Operational and Maintenance Performance Assessment of Arizona Public Service (APS)

Final Report

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Submitted By:

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Scope

In 2004, representatives of EPRIsolutions (EPRIsolutions), Inc., Arizona Public Service (APS), Inc., and Harold Moore & Associates (HM&A), Inc., investigated and assessed the operational and maintenance performance of APS as related to the events and issues raised by the June 14, 2004, Grid Disturbance and subsequent equipment failures at the Westwing (July 4th, 2004) and Deer Valley (July 20th, 2004) substations. The scope of this report, developed in close collaboration with staff of the Arizona Corporation Commission (ACC), is to summarize the results of the operational and maintenance performance assessments as well as the various actions taken by APS prior to and during the investigation. Supporting documents are:

- *Transmission & Substation Maintenance Practices Assessment for Arizona Public Service Company (APS)*, EPRIsolutions, Inc., completed December 31st, 2004.
- *Root Cause of Failure Report for the June 14th, 2004, Grid Disturbance*, Donald Lamontagne, Arizona Public Service Company (APS), completed October 1st, 2004.
- *Review of APS Response to 6/14/04 Event as Related to the 7/4/04 Westwing Event*, Al Fluegge, Arizona Public Service Company (APS), completed December 3rd, 2004.
- *June 14, 2004, 230-kV Fault Event and Restoration*, Jeff Court, Arizona Public Service Company (APS), completed December 3rd, 2004.
- *Arizona Public Service Westwing Substation Autotransformer Failure Analysis Report*, James B. Templeton, Harold Moore & Associates (HM&A), completed November 1st, 2004.

Objectives

EPRIsolutions staff completed an assessment of APS's operational and maintenance practices, effectiveness and performance. The assessment was completed in the third and fourth quarter of 2004 and is based on contributions made by APS, HM&A and EPRIsolutions. Primary objectives of the performance assessment were the evaluation of APS's operational and maintenance performance and the organization's response as related to the events and issues of the June 14, 2004, Grid Disturbance and subsequent equipment failures at the Westwing (July 4th, 2004) and Deer Valley (July 20th, 2004) substations.

Results of the operational and maintenance performance assessment and the corresponding improvement plans and targeted recommendations are contained herein. The operational and maintenance performance assessment is based on comprehensive interviews of more than 100 of APS's personnel, operational and maintenance staff, contract workforce, construction crews, the inspection and engineering teams as well as the leadership. The comprehensive assessment focused on operational and maintenance practices and processes, the analyses of the events and issues surrounding the June 14, 2004, Grid Disturbance and subsequent equipment failures at the Westwing (July 4th, 2004) and Deer Valley (July 20th, 2004) substations, the forensic examination of failed equipment, as well as the investigation of APS's actions in response to those events. Applicable operational and maintenance processes, documents, procedures, software tools and diagnostic technologies as well as program plans and performance indicators were also reviewed and evaluated. The goals of the operational and maintenance assessment were to:

- Provide an independent evaluation of APS's operational practices and processes as well as the organization's operational performance, actions and response to the events.

- Provide an independent evaluation of APS's maintenance practices and processes as well as the organization's overall maintenance practices, effectiveness and performance.

- Perform root cause of failure investigations to identify the sequence of events in each event, the organization's action and response to each event and to determine dependencies (cause and effect relationships) among the events.

- Identify needed improvements in the organization's operational and maintenance performance, if any, and provide targeted recommendations and actions, where applicable.

Reliability

EPRIsolutions staff has compared the reliability and service effectiveness achieved by APS in the years ranging from 1996 to 2004 with the effectiveness and performance of other organizations in the WECC and the United States (USA). The reliability and service effectiveness benchmarking information was developed by EEI (Edison Electric Institute) and its use for the benefit of the overall assessment was granted by EEI. All reliability and service level indices and values referenced to EEI as provided in this report exclude the effects of major events. Reliability and service effectiveness indices that exclude major events provide a more accurate assessment of the effectiveness and performance of an organization's operational and maintenance practices and programs than comparable parameters that do not exclude major events.

Table 1 provides a comparison of the reliability and service effectiveness indices (exclusive of major events) recorded for APS's organization relative to the performance and reliability levels of power delivery organizations within the

WECC and the USA as benchmarked by EEI (5 Minute Basis) in early 2003. Based on EEI's benchmarking study, APS's reliability and service effectiveness is ranked 1st Quartile (Q1, Top 25 Percent) in ASAI, SAIDI, and SAIFI, and 2nd Quartile (50 to 75 % Percent of the Benchmarked Organizations are ranked at a level below APS) in CAIDI and MAIFI.

Table 1
Performance & Reliability – Comparison to Industry (Source: EEI, 2003)

Performance & Reliability Index & Metric	APS 2002 (Actual)	WECC 2002 (Actual)	USA 2002 (Actual)
ASAI	99.98 (Q1)	99.98	99.97
SAIDI	1.35 (Q1)	1.56	2.54
SAIFI	1.01 (Q1)	1.13	1.22
CAIDI	1.33 (Q2)	1.31	1.85
MAIFI	2.03 (Q2)	2.10	4.26
ASAI – Average System Availability Index; SAIDI – System Average Interruption Duration Index; SAIFI – System Average Interruption Frequency Index; CAIDI – Customer Average Interruption Duration Index; MAIFI – Momentary Average Interruption Frequency Index			

The results of the operational and maintenance performance assessment as well as the results of the EEI benchmarking study show that APS's effectiveness and performance in the operation and maintenance of the transmission and substation network over the last few years produced reliability and service effectiveness indices better (either Q1 or Q2 depending on the index used in the comparison) than the corresponding average value recorded for all utilities in the WECC. The review of the reliability indices also indicate that APS's reliability and service effectiveness as evidenced by the organization's record continues to improve year after year since 1996. Depending on the reliability or service level index evaluated, the performance of the organization has improved by nearly 42 percent in SAIFI, the System Average Interruption Frequency Index, 47 percent in SAIDI, the System Average Interruption Duration, and 21 percent in CAIDI, the Customer Average Interruption Duration.

Based on this information, the reliability indices indicate a level of effectiveness, performance and reliability at APS that exceeds the level of effectiveness, performance and reliability considered industry Standard (i.e., where industry Standard references the average performance and level of effectiveness observed) within the WECC as well as the USA overall (as demonstrated by the EEI benchmarking study as well as this investigation). Figure 2, 3, and 4 show APS's 'actual' (blue line) reliability and service effectiveness over a period of eight (8) years in conjunction with APS's 2004 'projection' and long term trend (red line). It is important to note that APS's organization internally tracks its performance and reliability based on the more stringent one (1) minute basis rather than the five (5) minute basis commonly encountered in the industry.

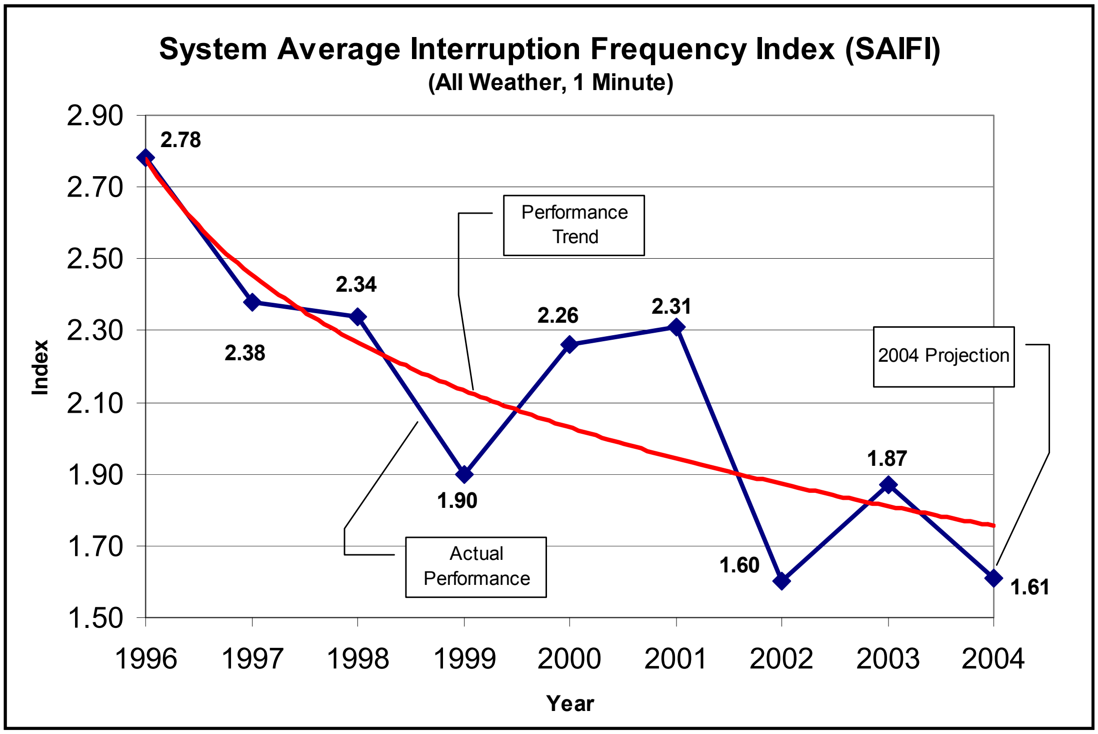

Figure 1
Reliability & Service Effectiveness – System Average Interruption Frequency Index (SAIFI)

