The "Wide-Area" Concept
Diverse Energy Transition Challenges [Guest Editorial]

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THE URGENT NEED FOR A SIGnificant reduction of greenhouse emissions (around 50% by 2030 and net zero by 2050) is driving an acceleration of major technological upgrades in electrical power systems. This is gradually translating into new architectures of transmission and distribution networks. Ideally, the upgraded networks enable the technoeconomic, reliable, and environmentally friendly deployment of a high share of emerging technologies, primarily based on power electronic converters. Such major upgrades occur in renewable power generation, responsive demand (including data centers and electrolysis plants), electrical and nonelectrical energy conversion and storage, and flexible compensation devices.

Engineers and researchers worldwide face unprecedented operating conditions arising in the progressively upgraded high-voltage direct current–high-voltage alternating current (HVdc–HVac) networks. Understanding the nature of such conditions and their relation with changing properties over different time scales constitutes a major challenge. Different new approaches are being proposed to improve or replace existing methods for applications in energy management systems, including off-line/real-time model tuning, off-line/real-time simulation-based stability assessment, and real-time measurement-based stability assessment. This is being done to support the trustworthy analysis and effective mitigation of undesirable threats that jeopardize compliance with steady-state and dynamic stability criteria.

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This special issue focuses on the "wide-area" (WA) concept, which utilizes synchronized measurements, such as phasor measurement units (PMUs) and waveform measurement units for various advanced applications, including monitoring-focused (WAMS) applications; control-focused applications; and comprehensive monitoring, protection, and control (WAMPAC) applications. The aforementioned WA applications have undergone significant advancements in both theoretical design and practical implementations to overcome widely recognized resiliency challenges related to factors such as data accuracy, synchrony, time-variant and fast changing multiconverter dynamics, and the nondeterministic nature and latency of modern communication infrastructure. Hence, the eight articles in this special issue provide an overview and discuss recent important developments, trends, and real-world experiences related to the implementation and uses of different WA applications.

The definition of practical roadmaps for the adoption and deployment of prioritized WA applications in active distribution systems is thoroughly discussed in [A1]. These roadmaps comprehensively take into account diverse technoeconomic objectives, which are pragmatically framed within utility-specific technical requirements, in addition to operational and developmental challenges.

Different recent experiences in systems from different continents, each with unique steady-state and dynamic properties and operational challenges, are addressed in the subsequent articles. To illustrate the diverse practical challenges that have been identified and resolved, selected examples are provided.

The multitool based collaborative centralized analysis frameworks developed for the Indian system are covered in [A2]. They were created to address various practical implementation challenges, which concern the use of WAMS data for locating and characterizing single or multiple excited dynamic phenomena (e.g., electromechanical oscillations) caused by different types of disturbances.

WA measurement-supported state estimation in the Malaysian system is presented in [A3], highlighting breakthroughs in handling measurement errors, network topology changes, and system uncertainties.

The integration of off-line and real-time analysis tools with data from the WA measurements and the communication infrastructure of the Ecuadorian power system is discussed in [A4]. The implementation and testing of big data analytics and artificial intelligence-based applications are described for various tasks related to the Ecuadorian WAMPAC. These capabilities have led to significant enhancements in operational security for real-time operation and short-term operational planning.

The rationale for an emerging technology related to synchro-waveform measurements is provided in [A5], reflecting on its potential benefits, main drawbacks, and improvements for significantly enhanced capabilities of WA applications in converter-dominated electrical networks.

The development and testing of novel WAMPAC services in the Hellenic system are outlined in [A6], highlighting significant improvements in the system performance through the effective management of controllable assets. This supports, for instance, the achievement of healthy voltage profiles, timely damping of critical low-frequency oscillations, adaptive deployment of dynamic line rating, and timely detection of risks related to loss of synchronism.

The value of the WA concept from the perspective of extra-high-voltage transmission network expansion, in the context of accelerated energy transition in Brazil, is insightfully discussed in [A7]. As a proof of concept, it demonstrates how time-synchronized control can be incorporated into the outer control loops of the converter stations of HVdc transmission systems to optimally manage power transfers, achieve significant reduction of losses, and mitigate the adverse impacts of loop power flows.

Finally, a network-based concept for time synchronization in a South Korean system is presented in [A8]. This article highlights improvements in the reliability of PMU measurements achieved through the use of atomic clocks synchronized with a country's national standard time via optical cables.

Appendix: Related Articles

[A1] J. R. Agüero, D. Novosel, D. Hart, A. B. Nassif, B. Enayati, and C. R. Black, "Applications of synchronized measurement technologies in power distribution systems: Helping to speed up technology deployment," *IEEE Power Energy Mag.*, vol. 23, no. 1, pp. 18–34, Jan./Feb. 2025, doi: 10.1109/MPE.2024.3422975.

[A2] K. V. Katariya, R. Yadav, S. Kumar, P. Ashok Kumar, and I. Kamwa "Wide-area-measurement-system-based event analytics in the power system: A data-driven framework for disturbance characterization and source localization in India grid," *IEEE Power Energy Mag.*, vol. 23, no. 1, pp. 35–46, Jan./Feb. 2025, doi: 10.1109/MPE.2024.3446737.

[A3] M. K. N. M. Sarmin et al., "Revolutionizing the grid of the future with a wide-area monitoring and control system: Phasor measurement unit applications in grid control, protection, and event analysis at Tenaga Nasional Berhad," *IEEE Power Energy Mag.*, vol. 23, no. 1, pp. 47–58, Jan./Feb. 2025, doi: 10.1109/MPE.2024.3443236.

[A4] J. C. Cepeda, D. E. Echeverría, M. S. Chamba, I. Kamwa, and J. L. Rueda-Torres, "Wide-area monitoring protection and control supported operation and planning in the ecuadorian power system: Improving security and reliability," *IEEE Power Energy Mag.*, vol. 23, no. 1, pp. 59–68, Jan./Feb. 2025, doi: 10.1109/MPE.2024.3435811.

[A5] H. Mohsenian-Rad, M. Kezunovic, and F. Rahmatian, "Synchro-waveforms in wide-area monitoring, control, and protection: Real-world examples and future opportunities," *IEEE Power Energy Mag.*, vol. 23, no. 1, pp. 69–80, Jan./Feb. 2025, doi: 10.1109/MPE.2024.3403800.

[A6] K. F. Krommydas et al., "Enhancing the operation of the hellenic transmission system through wide-area monitoring and control: Design, implementation, and evaluation of a phasor measurement unit-based system with advanced algorithms," *IEEE Power Energy Mag.*, vol. 23, no. 1, pp. 99–112, Jan./Feb. 2025, doi: 10.1109/MPE.2024.3435171.

[A7] G. Taranto, P. Esmeraldo, and John Graham "Integration of renewable energy with embedded high-voltage dc links in Brazil: A Time-synchronized angle difference controller," *IEEE Power Energy Mag.*, vol. 23, no. 1, pp. 90–112, Jan./Feb. 2025, doi: 10.1109/MPE.2024.3443785.

[A8] C. Kim, H. Kim, S. Lee, J. Noh, E. Ghahremani, and Y. Kim, "Enhancing synchrophasor reliability through network-based time synchronization: KEPCO's practical approach," *IEEE Power Energy Mag.*, vol. 23, no. 1, pp. 81–89, Jan./Feb. 2025, doi: 10.1109/MPE.2024.3430888.

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