Dynamic characterization of wind farms and their impact in power systems oscillations

Fernando Berrutti, Álvaro Giusto Michel Artenstein, Senior Member IEEE

Abstract: This paper has two main objectives: to explain the dynamic characterization of wind farms as part of their integration in power systems using modal analysis and to present a qualitative development for understanding the main factors that impact on the damping of the oscillation modes by incorporating wind farms based on variable speed wind turbines. Moreover, such developments are validated by performing simulations on a 2017 peak scenario for the Uruguayan electrical system, showing a strong interaction between the hydroelectrics power plants located on the Río Negro and future wind farms Palmatir and Agua Leguas.

Keywords: small-signal stability, angle stability, modal analysis, variable speed wind turbines, eigenvalues, eigenvectors, power system oscillations.

I. Nomenclature

\( \delta_S \): Internal angle of Baygorria.
\( \delta_m \): Internal angle of Terra.
\( \delta_1 \): Angle of Baygorria voltage in the interconnection node.
\( \delta_2 \): Angle of Terra voltage in the interconnection node.
CN: Negative load.
D: Damping constant.
DFIG: Doubly-fed induction generator.
FC: Full-load converter.
M: Inertia constant.
U: Line-to-line voltage magnitude in the interconnection node (Terra and Baygorria).
\( U_{\infty} \): Line-to-line voltage magnitude in the infinite bus.
Es: Internal voltage magnitude in Baygorria.
Em: Internal voltage magnitude in Terra.
Xs: Internal reactance, Baygorria.
Xm: Internal reactance, Terra.

II. Introduction

Electromechanical oscillations in power systems are the result of the parallel operation of synchronous machines. There exist different patterns of exchange of kinetic energy manifested through the oscillation of electric power flows in transmission lines that interconnect the machines. These oscillation patterns are strongly dependent on the characteristics of the synchronous machines, the network topology under study and the power flow for a particular scenario. To ensure reliable operation of power systems, modes of oscillation must present an acceptable damping, so that those oscillations die out quickly when small perturbations affect the power system. Also, it is necessary to ensure that there are no modes with negative damping, which would cause unstable oscillations that would involve the trip of the machines concerned by the protection system in order to maintain stable operation of the power system.

The classic definition of angle stability in power systems is conceived as the ability of the system to maintain synchronism when the system is subjected to a disturbance. This definition has to be adapted because of the incorporation of variable speed wind turbines. The variable speed wind turbines have the particularity of decoupling the rotation speed of the electric generators respect the frequency of the electrical network to which they are interconnected, through the inclusion of electronic converters that maximize power extraction process. This implies that the wind turbines will behave much as static sources of production of active and reactive power. Unlike synchronous generators, wind turbines are not linked to the grid through an internal angle, and therefore, no kinetic energy is exchanged with synchronous generators that originally forms part of the power systems.

Due to the asynchronous nature of the interconnection of these new machines, power systems will suffer changes in oscillatory dynamics, due mainly to the following reasons: changes in the architecture of transmission system to incorporate wind farms; replacement of part of the expansion of synchronous generators by wind farms; alteration in the dispatch of synchronous generators in order to incorporate the strongly

This work was partially supported by grant ANII/PR_FSE_2009_03 “Estudios dinámicos del sistema eléctrico uruguayo con creciente penetración de energía eólica y generación renovable”.

Fernando Berrutti is with the Instituto de Ingeniería Eléctrica, Facultad de Ingeniería, Universidad de la República, Uruguay (e-mail: berrutti@fing.edu.uy).
Álvaro Giusto is with the Instituto de Ingeniería Eléctrica, Facultad de Ingeniería, Universidad de la República, Uruguay (e-mail: alvaro@fing.edu.uy).
Michel Artenstein is with the Instituto de Ingeniería Eléctrica, Facultad de Ingeniería, Universidad de la República, Uruguay (e-mail: michel@fing.edu.uy).
varying wind power which depends on weather conditions; and
the reduction of the power system inertia due to the injection
of large amounts of power from wind turbines. All these
distortions will result in an alteration of the synchronizing and
damping torques of synchronous generators that may be
beneficial or detrimental to the damping of the oscillatory
modes depending on the particular operating conditions, and
the relative location between conventional plants, demand
centers and wind farms.

