Wide-Area Monitoring Protection and Control Supported Operation and Planning in the Ecuadorian Power System

Improving Security and Reliability

Cepeda, Jaime C.; Echeverria, Diego E.; Chamba, Marlon S.; Kamwa, Innocent; Rueda-Torres, J. L.

DOI
10.1109/MPE.2024.3435811

Publication date
2025

Document Version
Final published version

Published in
IEEE Power and Energy Magazine

Citation (APA)
Cepeda, J. C., Echeverria, D. E., Chamba, M. S., Kamwa, I., & Rueda-Torres, J. L. (2025). Wide-Area Monitoring Protection and Control Supported Operation and Planning in the Ecuadorian Power System: Improving Security and Reliability. *IEEE Power and Energy Magazine*, *23*(1), 59-68. https://doi.org/10.1109/MPE.2024.3435811

Wide-Area Monitoring Protection and Control Supported Operation and Planning in the Ecuadorian Power System

Improving Security and Reliability

©SHUTTERSTOCK.COM/MILLENIUS

THE CONTINUOUS OPERATION AND planning of electric power systems undergoes several technical and economic changes associated with environmental and societal goals toward clean, affordable, and resilient sustainable energy supply and deployment. This entails diverse upgrades, which include, for instance, integration with other energy sectors and massive addition of renewable power generation, responsive demand, and different types of storage. The dynamic properties and strength of power systems are evolving toward unprecedented levels with lowered sources for the effective management of active and reactive power balancing in different time scales. Thus, the overall security and reliability performance can be seriously compromised as unexpected disturbances may eventually cause violations to the security limits that are established for the electric power system; this

By ***Jaime C. Cepeda***, ***Diego E. Echeverría***, ***Marlon S. Chamba***, ***Innocent Kamwa***, and ***J. L. Rueda-Torres***

Digital Object Identifier 10.1109/MPE.2024.3435811
Date of current version: 3 January 2025

may lead to the outage of important system elements and even partial or total blackouts.

Real-time monitoring of the static and dynamic security of the power system plays a fundamental role inside the applications used in control centers. The main purpose of real-time monitoring is to present an early warning to system operators so they can execute adequate control actions and, therefore, mitigate potentially harmful stress conditions in the system. In this context, in addition to the supervisory control and data acquisition and energy management system functionalities, it is necessary to include complementary technological solutions to evaluate and improve the security of the power system in real time, such as phasor measurement units (PMUs) as part of wide-area monitoring systems (WAMSs).

This article summarizes several experiences of Operador Nacional de Electricidad CENACE concerning the implementation of WAMSs and the different applications that have been developed thus far to safeguard secure power system operations. In addition, it also presents the results of academic research developed at Escuela Politecnica Nacional EPN, in collaboration with CENACE.

The Ecuadorian National Interconnected System

The Ecuadorian national interconnected system (Sistema Nacional Interconectado [SNI]) is a relatively small-size power system. Until 2003, it did not have interconnected operation with neighboring power systems. Currently, the Ecuadorian SNI has a synchronous interconnection, enabling power transfers up to 200 MW with the Colombian power system.

The SNI's installed generation capacity is 8,864.37 MW. Public companies produce 85% of the energy, and access to electricity reaches more than 97% of population. In 2022, the energy production was 28,863.00 GWh, of which 24,624.40 GWh (85.31%) was produced by hydroelectric power plants. The historical maximum total demand was registered in 2022 and was 4,528.67 MW.

The predominance of hydrogeneration in the SNI satisfies the current technical, economic, social, and environmental targets of the country. Nevertheless, due to the weakly meshed transmission network and limited controllable assets, the system may occasionally be exposed to some forms of stability phenomena, e.g., poorly damped nonstationary low-frequency oscillations.

Due to the SNI's particular dynamic properties, other issues have also been experienced in the interconnected operation Ecuador–Colombia. This includes, for example, temporary large congestion in transmission power lines and partial voltage collapses due to single contingencies.

The Ecuadorian SNI consists of a 230-kV trunk transmission ring, which circles the major generation centers and connection points of regional distribution systems; a 500-kV transmission corridor that connects the largest hydroelectric power plant Coca Codo Sinclair (CCS) with a capacity of 1,500 MW with the main load centers, Quito and Guayaquil; and several 138-kV transmission lines, most of them radially connected to the 230-kV transmission system.

The Ecuadorian WAMS

Motivated by the stability issues described in the section "The Ecuadorian National Interconnected System," a WAMS has been implemented since 2010, with the aim of allowing real-time monitoring, supervision, and control of the Ecuadorian system by deploying synchrophasor measurements. This initiative was based on the feasibility of synchronized phasor measurement technology for monitoring highly stressed operating conditions in real time that might eventually cause problems of small-disturbance angle or voltage stability, as well as oscillatory stability risks.

CENACE has concluded the installation of 68 PMUs in strategic buses of the SNI, along with a complex optical fiber communication infrastructure and a sophisticated phasor data concentrator (PDC), administered by the WAMS software. This WAMS manages the PMU data via the intranet communication network, and it connects to the PMUs using the IEEE C37.118 communication protocol.

This platform constitutes the CENACE's WAMS, and it has become the most important infrastructure to monitor and control critical dynamic phenomena, as well as to perform planning and postoperative analysis. Therefore, several important applications have been developed to improve the operations of the SNI, which are presented in Figure 1. From these applications, it is important to highlight the proper sequential order for achieving them. After implementing the WAMS, the data that are recorded and stored by WAMS are first analyzed by postoperative processes to learn about the phenomena existing in the power system and identify vulnerability patterns. Afterward, these analyses allow defining proper planning strategies to improve the power system behavior. Finally, the discovered knowledge gives the operators enough information to structure adequate early warning and situational awareness strategies that allow them to respond in real time.

