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# Dedicated Digital System Testing and Modeling in Power Systems

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**Abstract** – This paper presents a dedicated Digital System and the experience on real testings of controllers and turbine/generators for modeling and for stability studies. These real on site testings and data are compared to simulation studies in order to easily check accuracy of the mathematical models.

**Index Terms -** Modelling, Synchronous Machine, Electrical Power Systems, Stability studies.

## 1. Introduction

Stability studies in electrical power systems are necessary in planning and operating the grid. These studies comprise starting a new power station, sudden great changes in load and generation, growing the grid, contingencies, short circuits faults, and others.

They supply information enough to the analysis, such as:

- Frequency Variations
- Transient Rotor Angle Stability
- Oscillatory Rotor Angle Stability
- Short Term Voltage Stability
- Temporary Over-Voltages
- Long Term Voltage Stability
- Power System Stability and Dynamic Performance
- Maximum Total Fault Clearance Times

To guarantee that these studies give confident results, all the parameters and models of the generating unit as well its frequency/voltage controllers must be accurately represented through validated models. Representing protection systems properly is also a must.

Real on site testings and later simulation on a computer are recommended for getting and validating parameters and mathematical models of many different equipment of the grid.

Validation of the models trough on site testings is fundamental to get necessary accuracy in the studies, due to:

- The models supplied by the manufacturers are not apropriate;
- Controllers tuning used in simulation and models are not the same implemented on site.
- Excitation System driver is usually very simple, sometimes representing a wrong topology, as for example, a brushless instead of a static bridge.
- Synchronous machine parameters intended to simulation studies are not available. The use of typical values instead, does not represent the machine behaviour properly.
- Generator saturation is not represented.

- Synchronous machine parameters can change along time of operation and after a modernization service. Parameters must then be measured from time to time. Some authors suggest confirming parameters at each five years of operation.
- Turbine modelling is too much simple.
- Classical penstock representation is very poor. In case of shared penstock this effect is not considered. Reservoir level is also not taken into account.
- Gate servomotors and actuators are poorly represented.

Results coming from simulations based on inaccurate mathematical models can be:

- Simulations indicating restraints which are not really necessary
- Simulations indicating stable operation in conflict with real practice.

## 2. Identification metodology

Technical literature describes many different on site testing aiming at the identification and representation of the components of the grid:

- Synchronous generator: Load rejection; Frequency response and sudden short circuit tests have been carried on.
- Excitation System : Step response, Frequency response, Voltage Regulator Limiters , operative limits of active and reactive power.
- Speed Governor and Hydraulic turbine : step and frequency response, load rejection, islanding simulated operation at full load and load variation.

For each component tested, a set of variables are measured and recorded. These are inputs and outputs of the real model that are later used and compared with the correspondent inputs and outpus of the simulated model. The Figure 1 shows the identification process.

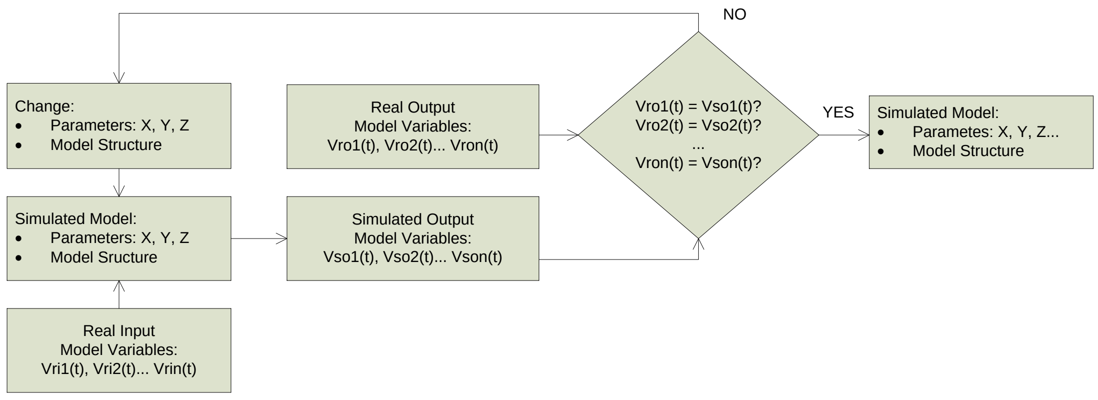



FIGURE 1 – Parameters identification process

After validation of the parameters and transfer function, the models are ready to be written in any commercial format for transient and dynamic studies such as ANATEM, DIGSILENT, PSS/E, EUROSTAG or other.