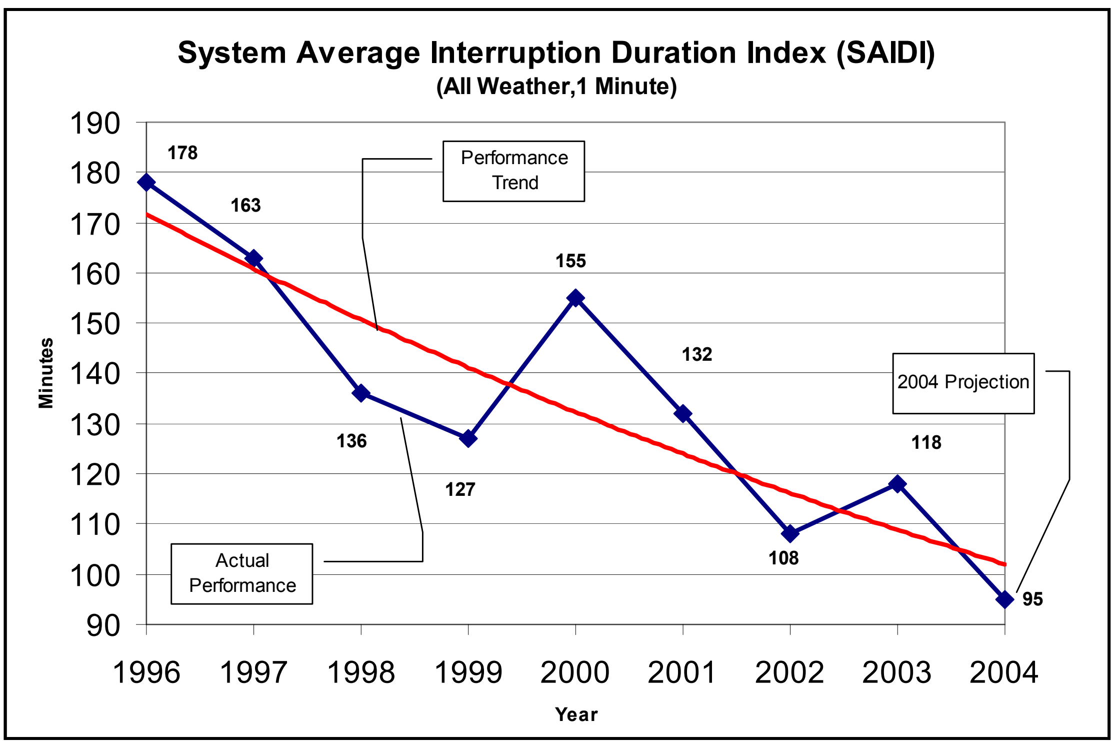

Figure 2
Reliability & Service Effectiveness – System Average Interruption Duration Index (SAIDI)

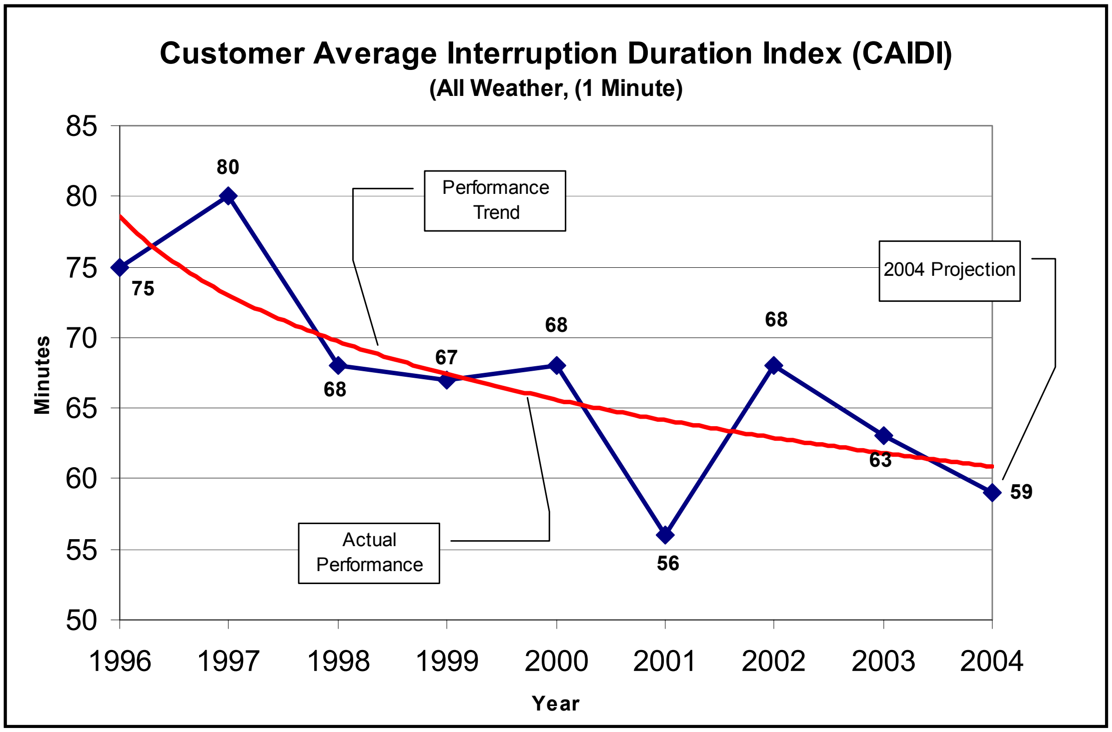

Figure 3
Reliability & Service Effectiveness – Customer Average Interruption Duration Index (CAIDI)

Analysis

In support of the analysis, EPRIsolutions staff and representatives of APS and HM&A developed a time line (Figure 4) to document the sequence of events (June 14, 2004, Grid Disturbance and subsequent equipment failures at the Westwing (July 4th, 2004) and Deer Valley (July 20th, 2004) substations) as well as to place each event as well as the various actions and responses provided by APS's organization in perspective. In 1996, APS started a major initiative to improve the organizations system reliability and service effectiveness. In 2000, APS's leadership partnered with EPRIsolutions in an initiative to benchmark their achievements as well as to continue to improve the organization's maintenance practices, effectiveness, overall performance, and equipment reliability. In this assessment, EPRIsolutions assisted in the identification of the progress made in the previous four (4) years.

As a proactive organization committed to continuously improving its service effectiveness and reliability, APS's leadership was working with EPRIsolutions to optimize its maintenance practices. Following the June 14th, 2004, Grid Disturbance, APS initiated a root cause analysis into the event as well as an assessment of the organization's human performance during the event. After the July 4th, 2004, Westwing event APS's leadership hired HM&A to perform a forensic analysis to determine the root cause of failure of the Westwing transformers and retained EPRIsolutions, following the July 20th, 2004, Deer Valley event to assess the organization's operational and maintenance practices, effectiveness and performance.

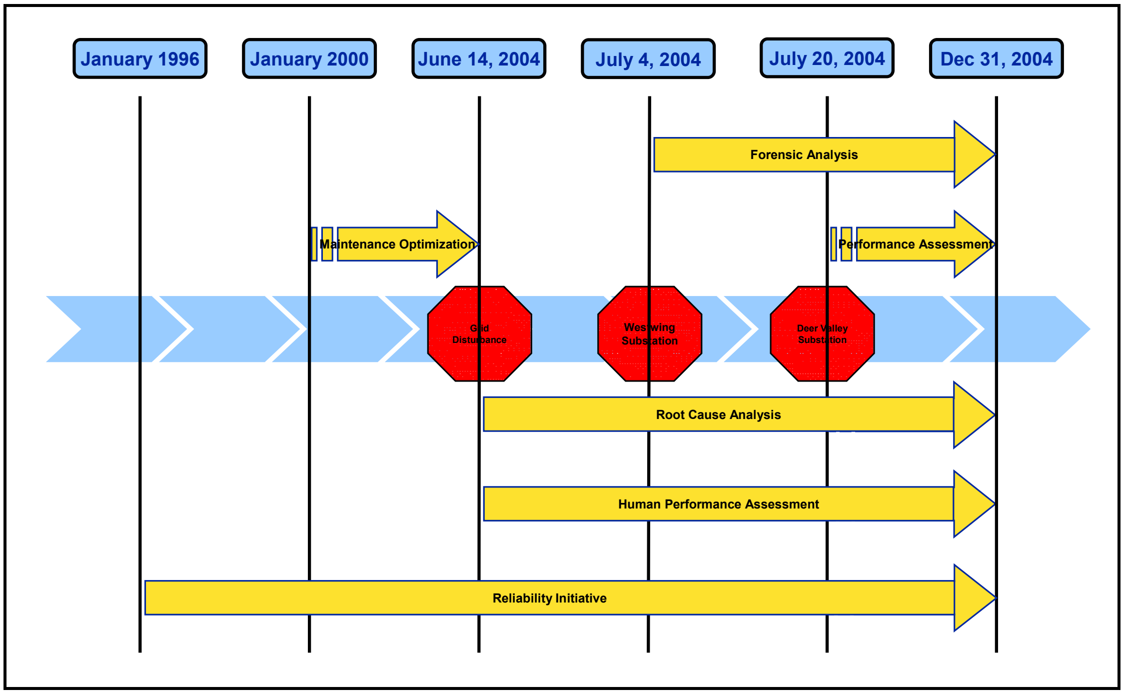

Figure 4
Sequence of Events, Actions and Response

Grid Disturbance (June 14th, 2004)

On June 14th, 2004, at 7:40am, Western Area Power Administration's (WAPA) 230-kV Liberty-Westwing transmission line faulted. This event cascaded into a grid disturbance resulting in the forced outage of three (3) Palo Verde reactors and a short disruption of service to nearly 20,000 APS and 35,000 Tucson Electric Power (TEP) customers. In response, APS initiated an investigation to determine why the protective systems in the 230-kV system did not contain the fault that caused the eventual loss of service to customers and what corrective actions, if any, were needed to prevent a recurrence of such an event.

