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Voltage dip generator for wind energy systems up to 5 MW

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ABSTRACT

The increase in installed wind power has brought a number of Grid Code areas into focus. The area of fault ride-through capability is one with serious implications for system security and thus has an impact on the allowed wind energy penetration in the network. There are several wind turbine models that can be used to study the effects of voltage dips and the corresponding wind turbine responses but these models need to be validated by comparing their results with the data obtained during field tests. This paper presents the design of a voltage dip generator that can be used to test wind turbines up to 5 MW and 20 kV. This system is able to adjust voltage dip depth and duration to the standards defined in different countries and also the fault impedance seen by the grid in order not to disturb its operation during the tests. Simulation results are validated using experimental data obtained at a laboratory-scale prototype (400 V, 90 kW). Finally, the actual 5 MW system and the results obtained during field tests are presented.

1. Introduction

The present wind energy penetration into the electrical network has forced system operators to adapt their Grid Codes to this new generation, preventing an unacceptable effect on the system safety and reliability [1–6].

One of these new connection requirements regarding wind energy is fault ride-through capability. In the past [7,8], wind generators were not allowed to remain connected to the utility when voltage at the point of common coupling (PCC) fell below 85%, forcing their disconnection even when the fault happened far from the wind farm [9]. That is the reason why, in grids with significant wind energy penetration, the voltage dip and the subsequent wind farm disconnections would create an important stability problem [10,11].

System operators of the different countries have established diverse voltage limit curves for fault ride-through [1–6]. For instance, in Spain, Red Eléctrica de España (REE), has developed operation procedure P.O. 12.3 describing ride-through requirements for wind farms [11]. Fig. 1 shows the voltage limit curves established by the system operators of the different networks. Wind turbines must remain connected to the grid when facing voltage dips, as long as voltage at the PCC remains above the line shown in Fig. 1.

Compliance with Grid Codes can be checked by means of simulation of validated models. Nowadays, there are models for the different generator types, required for grid stability studies through dynamic simulation [12–16]. However, in order to certify the validity of the simulation models when testing voltage dip ride-through capability, the obtained results must be validated by the ones measured on field tests. Once this validation is made, compliance with grid requirements can be certified using simulations of the validated model.

In order to test the behaviour of the turbine when a voltage dip occurs, a device able to generate voltage dips is required. This device must create a voltage variation according to the regulations of the different countries to check that the tested wind turbine fulfils the established requirements, such as voltage ride-through, short circuit contribution and power factor. Taking into account these conditions, the main characteristics that a voltage dip generator should have are variable sag depth, adjustable sag duration and flexible input to present high input impedance during the dip, compared to the short circuit power of the grid, preventing the system from affecting significantly its voltage. Other important characteristics are mobility, since the test equipment has to be transported to the wind turbine location, and simplicity to connect it between the wind turbine and the grid.

Voltage dip generators are based on the use of two impedances, as it is shown in Fig. 2 [17]. The parallel impedance enables the generation of the fault while the series impedance immunizes the grid from the dip and the test can be performed without affecting other systems connected to it. This structure is used in [18,19], which describe a device for generating voltage dips in an electrical power generator in low voltage up to 690 V. In this invention the dip is obtained by combining three fixed inductances per phase. These inductances are connected in parallel and short circuited.

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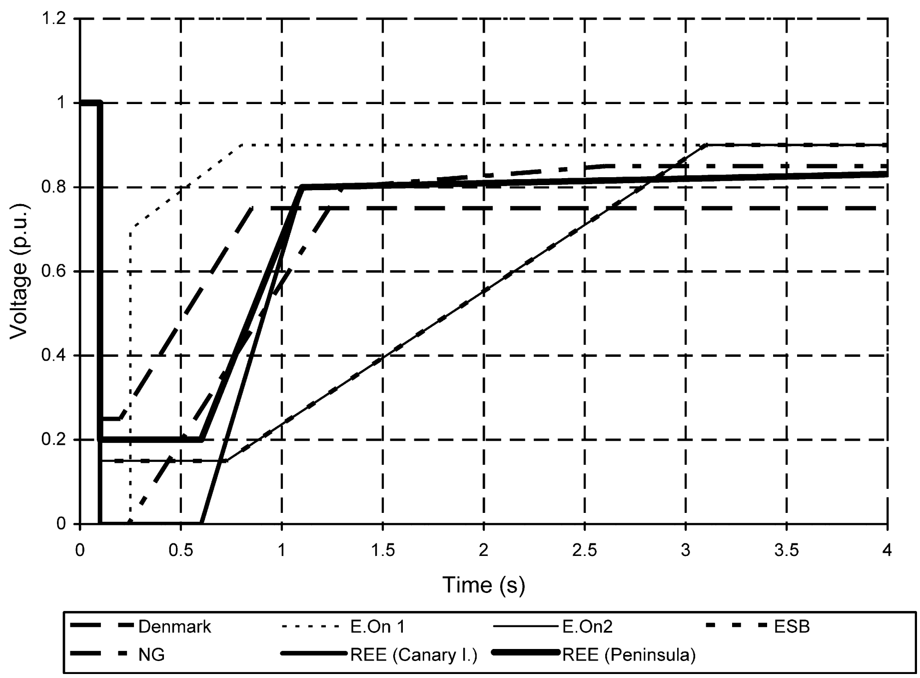

