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TECHNICAL REPORT

colour inside

Dynamic characteristics of inverter-based resources in bulk power systems – Part 4: Behaviour of inverter-based resources in response to bulk grid faults

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

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IEC TR 63401-4 has been prepared by subcommittee SC 8A: Grid Integration of renewable energy generation, of IEC technical committee TC 8: Systems aspects of electrical energy supply. It is a Technical Report.

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

Draft TR	Report on voting
8A/100/DTR	8A/104/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- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

Wind turbines and photovoltaic based power sources employ power electronic converters. Their controllable characteristics significantly change the behaviour of the power system to bulk grid faults, which brings new challenges to the reliability and safety of the modern power systems. Relay protection plays a key role in safe and stable operation of power systems for identifying and isolating faults quickly and reliably.

Relay protection operates on electrical characteristics when a fault occurs. Legacy protection principles are generally based on the fault characteristics of the synchronous machine. With the large-scale integration of these inverter-based resources (IBRs) into power systems, the diversity in IBR topologies and control strategies makes the fault behaviour turn to complex, and the electrical characteristics in the faulted power systems are significantly changed from the traditional. Legacy relay protections could be negatively affected.

Considering these challenges, this technical report aims at presenting the fault behaviour of IBRs in different topologies and control strategies, and then evaluating the adaptability of existing relay protection principles in IBR scenarios. In this report, IBRs are generally classified as full-scale converter based IBR (including Type-IV wind turbine and PV inverter) and Type-III wind turbine (also referred to as doubly-fed induction generator based wind turbine).

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

Part 4: Behaviour of inverter-based resources in response to bulk grid faults

1 Scope

This part of IEC 63401, which is a technical report, mainly focuses on the fault behaviour of IBRs and performances of the existing relay protection in grids with large-scale integration of IBRs.

This document mainly includes:

- The IBR fault current requirements in present grid codes, including the requirements of active and reactive currents in positive- and negative-sequence systems during symmetrical and unsymmetrical faults.
- Fault current behaviour of IBRs, including the current components in transient and fundamental frequency in different IBR topology and control schemes.

Adaptability of existing relay protection with the large-scale integration of IBRs, including the performances of distance protection, phase selector, directional relay and over-current protection.

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
DER	Distributed Energy Resource(s)
DFIG	Doubly Fed Induction Generator
EMF	Electromotive Force
ENSI	Equivalent Negative-Sequence Impedance
EPS	Electrical Power System
EPSI	Equivalent Positive-Sequence Impedance
ESE	Energy Storage Element
EZSI	Equivalent Zero Sequence Impedance
FRT	Fault Ride Through
FSC	Full-Scale Converter
GSC	Grid-Side Converter
IBR	Inverter-Based Resource
I1A	Positive-Sequence Active Current
I1R	Positive-Sequence Reactive Current
I2A	Negative-Sequence Active Current
I2R	Negative -Sequence Reactive Current
MSC	Machine-Side Converter
PMSG	Permanent Magnet Synchronous Generator
PCC	Point of Common Coupling
RCI	Reactive Current Injection
RSC	Rotor Side Converter
SG	Synchronous Generator
WT	Wind Turbine

4 Existing requirements for fault current behaviour of IBRs

4.1 Review of the present requirements

Considering the influence of IBRs during the fault, the technical requirements for connecting IBRs to power system have been established in many countries around the world. Taking the network code on requirements for grid connection of generators in EU as an example, the power-generating modules must be capable of remaining connected to the network and continuing to operate stably when a symmetrical voltage drop occurs at the point of common coupling (PCC), unless the protection scheme for internal electrical faults requires the disconnection of the power-generating modules from the network. The fault-ride-through capabilities in case of asymmetrical faults must be specified [1][1].

Table 1 shows the parameters for Figure 1 for fault-ride-through capability of power-generating modules and the detailed parameters in some countries are given in Table 2.

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

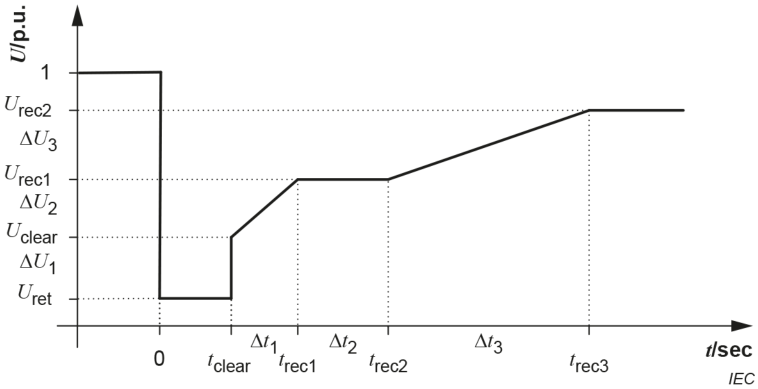

Figure 1 – Fault-ride-through profile of power-generating modules

The diagram represents the lower limit of a voltage-against-time profile of the voltage at the PCC, expressed as the ratio of its actual value to its reference 1 p.u. value before, during and after the fault, U_{ret} is the retained voltage at the PCC during the fault, t_{clear} is the instant after the fault is cleared, U_{clear} is the instantaneous voltage after the fault is cleared, U_{rec1}, U_{rec2}, t_{rec1}, t_{rec2} and t_{rec3} specify certain points of the lower limit of voltage recovery after the fault is cleared.

