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Generic RMS simulation models of inverter-based generators for power system dynamic analysis

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FOREWORD

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IEC TS 63406 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 Specification.

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

Draft	Report on voting
8A/188/DTS	8A/208/RVDTS

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 Specification 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/publications.

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- withdrawn, or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.

INTRODUCTION

This document addresses the generic root-mean-square (RMS) simulation models of inverter-based generators (IBGs) for power system dynamic analysis. The scope of the document covers the grid-connected IBGs for photovoltaic power generation systems, wind turbine generation systems with full-scale converters, wave energy generation systems, fuel cell energy generation systems, battery energy storage systems, supercapacitor energy storage systems, flywheel energy storage systems, AC- or DC-coupled hybrid energy generation or storage systems, etc. The models specified in this document can be primarily used for power system RMS dynamic simulation analysis in the electromechanical time scale.

Renewable energy sources (RESs) including wind energy, photovoltaic energy, wave energy, etc. have been increasingly integrated into modern power systems worldwide. A common feature of renewable energy power generation is that it is typically interfaced with the grid through power electronic inverters, and therefore it can also be called inverter-based generation.

Dynamic simulations play an important role in assessing the stability and security of power systems. Such studies are typically performed by power system planners and operators using models simulated in commercial software tools. To reduce the simulation loads, tailored dynamic models, reserving all critical elements in a power system, are developed, with model complexity adjusted to account for the key dynamic characteristics to be investigated.

In contrast to the models of synchronous generators, the development of publicly available generic models for representing different types of IBGs is still inadequate. Wind turbine generator models were specified by IEC 61400-27-1, but the models were prepared mainly for the application scope of wind power generation. There is a lack of widely accepted generic models of IBGs considering different types of RESs and different scenarios of distribution and transmission networks for dynamic studies. Regardless of the types of RESs, the technical grid compliance specifications stipulated by grid codes are similar, and therefore different types of IBGs have similar dynamic characteristics as seen from the points of common connection or coupling. In this respect, it is necessary to develop generic models for different types of IBGs. The generic models should accommodate different RESs as classified by the types of their primary energy source inputs, and also can be custom-parameterized and validated to capture the dominant dynamic characteristics of IBGs for power system dynamic simulations.

The purpose of this document is to specify generic dynamic models for various types of IBGs, which can be applied in power system stability studies. Referring to the stability categories defined by the IEEE/CIGRE Joint Task Force in 2004, the models are developed to represent IBGs in studies of large-disturbance short-term voltage stability phenomena. Similar to IEC 61400-27-1 for wind turbine models, the developed models in this document are also applicable to study other dynamic short-term phenomena such as rotor angle stability, frequency stability, and small-disturbance voltage stability. Thus, the models are applicable for dynamic simulations of power system events such as short circuits, loss of generation or loads, and system separation of a synchronous system into more synchronous areas. Referring to the stability categories extended by the IEEE in 2021 based on the version in 2004, two new categories were added: resonance stability and converter-driven stability. The developed models in this document can be potentially used to study the stability phenomena in these two new categories, provided that the associated dynamic phenomena are in the electromechanical time scale. This time scale limitation is due to the inherent capability of RMS-type models and simulations.

The models are developed with the following general specifications:

- The models can represent a diversity of IBG types, including but not limited to photovoltaic power generation systems, wind turbine generation systems with full-scale converters, wave energy generation systems, fuel cell energy generation systems, battery energy storage systems, supercapacitor energy storage systems, flywheel energy storage systems, and AC- or DC-coupled hybrid energy generation or storage systems.
- The models can adapt to the dynamic studies in both transmission and distribution network systems.
- The models can address short-term dynamic processes (10 s to 30 s following a disturbance).
- The models are to be used primarily for power system dynamic analysis, including rotor angle stability, short-term frequency stability, and short-term voltage stability.
- The models are specially targeted at large-disturbance stability studies, but can also address small-disturbance stability studies such as low-frequency oscillations.
- The models can exhibit both positive-sequence and negative-sequence dynamic responses under grid fault scenarios, and correspondingly the software platform should support the simulation of negative-sequence responses.
- The models can provide the control functionalities of grid ancillary services such as fast frequency response and voltage regulation, as required by system operators or grid codes.
- The models should work with integration time steps of about 1/20 cycle or larger, such that certain electromagnetic transients such as the dynamics of the synchronization control loop of IBGs (typically the phase-locked loop) can be retained.
- The models can be parameterized to represent any manufacturer-specific IBGs.

