

Real-Time Modal Analysis Scheme Maintains Central America's Power System Stability

J. VICENTE ESPINOZA

AMM-Guatemala

Guatemala

A. GUZMÁN, F. CALERO, M. V. MYNAM, and E. PALMA

Schweitzer Engineering Laboratories, Inc.

United States

papers@selinc.com

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1 INTRODUCTION

The power system in Guatemala, besides serving its local loads, also serves as the power corridor from Mexico to other Central American countries via its interconnection with El Salvador. The regional transmission network (RTN) interconnects Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. Guatemala is the most northern country of the Central American RTN and links the Central American network to the Mexican power system.

The Mexican power system (50 GW) is significantly larger than the total interconnected Central American system (7 GW) and is a very strong system compared with the Central American system.

Figure 1 illustrates the Central American Electrical Interconnection System, or SIEPAC (Sistema de Interconexión Eléctrica de los Países de América Central). A 230 kV transmission network wheels power among the members of this power system.

A 400 kV line from the Tapachula substation in Mexico to the Los Brillantes substation in Guatemala interconnects the two power systems. A power transformer steps down the voltage level to 230 kV, which is the SIEPAC transmission voltage level. The transmission system in Guatemala distributes the imported power to the local loads, but mostly wheels the power from Mexico to the SIEPAC system via the Ahuachapan substation in El Salvador.



Figure 1: Central American Electrical Interconnection System (or SIEPAC)

2 SYNCHRONIZED MEASUREMENTS IN GUATEMALA

In 2008, the wholesale electric market administrator Administrador del Mercado Mayorista (AMM) identified the benefits of using synchrophasor technology to operate the power system in Guatemala.

Based on their knowledge of the characteristics of SIEPAC interconnections and operating experiences with the Mexican power system, AMM conducted several power system stability and operational studies. Moreover, during the operation of the power system, occurrences of instability and blackouts provided information to propose a wide-area protection scheme (WAPS) to aid in guaranteeing secure operation of the power system. The implementation of the AMM wide-area supplementary control scheme (SCS) started in 2011.

One of the challenges of operating the interconnected system is complying with the security requirements of the interconnection with Mexico. In the past, the link with Mexico was not allowed to operate during certain periods of the day when the system is more prone to instability. This operation limitation was not in the best interest of AMM because not having the link with Mexico can compromise the security of the Guatemalan power system. AMM also has economic reasons for this interconnection.

2.1 Synchrophasor-Based Monitoring System

AMM now monitors the operation of the Guatemalan power system using supervisory control and data acquisition (SCADA) and synchrophasors. A traditional SCADA system is in operation supplying the pertinent data to the operators every 4 seconds.

AMM operators also have access to visualized, real-time synchrophasor data, which are updated 30 times per second. The faster rate allows the operator to view and recognize transients never seen in the SCADA system [1]. Preexisting but invisible phenomena are now visible and actionable due to low latency and the simultaneous measurement of information (data coherence). This overcomes the infrequent and incoherent data collection associated with typical SCADA client-server communication.

2.2 Control Using Synchrophasor Data

Synchrophasor data can be used to take control actions [2] [3]. AMM identified this technology and implemented several schemes as part of its wide-area SCS based on synchronized measurements refreshed 30 times per second. This refresh rate allows for fast control applications with operating times of less than 100 milliseconds, which is not possible with the slower refresh rate (once every 4 seconds) of traditional SCADA.

3 WIDE-AREA SCS DETAILS

3.1 Phasor Measurement and Control Units

The phasor measurement and control units (PMcus) used in this application have accurate synchronized measurement capabilities and receive control commands from the synchrophasor processing unit (SPU) where the control logic has been implemented. The PMcus report measurements at 30 messages per second, and they have the capability to report up to six single-phase voltages and six single-phase currents. The wide-area SCS collects three-phase voltages and three-phase currents at each monitoring node on the transmission line terminals.

The PMcus have programmable logic where schemes based on local information can be implemented. In addition to synchrophasor data, the PMcus have the capability of sending 16 analog and 64 binary bits in the IEEE C37.118 data stream.

Some of the programmed local functions in the PMCU calculate the derivative of the power and the derivative of the voltage with respect to time, which are monitored at the control center.

The total number of PMCU devices to be installed in the power system is 22, with 16 installed at the time of this writing.

3.2 Communications Infrastructure

AMM does not own a wide-area communications network. Fortunately, the substations in Guatemala can be accessed via a communications service provider.