Table 1 – Parameters for Figure 1 for fault-ride-through capability of power-generating modules

Voltage parameters (p.u.)		Time parameters (seconds)	
U_{ret}	0-0.2	t_{clear}	0,15-0,625
U_{clear}	$U_{\text{ret}} + \Delta U_1$	t_{rec1}	$t_{\text{clear}} + \Delta t_1$
U_{rec1}	$U_{\text{clear}} + \Delta U_2$	t_{rec2}	$t_{\text{rec1}} + \Delta t_2$
U_{rec2}	$U_{\text{rec1}} + \Delta U_3$	t_{rec3}	$t_{\text{rec2}} + \Delta t_3$

Table 2 – Detailed parameters for Figure 1 for fault-ride-through capability of power-generating modules in different countries

Requirements for different countries	Requirements for wind power in China	Requirements for PV power in China	Requirements for wind power and PV power in Germany	Requirements for wind power in Denmark	Requirements for wind power in USA
Duration of under voltage ride-through	U_{ret} = 0,2pu t_{clear} = 625 ms	U_{ret} = 0 t_{clear} = 150 ms	Symmetrical fault, U_{ret} = 0 t_{clear} = 150 ms Asymmetrical fault, U_{ret} = 0 t_{clear} = 220 ms	Symmetrical fault, U_{ret} = 0 t_{clear} = 250 ms	U_{ret} = 0,15pu t_{clear} = 625 ms
Duration of over voltage ride-through	None	U_{pcc} = 1,30pu t_{uni} = 500 ms U_{pcc} = 1,20pu t_{uni} = 10s	U_{pcc} = 1,30pu t_{uni} = 100 ms U_{pcc} = 1,24pu t_{uni} = 60s	None	None
Fault voltage recovery time	U_{rec2} = 0,9pu t_{rec3} = 2s	U_{rec2} = 0,9pu t_{rec3} = 2s	Symmetrical fault, U_{rec2} = 0,85pu t_{rec3} = 3s two-phase short-circuit fault U_{rec2} = 0,85pu t_{rec3} = 5s	Symmetrical fault, U_{rec2} = 0,9pu t_{rec3} = 10s	U_{rec2} = 0,9pu t_{rec3} = 3s
Active power recovery Rate	At least 10 % P_n/s	At least 30 % P_n/s	At least 20 % P_n/s	At least 10 % P_n/s	At least 10 % P_n/s
Dynamic reactive power capability	t_{res}≤ 75ms, t_{dur}≥550 ms I_T≥1,5 × (0,9-U_{pcc})I_n (0,2≤U_{pcc}≤0,9)	t_{res}≤ 60ms t_{adj}≤ 150ms η<20 % I_T≥K_1 × (0,9-U_{pcc})I_n (U_{pcc}<0,9, 1,5≤K_1≤2,5) I_T≥K_2 × (1,1-U_{pcc})I_N (U_{pcc}>1,1, 0≤K_2≤1,5)	t_{res}≤30ms t_{ste}≤60ms	I_T≥I_n	None
Requirements for positive-sequence and negative-sequence reactive current	None	None	$\Delta u_1 = \frac{\lvert U_1 \rvert - U_{1\min}}{U_n}$ $\Delta u_2 = \frac{U_2}{U_n}$ $\Delta i_1 = k \cdot \Delta u_1$ $\Delta i_2 = k \cdot \Delta u_2$	None	None

where U_{pcc} is the voltage at the PCC in p.u., P_n is the rated active power output of power-generating modules, I_n is the rated current of power-generating modules, I_T is the reactive output current of power-generating modules, t_{uni} is the uninterrupted operation time of power-generating modules, t_{res} is the response time of dynamic reactive current, t_{adj} is the adjustment time of dynamic reactive current, η is the maximum overshoot of dynamic reactive current, t_{dur} is the duration time of dynamic reactive current, t_{ste} is the steady time of dynamic reactive current, U_n is the rated line voltage at the PCC, U_{1min} is the average line voltage at the PCC within one minute, U_1 is the positive-sequence voltage during the short-circuit fault, U_2 is the negative-sequence voltage during the short-circuit fault, Δu_1 is the ratio of the difference positive-sequence voltage between average line voltage to rated line voltage during the short-circuit fault, Δu_2 is the ratio of negative-sequence voltage to rated line voltage during the short-circuit fault, Δi_1 is the positive-sequence reactive current during the short-circuit fault and Δi_2 is the negative-sequence reactive current during the short-circuit fault, and k is the scale factor.

