
REVIEW OF APS RESPONSE TO 6/14/04 EVENT AS RELATED TO THE 7/4/04 WESTWING EVENT

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EXECUTIVE SUMMARY

On 6/14/04 at 0740, a fault on the Liberty-Westwing line cascaded into a grid disturbance. The disturbance resulted in the loss of power to the Westwing substation and the loss of power generating units, most notably the loss of all three Palo Verde nuclear units. Power was restored to the Westwing substation on 6/14/04 after three unsuccessful alignment attempts by ECC failed. On 6/15/04, an investigation team was assigned to identify the root cause failure of the grid disturbance and determine corrective actions. All three Palo Verde nuclear plants were returned to service by 6/20/04. On 7/1/04, at a meeting between APS managers and Palo Verde station personnel it was determined that a human performance evaluation would be conducted to assess APS personnel response to the 6/14/04 event. On 7/4/04 at 1859, Westwing transformer T1 bank tripped off with the subsequent tripping of transformer banks T4, T7 and T10. Substation maintenance personnel responded to the Westwing substation and determined that transformer T1 bank was on fire. After the event had concluded a total of five transformers were damaged, all three phases of transformer bank T1, a spare transformer and phase-3 of transformer bank T4. Investigation of the transformers determined failure of transformer T732 in the T1 bank was the initiating event on 7/4/04. The most probable cause of transformer T732 failure was determined to be its alignment to the Liberty-Westwing line fault for 19.746 during restoration activities on 6/14/04. Further, transformer backup protection would have prevented damage to the transformer during this alignment. This report evaluated APS actions between 6/14/04 and 7/4/04 to determine if there are any lessons to be learned that could have led to transformer bank T1 being removed from service prior to the failure of transformer T732 on 7/4/04.

This evaluation concludes that with existing practices used at the time, that there was no indication of the impending failure of the T732 failure on 7/4/04. Once placed in service on 6/14/04 the transformer ran normally, subsequent oil samples and thermography readings did not indicate impending failure. Initial review of data from the 6/14/04 investigation focused on the initiating event and subsequent loss of generating units in an effort to support restart of the Palo Verde units. These efforts included meetings with SRP and WAPA to determine how and why the protective relaying systems responded to the grid disturbance, development of a detailed sequence of events leading to the loss of generation at Palo Verde, Redhawk, and Arlington, development of new protection schemes for EHV transformers at Westwing, Yavapai, and North Gila, analysis of relay changes at Hassayampa, meetings with Palo Verde and NRC personnel to discuss causes of the disturbance and corrective actions, and additional redundancy added to line protection schemes at the Westwing 230kV switchyard.

As a normal practice, review of data for restoration activities occurs later and is done for equipment reliability trending. Interviews of substation and ECC personnel was the best chance at identifying issues related to restoration activities that lead to the T1 transformer bank being aligned to the Liberty-Westwing line fault for a significant period of time on 6/14/04. Interviews of substation and ECC personnel did not occur prior to the 7/4/04 fire. However, quicker identification of fault current magnitudes would be possible if

complete DFR coverage of the Westwing switchyard was available. Currently, DFRs do not monitor the three 525/230kV transformers in the Westwing yard, and data has to be obtained from other sources and analyzed to determine the impact of faults on the transformers.

In conclusion, on 6/14/04 the focus was appropriately placed on the cause of the initiating event and on the loss of power to the Palo Verde Nuclear Plants. However, it is recommended that prompt interviews of personnel involved following a significant event should be a normal practice and may have led to identifying other issues that needed to be pursued. In addition, establishment of a rough sequence of events from the initiating event until an established point of stabilization should be pursued early in a large event. Further, DFRs should be added to the Westwing 525kV and 230kV substations to provide complete coverage. Finally, guidelines for the establishment of event investigation teams should be developed and published.

