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## **Benefits of Synchrophasors in Operation of the Future Grid**

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### **SUMMARY**

Phasor measurement units (PMUs) are being increasingly deployed across electric power grids worldwide. PMUs produce sub-second, high resolution, time-tagged synchrophasor measurements which augment the traditional 2-4 seconds asynchronous SCADA measurements. For the first time in history, control centers will be provided with a time-synchronized view of grid conditions.

This paper describes a revolutionary new paradigm where high-resolution (up to 60 samples a second) synchrophasor “measurement-based” analytics complement and augment traditional “model-based” analytics used in control center Energy Management System (EMS). An advanced visualization framework synthesizes information from the various analytics to provide operators with not just improved ‘situational awareness,’ but, more importantly, ‘actionable information.’

The benefits of applying synchrophasor applications within control center EMS systems include:

- Maximizing utilization of existing transmission capacity by confidently operating the grid closer to its actual, ‘true’ operating limit,
- Providing an early warning system to quickly identify grid disturbances and to guard against blackouts,
- Providing alerts to undesirable grid oscillations,
- Identifying islanding conditions, and
- Enabling efficient post-disturbance analysis - what happened, where and why?

These new capabilities will significantly enhance the future grid’s control center operator’s ability guard against blackouts to keep the lights on.

### **KEYWORDS**

Synchrophasors, PMUs, EMS, Control Center, WAMS

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Since the 1970s, system operators have relied primarily on SCADA (Supervisory Control and Data Acquisition) measurements to monitor the electric power grid. These measurements are asynchronous and typically updated every 2-4 seconds. Corrective action is predicated on intelligent analysis of SCADA data and human intervention. This is an inherently slow decision-making process. Since many of the disturbance phenomena we are trying to protect the grid against occur very quickly, the industry needs faster measurements and faster controls that do not require operator intervention.

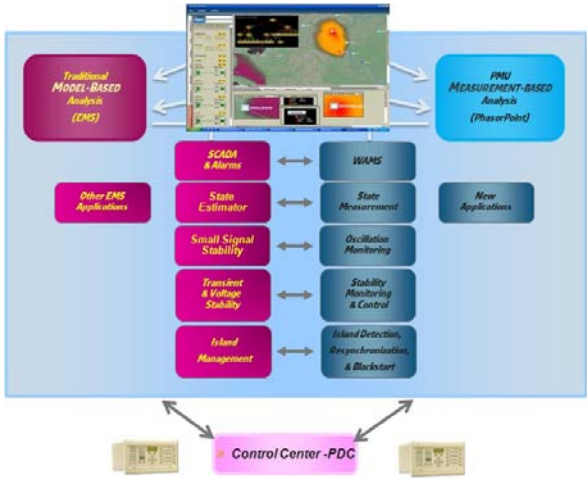
Synchrophasors are sub-second rate power system measurements of three conditions: three-phase voltages and currents, frequency, and rate of frequency change. These measurements are time-stamped to a common global time reference. This provides synchronized real-time monitoring of multiple remote points on the electrical grid and also provides monitoring of rapid shifts in grid behavior.

Synchrophasors are measured by Phasor Measurement Units (PMUs). A PMU can be a dedicated device, a meter, or any measuring device that can accept a global time reference and properly time-stamp power system measurements. A single PMU device typically provides 12-16 synchrophasor measurements.

For the first time in decades, utility EMS control centers will see some major new enhancements, driven by the growth of PMUs.

Because synchrophasors provide an instantaneous, synchronized view of the grid’s state, we can identify and locate abnormal behaviors more quickly. They also monitor the dynamic behavior of the grid. For the first time in history, the control center will benefit from snapshots of the grid based on sub-second, synchronized measurements. This allows for introduction of a new generation of innovative Energy Management System (EMS) software to analyze abnormal as well as dynamic behavior and to take corrective action (if required) automatically without operator intervention.

Figure 1 below is an illustration of today’s advanced EMS. With the introduction of fast synchrophasor measurements into the control center, the EMS now has real-time visibility into the dynamics of the power system. This complements the visibility of the steady-state behavior of the grid with traditional SCADA measurements.



**Figure 1: Advanced EMS with Synchrophasor Analytics**

The left side of Figure 1 above shows the traditional EMS ‘model-based’ applications that have evolved over the past several decades; these applications utilize a model of the grid to perform analyses. The right side of Figure 1 above shows the new ‘measurement-based’ applications that are being introduced in control centers today; here, no grid model is required since the actual power system serves as the model. These applications rely on sub-second PMU data and are sometimes called Wide-Area Monitoring Systems (WAMS). WAMS utilize very high volumes of data, the inherent challenge of which lies in transforming this massive amount of data actionable information.