The root cause analysis determined that a relay (Westinghouse AR, manufactured in October 1974) failed to function as intended as it did not cause breakers WW1022 and WW1126 to isolate the transmission line fault as intended by APS, the manufacturer and the system operator. The analysis also showed that the relay was designed, manufactured and used in a manner consistent with industry practice and that the relay should have provided adequate and sufficient protection to the system as intended. Maintenance records indicate that the AR relay satisfactorily passed the functional test in 2000. APS performs functional test on AR relays of this type every 6 years in alignment with common industry practices (i.e., testing intervals commonly used in the industry range from 4 to 6 years). A closer examination of the relay revealed that the relay did not operate as intended because two contacts in the device failed to close and make contact. As a result, breaker WW1022 did not only fail to operate as intended but also failed to communicate its failure to isolate the fault since both signals use the same contact in the protection device. Failure rates established by the manufacturer for this type of relay are approximately one (1) failure in 2000 years of use.

In response to the event, APS, as an interim corrective action, replaced the defective relay, tested the function of all other relays in the 230-kV switchyard and subsequently installed redundant relays where single relays had been used to communicate with multiple breakers. Additional steps taken by APS recognize that relay functional tests commonly used in the industry neglect to positively determine and ensure that all contacts will close as intended unless each contact is tested separately and that a lack of redundancy in the protection scheme will negate the successful transmittal of signals to the breakers allowing a fault to be transmitted to the transformer. In response, APS developed targeted corrective actions to eliminate a recurrence of this problem. Corrective actions are provided in the section entitled Conclusions & Recommendations.

APS's leadership also initiated an investigation to evaluate grid control and operating procedures, the effectiveness of the methods and practices used in the service restoration as well as to evaluate the organization's actions, response and human performance throughout the event. The investigation showed that the June 14th, 2004, transmission line fault initiated an event of a size and scope not previously experienced by the operators of the system. Interviews of the operators following the event revealed that the amount of data and communication entering the operations center in the form of system alarms, phone and radio traffic, and equipment status indicators inundated the staff consisting of two fully qualified Energy Control Center (ECC) Supervisors and one ECC Supervisor Trainee.

In response to the event, APS's operators utilized restoration strategies in accordance with the recommendations of the National Electric Reliability Council (NERC) and as outlined in NERC's Electrical System Restoration Reference Document. In accordance with NERC recommendations, the operator proceeded to open all those breakers deemed necessary to allow the restoration of the system. Records of the event show that this strategy was not successful in the restoration of the 230-kV switchyard and the operator decided to change to an 'all open' strategy to effectively de-energize and isolate the 230-kV switchyard. In the process of isolating the switchyard, the operator recognized that the EMS system showed WW1022 as closed. Communication with the field at the time of the event indicated that the breaker had been damaged. On the basis of this communication, the operator concluded that the breaker's 'closed' indication was incorrect and the result of the damage of the breaker and that the 230-kV bus was de-energized and isolated.

Next, the operator started the process of aligning the power on the 230-kV bus to eventually restore service. In this attempt, the operator closed breakers three (3) different times resulting in the inadvertent alignment and energization into the Liberty to Westwing 230-kV transmission line fault via the WW1022 line breaker. In the first two (2) attempts the protection systems functioned as intended and the breakers immediately opened after closing. On the third try, the protection system failed to function as intended and the closing of the W1322 breaker resulted in feeding the line fault through the Westwing T-1 transformer for a period of nearly 20 seconds until the operator managed to reopen the breaker.

The investigation showed that the operator's response to the June 14th, 2004, ground fault event was prompt, professional and in accordance with NERC guidelines and recommendations. However, the results also show that there are a number of opportunities for the organization to improve the response, reduce uncertainty and improve communication in service restorations. Therefore, APS developed targeted corrective actions and recommendations to minimize the potential for a recurrence of the June 14th, 2004, event. Again, corrective actions have been summarized and are provided in the section entitled Conclusions & Recommendations.

Westwing Substation (July 4th, 2004)

The investigation revealed that the June 14th, 2004, event as well as the subsequent actions in the restoration of service imposed a significant fault on Westwing's T-1 transformer unbeknown to APS's organization. Because of the focus on the June 14th, 2004, grid disturbance and service restoration, the nature, magnitude and duration of the June 14th fault current incurred by the T-1 transformer was not known and did not get communicated to all stakeholders until after the July 4th, 2004, transformer failure. It should be noted that the post-event analysis and system modeling as a means to assess the effects of a particular event on the condition of the system, sub-systems and equipment is not commonly exercised in the industry but demonstrates a 'Best Practice'. Also, it is important to note that Westwing's T-1 transformer as well as other transformers in the Westwing substation had been recently refurbished (expenditures for the refurbishment and retrofit totalled $ 2 Million) with the work having been completed prior to the June 14th, 2004, event. Upon completion of the refurbishment, APS's diagnostic team performed oil sampling, visual and infrared inspections and other diagnostics on the re-energized transformers that indicated the satisfactory functionality of all systems. Finally, a review of the maintenance history of the transformer, performed by HM&A, found that maintenance performed was appropriate for transformers of their age, that procedures used were adequate, and that the replacement parts and processing of the units for return to service appeared to be in order.

Following the June 14th, 2004, event, APS sampled the oil on the T-1 as well as other transformers to identify if any damage had been incurred as a result of the June 14th, 2004, grid disturbance. The results of the diagnostic oil tests came back as unremarkable requiring no further action. Even though the oil results indicated no change in the performance, APS also performed a comprehensive infrared inspection which was completed on July 1st, 2004. The results of the infrared inspection revealed normal operating conditions and temperatures. Field reports by substation technicians did not indicate increased levels of vibration and audible noise for the T-1 transformers relative to other transformers in the substation when placed back in service. It is important to note that APS was at this time not yet aware that Westwing's T-1 transformer had experienced a significant fault for nearly 20 seconds in the service restoration on June 14th, 2004, since the organization had not yet completed its analysis of the event to assess the effect on the systems and equipment. In 2000, APS, as a proactive organization, recognized the value of analyzing each event to assess the effects on related systems and equipment (recognized as an industry 'Best Practice' and implemented a policy to support this process unilaterally.

On July 4th, 2004, at 6:59pm, Westwing's T-1 transformer failed. The data indicates that the fault initiated in Phase 2 of the T-1 transformer bank (T732). The fault was cleared in approximately four (4) cycles and the failure was not anticipated or predicted by any operational data or measurements taken prior to the transformer failure event. The subsequent analysis and forensic examination of the Westwing substation transformers strongly suggests that the failure of the transformer can be attributed to the significant sustained fault endured by the T-1 transformer in the attempt to restore service on June 14th, 2004. The fault carried by the T-1 transformer on June 14th, 2004, lasted for nearly 20 seconds (Phase A = 12,390 Amps, Phase B = 13,780 Amps, and Phase C = 13,320 Amps) constituting a long duration fault likely to have terminally damaged the transformer (based on ANSI C57.109, Figure 4 for Category IV Transformers).

The analysis and forensic examination strongly suggests that the system fault experienced on June 14th, 2004, resulted in terminal damage to the transformer's phase assembly. While this fault was not sufficient to cause the immediate failure of the equipment it set forth the conditions that likely progressed into the ultimate failure of the transformer on July 4th, 2004. The results suggest that on July 4th, 2004, the internal failure in the T-1 transformer caused the internal pressure in the transformer tank to increase to a point at which the barrier between the transformer oil and the oil in the load tap changer broke. The increase of pressure in the load tap changer compartment caused the inspection door of the load tap changer to fail thus allowing the oil from the main transformer tank to drain to the outside environment. The draining oil caught fire and the ensuing fire eventually destroyed the adjacent transformers. Also, the forensic examination provided definite evidence of winding failures, large areas of conductor fractures, deformation, and melted material where the conductor's movement was most likely sufficient to result in coil-coil and/or winding-winding faults.

DGA oil samples, collected on June 16th, 2004, showed no remarkable gassing in the transformer. An infrared inspection on July 1st, 2004, revealed no elevated temperatures which indicates that the deterioration of the transformer may have progressed very rapidly from July 1, 2004, the day of the infrared inspection, to July 4th, 2004. The results show that there are opportunities for the organization to improve the response, reduce uncertainty and risk, and improve communication. Therefore, APS developed targeted corrective actions and recommendations to maximize the organization's chances to identify equipment damaged by faults more effectively. Again, corrective actions have been summarized and are provided in the section entitled Conclusions & Recommendations.