Each PMCU sends two data streams over the Ethernet network. Figure 2 shows the two synchrophasor message streams sent by one PMCU. Stream 1 goes to the control center phasor data concentrator (PDC) for publishing and archiving. Stream 2 goes to the online SPU, where control logic runs. There is a second, offline SPU that receives a repeated set of the synchrophasor messages received by the online SPU, and this second SPU is used to test and qualify control logic using the same data that the online SPU receives. AMM has found the offline SPU concept to be very useful for testing control logic and validating the programmed algorithms using active power system data. When the algorithm has been verified, it is sent to the online SPU for actual use.

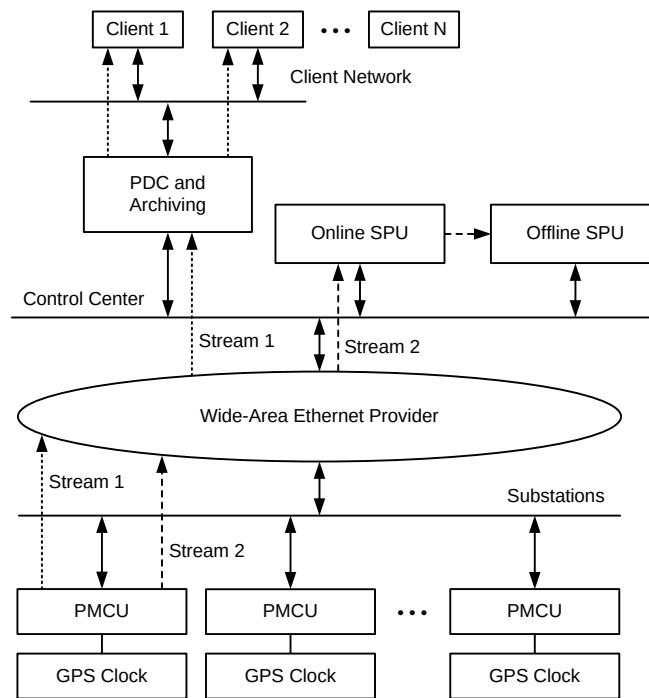


Figure 2: Synchrophasor data paths across the Ethernet network

The architecture in Figure 2 is typical for synchrophasor systems. In this application, no redundancy has been planned for the system. The software PDC that runs in a server computer collects synchrophasor messages at 30 times per second and publishes the data to several visualization clients in the control center.

The hardware where the software PDC is installed has a very large data storage capacity. It is equipped with 2 TB of storage. The system is set up to store every measurement sent to the PDC, and the system stores about 2 GB per day.

3.3 Control With Synchrophasor Data

Figure 2 shows the SPU receiving Stream 2 from a PMCU. The SPU can time-align synchrophasor messages from up to 20 PMCUs and has an IEC 61131 engine to customize the required logic.

The time-aligned synchrophasors, analog quantities, and binary bits in the IEEE C37.118 message sent by the PMCUs are available to the programmable logic engine of the SPU and can be used as inputs to prebuilt functions, like AND and OR logic gates, math functions, and timers. Advanced functions like modal analysis are also included in the SPU to create advanced algorithms. Furthermore, the SPU can send trip commands to the PMCUs. The IEEE C37.118 data stream carries the synchronized measurements to the SPU. With the same network configuration, the SPU sends control bits embedded in the IEEE C37.118 command message. In this application, the PMCUs decode the commands to trip the corresponding circuit breakers.

4 WIDE-AREA SUPPLEMENTARY CONTROL SCHEME IMPLEMENTATION

At Aguacapa and Moyuta, two PMCUs stream synchronized measurements to the online SPU at the control center (see Figure 3). This SPU collects the voltage (V) and current (I) phasors and calculates the active power flow exchange between Guatemala and El Salvador. P_{AGU} is the active power of the Aguacapa line, and P_{MOY} is the active power of the Moyuta line. The SPU calculates the total power flow ($P_{TOT} = P_{AGU} + P_{MOY}$) using the synchronized measurement from both terminals. The coherency of the measurement in P_{TOT} can be used to implement decisions based on its magnitude as well as its modal content obtained from modal analysis.

