23rd International Conference on Renewable Energies and Power Quality (ICREPQ'25)
Tenerife (Spain), 25th to 27th June 2025
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.23, September 2025

Analysis of fault ride through in wind farms during network faults

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Abstract. Fault Ride Through (FRT) is a term used to describe the ability of wind farms to remain connected to the system during disturbances, such as short circuits or voltage drops. This capability is vital for maintaining the stability of power systems and preventing the adverse consequences that may arise from wind power outages during disturbances. In addition to FRT, modern Grid Codes require wind farms to inject current during the fault under specific conditions, to sustain voltage and help protection relays detect and clear the fault. Wind farms achieve these goals through a combination of hardware capabilities and control algorithms. The goal of this paper is to analyse the Fault Ride Through capability of wind farms, using a test system modelled in the software tool Power Factory DIgSILENT, and to examine the characteristics of current injection under different control configurations. Through this analysis, the reaction of wind farms to different types of disturbances will be investigated, along with how their behaviour can be improved to ensure greater stability of the power system. This paper is the digest version of the full paper that will be sent in case of acceptance.

Key words. Fault ride through, short circuit current, wind farm, grid code, negative sequence.

1. Introduction

Wind farms have become an increasingly important source of electricity in the world, providing a sustainable and clean alternative to conventional energy sources. However, as they are more integrated into power systems, it is necessary to study their behaviour during disruptions in the system to ensure the stable and reliable operation of the power system. Changes in legislation in the field of power engineering, the liberalization of the electricity market, environmental requirements, energy efficiency and rational use programs, as well as the requirements for the self-sustainability of national energy systems have favoured the emergence of new renewable energy resources [1].

Fault Ride Through (FRT) is a term used to describe the ability of wind farms to remain connected to the system during disturbances, such as short circuits or voltage drops [2]. This capability is vital for maintaining the stability of the power system and preventing the adverse consequences that may arise from wind power outages during disturbances. The measures that can be taken are categorized based on their procedures to enhance the transient capability of the machines in the wind farm [3]:
- Protection devices during transient state [4-5].
- Reactive power injection devices during transient state [6-7].
- Control algorithms during both steady-state and transient state [8-9].

Dedicated regulations define the allowed voltage drop during faults and the requirements for current injection. These regulations are denominated Grid Codes and can vary between different countries. In this paper, the European Union Grid Code is mentioned [10], but similar requirements apply in other countries and regions around the world [11]. Additionally, Grid Codes are adjusted to technical constraints in power networks, such as the characteristics of generation technologies or network strength [11-12].

The goal of this paper is to analyze the FRT capability of wind farms and their behaviour regarding the characteristics of their current injection during balanced and unbalanced network faults. Through this analysis, the reaction of wind farms to different types of disturbances will be investigated, along with how their control algorithms can be improved to ensure greater stability of the power system while complying with Grid Code requirements [10].

The paper is organized into four sections, including this introduction. Section 2 introduces Grid Code requirements and discuses fault ride through in different countries. Section 3 analyses the response of a wind farm connected to the Serbian transmission system under balanced and unbalanced faults with positive sequence and negative sequence fault current injection. Finally, Section 4 concludes the paper and discusses the results of the case study.

2. Fault ride through and Grid Code

Wind farms must maintain the operational stability in the event of transient faults in the connected distribution network. The worst fault in terms of stability is the three-phase fault, as a result, transient stability is usually checked for this most critical fault. Three-phase short circuits in the connection network are characterized by voltage drops, the depth of which depends on the distance between the point of common coupling (PCC) and the point of failure, as well as the fault resistance value. In the case of closely bolted short circuits, the voltage can practically be equal to 0. The duration of the voltage drop depends on the reaction time of the protection system, that is, the so-called fault clearing time.

According to the protection concept, transmission system operators define the voltage profile that each wind farm must withstand to maintain stable system operation, also known as fault ride through capability. When a voltage drop is detected at the PCC, the wind farm management system activates the LVRT operating mode. This mode includes devices and/or control strategies. The voltage in the network is continuously monitored by a measuring system, and in the event of a fault detection in the network, control of the power plant is taken over by the local LVRT control, which manages the power plant during the fault.

Figure 1 shows the range of voltage deviations that the wind farm must withstand according to the EU Grid Code [10], for Type D wind farms (large wind farms connected to the transmission network), in the specific implementation of the Spanish Grid Code [13].

