TECHNICAL REQUIREMENTS FOR WIND AND PHOTOVOLTAIC POWER PLANTS. DIGSILENT TESTING TECHNIQUES FOR POWER PLANTS.

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1. Introduction

The Spanish Transmission System Operator (TSO), Red Eléctrica de España, has progressively modified its vision of wind farm operation and integration in the electrical grid due to the progressive increase in installed power and its concentration in some specific areas. The liberalization of the electricity market, the expansion plans for generation and the fulfillment of Spanish Kyoto's protocol commitments have led to new objectives in terms of wind energy penetration, which, in 2008, reached 16.740 MW in Spain. The requirements imposed by the TSO to large wind farms are every time more demanding and more similar to the ones that are imposed to conventional synchronous generators. The appendix on technical requirements of the Operation Procedure P.O 12.2 [1] "Generators connected to the transmission grid: minimum design requirements, equipment, operation, commissioning and safety" is nowadays under revision. This text is not only oriented to wind power generators (WF) but also to solar (PV) power plants of more than 10 MW registered power and every technology not based on a synchronous generator directly connected to the grid. This procedure shall be applicable from January 2011.

Due to these new requirements, the control algorithms under development are more complex and the need for testing those algorithms is emerging. Until today, tests at wind turbines or inverters terminals to check the correct behaviour of the control algorithms where carried out quite easily but testing distributed system control algorithms might be a difficult and dangerous task. In this paper, we will describe how simulation and reality can be combined to test a centralized control system of a wind farm at three different stages of the design thanks to the simulation platform DIgSILENT's PowerFactory V14 [2].

2. New technical requirements of P.O. 12.2 for wind and solar power plants

The appendix to the P.O 12.2 is introducing the following modifications:

LOW VOLTAGE RIDE THROUGH REQUIREMENTS: The PV or wind power plant must stand 0% remaining voltage dips without disconnecting (Figure 1)

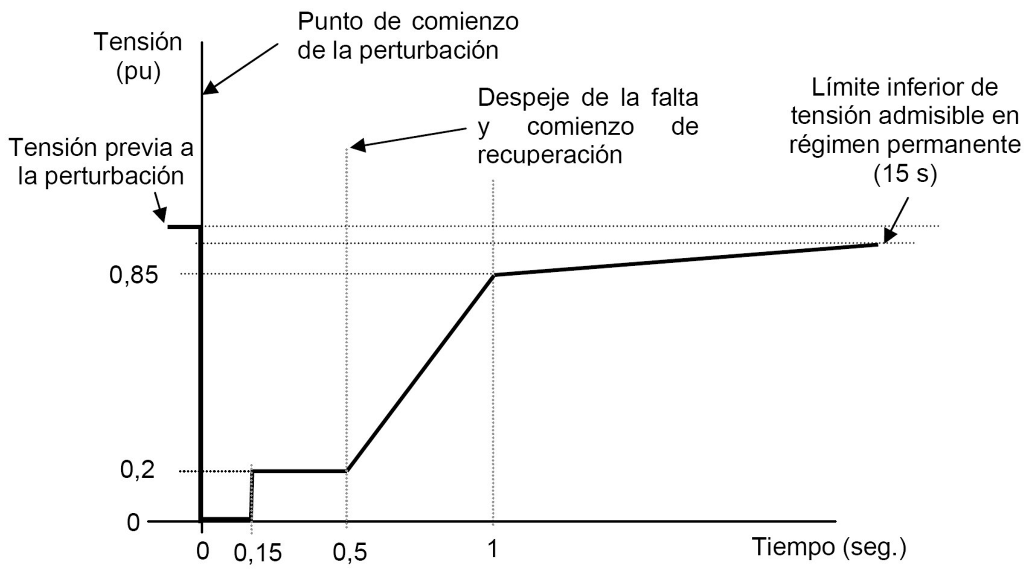

Figure 1: RMS profile of the three phase voltage dip as defined in the P.O.12.2 draft. Minimum voltage threshold to be stood without disconnection.

HIGH VOLTAGE RIDE THROUGH: The plant should be able to stand a voltage swell up to 130% at the connection point (Figure 2).