Ecuadorian WAMS Planning Applications

PMU Placement

The necessity of monitoring different areas and elements that are considered to have a relatively high operative relevance to perform a precise and reliable evaluation of the system's performance has been defined in a procedure for deciding the further PMU locations. In general terms, the main objectives for installing PMUs in the SNI, which have been defined in the CENACE's procedure, and also the Regulation Agencia de Regulacion y Control de Electricidad 003/16, are as follows:

- ✔ supervising the real-time dynamic operation of the SNI to allow the operators to take preventive actions while facing instability risks (early warning)
- ✔ having (numerically) trustworthy information and computational tools to perform stability analysis and determine the presence of poorly damped oscillation modes

- ✔ performing postmortem analyses to evaluate the system's behavior and then improve the procedures to restore the energy supply after fault events
- ✔ tuning of power plant controllers and validation of dynamic models
- ✔ monitoring the most congested transmission corridors via small-disturbance angle stability and voltage stability assessment tools.

For this aim, a practical procedure for PMU placement has been developed at CENACE based on a combination of both theoretical concepts and specific monitoring purposes. In this connection, a periodic study is carried out in order to determine 1) the most critical areas (using the concept of small-disturbance stability); 2) the most congested transmission corridors (based on the Thevenin equivalent method for voltage stability); 3) the presence of poorly damped oscillations (via indices of dynamic observability); and also, 4) focusing on classical static observability through the solution of the optimization problem or defining specific necessities such as the tuning of generators' controllers (in this case, the PMUs must be installed at the generator terminal).

Parametrization of WAMS Applications

Once each PMU is located, the measured data are delivered to the control center where the WAMS allows for their management and further power system analysis. Inside the WAMS server, data analysis and real-time assessment of system security, including the evaluation of small-disturbance stability and oscillatory stability phenomena, are carried out. The main applications available in CENACE's WAMS are small-disturbance angle stability (phase angle difference), voltage stability of transmission corridors, oscillatory stability, islanding detection, harmonic distortion analysis, historic data, and system event analysis, among others. WAMS' applications enable early-warning alerts when prespecified thresholds are exceeded; however, these limits must be configured by the user. Therefore, it is necessary to specify an adequate reference framework to allow the monitoring of specific power system thresholds related to the available supervisory applications. In this connection, three methodologies for determining adequate thresholds regarding 1) phase angle difference, 2) voltage profile power transfer of transmission corridors, and 3) oscillatory issues were proposed by CENACE. These limits are the referential framework for assessing stability in real time and constitute indicators that give the operators real-time early-warning signals in case of possible risk of system stress conditions. Interested readers can find additional information in the suggested literature.

Model Parameter Identification

Since simulations must accurately represent the actual power system dynamic behavior, detailed system modeling is a basic requirement. Thus, the power system model must be dependable enough, which is only possible via the application of a robust enough model validation methodology. Due to the complex nature of power system dynamics, the optimization problem of dynamic model parameter identification is a discontinuous multimodal and nonconvex landscape that could not be successfully handled by several of the existing heuristic optimization algorithms; this is because their searching performance is sensitive to appropriate parameter settings, which entails a high risk of premature convergence and local stagnation. To overcome these drawbacks, a general time domain parameter identification technique based on the heuristic optimizer mean-variance mapping optimization (MVMO) has been proposed and applied in the SNI. This method uses field test signal records as reference signals and, based on the solution of an optimization problem, ensures the accurate estimation of parameters belonging to dynamic components. The proposed parameter identification method begins with the definition of the dynamic

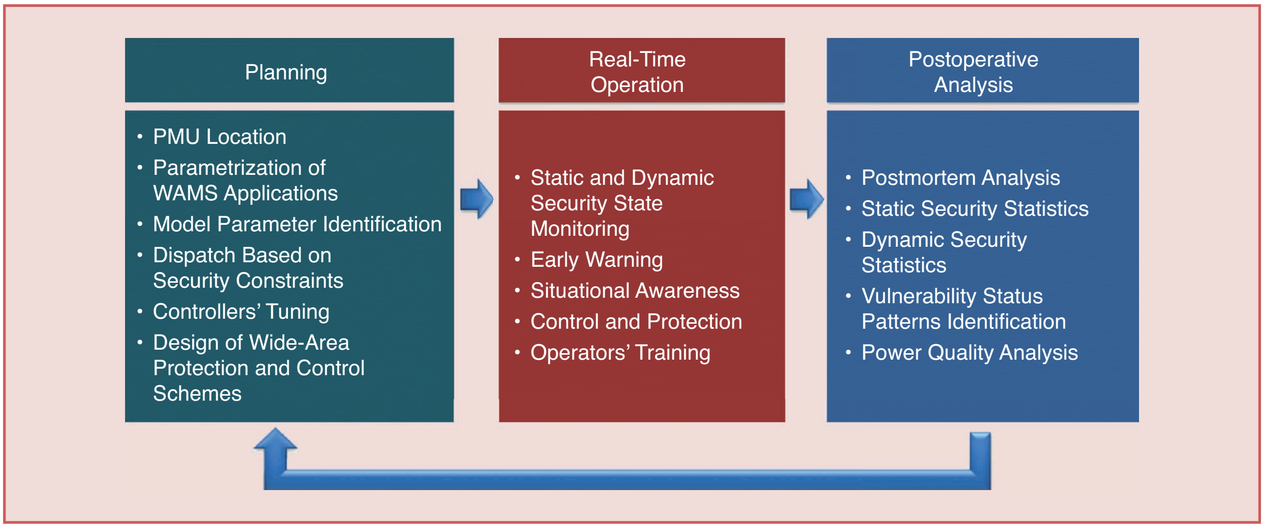

figure 1. Synchronized phasor measurement applications.

models that suitably represent the specific component of the system (i.e., automatic voltage regulators, high-voltage direct current transmission lines, wind farms, speed governors, dynamic equivalents, etc.). Next, an initial guess of the parameters to be identified is set. Time domain simulations are then performed for a specific set of predefined perturbations (i.e., the actual PMU recorded contingencies or specific field test records) that have occurred or been provoked in the system. Subsequently, a set of electric signals, which are compared with the measured reference signals corresponding to the abovementioned events, is selected. Afterward, the objective function for parameter identification is structured, and the underlying optimization problem is solved through MVMO. The parameter identification procedure is schematically summarized in Figure 2, whereas the parameter identification, conceived as an optimization problem, can be formulated considering the difference between recorded reference signals and the selected signals from dynamic simulations as the basic input.

