IEC TR 63401-2

Edition 1.0 2022-06

TECHNICAL REPORT

Dynamic characteristics of inverter-based resources in bulk power systems – Part 2: Sub- and super-synchronous control interactions

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160, 27.180, 29.020
ISBN 978-2-8322-3929-2

Warning! Make sure that you obtained this publication from an authorized distributor.

® Registered trademark of the International Electrotechnical Commission

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

Part 2: Sub- and super-synchronous control interactions

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TR 63401-2 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/99/DTR	8A/103/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.

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

Advancements in power electronic converters have led to an increased proportion of converter based renewable power generators in modern electric power systems. Power electronic converters use multi-time scale converter control structures to achieve smooth grid connection. Such control interactions cause oscillation with the frequency ranging from a few hertz to several kilohertz, which can interact with other converter-based devices or system components such as static compensators (STATCOM), series capacitors and weak AC grids. The interactions of converter control with series-compensated or weak AC grid cause oscillation in the subsynchronous and its complementary supper synchronous frequency ranges, named as sub- and super-synchronous control interaction or simply sub-synchronous control interaction (SSCI).

In the past decade, several incidents have been reported where wind turbine and photovoltaic (PV) converter controls interacted with series-compensated or weak AC grids at subsynchronous and/or supersynchronous frequencies. Post-event investigations have shown that the converter controls actively participate in these interactions. Unlike classical sub-synchronous resonance (SSR), SSCI is a system-wide phenomenon rather than a localized converter control issue. The mechanism and characteristics of SSCI are greatly influenced by converter control structures and parameters, generation resource intermittency, network topology change, grid strength, etc. Such factors distinguish the converter control participated interactions in converter-based generators from the classic SSR phenomenon associated with the conventional power generators. The oscillation caused by SSCI seriously threatens the stable and reliable operation of wind power systems.

Power systems with high-penetration of power electronic converters face a variety of oscillatory stability issues. Power electronic converter-based components such as converter-based wind turbine generators (WTGs), photovoltaic (PV), flexible AC transmission system (FACTS) and high voltage DC (HVDC) can interact with each other and/or with the series-compensated or weak AC networks. As a result of such interactions, oscillation from a few hertz to tens or hundreds of hertz could be triggered, as illustrated in Figure 1.

The interaction between doubly-fed induction generators (DFIGs) and series compensated transmission lines was first reported in the electric reliability council of Texas (ERCOT) wind power system in 2009. The frequency of triggered oscillation was 20 Hz to 30 Hz. Later on, from 2010 to 2016, frequent oscillation events were reported between DFIG and series-compensated network in the Guyuan system located in Hebei, China. In 2015, a new type of interaction was reported in the Hami wind power system in Western China. Post-event investigations showed that the full-scale converter (FSC) interacted with the weak AC grid causing strong sub- and super-synchronous oscillation. The frequency of oscillation originating from the FSC wind turbines matched with the shafts' natural frequencies of the nearby steam turbine generators, which resulted in intense torsional vibrations. In 2019, a power outage event in the UK's National Grid was also found to have been worsened by a 9 Hz oscillation. The converter controls of the FSCs in the Hornsea offshore wind farm participated in the event and amplified the negative resistance effect, which led to the sudden shutdown of the wind farm.

The frequency of oscillation triggered by the interactions between converter generators (e.g. wind or PV) and series-compensated or weak AC grid falls in the range of sub- and/or super-synchronous frequency. Due to the active participation of converter controls, the interaction is widely known as the subsynchronous 'control' interaction (SSCI). Note that although the frequency of the 2019 event in the UK's National Grid is below the system's synchronous frequency, careful consideration must be given before characterizing this event as an SSCI event.

Besides SSCI, several high-frequency resonance events have also been reported around the world. For example, the harmonic instability with frequency ranging from 100 Hz to 1 000 Hz in the Borwin1 offshore wind power project in the North Sea of Europe. In 2017, a high-frequency resonance was reported in the Yunnan grid after the Luxi project was put in operation. The high-frequency resonance occurred between the modular multilevel (MMC)-HVDC and the AC grid, triggering the 1 272 Hz and its complementary frequency oscillation. Similar events involving interactions between converter-based devices and the grid have occurred around the world. The interaction phenomenon causing such high-frequency oscillation is widely known as high-frequency resonance or harmonic resonance.

This technical report aims at revisiting the existing terms and definitions, proposing benchmark models, modeling and analysis methods and mitigation schemes to better understand, analyze and control SSCI.

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

Part 2: Sub- and super-synchronous control interactions

1 Scope

Based on the interaction phenomenon and frequency range, this part of IEC 63401, which is a technical report, covers the "control interactions" in converter interfaced generators e.g, wind and PV with the frequency of the resulting oscillation below twice the system frequency. SSCI can be categorized into:

1) SSCI in DFIG is caused by the interaction between DFIG wind turbine converter controls and the series compensated network.
2) SSCI involving FSC (both type-4 wind turbine or PV generators) is caused by the interaction between wind turbine or solar PV's FSC controls and weak AC grid.

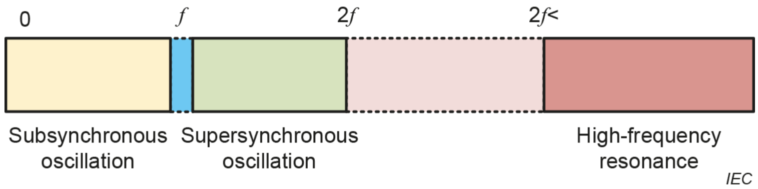

Figure 1 – Multi-frequency oscillations in the modern power system with high-share of renewables and power electronic converters

This technical report is organized into nine clauses. Clause 1 gives a brief introduction and highlights the scope of this document. Clause 4 presents the historical background of various types of subsynchronous oscillation (SSO) and revisits the terminologies, definitions, and classification in the context of classical SSR and emerging SSCI issues to better understand and classify the emerging interaction phenomena. Clause 5 provides the description, mechanism, and characteristics of the SSCI phenomenon in the framework of real-world incidents, including the SSCI events in the ERCOT, Guyuan, and Hami wind power systems. Clause 6 proposes two benchmark models to study the SSCI DFIG and FSC-based wind turbines or PV generators. Clause 7 gives an overview of existing and emerging modeling and stability analysis approaches to investigate the SSCI phenomenon. Clause 8 outlines various techniques to mitigate the SSCI. It discusses various SSCI mitigation schemes, such as bypassing the series capacitor, selective tripping of WTGs, generator, and plant-level damping control schemes. Clause 9 highlights the need for future works towards standardization of terms, definitions, classification, analysis methods, benchmark models, and mitigation methods.

2 Normative references

There are no normative references in this document.