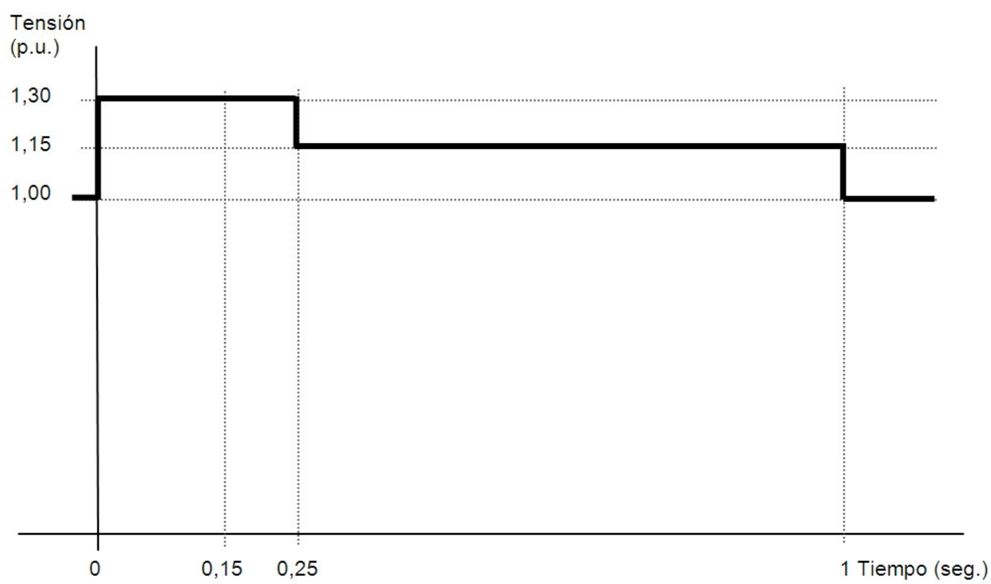

Figure 2: RMS profile of the three phase voltage swell as defined in the P.O.12.2 draft. Maximum voltage threshold to be stood without disconnection.

REACTIVE POWER CONTROL: The plant shall be able to generate/consume reactive current within the voltage margin defined by the set-points sent by the TSO in less than 20 seconds. During transients (voltage dips, swells, etc.), the control will switch to an automatic voltage controller using the previous unaltered voltage set-point as current set-point. The control can be implemented as a voltage, reactive power or power factor controller and will maintain the reactive current injection/consumption within the limits of saturation defined in Figure 3. The controller will remain active for at least 30 seconds after voltage recovery, returning then to the operational mode previous to the perturbation.

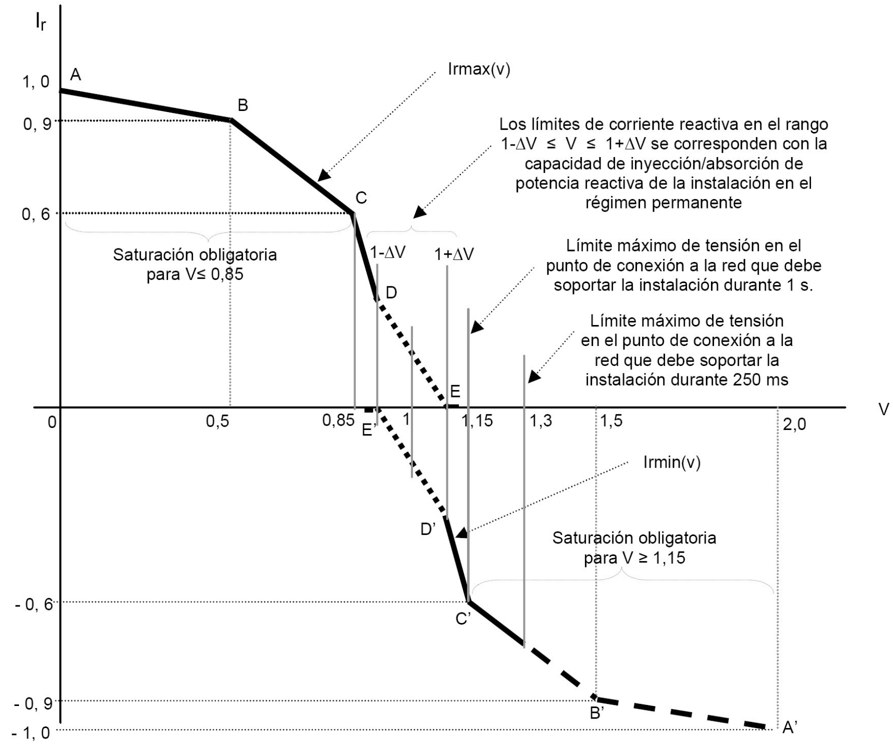

Figure 3: Current limit for reactive current generation/consumption during transients

ACTIVE POWER CONTROL: The plant shall include the required equipment to perform power-frequency control, equivalent to a proportional controller with adjustable dead-band. This controller shall receive active power set-points in real time sent by the TSO to increase or to reduce the reserve. The control will be transiently disabled while the voltage remains below 85% of its rated value; in this case, the active current injection/consumption will be controlled to be kept within the limits shown in Figure 4 in less than 40ms.

