Dynamic Modelling of Wind Farms: a Comparative Study between two Modelling Approaches

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Abstract.

World's energy needs have encouraged wind power sources. An increasing number of wind farms are being connected to the power grid and accurate wind farm models need to be developed to study the dynamic behaviour of them. This paper reports an investigation to compare two different modelling approaches of a real wind farm.

This study is applied to the dynamic model of a real wind farm located at El Perdón, in Navarre, (Northern Spain). It consists of 30 Squirrel Cage Induction Machine (SCIM) wind generators of 660 kW and a nominal voltage of 690V. The wind farm feeds three local loads at 66 kV and is connected through two transformers to the network of 220KV.

Key words

wind-energy, modelling of electrical systems, simulation of power plants**.**

1. Introduction

The development of dynamical models of wind farms could be made from different approximations. The first one, could be considering the whole set of N parallel-connected generators of the farm as a unique equivalent N-machine. This approach is the most simple, and hence, the most common in different references.

In previous works the development of the **N-machine model** has been done [1]. Where the model of the N-machine generator has been developed as a particular case of the electric machine general model: "The Quadrature-Phase Slip-Ring Model" [2] and includes the mechanical power characteristic of the wind hitting the blades of the wind turbine.

This model allows the analysis of the effects between the global farm and its surrounding electrical distribution network: contribution to fault current, interaction with power system protection system etc. [3]. The N-machine model also brings interesting information about transient behaviour and stability of wind farms under electrical disturbances. This problem has been studied for the case of three phase faults and for islanding operation [1]. The important results obtained via this approximation lead to a second approximation which concerns the study of wind farm internals.

A second approximation could be a deeper modelling of the wind farm in order to asses the interactions between particular generators, under different wind speeds and, hence, different mechanical generating powers [4]. The development of this **Multi-machine model** is more complex than the N-machine, not only due to the increasing number of non-linear state-equations of machines, but also because of the Dyn connection of step-up transformers used in Spanish electrical system.

The purpose of this work is to present a comparative study between these two modelling approaches. This study is applied to the dynamic model of a real wind farm located at El Perdón, in Navarre, (Northern Spain). The wind farm consists of N=30 wind generators of 660 kW. The line parameter values, and load and capacitor values have been provided by IBERDROLA S.A. electric generating company.

2. Case Study

Both models have been implemented as a C-MEX S-Function for Simulink, a dynamic system simulation package for MATLAB.

The model inputs are the voltage at infinite busbar and the wind speed of each generator. Outputs are: induction machine stator currents, stator voltages, rotor mechanical speed, electromagnetic torque and active and reactive power; wind farm busbar voltages, currents in the distribution lines and surrounding loads; fault currents and currents in the connecting point with the infinite busbar [4]. A comparative of models implementation characteristics is shown in Table I.

TABLE I. – Model implementation comparative

	N-machine	Multi-machine
Inputs	(3+N)	(3+N)
Outputs	10+15	(10*N+15)
Non-linear state equations	26	(14*N+12)

The N-machine model gives a set of 14 non-linear state-equations for the wind farm. Furthermore, a set of 12 state-variables describes the electrical system that connects the bus at 20 kV with the network at 220 kV.

The Multi-machine model gives a set of (14*N+12) non-linear state-equations. (In this case 432).

Both mathematical models of the wind farm have been directed to the possibility of checking their performance under different conditions of the electrical network.

A. Normal operation

Several cases of the normal operation of the wind farm are studied. First, the case in which the wind speed of all wind turbines is v_w= 13 m/s and suddenly decreases to v_w= 8 m/s in 15 of 30 wind turbines.

Figure 1 shows the evolution of the RMS value of the voltage at 20 kV busbar (the common busbar of the w ind farm, where all the induction machines are connected). In this figure both responses are not exactly equals.