Because of this complex relationship that determines the
operating conditions, it is very difficult to agree general
statements on the consequences of the large scale inclusion of
variable speed wind generation on power system dynamic
behavior. This reaches the small signal stability and the
transient behavior.

III. OBJECTIVES

The first aim of this paper is to analyze how the small signal
stability of power systems will be affected with the inclusion
of wind farms based on DFIG and FC technologies without
changing the power dispatch of the synchronous generators in
a hypothetical scenario of the Uruguayan power grid. The
results of modal analysis are compared with a simplified model
which assumes that wind farms act as a constant negative load.

The second objective is to show that the main effect that
determines the evolution of oscillatory modes of the power
grid due to the inclusion of wind power generation lies in the
alteration of the operating points of the involved synchronous
generators and the nature of the oscillatory modes affected.
The analysis is conducted by simulating a real scenario where
wind farms Palmatir/Agua Leguas and the hydroelectric plant
Terra form an area, and hydroelectric power plant
Baygorria conforms another.

Additionally, knowing the causes that determine the evolution
of the damping of the oscillation modes due to the
incorporation of wind power, it is analyzed and simulated the
effect of reactive power redispatch of wind farms in order to
clearly induce favorable changes on synchronizing and
damping torques on the oscillatory modes related to Baygorria
and Terra. This redispatch will improve substantially the
performance of small signal response and the oscillatory
behaviour when large disturbances occur, such as three phase
shortcircuits in the vicinity of the hydroelectric power plants.

IV. DYNAMIC CHARACTERIZATION OF WIND FARMS

A. Modal analysis

Table 1 shows the evolution of the dominant oscillatory modes of
the Uruguayan power system with and without the inclusion
of wind energy considering the three models of wind turbines: FC, DFIG, CN.

<table>
<thead>
<tr>
<th>MODO</th>
<th>FRECUENCIA (Hz)</th>
<th>AMORTIGUAMIENTO (Q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPM</td>
<td>1.45 1.45 1.45 1.45</td>
<td>4.15 4.13 4.12 4.12</td>
</tr>
<tr>
<td>PTI 1</td>
<td>3.08 3.06 3.05 3.05</td>
<td>6.68 6.44 6.43 6.43</td>
</tr>
<tr>
<td>PTI 2</td>
<td>3.23 3.20 3.20 3.20</td>
<td>6.74 6.59 6.58 6.58</td>
</tr>
<tr>
<td>TERRA 1</td>
<td>1.40 1.37 1.37 1.37</td>
<td>7.29 7.42 7.43 7.43</td>
</tr>
<tr>
<td>TERRA 2</td>
<td>1.40 1.37 1.37 1.37</td>
<td>7.29 7.42 7.43 7.43</td>
</tr>
<tr>
<td>TERRA 3</td>
<td>1.40 1.37 1.37 1.37</td>
<td>7.29 7.42 7.43 7.43</td>
</tr>
<tr>
<td>RN</td>
<td>1.20 1.19 1.19 1.19</td>
<td>8.01 7.64 7.48 7.48</td>
</tr>
<tr>
<td>IMPSA</td>
<td>x x 1.94 x</td>
<td>x x 7.78 x</td>
</tr>
<tr>
<td>PALMATIR</td>
<td>x x 1.94 x</td>
<td>x x 7.79 x</td>
</tr>
<tr>
<td>FINGANO</td>
<td>x x 1.94 x</td>
<td>x x 7.80 x</td>
</tr>
<tr>
<td>BY-T</td>
<td>1.30 1.29 1.29 1.29</td>
<td>8.69 9.18 9.23 9.25</td>
</tr>
<tr>
<td>PTI 3</td>
<td>1.30 1.29 1.29 1.29</td>
<td>9.32 9.17 9.17 9.17</td>
</tr>
<tr>
<td>PALMAR</td>
<td>1.51 1.48 1.48 1.48</td>
<td>8.43 9.51 9.52 9.53</td>
</tr>
</tbody>
</table>

The oscillatory behaviour is almost identical regardless of the
wind farm model, which is an indication that wind farms
effectively decouple the rotational speed of the machines from
grid frequency and behave essentially like static power
sources. In this analysis, the wind farms are not exchanging
reactive power with the grid.