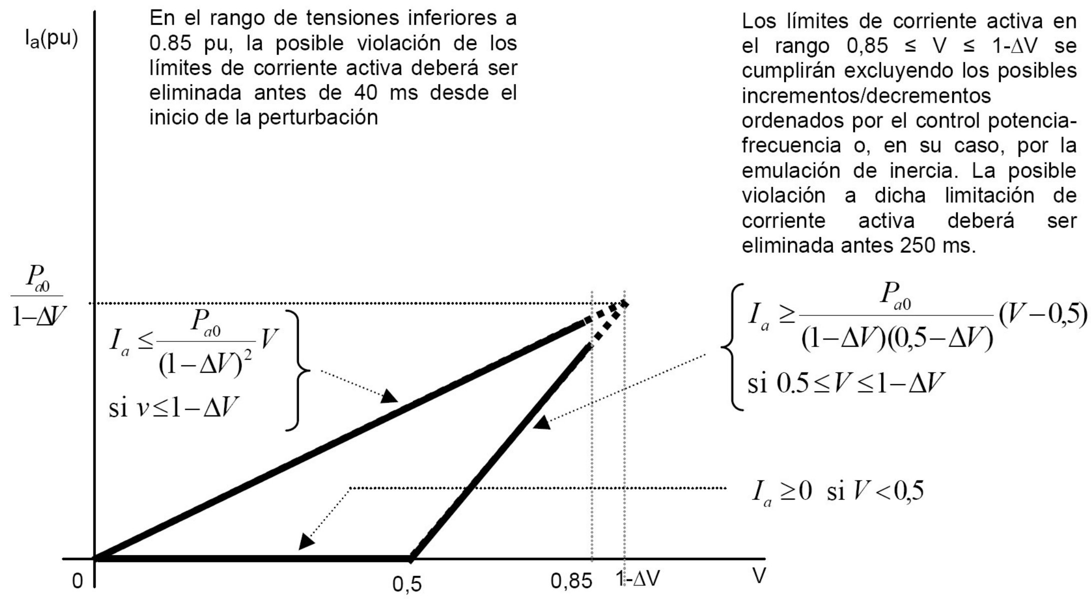

Figure 4: Upper and lower limits for active current control

3. Testing techniques for wind and solar power plant centralized control

As explained before, the TSO through its central dispatching center can send active and reactive power set-points to power plants of rated power over 10MW. The set-points are sent to regulate the entire power plant at its point of connection, and are thus distributed conveniently among the wind turbines or the PV inverters by the central controller of the power plant.

To illustrate how a central controller can be tested combining reality and simulation, we will present the case of a wind farm and a central voltage controller. The wind farm used in this example is composed by seven 2,1 MVA machines connected at a 20 kV wind farm distribution network. The wind farm is connected to an external 110 kV transmission system through a step-up transformer with automatic tap changing at the 20 kV side (+5% → -5%, 5 taps). The short-circuit power at the connection point with the network operator is around 300 MVA or 20 times the rated power of the wind farm. The single line diagram is shown in Figure 6.

The target is to control the voltage at the HV side of the wind farm step-up transformer. The voltage at the MV side is regulated by the wind farm transformer taps controller. The control can run in two different modes:

Mode 1: The reactive power set point is equally distributed among the available wind turbines in operation in the WF:

$$Q_{set}^{Total}(i) = \frac{Q_{set}^{Total}}{number\ of\ \ available\ wind\ turbines}$$

Mode 2: The reactive power set point is distributed according on how effectively each wind turbine can contribute to the voltage control. In our case, the reactive power produced by the closest wind turbine to the substation will be more efficient than the reactive power generated at the other end of the wind farm.

$$Q_{set}^{Total}(i+1) = Q_{set}^{Total}(i) - Q_{set}^{i}$$

where *i* is the index of the wind turbine, sorted by order of efficiency as explained before.

Every wind turbine has its own internal voltage control. If the voltage rises above its upper limit of operation or drops below the lower voltage limit, the set point sent by the central system is by-passed and the wind turbine own controller tries to maintain a safe voltage at its terminal. In this case, the central voltage controller receives a signal of unavailability from the wind turbine and takes it into account for the next step of set-point computation. The central controller is shown in Figure 5 where $\sum_{availability=ON} Q_{\max}^{i}$ is the sum of the maximum reactive power (Q>0) that can be generated, available to the central control system and where $\sum_{availability=ON} Q_{\min}^{i}$ is the sum of the reactive power (Q<0) that can be absorbed by the machines (availability=ON implies that the machine is not controlling the voltage at its terminal).

