supply as opposed to the standard 110VDC or 220VDC supplies available within substation control rooms are as follows:

- 24VDC is relatively safer for field personnel to work with.
- 24VDC is compatible with the optocoupler outputs used in older generation protection schemes for interfacing to the DFR. Due to the unavailability of a sufficient number of potential free contacts in these schemes, optocoupler outputs were used to simulate potential free contacts.
- 24VDC allows for the use of smaller size cabling (e.g. 0.5mm2 or ‘telephone’ cables)). In DFR schemes, where cabling from multiple bays is terminated and space is often a constraint, the use of smaller size cabling allows for optimising the use of available space within the panel.

3.4.2.3 Design Requirements

a) The DFR device shall make provision for the following number of binary channels for each application type:

Table 4: Binary Channel Requirements

	Application Type	**Number of Binary Channels**
1.	Line (Double Busbar)	32
2.	Line (Breaker-and-a-half Busbar)	32
3.	Transformer (Breaker-and-a-half Busbar) with Auxiliary Transformer	64
4.	Line/Busbar Reactor (Breaker-and-a-half Busbar)	32

b) Where hardwired interfacing is used for recording binary signals, a DC/DC converter shall be included in the DFR scheme design to convert the standard 110VDC or 220VDC to 24VDC, for the wetting supply (common positive) to the protection scheme(s).

3.5 Record Triggering

3.5.1 Analogue Triggers

3.5.1.1 Philosophy

The DFR shall support triggering of records by analogue inputs. Analogue triggers shall be settable for both measured as well as calculated signal quantities.

3.5.1.2 Rationale

Analogue triggers can be used for recordings of both faults as well as disturbances on the power system. Disturbances are not always as the result of a fault on the monitored item of plant, but could also be as a result of faults elsewhere on the power system (e.g. at sub-Transmission or Distribution voltage levels) or due to other system events/disruptions such as power swings, frequency variations, unbalance conditions, etc. Such recordings prove useful in studying the effects of these incidents on the Transmission system and on equipment performance and longevity/health.

Analogue triggering by calculated signal quantities is required to cater for breaker-and-a-half applications where the current inputs from bay CTs and tie bay CTs are summated internally to determine the current seen by the object being monitored.

3.5.1.3 Design Requirements

The DFR shall support the following type of analogue triggers:

- Level triggers (overcurrent, overvoltage and undervoltage)
- Rate of change triggers (current and voltage)

3.5.2 Binary Triggers

3.5.2.1 Philosophy

The DFR shall support triggering of records by binary inputs.

3.5.2.2 Rationale

Binary triggers are used to monitor the performance of protection equipment for the faulted plant/circuit, against operational philosophies.

3.5.2.3 Design Requirements

The DFR shall support the following type of binary triggers:

- Edge triggers - leading (rising) edge, trailing (falling) edge and both
- Level triggers - low to high and high to low

3.5.3 Other Triggers

3.5.3.1 Philosophy

The DFR shall support manual triggers, cross triggers and triggering by means of logical combinations of analogue and/or binary triggers.

3.5.3.2 Rationale

Manual triggers are used during commissioning, maintenance or troubleshooting activities to test the triggering response of the DFR and/or to record a snapshot of the analogue data to verify analogue channel calibration, etc.

Cross triggers are triggers that are transmitted to DFR devices within the same pre-defined group and are useful for monitoring the protection performance and fault contributions, of unaffected plant/circuits during through-faults.

Logical combination triggers can be used to trigger recordings for specific combinations of events of interest/significance (e.g. a recording is triggered from an undervoltage, overcurrent and circuit breaker open condition, as opposed to triggering for a circuit breaker open condition only).

3.5.3.3 Design Requirements

a) The DFR shall have the provision to manually trigger the device via a front panel MMI/keypad as well as by means of software functionality, locally or remotely.

b) The scheme design shall include provision for an Ethernet hub or switch, if required, to enable inter-communication between multiple devices in the scheme for the purpose of cross-triggering.

3.6 Sampling Rate

3.6.1 Philosophy

The DFR shall record frequencies up to the 25^{th} harmonic (i.e. 1250 Hz) in composite analogue signals, without any distortion due to aliasing.

3.6.2 Rationale

Analogue signals resulting from fast transient phenomena such as fault conditions, lightning strikes, switching operations or other disturbances on the system can consist of multiple frequency components – some of which are significantly higher than the nominal system frequency. To enable the proper analysis of protection performance and to provide better insight into the nature of the fault, the DFR should be able to record these high frequency signals without any distortion. Usually, the 25th harmonic is the highest harmonic of interest in power system studies/analyses and measurements up to this harmonic can adequately indicate the composition of the waveform.

According to the Nyquist sampling criteria, for any sampled analogue signal to be accurately represented in digital format without loss of data that could misrepresent the original signal (i.e. cause aliasing), the signal must be sampled at at least twice the highest signal frequency of interest. Therefore, in order to capture signal frequencies up to the 25th harmonic, analogue signals must be sampled at at least 2.5 kHz (i.e. 2 x 1.25 kHz). However, sampling at higher sampling rates will allow for better accuracy of the monitored signal, with compromises on the file size and storage space.