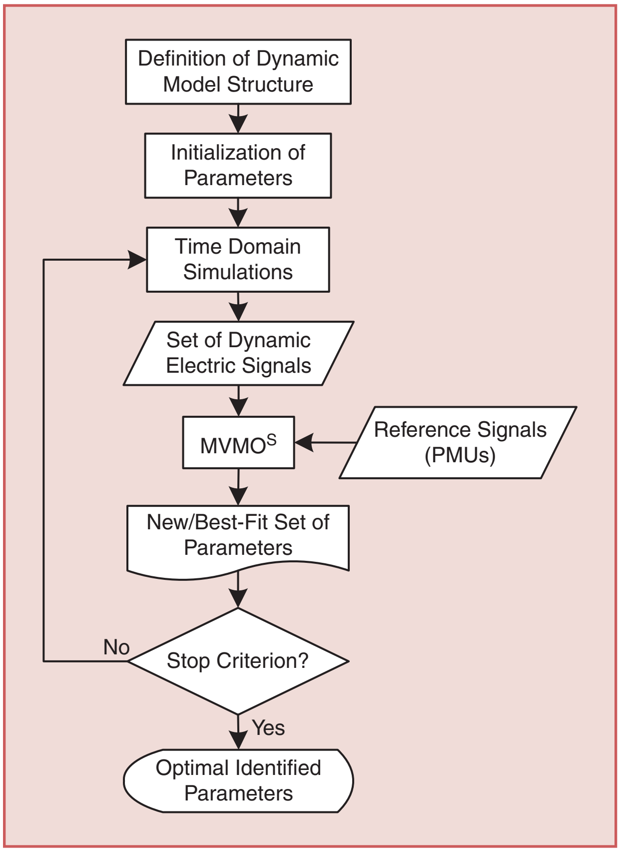

figure 2. Parameter identification.

Tackling Oscillatory Stability Issues: Security Constrained Dispatch and Power System Stabilizers Tuning

The Ecuadorian SNI keeps a permanent 60-Hz synchronous connection with the Colombian power system through four 230-kV transmission lines. It should be considered that due to voltage control strategies, some of these transmission lines are disconnected in low-demand scenarios, thus increasing the impedance in the connection between these two countries. Several offline analyses and constant monitoring of the oscillatory stability of the Ecuador–Colombia interconnected power system, via the Ecuadorian WAMS, have shown that there is a permanent presence of a poorly damped interarea mode whose frequency varies within the range of 0.3 to 0.4 Hz. In addition, there are some local modes that also are poorly damped, mainly in some stressed operating conditions. For instance, Figure 3 presents the excitation of the local mode of the CCS hydroelectric power plant during its commissioning tests.

To tackle this issue, two planning strategies have been determined: defining the emergent security constraint-based

figure 3. The CCS hydroelectric power plant local mode excitation.

dispatch of critical power plants and also the tuning of power system stabilizers (PSSs) as the sustainable solution.

In this sense, a novel comprehensive methodology for PSS tuning based on WAMS was proposed and implemented. This methodology exploits the digital technology available at CENACE to determine an optimal set of parameters for PSSs of the generation units. Figure 4 presents this comprehensive PSS tuning methodology that is made of five sequential stages: 1) the installation of PMUs at the terminals of the generation units; 2) model validation based on the previous explained model parameter identification methodology based on field tests; 3) probabilistic oscillatory stability assessment of the validated model using Monte Carlo simulation, modal analysis, time domain simulation, and frequency response analysis; 4) PSS tuning based on MVMO, but improved using robust control criteria as additional constraints, together with a real-time digital simulation (RTS) environment, implemented to verify the effectiveness of the tuning process, through tests in the time domain, using the real-time electromagnetic transients simulation (EMT-RTS) tool (i.e., the PSS tuning testbed); and 5) PSS tuning at generation power plants with proper field tests to validate the complete tuning process.

Figure 5 presents the proposed mathematical methodology for PSS tuning. This methodology begins with the definition of a single machine infinite bus model and seeks to solve an optimization problem that minimizes the difference between a damping threshold and the minimum global damping of the system subjected to side constraints and robust control-based constraints. Based on iterative modal analysis, the MVMO algorithm allows obtaining PSS parameters to achieve a desired damping in the power system. To ensure that these parameters will produce an adequate frequency-domain response, robust control indices are included as constraints of the optimization. In this connection, the joint use of modal analysis with MVMO and the robust response was considered necessary to ensure more robust results.

The obtained benefits, due to the development of the comprehensive PSS tuning methodology, are widely known. On one hand, the oscillatory instability issues evidenced in two of the intervened power plants (i.e., CCS and Delsitanisagua) made it necessary to restrict their power due to security constraint dispatch. Under these conditions and to safeguard the physical integrity of the generation units and the stability of the SNI, about 320 MW of hydraulic generation that could have been used to displace thermal generation was not considered in the dispatch, thus causing more expensive economic dispatches. Additionally, the CCS's PSS tuning improved the interarea mode damping. This increased the electrical energy export capacity to the Colombian system, making it possible to reach a maximum of 450 MW (instead of the previous 300 MW). Thus, 150 MW of surplus was accomplished, obtaining significant economic benefits for Ecuador and Colombia (in the case of Ecuador, during 2020 and 2021, the exportation income increased several tens of millions of U.S. dollars due to this export capacity increment).