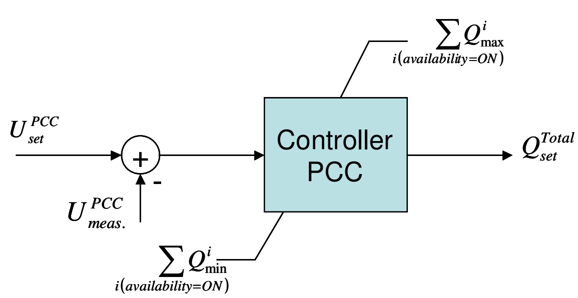

Figure 5: Central control system

Stage 1: Verification by simulation

When first studying the algorithms and overall control strategy, it is common to start implementing it directly within a simulation platform. In our case, it would be in PowerFactory using standard blocks and the DIgSILENT's Simulation Language (DSL), as shown in Figure 6. During this stage, we will check that our algorithms work, adjust some parameters, verify coherence of the overall strategy and look for possible causes of instability.

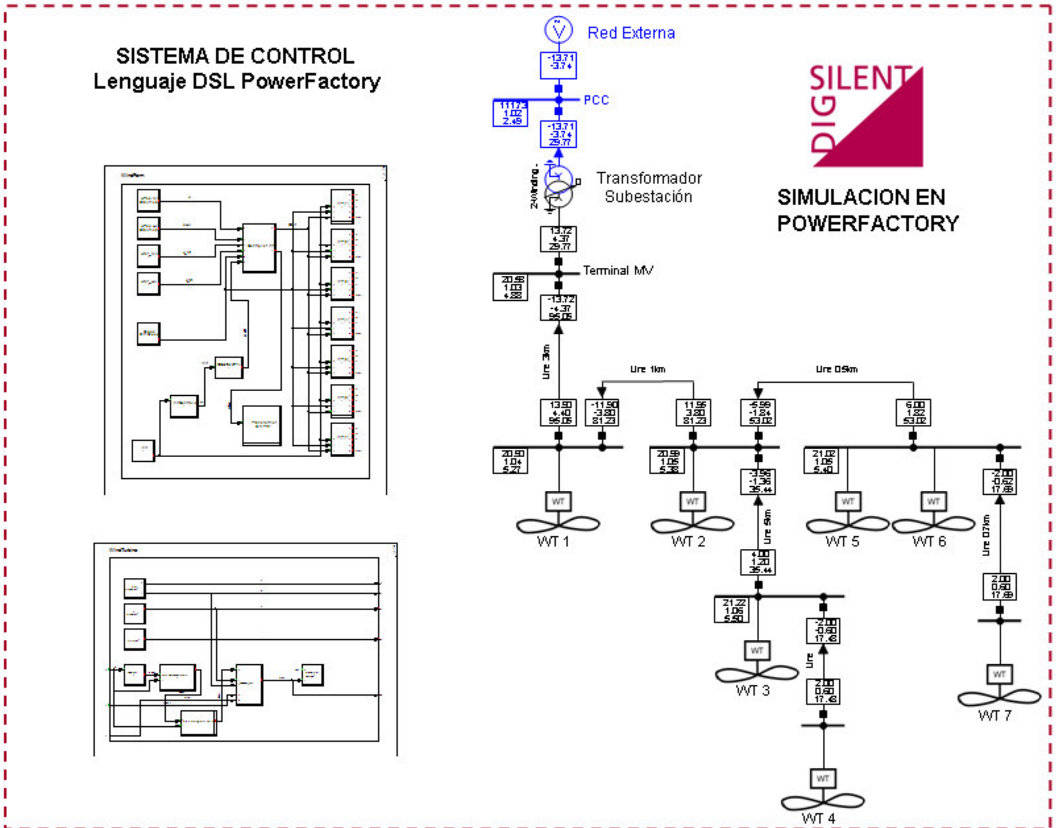

Figure 6: Building the control system in PowerFactory. Verification stage.

Stage 2: Testing the implemented routines

Once the control has been designed and implemented in a standard programming language to be compiled and run on real controller, it can be tested using the same platform as in Stage 1. In this example, we have implemented the controller in C++ because PowerFactory can run external dlls (dll=dynamic link library). C++/CLI allows using dlls programmed in .NET languages within the C/C++ interface with PowerFactory.

The wind farm is a class containing a vector of wind turbines, the voltage controller and the tap controller. Besides the control algorithms, other functions were implemented to add more functionalities, like adding wind turbines into the list of a wind farm, to sort the wind turbines vector according to their efficiency for voltage control, mode 1 and mode 2 set point calculations, etc. Methods to update the measured values and select the reactive power set-point have also been added.

