Using Synchronized Disturbance Recorders to Dissect a Complex, Short Duration Event

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Introduction

On June 17, 2004 at 19:00 hours the New York Independent System Operator (NYISO) control room shift supervisor reported the simultaneous loss of two (2) 345kV parallel overhead transmission lines, one (1) submarine 345kV transmission cable and both units of a 1200 MW generating plant. All of the facilities are located in southeastern New York, although the parallel overhead lines are approximately 20 miles and one bus removed from the submarine cable and generating plant. At the point in time of these simultaneous operations, combined with an emergency outage earlier in the day, all 345 kV transmission circuits between upstate and downstate New York were interrupted. The system remained interconnected and synchronized through the neighboring systems and underlying 115 kV and 138 kV paths). See Figure 1 below for a one-line diagram of the system.

Introduction (continued)

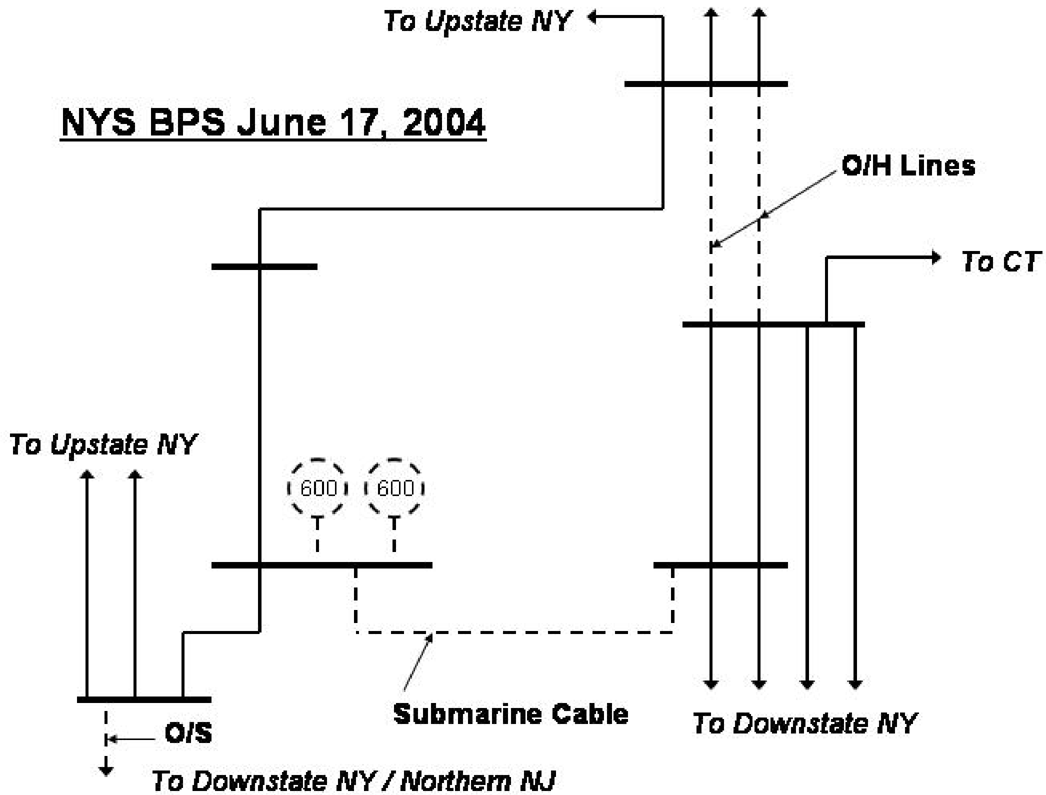

Figure 1
One-Line Diagram of NYS BPS on June 17, 2004

Twenty seconds into the event the NYISO reported that both of the two overhead transmission lines had automatically reclosed. Approximately 27 minutes later, the submarine cable was manually reclosed.

It was immediately known by way of a real time lightning detection system that a lightning strike had occurred at the onset of the event, in the vicinity of the two overhead transmission lines. Examination of Digital Fault Recorder (DFR) records quickly indicated that there had been single line to ground faults on both overhead transmission lines. For some time subsequent to the event it was unknown exactly what caused the other operations; but due to the timing of the events it was believed that all of the operations were related, despite being in separate zones of protection and separated by at least one bus.