Sequence of Events

- 6/14/04 0740 Fault occurs on 230 kV Liberty-Westwing line and Westwing breaker WW1022 breaker does not open to isolate fault.
- 6/14/04 0741 The Westwing substation is deenergized after back-up protective schemes within the 525kV system isolate the fault on the 230 kV Liberty-Westwing line.
- 6/14/04 0754 DOE closes in to the 230 kV Liberty-Westwing Line and the supply breaker immediately trips.
- 6/14/04 0800 ECC operator tags Liberty-Westwing line breakers WW1022 and WW1126 “Do Not Operate”. Breaker WW1126 is tagged while in the open position and WW1022 is tagged while in the closed position.
- 6/14/04 0803 ECC aligns Pinnacle Peak 230 kV line to fault and WW1222 breaker immediately trips (Transformer T1 bank is not in the flow path.)
- 6/14/04 0815 ECC aligns 525 kV power through Westwing transformer banks T4 and T10 to the fault and WW1252 breaker immediately trips.
- 6/14/04 0831 The ECC operator closes WW256 to energize Westwing 525/230 kV transformer T-1 bank.
- 6/14/04 0832 The ECC operator closes Westwing 230 kV breaker WW1322 to energize the 230 kV bus from the Westwing 525 kV through the T-1 transformer bank. The path is aligned to the Liberty-Westwing line fault due to 230 kV breaker WW1022 still being closed.
- 6/14/04 0832 The ECC operator opens breaker WW1322 based on reports from the field. The actual alignment through only transformer bank T1 is not determined until after investigation into the 7/4/04 T1 fire event.
- 6/14/04 0842 The ECC operator tags 230 kV disconnects WW1021 and WW1023 “Do not Operate” in the open position to isolate WW1022 breaker which isolates the Liberty-Westwing line fault from the Westwing substation.
- 6/14/04 0846 The ECC operator closes breaker WW1322 to energize the Westwing 230 kV bus from the 525 kV bus through Westwing T1 transformer bank.
- 6/14/04 ≈1430 APS System Protection personnel contact APS substation Maintenance personnel with suspected cause of the failure of WW1022 breaker to trip.

- 6/14/04 ≈1600 APS substation Maintenance personnel contact APS System Protection personnel with confirmation that the failed component (AR protective relay associated with breaker WW1022) was found.
- 6/15/04 APS, SRP, and WAPA protective relaying staffs meet to begin analysis of event cause, chronology, and potential corrective actions.
- 6/15/04 Assigned Westwing investigation team leader for the grid disturbance caused by the Liberty-Westwing line fault.
- 6/16/04 1519 Westwing transformers oil sample results are known. Engineering determines oil samples of Westwing 525/230/34.5 kV transformer banks (T1, T4 and T10) acceptable for continued operation.
- 6/16/04 1159 Redundant AR relays added to Deer Valley – Westwing line. Line returned to service.
- 6/16/04 1916 Redundant AR relays added to Liberty – Westwing line. Line repairs completed. ECC closes breaker WW1126 to place the Liberty-Westwing line in service.
- 6/16/04 Replacement of breaker WW1022 begun.
- 6/18/04 Palo Verde Unit 1 returned to service.
- 6/19/04 Palo Verde Unit 2 returned to service.
- 6/20/04 Palo Verde Unit 3 returned to service.
- 6/22/04 Additional members (organizations) for 6/14/04 event team requested.
- 6/24/04 Approval of additional protective scheme for EHV transformers at Westwing, Yavapai, and North Gila.
- 6/24/04 1035 APS completes replacement of WW1022 and closes breaker locally.
- 7/1/04 (days) An investigative team meeting was held to status Palo Verde staff on Westwing investigation and to assign investigator to perform a human performance evaluation of APS personnel response to the 6/14/04 fault event
- 7/2/04 0030 Substation maintenance reliability technician completes thermography readings on Westwing substation equipment. Transformer bank T1 readings are normal.

- 7/4/04 1859 Protective relaying isolates the Westwing T1 transformer bank and subsequent field reports determine that the T1 bank is on fire. All three phases (T731, T732 and T733) of the T1 bank are damaged along with spare transformer T734 and transformer T790 of the T4 bank.
- ≈7/13/04 Continued investigation into the 6/14/04 event determines the Westwing T1 transformer bank was aligned to the fault for 19.746 seconds during restoration activities at 0832 on 6/14/04.

Discussion of Interviews

Interviews were conducted with substation maintenance, system protection, reliability analysis, and ECC personnel after the 7/4/04 transformer fire event. Interviews indicate substation maintenance personnel were moving equipment from the T1 transformer bank to the T4 bank at 0740 on 6/14/04. The maintenance personnel exited the transformer area at the initiation of the event due to shaking and noise. At 0832, substation personnel directed communication to ECC to stop the restoration alignment (open the breaker) based on arcing on transmission lines. Substation personnel by the 525 kV control house indicated noise coming from the transformer area again during this alignment; however, they were not aware that only the T1 bank was aligned at that time. When asked during the interviews if the T1 transformer bank shook and made noise later that day when placed into service, substation personnel indicated that there did not appear to be anything unusual. An interview with the substation maintenance engineer indicated his initial focus and concerns on 6/14/04 was in the Westwing 230 kV yard. It was known that morning that 230 kV breaker WW1022 had failed to open. Substation maintenance personnel had witness arcing by breaker WW1022 and that the breaker had physical damage therefore, work had begun to evaluate the condition of breaker WW1022 and for its eventual replacement. The substation maintenance engineer had oil samples taken on all Westwing 525 kV transformers on 6/16/04. The engineer determined oil samples of Westwing 525/230/34.5 kV transformer banks T1, T4 and T10 acceptable for continued operation. Later a transformer expert hired to perform the root cause failure report on transformer T732 (H. Moore & Associates) determined the 6/16/04 oil sample results were unremarkable. On 7/1/04, a substation maintenance thermographer completed a normal PM for thermography readings on Westwing substation equipment. The thermographer indicated that readings for transformers T1, T4, and T10 were normal. The thermographer indicated he takes extensive readings on the transformers based on lessons he learned from a benchmarking trip to Southern California Edison; which had experienced a transformer failure in 2003 which also lead to collateral damage to adjacent transformers.