This is due to the fact that the N-machine model is a scaled machine that works with a total wind power,

$$P_w = \sum_{i=1}^{N} P_{wi} \qquad (1)$$

The approximation of a total unique generating power for an unique N-machine is equivalent to suppose that all the particular machines work at the same operation point. This operation point corresponds to the continuous curve at figure 2.

It could also be observed in figure 2 that, in fact, there are two operation points in the wind farm, related to the different wind speeds. Dotted upper curve shows the evolution of slip of the induction machines with v_w= 13 m/s. Dotted lower curve is the evolution of slip with v_w= 8 m/s. And the equivalent wind farm operates with an intermediate slip.

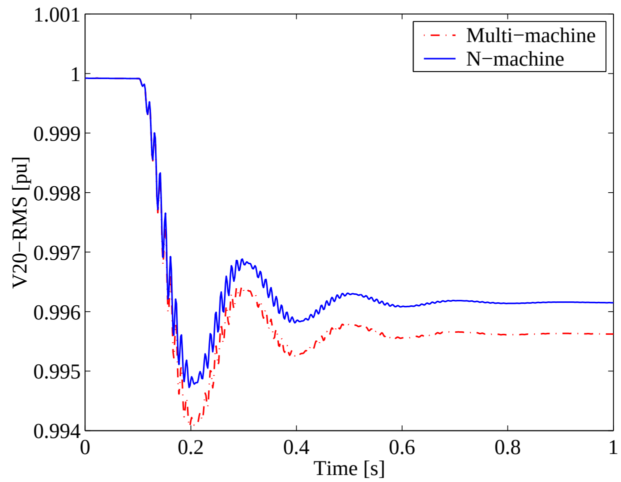

Fig. 1. Voltage at 20 KV busbar. Wind speed decreases

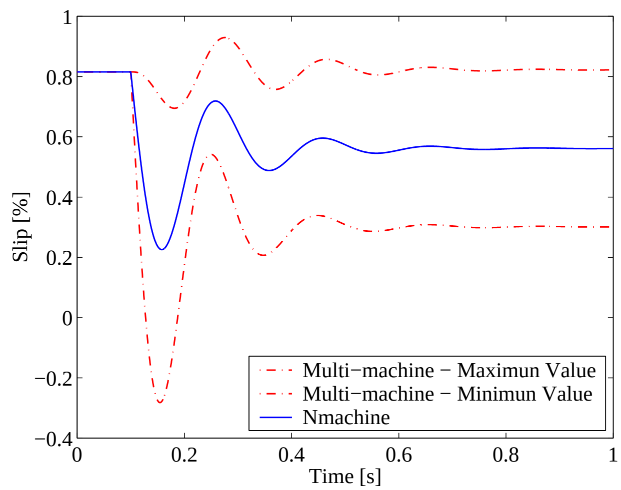

Fig. 2. Slip comparative. Wind speed decreases

Next, the effect of wind speed increase is analysed. In this case 15 wind generators have v_w= 13 m/s. The other 15, have initially a wind speed of v_w= 8 m/s and suddenly increases to v_w= 13 m/s.

Figures 3 and 4 show the evolution of the RMS value of wind turbines stator voltage and the RMS value of subterranean lines currents, respectively.

In this case, at initial conditions, two different operation points are observed in the Multi-machine model simulation and the N-machine works in some average operation point. When all the induction machines have the same wind power, both models response are identical.

