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TECHNICAL REPORT

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Dynamic characteristics of inverter-based resources in bulk power systems – Part 3: Fast frequency response and frequency ride-through from inverter-based resources during severe frequency disturbances

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IEC TR 63401-3 has been prepared by subcommittee 8A: Grid Integration of Renewable Energy Generation, of IEC technical committee 8: System aspects of electrical energy supply. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
8A/130/DTR	8A/150/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 63401 series, published under the general title *Dynamic characteristics of inverter-based resources in bulk power systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Primary frequency response (PFR) denotes the autonomous reaction of system resources to change in frequency. In most power systems, the main contributor to PFR is the governor response of synchronous generation. In the systems with less synchronous generators, the system inertia is relatively low and PFR capability is relatively weak and slow, so the system frequency tends to change dramatically in severe power imbalance disturbances, which will trigger under-frequency load shedding (UFLS) or OPC (over speed protection control) of synchronous generators possibly. Therefore, it is an effective coping method to introduce some new frequency responses in the systems with high penetration of inverter-based resources.

This document studies fast frequency response (FFR) as a potential mitigation option in maintaining grid security during severe frequency disturbances. Broadly, FFR is some kind of rapid injection of electrical power from inverter-based resources or relief of loads that helps arrest the decline of system frequency during severe disturbances.

DYNAMIC CHARACTERISTICS OF INVERTER-BASED RESOURCES IN BULK POWER SYSTEMS –

Part 3: Fast frequency response and frequency ride-through from inverter-based resources during severe frequency disturbances

1 Scope

This part of IEC 63401, which is a Technical Report, provides an insight into the various forms of fast frequency response and frequency ride-through techniques that involve inverter-based generation sources (mainly wind and PV) in a bulk electrical system.

This document first focuses on extracting the clear definition of FFR from different references around the world, while studying the mechanism of FFR acting on system frequency and the unique features of FFR. It then compares various kinds of frequency response and demonstrates the relationship among synchronous inertia response, fast frequency response, and primary frequency response. Several system needs and conditions where FFR is suitable are identified. This document also focuses on the performance objectives, practicality and capabilities of various non-synchronous resources, and discusses the test methods for verifying FFR capability at different levels. Finally, it focuses on the ROCOF issues and on the robust performances of FFR.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.2 Abbreviated terms

Abbreviated term	Description
AEMO	Australian Energy Market Operator
AGC	automatic generation control
BESS	battery energy storage systems
BMS	battery management system
BPS	bulk power system

Abbreviated term	Description
CLM	composite load model
CLOD	complex load model
DFIG	doubly fed induction generator
EFCC	enhanced frequency control capability
EFR	enhanced frequency response
ENTSO-E	European Network of Transmission System Operators for Electricity
ERCOT	Electric Reliability Council of Texas (US)
FCR	frequency containment response
FFR	fast frequency response
FLC	frequency limit control
IBFFR	inertia-based FFR
IBR	inverter-based resources
MPPT	the maximum power point tracking
NC RfG	Network code on Requirements for Generators
NERC	North American Electric Reliability Council
OPC	over speed protection control
PCS	power conversion system
PFR	primary frequency response
PMSG	permanent magnet synchronous generator
PMU	phasor measurement units
PSSE	Power System Simulator for Engineering
PV	photovoltaic
RES	renewable energy system
ROCOF	rate of change of frequency
SFR	system frequency response
SIR	synchronous inertial response
SNSP	system non-synchronous penetration
SONI	System Operator for Northern Ireland
UFLS	under-frequency load shedding
WECC	Western Electricity Coordinating Council (US)

Abbreviated term	Description
WSCC	Western Systems Coordinating Council (US)
WTG	wind turbine generators

4 Definition of fast frequency response (FFR)

4.1 General

In existing literature, there is no unified definition of fast frequency response, which seems sometimes to have different meanings depending on the context.

The typical definitions from different organizations or authors are reviewed here. Some existing usage does not give a clear definition in certain cases; thus the meaning of FFR is speculated from the context. In this case the recommended definition of FFR from inverter-based resources is given based on its impact mechanism on the system frequency.

4.2 Existing usage of term FFR

4.2.1 FFR in Australia and Texas

4.2.1.1 General

GE has prepared a report about FFR technology capabilities for the Australian Energy Market Operator (AEMO), in which a description of FFR is given [1][1]. It is summarized as follows:

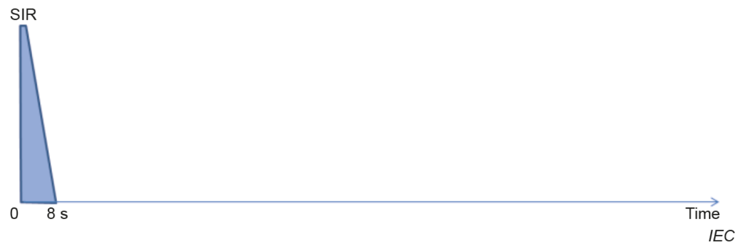
- Broadly, FFR is the rapid injection of power or relief of loading that helps arrest the decline of system frequency during disturbances.
- FFR is similar to PFR but acts much faster, providing power during the arresting phase, with the specific objective of providing arresting power before the frequency nadir.
- FFR and PFR both help to arrest frequency and interact with inertia to determine the frequency nadir. FFR will also contribute to establishing the settling frequency if the FFR is sustained past the time of the nadir into the rebound period.
- Both FFR and PFR are autonomous controls that act based on local conditions, that is, they respond to quantities like local frequency (or machine speed) that can be measured at, or very close to, the equipment providing the service.

The definition of FFR that was approved in the Electric Reliability Council of Texas (ERCOT) NPPR 863 [2] as a new reserve service is shown below.

The automatic self-deployment and provision by a resource of their obligated response within 15 cycles after frequency meets or drops below a pre-set threshold, or a deployment in response to an ERCOT Verbal Dispatch Instruction (VDI) within 10 minutes.

In general, this version of FFR is similar to PFR in function. The only difference between FFR and PFR is the response time. Figure 1 shows an example relationship between the three responses that was discussed in ERCOT.

[1] Numbers in square brackets refer to the Bibliography.



a) **SIR**

b) **FFR**

c) **PFR**

Figure 1 – Proposed response times by ERCOT as of 2014

It can be recognized that the three responses can contribute to mitigate the frequency nadir when the frequency drop event occurs although the contribution levels are different. On the other hand, the secondary frequency response is highly unlikely to contribute to mitigate the frequency nadir because the delivered secondary frequency control signal is regularly updated or renewed every few seconds, e.g. 5 s.

As seen from Figure 1, it is obvious that the initiating time of FFR is not zero. The response time of the fast frequency response consists of five elements and is summarized as Table 1.

1) Measure – Measure and identify frequency deviation and fast frequency decrease.
2) Identify – Identify the occurrence of severe event that involves FFR.
3) Signal – Communicate action to be taken.
4) Activate – Actuate the resource.
5) Activate fully – Full response from the resource.