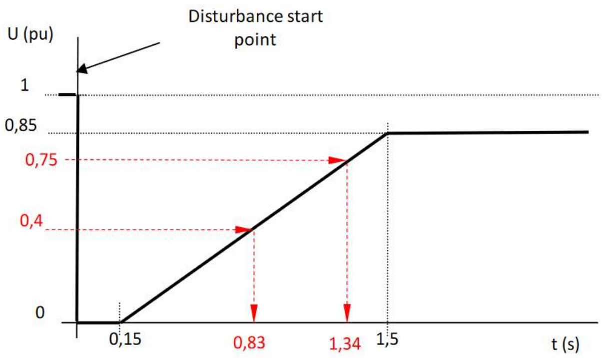

Fig. 1. Type D wind turbine FRT requirement according to EU Grid Code [10], and parameterized to Spanish Grid Code [13].

In addition, during the low voltage condition caused by the fault, the wind farm must inject reactive current in proportion to the voltage drop. This current must lead the voltage at the PCC in order to sustain the network voltage and contribute to the voltage recovery process after the fault is cleared.

Figure 2(a) shows the reactive current requirements defined in the EU Grid Code for balanced faults, as implemented in Spanish legislation [14]. The wind farm has to inject an additional amount of positive sequence reactive current proportional to the positive sequence voltage drop caused by the fault. The gain can be regulated between 2 and 6, in p.u.

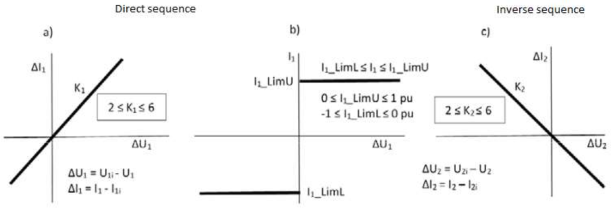

Fig. 2. Reactive current injection requirements according to EU Grid Code, as implemented in Spain for Type D wind farms [14].

In the case of unbalanced faults, modern Grid Codes require wind farms to absorb negative sequence reactive current to emulate the natural response of synchronous generators.

Figure 2c) shows the reactive current requirements defined in the EU Grid Code for unbalanced faults, as implemented in the Spanish legislation [14]. The wind farm has to absorb an additional amount of negative sequence reactive current proportional to the negative sequence voltage rise caused by the fault. The gain can be regulated between 2 and 6, in p.u.

3. Study Case

A. Test network model

The model of the wind farm consists of a Serbian network model with 6 nodes (three at 400 kV and three at 220 kV). The nodes are connected with overhead lines and one 400/220 kV autotransformer. Moreover, several loads are modelled. The scheme of the model is presented in Fig. 3, and the implementation in DIgSILENT PowerFactory software is shown in Fig. 4 after the load flow calculation [14-15], where the WF injects 50 MW and controls the voltage at the PCC to 1.01 pu.

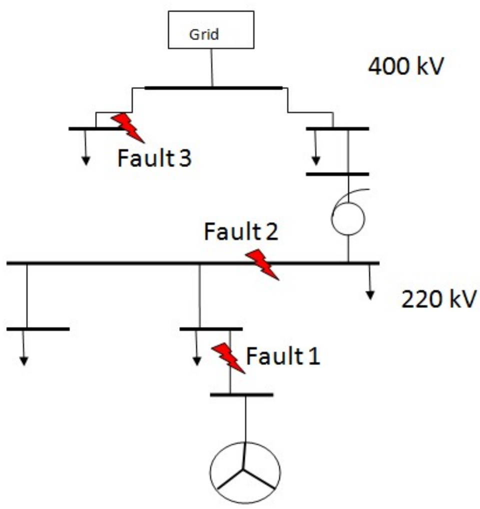

Fig. 3. The scheme of the model, with fault locations.