Deer Valley Substation (July 20th, 2004)

On July 20th, 2004, the bushing on transformer T928 at the Deer Valley substation failed explosively and caught on fire. The investigation indicates that the failure can be attributed to the explosive failure of a bushing located directly over the control cabinet. The removal of the failed General Electric (GE) Type U bushing revealed that the lower porcelain of the bushing disintegrated completely as a result of the explosion causing all of the debris to have accumulated at the bottom of the tank. A closer examination revealed that the blow-out occurred approximately one (1) foot below the bushing potential tap on the mounting flange. Also, the investigation showed a burn crater on the interior of the lower bushing ground sleeve casting directly adjacent to the condenser blow-out. Turn to turn ratio testing indicated no open or shorted windings within the transformer.

A review of the maintenance history of Deer Valley's T928 transformer and associated equipment revealed no indications of the impending failure of the GE Type U bushing. The bushing had been previously evaluated as part of the routinely scheduled field inspection providing no indication of distress. The explosive nature of the bushing failure indicates that the failure of the bushing was caused as a result of the sudden failure of a critical component of the bushing rather than a slowly proceeding deterioration of the equipment that could have been recognized by diagnostic systems in routine field inspections.

Based on the results of the investigation, APS and EPRIsolutions staff concluded that the probable cause of failure of the T928 transformer was the failure of the GE Type U bushing which in turn caused the ancillary damages and eventual destruction of the T928 transformer at the Deer Valley substation. Also, the analysis (based on the data provided by Digital Fault Recorders (DFR) and system performance simulations) clearly indicated that the condition of the transformer at the Deer Valley substation was not recognizably affected by the events on June 14th, 2004, and the events of July 4th, 2004 (i.e., the failure of the GE Type U bushing and the resulting damages to the transformer are unrelated to either of the other events).

GE Type U bushings are extensively used in the industry and their performance has been increasingly questioned over the last few years by utilities. Utilities and equipment experts have observed a successively increasing failure rate of these types of bushings both nationally and internationally. The consensus opinion in the industry concludes that the failures of this type of bushing as well as the successive increase in the failure rate can be attributed to a deficient design. In response, most organizations have recently decided to proactively replace existing GE Type U bushing designs with more competent bushing designs but in reality, the fact is that the significant number of installations in the USA as well as the limited availability of outages on the heavily tasked power grid have made the timely replacements of these units difficult for all organizations. Because of the risk associated with these bushings, it is recommended that APS's leadership and maintenance management develop a strategy for the phase-out and timely replacement of this type of equipment in alignment with the organization's planned, routine transformer refurbishments.

Operational & Maintenance Performance Assessment (July 30th, 2004)

EPRIsolutions performed a comprehensive assessment of APS's transmission and substation maintenance organization in each of the four major categories of maintenance processes, technologies, management and work culture, and people skills and human resources. The comprehensive assessment addressed all 19 elements of a 'standard' comprehensive maintenance program, 104 sub-elements and more than 1000 attributes. For each area, scores were developed based on a thorough review of current practices, process and other pertinent documentation and in depth interviews of APS personnel.

Each attribute, sub-element, element and category was scored on a scale of 0 to 10. A score of 0 to 3 is assigned to those attributes, sub-elements, elements and categories in which the practices, effectiveness or performance of the organization is either completely absent or fails to register at a noticeable level. A score of 7 to 10 is assigned to those attributes, sub-elements, elements and categories in which the practices, effectiveness or performance of the organization either noticeably lead the industry or indicate a significant leadership position in the industry. A score of 4 to 6 is assigned to those attributes, sub-element, elements and categories where the practices, level of effectiveness and level of performance is comparable to the Standard Practices, Standard Effectiveness and Standard Performance in the industry. Standard Practices, Standard Effectiveness and Standard Performance addresses those practices, effectiveness and performance considered 'normal', 'typical', 'common' or 'representative' for the industry. In this assessment, Standard Practices, Standard Effectiveness and Standard Performance refer to 'normal', 'typical', 'representative' or 'common' practices, e.g. practices that are neither legally mandated nor universally agreed upon by the industry as recommended practices or associated with an expected or consensus 'minimum' or 'maximum' level of performance. Assigned attribute, sub-element, element, and category scores are consolidated to develop an overall rating for APS's transmission and substation maintenance organization.

The practices, effectiveness and performance of APS's transmission and substation maintenance organization was compared to the practices, effectiveness and performance of a peer group of 38 transmission and substation maintenance organizations. The assessment indicates that the overall practices, effectiveness and performance of APS's maintenance organization compare favorably with industry Standard Practices, Standard Effectiveness and Standard Performance (Figure 5). The overall score assigned to APS's maintenance organization is 4.45 on a scale of 0 to 10 compared to a score of 5.02 established for a peer group of 38 transmission and substation organizations (the peer group). The score of the top 25 percent (Q1) of the peer group exceeds 5.95 while the score of the bottom 25 percent (Q4) is less than 4.25. The score of the remaining 50 percent of the peer group falls equally above and below the median value of 5.02.

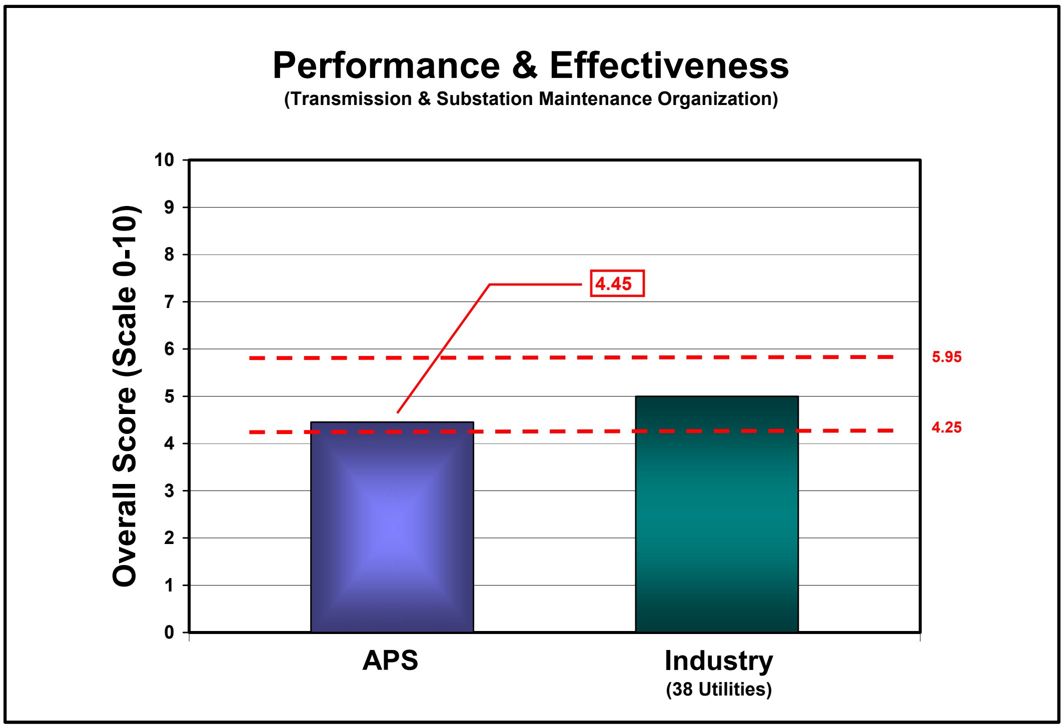

Figure 5
Overall Score (Performance & Effectiveness)

APS's overall score developed as part of the assessment indicates that there are opportunities to improve the overall practices, effectiveness and performance of the transmission and substation maintenance organization. The score also clearly indicates that overall practices, effectiveness and performance of APS's transmission and substation maintenance organization are comparable to industry Standard Practices, Standard Effectiveness and Standard Performance.

Practices, effectiveness and performance are Competencies and Strengths wherever the areas of practice, effectiveness and performance of APS's transmission and substation maintenance organization exceeds the industry

Standard Practices, Standard Effectiveness and Standard Performance. On the other hand, challenges and opportunities are assigned wherever the maintenance organization's practices, effectiveness and performance do not meet industry Standard Practices, Standard Effectiveness and Standard Performance. APS's strengths and competencies as well as challenges and opportunities are:

Competencies & Strengths

- Employee Morale, Motivation, and Empowerment
- Craftsmanship, Equipment, and Tools
- Infrared (IR) Diagnostic Program
- Vegetation Management Program
- Wood Pole Management Program
- Battery Maintenance & Replacement Program
- Safety Program & Record
- Reliability Performance Metrics and Management
- Construction, Design, and Material Standards
- Proactive Culture & Commitment to Continuous Improvement
- Benchmarking
- Work Quality & Housekeeping
- Management & Union Interaction
- Behaviors & Values

Challenges & Opportunities

- Protective Relaying
- Communication
- Post-Event Actions & Planning
- Bushings
- Industry Standard Diagnostics
- Maintenance Basis & Discipline
- Work Prioritization & Backlog Management
- Equipment Maintenance Procedures
- Data Automation & Maintenance Intelligence
- Planning, Scheduling & Outage Coordination
- Productivity, Planning & Scheduling Metrics
- Ownership, Roles, and Responsibilities
- Staffing Levels, Resource Availability, and Overtime Use
- Periodic & On-Line Monitoring
- Training (Non OTJ)

Conclusions & Recommendations

APS, as a proactive organization, is committed to the continuous improvement of its service effectiveness and reliability. At the time of the events, in 2004, APS's leadership was working with EPRIsolutions to optimize the organization's maintenance practices. Independently from this effort, EPRIsolutions completed an assessment of APS's operational and maintenance practices, effectiveness and performance as well as its response to the 2004 events. The assessment was completed in the fourth quarter of 2004 and is based on contributions made by APS, HM&A and EPRIsolutions. Primary objectives were the evaluation of APS's operational and maintenance performance as well as its response to the June 14, 2004, event and subsequent equipment failures at the Westwing (July 4th, 2004) and Deer Valley (July 20th, 2004) substations.

