# SmartWAMS-The approaches for stability improvement in power system

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**Abstract**

The main cause of wide-area disruptions in the present power network is due to the relatively long transmission lines between regions, the continuous load growth without a corresponding increase in transmission network capacities. This disturbances have stressed power systems further and forced them operate closer to voltage and angle instabilities. As a result, stability of such power systems becomes a serious issue in operation and control process. In recent years, the advance technology of Wide Area Measurement System (WAMS) provides observability of the status of the power system to operators in real time. In addition to, preplaned corrective actions of WAMS can be taken to minimize the risk of wide-area oscillation, increase the power transfer capability of the system and led to advanced application in wide area monitoring, protection, control system.

*Keywords:* WAMS; SCADA-Supervisory control and data Acquisition; PMUs; Synchrophasor; RTU-Remote terminal unit.

## 1. Introduction

The complexity of operating and controlling large interconnected power systems, the continuous increase on demand of consumers are pushing power systems expand in size and experience significant changes in their operational criteria. On the other hand, rising concerns about stability of power system are forcing operators and utilities to be more careful about how far they can ensure reliable and efficient power supply to their consumers, there is an increasing need for close monitoring of the electric grid infrastructure. Real time situational awareness provided by an efficient wide area monitoring system is key to ensuring reliable power supply and a critical component of Smart Grid enablement in the transmission grid.

SCADA systems are designed to remotely acquire substation parameters from IED's (Intelligent Electronic Devices) and RTU's (Remote Terminal Units) and process this data to provide real-time operational support to the transmission grid [1]. However, recent developments in measurement, communications, and analytical technologies have introduced a range of new options. In particular, the evolving technology of Wide Area Measurement Systems (WAMS) and the use of Phasor Measurement Units (PMUs) have made accurate time synchronization facility using GPS (Global Positioning System) clocks, it is possible to monitor the dynamic of power grid more accurately and in real-time. This technology facilitates early detection of disturbances and degradation in the grid and helps prevent outages that conventional SCADA systems have failed to do [1]. The development of the synchronised PMUs which use advances in communications, computation capabilities and GPS technologies, provides the bases of WAMS, which offers utilities communication networks transmitted data at high speeds with low latency, enable measurement of voltage, current and frequency at very fast rates, and allow real time transmission of data to the central situational awareness control system. Wide Area measurement Systems (WAMS) open a new path to power systems stability analysis and control. These system are capable of providing a snapshot of the systems states in real time and update it every 20ms [3]. The enhancement of the system performance based on WAMS technologies includes [4]: (1) Avoiding large disturbances, improving exploitation of existing assets; (2) Increasing power transmission capability with no reduction of system security; (3) Better access to low cost generation; (4) Better visualization and assistance tools for operator to manage the system; (5) Assuring power system integrity. WAMS offer promising tools for better visualisation, better monitoring, better management, and better control of power systems.

## 2. WAMS application in power system

WAMS application to power systems can be recognised in three main areas: Protection, Control, and Monitoring [5]. A number of these applications are starting to evolve in many power systems around the global. A good examples are those being developed in Vietnam.

### 2.1. Protection

Recent blackout reports have identified that failings in protection systems have contributed to several recent blackouts [15, 16]. Therefore, the role that WAM may be able to play in enhancing power system protection has become an area of great interest.

One of the potential applications of WAMS in the wide area of power system protection is the possibility of developing adaptive protection schemes. Adaptive protection permits and seeks to make automatic adjustments in various protection functions so as to give better performance of the protection schemes. On the

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other hand, conventional relaying is determined by compromised setting of protection relays, which are reasonable for many alternative conditions that may exist in power system [3].

The overall objective of using wide area monitoring to enhance protection is to create new protection concepts that will make blackouts less likely to occur and less intense when they do occur. WAMS can contribute to power system protection are as follows [17]:

- ✓ Avoiding inappropriate relay settings for the prevailing system conditions
- ✓ Managing wide area disturbances
- ✓ Mitigating the impact of hidden failures
- ✓ Ensuring a suitable balance between the security and dependability of protection

The goal of protection is to protect individual elements of the power system from damage and to protect the security of the power system itself.