The tasks for simulating and consolidating models and parameters demand a lot of time after on site testing has been done. This task can be significantly reduced if a dedicated digital system is available on site during testing.

## 3. Dedicated Digital System Testing and Modeling in Power Systems

The equipment MAX10 is a dedicated digital system based on a PLC and a set of transducers capable of communicating with the various existing sensors and devices in a Power Plant. Figure 2 illustrates the application of MAX10.

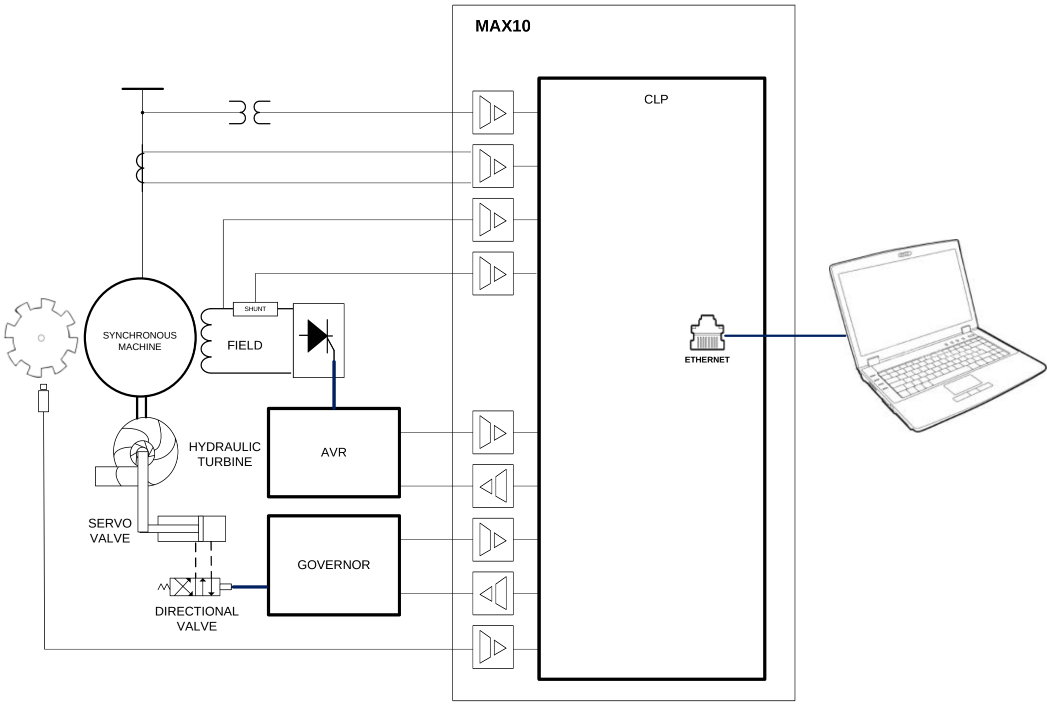



FIGURE 2 – MAX10 application

Max10 PLC is programmed through block diagram, based on Standard IEC 61131-3. The Configuration Edit System (SEC) developed by REIVAX in a Windows environment, is oriented to create a set of configured files in the embeded basic software of the PLC. The SEC tool has available a wide library that permit complex logics program creation, dedicated to tests in Electrical Power Systems.

Figure 3 presents a piece of the program for acquisition of data signal, as part of SEC tool. Figure 4 shows a screen to viewing signals.