Conclusions

The analysis of the cause and effect during the June 14th, 2004, and July 4th, 2004, events showed that the primary cause for the damages to Westwing's T-1 transformer was the failure of the AR Relay as shown in Figure 6. As it relates to the sequence of events, the failure of the AR Relay caused the resulting breaker operation, communication of the signal and system alarms at the operations center. In response to the system alarms, the ECC operator analyzed the situation and implemented restoration procedures in accordance with NERC policies, guidelines and recommendations. A miscommunication between the field personnel and the ECC operator as well as the use of the AR Relays with primary and secondary signals linked to a single channel and the lack of backup protection systems on the transformers facilitated the breaker to be closed into the fault resulting in a deep, sustained fault to Westwing's T-1 transformer.

The use of relays with primary and secondary signals linked to a single channel constitutes acceptable practice in accordance with WECC guidelines and requirements. However, in retrospect, it is apparent that a separation of the signals to different channels would have increased the robustness of the protection system. Similarly, while the use of transformers without backup protection constitutes an acceptable design in accordance with WECC guidelines and requirements, the events clearly indicate that the presence of transformer backup protection systems would have increased the robustness of the system. Transformer backup protection systems are likely to have minimized the duration of the fault as well as the damages caused to the transformer.

The investigation showed that the service restoration attempts in the June 14th, 2004, event produced fault currents in Westwing's T-1 transformer that seriously affected the equipment's ability to continue to reliably serve the load and function as intended. The damages caused by closing into the fault on June 14th, 2004,

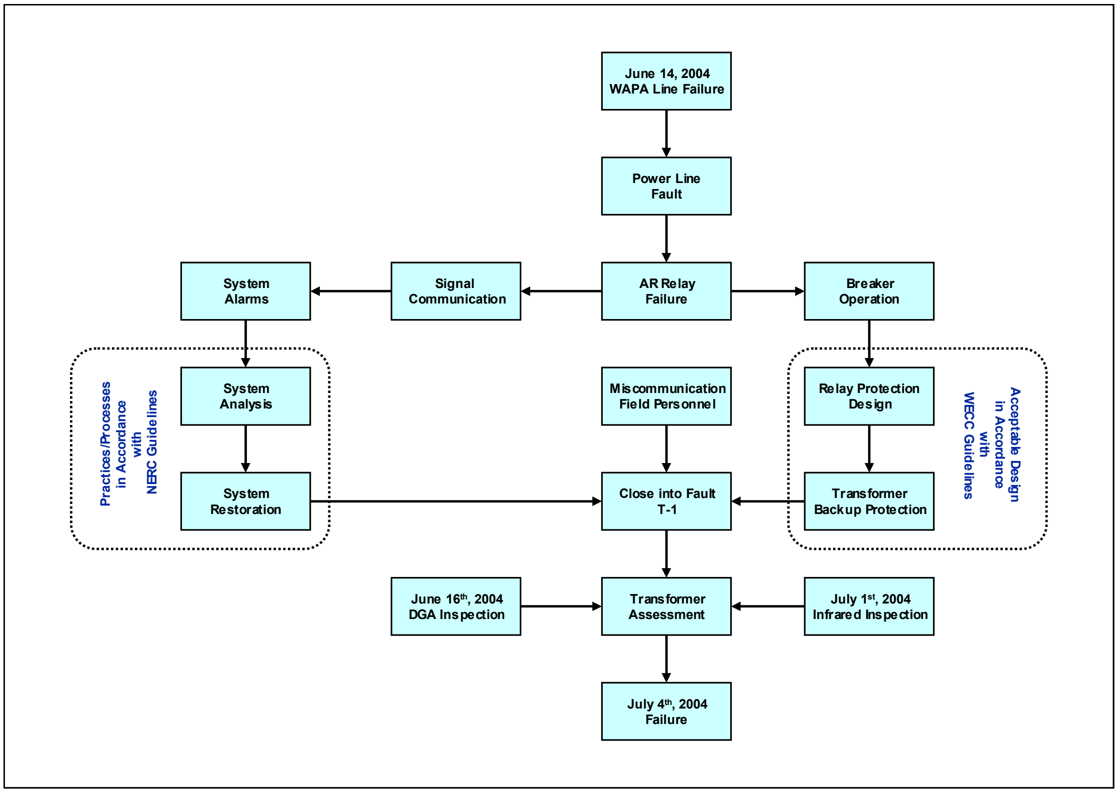

Figure 6
Sequence of Events

led to the eventual failure of the transformer on July 4th, 2004. The cause for the closure into the fault during restoration of service on June 14th, 2004, is attributed to a miscommunication (and contributed by the relay signal scheme and lack of transformer backup protection systems) between field personnel and the ECC operator. Policies and procedures used by the ECC operator adhered to NERC policies, procedures, guidelines and specifications. The analysis also shows that the failure of Deer Valley's transformer bushing was not related to the June 14th, 2004, event or the subsequent July 4th, 2004, Westwing event.

Field inspections and diagnostics performed following the June 14th, 2004, event on Westwing's transformer banks just prior to the July 4th, 2004, event did not reveal any gassing or rise in temperature which would have indiated the impending failure of Westwing's transformer. However, the analysis also indicates that if the effects of the June 14th, 2004, service restoration on the transformer could have been modeled, analyzed and identified more quickly (essentially prior to the July 4th, 2004, event), this 'Best Practice' deployed by APS may have provided a chance to take the transformer off line to deploy more sophisticated diagnostics as well as to closely examine the windings of the damaged unit internally. Based on the depth and duration of the fault experienced by the transformer, APS standard procedures would have stipulated the use of sophisticated diagnostics to closely examine the winding ratios which would have provided an indication of the damages incurred in the June 14th, 2004, service restoration.

An examination of the data and failed transformer at Deer Valley indicates that the most probable cause of failure for the T928 transformer is the explosive failure of the GE Type U bushing which in turn caused the ancillary damages and eventual destruction of the transformer. Also, the analysis shows that the condition of the transformer at Deer Valley was not recognizably affected by the events on June 14th, 2004, and the events of July 4th, 2004 (i.e., the failure of the GE Type U bushing and the resulting damages to the transformer are unrelated to either of the other events). A review of the maintenance history of Deer Valley's transformers revealed no indication of the pending failure of the bushing.

Recommendations

EPRIsolutions' project team formulated specific recommendations for APS's organization to address each of the challenges and opportunities identified in the assessment as well as the results of the investigation into the June 14th, July 4th, and July 20th, 2004, events. In each case, EPRIsolutions compared APS's practices, effectiveness and performance to industry Standard Practices, Standard Effectiveness and Standard Performance to identify those specific actions required to raise the organization's practices, effectiveness and performance to a level to meet or exceed comparable industry values. Individual actions and recommendations derived from the gap analysis as well as from the investigation into the failures were consolidated and grouped into functional and process areas and are provided in this report.

EPRIsolutions prioritized (Column 'P') each recommendation based on the perceived (as perceived by EPRIsolutions maintenance experts) value to APS, its customers, and the public, where 'value' is a parameter (column 'V') that considers the cost to APS, any financial benefits, and the impact to the operation and reliability of service. Priority and value are differentiated in this report as either 'high', medium' or 'low'. The objective of assigning a priority and value to each recommendation is to allow APS's transmission and substation maintenance organization to sequence tasks and allocate sufficient resources. The objective is not to indicate that some recommendations are more important than other recommendations or the need to address one item supercedes the need to address another.

Clearly, to support improvement and to increase APS's effectiveness and level of performance, the organization needs to take action to address each of the recommendations provided in this report. However, it is recognized that the priority with which to address some recommendations is higher relative to the priority of others. Similarly, the relative value associated with one action differs from another. Therefore, it should be recognized that the premise of the prioritization and valuation (on a relative basis) is to allow APS to sequence the actions that should be taken first and to plan those actions that are to follow upon completion of leading steps and improvement initiatives. Similarly, the value (on a relative basis) assigned by EPRIsolutions to each action or recommendation provides APS with an indication as to the anticipated effect on the organization's practices, effectiveness and performance to support the allocation of appropriate resources to each initiative.

At the time of the assessment, APS's organizational management and leadership was actively engaged in improving the organization's practices, effectiveness and performance based on the direction received from previous maintenance assessments and benchmarking studies. It should be noticed that these initiatives continue today and the existence of these ongoing improvement initiatives as well as their status (column 'S') are indicated in the Summary of Recommendations included in this report.