The models have the following limitations:

- The models are not intended for long-term stability analysis since the characteristics of the primary energy source conversion (e.g. wind turbine aerodynamics, PC arrays) are not sufficiently represented.
- The models are not intended for investigation of the impact of the fluctuations of the primary energy source.
- The models can be used for both large-disturbance and small-disturbance simulations. Although fast dynamics such as the phase-locked loop (PLL) dynamics are represented, the models are probably still not sufficient for the investigation of sub-synchronous interaction phenomena (e.g. oscillation in the frequency range above a typical PLL bandwidth of 10 Hz).
- The models are not necessarily able to represent oscillatory behaviours that typically occur in an extremely weak grid connection (e.g. short-circuit ratio less than 2).
- The models do not cover phenomena such as harmonics, flicker, or any other EMC emissions included in the IEC 61000 series.
- The models do not address the specifics of short-circuit calculations.
- The models are based on classical voltage vector-oriented grid-following controls and do not address grid-forming controls. The models do not apply to studies where the inverter-based generation systems are islanded without synchronous generation as well as studies where there are not enough voltage sources such as synchronous machines.

The models in this document are to represent the dynamic behaviour of a single IBG. For a power plant comprised of many IBGs, the appropriate number of IBG models should be incorporated or aggregated by appropriate approaches. Moreover, the validation specification for the models in this document will be developed exclusively in a new document. Before it is released, the validation of the models can follow the same procedures, requirements, and methodologies specified in IEC 61400-27-2.

Please note that IEC 61400-27-1 has released generic models for wind turbine systems earlier. However, it normatively applies to wind turbine systems only. In contrast, the specifications developed in this document are broad enough to encompass various types of renewable energy systems, including but not limited to wind turbines. This is achieved by encompassing common modules of different types of renewable energy systems in the generic models. Additionally, it fills in the gaps left by IEC 61400-27-1 by identifying its limitations and developing new and necessary modules. As a result, the specifications in this document are backward compatible with the existing technical specifications by IEC 61400-27-1 and do not pose any technical conflicts. Specifically, the major differences between this document and IEC 61400-27-1 as well as the gaps filled lie in the following aspects:

– This document covers a diversity of IBGs, including but not limited to wind turbines. Therefore, this document fills the gap that there are no IEC standards of generic simulation models for photovoltaic generation, wave energy generation, fuel cell energy storage, battery energy storage, supercapacitor storage systems, flywheel energy storage, and AC- or DC-coupled hybrid energy generation or storage systems. More importantly, the models are generic for as many types of RESs as possible, thus avoiding creating more and more models for different RESs.
– The primary energy source model is simply presented to provide a unified model for a diverse range of renewables.
– The models for grid ancillary services, e.g. fast frequency response, are provided.
– As many types of Var-Volt control modes as possible are provided, covering almost all possible modes.
– Both positive- and negative-sequence dynamic responses under grid faults are provided.
– Two types of interface modules, namely current-source and voltage-source types, are provided.
– Different detection techniques for the grid phase-angle are provided, including a phase-locked loop.

The following stakeholders are potential users of the models specified in this document:

– System operators are end users of the models, performing power system stability studies as part of the planning as well as the operation of the power systems.
– Renewable energy generation manufacturers will typically provide the models of the generation technologies to the owner.
– Developers of modern software for power system simulation tools will use this document to implement standard inverter-based generator models as part of the software library.
– Certification bodies in case of independent model validation.
– Consultants who use models on behalf of system operators or renewable energy generation plant developers.
– Education and research communities who can also benefit from the generic models, as the manufacturer-specific models are typically confidential.