Design of a WAMPAC System for Implementation in the Greek Transmission System

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***Abstract*—The Greek power system is facing significant changes as the government's policy is focused on an energy transition aligned with the EU future plans by implementing comprehensive reforms in the energy sector to drive decarbonization, increase the share of renewable power plants and foster competitive markets. This transition is expected to create significant challenges to the operation of the future Greek power system. In this context, a Wide Area Monitoring, Protection, Automation and Control (WAMPAC) System is developed that is expected to serve as a useful tool for monitoring and control of the steady state and dynamic limits of the power grid. Fifteen (15) time synchronized phasor measurement units are currently being installed in critical locations to gather data and online transmit them to phasor data concentrators in order to be used by the WAMPAC system. Moreover, a holistic design approach is adopted for the WAMPAC system with various protection and control services that aim to deal with the expected upcoming challenges. Overall, in this paper the developed augmented WAMPAC design approach and implementation is thoroughly described in order to serve as a roadmap for future power systems.**

***Index Terms*—Power Systems, WAMPAC, PMUs.**

I. Introduction

The European power Transmission System Operators (TSOs) face several challenges in the way they manage each power grid due to the increasing demand and the changes of the energy mix [1]. The considerable deployment of renewable generation, in particular large-scale wind farms and solar power plants, results in growing dynamic stability issues for the power system. As an example, the reduced contribution of renewables during faults, causes failures and slow operation of network protection systems. In addition, inter-area oscillations due to small frequency variations in different parts of the system, mainly caused by disturbances in the network, may cause a series of unexpected cascade events. As a result, the power system may be driven to a more vulnerable state of operation [2]. Therefore, control actions such as load shedding or more advanced protection schemes must be taken in order to ensure secure energy supply and mitigate the negative effects of fault conditions and protect the power system from further cascading events [3].

Power system blackouts have shown that the stability and secure operation of power systems can only be achieved if TSOs have reliable information of the state of the system as a whole [4]. The traditional Energy Management System (EMS) used for the power system online monitoring, its security assessment, and its operating condition estimation, uses measurements from Conventional Supervisory Control and Data Acquisition (SCADA) systems [5]. These systems provide steady, non-synchronous information of the power system with time resolution between 1 and 10 s. This information is sufficient for an EMS to plan the response of the power system to slow changes in its operating conditions. However, the fact that conventional SCADA systems are limited to steady-state measurements, does not allow TSOs to use them to track system dynamics in real time, or to fully predict all the conditions for offline studies.

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The use of a Wide Area Monitoring System (WAMS) can meet these issues since it is based on real-time information, gathered from synchronized measurement technology devices distributed through the power grid [6]. Currently, Phasor Measurement Units (PMUs) are the most accurate and advanced measurement technology and can provide time-synchronized information (measurements from voltage and current phasors of the electrical grid) with high frequency, e.g., every 20 ms in 50 Hz systems. When combined with novel communication techniques for accurate time stamping of measurements, data can be synchronized with a minimal accuracy of 1 µs. Then, the time synchronized data from PMUs is transmitted and collected at phasor data concentrators (PDCs) [7]. A super PDC can then collect the data from the PDCs, process these large quantities of data in real time and send selected data to any PDC, resulting in a hierarchically distributed architecture [8]. Various data transmission protocols can be handled by super PDCs [9].

When this philosophy is used in a wide geographical area, the term Wide Area Monitoring, Protection, Automation and Control System (WAMPAC) is used. It enables TSOs to permanently monitor the power system dynamic behavior and control the stability and safe operation of the whole power grid [6]. WAMPAC systems receive the data from PMUs, installed in different locations of the transmission network, process all this information, and carry out monitoring and control applications directly, either by the PDCs or by the super PDCs, helping TSOs to determine and generate the appropriate response for solving in real time the problems that appear at the power system. Over the last years, the necessity to develop WAMPAC systems has grown rapidly, mainly due to the difficulties encountered for correct fault detection, along with the changes in the generation technologies portfolio [10]. Several power utilities in various countries throughout the world have established WAMPAC systems [11].