3.6.3 Design Requirements

The DFR shall have a sampling rate of at least 50 samples per cycle (i.e. 2.5 kHz sampling frequency), for all analogue channels.

3.7 Time Synchronisation

3.7.1 Philosophy

The DFR shall be time synchronised to the substation GPS clock or other relevant time source used in the substation.

3.7.2 Rationale

Time synchronisation is critical for post fault analysis and analysis of complex power system conditions such as power swings and wide area system disturbances. Records from multiple DFR devices at the same location and/or from a different geographical location are often used for event analysis to generate a sequence of events timeline. Therefore, it is critical that all records use the same time reference for proper alignment of records from these various sources. Clocks and/or time sources used across Transmission substations are synchronised to GPS satellites, referenced to UTC standard time.

3.7.3 Design Requirements

a) The DFR shall have an internal/built-in real time clock (RTC) and built-in calendar with a facility to synchronise the clock by means of a suitable time synchronisation protocol, time code format and/or time signal supported by the substation clock or time source (e.g. NTP, SNTP, PTP, IRIG-B, ppm, pps).

b) For designs where ppm or pps signals from the substation clock or time source are used, the DFR scheme shall provide the wetting supply (24VDC) for these input signals.

3.8 Data Storage

3.8.1 Philosophy

The DFR shall have sufficient non-volatile memory allocated for storage of fault records, to ensure that important fault data is not lost or overwritten due to delays in retrieving captured fault records.

3.8.2 Rationale

The storage capacity/memory allocation of DFRs can quickly fill up due to various reasons, such as:

- Multiple faults or disturbances on the system
- Commissioning/maintenance testing
- Cross-triggering by other DFR units

The storage is required to be non-volatile to prevent data loss due to interruptions to the power supply or due to the device being powered off purposefully or inadvertently.

3.8.3 Design Requirements

The DFR shall have non-volatile storage capacity for at least 400 recordings, where each recording consists of 8 analogue channels, 32 binary channels and has a record length of 12 seconds, at a sampling rate of 2.5kHz.

3.9 Record Duration

3.9.1 Philosophy

The DFR shall allow for sufficient pre-fault, post-fault and total record lengths to cater for the recording of various types of short and long duration events that can occur on the system.

3.9.2 Rationale

Pre-fault data primarily consists of analogue data and provides a snapshot of the system prior to the inception of the disturbance or fault. This is useful for system modelling and for assessment of conditions that could lead to unnecessary tripping due to power swings or transients. [3]

The pre-fault record length should cater for the monitoring of long-duration phenomena such as power swings and clearance of faults by back-up protection devices.

Post-fault data consists of both analogue and binary data and provides information about the fault duration, ARC operation and the protection operation.

The post-fault record length should cater for the monitoring of all protection operations related to the event. This includes, but is not limited to, circuit breaker pole discrepancy, breaker fail and single pole ARC operations.

The total record length caters for pre-fault, fault and/or post-fault data.

3.9.3 Design Requirements

All fault records shall consist of at least 200-2000 milliseconds of pre-fault data and 100-10000 milliseconds of post-fault data. The total record length shall consist of at least 750-12000 milliseconds of data.

3.10 Frequency Monitoring

3.10.1 Philosophy

The recording device shall cater for monitoring of variations in the system frequency by means of dynamic disturbance (or swing) recording (DDR/DSR) functionality. The DDR/DSR function shall be an integrated function within the DFR device and shall have its own triggers, sampling rate and pre/post-trigger record length settings.

3.10.2 Rationale

Monitoring of the frequency is done to obtain a global view of the electrical system's behaviour and response during conditions of unbalance between power generation (supply) and load (demand).

DDR/DSR functionality is typically available as an integrated function on most DFR devices.

As compared to fault conditions, system frequency variation is a relatively slow phenomenon, occurring at significantly slower rates and over extended periods of time – resulting in requirements for significantly lower sampling rates and significantly longer record lengths, compared to the fault/disturbance recording function.

3.10.3 Design Requirements

a) The DDR/DSR function shall support the following types of frequency triggers:

- Level triggers (over-frequency and under-frequency)
- Rate of change trigger

b) The sampling rate of the DDR/DSR function shall be adjustable from 1 Hz (one sample per second) to 100 Hz (one hundred samples per second).

c) The DDR/DSR recording shall include at least 10-1000 seconds of pre-trigger data and at least 10-1000 seconds of post-trigger data.

3.11 Record File Format

3.11.1 Philosophy

All fault records shall either be directly stored in the DFR's memory in the COMTRADE format or shall have the option to be converted from the DFR's native file format into the COMTRADE format.

3.11.2 Rationale

The use of the COMTRADE file format as a standard is a well-established practice across many electrical power utilities and the industry at large. Most fault recording devices either store their records natively in this file format or offer the option to save/export the records in the COMTRADE format. The use of a standardised file format allows for the analysis and comparison of fault records from multiple sources using common fault analysis software tools.

3.11.3 Design Requirements

The COMTRADE file format shall conform to IEEE Standard C37.111-2013 version (including support of binary file import/export and xml file format export of fault records) for interoperability with the AFAS.

