DRAFT Preliminary Root Cause Of Failure Analysis
13.8kV Breaker Failures during Loss of Switchyard Event

Event Date: 6/14/04
Revision 0, 7/05/04

Executive Summary

Two out of twenty 13.8kV breakers that provide offsite power to the units failed to close on demand from the control room during the Loss of Offsite Power event on June 14, 2004. One of these breakers has been removed for root cause of failure testing. These tests indicate that the breaker could have failed by either hardened grease that caused binding of the breaker mechanical linkage or high contact resistance in a relay in the close circuitry. These breakers were repeatedly cycled during the event so the true root cause may never be known. The second breaker that failed is still in service awaiting an opportunity to remove it for testing.

A review of the failure history of these and similar breakers revealed that we have had, including these two failures, seven similar failures since 1988, three of which happened this year. Action was taken in 2000 that cut the PM frequency on these breakers in half. This is apparently not enough to prevent these failures. A modification is in progress to provide air conditioning for these outdoor switchgear that will reduce temperatures and hopefully extend grease life.

A review of the maintenance history for these and similar breakers shows that the maintenance has been performed on them in accordance with the existing PM program, although we are still in the final stages of adapting to the periodicity change that took place in 2000. We have only three spares of these large breakers, which may be partly to blame for the length of time required to accomplish this goal.

The final corrective actions for this condition have not been determined but will include the air conditioning currently scheduled for installation in the W05 window (winter of 2005), and may include use of an alternate grease, exercising the breakers more often, and periodic replacement of the circuit breaker anti-pump relay.

Background

On 6/14/04, while recovering offsite power to the three PVNGS units after a Loss of Offsite Power event, 13.8kV circuit breakers 1ENANS06K and 3ENANS05D failed to close on demand from the control room. Electrical Maintenance and Engineering were dispatched to investigate. With maintenance personnel in attendance, and while repeating the attempts to close each of these breakers from the control room, a clicking sound could be heard from the breaker cubicles but the breakers would not close. The breakers were moved to the test position, cycled closed and open several times, racked into the operating position and closed normally to re-energize the system. Closure problems with 1ENANS06K delayed restoration of offsite power to the unit 1 Train B 4160V bus and problems with 3ENANS05D delayed restoration of offsite power to the unit 3 Train A 4160V bus. Although these breaker problems delayed restoration of offsite power to the affected busses by approximately 2 hours, both of the busses were powered from their respective EDGs during this period. Both of these breakers had been successfully manually tripped per procedure in response to the event.

Each unit's E-NAN-S05 and -S06 switchgear are located outdoors in the startup yard near the 525kV switchyard. These busses are cooled by ventilating fans that circulate filtered outside ambient air through them. Especially during the daylight hours of the summer months, these

C141

switchgear are exposed to high temperature conditions that lead to drying out of the breaker lubricating grease. Although the ventilating air is filtered, dirt accumulation still occurs. This condition also applies to outdoor busses E-NAN-S03 and -S04, which are other intermediate 13.8kV busses that are also in the offsite power lineup to the class 1E 4160V busses. All breakers in these busses operated properly during the event.

Because these breakers provide offsite power to the units, they cannot be cycled frequently and are typically cycled only every 18 months during refueling outages. This mechanically static condition exacerbates the effects of the high temperatures because the lubrication is never freed up through exercise.

One function of these breakers is to open (trip) to provide electrical protection during electrical disturbances. They properly tripped in response to procedurally directed operator actions. The second function of these breakers is to provide offsite power to the units. For this latter function, they must be closed. They are currently closed and are in the required position per the Technical Specifications.

Evaluation

From a work history standpoint, breaker S/N 269A7243-020 was rebuilt on 01/01/2002 and installed in cubicle 1ENANS06K on 11/18/2002. Breaker 269A7245-023 was rebuilt on 11/04/2002 and installed in cubicle 3ENANS05D on 12/24/2002. Breaker 1ENANS06K was operated in the last unit 1 refueling outage during the clean/inspect PM for the switchgear conducted in the second week of April 2004.

The higher than expected failure rate, coupled with similar industry operating experience, was recognized several years ago. Procedure 32MT-9ZZ37 implements periodic overhaul of 13.8kV breakers. Originally, testing and overhaul of these breakers was scheduled to be completed every 4 refueling cycles for breakers that cannot be done online, or every 8 years for those that can be done online. In 2000, this schedule was cut in half. These breakers are now tested and overhauled every 2 cycles (3 years for offline) or 4 years for those that can be worked online. PVNGS is nearly complete with the last breaker under the new PM schedule. The last breaker (3ENANS06A) was actually scheduled for replacement on the day of the event.

On 6/19/04, breaker 3ENANS05D was removed from service for an Equipment Root Cause of Failure Analysis (ERCFA). However, because of the repeated cycling of the breaker during the event, root cause of failure evidence was unavoidably tampered with and lost. This investigation was performed in accordance with the ERCFA Plan provided in Attachment A.