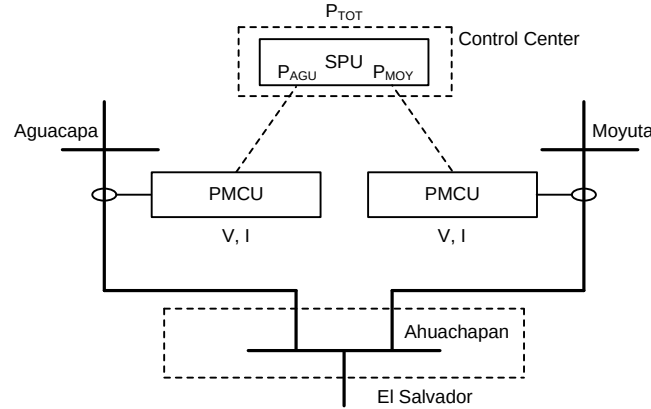


Figure 3: Interconnection between Guatemala and El Salvador

4.1 Power Level Scheme

A power level scheme was previously implemented by programming the protective relays on the Aguacapa and Moyuta lines. These magnitude level checks were not reliable because decisions were made on measurements from individual lines.

An SCS that is based on the architecture shown in Figure 2 and uses the total power exchange P_{TOT} to open the interconnection is a better choice than the power level scheme implemented in protective relays.

4.2 Modal Analysis Scheme

A real-time modal analysis scheme is also part of the SCS. Modal analysis uses synchrophasors to estimate power system oscillation modes and their associated amplitude and damping ratio. Low damping ratio values are good indicators of possible unstable oscillations. Therefore, having an early indicator to alert operators or a control scheme that triggers a remedial action to prevent growing oscillations that can cause system collapse is beneficial to the operation of the power system [4]. Typical oscillation modes for inter-area oscillations are in the order of 0.2 to 0.7 Hz, and local-area oscillations are in the order of 0.7 to 2.0 Hz [5].

4.3 Identification of Oscillation Modes

Based on the operating experience and recorded data of oscillatory events from AMM, oscillating modes that cause instability were identified and used in a modal analysis scheme that detects these undesired oscillations.

One such analysis is shown in Figure 4. Modal analysis on the active power flow from Guatemala to El Salvador showed a 0.19 Hz oscillation with a decreasing damping ratio that eventually became negative, as indicated by the growing oscillation in the power exchange. Additional system events also confirmed that the 0.19 Hz mode typically results in underdamped oscillations. This analysis used a 20-second observation window of synchrophasor data recorded at 30 messages per second.

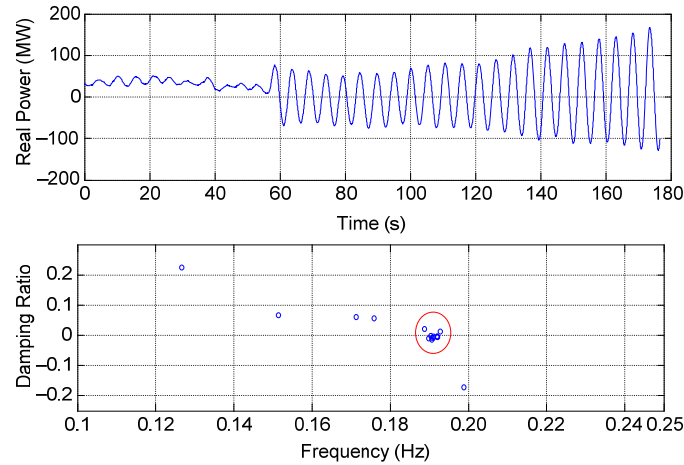


Figure 4: Modal analysis identifies 0.19 Hz oscillations

4.4 Real-Time Modal Analysis Scheme

This scheme uses synchrophasors to calculate the active power exchange between Guatemala and El Salvador. The modal analysis scheme also uses the time-synchronized power measurements of the two lines that interconnect these two countries. This active power sum P_{TOT} is the input signal to modal analysis. Modal analysis calculation results include the following information for each mode: amplitude, phase, frequency, damping, and damping ratio. The results of the modal analysis calculations are configured in the local PMCU server to output the modal analysis data to an external IEEE C37.118 client for monitoring purposes. The modal analysis calculation results are also available to the mode identification and control logic (MICL). MICL identifies a particular mode frequency, issues oscillation alarms and trip commands when the mode amplitude exceeds a user-programmable threshold, and enables the damping ratio check. Low damping ratio values (less than 0.05 per unit) activate the damping ratio alarm. If the mode damping ratio is decreasing and its amplitude is increasing, the logic activates a remedial action command. The alarms and remedial action command are routed to selected external devices through the command server.