Fig. 1. Voltage–time curves for the limits specified by different system operators.

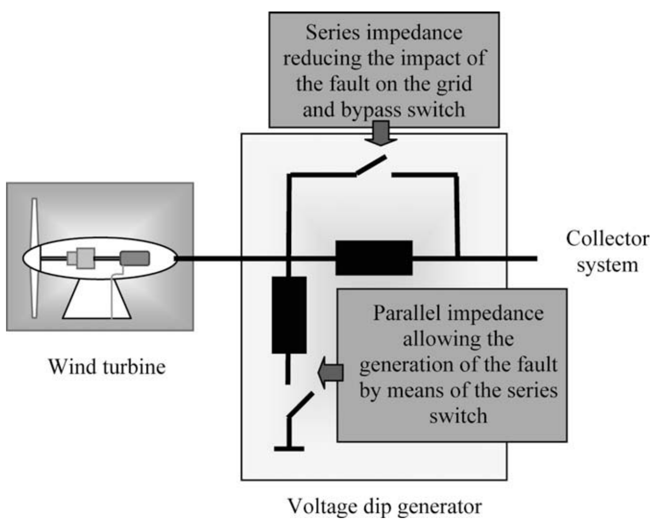

Fig. 2. Dip generator scheme and its position with respect to the windmill and the wind farm.

This system can perform only eight voltage dip types, varying depth and duration but it is not enough to satisfy the several dips required by the international Grid Codes. Furthermore, some wind generators operate in medium voltage and in these cases this device is not directly applicable. If the LV/MV transformer is located in the nacelle, the length of the 6 required cables makes this system non-practical.

In [20,21] the voltage dip is obtained by using three identical transformers with fixed taps in the parallel branch. These transformers are connected in parallel and short circuited. It can test wind turbines connected in MV but it needs the connection of two transformers in series with the generator and it makes the connection of the system more difficult.

The first important disadvantage of the previous designs is that the series impedance can not be regulated, so the short circuit power in the test point depends on the external system. The second disadvantage is the poor regulation capability because, as shown in Section 5, this feature depends on the value of the series, parallel and grid impedances.

This paper shows the design of a voltage dip generator able to test wind systems up to 20 kV and 5 MW, presents the experimental results obtained at a laboratory-scale prototype (400 V, 90 kW) and the final implementation of the 20 kV, 5 MW system. This device is installed in a trailer in order to be transported to the wind turbine location. The presented voltage dip generator can be adapted to the specific system and location with only a few adjustments.

The proposed system can widely control the short circuit power in the test point and its extended regulation capability allows performing up to 4200 different voltage dips adjusting depth between 0 and 0.9 p.u. of residual voltage. The duration of the voltage dip can also be adjusted to the specific regulation. These features can be achieved in low voltage by using power electronic, like the low power application presented in [22]. However a medium voltage electric design is more robust and has a lower cost.

2. Description of the proposed system

Fig. 3 shows a scheme of the proposed voltage dip generator. It is based on an inductive divider composed of a series and a parallel branch, and its main components are a three-phase series impedance (2) at the system input, a parallel tap transformer (5) and a three-phase impedance (9) grounded through a control switch in the secondary of the transformer. This impedance allows the adjustment of the dip depth to the desired value, along with the regulation of the transformer, because the impedance (9) connected to the secondary winding is referred to the primary winding by multiplying it by the square of the turns ratio. Switches (3) and (7) make possible the generation of a 100% depth voltage dip.

A tap transformer is usually designed to work within a 10% regulation interval, but for this application a special transformer is used, having a 40% regulation range in ten steps, necessary to meet the different requirements.