In this context, this paper presents the design of a WAMPAC system for the Greek TSO, in order to be used as a powerful tool to protect and enhance its power network and develop advanced services for improving its stability. A holistic design approach has been adopted for the WAMPAC H2020 FARCROSS project that includes: a) choosing for the PMU installation the most critical locations by using also an automatic toolbox b) developing various algorithms to deal with the upcoming challenges of the Greek power system c) pre-evaluating the developed algorithms with real-time controllers and laboratory tests d) defining representative key performance indicators (KPIs) to effectively evaluate the WAMPAC performance. The information provided in this paper for the developed augmented WAMPAC design approach and implementation aims to serve as a roadmap for future power systems to deal with some of the upcoming challenges.

II. Greek Transmission Network

Independent Power Transmission Operator (IPTO) is the Greek TSO and responsible for the continuous monitoring and stable and secure operation of the Greek transmission grid. The transmission system line extends 12,300 km in length. There are 22 extra high voltage (EHV) substations (400/150 kV), 243 high voltage substations (150 kV/MV) and 28 power plant substations (MV/150 kV). Currently, there are 68 renewable energy sources (RES) substations in the network, but this number is expected to be significantly increased during the following years [12]. The country is also well interconnected with all the neighboring countries at either voltage level of 150 kV or 400 kV. Specifically, the list of interconnections is the following: i) North Macedonia; ii) Albania; iii) Bulgaria; iv) Turkey; v) Italy [13].

III. WAMPAC Design for Greek Network

A. Overview

The state of a power system is expressed in terms of state variables, such as voltage at a load and phase angle at a generator. Typically, measurement devices are placed at selected points in the power system to monitor values of the state variables, which are fed back to the central control. The central control adjusts the power system to compensate for imbalances and to prevent hazardous (e.g., fault) situations. For proper control, it is essential that all state variables are communicated to the central control in real time.

B. WAMPAC Architecture

The WAMPAC will integrate: a) A synchronized data acquisition system: Fifteen (15) PMUs are planned to be installed in the Greek power network that will provide measurements of different electrical variables of the grid; b) Real time monitoring and control center: PDCs and Real-Time Automation Controllers are the core of the WAMPAC. They receive synchronized data streams and process the data to serve real time applications. Two PDC units will be placed in the dispatch center of IPTO; c) GPS clocks: These elements will provide the time reference to all the elements in the system to keep WAMPAC synchronize; d) Synchrophasor communication protocol: IEEE C37.118 phasor communication and data protocol will be used for the data transmission.

Based on an analysis of the Greek transmission system under inter-area oscillation scenarios with the automatic toolbox developed in [14] as well as taking into consideration the experience and recommendations of IPTO, critical points have been proposed to install PMU devices, including interconnection lines, generators with a Power System Stabilizer (PSS), main consumption areas, and a location where a Modular Power Flow Controller (MPFC) has already been installed. The PMU locations are (see Fig. 1):

(i) *Sklavouna and Chania substation (SS)*: SS Sklavouna is in the eastern coast of the Peloponnese peninsula, in southern Greece. The location is of particular importance because new submarine interconnection lines of 150 kV have been constructed to interconnect the mainland from SS Sklavouna with the island of Crete (SS Chania). Specifically, the line consists of two submarine cables (each 135 km long) making this the longest sub-sea alternating current connection in the world.

(ii) *EHV Center Agios Stefanos*: it is in Attica region, close to Athens. Its geographical location is highly crucial, as it is connected to four EHV Centers.

(iii) *EHV Center Lavrio and SS Syros*: Syros is a Greek island in Cyclades, in the Aegean Sea. The island of Syros is connected with the mainland of Greece through Lavrio. It is considered of crucial importance since it facilitates the high potential growth of RES on Aegean islands and has a positive impact on electricity production costs.

(iv) *EHV Center Melitis and EHV Center Kardia*: both locations are critical since they connect Greece with North Macedonia and Albania respectively.

(v) *EHV Center Nea Santa*: it is located in the Eastern Macedonia and Thrace, in northern Greece. Due to its geographical location (close to the border with Turkey and Bulgaria) and the extremely high-RES integration, the substation is significantly important. In the context of the FARCROSS project, a FACTS device, namely an MPFC, has been installed in the transmission line that connects EHV Nea Santa with SS Flampouro. It can actively change the power flow in a line by injecting a leading or lagging voltage in quadrature with the line current [15].