The interface between the functions and data structures described in the above paragraph is made through a specific dll file (programmed in C/C++) that should be copied in the PowerFactory running directory. The functions contained in the dynamic library have a specific calling convention, passing values from and to PowerFactory by pointers. Therefore, we only have to write a small interface to pass the parameters to our controller functions and send the results back to the simulation platform (Figure 7).

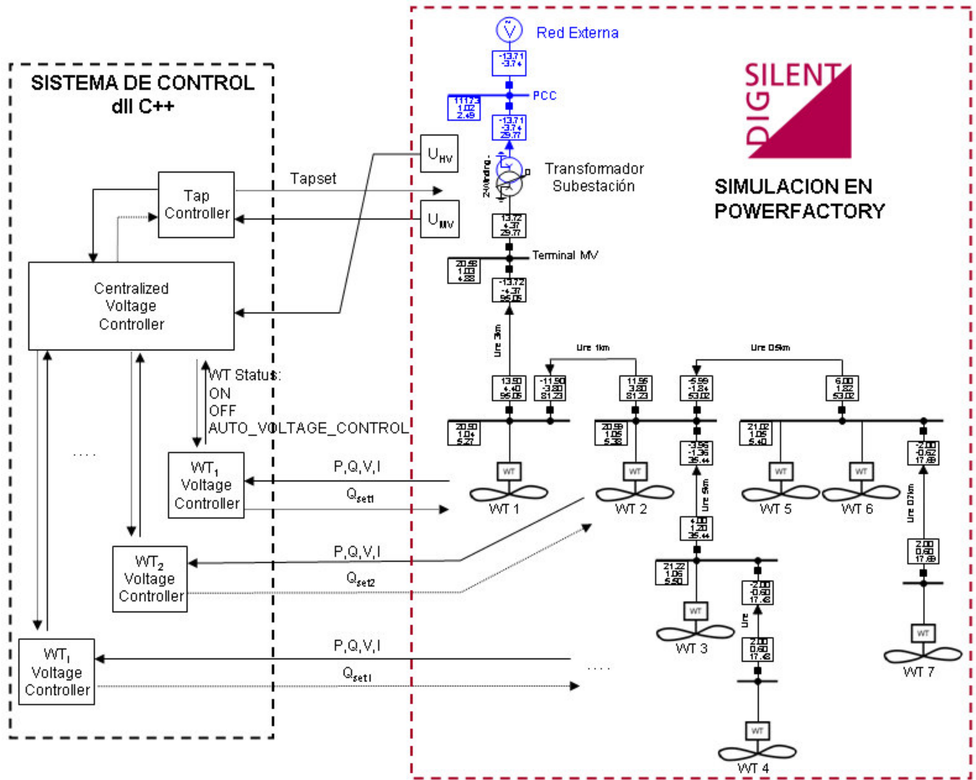

Figure 7: Control system implemented in DLL C++, direct communication with PowerFactory

Now, by running the simulation on the same wind farm – regarding to stage one, we have only changed the way the controllers are implemented –, we can observe the behavior of the controller, adjust parameters and we can be sure that the final functions are correctly programmed. We have saved the time of developing our own test platform.

Stage 3: “Almost full-scale test” with OPC server

Last step before commissioning is to test the system as in a real wind farm. Figure 8 shows the capability of PowerFactory to open a connection with an OPC server to perform real-time simulations [3]. On one side, the control system is programmed in C++ and compiled as a dll, on the other side the virtual power plant model (wind generators, lines and transformers) is implemented and simulated in PowerFactory and in between an OPC server.

The layer making the whole system communicating via the OPC protocol is added to the control routines and external measurement points matching the OPC tags are created in PowerFactory. This way, the control will read the measurements written by PowerFactory in the OPC variables, it will generate set-points, and set-points will be read by PowerFactory also via OPC variables. We have then very rapidly set up a “full-scale” test system, insuring safety during commissioning because all the algorithms and the overall strategy have been prior submitted to intensive study cases during simulation tests.

