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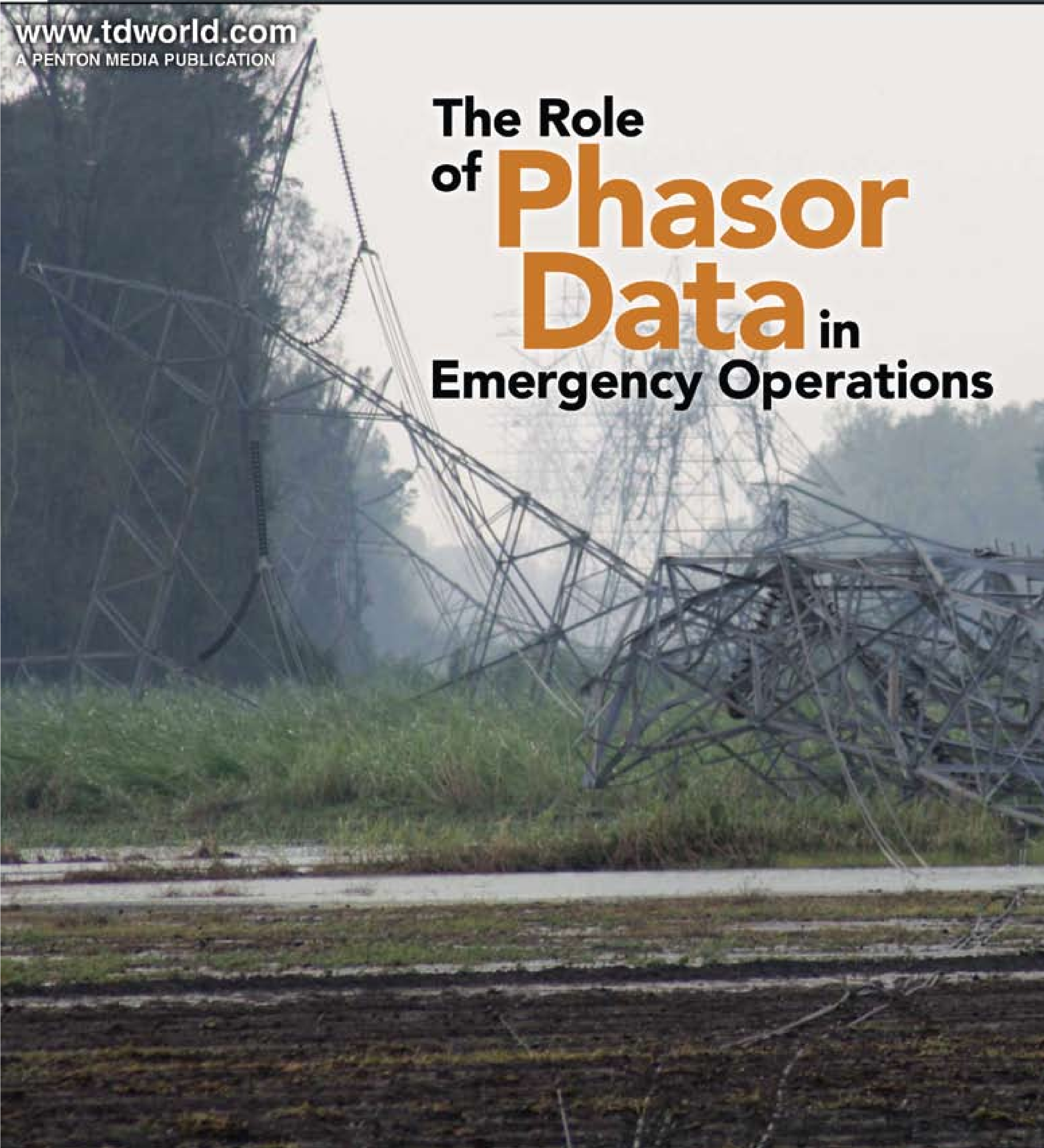

The Role of Phasor Data in Emergency Operations

The Role of PHASOR DATA in Emergency Operations

Hurricane Gustav approaches South Louisiana, causing widespread damage to the transmission grid in the area, such as this downed 500-kV line.

PMUs are vital in the identification and warning of islanding conditions during emergencies and can provide significant insight in managing an island.

By **Floyd Galvan**, **Sujit Mandal** *and* **Mark Thomas**, *Entergy Transmission*

HURRICANE GUSTAV REACHED THE LOUISIANA COAST ON THE MORNING OF SEPTEMBER 1, 2008. As the storm moved inland, many of the transmission lines throughout South Louisiana experienced outages. Fourteen of the transmission lines in the Baton Rouge to New Orleans area tripped out of service during the storm. The New Orleans metropolitan area and a corridor along the Mississippi River between New Orleans and Baton Rouge essentially became an independent electrical island, no longer electrically connected to the rest of the Entergy system or the electric grid of the Eastern United States.