The most effective meaning for ensuring that the system will survive extreme conditions and wide area disturbances is a high degree of built in redundancy and strength. However, this over engineering of the system is not compatible with the economic and environmental demands placed upon modern power systems. Therefore, a significant role for wide area monitoring enhanced protection may be to enable system operators to deliver the existing level of security and reliability in these new operating conditions.

## 2.2. Control

As for protection schemes, wide-area synchronised measurement technology offers a unique opportunity to utilise wide-area system information in the design of control schemes that are aimed to enhance system performance and guarantee system stability.

Inter-area electromechanical oscillation has been one of the most severe threats for the safe and economic operation of modern power systems. This is due to increasing interconnections between utilities and increase in the amount of power transfer across these interconnections [6]. This phenomenon may reach to limit the amount of power transfer between regions, and it can cause the collapse of the entire system [13]. Most investigations show that the local measurement-based power system stabilizer (LPSS) is effective in damping local oscillation modes, but its effectiveness in damping inter-area mode oscillations is limited. Hence, damping of power system oscillations between interconnected areas is an important controlling task for secure and stable operation of power systems.

Power system oscillation are of two modes [7]. Local modes, which is the notion of the oscillation of one generator or one plant in an area against the rest of the system, and inter-area modes, which are associated with the oscillations of groups of generators or plants in different areas against each other.

Local modes of oscillation are largely determined and influenced by local area states and, in most cases, control measures in the form of local conventional power system stabilisers PSS can be sufficient enough to deal with them and provide the required damping for the oscillations. However, oscillation in the form of inter-area modes are not as highly observable and controllable using local system observations as local modes. As a result, control measures for inter-area modes of oscillations are rather complicated and, therefore, concerns arise in this area giving the rising complexity of power systems [13].

Sine inter-area oscillations are more of a wide-area phenomenon, the applications of WAMS via phasor measurement unit (PMU) have influenced the future of development of advanced technique implemented in electrical power engineering. The WAMS will be a solution of the smart grid implementation, and WAMS for smart grid applications involves the power system measurement, monitoring, protection and control. Wide-area signal measurements provide by WAMS can be utilised to provide appropriate remote signal to optimally located damping devices, such as PSS or FACTS (Flexible AC Transmission Systems) controllers, to damp the oscillations. Thus, allowing maximum utilisation of interconnections without violating stability, security and reliability constraints. Applications of WAMS for control of power system oscillations can be categorised based on three control design techniques which are:

- ✓ De-centralised controllers
- ✓ Centralised controllers
- ✓ Multi-agent controllers

## 2.3. Monitoring and Recording

To ensure system stability in a over loaded system, all or most installed components should remain in service and right actions must be taken quickly if the system has not recovered after a serious event. Meeting this requirement, the solution is to have real time monitoring. Such a wide area measurement system provides operators with real time knowledge of various instability issues and events as they occur. This early warning system provides operators with much needed time for counteraction as well as choices for suitable action. Eventually, such a system can provide leading operator guidance on the best course of action as well as a base for automatic wide area control.

The implementation of WAMS technologies in power system significantly improves the possibilities for monitoring and managing power system dynamics [8].

Besides the improvement in the monitoring and recording of power system dynamics, WAMS enables the improvement of the task of state estimation [9]. The inaccuracy and delays of traditional SCADA systems can be eliminated by PMU/WAMS based systems. The accurate time-stamped data provided by PMUs can be used as the basic for improved state estimations; thus, allowing instant calculations of system states. Based on fast, accurate and reliable state estimation, a variety of online system stability indices regarding different stability phenomena can be made available for system operators. As a result, the task of optimised operation of existing power systems can be fulfilled.

## 3. Wide Area Monitoring System in Vietnam

The main cause of wide-area disruptions in the present Vietnam National Power Transmission (NPT) network is due to the relatively long 500kV transmission line between Hoa Binh (Northern region) and Ho Chi Minh City (Southern region), which is susceptible to voltage and angle instabilities when there are variances in load and generation sources.

Synchrophasor technology provides observability of the status of the power system to operators in real time, which facilitates the calculation of the maximum loading condition for each system bus connected to the transmission network. Furthermore, pre-planned corrective actions can be taken to minimize the risk of wide-area disruptions and increase the power transfer capability of the system. The availability of a high speed, high-bandwidth network architecture makes synchrophasors ideal for this application.