	Recommendation	P	V	S
Protective Relaying	While APS's protective relaying systems are engineered, manufactured, and used in a manner consistent with the industry, APS is recommended to add redundant relays in all protection systems where a single relay is used to communicate with multiple breakers as well as additional backup protection systems on the transformers. Also, while it is common practice in the industry to perform a functional test on a single relay contact only, it is recommended that APS revises and expands their functional testing procedure to test all four (4) contacts to ensure that each contact closes completely as intended. Next, APS should evaluate the proper function of all AR relays in the system. Finally, it is recommended that APS reviews the design of all high voltage protection systems to ensure an appropriate level of redundancy and to eliminate the potential for any other single failure consequences.	**H**	**H**	**IP**
Communication	Communication from the operator to the field and vice versa was not effective in the service restoration on June 14th, 2004. As a result of a miscommunication or incomplete communication the operator believed that the W1022 breaker had been damaged and was open contrary to the indication provided by the organization's EMS system that showed the breaker as closed. It is recommended that APS either develop, review and/or modify its current communication protocols as it relates to communication from the field to the operation's Center or vice versa. Formal, clear and precise communication protocols as well as associated verification routines and backup measures need to be defined and communicated to all stakeholders to eliminate ambiguity, uncertainty and human error in all communications.	**H**	**H**	**IP**
Post-Event Actions & Planning	It is recommended that APS's leadership develop the appropriate policies, procedures and resources to effectively analyze the effects of a system fault, outage or other event on the viability and performance of the remaining systems and equipment in a timely and responsive manner. Policies and procedures should clearly address the criteria that trigger a detailed post-event investigation as well as guidelines as to the expectations of the organization, the system operator and the regulator. Policies and procedures should be formally documented, regularly reviewed and clearly communicated to all stakeholders.	**M**	**H**	**NS**
Bushings	GE Type U bushings are extensively used in the industry and their performance has been increasingly questioned over the last few years by utilities. Utilities and equipment experts have observed a successively increasing failure rate of these types of bushings both nationally and internationally. The consensus opinion in the industry concludes that the failures of this type of bushing as well as the successive increase in the failure rate can be attributed to a deficient design. Because of the risk associated with these bushings, it is recommended that APS's leadership develop a strategy for the phase-out and timely replacement of this type of equipment in alignment with the organization's planned, routine transformer refurbishments.	**M**	**M**	**NS**
Industry Standard Diagnostics	While APS uses a number of industry recognized diagnostic tools in the condition assessment of APS's transmission and substation systems and equipment, there are some commonly used diagnostic technologies that are not currently used by APS. It is recommended that APS use industry Standard Practices diagnostic tools at intervals as determined by industry recognized Standard Practices maintenance bases and practices.	**H**	**H**	**IP**
Maintenance Basis & Discipline	APS started the process of defining the maintenance basis for transmission and substation systems and components in 2000. While a maintenance basis (maintenance templates) exists for a significant number of substation systems and components the assessment indicates that the existing templates are not currently executed with the appropriate level of	**M**	**H**	**IP**

	Recommendation	P	V	S
	discipline and that the development of maintenance basis templates for the remaining systems and components has stalled. APS should continue the development of a comprehensive maintenance basis for all non-trivial transmission and substation systems and components. The maintenance basis should be documented and integrated into the Computer Maintenance Management System (CMMS), effectively communicated to all stakeholders and executed by operations.			
Work Prioritization & Backlog Management	APS's maintenance organization should define system and equipment prioritization criteria in accordance with the corporate strategic objectives and values. The current prioritization of all non-trivial transmission and substation systems and equipment should be reviewed, documented, and integrated in APS's Maximo work management system (CMMS) and effectively communicated to all stakeholders. APS should also develop an effective process for the analysis, forecasting and management of the maintenance backlog.	**H**	**H**	**NS**
Equipment Maintenance Procedures	A significant number of APS's current maintenance procedures for transmission and substation systems and equipment are manually developed for each work order and these procedures are not readily available to all stakeholders. APS should develop standard maintenance procedures in electronic format for all non-trivial transmission and substation systems and equipment. This work will facilitate the creation of a library of standard procedures to be issued with each work order, ensure the availability of these procedures to all stakeholders, the integration of standard procedures in the CMMS for the automated creation of effective work packages, and the capture of the maintenance staff's current knowledge and expertise to develop new employees and address future training needs.	**L**	**M**	**IP**
Data Automation & Maintenance Intelligence	The collection, analysis, management and forecasting of transmission and substation conditions as well as the extraction of intelligence from the data is not exercised as well as generally encountered in the industry. Specifically, APS should review the process used in the identification and reporting of transmission and substation system and equipment conditions as well as tools to facilitate the automated collection and processing of field conditions to an enterprise application that is integrated with APS's Maximo system. Therefore, it is recommended that APS develop the appropriate processes and tools to acquire and integrate all transmission and substation condition data to facilitate the effective analysis, forecasting and management of corrective, preventive and predictive maintenance tasks and processes. Processes and/or tools should be integrated with the CMMS to provide the organization with high level, near-time intelligence and condition status.	**M**	**M**	**NS**
Planning, Scheduling & Outage Coordination	APS should develop a planning and scheduling organization as well as the appropriate processes and tools to increase the effectiveness of the planning and scheduling processes. The implementation of improved planning and scheduling processes and tools will maximize the effective use of the current work force and minimize outage requirements as well as the number of outage requests. In support of this change it is also recommended that APS continue to improve the effectiveness of current backlog management processes and tools.	**H**	**H**	**PL** (05)
Productivity, Planning, & Scheduling Metrics	APS's leadership should develop the appropriate process metrics to evaluate and track the transmission and substation maintenance organization's effectiveness in the areas of planning, schedule adherence, productivity, and the management of the maintenance backlog. The development of these metrics shall not distract from the organization's strong focus and performance in the area of reliability metrics but rather serve to extend the organization's focus.	**H**	**H**	**NS**

	Recommendation	P	V	S
Ownership, Roles & Responsibilities	Equipment and technology ownership as well as employee roles and responsibilities are not clearly defined, documented and communicated in APS's maintenance organization. APS's maintenance leadership and management should clearly define system, component, and process ownership within the organization. The development, documentation, and effective communication of roles, responsibilities, and system and component ownership will allow the organization to quickly adapt to organizational changes and succession planning challenges as well as to significantly reduce employee start up training time.	**M**	**M**	**NS**
Staffing Levels, Resource Availability & Overtime Use	APS's maintenance organization is not sufficiently staffed at this time to adequately service and maintain the system in accordance with the organization's current maintenance basis without the extensive use of craft overtime. A review of the existing backlog, the current maintenance basis, current work force availability, the applied time (wrench time) of the work force and the level of overtime worked in 2001, 2002, and 2003 demonstrates the need to at a minimum add positions for a maintenance planner, a maintenance scheduler, two predictive maintenance (PdM) technicians, two substation maintenance teams, and two linemen to support the transmission system. Upon review of the current maintenance basis, it is recommended that a more detailed staffing and resource analysis is performed to accurately define the resources required to support industry Standard Practices maintenance requirements (Industry Standard Practices Maintenance Basis	**H**	**H**	**IP**
Periodic & On-Line Monitoring	APS should increase its investment in on-line monitoring technologies in out years to maximize its maintenance intelligence while maintaining an economic labor cost structure. On-line monitoring technologies should be leveraged wherever the risk or impact associated with a failure or loss of a particular system or component is significant and poses a threat to the organization. On-line monitoring technologies should also be used where the technologies significantly reduce craft wind shield time. APS should review and modify current periodic monitoring tasks to increase the type and frequency of diagnostic and inspection tasks to a level comparable to industry Standard Practices.	**L**	**H**	**PL** (05)
Training (Non OTJ)	APS provides training to develop personnel skills; supervisory skills; and other human resource (HR) related training. APS's leadership should develop, document and effectively communicate a comprehensive strategy for the technical training and skills development (as it relates to systems and components). The strategy should address the on-the-job as well as technical training in alignment with corporate training goals and opportunities.	**L**	**L**	**NS**
P – Priority; V – Value; S – Status; IP – In Progress; PL – Planned (Year); NS – Not Started; H – High Priority or Value; M – Medium Priority or Value; L – Low Priority or Value				

Appendix A - Glossary of Terms

Accountability & Ownership addresses how all maintenance personnel recognize what is expected of them and how they perform accordingly at every level within the maintenance organization.

Benchmarking addresses the maintenance organization's process and proficiency, with benchmarking of the assets performance to allow for a direct comparison of the organizational practices with those considered 'best-in-class' within the utility industry and among all other industries.

Best Practices addresses those practices considered 'superior', 'leading', or 'optimum' for the industry. In this assessment, Best Practices refer to 'superior', 'leading', or 'optimum' practices.

Communication addresses the quality (formal and informal) of communications and information exchange between Maintenance, Management, Operations, Engineering, and others within the organization.

Continuous Improvement addresses the organization's ability to be a 'Learning' organization that is able to avoid repetitive mistakes.

Contract Management addresses the organization's methods and practices associated with managing contractors used to complete specific maintenance work.

Corrective Maintenance tasks (CM) result from, loss-of-performance, component breakdown or catastrophic equipment failure that must be dealt with immediately.

Data Capture and Utilization addresses the effective capture of equipment maintenance history, performance, and reference information.

Goals and Business Plan addresses the maintenance organization's process for creating a business plan that clearly addresses the maintenance organization's vision and mission, internal and external customers, strategy, goals and objectives, key performance indicators and initiatives as well as their associated benefit.

House Keeping addresses the material conditions, cleanliness, and housekeeping of facilities, systems, and equipment upon completion of work activities.

Human Performance addresses the evaluation of maintenance leadership desired behaviors for maintenance personnel that will ensure the appropriate level of professionalism by all workers.

