Using Synchrophasor Data to Diagnose Equipment Health and Misoperations
Event Summary Table

For more information refer to: Silverstein, A. May 2015. Diagnosing Equipment Health and Mis-operations with PMU Data (https://www.naspi.org/File.aspx?fileID=1530).

Event ID	Event	Event Category	Entities Involved	Event Description	Extended Description in Related NASPI Technical Paper	Safety Impact	Reliability Impact	Budgetary Impact
GEN01	Generator PSS setting issue	Gen. Equip. Failures & Setting Issues	TVA	Faulty generator PSS card found after oscillations indicated the PSS may not be operating effectively.	p.9		Utility eliminated forced oscillations and reduced risk of PSS operating improperly during a system disturbance (which could increase impact and severity of such an event).	Utility avoided costs associated with generator wear and tear caused by forced oscillations.
GEN02	Generator start-up control setting issue	Gen. Equip. Failures & Setting Issues	OG&E	PMU data helped determine that voltage oscillations at power plant were occurring during start-up of a specific unit. Voltage oscillations were eliminated by changing the unit from VAR control to voltage control mode during start-up.	p.10			Utility avoided costs associated with generator wear and tear caused by forced oscillations.
GEN03	Generator AVR malfunction	Gen. Equip. Failures & Setting Issues	NYISO	Malfunctioning generator AVR found after transient voltage oscillations were noticed with SCADA data and verified by PMU data.	p.11		Utility eliminated forced oscillations and reduced risk of AVR operating improperly during a system disturbance (which could increase impact and severity of such an event).	Utility avoided costs associated with generator wear and tear caused by forced oscillations.
GEN04	Generator PSS malfunction	Gen. Equip. Failures & Setting Issues	NYISO	Malfunctioning generator PSS found after inter-area oscillations were observed across the electrical system and PMU voltage data was used to determine the location of the problem.	p.13		Utility eliminated forced oscillations and reduced risk of PSS operating improperly during a system disturbance (which could increase impact and severity of such an event).	Utility avoided costs associated with generator wear and tear caused by forced oscillations.

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GEN05	Nuclear power plant voltage oscillations	Gen. Equip. Failures & Setting Issues	Dominion	Real and reactive power oscillations observed at a nuclear plant and arrested by raising plant voltage output. Next-day analysis of PMU data identified large oscillations and significant dynamic movement in generator shaft subjecting unit to possible pole slipping. A generator PSS was later installed at plant.	p.16		Utility eliminated forced oscillations and excessive generator shaft movement that posed risk of generator pole slipping.	Utility avoided costs associated with significant generator damage.
GEN06	Generator governor control malfunction	Gen. Equip. Failures & Setting Issues	AESO, BPA, CISO and PGAE	Sustained oscillations initiated by a malfunctioning generator steam extractor control valve caused inter-area oscillations in Western Interconnection. Oscillations ended when steam supply to industrial process was reduced. PMU data revealed details of the forced oscillation and illustrated link between oscillations in Alberta, Canada and California-Oregon Intertie.	p.17		Utilities eliminated forced inter-area oscillations that, if left unaddressed, might have adversely impacted reliability.	Utilities avoided costs associated with generator wear and tear caused by forced oscillations.
GEN07	Generator relay misoperation	Gen. Equip. Failures & Setting Issues	ATC	An analysis of PMU data collected during a generator trip revealed the unit tripped at the exact same time as a 69 kV line relay operation, indicating a relay misoperation to be the cause, rather than the initially presumed lightning strike.	p.19		Utility corrected generator relay setting issue and avoided future misoperations that may have adversely impact reliability.	Utility avoided costs associated with generator outages.

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GEN08	Faulty generator control card	Gen. Equip. Failures & Setting Issues	ERCOT	Modal oscillations indicating an issue internal to a power plant were significantly reduced after replacing multiple unit control cards at that plant.	p.21			Utility avoided costs associated with generator wear and tear caused by forced oscillations.
GEN09	Generator control system malfunction	Gen. Equip. Failures & Setting Issues	MISO	Short-term, locally-forced oscillations resulting from a generator control system malfunction were identified through analysis of PMU data. Malfunction likely resulted from recent control system upgrade and was quickly resolved.	p.22			Utility avoided costs associated with generator wear and tear caused by forced oscillations.
GEN10	Generator PSS performance issues	Gen. Equip. Failures & Setting Issues	BPA	Analysis of PMU data collected during disturbance revealed significant differences between expected and observed response of a large hydro plant. Testing found PSS signal was not being sent to the voltage regulator and PSS status indicator was not operating correctly. Subsequent analysis found other generator PSS's that not performing effectively, all of which have since been fixed.	p.23		The utility reduced risk of multiple PSSs not operating properly during a system disturbance (which could increase impact and severity of such an event).	The utility avoided costs associated with generator wear and tear caused by PSSs not operating properly during system disturbances.