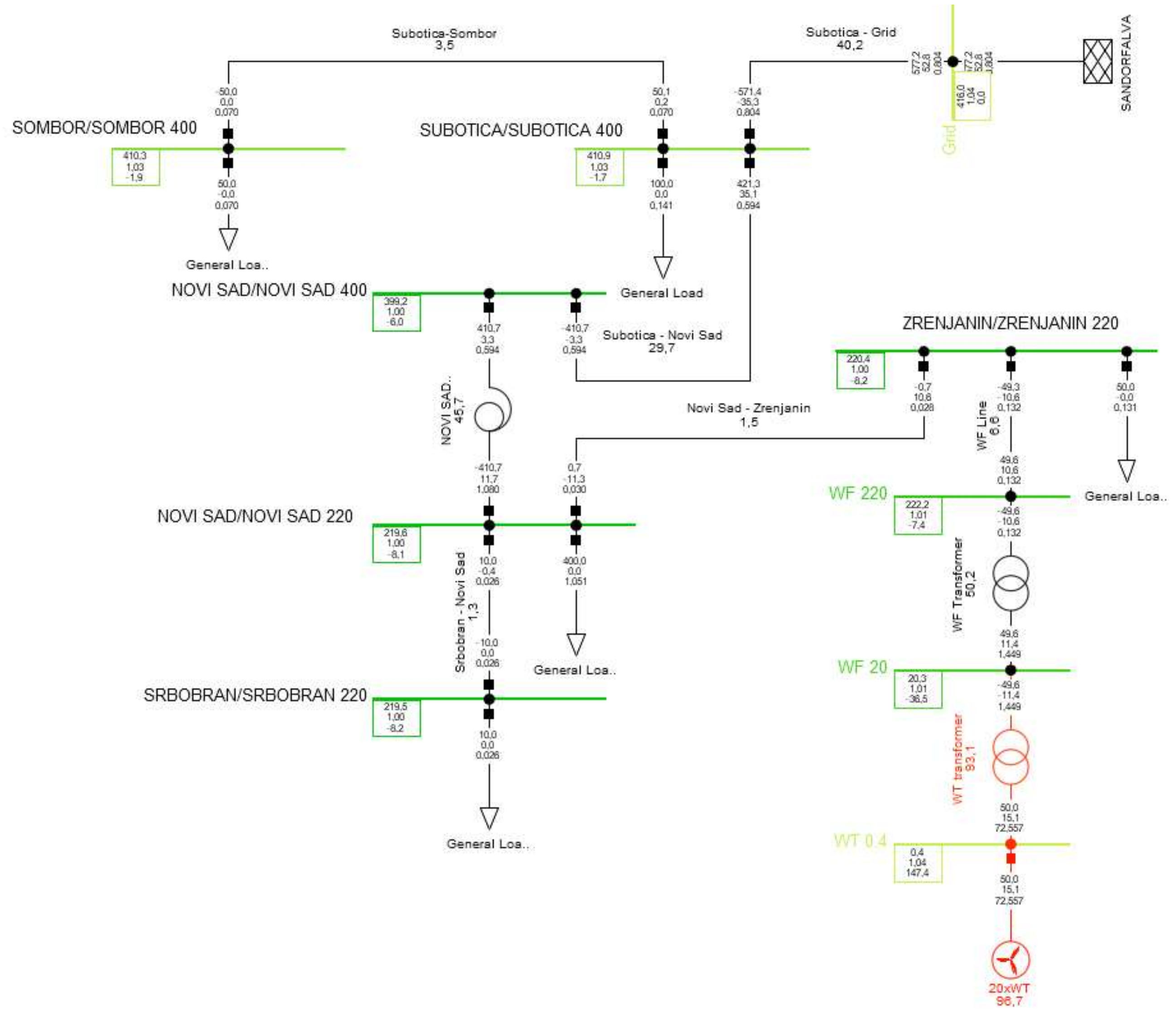

Fig. 4. DIgSILENT model after full active power output load flow solution.

The wind farm consists of 20 2.78 MW wind turbines. Each unit is equipped with a 20/0.42 kV step-up transformer. Finally, a 220/20 kV power transformer is connected between the wind farm and the network.

B. FRT capability for balanced faults

Three phase faults, at the locations presented in Fig. 3, with zero fault resistance, are simulated. Looking at Fig. 1 it can be determined how long the fault should be attended before the wind farm is switched off. This analysis can help define the voltage drop during the planning of the future network. This could be helpful for engineering studies before connection of the renewable power plant.

Four key parameters are analysed at the PCC: positive sequence voltage, positive sequence current, total active power and total reactive power. The results are presented in Figs. 5-7.

