Development of a Generic Future Grid Code regarding Wind Power in Europe

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***Abstract*—Present grid codes might not be a suitable reference for future-oriented research. The diversity of grid codes by different transmission system operators makes it challenging to get a clear and compact general overview on grid code requirements. ENTSO-E aims to develop a uniform grid code framework for Europe, which at present, however, still leaves many key aspects unspecified, referring instead to regulation by the relevant transmission system operator.**

To enable for general assessment of grid code compliance in future scenarios, a generic future grid code is required for academic research purposes, hence the compliance test is generalised and future-oriented rather than examining it with actual grid codes of today. The generic grid code under development provides fault ride through voltage profile and the required response, as well as frequency and rate of change of frequency requirements and the demanded power-frequency response. The specifications are inspired by the European grid codes, by ENTSO-E and the Irish grid code, which is seen by many as progressive when it comes to wind power integration.

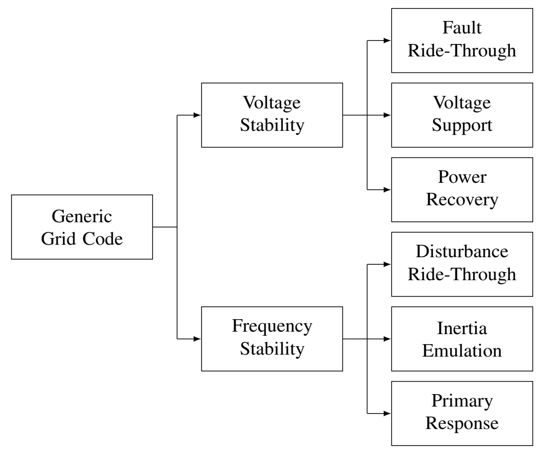


Fig. 1: Overview of key requirements

I. INTRODUCTION

Grid codes are technical specifications that define requirements for any facility connected to electricity grids to ensure the integrity and safe, secure and economic operation of the electricity system. Such facilities include both power plants and loads, although only power plants are addressed in this publication. More or less standardised grid codes are available in most of the developed countries, aiming to make the development and planning of new projects simpler, streamlined and predictable.

However, grid codes can differ significantly between Transmission System Operators (TSOs). This results in a severe challenge to get a quick and easy overview on grid code requirements in general. To asses, if the new wind turbine control concept could be compliant with 'grid codes' in general, is almost impossible. But for a generic concept when no specific grid code is applicable, general compliance evaluation would be useful. Academia often uses generic models to develop and test new concepts, and these concepts are not TSO-specific as real grid codes are.

To enable for generalised and future-oriented assessment of grid code compliance, a generic future grid code is required for academic research purposes. The main requirements, which are displayed in Figure 1, and the compliance assessment are given in this article.

The specifications here are inspired by the European grid codes, by ENTSO-E [1] [2] and the Irish grid code [3], which is seen by many as progressive regarding wind power integration.

In Section II, voltage disturbances are addressed, and in Section III, frequency deviations are addressed. In Section IV, the conclusions of this work are given.

II. VOLTAGE-RELATED REQUIREMENTS

Voltage support is done by injecting additional current or power (active or reactive) in the fault affected region. In this article, current is chosen for specifying the Fault Ride-Through (FRT) behaviour, even though power is often used in grid codes. The determination of power during moments of fast changing voltages (faults) is not straightforward, making the utilisation of the directly measurable current more convenient and meaningful.

The voltage support requirements of the proposed grid code are detailed in the following subsections: The FRT requirement, given in Subsection II-A, denotes the fault duration and severity where the wind power plant must remain connected to the grid and provide voltage support. The required response regarding current injection during the fault is provided in Subsection II-B. The guidelines to evaluate compliance with these requirements are given in Subsection II-C.

A. Fault Ride Through Requirement

The FRT-curve and the test fault are displayed in Figure 2, and the relating parameters are specified in Table I.