It was necessary for the affected transmission owners, the generation owner, and the NYISO to assemble all of the Digital Fault Recorder records and develop a synchronized time line to the nearest millisecond in order to further dissect the event and identify the root causes as quickly as possible.

Analysis

Parallel Overhead Lines

The two 345kV overhead lines, which tripped and automatically reclosed by design twenty seconds into the event, were immediately suspected as having been struck by lightning. One of the transmission owners reported lightning in the area, and with a real-time lightning detection system its system operators quickly surmised that lightning was the cause of the trips. Further examination of the DFR data revealed the lines tripped due to a phase A-to-ground fault. These two lines are connected in parallel and occupy the same right-of-way throughout their entire 39 mile length, although on separate towers; however, the last span before the substation at the southern end the lines occupy a common tower with both A phases at the top of that tower. The span between that tower and the substation deadend does not have lightning shielding, and the day after the event a broken insulator on phase A of one of the lines was discovered.

The lightning detection system revealed that a 68 kA magnitude cloud-to-ground strike occurred in at the location of the unshielded tower at 19:00:21.700 EDT. Figure 2 below illustrates graphically the location of lightning strikes throughout the day relative to the facilities in question.

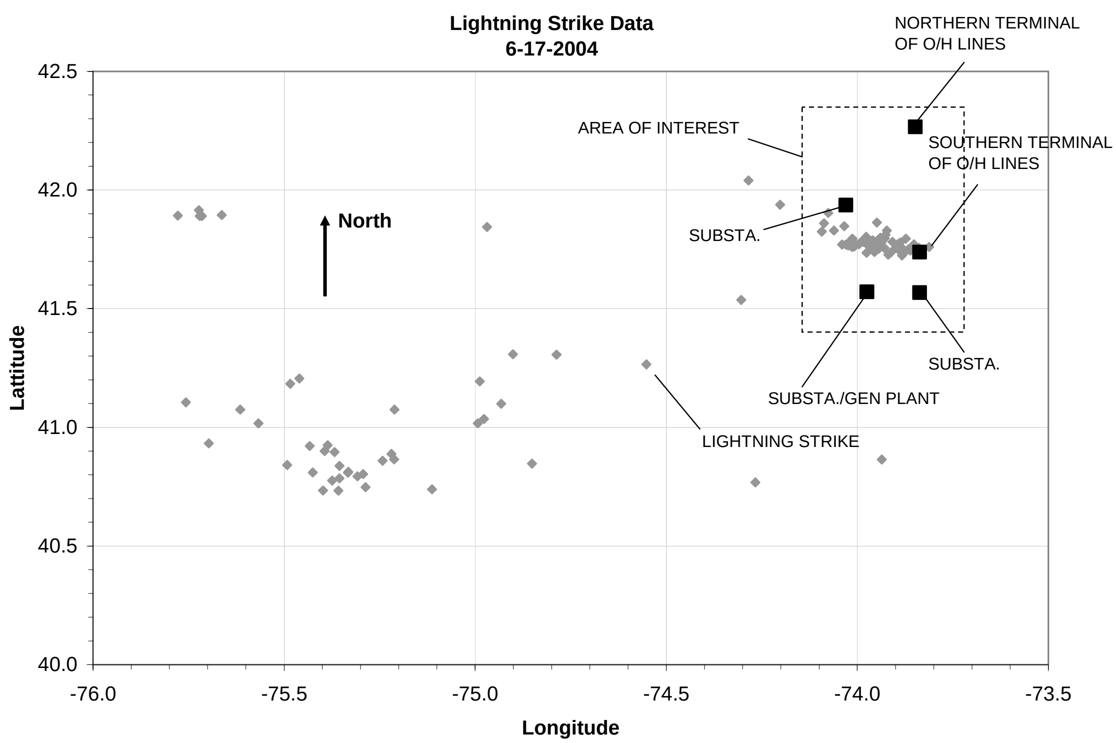

Figure 2
Location of Lightning Strikes on June 17, 2004

The DFRs located at the northern and southern terminals of the overhead lines revealed a trigger time of 19:00:21.706 and 19:00:21.707, respectively. These trigger times are consistent with the time of the strike as recorded by the lightning detection system. The lines were cleared at 19:00:21.773 and 19:00:21.819, respectively (4.4 and 7.1 cycles after the lightning strike). All of these facts showed that the overhead lines were most likely struck by lightning.