To be more decisive in this conclusion it is examined the
participation factors (tables 2 and 3) and mode shapes for RN
and BY-T oscillatory modes (figures 2 and 3), that are almost
identical for the three models of wind farm examined. In
particular, small variations that exist in the damping calculated
for the NL model compared to models of DFIG and FC modes
are observed for RN and BY-T modes. Since the power flow
scenario is identical in all cases, the reason attributed to the
differences showed lies in the different control loops in the FC
and DFIG models and the nonexistence of such a loop in the
NL model. Additionally, it is observed the occurrence of torsional modes in the case of DFIG wind turbine generators which do not interfere with the electromechanical oscillation modes.

From these studies, it is concluded that wind farms behave as static sources of active power or negative loads, and the impact of control loops on electromechanical modes are negligible. Furthermore, variations of the oscillation modes are mainly influenced by the setting of new operating points of synchronous generators due to redistribution of the power flow through the system.

### Table 2: RN oscillatory mode: participation factors

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>ESCENARIO</th>
<th>BASE</th>
<th>CN</th>
<th>DFIG</th>
<th>FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>98551 : BAYG $\omega_1$</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>98552 : BAYG $\omega_2$</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>98553 : BAYG $\omega_3$</td>
<td>0.78</td>
<td>0.80</td>
<td>0.80</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>98177 : PTIG $\omega_7$</td>
<td>0.63</td>
<td>0.90</td>
<td>0.90</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>98178 : PTIG $\omega_8$</td>
<td>0.63</td>
<td>0.90</td>
<td>0.90</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>98541 : TERRA $\omega_1$</td>
<td>0.43</td>
<td>0.64</td>
<td>0.67</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>98542 : TERRA $\omega_2$</td>
<td>0.43</td>
<td>0.64</td>
<td>0.67</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>98543 : TERRA $\omega_3$</td>
<td>0.43</td>
<td>0.64</td>
<td>0.67</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>98544 : TERRA $\omega_4$</td>
<td>0.43</td>
<td>0.64</td>
<td>0.67</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>Amortiguamiento (%)</td>
<td>8.01</td>
<td>7.64</td>
<td>7.48</td>
<td>7.48</td>
<td>7.64</td>
</tr>
<tr>
<td>Frecuencia (Hz)</td>
<td>1.20</td>
<td>1.19</td>
<td>1.19</td>
<td>1.19</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2: RN mode shape: base scenario (blue); NL, DFIG, FC scenarios (red)**

### B. Reactive power exchange

In case that wind farms inject or absorb reactive power from the grid, it can be reached the same conclusions: the main factor influencing the damping and frequency of the oscillation modes is due to the new operation points of synchronous generators. Further details on the analysis are provided in [2].

The differences in damping and synchronizing torques observed when wind farms inject or absorb reactive power will be analyzed for the particular case of the inclusion of wind farms Palmatir/Agua Leguas that will affect Terra-Baygorria.

### C. Increased power injected by wind farms

This section examines the increasing power injection of Palmatir wind farm on the behaviour of RN mode and BY-T oscillatory modes. For this purpose, the power dispatched by the wind farm varies from 50MW to 150MW and the power factor varies between 0.95 inductive, 1 and 0.95 capacitive.

From Figures 4 and 5 it can be concluded that increasing active power injection from the wind farm, the RN mode damping tends to decrease, and BY-T mode damping tends to increase. Moreover, the reactive power consumption by the wind farm tends to improve the damping of RN mode for a given active power injection, while the damping BY-T mode is decremented. The opposite is also true. Injection of reactive power from the wind farm decreases the damping buffer RN and increases the damping of BY-T.