Taking the technical requirements for connecting IBRs to power system in USA, China and Germany as an example, as shown in 4.2, 4.3 and 4.4.

4.2 Requirements for wind power stations and PV stations by NERC

According to IEEE 1547-2018 and its amendment published in 2020 [2], there are 3 different voltage ride-through capability abnormal performance categories shown as follows,

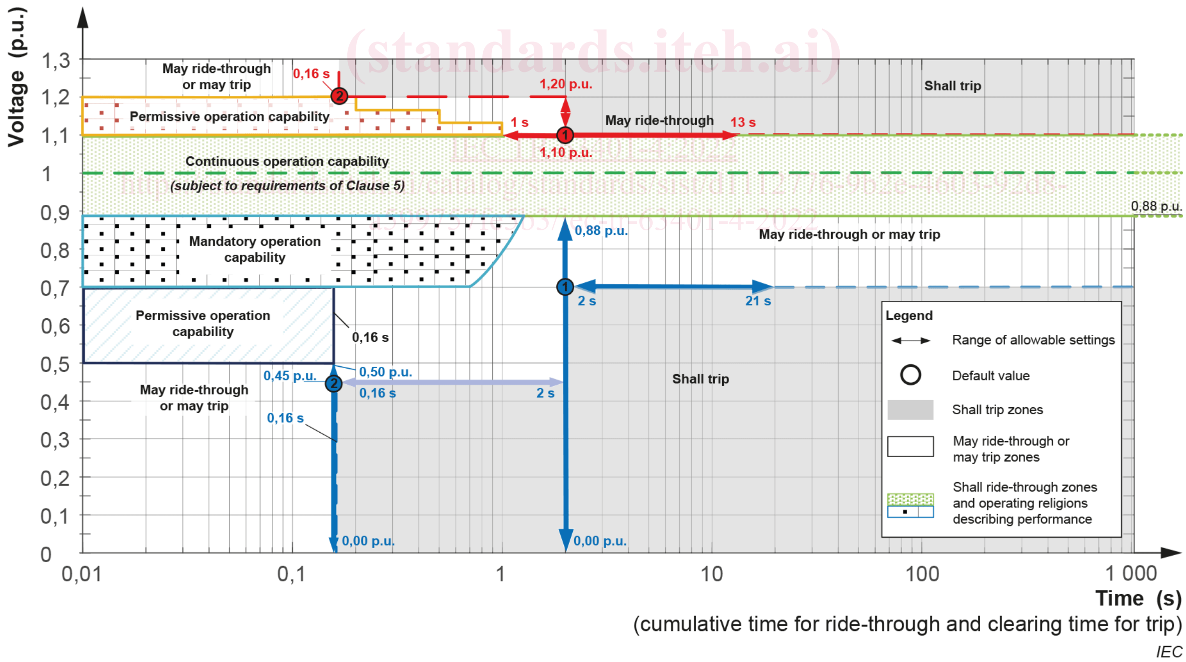

Figure 2 – Category Ⅰ Abnormal voltage ride-through requirement [2]