In conclusion, oil samples and thermography readings taken prior to 7/4/04 by substation personnel did not indicate any abnormalities with any of the Westwing transformers. In hindsight, had it been known that the T1 transformer bank alone had been aligned to the Liberty – Westwing line fault for 19.746 seconds, coupled with field reports of the transformer shaking and making noise, additional testing of the T1 transformer bank would have been warranted prior to 7/4/04. Substation Maintenance Engineering

personnel interviewed indicated that had they been aware of these facts, they would have recommended additional testing of transformer T1.

Interviews with system protection personnel indicate their initial focus was on the cause of the grid disturbance. They were trying to determine what went wrong and why it happened. By 1430 on 6/14/04, they relayed their suspicions to substation maintenance personnel and by 1600, maintenance technicians had confirmed their suspicion. Breaker WW1022 did not open to isolate the Liberty-Westwing line fault due to failure of its associated "AR" relay. System protection personnel in the following weeks were tasked with obtaining and analyzing data from as much as 100 sources. EMS (ECC alarm log), DFRs (digital fault recorders) and data from other utilities was analyzed. In the case of the Westwing substation alone, there were six DFRs to analyze. The system protection section leader was also spending time at the Palo Verde nuclear plant working with PVNGS personnel to answer questions the Nuclear Regulatory Commission (NRC) had related to the grid disturbance and the resultant loss of offsite power to Palo Verde and all three units tripping. Specifically they were being asked about the impact on grid stability due to the unexpected loss of the Hassayampa lines to Palo Verde. System protection personnel indicated in interviews that they are charged with protective relaying and if an event occurs, they are focused on whether or not protective relaying operated as intended. Approximately 4 years ago, upon request from the reliability analysis department, they started analyzing restoration activities as well. Interviews of analysis personnel indicate they use the data to help determine equipment reliability by looking at the time equipment is out of service. System protection personnel indicated their analysis of restoration activities might not start for weeks, after they had evaluated the initiating event. In conclusion, without a specific concern to focus on restoration activities from the 6/14/04, system protection personnel were properly focused on the initiating event of 6/14/04 and its effect on the grid. That focus was e critical than usual due to the extent of the event and its effect on the loss of power to the Palo Verde nuclear plants. Their focus did not shift to restoration activities of the 6/14/04 event until after the 7/04/04 event when it was thought the two events might be linked.

On 7/1/04, an organizational meeting was held with several department representatives and with management sponsors to form an event analysis team. The meeting also included members of the Palo Verde event investigation team, and issues related to the continued operability of the Palo Verde units and status of corrective actions to the T&D system were also discussed. From that meeting it was decided to perform a human performance evaluation of the 6/14/04 event due to safety issues related to arcing and flashing that occurred on the Liberty – Westwing line during restoration activities on 6/14/04. Actual interviews of ECC personnel did not start until after the 7/4/04 event. In interviews, ECC personnel indicated that there were several failed restoration attempts. The lead ECC supervisor performing restoration activities on the Westwing substation could not recall in detail restoration activities the day of 6/14/04. He was not aware of restoration sequences until the interviewer used marked up prints to show restoration activities. The marked up prints were made from data provided by system protection personnel. Questions concerning the tagging of Westwing breaker WW1022 during the event were asked and indicated a break down in communication; specifically lack of

“repeat back” or three legged communication techniques, which resulted in a lack of mutual understanding as to the open or closed position of the breaker. The stopping of the last alignment (19.746 seconds) was determined to be a manual action by the ECC lead supervisor based on negative field reports. It cannot be concluded with certainty that timely interviews of ECC personnel would have identified that the T1 transformer bank was aligned to the fault for a significant period. However, the failed restoration attempts and the subsequent opening of disconnects surrounding breaker WW1022 were known by the ECC staff. These actions, along with large and abnormal response of protective equipment to the fault, indicated that system protection did not operate as intended and warranted a timely investigation by ECC for lessons learned, if nothing else.