### Table 3: BY-T oscillatory mode: participation factors

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>ESCENARIO</th>
<th>BASE</th>
<th>CN</th>
<th>DFIG</th>
<th>FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>98551 : BAYG $\omega_1$</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>98552 : BAYG $\omega_2$</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>98553 : BAYG $\omega_3$</td>
<td>0.69</td>
<td>0.58</td>
<td>0.57</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>98541 : TERRA $\omega_1$</td>
<td>0.82</td>
<td>0.57</td>
<td>0.55</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>98542 : TERRA $\omega_2$</td>
<td>0.82</td>
<td>0.57</td>
<td>0.55</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>98543 : TERRA $\omega_3$</td>
<td>0.82</td>
<td>0.57</td>
<td>0.55</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>98544 : TERRA $\omega_4$</td>
<td>0.82</td>
<td>0.57</td>
<td>0.55</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>Frecuencia (Hz)</td>
<td>1.30</td>
<td>1.29</td>
<td>1.29</td>
<td>1.29</td>
<td>1.29</td>
</tr>
</tbody>
</table>

**Figure 3: BY-T mode shape: base scenario (blue); NL, DFIG, FC scenarios (red)**
The exception to this is observed in the last point of active power (150MW) of Figure 3 due to a change in the pattern of oscillation caused by an increase of the participation factor of Punta del Tigre. More details are provided in [2].

V. GRAPHICAL ANALYSIS OF THE IMPACT OF WIND FARMS ON COMMON MODES (RN)

The impact of wind farm power injection on RN oscillatory mode can be explained with the aid of Figure 6, where a phasor diagram of Terra power plant is plotted, with (blue) and without (black) the inclusion of wind farms. It is supposed that Terra active power output remains constant:

1. The voltage at the busbar in Terra, must remain constant, regardless the amount of wind power injection. This is manifested through the increasing of internal angle of the generators of Terra. This will decrease the damping torque and synchronizing torque simultaneously, as it can be seen in Figure 4.

2. Additionally, a decrease of the reactive power output from Terra will be observed, as long as less reactive power is needed to maintain the busbar voltage in its nominal value. This situation will also induce the increasing of the internal angle, decreasing damping and synchronizing torques.

3. In accordance with the previous statement, if reactive power is injected by Terra due to reactive power consumption in Palmatir, the internal angle will decrease improving the synchronizing and damping torque.

4. The opposite is also true, it can be observed that reactive power production in Palmatir will induce reactive power absorption in Terra increasing its internal angle, and decreasing the damping and synchronizing torques.

From these statements and the modal analysis performed, it can be concluded that when wind farms are located close to synchronous generators, they will tend to deteriorate the damping of common modes and the synchronizing torque, as long as the active power injected by them is increased. Also, to mitigate this undesirable effect it is suggested that the wind farm absorbs reactive power, inducing an increase in damping and synchronizing torques.

VI. MATHEMATICAL ANALYSIS OF THE IMPACT OF WIND FARMS ON COMMON MODES (RN) AND INTERAREA MODES (BY-T)

To provide a mathematical explanation of the damping of common and interarea oscillatory modes, it will be used the simplified system represented in figure 1 in which the inertia and the damping of both machines are supposed to be the same. The swing equations of the synchronous generators are linearized in an operating point:

\[
M \ddot{\delta}_s + D \dot{\delta}_s = -k_{s1} \delta_1 - k_i (\dot{\delta}_1 - \dot{\delta}_2) = -k_1 (\delta_s - \delta_1)
\]

\[
M \ddot{\delta}_m + D \dot{\delta}_m = -k_{s2} \delta_2 - k_i (\dot{\delta}_2 - \dot{\delta}_1) = -k_2 (\delta_m - \delta_2)
\]

(1)

Where:
To make simpler the analysis it will be supposed that:

\[ \begin{align*}
  k &= k_1 \approx k_2 \\
  k_s &= k_{s1} \approx k_{s2}
\end{align*} \tag{3} \]