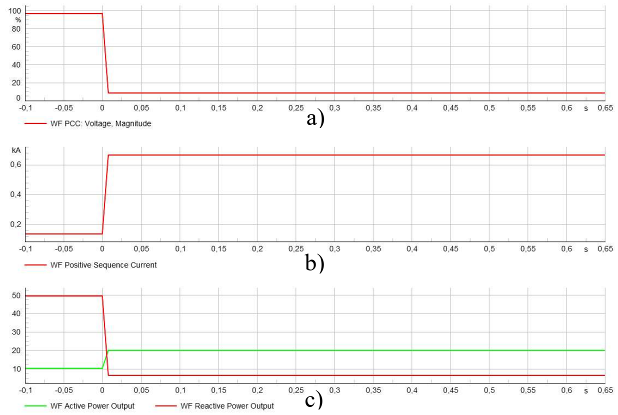

Fig. 5. Three phase Fault 1. a) PCC positive sequence voltage (%), b) WF positive sequence current (kA), c) WF Active power (MW) and Reactive power (MVAr) output.

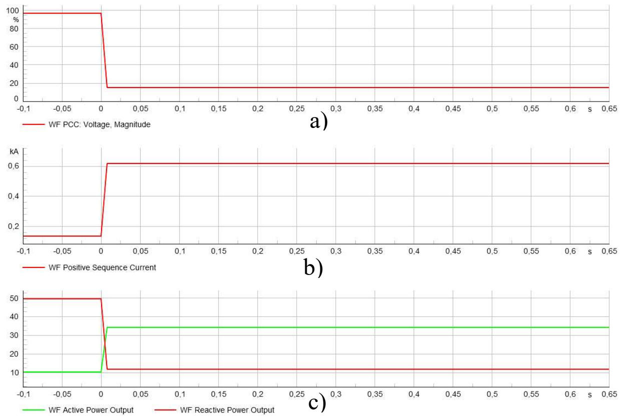

Fig. 6. Three phase Fault 2. a) PCC positive sequence voltage (%), b) WF positive sequence current (kA), c) WF Active power (MW) and Reactive power (MVAr) output.

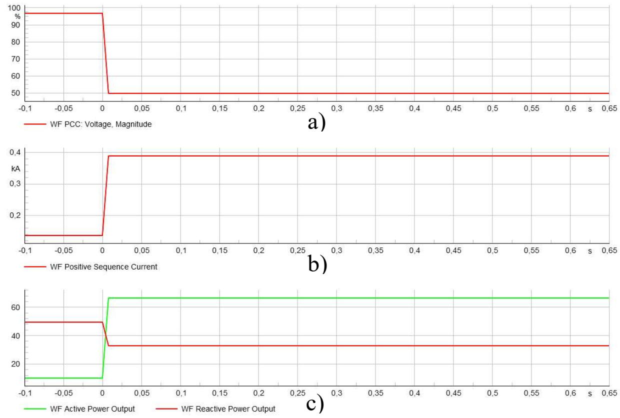

Fig. 7. Three phase Fault 3. a) PCC positive sequence voltage (%), b) WF positive sequence current (kA), c) WF Active power (MW) and Reactive power (MVAr) output.

It can be seen that the voltage drop is lower than expected at the fault location furthest from the PCC. Positive sequence current is lower as well. Finally, the injected reactive power is higher. In the case of symmetrical voltage faults, the wind farm is switched from normal control to LVRT control, which enables the operation of the wind turbine during the fault. The reactive current at the generator connections is adjusted based on the voltage at the connections and depends on the type of wind generator. Reactive current injection during the fault is of great importance for voltage stability in the system and for quick recovery from a short circuit. As the short circuit is closer to the location of the WF, the amount of reactive power injected during the fault reduces.

C. FRT capability for unbalanced faults

During network unbalance faults, the FRT capability of the windfarm depends on the fault location and the type of current injection performed by the LVRT control. Fig. 8 shows the response of the WF under study to a 200 ms BC fault at point 1, when the LVRT control only injects positive sequence current. Fig. 9 shows the response of the WF to the same fault when the LVRT control injects active and reactive sequence current with the same droop gain (3.5). If only positive sequence current is injected, the phase that is not affected suffers an overvoltage condition. This can compromise the ability of the WF to ride through the fault if the overvoltage condition is above the maximum supported. If the WF injects positive and negative sequence current, the voltage in the phase not affected is controlled, at the expense of a lower reactive power injection during the fault.