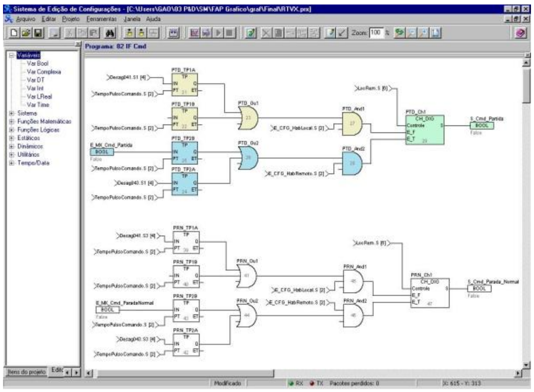


FIGURE 3 - Signal acquisition program

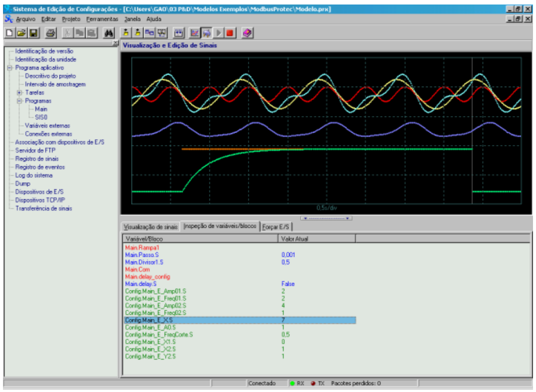


FIGURE 4 - Viewing signals screen

MAX10 system has common features and functionality to a commercial data acquisition system, shown below.

- 16 analog inuts
- 5 fast inputs
- 5 digital inputs
- 8 analog ouputs
- Algorithms for calculation of quantities (apparent power, active and reactive, power factor, positive sequence voltage, zero sequence current, and others);
- Signal conditioning by hardware and software;
- Sampling time of 0.5 ms for all inputs simultaneously;
- Check for IRIG-B signal to GPS absolute time reference;
- Real-time signal viewing.

In addition to a traditional acquisition system, the MAX10 Digital System promotes specific funcionalities for on site testing and modelling in Electrical Power Systems, shown below.

- Islanding simulated operation at full load according to IEEE Std 1207. This functionality allows the evaluation of the speed governor performance in primary frequency regulation;

- Frequency response testing of Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS) through low eletromechanical frequency oscillations, typically ranging from 0,01Hz to 3,0Hz, allowing a better analysis and criterious tuning of the AVR and PSS.
- Applying different disturbances, such as step and ramp signals to get trasfer functions of the AVR and Speed Governor.
- Applying external input signals to the AVR, like a PSS signal modelled in MAX10.
- Available algorithms dedicated to the analysis of the behaviour of synchronous generators subtransient.
- Simultaneous aquisition of signals at different sampling times for short, medium and long term disturbances.
- Multiple triggering configurations to start recordings.
- On site simulations and validation of the models under testing (just in time), reducing later work and preparation of report in the office. It also avoid errors by repeating tests if necessary.

## 4. Field tests and simulations

The system installation is usually done in an appropriate place near the generating unit. Minimum amount of cables and connections is required.

A computer must be connected to the MAX10 system via Ethernet communication for configuration of the signals to be monitored and acquired.

Figure 5 shows an example of field installation.

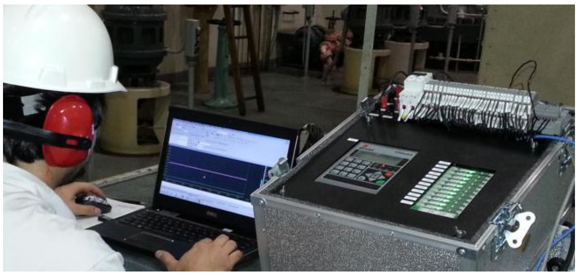
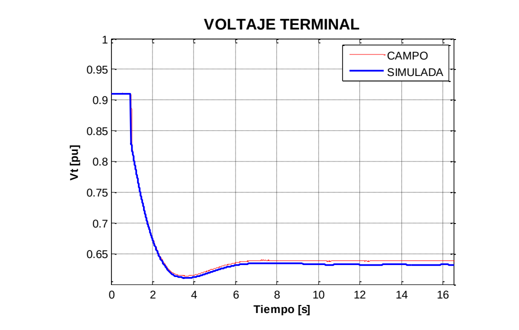