Figure 6 shows how the CCS PSS tuning allows increasing the exports to Colombia, enabling the occurrence of a high enough number of stable operating scenarios.

An important milestone regarding the development and implementation of this comprehensive PSS tuning methodology is that it won the Second Prize of the 2021 Innovation Award of the Comision de Integracion Energetica Regional in the digitalization category.

Likewise, the development of the comprehensive tuning methodology has also made it possible to analyze alternatives for tuning other types of controllers, such as speed governors and automatic voltage regulators, which can improve the system stability. These analyses are part of further research that is currently ongoing.

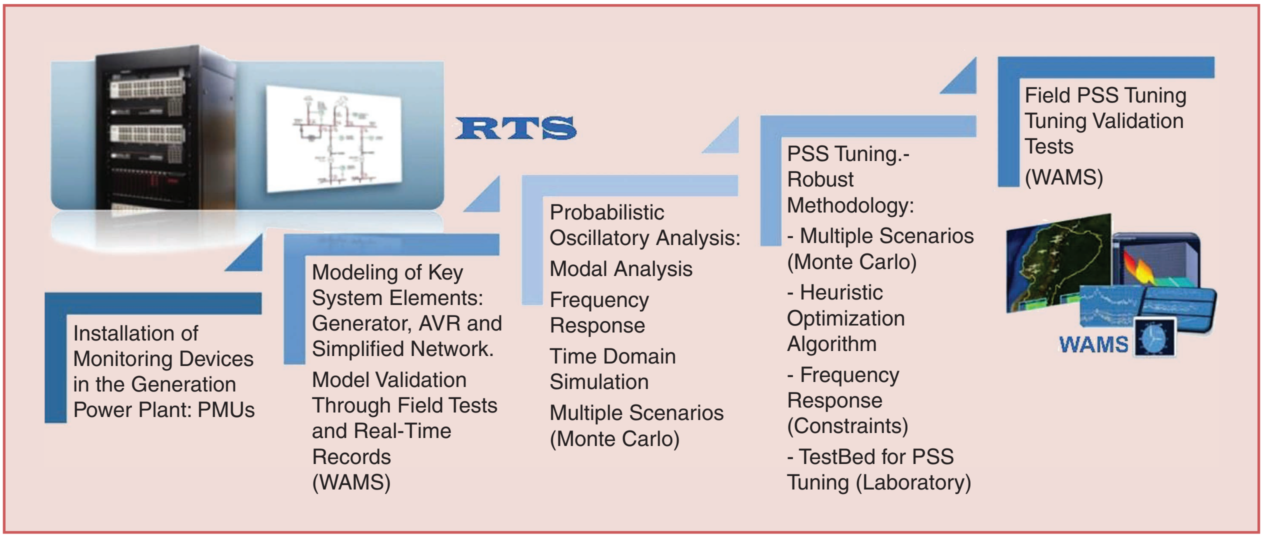

figure 4. A comprehensive PSS tuning methodology based on WAMS.

Design of Control and Protection Schemes

The design of control and protection schemes is also part of the research related to WAMS implementation in Ecuador. In fact, an automatic special protection scheme (SPS), also called a system integrity protection scheme, was implemented in the SNI. In this scheme, a so-called mitigation matrix is defined based on a set of linear equations, for each of the strategies determined by planning studies. These equations allow for the calculation of the amount of load and generation that must be disconnected to avoid system instability, in the occurrence of predefined critical perturbations; this is mainly related to N-2 contingencies, considering the prefault power flow of the transmission corridors.

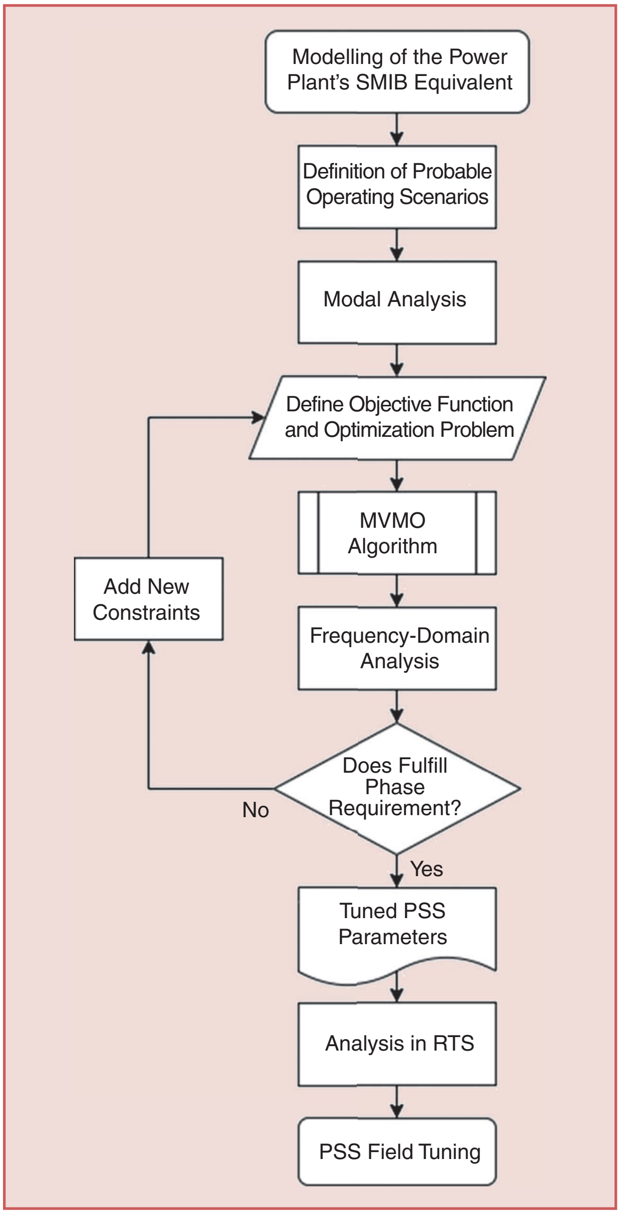

figure 5. The PSS tuning methodology. SMIB: single machine infinite bus.