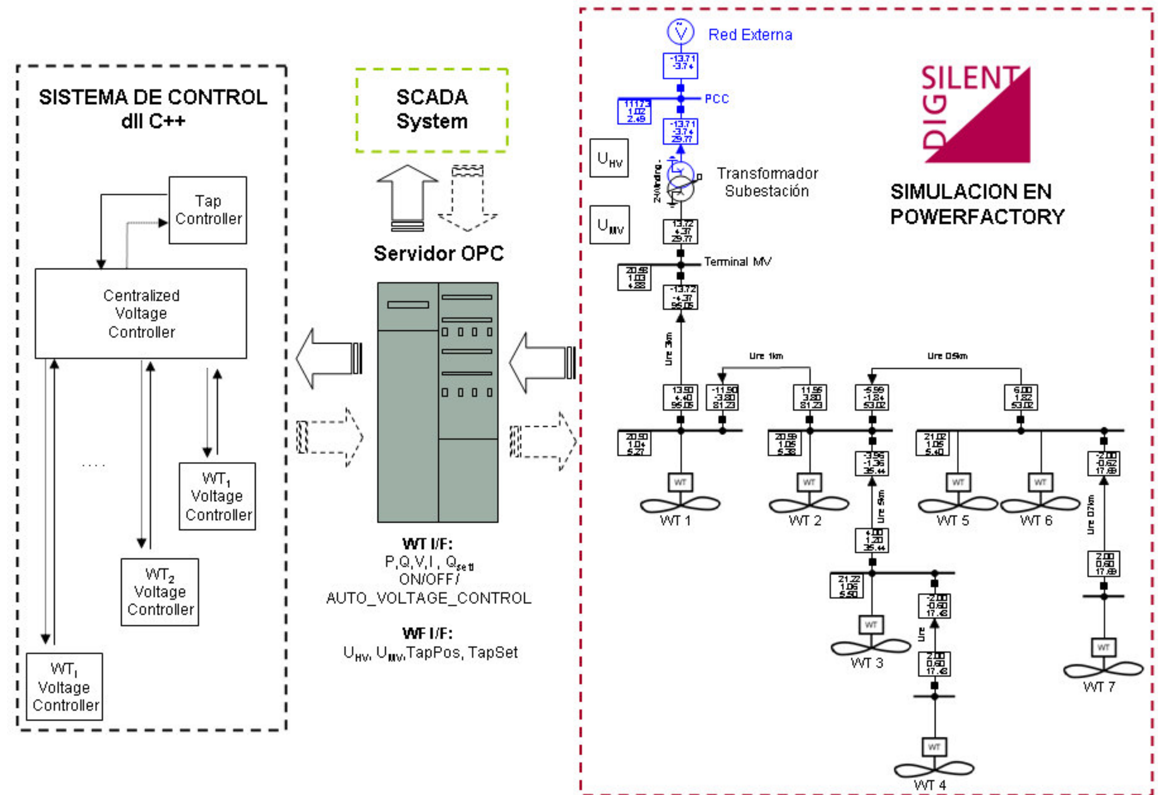

Figure 8: Control system implemented in DLL C++, interface through OPC server

For the purpose of our example, we have programmed an OPC client (Figure 9 and Figure 10) displaying the status of the wind turbines and the substation variables. The voltage control of the wind farm and the tap controller of the step-up transformer run in thread of the application.