(vi) *EHV Center Acharnon, Pallini, Larymna*: they are located in the Attica region, very close to Athens. Its geographical location are highly crucial since they are connected with others EHV Centers.

(vii) *EHV Center Trikala and EHV Center Acheloos*: they are located in central Greece. These locations are crucial since both substations are connected with EHV Center Arachthos which connects Greece with Italy.

(viii) *EHV Center Lagkada*: it is located close to Thessaloniki, in the north of the country. The existing interconnection line Greece-Bulgaria will have EHV Center Lagkada as the starting point in the near future (still under construction). The substation of Lagkada also plays a critical role since it: (a) increases the production capacity from wind farms and/or conventional units that are located in near areas, (b) enhances the security of supply for the loads in the area, (c) enhances the transmission system of the Southern Balkans, particularly regarding the low-frequency oscillations that have occurred after the interconnection with Turkey.

(ix) *EHV Center Aliveri*: it is located in the island of Evoia, in the central region of Greece. It plays a crucial role since it increases the production capacity from wind farms and/or conventional units nearby. Moreover, an additional interconnection line with the Aegean islands is planned to start from EHV Aliveri.

C. Communication Architecture

1) Overview: The distributed architecture of the system is illustrated in Fig. 2. First, the PMUs are in charge of data acquisition from different locations. They send their data to two different PDCs from the two vendors participating in the project (SEL, STER), where the software of the monitoring, automation, and protection applications runs. As it can be observed from Fig. 2, a centralized architecture is being used: all the decisions are made by the PDCs, i.e., the PMUs do not make any decision by themselves. Each PDC runs a subset of the implemented WAMPAC services.

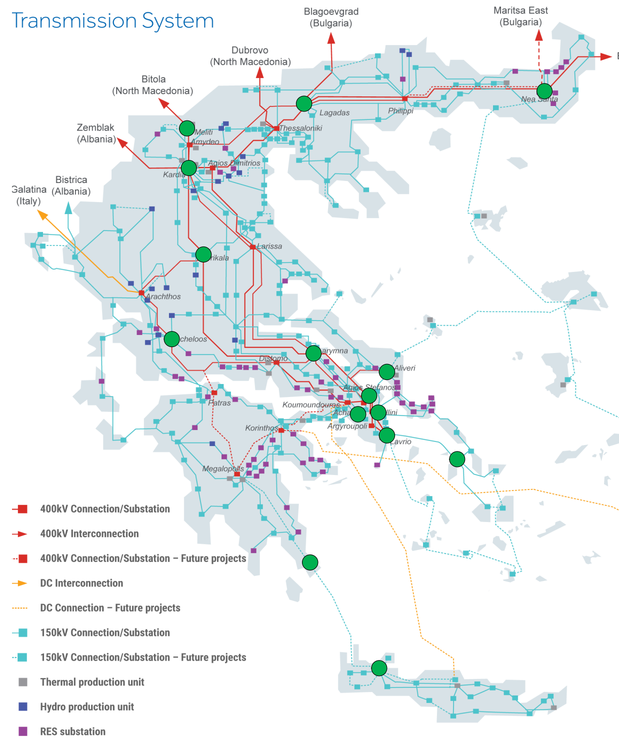

Fig. 1. PMUs location.

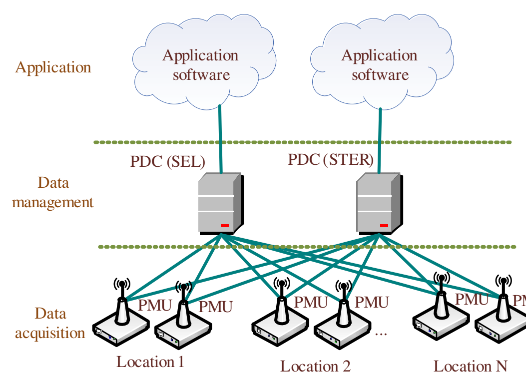

Fig. 2. Communication architecture.