The range of advanced analytics currently available in WAMS includes:

- Angular Separation
- Oscillatory Stability
- Disturbance Location Identification
- Islanding and Resynchronisation

One focus of analytics for synchronized measurement data is the extraction of information independently from a system model and without full observability. The approach is particularly valuable for large interconnections where the individual system operators do not have full observability or models of the entire system.

The traditional EMS does not monitor oscillations in the grid. Oscillations are continually happening on the grid and, fortunately, most of them simply disappear over time. The ones we care about the most are those that are not ‘damped,’ meaning they do not disappear gradually over time and hence corrective action is needed to mitigate their impact on the grid. Today, grid oscillations are essentially invisible to control room operators. With the introduction of synchrophasor applications we will be able to monitor and observe them. This further enhances operator situational awareness, which is an essential first step for informing proper operator decision-making.

EMS applications are also available to advise operators on how to fix oscillations with corrective actions such as re-allocation of generation and switching reactive resources such as capacitors. Operators want to fix problems, not just observe them!

Many of the new synchrophasor analytics complement and corroborate traditional EMS analytics and can therefore be used together to jointly validate and fine-tune the analytics themselves, for improved precision and accuracy. For example, the oscillation monitoring analytic using a network model can be ‘married’ with its counterpart measurement-based analytic to compare results and gradually improve the network dynamic model parameters. Similarly, other model and measurement-based analytic ‘marriages’ can provide beneficial synergies; these include SCADA and WAMS, State Estimator and State Measurement, Voltage Stability Monitoring, etc.

A key additional benefit of model-based analysis is that it can perform “what-if” analysis to study potential contingencies and to simulate transmission stress, to determine the most limiting operational limit (OL) for a particular transmission corridor. This OL can then be used in the faster measurement-based analytic to quickly alert the operator to when a limit is being approached.

Model-based analytics can perform what-if studies to study alternate projected scenarios of future grid conditions. These analytics determine the current, critical system operating limits online, the security margin, and how the margin is trending over time. A key benefit of model-based analytics over measurement-based analytics is that they can identify and recommend solutions to problems; i.e. propose a course of action to mitigate problems.

Measurement-based analytics can quickly identify if there is a problem in the grid and where it is, and model-based analytics can determine the appropriate corrective actions. This provides operators with exactly what they need - 'actionable information.'

Working in tandem over time, the respective EMS and synchrophasor analytic 'marriages' will produce more accurate and reliable results, as well as up-to-date, real-time operational limits and faster limit alerts. This will further enhance operator trust in the analytics; this trust is an absolute necessity if we want the operator to subsequently 'pull the trigger' and implement controls to protect the grid.

Through application of this technology, utilities will be able to do a much better job of maximizing the utilization of their existing transmission assets. They will be able to use synchrophasor measurements to improve the models on which their EMS tools are built. This will result in more accurate evaluation of transmission congestion as well as more aggressive, confident decision making.

*Here's an example.* Many 500 KV transmission systems have restrictive congestion operational limits that are designed to protect the grid in the event of a disturbance. The operator manually enters these limits in the EMS in order to ensure load on the lines do not violate the congestion limit; these limits are not changed very often and hence need a built-in safety factor to accommodate the diverse varying system conditions that occur throughout the day. Having time-stamped, real-time data about the grid will allow us to relax the safety factor and operate the system closer to the real limit by intelligently changing this limit dynamically, during the course of the day, based on analysis of current system conditions.

Operating this way has the additional benefit of avoiding new transmission line construction just to meet an unrealistically high and somewhat pessimistic safety margin. It is very expensive to put in a new line. It is also very time consuming, because transmission lines traverse hundreds of miles and rights-of-way have to be established and neighbors very often object.

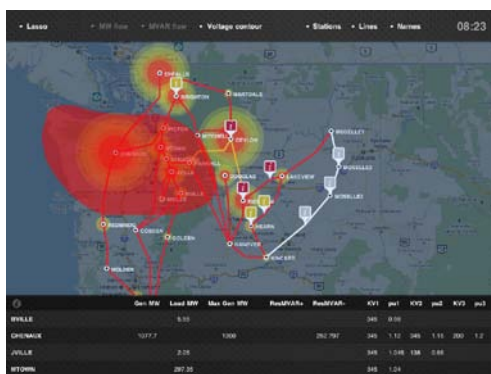
*Advanced Visualization...* With the sudden growth of analytical capabilities and applications in an EMS it is essential to translate the results and data from the various sources into information that needs immediate operator attention. This requires an advanced visualization framework that intelligently processes data and results from multiple diverse sources and then prioritizes and condenses it into a 'dashboard' for operator review, so as to improve operator situational awareness.