The electrical island was formed south of Lake Pontchartrain, including Orleans, Jefferson, St. Bernard, St. James, St. John the Baptist, St. Charles and the upper Plaquemines parishes, which are sometimes referred to as the “river” parishes. Entergy’s generating units at the Waterford, Nine Mile Point and Little Gypsy stations were the generating sources available to meet the island’s load demand.

Prior to Gustav’s landfall, Entergy took precautionary measures to protect and limit damage to its systems. This included placing generators on hot standby, serving only Entergy’s station load, and isolating them from the grid. These advance storm preparations contributed directly to sustaining power in New Orleans and surrounding areas.

PMUs DETECT ISLAND FORMATION

As Gustav made its way across Louisiana, it left behind a wide path of transmission and distribution system outages. The Entergy system coordinators maintained vigilance on the system as lines, generators and system equipment faced the winds and storm surge of Gustav. The sharp frequency spikes in Fig. 1 reflect extensive line outages caused by the dramatic weather conditions as observed by the phasor measurement units (PMUs) monitoring the system.

At approximately 2:49 p.m. on Sept. 1., the Baton Rouge–New Orleans island was created by the outage of the Gypsy to Fairview 230-kV transmission line, which is a 55-mile (89-km)

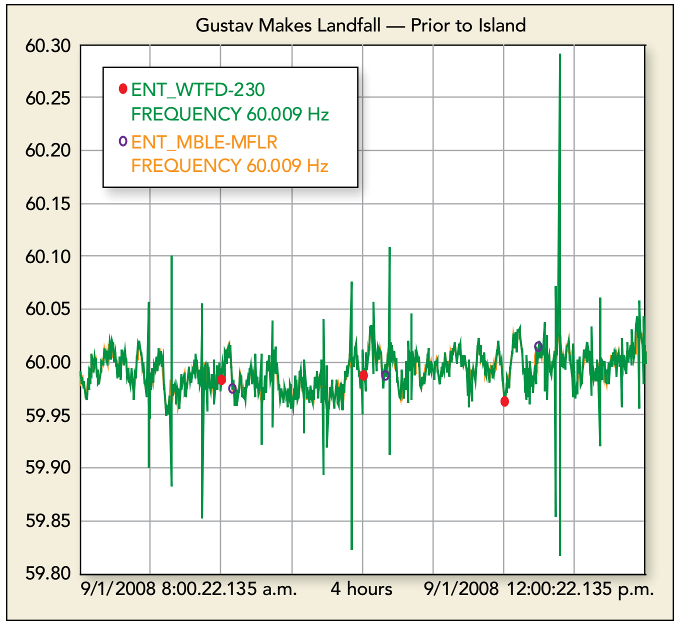

Fig. 1. Entergy system frequency spiked as various lines went out on the Sept. 1, 2008. Data taken from Entergy Phasor Measurement System.

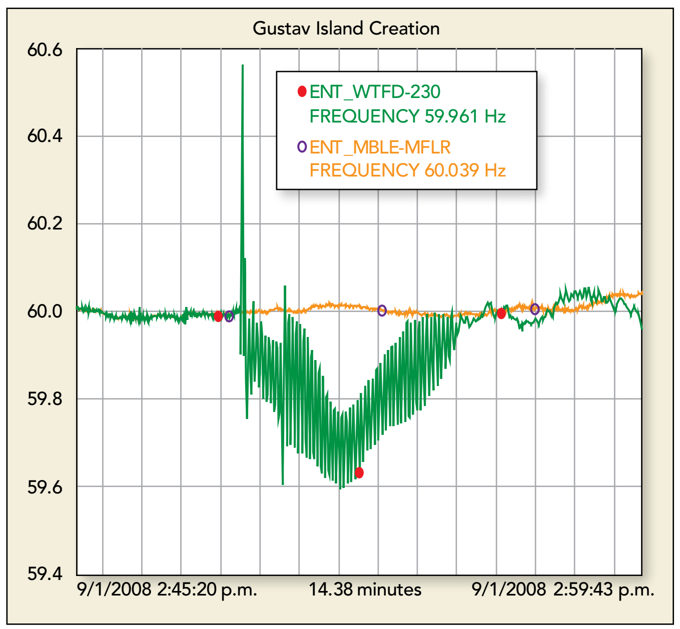

Fig. 2. The green trace shows the Entergy frequency excursion at the Waterford Station after the Gypsy to Fairview line outage, which marked the creation of the island. The Eastern Interconnect is the orange trace.

line across Lake Pontchartrain. The Gypsy to Fairview 230-kV line was the 14th and final transmission line to outage prior to the island formation. The dispatchers were alerted to the island's creation by the diverging system frequencies being monitored by the Entergy Phasor Measurement System (Fig. 2).