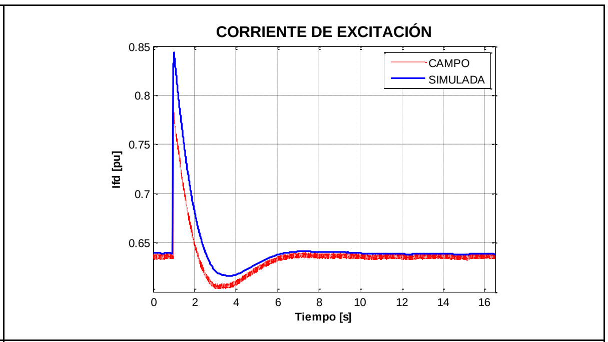
FIGURE 5 - Field installation

Examples of field tests, using the dedicated system, and validation with simulations are presented in the following topics.

### 4.1 Synchronous Generator Identification

The load rejection test has been widely applied to identify synchronous generators. Example of the realization of this type of test is shown in Figure 6, comparing the curves obtained in the field (red) with those generated by the simulation model (blue).




| Terminal Voltage | Field Current |
|---|---|

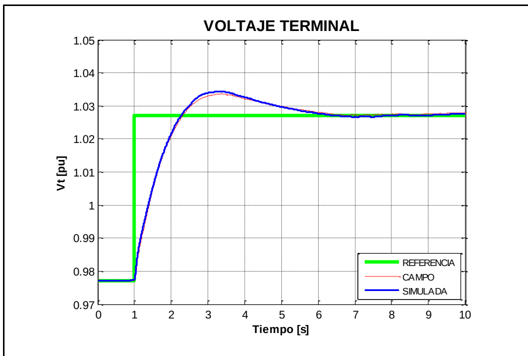
FIGURE 6 - Synchronous Generator Identification

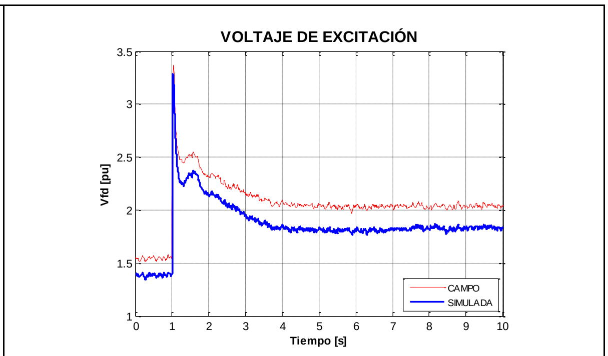
### 4.2 Excitation System Identification

The most traditional way of excitation system identification is through the step response in voltage reference. Some devices do not have this function, then the MAX10 system can be programmed to inject the signal regulator reference.

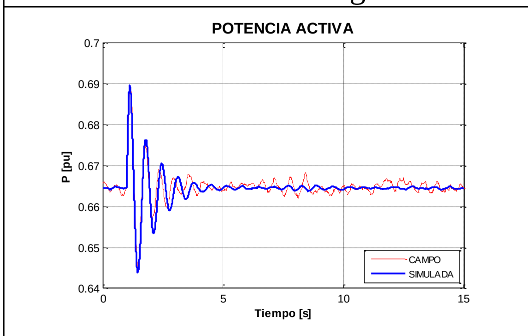
If you do not have available the block diagram of the excitation system, further testing should be carried out to identify single block.