The clicking sound heard from the cubicles was at first believed to be indicative of the electrical circuitry of the breakers to be working properly, leaving only the mechanical linkage of the breakers as the cause of the failure. However, after closer review of the control circuit, there is an interposing relay 'CR' that receives the signal from the control room handswitch. This relay picks up and closes a contact that actually closes the breaker. Because the clicking heard could be coming from the CR relay by itself, or the combination of the CR relay and the close coil armature, the exact source of the click is indeterminate.

DRAFT Preliminary Root Cause Of Failure Analysis
13.8kV Breaker Failures during Loss of Switchyard Event

The following conditions were investigated or found that were potential contributors to the breaker's failure to close during initial attempts from the control room.

1) The control circuit secondary disconnect male disconnect stab at pin 8 had evidence of arcing which was a potential poor contact for the close circuit. On June 23, the mating socket was retrieved from the 3ENANS05D cubicle. It had no evidence of arcing. Therefore, this arcing does not appear to be a contributing factor.
2) The control circuit secondary disconnect male disconnect stab at pin 8 is positioned ~1/8" lower than adjacent stabs. Shop testing has demonstrated satisfactory performance due to approximately ½" wipe between the male stab and the socket. This does not appear to be a contributing factor.
3) Also on June 23, the proper operation of the CR relay in 3ENANS05D was tested. The relay tested satisfactorily. This does not appear to be a contributing factor.
4) The anti-pump relay circuit had high intermittent contact resistance that could have prevented breaker closure. However, even with high resistance, the breaker would close on demand in the shop. This is a potential contributor to the failure.
5) The as-found breaker Close function was tested. Satisfactory results were obtained for both the minimum operating voltage (~42Vdc vs. maximum allowed of 90Vdc) and the close timing tests (72ms vs. maximum allowed of 100ms). This result is inconclusive due to the preconditioning that took place while cycling the breaker on the day of the event.
6) The as-found breaker Trip function was tested. Unsatisfactory results were obtained for both the circuit minimum operating voltage (77Vdc vs. maximum allowed of 70Vdc) and trip timing (77ms vs. maximum of 55ms). This condition could have been worse on the day of the event because the cycling of the breaker on the day of the event likely improved this condition. This is indicative of a hardened grease condition.

The as-found test history of these offsite breakers and other breakers in similar environments was reviewed and is presented in Attachment B. Failures to meet the acceptance criteria are highlighted in red. The data show that these breakers are three to four times more likely to fail the trip function acceptance criteria than the close function acceptance criteria. This is consistent with the findings for breaker 3ENANS05D presented above. The high failure rates indicate that the PM program effectiveness needs to be improved although it should be noted that the acceptance criteria are generic and failure to meet them does not necessarily indicate an inability of a specific breaker to perform its design function. For example, the timing of these breakers to close is not particularly relevant; it matters little whether the breaker closes in 70 milliseconds or 170 milliseconds in response to a manual operator action to close the breaker during restoration of the breaker lineups. Similarly, available DC bus voltage is not expected to drop below approximately 112Vdc even though the close function acceptance criterion is conservatively set at 90Vdc.

Two more activities are planned that will hopefully shed addition light on the cause of the failures of these breakers. During the week of 7/26/04, breaker 3ENANS06A will be replaced with an overhauled breaker. This breaker is the oldest breaker in service and was scheduled for replacement on the day of the event. The same tests as described above will be performed on it.

However, this breaker had a failure-to-close event in April 2004 and it was somewhat lubricated in the field. Therefore, the results may not be very revealing.

The second activity is the retrieval of breaker 1ENANS06K to perform the same battery of tests. To remove this breaker from service requires that unit 1's 'B' class 1E 4160V buss be put on its alternate source of power. Procedural revisions are in process to direct this configuration and a spare breaker must be overhauled to support this. This breaker replacement is not yet scheduled.

Transportability

The failure history of these breakers and all breakers like them was investigated and is presented in Attachment B. There have been seven failures since 1988 that are possibly related to these recent breaker failures, three of which happened this year. Before that, the last one was in 1998. One of these seven involves degraded relay contacts. In addition, there is a significant amount of industry operating experience involving GE Magne-Blast circuit breakers and hardened grease causing mechanical binding. This condition is believed transportable to all Magne-Blast breakers located in outside or hot switchgear locations.

The maintenance history of all breakers affected by this transportability has been reviewed and is presented in Attachment C. Although we are in the final stages of adapting to the PM frequency revisions implemented in 2000, all breakers have had appropriate periodic maintenance performed.

Apparent Cause

Because of the preconditioning that occurred during the event on the two breakers that failed, their root cause of failure may never be known. At this time, based on only the findings of the assessment of 3ENANS05D, the apparent cause of its failure to close is improper operation of the close latching mechanism either due to poor lubrication and contamination by dirt or due to high contact resistance of the anti-pump relay.

Corrective Actions

Modification WO 2508436 was initiated in April 2002 to add air conditioning to the outdoor switchgear to provide cooling and reduce dirt intrusion. This mod is scheduled for implementation per the 3-cycle plan in late 2005 or early 2006.