The FRT-curve is taken from the ENTSO-E grid code [1] and shows the maximum requirement, meaning the most severe voltage dip, which the relevant TSO may demand withstanding capability. In this generic grid code, there is no range of

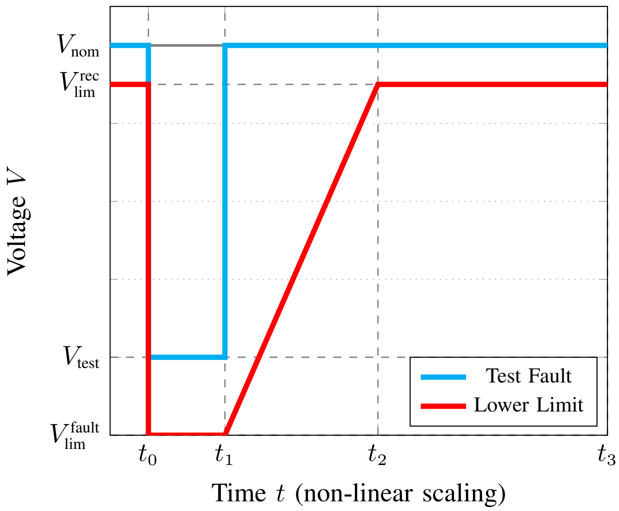


Fig. 2: Fault ride through requirement and test fault

TABLE I: FRT curve and test fault parameters

Parameter	Unit	Value
t_0	s	0.0
t_1	s	0.25
t_2	s	3.0
t_3	s	60.0
V_{nom}	pu	1.0
$V_{\text{lim}}^{\text{rec}}$	pu	0.9
V_{test}	pu	0.2
$V_{\text{lim}}^{\text{fault}}$	pu	0.0

possible requirements; only the strictest one is valid. As shown in Figure 2, the wind turbines must remain connected and providing voltage support as long as the grid voltage is above the lower limit in the event of a voltage drop.

Two sequential events are considered as separate, if there is at least t_3 between them, meaning that the voltage needs to be at least $t_3 - t_2$ above $V_{\text{lim}}^{\text{rec}}$ before a new event must be tolerated.

B. Response towards Voltage Changes

In the event of a voltage disturbance in the grid, two main aspects are to be regulated:

- the reactive current as a function of the voltage during the fault
- the active current as a constant during the fault and recovery after fault clearance

Active current is required to remain constant (pre-fault value) during the fault in order to limit the impact on the active power balance of wind turbines and the grid. This is inspired by [4] [3].

The reactive current injection in case of undervoltage as a function of the voltage drop is expressed in Equation (1).

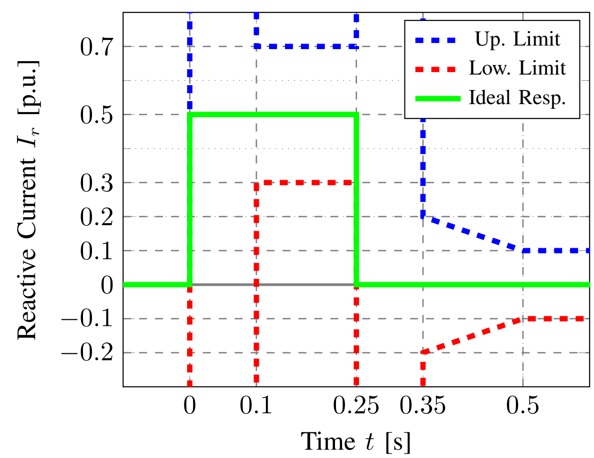
$$I_r^{\text{set}*} = I_r^{t_0^-} - K_V(\Delta V + V_{\text{DB}}) \tag{1}$$

$I_r^{\text{set}*}$ is the desired reactive current, $I_r^{t_0^-}$ is the reactive current previous to the fault, K_V is the gain, with $\Delta V = V - V_{nom}$ and V_{DB} is the width of the deadband where no reaction from the system is required.

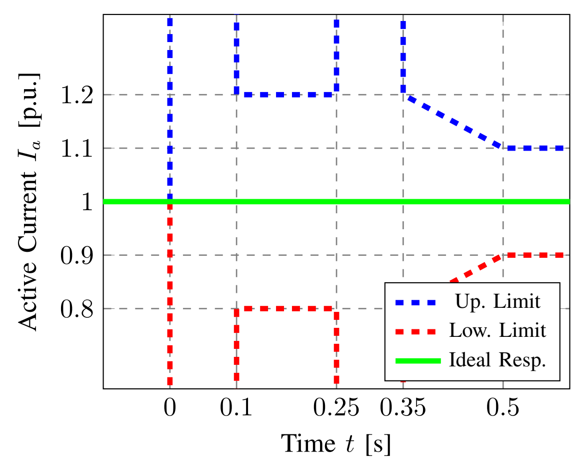
The upper limit of the reactive current saturation depends on the amount of active current I_a being generated, since the active current has priority. The maximum achievable current by the power converter I_{max} is required to be overrated with respect to the wind turbine nominal current, in order to allow the system to deliver reactive current even when the turbine is at full active current/power.