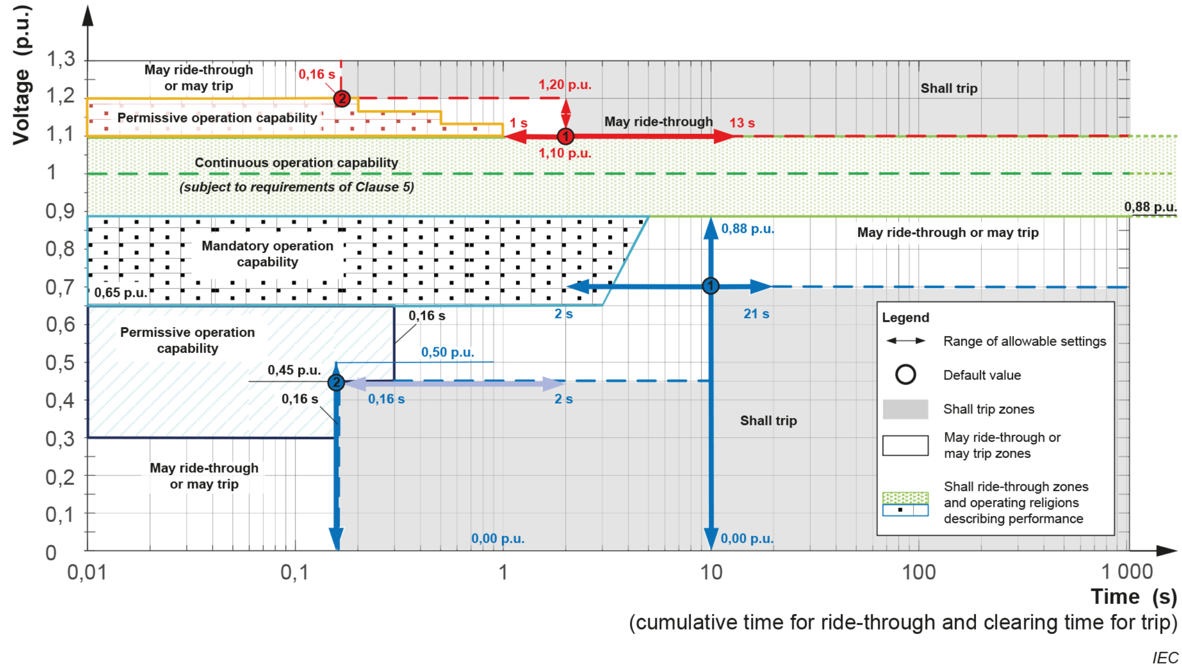

Figure 3 – Category Ⅱ Abnormal voltage ride-through requirement [2]

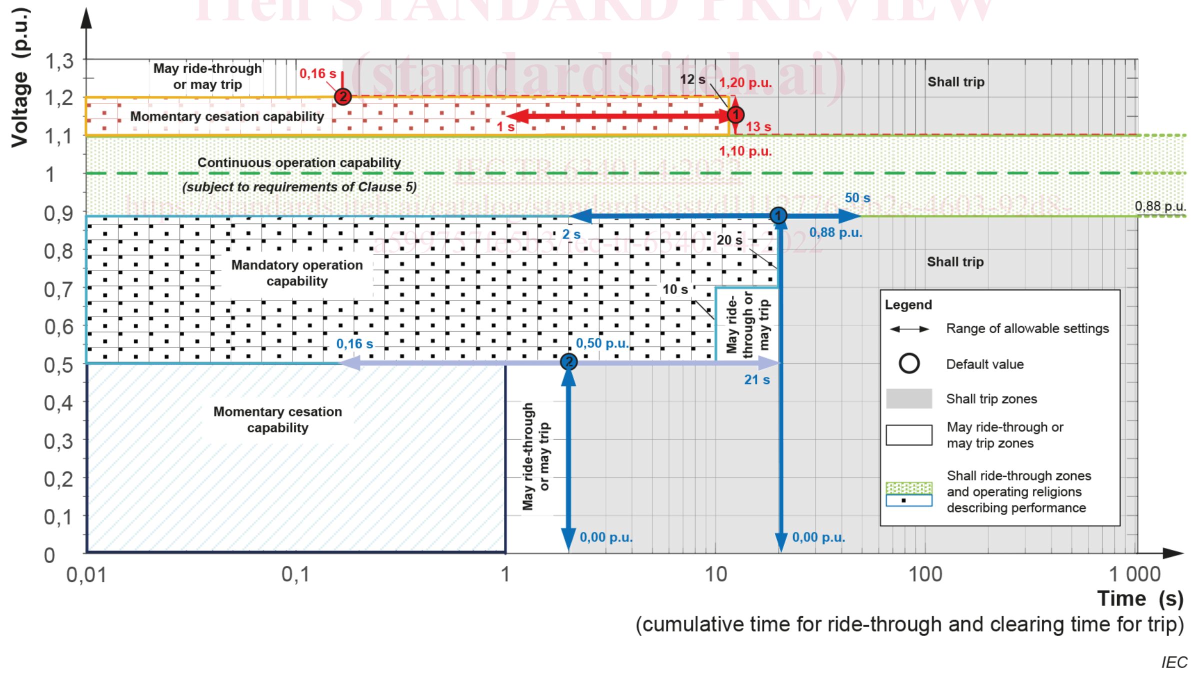

Figure 4 – Category Ⅲ Abnormal voltage ride-through requirement as amended in [2]

In Figure 2, Figure 3 and Figure 4, depending on the magnitude of voltage and disturbance duration time, different operation regions are presented. The differences among three performance categories also lie in the disturbance duration time and range of magnitude of voltage. The low-voltage ride-through performances in different operation regions for all three performance categories are as follows:

1) within the mandatory operation region, the distributed energy resources (DER) must operate synchronously with the Area electrical power system (EPS) and continue to exchange current with the Area EPS without stopping power supply and tripping-off.