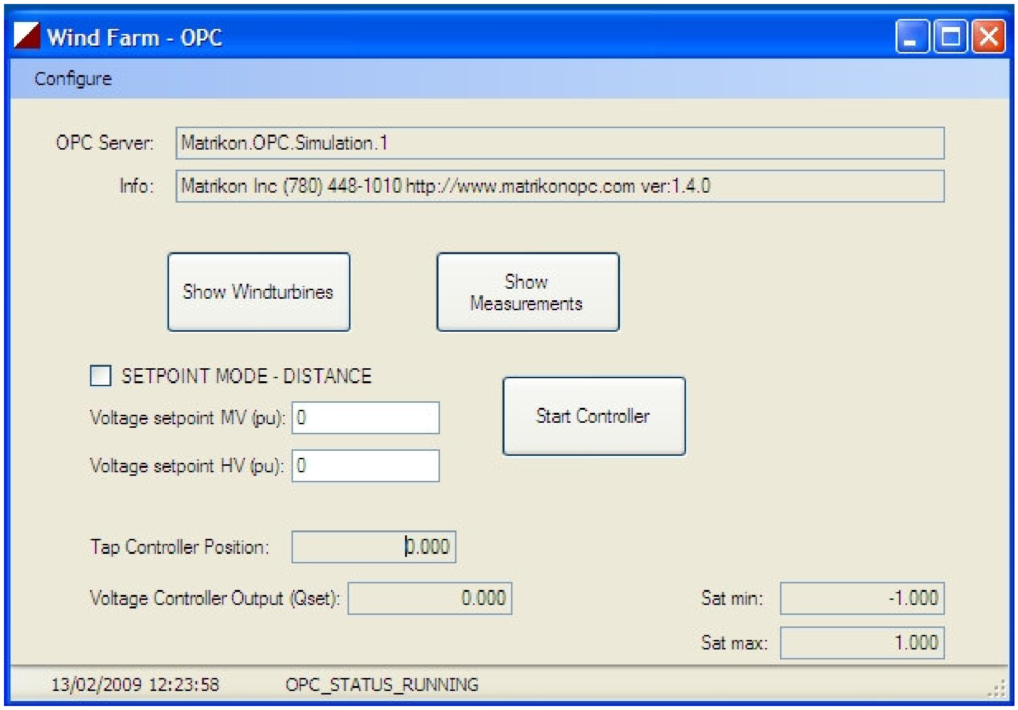

Figure 9: Wind farm central controller

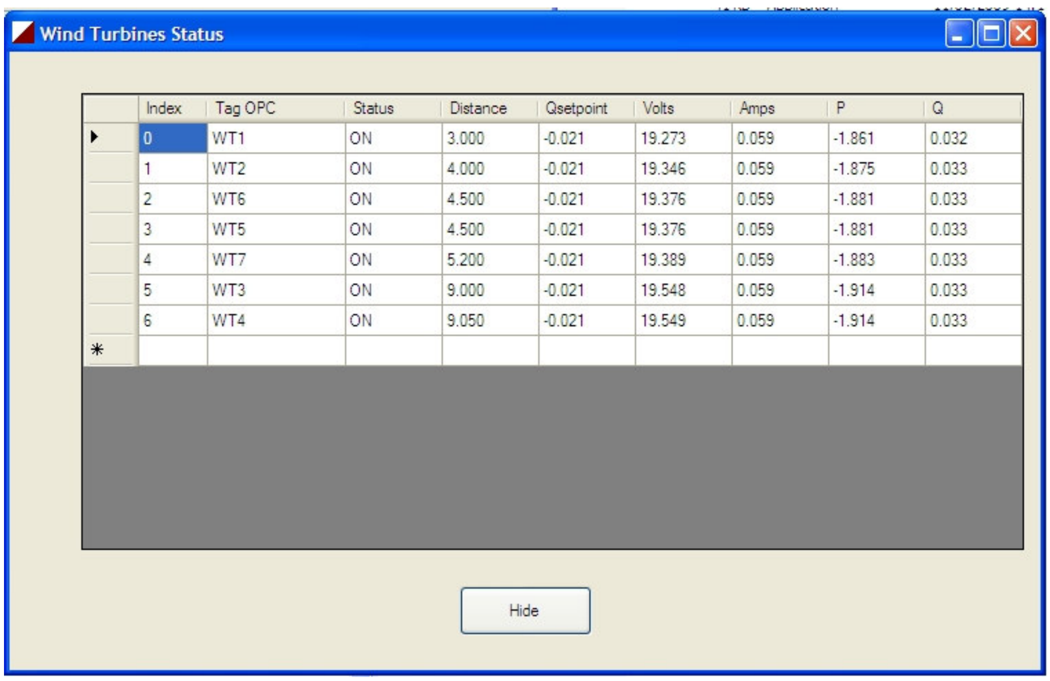

Figure 10: Status of all wind turbines in the wind farm

At this stage, we can implement and test the control under conditions that are hardly reproducible in “conventional simulation”: lost of communication, expected and unexpected delays etc. and find out cases that we would not have imagined if we would have stopped the tests at stage 1. The control designer can therefore be more confident at the time of real-life implementation and spend less time on site prior to commissioning, a period which can be long and costly because the resource is not always available when tests have to be performed.

4. Simulation results

The results obtained during a real-time simulation are presented in Figure 11, where:

- Upper left graph: Voltage at substation MV and HV sides
- Upper right graph: Voltage at terminals of the wind turbines in the wind farm
- Lower left graph: Tap position at the step-up transformer
- Lower left graph: Reactive power set-point, sent to every wind turbine in the wind farm