Conclusion

Interviews of personnel involved in an event are important to the investigation team. New concerns and issues may be raised and sequence of events might become clearer. What tools were effective, which ones were not effective, and which ones were not used can be determined. Different perspectives can be obtained from field personnel, control room personnel, management, and engineers. To be of the most benefit, interviews after an event need to be as prompt as possible so as the event is fresh in the mind of the individuals involved. This event caused the first total loss of offsite power and three unit trip in the history of U.S. nuclear power. Due to the intense focus of all APS personnel on understanding the cause of the disturbance and what corrective actions could be taken, and with review of restoration activities being a secondary concern, system protection personnel properly focused on the initiating event, as is their normal practice. Although ultimately discovered by system protection personnel, prompt interviews of ECC personnel and substation field personnel may have identified a concern with restoration activities that may have led to evaluating restoration data earlier. Rarely is a significant event caused by the breakdown of just one barrier and often a significant event raises other issues that need to be resolved. Interviews of involved parties are a key to getting all issues and concerns on the table. Lastly, quicker identification of fault current magnitudes would be possible if complete DFR coverage of the Westwing switchyard was available. Currently, DFRs do not monitor the three 525/230kV transformers in the Westwing yard, and data has to be obtained from other sources and analyzed to determine the impact of faults on the transformers.

Findings

- Prompt interviews of all involved parties was not completed for the 6/14/04 event. The 6/14/04 was a significant event, described as a “once in the career” event for an ECC operator. On such a large event, normal practice should be to perform a human performance evaluation to review how established barriers to failure performed. Communication, training, crew composition, procedures, environment and tools are some of things that can be evaluated for lessons learned.
- Establishment of a rough sequence of events from the initiating event until an established point of stabilization was not accomplished early in the 6/14/04 event.

Recommended Corrective Actions

- Management should establish an interview team as part of the investigation early in a large event. The interview team should consist of at least one person trained in human performance evaluation and a peer to the personnel involved.
- Management should request a Sequence of Events from the initiating event up to an established point of stability early in the event.
- Additional DFRs should be installed in the Westwing 525kV and 230kV switchyard to provide coverage for all critical equipment, particularly the 525/230kV transformers.
- Management should establish and publish guidelines for event type and sizes that warrant creation of investigative teams.

REFERENCES

- Drawing G-32900 (sheets 1&2), Westwing 500kV Switchyard Bays 1-9 one line Diagram.
- Drawing G-32901 (sheets 1&2), Westwing 500kV Switchyard Transformer Bays 1& 4 one line Diagram.
- Drawing G-33300 (sheets 1&2), Westwing 230kV Switchyard Bays 1-9 one line Diagram.
- Drawing G-33301 (sheets 1&2), Westwing 230kV Switchyard Bays 10-18 one line Diagram.
- Drawing G-33334, Westwing 69kV Substation one line Diagram.
- Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations (April 2004)
- The August 14, 2003 Blackout One Year Later: Actions Taken in the United States and Canada to Reduce Blackout Risk (August 13, 2004)
- Status report on NERC Implementation of August 14, 2003, Blackout Recommendations (August 11, 2004).
- August 14, 2003 Blackout; NERC Actions to Prevent and Mitigate the Impacts of Future Cascading Blackouts (February 10, 2004)
- Letter sent to CEO's of all NERC control area and reliability coordinators: Near-Term Actions to Assure Reliable Operations (October 15, 2003)
- APS letter (12/5/03) to WECC-Dennis Eyre in response to letter sent to CEO's of all NERC control area and reliability coordinators: Near-Term Actions to Assure Reliable Operations (October 15, 2003)
- ECC communication transcripts for 6/14/04 event.
- ECC alarm typer for 6/14/04 event.
- ECC alarm typer for 7/4/04 event.
- Control Area Readiness Audit Report –Duke Power (June 3-4, 2004)
- Control Area Readiness Audit Report –TVA (April 21-22, 2004)
- January 9, 2003 ECC file letter 13.4.1, Tom Glock to ECC Supervisors: Responsibilities and Authorities
- APS Black-Start System Restoration Guideline (April 2003)

- ECC logs for 6/14/04
- ECC logs for 7/4/04
- ECC logs back to December 2003 (review)
- ECC alarm report on breaker WW0122 manipulations back to May 2002
- Transmission Operations Work Request (040773)-Repair conductor on WAPA's Liberty-Westwing 230kV Line (5/14/04)
- WECC MORC Section 8.C-Training (Approved 4/23/04)
- NERC Policies (1-8)
- NERC compliance template for policy 8 (Operating Personnel and Training) and Policy 6 (Operations Planning)
- NERC Compliance Template Task Force (CTTF) Implementation Plan for the Compliance Templates
- NERC Continuing Education Program Criteria for Approving and Granting NERC Recognition to Qualified CE Program Providers and Learning Activities (April 14, 2004).
- Sample NERC Certification Test Questions
- NERC Transmission Operator Certification Examination Content Outline
- Draft: Root Cause of Failure Report for the June 14, 2004 Grid Disturbance
- DFR report for 6/14/04
- DFR report for 7/4/04