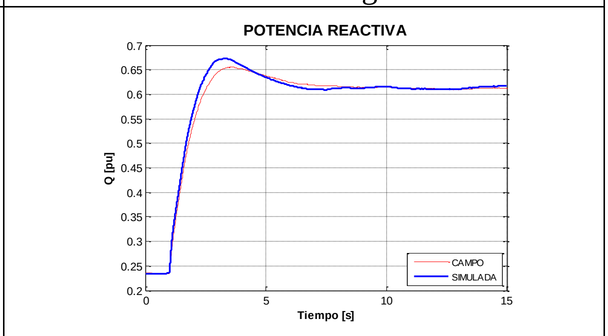
Example of the step response in the regulator voltage reference is shown in Figure 7, comparing the curves obtained by the field test (red) with those generated by the simulation model (blue).




| Terminal Voltage | Field Voltage |
|---|---|




| Active Power | Reactive Power |
|---|---|

FIGURE 7 - Excitation System Identification

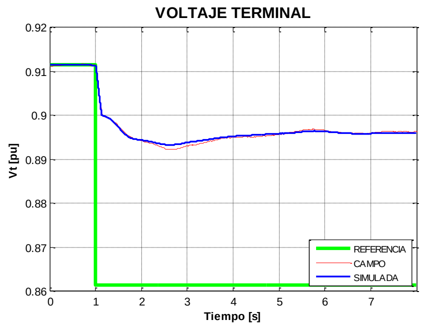
### 4.3 Identification of Excitation System Limiters

The modeling of excitation system limiters is of fundamental importance in the stability studies, as the same may exhibit unstable behavior in certain machine loading levels.

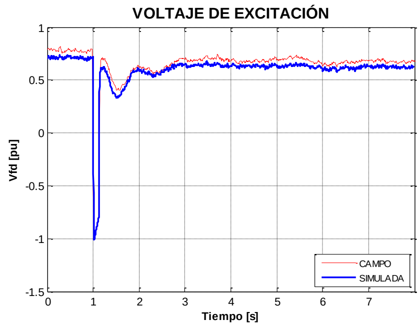
For this task, the step response in voltage regulator reference is traditionally done, with the generator operation near of the limiter adjust. In some cases, the limiter setting can be modified to avoid the action of the protection system.

Example of underexcitation limiter identification from a step response in voltage regulator reference is shown in Figure 8. The curves from field tests are shown in red and the curves generated by the simulation model are shown in blue.

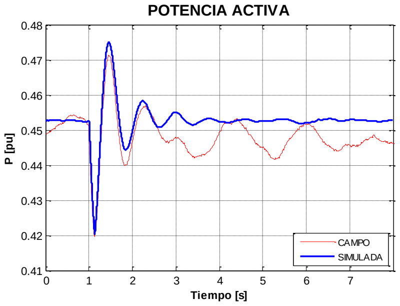
The identification of the other limiters can be performed similarly.



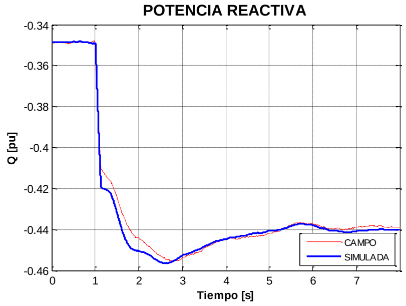

Terminal Voltage




Field Voltage




Active Power




Reactive Power

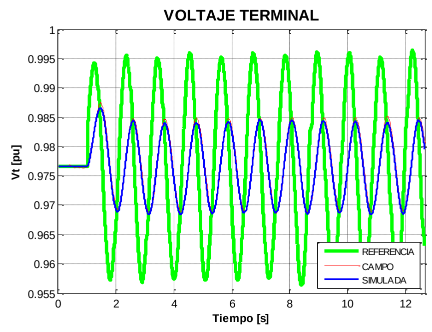
FIGURE 8 - Identification of Excitation System Limiters

### 4.4 Stabilizer Identification by Frequency Injection

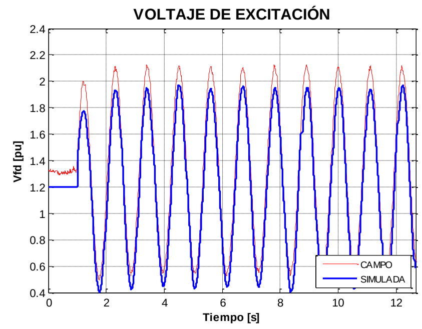
The modeling of the Power System Stabilizer can be performed from the injection signals in the frequency range of 0.01Hz to 3 Hz. Such injection may be achieved using MAX10 system.