From Contemporary Psychology: "Situation Awareness (SA) is, simply put, understanding the situation in which one is operating." SA is more comprehensively defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." The inherent challenge of SA is to maximize human understanding and comprehension without increasing operator stress.

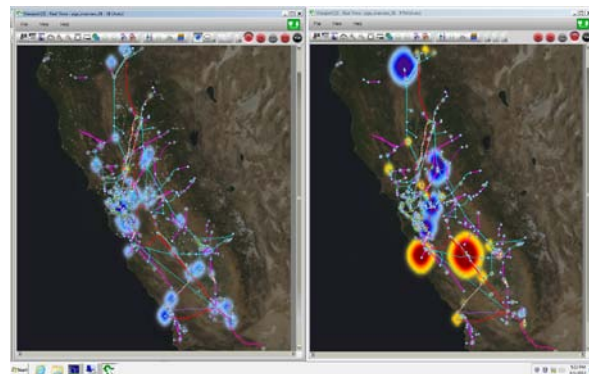
Recent trends that are advancing visualization capabilities for power grid operators include:

- Geospatial displays & Geographic Information Systems (GIS)
- MS Virtual Earth, Google Maps and Google Earth
- Visual Correlation techniques
- Citrix to share common displays
- iPad displays for mobile, decentralized decision-making

Figures 2 and 3 below are examples of recent advances in visualization capabilities being implemented in control centers. Figure 2 is an iPad display that is shared by various utility stake-holders; these stake-holders include the EMS operator, field engineers, operations engineers, planning engineers, protection and control staff, managers and executives. Looking at a common display snapshot facilitates and expedites shared decision-making since they are all simultaneously looking at the same picture. Figure 3 on the right is a depiction of how a sudden grid disturbance is portrayed to an operator – the left panel shows the normal pre-disturbance conditions and the right panel shows the post-disturbance condition, where there are multiple regions of voltage violations; red & orange contours indicating low voltage regions and blue contours indicate high voltage regions.



**Figure 2: iPad display of Violations**

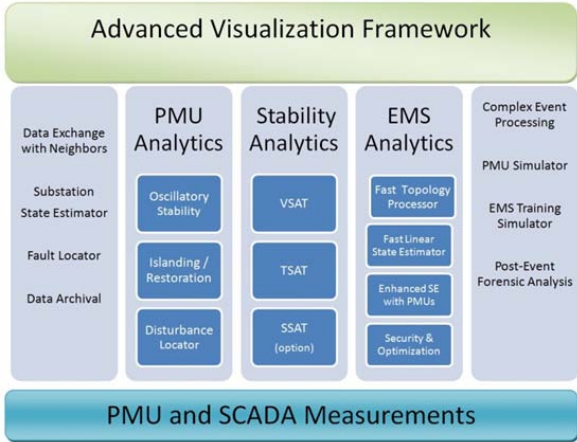


**Figure 3: Pre- and Post-disturbance Voltages**

Integrating advanced visualization with EMS synchrophasor measurement-based analytics provides a significant enhancement to operator situational awareness and the ability to identify a grid problem quickly. Next, if model-based EMS analytics are also integrated they can recommend corrective and preventive actions to take, to correct the problem. This provides the operators with ‘actionable information’ upon which he can act.

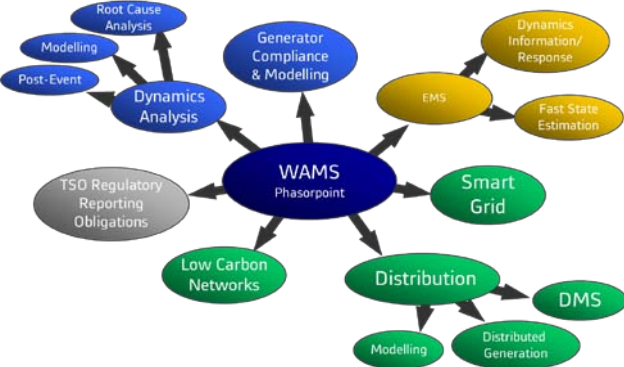
*To reiterate....* Operators do not just want to know that ‘we have a problem’, they want to know ‘how can we fix the problem?’