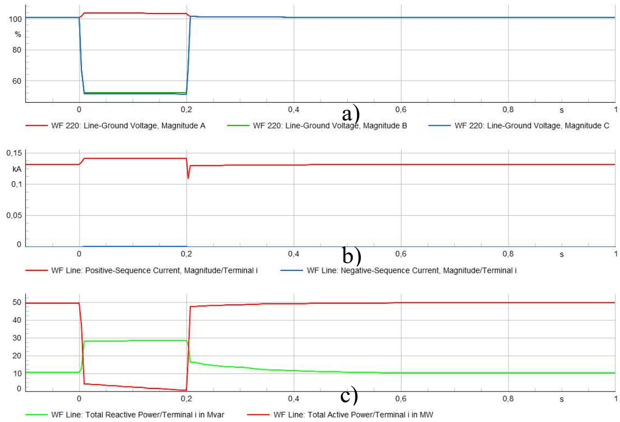

Fig. 8. Two phase Fault 1. Only I_1 injection. a) PCC phase voltages (%), b) WF positive & negative sequence current (kA), c) WF Active power (MW) and Reactive power (MVAr) output.

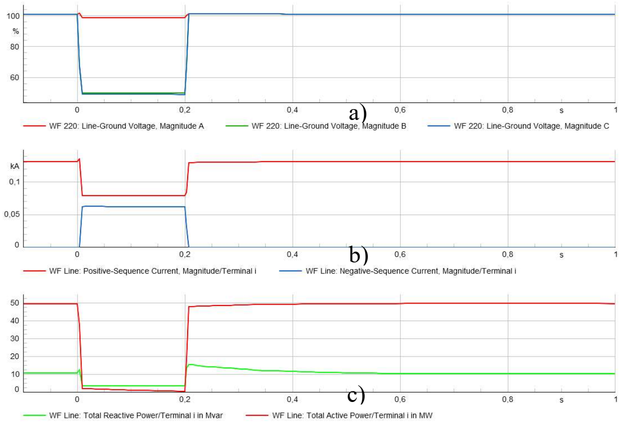

Fig. 9. Two phase Fault 1. I_1 & I_2 injection. a) PCC phase voltages (%), b) WF positive & negative sequence current (kA), c) WF Active power (MW) and Reactive power (MVAr) output.

Fig. 10 & 11 analyse the response of the WF for a BC fault farther away (Fault 3) and cleared in 600 ms, with only positive sequence injection and with positive and negative sequence current injection.

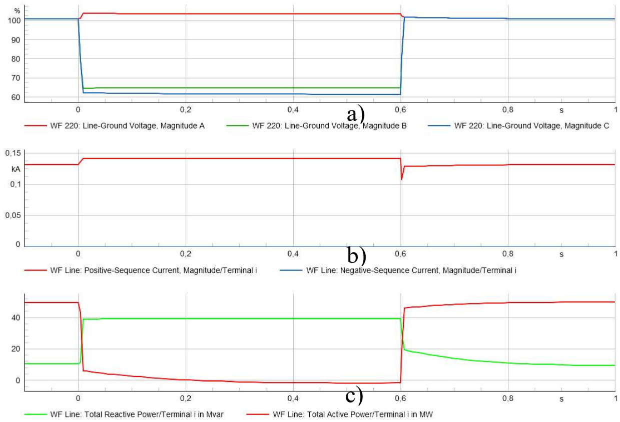

Fig. 10. Two phase Fault 3. Only I_1 injection. a) PCC phase voltages (%), b) WF positive & negative sequence current (kA), c) WF Active power (MW) and Reactive power (MVAr) output.

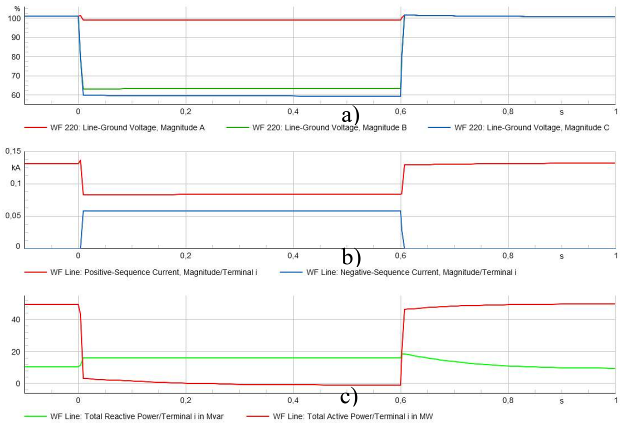

Fig. 11: Two phase Fault 1. I_1 & I_2 injection. a) PCC phase voltages (%), b) WF positive & negative sequence current (kA), c) WF Active power (MW) and Reactive power (MVAr) output.

