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Fault ride through capability of round rotor synchronous generators: Review, analysis and discussion of European grid code requirements

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ABSTRACT

A fault ride through (FRT) capability of synchronous generators is currently required by most grid codes, beyond what is required by International Electrotechnical Commission (IEC) and Institute of Electrical and Electronics Engineering (IEEE) standards for round rotor generators. This article reviews and compares FRT as required by European grid codes, and the European Network of Transmission System Operators for Electricity (ENTSO-E) grid code proposal. It investigates whether a typical round rotor turbogenerator fulfils the FRT requirements. The response of power plant auxiliaries is also analyzed. Recommendations to improve the formulation of FRT requirements are made based on thorough sensitivity studies of the response of such turbogenerators with respect to a number of variables and parameters.

Contents

1. Introduction

Grid codes have been developed by transmission system operators (TSOs) to formalize their obligations and to establish the framework of their technical relationships with generation and distribution companies. Grid codes are legally binding in the region or country to which they apply. One of the requirements imposed by grid codes on generators of any kind is fault ride through (FRT). FRT refers to the ability of the generator to remain connected to the grid in the event of an external fault as long as the voltage at the connection point remains above a defined voltage. Wind turbine generators were first required to have FRT for the prevention of massive wind generation disconnection if a fault should occur in the transmission network [1] and it was subsequently imposed on synchronous generators. Synchronous generators can disconnect from the grid due to either loss of synchronism or power plant auxiliaries tripping. Most European FRT formulations for synchronous generators include the obligation to remain transiently stable when the voltage at the connection point remains above the time-voltage curve. However, not all of them take into account the effect of power plant auxiliaries.

Grid codes have been developed in all European countries. Some regions, like Nordel in Scandinavia, have adopted a single code for all countries of the region, but most of the grid codes

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apply to a single country. Only a few of those individual grid codes share the same criteria and requirements [2]. The best example of this diversity is the formulation of FRT requirements. The European Network of Transmission System Operators for Electricity (ENTSO-E) has made a grid code proposal to harmonize European grid codes [3] that will enter in force soon [4]. ENTSO-E grid code requirements are discussed in [5].

For many years, manufacturers have been developing turbogenerators according to IEC [6] and IEEE [7] standards. As these standards are widely accepted, compliance with them gives the manufacturer the confidence of developing a product which is acceptable for a wide range of customers. This approach allows keeping costs at a reasonable level, while benefiting from a large fleet experience, leading to increased reliability. However, manufacturers are facing increasing difficulties to fulfil FRT requirements in some countries and regions, because FRT requirements go far beyond what is required by IEC and IEEE standards. This article demonstrates through simulations that these difficulties cannot be easily solved by modifying turbogenerator parameters, and that a reformulation of FRT requirements might be necessary.

This article reviews and compares FRT as required by European grid codes and the ENTSO-E grid code proposal. In addition, it investigates whether a typical turbogenerator fulfils the FRT requirements of these codes and analyzes the response of power plant auxiliaries. Recommendations to improve the formulation of FRT requirements are made based on thorough sensitivity studies of a typical turbogenerator response with respect to a number of variables and parameters. Although, ENTSO-E has reviewed European grid codes within its harmonization effort [8], it has not checked the impact of its requirements as this article does.

Some references have addressed the impact of grid code requirements on generator design (see [9] and [10]). However, little attention has been paid to the impact of FRT requirements on synchronous generators (see the very recent reference: [11]).

2. Review of European grid code FRT requirements

IEC and IEEE standards require that round rotor generators be capable of continuous rated output at a rated power factor within the range of ±5% in voltage and ±2% in frequency. In contrast, many grid codes require that synchronous generators remain connected to the grid in the event of transient variations of voltage at the generator step-up transformer high voltage (HV) terminals defined by a time–voltage curve. This section reviews FRT of synchronous generators as required by European grid codes.