The sequence of events as of this point in the investigation was as follows:

19:00:21.700	Lighting Strike	Real Time Lightning System
19:00:21.706	Fault Inception – Overhead Lines	DFRs at Terminals
19:00:21.773	First Overhead Line Clears	DFRs at Terminals
19:00:21.819	Second Overhead Line Clears	DFRs at Terminals

Generating Plant

The 1200 MW (capacity) generating plant in question is comprised of two 600 MW fossil fueled units. Just prior to the event, unit 1 was operating at a net output of 365 MW and unit 2 at 265 MW, for a total combined net output of approximately 630 MW. The DFR at the plant triggered at 19:00:21.711, just behind the time of the lightning strike and the other previously mentioned DFRs associated with the overhead lines.

Plant personnel initially believed the plant had been struck by lightning, based on the number of lightning flashes in the area. The DFR traces from the plant DFR showed each unit ramping up its output over the next 5.5 cycles, just prior to the units tripping 6.3 cycles after the lightning strike to the overhead lines. The timing of these events suggested that the lightning strike to the overhead lines occurred first, and then the plant tripped shortly thereafter. The timing was too quick to suggest that lightning struck simultaneously 20 miles apart. Again, the lightning strike to the overhead lines was outside the zone of protection.

The sequence of events as of this point in the investigation was as follows:

19:00:21.700	Lighting Strike	Real Time Lightning System
19:00:21.706	Fault Inception – Overhead Lines	DFRs at Terminals
19:00:21.711	Fault Detected at Plant Switchyard	DFR at Switchyard & Plant
19:00:21.773	First Overhead Line Clears	DFRs at Terminals
19:00:21.805	Plant Trips	DFR at Switchyard & Plant
19:00:21.819	Second Overhead Line Clears	DFRs at Terminals

There was an absence of relay target information at the plant and its switchyard to narrow down exactly what caused the plant to trip subsequent to the fault inception. Unit 2 at the plant did yield a differential target on the Generator Step-Up (GSU) transformer; the focus of the investigation into unit 2 turned to the GSU, and weeks later a damaged current transformer secondary in the GSU differential scheme was discovered and repaired. The unit 1 investigation is ongoing, and at this time it is unknown what exactly caused that unit to trip (the unit 1 GSU subsequently failed 6 months later, along with a 345kV circuit breaker in the substation).

Submarine Cable

The 345kV submarine-type cable is one bus removed from the overhead lines which were struck by lightning. In the early stages of the event it was unknown what caused this line to trip and whether it tripped prior to or after the overhead lines, and if its cause perhaps contributed to the tripping of the overhead lines and generating plant. Similarly, the generating plant is two busses removed from the overhead lines, but the submarine cable interconnects with the same bus as the plant. Furthermore, the cable shares a circuit breaker with each of the generating plant units; therefore, a simultaneous loss of both generating units will open the cable from one end, only. After a substation electrician was dispatched to either terminal substation of the cable and no targets were reported, it was concluded that the line tripped as a result of configuration at the generating plant substation, and the line was manually reclosed.

The sequence of events as of this point in the investigation was as follows:

19:00:21.700	Lighting Strike	Real Time Lightning System
19:00:21.706	Fault Inception – Overhead Lines	DFRs at Terminals
19:00:21.711	Fault Detected at Plant	DFR at Plant
19:00:21.773	First Overhead Line Clears	DFRs at Terminals
19:00:21.805	Plant Trips	DFR at Plant
19:00:21.805	Submarine Cable Open	DFR at Switchyard
19:00:21.819	Second Overhead Line Clears	DFRs at Terminals

The NYISO owns several Dynamic Data Recorders (DDRs) which are installed at Transmission Owner substations throughout the State. These DDRs primarily record system frequency during events, but also record bus voltages. These DDRs are time-synchronized, and provided an additional level of detail for the investigation. Figure 3 below shows the voltage and frequency as recorded to the north and south of the incident.