From the responses, can be built Bode Diagrams representing the frequency range in which the stabilizer is operating properly, to damp oscillations.

Model simulations constructed for comparisons with field curves can also be carried out for each of the frequencies injected. An example is shown in Figure 9, with field curves shown in red and simulated curves in blue.




Terminal Voltage




Field Voltage

FIGURE 9 - Stabilizer Identification by Frequency Injection

### 4.5 Penstock and Speed Governor Modeling

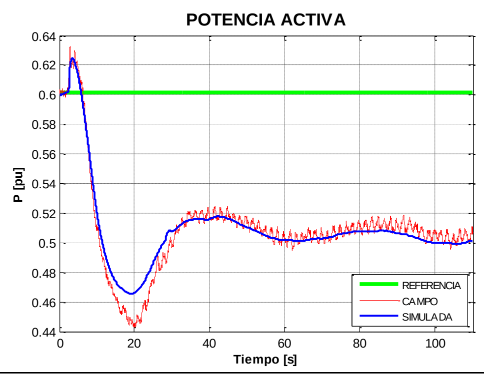
Penstock, valves and hydraulic gate servomotors as well the speed governor request some special tests to get precise identification and modeling.

They can be splitted into tests to be carried on with the generating unit running at no load or full load and the unit at stand still, sometimes named at “dead water” condition.

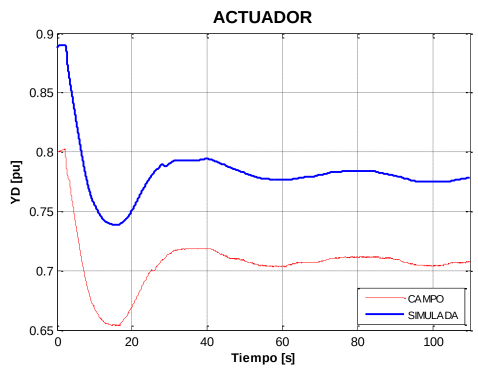
An example of a test at full load is the islanding condition simulated. The MAX10 system permits safely open the frequency loop of the speed governor, at full load, and close it trough a block simulating the turbine.

This test permits checking the performance of the Speed Governor at the worst condition of islanding operation.

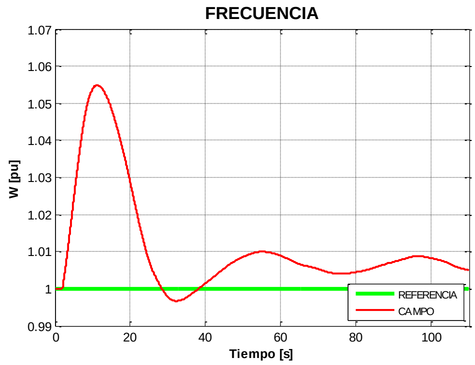
Figure 10 shows a real example of this islanding simulated operation, and compaires the real responses in red with blue corresponding simulation studies.




Active Power




Hydraulic Gate




Simulated Frecuency

FIGURA 10 - Penstock and Speed Governor Modeling

## 5. Conclusion

As there is great need for using accurate and validated modelling of all the components of the electrical power system in order to support the electromechanical transient studies, the digital system above described comes to be an efficient instrument to be used by the experts in charge of theses tasks.

Considering the tests for on site modelling, this system reduces requested man-hour due to quick and easy installation of the instrument. Existing powerful functionalities guarantee safe testing execution.

Even during site testing, it is possible to run the simulation studies almost simultaneously in order to get the identification and validation modelling in advance.

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