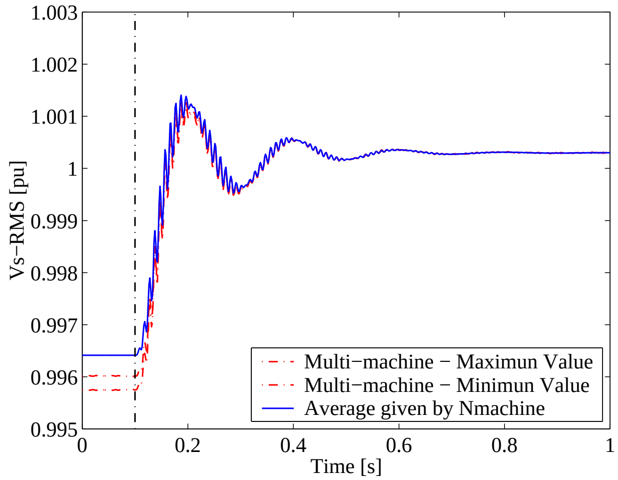

Fig. 3. Wind generators stator voltage. Wind speed increases

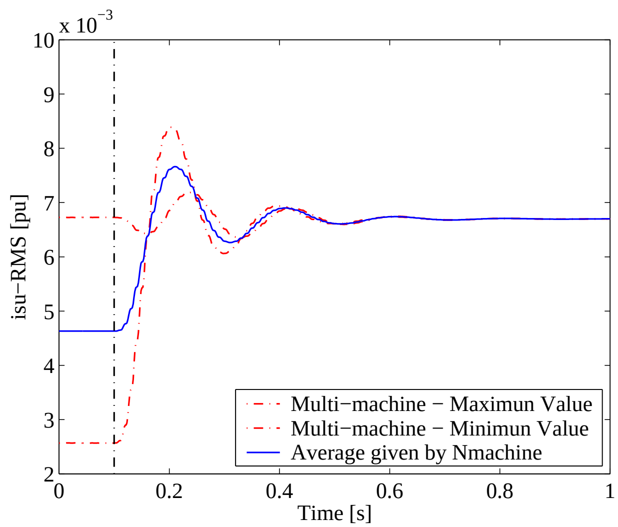

Fig. 4. Subterranean lines currents. Wind speed increases

B. *Short Circuits*

In the study of short-circuits, all induction machines have different wind-speed. Figure 5 shows the evolution of currents in subterranean lines that connect each machine with the common busbar of the wind farm in normal operation.

The impact of different short-circuits has been studied: one-phase, two-phase and three-phase resistive short-circuits. The resistance value is variable: from direct ground fault (R=0 pu) to a very resistive fault (R=1 pu). The fault can be placed at different positions into the intermediate network at 66 kV. In all cases the fault length is set to 100 msec.

Figures 6 and 7 show simulation results of one-phase fault located at the connection point of the wind farm with the distribution network. Figure 6 is the evolution of the RMS value of the voltage at the wind farm busbar (20 kV).

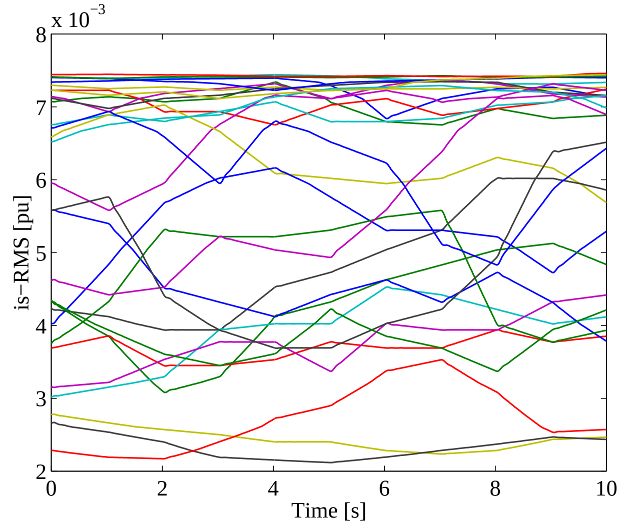

Fig. 5. Subterranean lines currents. Normal operation

Figure 7 presents the evolution of the RMS value of currents at the connection point with the transport network at 220 kV (infinite busbar).