WAMS is a key Smart Grid application because its data provides the basic raw input for a large number of advanced functions serving network operation and control. NPT has already planned to develop advanced synchrophasor applications and functions for wide-area real-time control actions such as under voltage load shedding of noncritical loads, contingency-based remedial action schemes, automatic generation tripping, switching of shunt capacitors and system islanding detection.

All of them will be extremely useful but there are further applications that can use PMU data to deliver improved monitoring and control of the Vietnamese transmission network. In the main these applications are oscillation detection and monitoring, phase angle monitoring, voltage stability monitoring, event detection and management, alarming, backup and integration for SCADA system.

In the following section, the four most significant applications will be described briefly, suggesting possible techniques and implementation strategies to apply as well as underlining their added value [2].

### 3.1. Transformer on-line monitoring

Transformer is the most important and expensive device of grid. The main monitoring functions for transformer protection are: (F63) Hot-spot temperature; (F87) Top-oil temperature; (F49) Winding temperature; F50/51 Gas dissolved content; (F64) Partial discharge; Oil flow…[14].

A transformer's length of life depends on the life length of its insulation. While the insulation life depends mainly on the temperature of the operational winding hot-spot. Methodology for transformer out of paper insulation decays when overloading uses monitoring functions integrated in WAMS, which applies IEC standard 60076-7&60354 for oil-immersed power transformers and IEEE standard C57.91 for mineral-oil-immersed transformer. Data, which are collected from WAMS, alarm and forecast remote to operator in control centre.

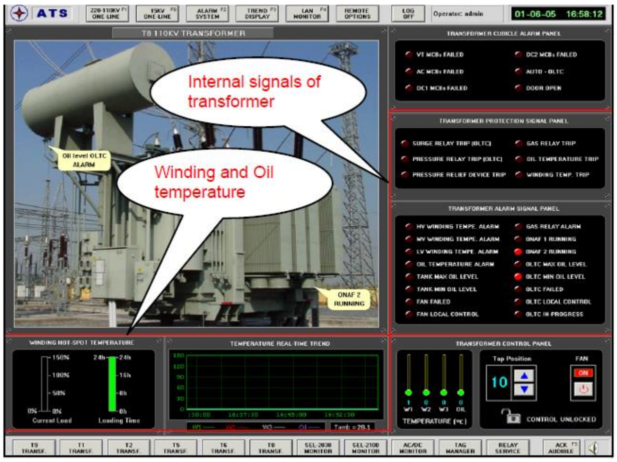


***Figure 1.*** *Transformer parameters on display screen*

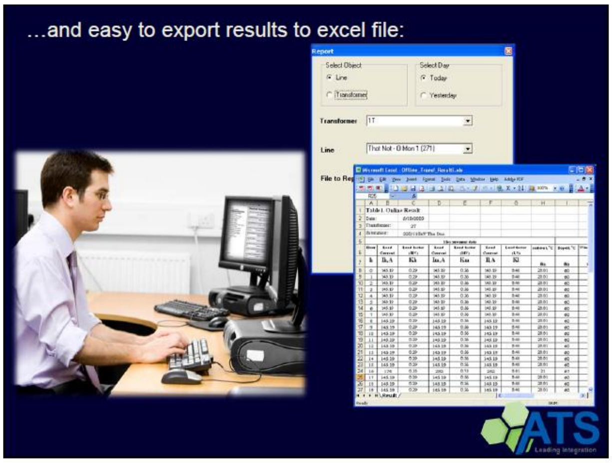


***Figure 2.*** *Computational Results Layout in control centre*

### 3.2. Transmission line on-line monitoring

The on-line ampacity of transmission over head line is main reason for increasing Available Transfer Capacity (ATC), improving system security, saving cost. The factors of conductor temperature are load current, ambient temp, solar radiation, wind speed…The methodology for monitoring conductor temperature of transmission line trigged Thermal Behaviour model (CIGRE WG 22.12) [14] in WAMS.