Since 2015, when the SPS was implemented in the SNI, this scheme has operated at least once per year, avoiding several blackouts. Based on postmortem analyses and assuming the feasibility of restoring the power supply to the affected areas in approximately 1.5 h, it is possible to estimate the energy not supplied for each SPS operation, considering the SPS was not available and, also, considering its proper operation. Since in Ecuador the energy not supplied has a cost of US$1,533.00/MWh, the actuation of the SPS was able to prevent the loss of approximately US$1.5 million in each operation. In this connection, the implementation of this wide-area monitoring, protection and control system solution has, in fact, brought economic benefits for the SNI operations.

In addition to this SPS, further proposals are being developed to exploit the WAMS capabilities for computing and triggering wide-area protection. For instance, an adaptive load shedding scheme has been proposed and implemented using WAMS' programming options. This proposal has been tested in the RTS laboratory, and a project to implement a prototype of this proposal in the SNI is ongoing.

Area Separation Scheme Based on Synchrophasor Measurements for Ecuador–Colombia Power System

International or regional grid interconnections are links among the electricity transmission systems of two or more adjacent countries or regions, allowing the mutual exchange of generation resources. When the power systems are interconnected, their operation becomes more complex, and the network reliability and stability could be reduced due to stressed phenomena occurring in an electrical area. In these situations, it is desirable to separate the regional power system into islands in a controlled way. Based on this, the protection scheme could be implemented to isolate an electric power system area based on accurate real-time measurements. The scheme makes it possible to determine if a power system is moving toward an unstable condition by dynamically identifying the defined separation limits.

From 2022 onward, the area separation protection scheme (Esquema de Separacion de Areas) has been implemented by using synchrophasor measurements in the Ecuadorian and Colombian power systems. The implementation is done through phasor measurements of voltage and current in real time and is provided by PMUs. PMUs, through protocol IEEE C37.118 and the IEC 61850 standard, allow a central controller to process information and perform protection actions to provide the ability to observe what is occurring in the interconnection at any time. The implemented data pipeline of the Ecuador–Colombia interconnection Esquema de Separacion de Areas has been conceived for interoperating different protocols, such as IEEE C37.118, Generic Object-Oriented Substation Event protocol, and supervisory control and data acquisition IEC 60870-5-104. Additionally, by monitoring the real behavior of the power system and through the following "logics," the separation protection

In this scheme, a so-called mitigation matrix is defined based on a set of linear equations, for each of the strategies determined by planning studies.

scheme allows for the determination of whether the systems should be separated to avoid the collapse of each area:

- ✔ *Logic based on angular difference*: based on angular difference between Ecuador and Colombia to determine the power transfer limits in the interconnection lines
- ✔ *Logic based on voltage derivative*: actuation by critical voltage variations in the interconnection busbars
- ✔ *Logic based on modal analysis*: detection of interarea power oscillations with low damping to ensure the operation of electrical systems of Ecuador and Colombia.

Ecuadorian WAMS Operations Applications

Under certain stressed operational conditions, the electric power system is more vulnerable to face failures. If these phenomena are not controlled sufficiently in advance, they could lead to a risky vulnerability status for the system, eventually leading to a collapse. In this context, WAMS becomes a fundamental tool for operators that gives them enough information to define early warning indicators among the required situational awareness. Therefore, as part of the WAMS implementation at CENACE, for improving the real-time operations, the operators are permanently monitoring the WAMS' security applications' 1) phase angle difference, 2) voltage stability of transmission corridors, and 3) oscillatory stability, as well as the SPS server. In this connection, the operators require a good enough knowledge regarding the dynamic phenomena, including the definition of basic control actions to be performed to avoid reaching critical excursions. Figure 7 presents a view of WAMS' applications regarding small-disturbance angle stability (angle difference) and voltage stability of the transmission corridor Molino–Pascuales.

Based on this necessity, an operators' training environment based on a local WAMS' PDC has been developed. This training environment is fed by the results of the RTS software for rms simulation (RMS-RTS). The aim of this environment is to allow for the structuring of a digital twin of the SNI that resembles its dynamic response that is observed via WAMS. With this platform, the operators' trainers can define different dynamic scenarios to teach operators about key control actions. This environment is designed to exploit the capabilities of the RTS for structuring a digital twin resembling the SNI's dynamic behavior. The platform uses the static model of the Ecuadorian Power System available in the CENACE's electric power system simulation software via the "dgs" interface, whereas the dynamic models are implemented via functional mock-up units based on Modelica. Inside RMS-RTS, virtual PMUs are programmed to reproduce the actual PMUs. These components give the operators the possibility of facing a very close to reality training environment via the WAMS' human–machine interface, providing them with access to each of the WAMS' applications. Figure 8 presents the proposed dynamic simulation environment architecture.

One important aspect to be considered in real-time operations is the availability of early warning indicators that provide alerts regarding vulnerable conditions that could potentially push the system to the verge of collapse. The goal of these indicators is to allow the operators to make decisions sufficiently in advance to carry out control