TABLE II: Voltage support parameters

Parameter	Unit	Value
V_{DB}	pu	0.1
K_V	—	2.0
I_{max}	pu	1.12



(a) Reactive current response compliance



(b) Active current response compliance

Fig. 3: The current response towards the test fault

C. Voltage Response Compliance

Since a real system may not offer a perfect response due to non-linearities, model simplifications, controller limitations or measurement noise, the compliance with the grid code requirements allows certain deviations within reasonable limits. A tolerance band that envelopes the desired setpoint is implemented, as shown in Equation (2). As a consequence, the system response is considered correct if it remains within the tolerance band during the compliance analysis.

$$|I - I^{\text{set}}| \leq I^{\text{lim}}(t) \tag{2}$$

Where I^{set} is the current setpoint and I^{lim} is boundary defining the tolerance band. The compliance analysis is shown in Figure 3a for the reactive current and in Figure 3b for the active current. The depicted data corresponds to the test fault, applied on a wind power plant operating at full power ($I_a = 1$). The depicted tolerance band shape (dashed lines) is given as an example to show a possible shape. However, the exact shape is still subject to research.

III. Frequency-Related Requirements

This section describes the proposed frequency support requirements.

A. Disturbance Ride Through Requirement

A Wind Power Plant (WPP) has to be able to operate down to 49 Hz on a continuous basis, and down to 47 Hz for a limited time. It has to tolerate frequency gradients of up to 2 Hz/s [2]. This defines the disturbance ride through characteristic, as displayed in Figure 4. The generic frequency disturbance event, as also displayed in Figure 4, is used to assess compliance.

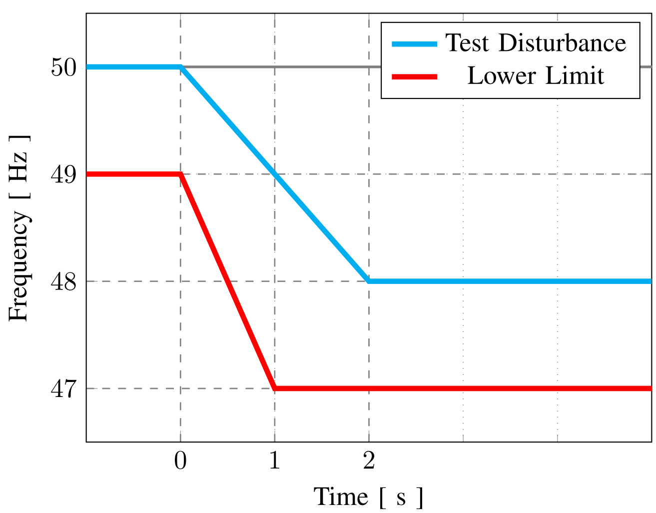


Fig. 4: Disturbance ride through requirement

B. Response towards Frequency Changes

The developed frequency requirements are inspired by the proposed PD controller, which is composed of two components, one relies on frequency deviation, and the other is proportional to Rate of Change of Frequency (RoCoF). The controller is decribed by Equation (3)

$$P^{\text{set}*} = P^{t_0^-} - R(\Delta f + f_{\text{DB}}) - T_j \left(\frac{df}{dt}\right) \tag{3}$$

The proportional part reflects the response of conventional synchronous generator of a certain droop (R), which helps Transmission System Operators to maintain the traditional system dynamics during frequency excursions, at high penetration of wind power. The differential part reflects the response of inertia.

The WPPs have the freedom how to implement the two parts only as long as it provides the required response explained later. Using RoCoF is not mandatory, but will enable an early detection of frequency events, even before the frequency violates the applied deadband.

The main parameters are given in Table III.

TABLE III: Frequency support parameters

Parameter	Unit	Value	
f_{DB}	mHz	± 20	(± 0.0004 pu)
R	%	4	
T_J	s	10	
$P^{\text{D}}_{\text{lim}}$	% of P_{set}	± 10	
$P^{\text{P}}_{\text{max}}$	% of P_{set}	10	
$P^{\text{P}}_{\text{min}}$	% of P_{set}	-90	

The proposed response and limits are given as a percentage of pre-event generation magnitude (P_{set}), which is a different approach compared to conventional grid codes where the power surge is assessed against rated power of the generator.