2) IPTO's existing telecommunication infrastructure: IPTO uses different communication technologies in order to efficiently operate the Greek transmission system, depending on the communication infrastructure available at each location: a) Fiber-optic; b) Power Line Communication (PLC); c) Very high-speed digital subscriber line (VDSL); d) Broadband cellular network technology. In order to route all the required data (e.g., measurements of RTUs in substations to the EMS in the dispatch center) the two main communication technologies used by IPTO are Synchronous Digital Hierarchy (SDH) and Multi-Protocol Label Switching (MPLS) solutions. The average speed in IPTO's network, considering all the different types of technology used is around 20 Mbps. The above can be significantly different if the selected network is only covered by fiber optic, which average speed is around 1 Gbps, with a peak value of 10 Gbps.

3) Network Topology: The coexistence of recent technology equipment (Ethernet interfaces, higher serial speed transmission, and new SCADA protocols) with legacy infrastructure and substation devices results in two types of communications traffic over the IPTO's telecommunication network: (a) Ethernet and IP-based data, and signals from/to substations, and (b) TDM - based traffic from existing equipment, e.g., analog voice, serial SCADA, and Teleprotection signals. For interconnecting these data, the MultiService MUX equipment operates in a multivendor network environment, with EM, RS232, nx64kbps, E1, and STM-1/STM-4/STM-16 protocols. Equipment currently installed in the IPTO network includes AM3440 O9500 LOOP Telecom, ABB FOX 512, and 1662 SMC ALCATEL. All multiplexers are configured as Terminal Add/Drop and Cross-Connect multiplexer to work in line, ring, star, and meshed networks, fulfilling the requirement of multiplexers according to ITU-T G.783 and MEF CE2.0 or MPLS-TP. The network is configured as shown in Fig. 3.

4) Communication technology: In all locations, the internal network will support Ethernet over twisted pair (10BASE-T/100BASE-TX) and over optical fibers (100BASEFX). The minimum communication requirements for the standard C37.118 protocol with 50 Frames Per Second (FPS) is 100 kbps (8,800 bytes per second).

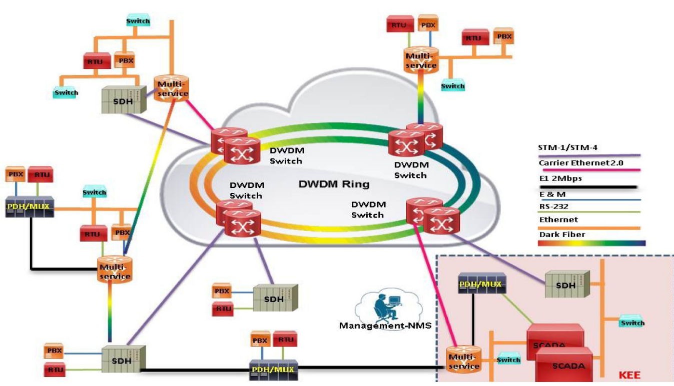

Fig. 3. Network configuration.

IV. Services to be Implemented in WAMPAC PDCs

Based on voltage and current synchrophasors, different services for power system WAMPAC are being implemented. a) *Voltage Stability:* This service monitors the angle difference between the local and remote bus positive-sequence voltage of different interconnections. This angle is a good indicator of the active power transferred to the remote load. Therefore, to avoid reaching unstable voltages, critical voltage stability margins can be correlated with respective critical difference angles, and those values can be used as thresholds to trigger critical voltage stability margin alarms in the Control Center [16].

b) *Power Oscillation Monitoring*: The power oscillations have become even more significant nowadays in the Greek power system due to the increased integration of RES and the development of large-scale interconnecting systems. This service executes a continuous online modal analysis of the active power transfer through different interconnections, to estimate the frequency, amplitude, and damping of their respective oscillations, and to trigger alarms on the Control Center when low-damped local or interarea oscillations of relevant amplitudes and frequencies are detected before the amplitudes become critically high and a local protection trip a heavily loaded line [17], [18].

c) *Dynamic Line Rating*: This service estimates the online average operating temperature of the conductor using the PMU synchrophasor current measurements on each cable end, and the ambient temperature input setting. This service declares an overload condition when the estimated operating temperature exceeds the maximum allowable temperature setting, triggering an "Cable Overloaded" alarm indication on the Control Center. Also, if the predicted steady-state temperature that would result with the actual current and ambient temperature is larger than the maximum allowable temperature setting, the service triggers an "Imminent Cable Overload" warning and displays the amount of time remaining until the overload alarm is declared [11].