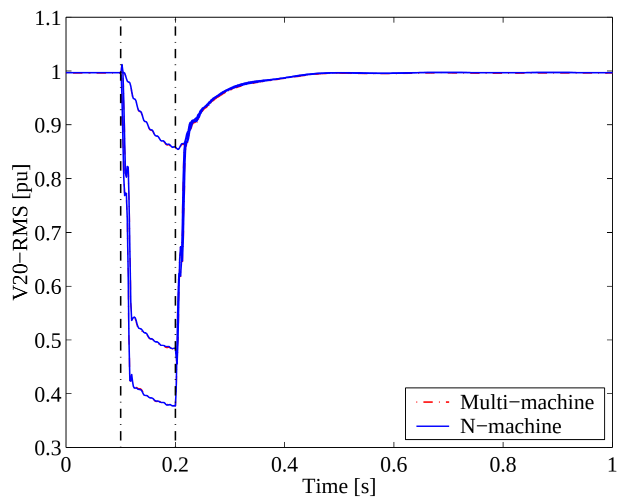

Fig. 6. Voltage at 20 KV busbar. One-phase fault

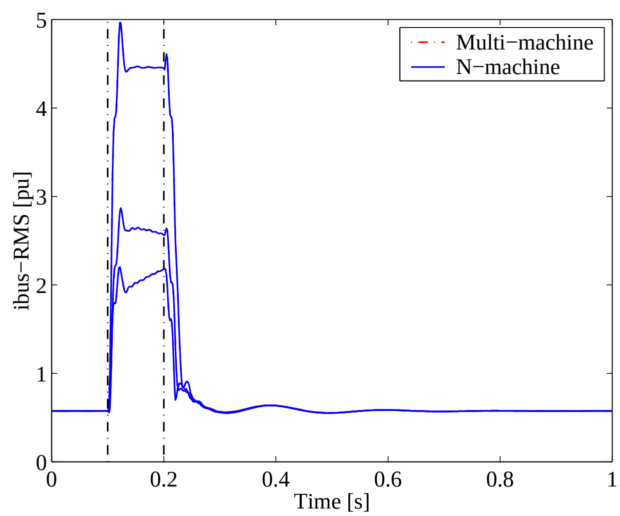

Fig. 7. Currents in the infinite busbar. One-phase fault

In this case, both models lead to practically indistinguishable results. That means that the transient evolution of external magnitudes could be evaluated with the N-machine model.

Figures 8 and 9 show simulation results of two-phase fault located at the connection point of the wind farm with distribution network. Figure 8 is the evolution of the RMS value of the voltage at the wind farm busbar (20 kV). Figure 9 is the evolution of the RMS value of currents at the connection point with the transport network at 220 kV (infinite busbar).