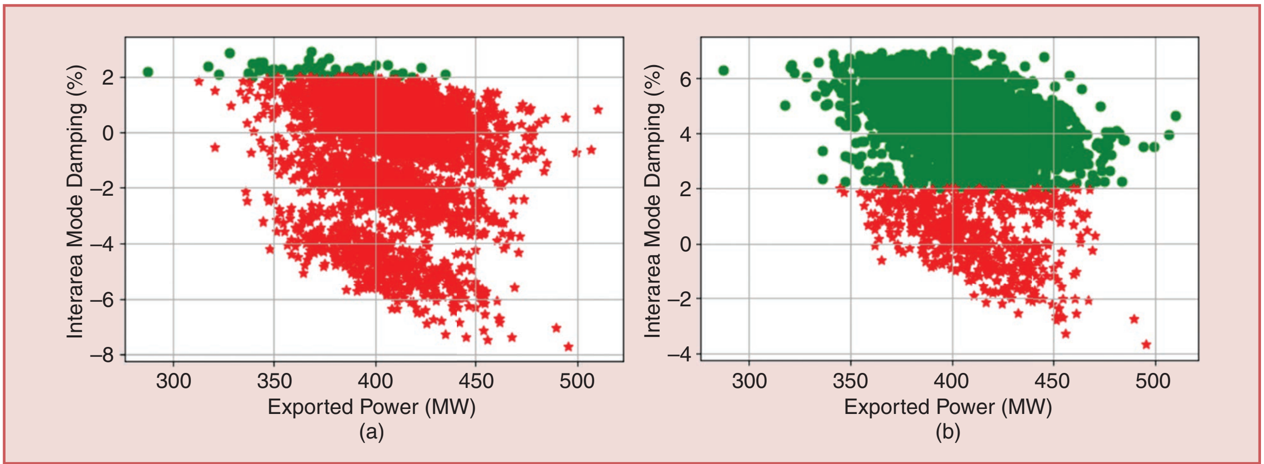

figure 6. Interarea mode damping versus exported power: (a) without CCS PSS tuning and (b) with CCS PSS tuning.

actions. In this connection, some methods have been proposed in the literature to predict the near-future vulnerability status of the power system regarding the different symptoms of system stress, such as transient stability, oscillatory stability, voltage stability, frequency stability, and overloads. However, most of these proposals are yet oriented to academic solutions.

Thus, a more practical proposal has been developed at CENACE, specifically to have short-term prediction mechanisms (a few seconds in the future) of the modal identification results, which allow the operator to anticipate the evolution of the operating state to predictively evaluate the oscillatory stability of the system. In this sense, a big data platform has been designed that automatically analyzes the data from the WAMS' modal estimation and performs a predictive evaluation of the oscillatory stability status. This platform is based on data management technologies (Cassandra), together with data analytics software (Python), in which a time series regressor is trained based on recurrent neural networks (RNNs) and whose general architecture for the data pipeline is shown in Figure 9. After the application of the proposal, the obtained predictions achieved good precision, which can be observed in Figure 10, which presents four examples of the prediction made by the trained RNN model for random samples. Similar applications for the other symptoms of system stress are in development.

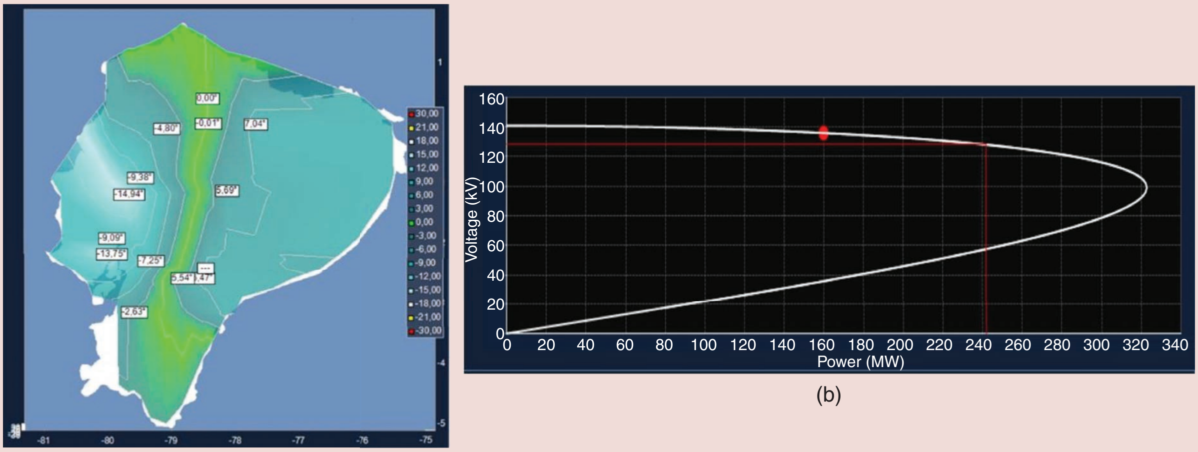

figure 7. WAMS' security monitoring applications: (a) the angle difference dynamic contour plot and (b) the voltage stability PV curve (the Molino–Pascuales corridor).

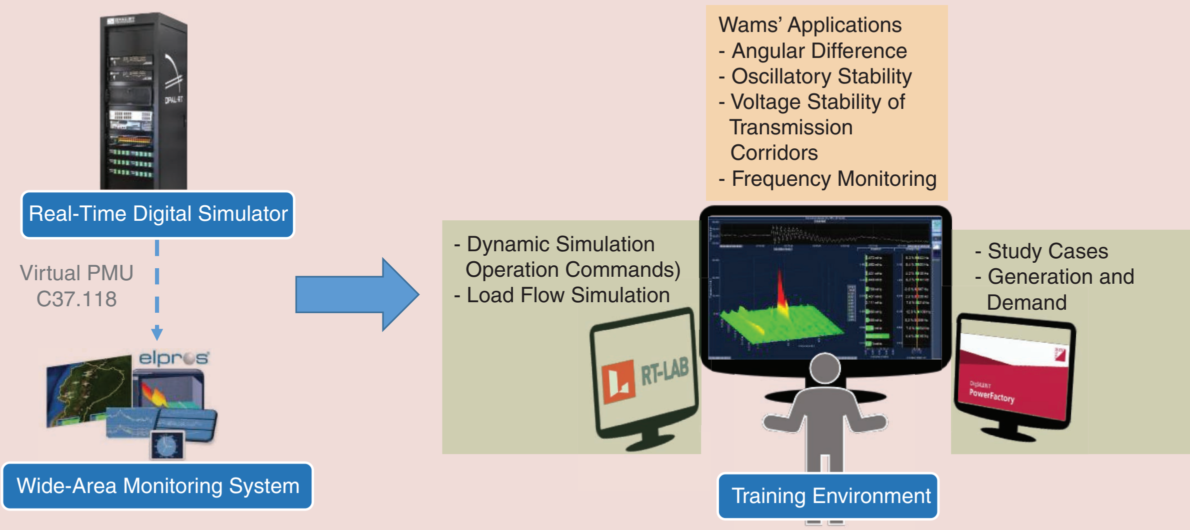

figure 8. The operator's training environment for dynamics based on RMS-RTS and WAMS.