The effect of the current injection is similar than for a close in fault (Fault 1). If only positive sequence current is injected, the phase not affected suffers an overvoltage, while the combined injection of positive and negative sequence current keeps the voltage around the prefault value, although with a reduction in the reactive power injection.

Finally, Fig.12 and 13 study the same fault cases, Fault 1 and Fault 3, but with different droops for the positive (3.5) and negative (1) sequence current injection.

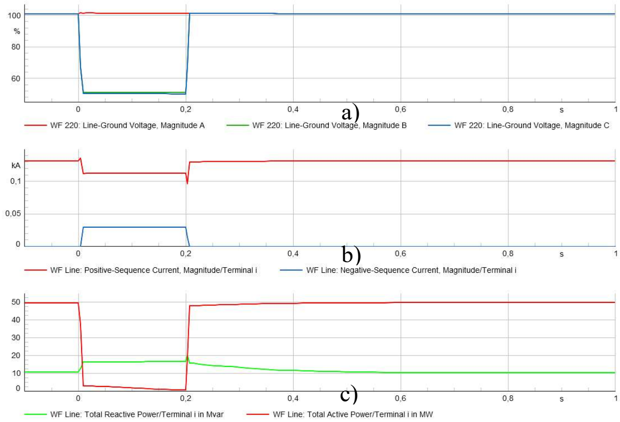

Fig. 12: Two phase Fault 1. $I_1 > I_2$ injection. a) PCC phase voltages (%), b) WF positive & negative sequence current (kA), c) WF Active power (MW) and Reactive power (MVAr) output.

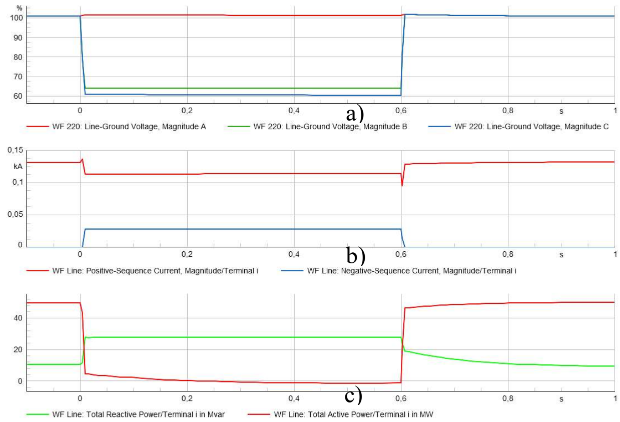

Fig. 13: Two phase Fault 3. Only I_2 injection. a) PCC phase voltages (%), b) WF positive & negative sequence current (kA), c) WF Active power (MW) and Reactive power (MVAr) output.

When the LVRT control gives more priority to the injection of positive sequence current than negative, the voltage of the phase not affected by the fault is still under control, and the reduction of reactive power injection, compared to the case with only positive sequence current injection, is lower.

4. Conclusion

New large renewable energy plants along with the uncontrolled placement of distributed energy resources in networks have brought serious problems and challenges that transmission system operators have to face. During faults, wind farms face the challenge of staying connected. According to national regulations or Grid Codes, certain rules are defined that must be fulfilled to protect the transmission network as well. Therefore, the analysis of voltage drops during balanced and unbalanced phase faults is required before the commissioning of wind farms.

In this paper, the DIgSILENT software tool has been used, as it offers great possibilities for this kind of study. First, a small part of the Serbian national transmission system has been modelled. Several faults at different locations have been simulated, and the resulting voltage drop, positive and negative sequence current, total active power and total reactive power are calculated.

The results of the study highlight the importance of a proper balance between positive and negative sequence current injection during unbalance faults, to avoid an overvoltage condition in the sound phase, and to keep a sustained reactive power injection during the fault, in order to sustain the voltages in the surrounding network buses.

Acknowledgement

Funded by the Basque Government (GISEL research group IT1522-22) and European Union (Project 101079200 - SUNRISE). Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the Basque Government, European Union or European Research Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

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