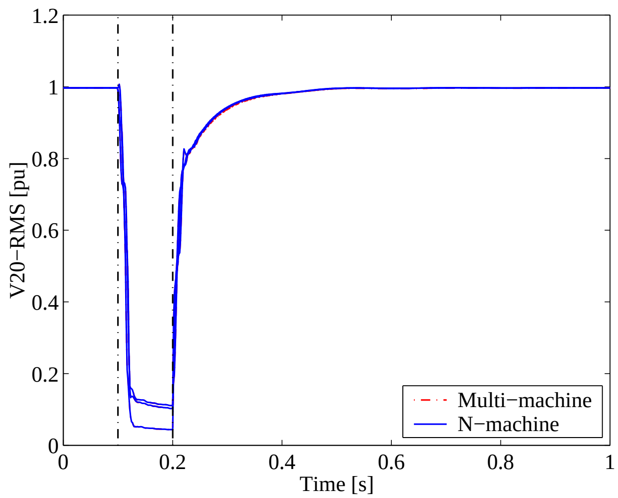

Fig. 8. Voltage at 20 KV busbar. Two-phase fault

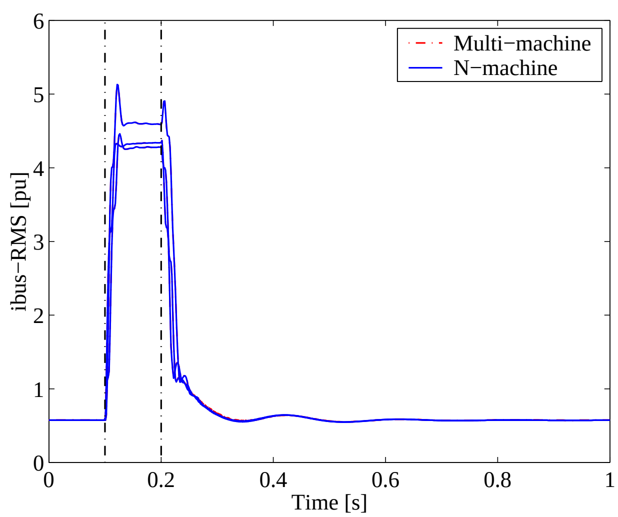

Fig. 9. Currents in the infinite busbar. Two-phase fault

In this case, both models leads to similar results. It could be observed that the two faulted phases are coupled in voltages and in currents values.

Figures 10 and 11 show simulation results of three-phase fault located at the connection point of the wind farm with distribution network.

Figure 10 presents the evolution of the RMS value of the voltage at the wind farm busbar (20 kV). Figure 11 is the evolution of the RMS value of currents at the connection point with the transport network at 220 kV (infinite busbar).

For the symmetric three-phase fault both models leads to similar results. It could be observed that the all three phases have the same voltage collapse and the same overcurrent behaviour.

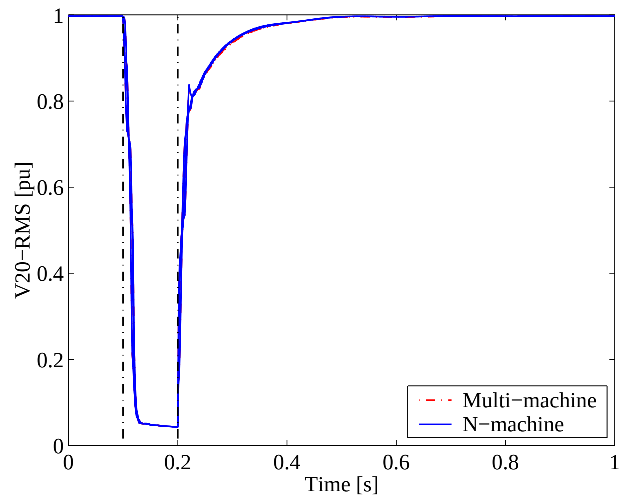

Fig. 10. Voltage at 20 KV bus . Three-phase fault

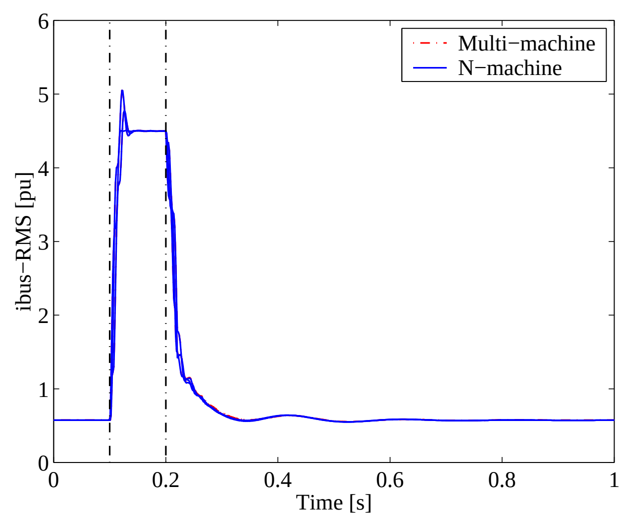

Fig. 11. Currents in the infinite busbar. Three-phase fault

Furthermore, the dynamic response of generators can be observed with the multi-machine model. Figures 12, 13 and 14 show the evolution of the stator currents of induction machines with different wind speed when one-phase, two-phase and three-phase faults located at the connection point of the wind farm with the distribution network.