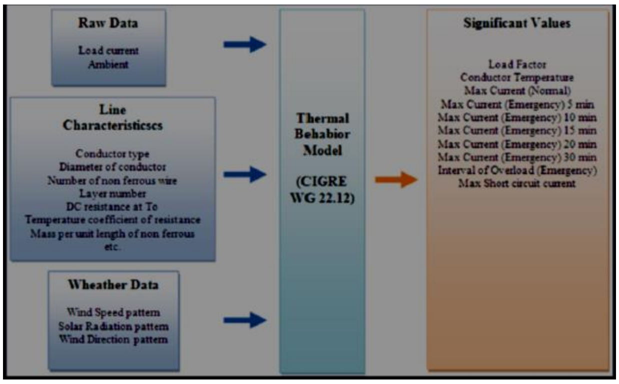


***Figure 3.*** *Input/output of Thermal Behaviour Model*

Benefit of using this model is maximize productivity with knowledge-based maintenance critical assets.

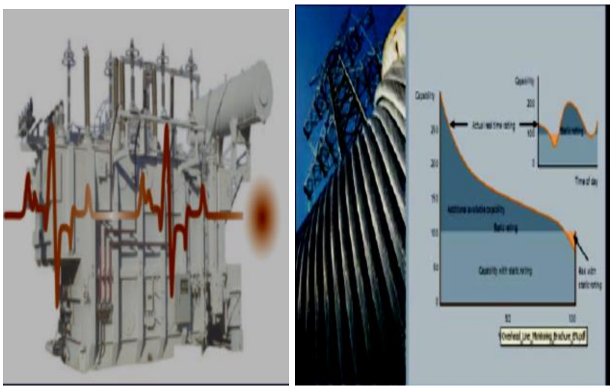

***Figure 4**. Thermal monitoring of transformer oil and overhead line*

### 3.3. Voltage stability monitoring

In the literature on the subject there are many articles of Wide Area Measurement based voltage instability detection algorithms. PMU measurements have been used for voltage instability monitoring because of their greater precision rather than for their time-synchronization. Voltage stability, in fact is more a local than a network wide phenomenon. An effective voltage instability predictor is the S-Difference Index. This index is based on the variation of complex power at the receiving end of a transmission line.
The first condition is the normal system operation behaviour, when voltage and current phasors change at a very slow rate and may be negligible. The latter is the operating condition when a voltage collapse occurs. Every increase in the source of the transmission line is not reflected by any increase of the complex power at the receiving end, even though voltage and current phasors vary significantly over time.
The SDI (S-difference indicator) algorithm is proposed as a voltage stability monitoring feature but it could trigger corrective actions, like under voltage shedding, once implemented as the trigger (or part of it) logic of an under voltage load shedding relay.
Although SDI is maybe the simplest implementation index, it is just as the ISI (Impedance stability index) based on local bus measurements. There are other algorithms and Mathematical models developed for voltage stability monitoring, in most cases based on Thevenin equivalents (e.g. Voltage Instability Predictor – VIP, VIP++ [10], [11]). The precise methodology and the prediction algorithm to be implemented for voltage instability monitoring is a matter that should be investigated further taking account of the particular Vietnamese issues and the requirements for EMS (Energy management system).

### 3.4. Oscillation detection and monitoring

Another key application of the wide area monitoring system consists of a real time and off-line identification of oscillatory behaviours. The identification of unstable modes and the knowledge of their damping made it possible to determine the degree of stability of the operating condition. The subsequent analysis of the participation factors of such a condition can suggest the appropriate measurement that will need to be implemented [12].
There are lots of techniques that are available for stability monitoring and include nonparametric, parametric and subspace methods, maximum likelihood estimation, etc. All of them aim to identify weakly damped oscillatory behaviours, mainly inter-area, with a particular focus on the time at which these dynamics took place and their trend. All these techniques are usually fed by significant data from the power network such as active power flows or system frequency, where the power spectral density of the electromechanical modes is greatest.
These measures have merits and demerits that are often complementary and it is for this reason that the use of more than one method not only serves to validate the various improvements, but also helps to better validate the information obtained.
Furthermore, post-event analysis of the results obtained by the application of these techniques, both of single events (contingencies, relevant oscillations, etc.) and of long sequences of events, could help to identify the characterization of the dynamic behaviour of the Vietnamese transmission system and increase awareness of transient stability assessment. The study of the distribution of frequency and damping has proven useful with the identification of typical oscillatory modes crossing the different parts of the electrical network and have aided in the investigation of the effects of possible different damping values.
Finally, this experience of monitoring oscillatory modes, especially inter-area, will be very useful for future interconnections with neighbouring countries. In a large interconnected network, inter-area oscillations are frequent and it is important to be prepared to identify and adopt countermeasures against this type of system behavior.