Information Integration Systems addresses the use of integration systems that relay on the local area networks, and web-based Intranet and Internet networks.

Leadership provides direction for the organization by clearly defining expectations and providing the necessary support and budgets for initiatives to be successful.

Appendix A - Glossary of Terms (Cont'd)

Maintenance & Diagnostic Technologies addresses the use and availability of monitoring and diagnostic technologies, including both periodic and continuous on-line systems.

Maintenance Basis (MB) addresses the process used in determining the basis (i.e., what and how maintenance work is performed for specific equipment as well as the timing of such work)) for identifying the optimum maintenance work task balance as well as the overall strategy for maintaining reliability.

Maintenance Management System addresses the technologies required to support the workforce in the maintenance optimization process, which includes all technical advances such as: automation, condition monitoring technologies, maintenance management systems, process data historians and distributed control systems.

Metrics addresses the quality and effectiveness of a maintenance organization's key performance indicators including global goal measurements, such as: availability; cost and reliability; and specific maintenance department goal measurements.

Organization addresses the organizational structure in place to provide for coordinated maintenance decision-making, and successfully accomplishing system and equipment maintenance (e.g., process teams, component and process ownership, fix-it-now, etc.).

Outage Management Processes/Procedures addresses the organization's formal policies and procedures that are in place to manage 'How' maintenance is accomplished in a planned maintenance or rehabilitation outage including work initiation, planning and scheduling, risk assessment, and contract management.

Perform Maintenance Tasks addresses the actual as measured performance of the maintenance task.

Planning addresses the organization's proficiency and effectiveness of work activity planning including determining what activities will involve detailed planning (infrequently performed work, complex tasks, work requiring specialty resources, work requiring post maintenance testing, etc.).

Post Job Critique addresses the supervisory review and comparison of the work accomplished as well as the post-maintenance testing or inspection performed to determine that work is acceptable before the system is returned to normal service.

Post Maintenance Testing addresses post-maintenance or post-modification testing, inspection, or surveillance performed following maintenance or modification installation to verify that performance is based on design criteria, that the original deficiency was corrected, and that no new deficiencies were introduced due to maintenance.

Predictive Maintenance tasks (PdM) are tasks that must be performed as a result of detecting an equipment problem based on a diagnostic technology.

Appendix A - Glossary of Terms (Cont'd)

Pre-job Briefings addresses the guidance for the performance of routine pre-job briefings for maintenance activities.

Preventive Maintenance tasks (PM) are scheduled tasks that are time based recurring work that has been demonstrated to be necessary to keep equipment in optimum running condition.

Proactive Maintenance tasks (PAM) are improvement projects that have been initiated to resolve recurring maintenance problems.

Qualifications addresses the maintenance organization's methods associated with the qualifications and skills of functions within the organization, with a focus on whether qualifications and skills are capable of supporting program goals.

Return Equipment to Service addresses the processes required to return equipment to service to ensure that the proper testing has been accomplished and that the equipment is ready for service.

Risk Assessment addresses the process of establishing the risk associated with planning and execution of work as well as safety and reliability concerns.

Safety addresses the awareness of the personnel of the importance of safety. It is the processes/procedures that are in place and being followed to address safety concerns.

Scheduling addresses an organization's proficiency and effectiveness with scheduling of maintenance tasks, resource loading and monitoring schedule adherence throughout the work control, execution, and closeout processes.

Standard Effectiveness addresses a level of effectiveness considered 'normal', 'typical', 'common' or 'representative' in the industry. In this assessment, Standard Effectiveness refers to a level of effectiveness considered 'normal', 'typical', 'representative' or 'common' level of effectiveness, e.g. a level of effectiveness neither legally mandated nor universally agreed upon by the industry as a recommended level of effectiveness or associated with an expected or consensus 'minimum' or 'maximum' level of effectiveness.

Standard Performance addresses a level of performance considered 'normal', 'typical', 'common' or 'representative' in the industry. In this assessment, Standard Performance refers to a level of performance considered 'normal', 'typical', 'representative' or 'common' level of performance, e.g. a level of performance neither legally mandated nor universally agreed upon by the industry as a recommended level of performance or associated with an expected or consensus 'minimum' or 'maximum' level of performance.

Standard Practices addresses those practices considered 'normal', 'typical', 'common' or 'representative' for the industry. In this assessment, Standard Practices refer to 'normal', 'typical', 'representative' or 'common' practices, e.g. practices that are neither

Appendix A - Glossary of Terms (Cont'd)

legally mandated nor universally agreed upon by the industry as recommended practices or associated with an expected or consensus 'minimum' or 'maximum' level of performance.

Stores/Inventory Management addresses an organization's proficiency with ordering, handling, storing, and issuing all parts and materials for the maintenance tasks.

System and Equipment Clearance and Tagging addresses the process of clearing and tagging out equipment in a timely manor in preparation for maintenance work.

Tools & Materials Staging and Control addresses the accessibility of tools including specialty and diagnostic tools needed to execute maintenance tasks effectively.

Training addresses the policies, processes and procedures in place to govern the maintenance Training and Qualification program.

Utilization addresses the organization's effectiveness in actively and positively managing the relationship between Management and Craft (Union or Non-Union) to provide a win-win situation in most or all cases.

Work Close-Out includes the maintenance organization's proficiency with prescribing and performing post maintenance testing, post job critique, housekeeping practices upon completion of work, transfer of equipment ownership to operations for return to service (Return Equipment to Service), the capture and documentation of 'as-found' and 'as-left' information and the effective utilization of the information to proactively improve future maintenance and equipment reliability.

Work Close-Out Procedures addresses the administrative procedures and policies in place to govern and guide the maintenance work closeout processes.

Work Control signifies those processes and procedures that address the 'How' an organization accomplishes all of maintenance tasks. Therefore Work Control includes work and task prioritization, risk assessment (where the risk associated with the completion is considered equally important as the risk associated with not completing a maintenance task), and the planning and scheduling of maintenance work.

Work Execution addresses the performance of work and execution procedures, clearance of equipment, staging of materials, pre- job briefing, quality assurance and verification programs, safety practices and processes, and post-job critiques.

Work Execution Procedures addresses the existence and quality of work execution procedures that an organization uses to ensure the safe and effective operation and maintenance of the assets.

Work Identification provides the overall strategy and approach applied to determine what specific task(s) are required to ensure that the appropriate work is performed to achieve high levels of equipment reliability at the lowest or reasonable cost.

Appendix A - Glossary of Terms (Cont'd)

Work Management Processes/Procedures addresses the organization's formal policies and procedures that are in place to manage 'How' maintenance is accomplished including work initiation, planning and scheduling, risk assessment, and contract management.

Work Order Generation (WOG) addresses the processes associated with how a request to perform work is initiated in the organization and administered at the facility.

Work Prioritization addresses the process of 'How' an organization screens, and determines and tracks the priority of all work requests identified.

Work Quality addresses the process of assuring that the work performed maintains a high standard and that all aspects of ensuring quality are employed.

Appendix B – Company Profile

EPRIsolutions, Inc., a wholly owned subsidiary of the Electric Power Research Institute (EPRI), provides a unique combination of expertise, problem-solving, and technology implementation know-how. Our services build upon EPRI's more than 25-year history as the leading collaborative research and development organization for the electric power industry. Not only have these technologies helped utilities generate and deliver power more efficiently and reliably, but also they have done so while reducing the environmental impact of energy growth.

EPRIsolutions provides clients with an array of coordinated services in all areas of electric power generation, transmission and distribution, asset and maintenance optimization, and environmental services unmatched by any other organization, but we also offer state-of-the-art engineering, planning, maintenance and asset-management solutions based on breakthrough EPRI products and other leading-edge technology.

For 25 years the Electric Power Research Institute (EPRI) has been electrifying the world with its focus on collaborative research and development. EPRI has fostered the successful introduction of technologies to improve the efficient production, delivery, and use of electric energy while reducing the environmental impact of energy growth. In establishing EPRIsolutions, EPRI has taken an important step toward helping energy companies adapt and deploy the products of its leading edge research.

But access to the latest technology is only part of EPRIsolutions' advantage. What makes us truly unique is the skill and expertise of our nationally and internationally respected staff. Because of them, EPRIsolutions is able to provide a coordinated suite of services unmatched by any other organization. Our consulting services include: asset management optimization, risk management, asset valuation, maintenance optimization services, operations support services (including plant monitoring, engineering studies, and transmission performance services) and planning and design services (ecology asset management, grid studies, plant design studies). We can revolutionize asset management, maintenance activities, and system performance while reducing operational and maintenance costs and improving availability. We deliver more than 150 training courses on every aspect of electricity generation, delivery and use.

EPRIsolutions is a financially stable and growing organization with a staff approaching 150 management consultants, engineers, scientists and technicians that are recognized experts in their respective fields. As an independent expert consulting organization we maintain no ties, alliances or partnership with manufacturers of transmission or distribution equipment in delivering value to our clients and support of EPRI, our nonprofit corporate parent. EPRIsolutions is the premiere organization delivering value to our clients in the areas of:

- Asset Management
- Risk Management
- Maintenance Optimization

Appendix B – Company Profile (Cont'd)

- Performance Optimization
- Engineering & Testing
- Human Performance & Work Culture
- Environmental Services
- Information Technologies

EPRIsolutions, Inc., provides the means to assist our clients in overcoming problems and in achieving their financial, operations and organization strategy. We provide the means to identify and remove barriers, implement improvements and deliver quantum future-state performance.