Ecuadorian WAMS Postoperative Analysis Applications

The postoperative analysis has the aim of summarizing the most important findings regarding the power system operations (i.e., main statistics, accomplishment of the predefined dispatch, and important faults postmortem analysis, among others).

In this connection, WAMS becomes a key source of data and information that needs to be properly analyzed. In fact, the

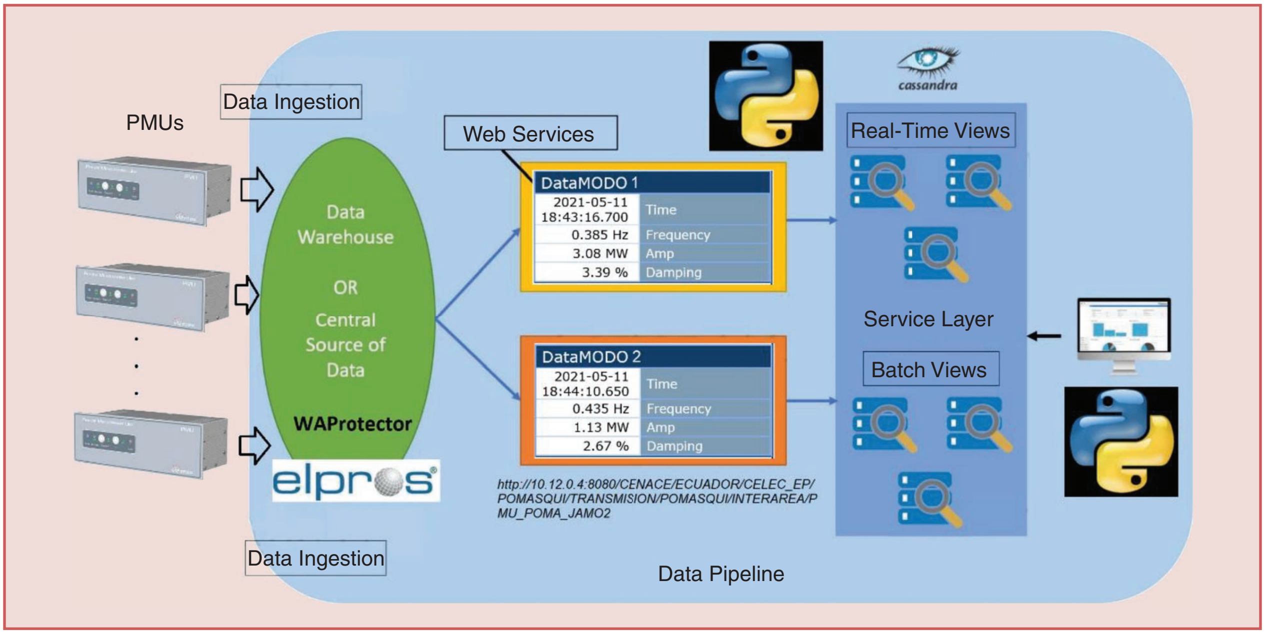

figure 9. The architecture of the big data platform for predictive assessment of oscillatory stability.