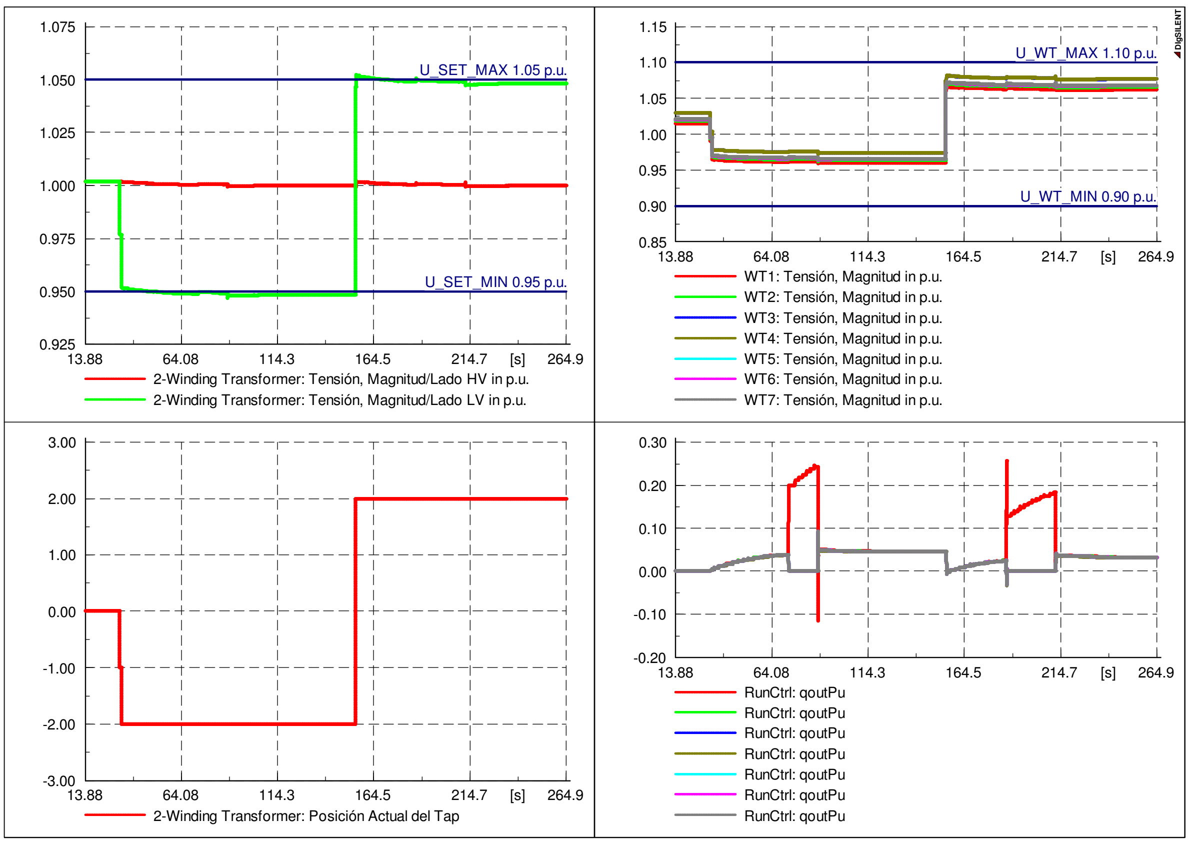

Figure 11: Results of a real-time simulation.

The following events have been tested during this simulation run:

- Time=30s: Starting the wind farm central controller in Mode 1 with voltage set-point: 0.95 p.u. at MV and 1.00 p.u. at HV.
- Time=75s: Changing central controller mode from Mode 1 to Mode 2. We can observe how the set-point is re-distributed, only wind turbine 1 generates reactive power.

- Time=100s: Back to Mode 1, all the wind turbines receive the same set-point.
- Time=155s: Modifying set-points from 0.95 p.u. to 1.05 p.u. at MV side. The tap controller changes from position -2 to 2, wind turbine set-points are changing to maintain 1 p.u. at HV-side.
- Time=185s: Central controller is changed from Mode 1 to Mode 2.
- Time=210s: Central controller is changed back to Mode 1.

5. Conclusions

In the near future, manufacturers of wind turbines and wind farm developers will face stronger requirements emitted by TSOs all over the world to facilitate the integration of a greater percentage of renewable generation into the grid, aiming to preserve the security and reliability of the system. New requirements are under study in Spain for wind and PV power plants over 10MW, due to the fast increase of installed power in the system. These requirements are under discussion and have been presented in the first part of this paper.

Simulation tools are emerging as an option to test very large installations. In this paper we have presented three different ways of testing central control systems at three different stages of its implementation using DIgSILENT's PowerFactory as the simulation platform. We have demonstrated the different methods, from a classical simulation to the pre-installation tests, using the example of a centralized voltage control of a wind farm. This example can be applied to a PV plant.

The capabilities of PowerFactory of using external dlls and communicating with OPC servers extend the possibilities of testing systems to almost full-scale tests, insuring a smoother, safer and faster commissioning on site.

6. References

[1] "Requisitos técnicos de las instalaciones eólicas, fotovoltaicas y todas aquellas instalaciones de producción cuya tecnología no emplee un generador síncrono conectado directamente a red". Draft of the appendix to the P.O.12.2 "Instalaciones conectadas a red de transporte y equipo generador: requisitos mínimos de diseño, equipamiento, funcionamiento, puesta en servicio y seguridad", October 2008.

[2] "PowerFactory manual. DIgSILENT PowerFactory Versión 14.0", November 2008.

[3] "PowerFactory OPC Guide", DIgSILENT, Version 002, October 2008.