FRT requirement has been formulated in different ways. In this article, four categories are proposed to classify them:

- rectangular time–voltage curve
- polygonal time–voltage curve
- single-machine infinite bus transient stability study (SMTSS)
- multi-machine system transient stability study (MMTSS)

Despite the diversity of FRT formulations, most European grid codes combine a voltage and a stability requirement that can be defined as the obligation of synchronous generators to stay connected and transiently stable after a fault in the transmission grid as long as the voltage at the connection point remains above a defined time–voltage curve. This minimal definition has been integrated into the ENTSO-E grid code proposal [3]. This was the case of other grid codes worldwide, like the Western Electricity Coordinating Council (WECC) PRC-024 Protection and Control draft proposal [12]. However, in the current PRC-024 version prepared by the North American Electric Reliability Corporation (NERC) [13], the transient stability requirement has been eliminated by means of allowing the generating unit disconnection if there is a loss of synchronism. Therefore, PRC-024 has evolved into a voltage protection code, and not a stability code.

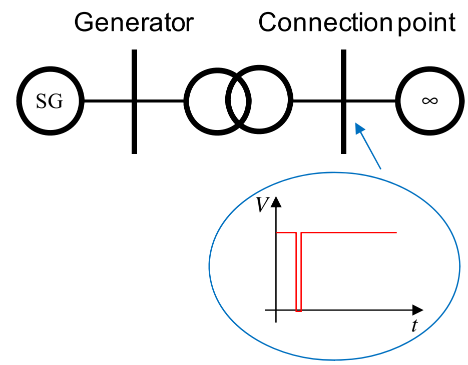

Fig. 1. Network model for a rectangular time–voltage curve.

The grid codes of Cyprus [14], Ireland [15], Italy [16], the Netherlands [17], Poland [18], Portugal [19] and the United Kingdom (UK) [20] require that generators withstand a rectangular voltage variation at the generator HV bus (point of connection). A rectangular voltage variation occurs if the generator is directly connected to an infinite grid through the step-up transformer without any external reactance (as shown in Fig. 1). This formulation neglects the short circuit capacity of the grid at the point of connection. The retained voltage and the duration of the transient voltage variation depend on the grid code as shown in Fig. 2. Duration of the required three phase solid fault ranges from 100 (Portugal) to 300 ms (the Netherlands). The Dutch fault duration can be relaxed to 90% of the actual critical clearing time of the generator in the event that the latter is not able to withstand faults of 300 ms. The grid codes of Cyprus, Ireland and the UK impose fulfilment of FRT not only in the case of zero retained voltage faults but also in case of faults with several values of their retained voltage (the UK grid code determines the retained voltage and the fault duration from a given time–voltage curve).

The grid codes of Belgium [21], Greece [22], Iceland [23], Scandinavia [24], Spain [25] and Switzerland [26] forbid generator disconnection from the grid if the HV bus voltage is over a time–voltage curve (see Fig. 3). The polygonal time–voltage curve depends on the grid code. A transient voltage variation over a polygonal time–voltage curve may occur if a fault occurs at the generator HV bus, assuming that the generator is connected to an infinite grid

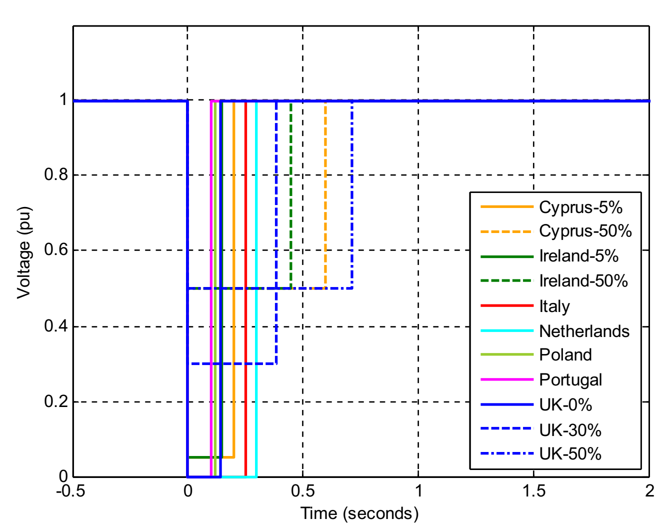

Fig. 2. Comparison of rectangular time–voltage requirements.