d) *Islanding Detection and Loss of Synchronism*: This service will be very beneficial since the electricity interconnection between Crete and mainland of Greece is of critical importance since it will provide the island with less expensive and more secure energy supply. This service monitors the difference, slip and acceleration of the angle between the local and remote bus positive-sequence voltage of the interconnection between Crete and mainland of Greece. The angle difference is compared against a set threshold. The angle slip and the angle acceleration are compared against an acceleration vs. slip characteristic conformed by operating and non-operating zones delimited by straight lines with a negative slope given by the ratio of the acceleration and slip set thresholds ($m = -A_{th}/S_{th}$). In the event of islanded operation or loss of synchronism between the Greek mainland and the island of Crete, the indicated angle variables meet the operating conditions, and this service triggers the alarm "Islanding Condition or Loss of Synchronism" in the Control Center. With this information, the power system operator can decide to decouple the two electrical systems, or other remedial actions to reduce the loss of synchronism [19], [20].

e) *Rate of Change of Active Power*: This service provides a fast detection of active power swings transferred through the two underground/submarine cables in the interconnection line between mainland Greece and Crete. These swings could be caused by a sudden load or generation imbalance, or after a cable line trip. The output of this service are fast response-based alarms on the Control Center that detects events that risks the stability of the interconnected system formed by the mainland and island grids. With these alarms, the system operator can take remedial actions to preserve the interconnection [21].

f) *MPFC for Power Oscillation Damping*: The final scope of this service is to damp power oscillations, using as control inputs the frequency, amplitude and damping of active power oscillation detected. The control actions will be executed by an MPFC. This service aims to investigate and utilize the possibilities of using these active elements to damp oscillations.

g) *Feed EMS System*: The scope to this service is to feed the EMS of the TSO's control center with the measurements of PMUs in order to improve the state estimator performance.

h) *Zone IIA Protection*: This service can send an alarm to the TSO's control center when a fault is detected inside the protected zone. Since tripping the breaker is a critical application for the protection department of a TSO, this service can be used as a backup for short circuit protection in WAMPAC systems.

As a summary, the PMUs location and the services that will be implemented in each location are shown in Table I.

TABLE I
WAMPAC SERVICES IN SELECTED INSTALLATIONS.

No	PMU Location	WAMPAC Services
1	SS Sklavouna	-Voltage stability -Islanding detection -Loss of synchronism -Rate of change of active power to determine load shedding -Feed EMS system -Zone IIA Protection -Power Oscillation Monitoring
2	SS Chania	-Voltage stability -Islanding detection -Loss of synchronism -Rate of change of active power to determine load shedding -Feed EMS system -Zone IIA Protection -Power Oscillation Monitoring
3	EHV Center Agios Stefanos	-Voltage stability -Feed EMS system -Power Oscillation Monitoring
4	SS Lavrio	-Voltage stability -Dynamic line rating with PMUs in both sides of the line -Feed EMS system -Power Oscillation Monitoring
5	SS Syros	-Voltage stability -Dynamic line rating with PMUs in both sides of the line -Feed EMS system -Power Oscillation Monitoring
6	EHV Center Meliti	-Voltage stability -Feed EMS system -Power Oscillation Monitoring
7	EHV Center Kardia	-Voltage stability -Feed EMS system -Power Oscillation Monitoring
8	EHV Center Nea Santa	-Voltage stability -Feed EMS system -Power Oscillation Monitoring -MPFC control for Power Oscillation Damping
9	EHV Center Acharnon	-Voltage stability -Feed EMS system -Power Oscillation Monitoring
10	EHV Center Trikalon	-Voltage stability -Feed EMS system -Power Oscillation Monitoring
11	EHV Center Acheloou	-Voltage stability -Feed EMS system -Power Oscillation Monitoring
12	EHV Center Lagkada	-Voltage stability -Feed EMS system -Power Oscillation Monitoring
13	EHV Center Pallini	-Voltage stability -Feed EMS system -Power Oscillation Monitoring
14	EHV Center Aliveri	-Voltage stability -Feed EMS system -Power Oscillation Monitoring
15	EHV Center Larymna	-Voltage stability -Feed EMS system -Power Oscillation Monitoring