4.5 Operational Experience

Time-synchronized measurements provide additional insight into power system operating conditions. Figure 5 shows the active power flows from Guatemala to El Salvador in the Aguacapa-Ahuachapan line, from El Salvador to Guatemala in the Moyuta-Ahuachapan line, and the total power exchange (the sum of the two power flows) from Guatemala to El Salvador. Notice the existence of circulating power flow when the power exchange is low. Also observe the power exchange fluctuations, which can be an indication of a system prone to instability.

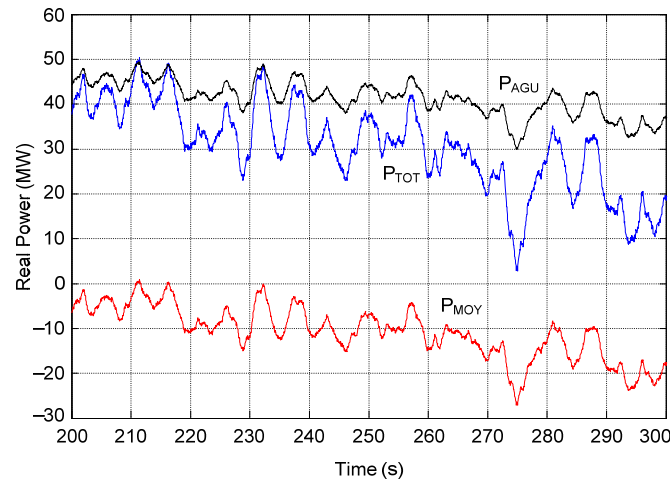


Figure 5: Active power flow exchange in the interconnection between Guatemala and El Salvador

5 FIRST OPERATION OF THE WIDE-AREA SUPPLEMENTARY CONTROL SCHEME

The modal analysis scheme was commissioned on June 8, 2012. On July 28, 2012, the interconnected SIEPAC power system was operating on two islands. The larger island included the power systems of Mexico, Guatemala, El Salvador, and Honduras. The smaller island included the power systems of Nicaragua, Costa Rica, and Panama. Undamped active power oscillations between Guatemala and El Salvador started to occur right after the synchronization of the two networks, as Figure 6 illustrates. The wide-area SCS correctly identified the oscillation mode of 0.22 Hz and issued a trip command to open the interconnection between Guatemala and El Salvador. Figure 7 shows the frequencies of the two networks before and during the power oscillation and after the opening of the interconnection. We can observe that the two systems maintained stability. The frequency of the Guatemala-Mexico network settles around 60.09 Hz and the rest of Central America at 59.95 Hz.

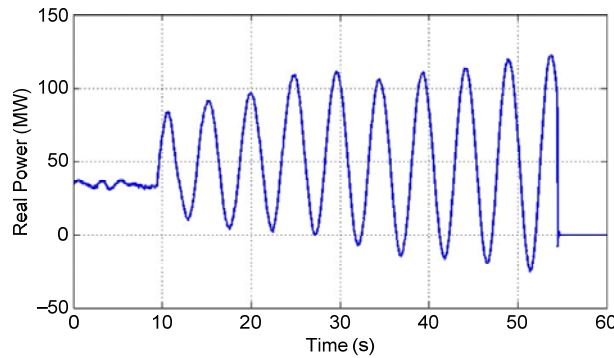


Figure 6: Undamped active power oscillations and operation of the wide-area supplemental control scheme

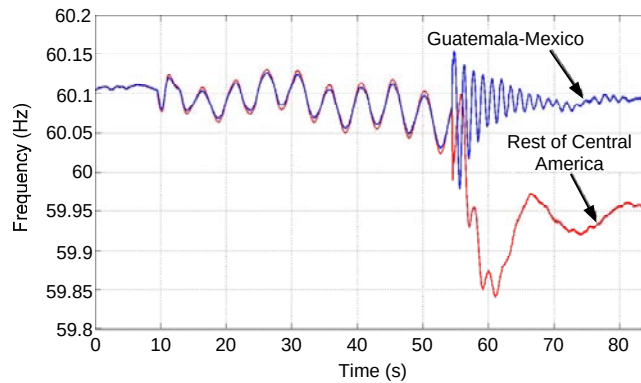


Figure 7: Frequencies of the Guatemala-Mexico and the rest of Central America networks before and after system separation

6 CONCLUSION

This paper presents an innovative WAPS based on synchrophasors that is in service in Guatemala. This scheme identifies abnormal operating conditions and opens the interconnection with El Salvador to maintain the stability of the power system.

Having this modal analysis-based SCS in service allows the Guatemalan network to be connected to the Mexican network. This interconnection improves the stability of the Central American power system and provides more electrical energy resources to this region.

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