3.12 Data Transmission

3.12.1 Philosophy

The DFR shall make provision for transmission of data from the DFR in the following modes:

- Manual mode – the DFR shall hold its data transmission until polled by a local or remote user.
- Auto-polling mode - the DFR shall hold its data transmission until automatically polled by a local or remote data server or PC.
- Auto-transmit mode – the DFR shall automatically send new records to a local or remote data concentrator or PC, either immediately after the record is created or periodically.

3.12.2 Rationale

The auto-polling and auto-transmit modes cater for interoperability of the DFR with current Transmission systems such as the AFAS (Automatic Fault Analysis System) and EADS (Engineering and Data Server).

The AFAS is a system that automatically implements basic analysis of fault records and automatically relays critical data to National Control, to assist in the making of operational decisions.

EADS is a server/data concentrator system used for managing remote access to OT systems such as IEDs and other substation devices for engineering access and data retrieval and storage.

3.12.3 Design Requirements

a) The manual mode shall always be active such that engineering access to the DFR by local or remote users, is always possible, irrespective of the configuration of the DFR for the auto-polling or auto-transmit modes.

b) The auto-polling and auto-transmit modes shall allow for transmission of all new fault records to a user selectable folder. It is preferable if the option to automatically save these records in the COMTRADE format is available.

3.13 Remote Engineering Access

3.13.1 Philosophy

The DFR shall have provisions for both local and remote engineering access. Remote access shall be IP-based.

3.13.2 Rationale

Local engineering access is primarily required for retrieving/implementing settings and retrieving fault records or device logs by users on site who are involved with commissioning, maintenance and trouble-shooting activities.

Remote engineering access is primarily required for the retrieval of fault records for post-fault analysis by System Operator. The fast retrieval of fault records enables the provision of timeous standby support to National Control to assist in the making of operational decisions. Grid personnel also require remote engineering access for retrieval of settings, log files and fault records, especially where substations are located at great distances from their office-base.

IP-based communication is considerably fast, compared to previously used protocols such as X.25 or other serial protocols. The Eskom Telecommunications IP network, which is used for the transport of OT data, is well established and maintained. Support for legacy serial protocols is also a major challenge as they are being phased out by most industries.

3.13.3 Design Requirements

Where the scheme design caters for multiple DFR devices, the scheme design shall include provision for an Ethernet switch to enable remote communication to all DFR devices in the scheme via a common trunk connection to the ET IP router.

3.14 Alarms and Indications

3.14.1 Philosophy

The DFR/scheme shall monitor and report at least the following conditions both locally, as indications via LEDs on device front panel or panel lamps and remotely, as alarms to National Control:

- Watchdog alarm
- Scheme DC supply failure
- Wetting supply failure
- Time synchronisation failure
- GOOSE communication failure
- Memory low

Where the DFR supports the IEC61850 standard and the relevant infrastructure is available in the substation, device alarms from the DFR shall be sent as MMS messages to the SCADA equipment (station gateway or RTU). If the DFR does not support the IEC61850 standard or where the relevant substation infrastructure does not support the IEC61850 standard, the device alarms shall be hardwired to the IDF.

The watchdog alarm and all scheme alarms (scheme DC supply failure and wetting supply failure) shall be hardwired to the IDF.

3.14.2 Rationale

The general purpose of reporting alarms is to make end-users aware of the unavailability/malfunctioning of the required equipment/functionality so that the appropriate corrective action (e.g. inspection, repair and/or replacement) can be implemented to restore the equipment/functionality.

- Watchdog – reports the failure of the DFR device. This typically is as a result of a critical error (e.g. faulty hardware or programme malfunction).
- Scheme DC supply failure – indicates failure of 110VDC or 220VDC supply used to power the DFR device(s) and other components in the scheme's DC circuitry.
- Wetting supply failure – indicates failure of the 24VDC wetting supply used for monitoring of hardwired binary inputs from the protection scheme or substation time source (for ppm and pps signals).
- Time synchronisation failure – indicates failure of time synchronisation signal from substation time source (signal lost or determined to be invalid by device).
- GOOSE communication failure – indicates the failure of GOOSE communication with the protection devices, where IEC61850 is used for monitoring of binary signals from protection devices.
- Memory low - indicates the memory allocated for storage of fault records has reached a pre-set limit (e.g. 80% or 90% of allocated capacity). This alarm is not applicable if the DFR is configured to use the FIFO buffer principle, where older records are automatically overwritten when the memory is full.

3.14.3 Design Requirements

a) Isolated potential free (dry) contacts shall be provided as alarm outputs. These contacts shall be able to withstand up to 220V DC.

b) All DFR alarm outputs shall be user configurable.

c) User-selectable grouping of alarms shall be available in the DFR i.e. multiple alarms shall be combined (marshalled) by way of software selection to produce a single alarm.

4. Authorization

This document has been seen and accepted by:

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5. Revisions

Date	Rev	Compiler	Remarks
July 2022	1	E Thekkekottaram	First issue.

6. Development team

The following people were involved in the development of this document:

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7. Acknowledgements

- Malcolm Govender
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