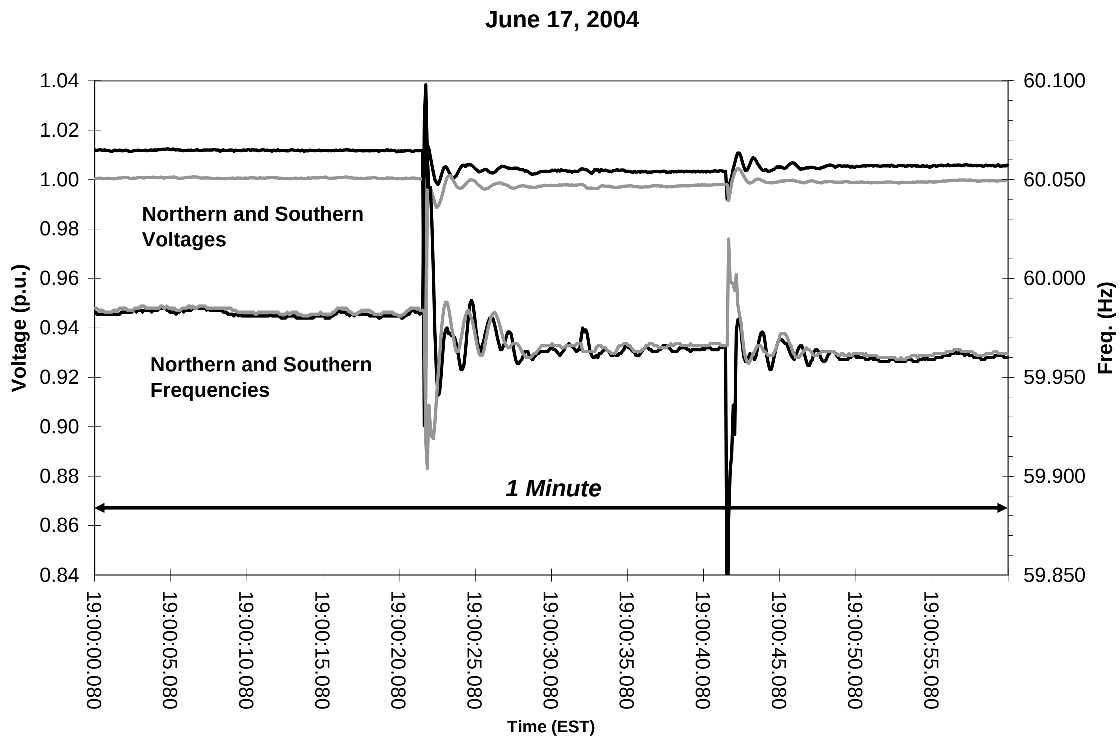

Figure 3
Northern and Southern System Frequency and Voltage Response

Conclusions

It was imperative that this incident be analyzed and problems addressed as quickly as possible due to the potential effect of such an incident on the New York State Bulk Power System and underlying systems. The investigation was complicated by the number of operations, the short duration of the events, some lack of relay target information, and the number of facilities and owners involved. The availability of time-synchronized data proved invaluable to this end.

The availability of time-synchronized lightning data immediately pointed to lightning as the initial cause of the events. Additionally, time-synchronized data at the plant, which was somewhat removed from the initial incident, allowed the investigation to determine if the plant was a victim of lightning itself, or tripped erroneously due to effect of faults on the overhead lines.

Digital Fault Recorders and other devices produce records in a variety of proprietary formats. Efforts to make this data readable across a variety of platforms are extremely important so that data can be quickly and accurately be shared among investigators.

Lastly, it should be noted that the views expressed in this paper and in the presentation of this paper are solely those of the authors, and do not necessarily represent the views of the NYISO or any other organization involved with this event.

Author Biographies

James W. Ingleson began his electric power career with the municipal electric utility in his hometown, Jamestown, New York. He received his B.S. and M. Eng. degrees in Electric Power Engineering from Rensselaer Polytechnic Institute in 1970 and 1975. He worked for General Electric Company in various capacities, including design and construction of substations, generating plants, HVDC projects, and in system protection engineering. Jim is now with New York Independent System Operator, Inc. (NYISO) as Senior Operations Engineer. He is a registered professional engineer, has long been an active member of the IEEE Power System Relaying Committee (PSRC), and is currently Chairman of PSRC's Relaying Practices Subcommittee.

Dean M. Ellis began his electric power career working for Orange and Rockland Utilities and Central Hudson Gas and Electric Corporation in New York State. He received his B.S. degree in Electric Power Engineering from Rensselaer Polytechnic Institute in 1991. He has also worked in the engineering consulting field, focusing on the design and construction of electric power facilities. Dean is now with New York Independent System Operator, Inc. (NYISO) as Senior Operations Engineer. He is a registered professional engineer in the State of New York.