Figure 4 below is an illustration of this new advanced EMS paradigm for the future grid and is being implemented at a proof of concept facility at a major utility in California. This project will be completed in 2013.



**Figure 4: A Practical Integrated Advanced EMS Solution Suite**

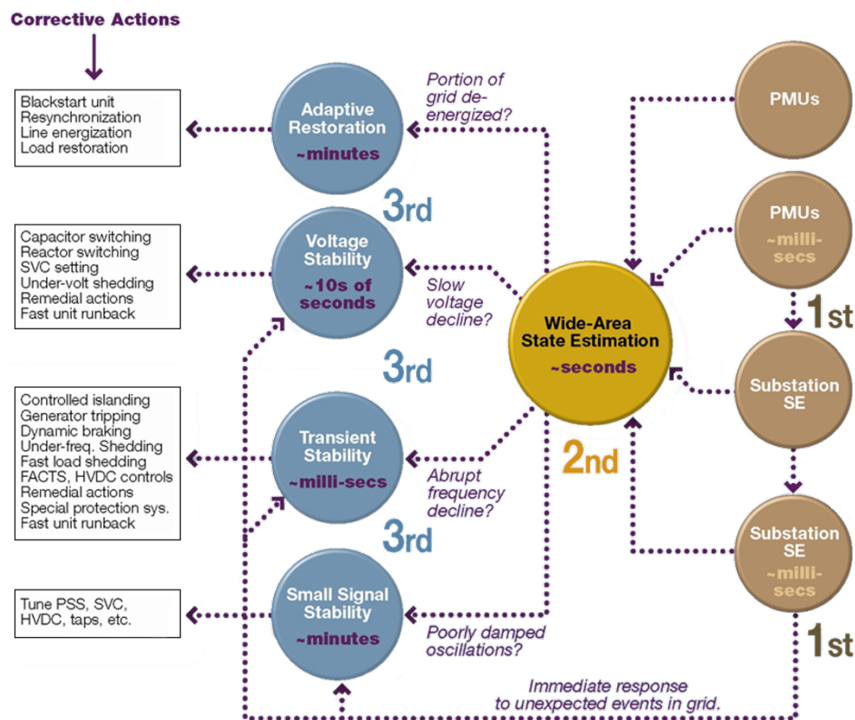
In the future grid, wide area monitoring systems (WAMS) will be the axis for the other grid analytical intelligence spokes, since it contains the mother-lode of fast high-resolution grid data that are needed by these other applications. This is illustrated in Figure 5 below.



**Figure 5: WAMS: source of real-time data for other advanced grid analytics**

In the future grid, automation will be deployed at various levels of voltage to provide local control as well as wide area control. As the industry gains confidence and trust in the synchrophasor data, advanced automation controls are a logical next step. These will happen in a decentralized manner across the entire grid.

Figure 6 is an illustration of this pragmatic vision of wide area decentralized automation and control. The vision is that grid automation will respond to disturbances locally first and try to contain and fix the problem locally, and will only invoke central wide area automation and control when absolutely needed.



**Figure 6: Future Grid: Local and Global Automation & Control**

*In Closing....*The electricity grid is too complex to eliminate blackouts completely. Deployment of WAMS will enable enhanced system monitoring, advanced measurement and control technologies, and innovative analytics to help reduce the number of blackouts or help contain a local blackout from becoming a widespread system outage.

The 2003 blackout on the East Coast was estimated to cost the U.S. economy \$6 to \$8 billion. Preventing or mitigating losses of this magnitude quite easily justifies increased funding for new investments in emerging technologies such as synchrophasors.

With PMUs at all major substations across the future grid, operator situational awareness will be significantly enhanced. Coupling these PMU synchrophasor measurements with fast acting controls - such as FACTS, SVCs and HVDC - will significantly enhance the ability of the grid to automatically protect itself.

## BIBLIOGRAPHY

- [1] J. Giri, D. Sun, R. Avila-Rosales, "Wanted: A More Intelligent Grid", IEEE Power & Energy Magazine, Digital Object Identifier 10.1109/MPE.2008.000000, jan/feb 2009
- [2] D. Wilson, et al, "Identifying Sources of Damping Issues in the Icelandic Power System", PSCC, Glasgow, UK, 2008
- [3] D. Novosel, V. Madani, et al, "Dawn of Grid Synchronization", IEEE Power & Energy Magazine, Digital Object Identifier 10.1109/MPE.2007.911811, jan/feb 2008