The Entergy Phasor Measurement System has 21 PMUs across the four-state area of Mississippi, Louisiana, Arkansas and non-ERCOT east Texas. During the islanding event, the Waterford PMU was located within the island. The Mabelvale, Arkansas, PMU was chosen as the temporary reference frequency for the Entergy system during the hurricane, because it was well outside the storm path. The location of these PMUs proved to be vital in detecting and managing the island. With one PMU within and others outside of the island (and the hurricane path), Entergy was able to monitor the real-time changes of the island. By having the PMUs' global positioning system (GPS) time-synchronized and taking frequency measurements at 30 samples/sec, Entergy had an advantage not possible with supervisory control and data acquisition (SCADA) data. Since SCADA data is non-GPS synchronized and collected only once every 2 to 4 seconds, it could never have captured the event with quality of PMU measurements. When operators compared the data from the Waterford and Mabelvale PMUs, as shown in Fig. 2, they saw the frequency oscillations created from the birth of the island and were alerted of the island's creation.

The Entergy system coordinators verified the phasor equipment was responding properly and identified line outages within the region to determine the extent and size of the island. The phasor system monitored the island formation in South Louisiana, which took approximately 20 minutes. Without the phasor system, the electrical island may have gone undetected by Entergy, potentially leading to wider-spread outages throughout the service area.

PHASORS MONITOR GUSTAV ISLAND

The Baton Rouge–New Orleans area existed as an island, as depicted in Fig. 3, for approximately 33 hours. During this time, service restoration within the island was restricted to prevent demand from exceeding the available generation in the island. If load levels fluctuated too quickly, the generation might have tripped off-line, causing the entire island to lose power.

There was also a slight possibility that connecting the islanded area to the rest of the system could cause an outage due to the delicate nature of synchronizing a separated multi-generator system.

It is important to note the significance of maintaining an island, when at all possible, remembering that a successful island is a much-better condition than a blackout. A successful island ensures that, even though the island is operating at a suboptimal state, customers are still being served. Once in an islanding situation, the challenge is to ensure a continual balance between generation and load, and to maintain the island frequency as close to 60 Hz as possible. During Gustav, Entergy had the added challenge of maintaining the island in the aftermath of a major hurricane, with flooded areas and much of the grid down, with real-time information about the island limited to sparse SCADA system information and with only one PMU located within the island.

The governors of the three on-line units in the island were in automatic mode prior to the formation of the island. Once the island formed, its electrical strength was much less than when connected to the grid, and any variation in load could have led to significant frequency oscillations. Such oscillations could have resulted when all three generators attempted to respond to a change in demand because of their pre-island-formation governor droop setting. To prevent this scenario and stabilize the frequency in the island, the governors of the Waterford and Gypsy units were locked down and placed on manual mode. The Nine Mile unit, being the largest of the three generating units in the island, was put on automatic mode, allowing it to swing to meet the varying load changes in the island. The PMU at the Waterford Station was used to monitor the stability of the island and to help in maintaining the best-possible frequency.

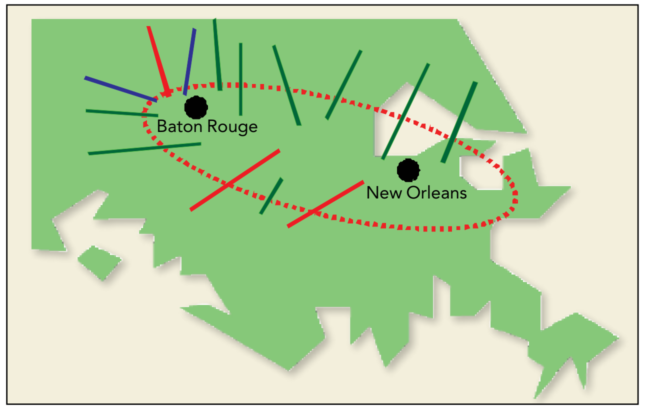

Fig. 3. Transmission line outages from Hurricane Gustav around the New Orleans and Baton Rouge areas, which contributed to the island formation.

The Entergy Phasor Measurement System also was instrumental in warning of hunting among the three units when the governor at the Gypsy facility was inadvertently switched from manual to automatic mode. The PMUs showed the oscillations growing between the units and warned system dispatchers of the hunting condition, as shown in Fig. 4. This allowed control-room personnel to make quick decisions to prevent any further oscillations between the units and keep the island intact.