Furthermore, it is assumed that the term \( k_i \) is relatively small compared to \( k \) and \( k_s \) to represent the situation of a weak tie that interconnect two generation areas. This will allow to express the swing equations in a simple form:

\[ \begin{align*}
  M \ddot{\delta}_s + D \dot{\delta}_s + \frac{k}{k_s + k} \delta_s - k_i \left( \frac{k}{k_s + k} \right)^2 \delta_m &= 0 \\
  M \ddot{\delta}_m + D \dot{\delta}_m + \frac{k}{k_s + k} \delta_m - k_i \left( \frac{k}{k_s + k} \right)^2 \delta_s &= 0
\] \tag{4} \]

This system can be expressed in a decoupled form if the following change of variables is made:

\[ \begin{align*}
  \theta_1 &= \delta_s - \delta_m \\
  \theta_2 &= \delta_s + \delta_m
\] \tag{5} \]

\[ \begin{align*}
  M \ddot{\theta}_1 + D \dot{\theta}_1 + \frac{k}{k_s + k} (k_s + k) + k^2 k_i \theta_1 &= 0 \\
  M \ddot{\theta}_2 + D \dot{\theta}_2 + \frac{k}{k_s + k} (k_s + k) - k^2 k_i \theta_2 &= 0
\] \tag{6} \]

In this case, the modal variable \( \theta_1 \), represents the response of the interarea mode (BY-T) and \( \theta_2 \) represents the response of the common mode (RN). The following analysis will take into account equations 4 and 6. These equations will provide the necessary information to explain the behaviour of the mode dampings analyzed in figures 4 and 5.

### A. Impact of wind farms on interarea modes (BY-T)

As was stated, the active power injection will increase the angles of the system. In that case, \( k \) and \( k_s \) will suffer a reduction that will decrement the power exchange between the synchronous generators. This effect will improve the damping of interarea oscillation modes, particularly the damping of BY-T in this case. Furthermore, the incidence of reactive power exchange between wind farms and synchronous generators on interarea damping can be analyzed in equation 3. Given an active power output, if the wind farm begins to absorb reactive power, this reactive power must be generated by Terra to preserve the voltage in its busbar. This will induce an increment on \( k \), which benefits the exchange of kinetic energy between the synchronous generators and consequently, the damping of interarea mode (BY-T) decreases. If the wind farm injects reactive power, the opposite effect takes place, the exchange of kinetic energy decreases and the mode damping increases.

### B. Impact of wind farms on common modes (RN)

When a wind farm injects active power, the modal variable \( \theta_2 \), will exhibit an important decrement on its synchronizing torque due to the marked reduction of the term \(-k^2 k_i\). This will lead an increment in the internal angle of the equivalent synchronous generator of power plants Terra and Baygorria. If the wind farm absorbs reactive power, the term \( k^2 \) increases due to the production of reactive power in Terra, and consequently, the internal angle will decrease, providing a better performance in damping and synchronizing torques. If the wind farm injects reactive power, the opposite situation is valid, the mode damping and synchronizing torque will decrease.

### C. Impact of wind farms on mode damping

From the previous sections, it is clear that the wind farms will deteriorate the common mode damping (and synchronizing torque) and benefit the interarea mode damping. From the physical reasons discussed, it is not possible to improve the damping of both oscillatory modes at the same time. Anyway, it should be noted that in power systems, the common mode is dominant in the transient response due to the initial conditions prior to any type of disturbance, hence, to improve the oscillatory behaviour of the power system, it is suggested to impose the reactive power consumption of the wind park, to improve the common mode damping and synchronizing torque. This is conditioned by the damping of the interarea mode, and the capability curve of the synchronous and wind generators.

### VII. Transient and Modal Analysis

In order to validate the analysis performed, it was evaluated the system response when subjected to a three phase shortcircuit self cleared in 100ms in the line Terra-Young. Figures 7 and 8, shows of the internal angle of Terra and Baygorria for different scenarios:

- **Scenario 1**: Base case, without wind power.
- **Scenario 2**: Identical to scenario 1, but with wind power injecting nominal active power and without exchanging reactive power with the grid.
- **Scenario 3**: Identical to scenario 2, but with wind farm absorbing reactive power (power factor 0.95).
- **Scenario 4**: Identical to scenario 2, but with wind farm injecting reactive power (power factor 0.95).