## 4. Demo model of smart-WAMS in Vietnam grid.

Monitoring range: Entire Vietnam 500kV grid.
Number of PMU installed in substations: 17

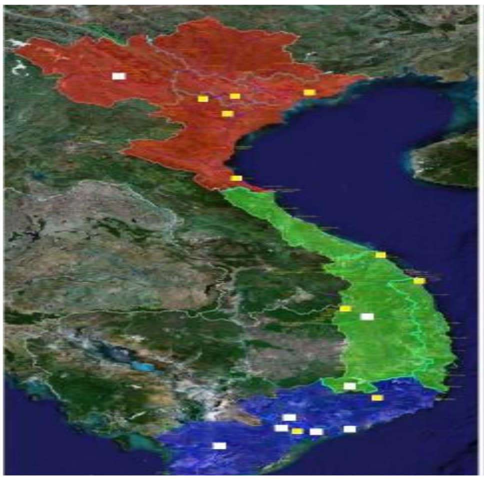

***Figure 5**. PMU locations in 500kV Vietnam grid*

Implement re-calculation blackout on the Pleiku-Dak Nong power line (southern in Vietnam) happening 22 May 2013 by PSS/E. The voltage at the adjacent busbars with shortage Pleiku-Dac Nong line significant reduced (voltage damping rate at Di Linh bus 1.07% and Dak Nong bus 1.21%).

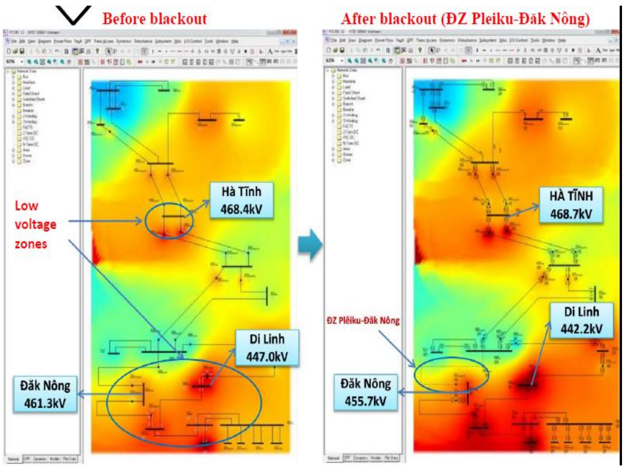


***Figure 6****. Calculation results on PSS/E when blackouted Pleiku-Dak Nong power line (22 May 2013)*

Then running smartWAMS model from the results gained by calculating and analysing operation of system via parameters as voltage, phase angle, changing of frequency, power flow, voltage sensitivity, phase angle sensitivity.

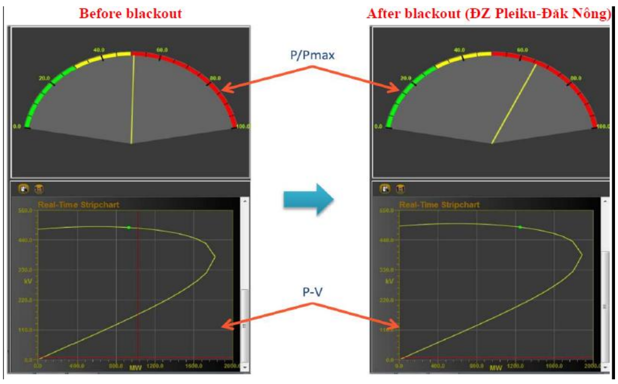


***Figure 7****. Voltage sensitivity on SmartWAMS*

## 5. Conclusion

Wide area monitoring (WAM) is one of the most significant new developments in modern power systems. Through developments in synchronized measurement technology and the creation of phasor measurement units (PMUs), WAM is able to offer a real time view of the dynamic behavior of a power system that updates once per cycle. This information has proven an invaluable resource for creating new applications that can benefit power system stability.

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