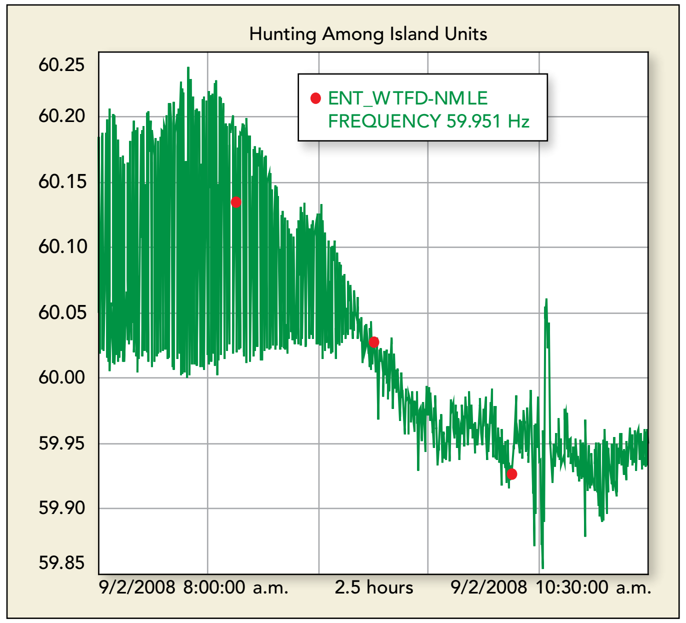

Fig. 4. Frequency excursions from the Waterford PMU indicate hunting among the three generation units in the island.

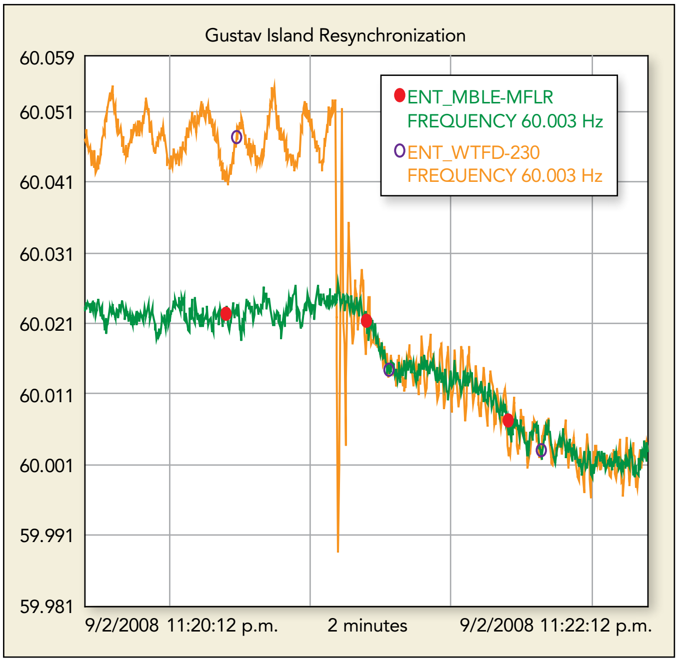

Fig. 5. The resynchronizing of the island as captured by the Entergy Phasor Measurement System.

Fig. 6. Resynchronizing the island to the grid using a synchroscope.

SUCCESSFUL RECONNECTION

On Sept. 2 at approximately 11:21 p.m., the island formed in the aftermath of Hurricane Gustav was reconnected to the Eastern Interconnect without incident and without loss of load or generation (Figs. 5 and 6). A synchroscope was used to connect the island at the Almonaster Substation to the rest of the Entergy grid. While PMUs were used to monitor and capture the resynchronizing event, the synchroscope was the tool of choice for reconnecting the two systems.

Hurricane Gustav brought many difficulties to South Louisiana, but it also brought a deep understanding of the value of the Entergy Phasor Measurement System. At a time of great need, this system warned the utility of a major event on its system. Hurricane Gustav also made Entergy aware of areas where additional PMUs are needed and of the value of continuing to add PMUs throughout its service territory.

Hurricane Gustav has made it quite clear that the role of PMUs is changing. They are no longer simply monitoring the grid and being used for post-mortem analysis. With Gustav, PMUs stepped into a truly operational role of helping to identify and manage major grid events. In doing so, PMUs have moved from being optional equipment to playing a vital role in grid reliability. TDW

GUSTAV BY THE NUMBERS

Hurricane Gustav made landfall on Sept. 1, 2008, at 9:30 a.m. at Cocodrie, Louisiana, U.S., as a Category 2 hurricane. In comparison, Hurricanes Katrina and Rita both made landfall as Category 3 hurricanes.

At its peak, Hurricane Gustav caused the outage of 241 transmission lines and 354 substations. In its path were two nuclear and 13 non-nuclear generating plants. Hurricane Gustav was the most destructive storm in terms of distribution transformers, with 4349 transformers damaged or destroyed, and more than 2500 miles (4023 km) of circuit affected. It was the second-most destructive storm in terms of customer outages in the 95-year history of Entergy's four-state utility system. Customer outages from Gustav peaked at 964,000, second only to the 1.1 million customer outages in 2005 during Hurricane Katrina.

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