Also, it was performed the modal analysis for the scenarios described. The evolution of the damping of the modes RN and BY-T are showed in table 4.

<table>
<thead>
<tr>
<th>Mode/Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN</td>
<td>8.01%</td>
<td>7.64%</td>
<td>7.95%</td>
<td>7.37%</td>
</tr>
<tr>
<td>BY-T</td>
<td>8.69%</td>
<td>9.18%</td>
<td>8.63%</td>
<td>9.68%</td>
</tr>
</tbody>
</table>

Table 4: Damping evolution of modes RN and BY-T

Both analyses show that RN mode damping decreases when wind power is included and BY-T damping increases. In scenario 3, it is shown an improvement in the oscillatory behaviour of RN, while the damping worsens in scenario 4, if it is compared with scenario 2. The opposite is true when BY-T oscillation mode is considered.

VIII. CONCLUSIONS

1. The impact of wind generation is highly dependent on the relative location between synchronous generators, wind farms and major load centers. When wind farms are electrically interconnected at points near synchronous generators tend to degrade the damping torque and synchronizing torque that characterize the local oscillatory modes. Moreover, if the wind farms are placed away from the synchronous machines, feeding local loads, they will tend to decrease the power transfer of synchronous generators, improving the damping and synchronizing torque.

2. If wind farms are installed in the vicinity of power plants, as in the case of Baygorria and Terra, the damping of the common mode, in which both plants are oscillating in phase with the rest of the power system, is degraded when power injection of the wind farm rises. Moreover, the damping of the interarea oscillation mode, which reflects the oscillation of each plant to the other, is increased.

3. In cases such as those described in the previous paragraph, this pattern is consistent: the incorporation of wind power tends to degrade the damping of the common modes and to enhance the damping of the interarea modes.

4. Due to the nature of the control system implemented in wind farms is not possible to simultaneously improve the two modes of oscillation, unless structural changes are made, including a power system stabilizer, for example.

5. Since the common modes are dominant in the dynamic response of power systems after severe disturbances, the degradation of them can be mitigated or even improved through the imposition of operating restrictions on wind farms. Particularly, reactive power consumption of certain wind farms will induce increased synchronizing torque in synchronous generators located close to them. In return, the reactive power exchange will be limited by the degradation of the interarea mode damping; therefore, it must be find a compromise to improve the performance of synchronous generators oscillations against severe disturbances without compromising the interarea mode damping.
IX. REFERENCES


X. BIOGRAPHIES

Fernando Berrutti was born in Montevideo (Uruguay) in 1980. He graduated in Electrical Engineering (2006) and obtained the M.Sc. degree (2012) from the Universidad de la República. He is with the Instituto de Ingeniería Eléctrica and the public Uruguayan utility (UTE) since 2007. He worked as designer of high-voltage facilities at the Special Projects Department until 2012. He is now at the Dynamic Studies Department in the Uruguayan Transmission System Operator (Despacho Nacional de Cargas).

Alvaro Giusto was born in Montevideo (Uruguay) in 1965. He graduated in Electrical Engineering (1992) and obtained the Ph.D. Degree (2010) from the Universidad de la República, Montevideo (Uruguay) and his M.Sc. degree from the Universidade Federal de Santa Catarina, Florianópolis (Brazil). He is with the Instituto de Ingeniería Eléctrica, Facultad de Ingeniería, Universidad de la República since 1990. He has been working as independent consultant in automation and control since 1998. His research interests are power system stability, control theory and control applications.

Michel Artenstein (M’1989, SM’2004) was born in Montevideo (Uruguay) in 1955. He graduated in Mechanical Engineering (1979) and Mathematics (1989) from the Universidad de la República, Montevideo (Uruguay) and obtained a Msc. Degree in Mathematical Engineering (2010) from the same University. He is with UTE (the national power utility of Uruguay) since 1980, where he is currently manager of the Transmission Studies and Projects Department. He is also a part-time professor at the Universidad de la República. His main fields of interests are power system stability, electromagnetic transients and design of high voltage installations.