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GEN11	Wind plant oscillations	Gen. Equip. Failures & Setting Issues	OG&E	After performing switching to isolate individual wind plants from one another while investigating oscillations observed during high wind periods, oscillations were attributed to windfarms that shared a specific turbine model. Those windfarms would later be curtailed during high wind conditions to avoid occurrence of such oscillations and reduce flicker experienced by customers located in the area.	p.25		By correcting the oscillations, the utility reduced risk to its system security and harm to customer equipment.	Utility avoided costs associated with generator wear and tear caused by forced oscillations and turbine damage that might have occurred had the oscillations continued.
GEN12	Flawed wind controller settings	Gen. Equip. Failures & Setting Issues	ERCOT	Wind controller settings that had been altered by the manufacturer were found to be the cause of frequency oscillations following the investigation of oscillations identified in PMU data.	p.29			Utility avoided costs associated with generator wear and tear caused by forced oscillations.
GEN13	Turbine controller issues during high wind events	Gen. Equip. Failures & Setting Issues	ERCOT	Severe oscillatory events noted during high wind conditions led to dynamic studies that identified the need for transmission system upgrades, improved wind controller tuning practices and wind curtailments under certain conditions.	p.31		Utility eliminated severe oscillatory events that, if left unaddressed, might have adversely impacted system reliability.	Utility avoided costs associated with generator wear and tear caused by forced oscillations and equipment damage that might have occurred had the oscillations continued.

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GEN14	Wind plant high frequency oscillations	Gen. Equip. Failures & Setting Issues	BPA	High-frequency oscillations were observed and an oscillation detection application consistently alarmed when a specific wind plant operated at high power output. Impacted utility became concerned about the oscillation frequency, which was close to the modulated resonance frequency of a series-compensated 500 kV line adjacent to the plant, due to the risk of sub-synchronous control interactions if the wind plant were to become isolated to the series-compensated line. Plant operator requested the wind generator manufacturer to upgrade the plant's controls and oscillations ceased.	p.34		Utility eliminated forced oscillations that might have resulted in significant equipment damage had the wind plant become isolated to the series-compensated 500 kV line.	Utility avoided costs associated with generator wear and tear caused by forced oscillations and equipment damage that might have occurred had the wind plant become isolated to the series-compensated 500 kV line.
TE01	PDCI controller oscillations	Transmission Equipment	BPA, CISO and LDWP	Frequency oscillations observed following loss of multiple 500/230 kV transformers led operator to remove 1000 kV Pacific DC Intertie from service to mitigate risk of equipment damage that might have occurred had the oscillations continued.	p.36		Utilities eliminated forced oscillations that, if left unaddressed, might have caused equipment damage and adversely impacted system reliability.	Utility avoided costs associated with generator wear and tear caused by forced oscillations and equipment damage that might have occurred had the oscillations continued.

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TE02	Failing potential transformer	Transmission Equipment	ATC	Abnormal voltage signature found while reviewing PMU data led to discovery of a failing potential transformer which was subsequently isolated and replaced.	p.38	The utility avoided safety risk to personnel that might have been in close proximity to the PT during its failure.		Utility avoided costs associated with customer minutes of interruption that would have resulted from the potential transformer's failure had the condition not been identified and a mobile transformer placed in service to facilitate the outages necessary for its replacement.
TE03	Loose connections in potential circuits	Transmission Equipment	OG&E	Fluctuations observed in positive sequence voltage data collected from PMUs led to discovery of a loose fuse connection in a CCVT safety switch. PMU data has been used in a similar fashion to reveal faulty terminations, animal-damaged conductor and contact corrosion.	p.40			Utility avoided costs associated with equipment damage and customer minutes of interruption that might have resulted had the issues not been addressed.
TE04	Failing voltage transformer	Transmission Equipment	Dominion	Sporadic voltage dips and fluctuations observed on a 500 kV line led to discovery of a failing CCVT which was subsequently isolated prior to its imminent failure.	p.42	The utility avoided safety risk to personnel that might have been in close proximity to the CCVT during its imminent failure.		Utility avoided costs associated with equipment damage that might have resulted from the CCVT's failure.
TE05	Identifying 69 kV arrester failure	Transmission Equipment	ATC	The details of a 69kV customer impact event were identified within two minutes by control room engineers reviewing PMU data. The fault could not be observed with SCADA data.	p.44		Utility able to identify and isolate the failed lightning arrestor shortly after relay operation occurred.	