V. LAB TESTBED

A lab testbed has been developed for pre-evaluating the developed algorithms with real-time controllers and laboratory tests. In particular it includes: a) a Real-Time Digital Simulator (RTDS) that simulates the Greek electric grid, where different faults can be forced. This makes it possible to connect actual intelligent electronic devices to it and perform hardware-in-the-loop tests; b) PMUs that take measurements from the RTDS amplifiers and generate C37.118 synchrophasors; c) PDCs where the different protection and monitoring services run; d) an NTP server used for synchronization via GPS; e) two routers that capture the traffic with the corresponding devices and send it through a tunnel to the other end. All WAMPAC algorithms were tested firstly in the laboratory environment. After an extensive debugging process, the algorithms met IPTO's network specifications and were installed in the PDCs that will be used in the WAMPAC implementation in Greece.

VI. KPIS - BENEFITS

Based on the Cost Benefit Analysis (CBA) methodology pursued in the context of the FARCROSS project, several KPIs have been identified to evaluate WAMPAC's impact that are presented in Table II.

VII. CONCLUSIONS

In this paper, the layout for a complete WAMPAC system to be used by the Greek TSO (IPTO), has been presented. Voltage and current phasor measurements acquired by PMUs, installed in critical locations of the Greek transmission network, will be collected by two PDCs utilizing IPTO's communication infrastructure. Through the real-time processing of these data, the WAMPAC tool will act as an upgrade to the existing SCADA schemes, providing wider and more accurate monitoring of the various assets, as well as improving the overall transmission system's performance and response under healthy, transient and faulty conditions.

TABLE II
WAMPAC KPIS.

No	KPIs	Description of KPIs
1	Decrease in Capital Expenditures (CAPEX)	Representing the total upfront investment required for the implementation of a project, CAPEX sum the net present values (NPVs) of the hardware used, including its installation, with the one of the various ICT components utilized within the WAMPAC framework
2	Decrease in Operational Expenditures (OPEX)	OPEX reflect the recurring costs that derive from a project's proper operation, as well as from its maintenance needs throughout a certain period. To correlate the project's feasibility, the respective O&M costs are converted to NPVs
3	Cost reduction due to the deferral of the Business as Usual (BaU) grid upgrades	This KPI will present a longterm revenue deriving from minimum targeted investment for the existing grids' optimization, given that future larger costs and complexities are avoided
4	Increase in utilization factor of large scale facilities	Through WAMPAC's action, increased grid observability is expected to provide better utilization of the existing power generation assets (conventional or RES). This KPI will thus reflect the act of WAMPAC as a supervising tool that provides optimal response and coordination between the various assets
5	Increase cross border utilization	WAMPAC will be used to monitor the real-time transmission conditions in lines connecting neighboring countries. Combined with the previous two indexes, it will present WAMPAC's contribution to the mitigation of typical problems such as underutilization of certain plants or lack of contingencies
6	Decrease the number of over/under voltage phenomena	Wider grid monitoring and more effective response under critical conditions are expected to limit voltage deviation occurrences. This KPI will exhibit the percentage drop in voltage dips or sags before and after the WAMPAC's implementation. Consequently, it will act as an index of voltage stability and power quality improvement resulting from the project's action
7	Decrease the number of lines overload situations	This KPI will assess WAMPAC's contribution to handling congestion and overload issues in cross border transmission connections. It will be calculated as a numerical difference of congestion events before and after WAMPAC's deployment, setting as a congestion threshold 75% of the OHL's rated ampacity value
8	Decrease the number of load or/and generator disconnec-tions	This KPI will provide a direct comparison of the grid's proper and secure operation, by calculating the difference of the number of unplanned generation and load disconnections prior and during WAMPAC's demonstration
9	Decrease the magnitude of inter-area active power oscillations	The specific KPI compares the average magnitude of interarea active power oscillations, as recorded for a total of k transmission lines, in the BaU and the WAMPAC demonstration cases, through the relative percentage calculation. The goal is to demonstrate the reduction of transient phenomena, which through WAMPAC's supervision must be detected and damped even more quickly and efficiently

REFERENCES

[1] A. C. Stratigakos, K. F. Krommydas, P. C. Papageorgiou, C. Dikaiakos, and G. P. Papaioannou, "A suitable flexibility assessment approach for the pre-screening phase of power system planning applied on the Greek power system," in *Proc. IEEE EUROCON 2019 -18th International Conference on Smart Technologies*, 2019, pp. 1–6.