Appendix C - Biography

Mark Ostendorp, PhD, PE
Director, T&D Asset Management

SUMMARY

Dr. Ostendorp manages EPRIsolutions' Transmission and Distribution Maintenance and Asset Management Optimization Services and the Engineering & Test Center in Haslet, Texas, USA. The Center is the utility industry's premiere resource in developing, implementing, and applying power delivery asset management, inspection and maintenance, engineering and planning, and testing processes, methods, tools, and systems. Dr. Ostendorp manages a staff of more than 20 of EPRIsolutions' 90 employees. He serves as the technical lead on asset management, strategic planning, risk assessment, maintenance optimization, construction management and execution, engineering analysis and design, structural and mechanical testing, inspection and maintenance issues, and software development projects for transmission, distribution, and substation owners and organizations.

WORK EXPERIENCE

Dr. Ostendorp has more than 15 years experience in analyzing, designing, inspecting, maintaining, and managing transmission and distribution systems. Dr. Ostendorp is the technical lead in the area of asset management and maintenance optimization providing targeted utility solutions via the development of sustainable asset management and maintenance strategies, reliability management, risk management processes, asset valuation, short and long range business planning, performance optimization, and change management.

Previous experience includes but is not limited to optimizing maintenance processes as well as developing inspection and maintenance tools, optimizing maintenance strategies and processes, and developing sustainable inspection and maintenance processes and key performance indicators and performance monitoring processes. He has designed and evaluated concrete, steel, masonry, and timber building, communication, transmission, and substation structures subjected to static and dynamic loads using Allowable Stress Design (ASD), Ultimate Stress Design (USD), and Load Resistance Factor Design (LRFD) methods in accordance with the International Building Code (IBC), the Unified Building Code (UBC), American Society of Civil Engineers (ASCE), and Institute of Electrical and Electronics Engineers (IEEE) standards. He has more than 10 years' experience performing forensic engineering and failure investigation of foundations, structures, high-voltage systems, and communication equipment and components.

EDUCATION/AFFILIATIONS

Ph.D., Civil Engineering – Systems Science, MS degree, Civil Engineering, BS degree, Civil Engineering, Portland State University, Portland, OR

Member of the American Management Association (AMA), the American Society of Civil Engineers (ASCE), the Institute of Electrical and Electronics Engineers (IEEE), the International Electrical Commission (IEC), the Conference Internationale des Grand Reseaux Electriques (CIGRE). Dr. Ostendorp is a registered Professional Engineer.

Appendix C – Biography (Cont'd)

James Alligan
Senior Consultant, T&D Maintenance Optimization

SUMMARY

James Alligan is a Senior Consultant, T&D Maintenance Optimization at EPRIsolutions, Inc.. He leads and manages the organizations various transmission, substation and distribution consulting services on EPRI's family of asset management programs which include T&D maintenance optimization, condition assessment and strategies for equipment end-of-life asset management. Mr. Alligan is a recognized industry expert in the areas of reliability centered maintenance (RCM), substation diagnostics and asset inspection strategies, practices, tools and technologies.

WORK EXPERIENCE

National Grid Company, London Area Manager responsible for forty engineers and technicians undertaking maintenance and construction work on all peak load generation, substation and transmission equipment from 13kV to 400kV.

Asset strategy experience includes preparing T&D engineering financial justification, insurance loss adjustment assessments, transmission infrastructure security assessments, environmental improvements, project planning, operations, safety, equipment health assessments, system reliability studies, equipment predictive performance, and root cause failure analysis.

As a US utility company maintenance optimization project manager, Mr. Alligan was a leader in the application of T&D RCM (reliability centered maintenance) studies, equipment assessments and end of life strategies. In his role he closely worked with US companies to pioneer leading practices, tools and technologies to advance asset strategy, maintenance and diagnostics.

EPRIsolutions project lead for enhancing the sub-transmission reliability performance of the Taiwan Power Company at critical system locations.

Undertaken distribution overhead line inspection program process reviews, audits and route cause analysis studies. Performed line component RCM studies. Developed sub-transmission key performance indicators for T&D clients.

Currently responsibilities are managing and providing advice on asset management programs including reliability centered maintenance, asset condition assessment, equipment end-of-life assessment, maintenance optimization, power system equipment life cycle management and maintenance policy.

Mr. Alligan is a member of the IEEE, has an HTD in Power Engineering and is a graduate from the UK Central Electricity Generating Board Student Engineer program 1979.

EDUCATION/AFFILIATIONS

HTD Power Engineering, UK Central Electricity Generating Board, 1979.

Appendix C – Biography (Cont'd)

Garry Sparks
Senior Consultant, T&D Maintenance Optimization

SUMMARY

Mr. Sparks, a reputed expert in the area of maintenance optimization has over 29 years of electric utility experience in the power industry. His extensive experience in maintenance optimization spans more than 17 years covering 300 substations and 5,000 miles of transmission lines. Previously, he worked for more than 12 years in the construction of substations and hydro/steam generation facilities, transmission lines ranging from 4 kV to 500 kV providing a pragmatic understanding that greatly contributes to his expertise in the inspection and maintenance area. During his career, he performed in-depth analyses of transformer and circuit breaker equipment failures that ultimately led to the development and implementation of updated maintenance practices and procedures in the industry. Based on the success of this work, he was tasked to support the development of computerized maintenance processes and tools that assist utilities in the evaluation of field maintenance data and the implementation of preventive, proactive, reliability centered, and predictive maintenance practices.

WORK EXPERIENCE

Early in his career, Mr. Sparks managed the installation and commissioning of complex substation monitoring systems in a challenging business environment to the complete satisfaction of the organization's clients. In support of this effort, Mr. Sparks developed a significant number of industry leading processes and tools for the real-time monitoring of high voltage substation equipment. In this challenge, Mr. Sparks was directly responsible for the development of the technical direction as well as the eventual implementation in industry facilities. Advances made by the work and guidance provided by Mr. Sparks has resulted in numerous installations of this technology worldwide.

Later in his career, Mr. Sparks provided technical consulting services on substation equipment maintenance practices, protection device installation and testing, as well as on the development of electronic devices that enhance system performance. Additionally, he has served clients in improving the use and benefit derived from telecommunication technologies by providing his extensive experience to the installation of microwave equipment, the integration and testing of mobile field communication systems, and the maintenance and testing of power line carrier systems.

Mr. Sparks served as the Project Engineer and primary technical lead for General Electric Substation Automation Services responsible for the protection and control development for substation control rooms. In this development, Mr. Sparks analyzed and synthesized specifications from ComED's three major principles (Protection, SCADA and Communications) to deliver the final system to the General Electric Protection and Control Group as part of a significant change management effort.

EDUCATION/AFFILIATIONS

BS in Management and Organizational Behavior, University of San Francisco, DOG 1993

Appendix C – Biography (Cont'd)

Nick Abi-Samra, PE
Director, T&D Planning & System Operations

SUMMARY

Nick Abi-Samra is the Senior Technical Director in the area of transmission and substation operations, planning, and design of distribution and transmission systems; system control; reliability studies; risk assessment; capital transmission planning studies; system stability and security; FACTS and Custom Power applications; and transmission ancillary services. In his career, Mr. Abi-Samra has contributed to or led a significant number of in-depth electric utility system assessment investigations for utilities as well as regulators and independent system operators.

WORK EXPERIENCE

Mr. Abi-Samra joined the Electric Power Research Institute (EPRI) in 1997 as a manager in the Grid Operations & Planning business area. There he had the fiscal and technical responsibility of a number of projects at the (EPRI) dealing with system planning; system reliability; energy tracking; generation and transmission pricing; services; risk and decision making; least cost planning and system operation. He also led the development of a number of strategic and cutting edge projects dealing with the future of power delivery and utilization.

Mr. Abi-Samra spent most of his career at Westinghouse Electric. He joined the Advanced Systems Technology (AST) Division of Westinghouse (Pittsburgh, PA) in 1977 where he held positions of increasing responsibilities (including the management of a large utility and industrial consulting group). There he conducted and supervised projects in the areas of: transient analysis; transmission and distribution systems expansion an planning; Sub-synchronous resonance; HVDC protection; industrial systems applications; power quality; turbine generator protection; and insulation coordination. In 1982, he designed an engineering center, high-voltage test laboratories and consulted on insulator contamination while on loan from Westinghouse to Saudi Arabia.

In 1991 Mr. Abi-Samra joined the Power Generation Business Unit where was instrumental in building Westinghouse's consulting and training services in the Western Region of the USA. As the Operations Manager, he conducted and directed projects on the design and analyses of industrial and utility power systems. He had the responsibility of trouble-shooting and implementing cost effective solutions to problems at several industrials and utilities. He also led the modeling, application and analyses efforts of Westinghouse's Custom Power devices (DVR, and DSTACOM, and solid-state breaker) and developed numerous courses in power systems assessment, protection and design.

EDUCATION/AFFILIATIONS

BS in Electrical Engineering, American University of Beirut, MS in Power Systems, University of Missouri, Post Graduate Work at Carnegie Mellon University. Mr. Abi-Samra has published over 50 technical papers and articles in IEEE, IEE, CIGRE and other trade magazines as well as over 100 technical reports in various venues. In addition, he has developed and taught numerous courses in power systems assessment, protection and design.