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TE06	Voltage dips linked to comm. carrier protection outages	Transmission Equipment	OG&E	Unacceptable voltage dips resulting from fault conditions were discovered while reviewing PMU data. This discovery led to the discontinuation of a company policy to remove line carrier protection from service for inspection following a possible relay misoperation in favor of risking a potential misoperation rather than exposing customer equipment to potential that damage.	p.45		Utility eliminated unacceptable voltage dips that, if left unaddressed, might have resulted in unacceptable system performance.	Utility avoided costs associated with equipment damage and customer minutes of interruption that might have occurred had the policy not been changed.
TE07	Finding open phases and unbalanced phase currents on circuit breakers	Transmission Equipment	ATC	PMU data revealed unbalanced phase currents that resulted from a relay operation that occurred during circuit breaker maintenance. The issue was later attributed to a relay logic issue.	p.47		Utility corrected relay logic issue and avoided future misoperations that might have adversely impact reliability.	
TE08	Power quality monitoring	Transmission Equipment	OG&E	PMU data identified power quality issues attributed to a large industrial load. Power quality issue had not been observed with SCADA or DFR data and went unnoticed until PMUs were placed on the system.	p.48		Utility mitigated load-induced oscillations and power and voltage variations that caused observable flicker and nearby wind generation to react.	

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TE09	Monitoring harmonics and noise injection from new equipment	Transmission Equipment	ATC	PMU measurements captured noise and harmonics being injected in to the local transmission system while placing new equipment in service. PMU data analysis is now included as part of the in-servicing process to identify and address potential operational issues that may result.	p.49		Utility identified and addressed abnormal operating conditions caused by placing new equipment in service.	Utility avoided costs associated with operational issues that might have resulted from excessive noise and harmonics being injected in to the transmission system had the condition gone undetected.
TE10	Negative sequence alarms	Transmission Equipment	ATC	PMU data reviewed during investigation of a generator negative sequence alarm helped identify a single phase arc furnace as the most likely cause.	p.50			Utility reduced costs associated with analysis of negative sequence alarm by using PMU data to derive negative sequence data and determine cause.
TE11	Capacitor bank switching problems	Transmission Equipment	ATC	PMU data reviewed during the analysis of a capacitor bank relay operation revealed that two capacitors had closed at the same time causing the second capacitor bank to relay.	p.50		Utility reset capacitor voltage control scheme to avoid multiple capacitors closing at same time resulting in a relay operation.	Utility avoided costs associated with equipment wear and tear associated with excessive operation of capacitor banks.
TE12	Transmission level fault analysis	Transmission Equipment	NYISO	Synchrophasor applications routinely used to conduct off-line voltage and oscillation analyses, transient voltage recovery analyses and system stress analyses of disturbance events.	p.51		Utility able to identify and address issues resulting in abnormal voltages or oscillations, unacceptable transient voltage recovery, or high system stress conditions during disturbance events.	Utility able to avoid costs associated with equipment damage and customer minutes of interruption that might have resulted from forced oscillations, poor transient voltage recovery, or high stress conditions during disturbance events.

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EIP01	Commissioning PSSs	Equip. Installation and Protection	Manitoba Hydro	PMU data used to commission PSSs more efficiently by allowing test technicians to observe PSS modes in real-time at the moment of tuning thereby completing the necessary testing during the installation process.	p.52			Utility able to avoid costs associated with on-site testing by completing necessary testing during installation process.
EIP02	Verifying equipment phasing	Equip. Installation and Protection	ATC	PMU data used to validate correct phasing prior to or during construction to resolve designation issues on existing Facilities.	p.52			Utility able to identify and resolve phasing discrepancies before construction begins, thereby avoiding costs and time delays associated with correcting phasing at a later time (e.g., rolling phases).
EIP03	Checking system protection device operations	Equip. Installation and Protection	ATC	PMU data used to verify system faults cleared within an acceptable amount of time and all three phases opened at or near the same time.	p.53		Utility able to identify and address issues that prolong fault clearing time or cause phases not to open at same time.	Utility able to avoid costs associated with equipment damage and customer minutes of interruption that may result from prolonged fault clearing time.
EIP04	Installing and calibrating instrument transformers	Equip. Installation and Protection	Dominion	PMU data is used to determine RCFs with a very high level of accuracy and calibrate instrument transformers accordingly, across all owned substations, without field testing.	p.53	Utility improves field crew safety by reducing amount of item spent near energized bus work to perform instrument transformer testing.	Utility improved accuracy of current and voltage readings used by System Operator to determine system conditions and identify unacceptable performance.	Utility avoided costs and time associated with field testing of instrument transformers and analyzing test results to calculate new ratio correction factors.

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EIP05	Monitoring system current imbalance to protect large generator rotors	Equip. Installation and Protection	Dominion	PMU data used to measure three phase current in all transmission lines, calculate phase currents and identify negative sequence currents that could damage generation equipment or result in relay misoperations.	p.55		Utility identified abnormal operating conditions that could adversely impact reliability.	Utility avoided costs associated with equipment damage and relay misoperations.