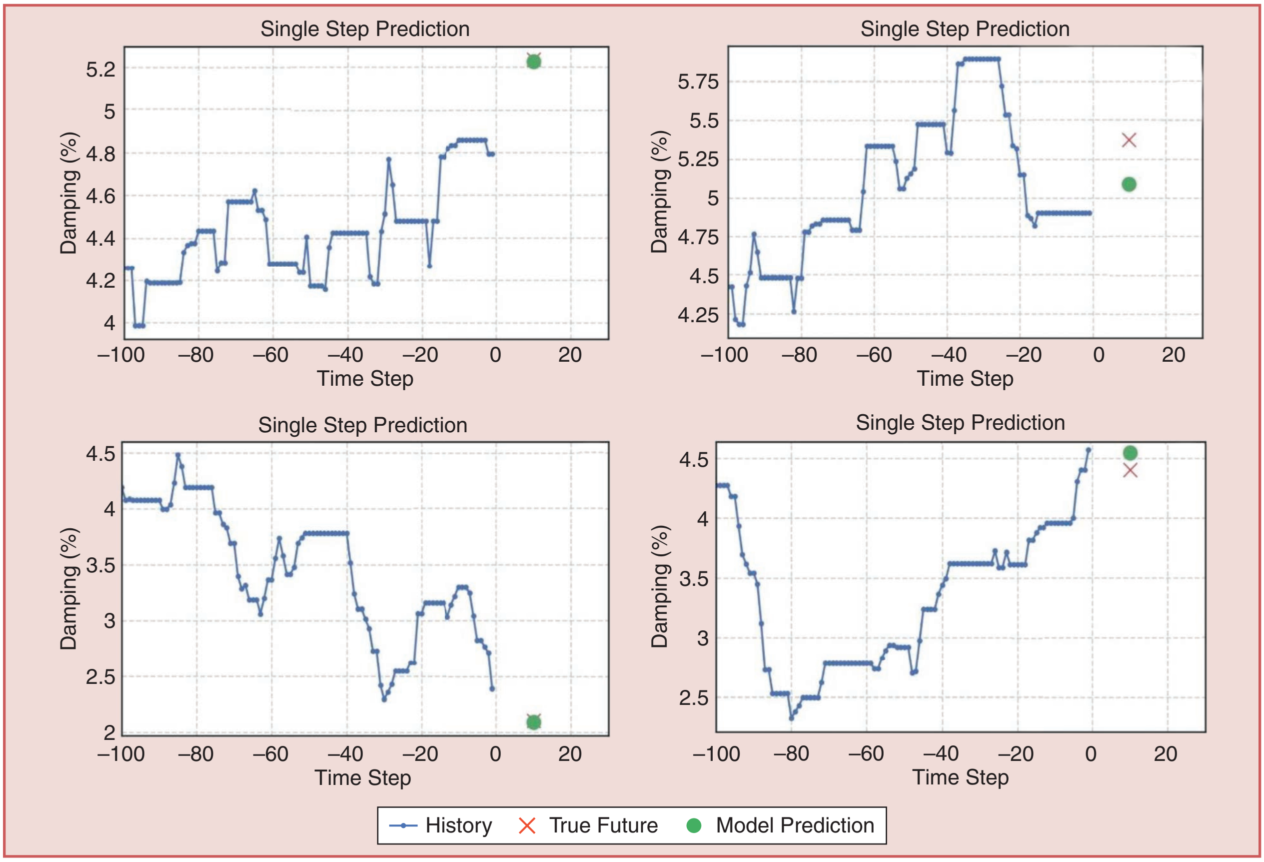

figure 10. Examples of prediction achieved by the RNN model.

> The scheme makes it possible to determine if a power system is moving toward an unstable condition by dynamically identifying the defined separation limits.

starting point of exploiting the WAMS potential is the postoperative analysis as it allows determining the dynamic phenomena's behavior and its patterns, which help to structure the basic knowledge regarding the dynamic performance and needs of the power system. For this aim, multivariate data analysis is the most important tool that is being used at CENACE.

Based on this fact, several postoperative processes have been developed using the WAMS data: 1) postoperative analysis of faults related to stability issues; 2) daily, weekly, and monthly statistics of important phenomena (i.e., small-disturbance angle stability, voltage stability of transmission corridors, and oscillatory stability); 3) dynamic behavior characterization (mainly for oscillatory stability); or even 4) power quality assessment.

The results of these postoperative analysis constitute a key input for deciding the most critical planning strategies and the basic considerations for real-time operations since they need to be defined for tackling the phenomena that in fact are disturbing the power system.

Conclusions

In Ecuador, the National Electricity Operator CENACE is the institution that operates the National Interconnected System SNI. Since 2010, CENACE has implemented the WAMS platform that constitutes the PDC, which provides several applications for dynamic phenomena monitoring, such as electric variable performance, small-disturbance angle stability (angle difference), voltage stability of transmission corridors, and modal identification that allows the estimation of oscillatory modes in quasi-real time, among others. Using the WAMS available data and information, several applications have been developed by the research and development department of CENACE to improve the different processes related to operative planning, real-time operations, and postoperative analysis of the Ecuadorian power system. This article summarizes the most important developments regarding the exploitation of the Ecuadorian WAMS. The most important contribution has been the PSS tuning comprehensive methodology implementation, being even awarded with the Second Prize of the 2021 Innovation Award of Comision de Integracion Energetica Regional in the digitalization category.

Acknowledgment

The article includes work performed at Operador Nacional de Electricidad CENACE since 2013 and academic research developed at Escuela Politecnica Nacional EPN, related to research projects and theses. We express special recognition to the authorities of the Ecuadorian electricity sector for having supported the implementation of the developments, mainly the PSS tuning. We especially thank Medardo Cadena, former minister of electricity and renewable energy, and Gabriel Arguello, former CENACE CEO, for their confidence and support.

For Further Reading

R. Segundo et al., "Application of spatio-temporal data-driven and machine learning algorithms for security assessment," IEEE Power and Energy Society, Piscataway, NJ, USA, Tech. Rep. PES-TR104, Nov. 2022.

R. Segundo et al., "Present situation on data acquisition, handling, and analytics of operators of the transmission system in different countries and their future needs to cope with the continuous growth of data," IEEE Power and Energy Society, Piscataway, NJ, USA, Tech. Rep. PES-TR100, Jul. 2022.

T. Babnik, B. Mahkovec, and S. Subotić, "Centralised system for overfrequency real-time dynamic settings for generators," in *Proc. Int. Conf. Smart Grid Synchronized Meas. Analytics (SGSMA)*, Split, Croatia, 2022, pp. 1–5, doi: 10.1109/SGSMA51733.2022.9805855.

L. J. Rueda-Torres and F. González-Longatt, *Dynamic Vulnerability Assessment and Intelligent Control: For Sustainable Power Systems*. Hoboken, NJ, USA: Wiley, 2018.

J. Cepeda, J. Rueda, I. Erlich, A. Korai, and F. Gonzalez-Longatt, "Mean-variance mapping optimization algorithm for power system applications in DIgSILENT powerfactory," in *PowerFactory Applications for Power System Analysis Book*, F. Gonzalez-Longatt and J. Luis Rueda, Eds., Cham, Switzerland: Springer-Verlag, 2015, pp. 267–295.

T. Babnik, K. Görner, and B. Mahkovec, "Wide-area monitoring system," in *Monitoring, Control and Protection of Interconnected Power Systems*, U. Häger, C. Rehtanz, N. Voropai, Eds., Berlin, Germany: Springer-Verlag, 2014, pp. 65–82.

Biographies

Jaime C. Cepeda is with Escuela Politecnica Nacional, Quito EC170525, Ecuador.

Diego E. Echeverría is with Operador Nacional de Electricidad, Quito EC171108, Ecuador.

Marlon S. Chamba is with Operador Nacional de Electricidad, Quito EC171108, Ecuador.

Innocent Kamwa is with Université Laval, Quebec, G1V 0A6, Canada.

J. L. Rueda-Torres is with Delft University of Technology, Delft, 2628 CD, The Netherlands.