[2] D. Cai, *Wide area monitoring, protection and control in the future Great Britain power system*. The University of Manchester, 2012.

[3] V. Terzija, G. Valverde, D. Cai, P. Regulski, V. Madani, J. Fitch, S. Skok, M. M. Begovic, and A. Phadke, "Wide-area monitoring, protection, and control of future electric power networks," *Proceedings of the IEEE*, vol. 99, no. 1, pp. 80–93, 2011.

[4] C. Rehtanz, N. Voropai, and U. Häger, *Requirements for Monitoring, Control and Operation*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2014, pp. 3–17.

[5] A. Bose, "Smart transmission grid applications and their supporting infrastructure," *IEEE Transactions on Smart Grid*, vol. 1, no. 1, pp. 11–19, 2010.

[6] C.-S. G. Karavas, K. A. Plakas, K. F. Krommydas, A. S. Kurashvili, C. N. Dikaiakos, and G. P. Papaioannou, "A review of wide-area monitoring and damping control systems in Europe," in *Proc. 2021 IEEE Madrid PowerTech*, 2021, pp. 1–6.

[7] National Electric Sector Cybersecurity Organization Resource (NESCOR), "Wide area monitoring, protection, and control systems (WAMPAC) - standards for cyber security requirements," Tech. Rep., 2012.

[8] S. Gamboa and E. Orduna, "Hierarchically distributed architecture for large-scale integrated WAMPAC system," in *Proc. 2015 International Conference on Electronics, Communications and Computers (CONIELE-COMP)*, 2015, pp. 16–20.

[9] P. Myrda, E. Gunther, M. Gehrs, and J. Melcher, "EIPP data management task team architecture," in *Proc. 2007 40th Annual Hawaii International Conference on System Sciences (HICSS'07)*, 2007, pp. 118–118.

[10] CIGRE WG C4.601, "Wide area monitoring and control for transmission capability enhancement," Tech. Rep., 2007.

[11] CIGRE WG C2.17, "Wide area monitoring systems - support for control room applications," Tech. Rep., 2018.

[12] [Online]. Available: https://www.admie.gr/

[13] ADMIE Holding, *Annual report*, 2019.

[14] J. F. Patino Duque, M. T. Villen Martinez, A. P. Hurtado, E. M. Carrasco, B. L. Sancho, K. F. Krommydas, K. A. Plakas, C.-S. G. Karavas, A. S. Kurashvili, C. N. Dikaiakos, and G. P. Papaioannou, "Inter-area oscillation study of the greek power system using an automatic toolbox," in *2021 IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe)*, 2021, pp. 1–6.

[15] [Online]. Available: https://www.smartwires.com/

[16] Y. Jacome, L. Figueroa, E. Palma, F. Calero, P. Loza, A. Carbajal, and A. Upreti, "Remedial action scheme based on synchrophasor measurements and system angle difference for Peru's 500 kv grid," in *Proc. 8th Annual Protection, Automation and Control World Conference*, 2017.

[17] Y. Gong and A. Guzman, "Synchrophasor-based online modal analysis to mitigate power system interarea oscillation," in *Proc. DistribuTECH Conference*, 2009.

[18] J. V. Espinoza, A. Guzman, F. Calero, M. V. Mynam, and E. Palma, "Wide-area measurement and control scheme maintains central America's power system stability," in *Proc. DistribuTECH Conference*, 2014.

[19] K. G. Ravikumar, A. Upreti, and A. Nagarajan, "State-of-the-art islanding detection and decoupling systems for utility and industrial power systems," in *Proc. 69th Annual Georgia Tech Protective Relaying Conference*, 2015.

[20] J. Mulhausen, J. Schaefer, M. Mynam, A. Guzman, and M. Donolo, "Anti-islanding today, successful islanding in the future," in *GRIDTECH*, 2011.

[21] F. Iliceto, O. Akansel, M. Akdeniz, S. Erikci, Y. Z. Korkmaz, and K. G. Ravikumar, "System integrity protection schemes in the 400 kv transmission network of Turkey," in *Proc 7th International Conference on Power System Protection and Automation*, 2018.