The RoCoF-based response component requires a power increase of short duration, which might be challenging for Wind Turbine Generators (WTGs) due to the rate of change limits on active power set-points implemented by WTG conventional controls. To provide this short-term power injection, it might be useful to slow down the WTG to extract rotational energy or to draw the energy from another storage. It will be a question of design optimisation to decide how much of this response is coming from the actual WTGs, and if additional hardware with included short-term energy storage is applied to comply, e.g. a Battery Energy Storage Systems.

It should be noted that the provision of proportional response component during under-frequency events (upward regulation) requires the WTGs to normally operate below maximum available power. Otherwise, a limited overloading of the WTG should be allowed (i.e. when the WTG is already providing its rated power)

C. Frequency Response Compliance

The active power surge should be manipulated to comply with grid code requirements. The code should not apply a firm profile, but a relatively relaxed margin.

The ideal PD response is displayed as green line in Figure 5. However, as the grid code does not obligate a certain control method to be used, a wide margin of tolerated responses is defined, the tolerance band (area between the red and the blue curves). However, the exact shape of the tolerance band is still subject to research.

The first interval (falling frequency) of the proposed response (i.e. initial 2 s) reflects the inertia and primary response [5] [6] [7] [8].

As seen in Figure 5, the ramping rates of output power should ideally be infinite. This is impossible in practice, however a

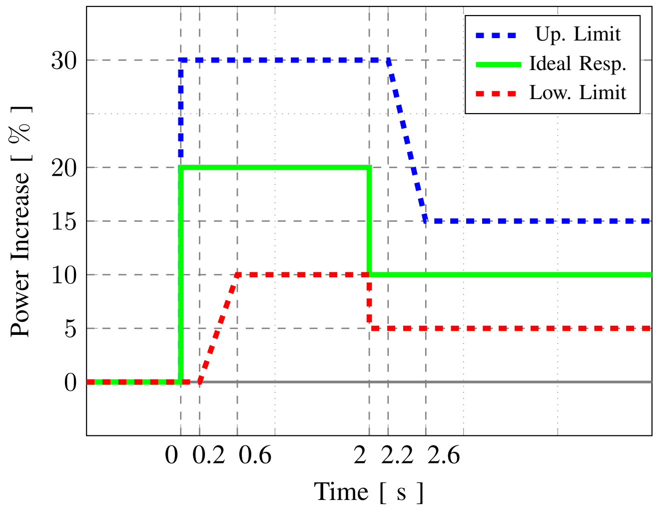


Fig. 5: The power response towards the test disturbance

grid code should allow an ideal response. However, the area between blue and red patterns refers to the acceptability of realistic ramp-up rates. Renewables based on variable primary sources have difficulties providing a constant response, but its generation should be kept between the min. and max. margins.

Another challenge is securing the required surge if the WTG/WPP is formerly providing its rated output. In that case, the WPP still has to provide the minimum P_{PD} as indicated in Figure 5 for 2s. To make this possible, a supplementary controller should curtail the normal output to secure this margin (i.e. output de-loading by the minimum P_{PD}) or apply an alternative method.

The second interval starts when frequency stabilises at a lower value, as shown in Figure 4.

The generation assets have to ramp-down their output to match the new steady state. Afterwards, the generation should be sustained within the mentioned margins until the event is declared over. Similar to the first interval, WPPs have to maintain their output within a certain margin as it would be impractical to force them to provide a perfectly constant output.

IV. Conclusions

A. Summary

A generic future grid code has been developed for academic research purposes, to enable for general assessment of grid code compliance in future scenarios, hence the compliance test is generalised and future-oriented rather than examining it with actual grid codes of today. The generic grid code provides fault ride through voltage profile and the required response, as well as frequency and rate of change of frequency requirements and the demanded power-frequency response. Compliance is assessed through a reference fault and a reference disturbance, to which a wind power plant would need to respond in a specified way, within tolerance margins. The specifications are inspired by the European grid codes, by ENTSO-E and the Irish grid code, which is seen by many as progressive when it comes to wind power integration.

B. Outlook

The generic grid code in its present state still does not address (or not completely address) all important aspects. The most relevant subjects still missing are:

- Exact shapes of the tolerance bands
- Consideration of asymmetric faults
- Over-voltages
- Over-frequency events

Acknowledgement

The activities here have partly been funded by the IRPWind project, and cooperation has been significantly improved the IRPWind mobility programme. The activities have also been supported by NOWITECH.

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