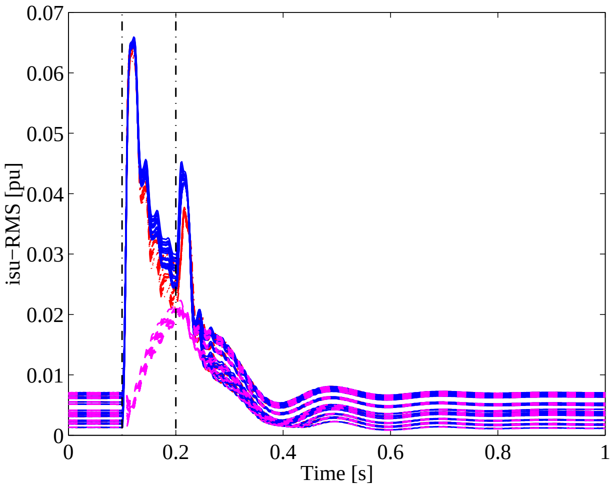

Fig. 12. Induction machines stator currents. One-phase fault

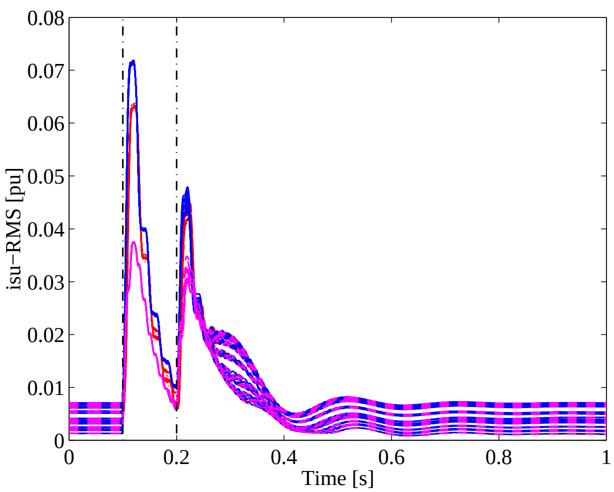

Fig. 13. Subterranean lines currents. Two-phase fault

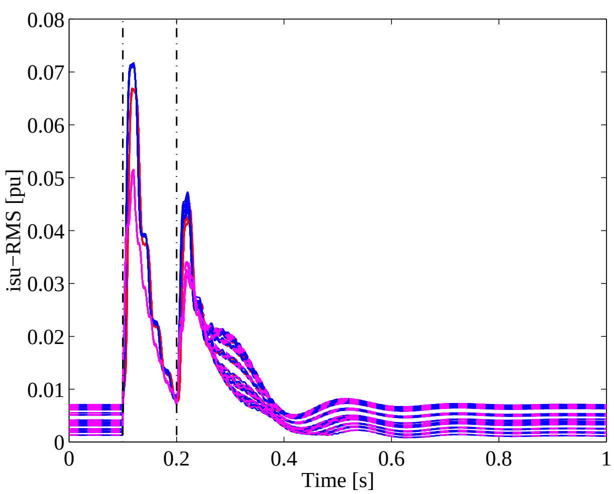

Fig. 14. Subterranean lines currents. Three-phase fault

4. Conclusion

The systematic modelling of the electrical network and a general wind farm is the main contribution of the study carried out.

The N-machine model purpose has been the deep study of the fundamental magnitudes of the wind farm and the surrounding network. Simulation results show that the equivalent N-machine works at somewhat representative (but not real) slip. Nevertheless, the study of different short-circuits has revealed that this difference is not significant and the evolution of main wind farm external electrical magnitudes can be simulated with the N-machine. Therefore, this modelling could support the design of the electrical protections and operational strategies for the wind farm taken as a whole.

On the other hand, the development of a complex Multi-machine model explains the particular behaviour of each generator of the wind farm. This model gives the power exchange between generators. With this model, different short–circuits have been simulated. These experiments allow the evaluation of current flows and stabilisation times. Both values will be very interesting information to the coordination of the system protection.

The choice of the Multi-machine or N-machine model depends on the application.

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