Other potential corrective actions that may come out of the final assessment of this condition include use of an alternate grease that is less susceptible to hardening, more frequent exercise of the breakers, and periodic replacement of the anti-pump relay.

Conclusion

Continued use of these breakers is acceptable based on their ability to properly trip and the fact that they are in the desired position thus obviating the need to close them. Additional preventative maintenance actions may be instituted during the final evaluation of the associated CRDR 2716019.

ATTACHMENT A
Breaker 3ENANS05D Failure To Close
Equipment Root Cause of Failure Investigation Plan
WO 2717143

POTENTIAL CAUSES:

1. Breaker problem - mechanical, alignment, close latch wipe & lubrication issue

REFERENCES:

1. 03-E-NAB-0001
2. 32MT-9ZZ33, Maintenance of Medium Voltage Circuit Breakers Type AM-13.8-1000
3. 32MT-9ZZ37, Overhaul of AM-13.8-1000 Magne-blast Circuit Breakers

PLANT IMPACTS:

None – This investigation is being performed on Out-Of-Service equipment.

INSTRUCTIONS:

Breaker 3ENANS05D failed to close from the control room on 6/14/04. Electrician at the switchgear distinctly heard the closing coil attempting to pick up when Operations tried to close the breaker. The breaker was racked down, placed in TEST position and successfully cycled twice. The breaker was then racked up and was satisfactorily closed from the control room. Due to the emergent condition of the plant at the time, neither detailed troubleshooting plan nor a follow-up plan was issued until now.

This plan entails troubleshooting, overhaul and maintenance of the breaker only. The transfer of power from the normal supply to the alternate supply is a normal Operations activity and will not be covered by this plan.

The breaker replacement and breaker alignment are normal maintenance actions and will not be covered under this plan.

1. Verify breaker S/N and transport the breaker to the shop.
2. Before any overhaul or maintenance is done on the breaker perform the following:
   a. Visually inspect the breaker. Look for signs of excessive dust and dirt build up.
   b. Visually inspect the closing and tripping linkages for any signs of binding or misalignment that could cause breaker failure to close or open.
   c. Check that the close latch & roller and the trip latch & roller are rotating freely and no hardened lubricant is present on the surface.
   d. Perform step 4.21 "Closing Latch Wipe" check per procedure 32MT-9ZZ33 then perform a main contact closing time test.
   e. Perform a main contact opening time test.
   f. Repeat step 2.d for spring release coil pickup voltage test.
   g. Repeat step 2.e trip coil pickup voltage test.
   h. Repeat steps 2.d thru 2.h a minimum of three times.

3. Perform breaker overhaul & maintenance per procedures 32MT-9ZZ33 & 32MT-9ZZ37. Using clean rags wipe, bag & tag the lubricant from bearings.
4. Steps in this plan may be performed out of sequence at the discretion of the Maintenance Engineer. The engineer may add, delete, or modify steps to accomplish the troubleshooting task. All additions, deletions, or modifications will be recorded in the troubleshooting work order continuation sheet. The additional steps may require lifting and landing leads.

TEST EQUIPMENT:

No special test equipment is required for this ERCFA investigation. Required M&TE are contained in procedure 32MT-9ZZ33 & 32MT-9ZZ37.

RETEST

Functionally test breaker per procedure 32MT-9ZZ33.

ATTACHMENT B
Offsite Power Breaker As-Found Condition Data

BREAKER LOCATION	BREAKER RATING	BREAKER S/N	DATE	WORK MECH	DATA	CLOSE COIL P/U VOLTAGE (<90V)	CLOSE TIME (<91.3MS)	TRIP COIL P/U VOLTAGE (<70V)	TRIP TIME (<55MS)
1ENANS01A	3000A	269A7241-023	02/08/01	OH - 2342067	AS FOUND	89	113	96	79
1ENANS01A	3000A	269A7241-023	04/30/04	I/A - 2611727	AS FOUND	48	76	62	68
1ENANS03A	1200A	269A7239-005	06/15/99	OH - 877126	AS FOUND	59	69.1	62	46.7
1ENANS03A	1200A	269A7239-005	04/22/01	I/A - 2331359	AS FOUND	55	72.3	59	42.8
1ENANS04A	1200A	269A7247-010	03/16/99	OH - 870287	AS FOUND	54	76	55	47
1ENANS04A	1200A	269A7247-010	10/13/02	I/A - 2484885	AS FOUND	46.5	>99.9	64.3	52.2
2ENANS01A	3000A	269A7236-020	11/03/00	I/A - 225860	AS FOUND	43	77	77	60.2
1ENANS05A	3000A	269A7236-020	01/08/04	OH - 2627363	AS FOUND	49	75	68	63
1ENANS02A	3000A	288A3669-001	10/16/96	I/A - 762929	AS FOUND	54	69.8	47	41.8
1ENANS05B	3000A	288A3669-001	11/08/99	OH - 901601	AS FOUND	59	73.2	65	63.5
1ENANS06F	3000A	269A7235-020	04/02/98	I/A - 825861	AS FOUND	48.5	76.8	58	54.8
1ENANS06F	3000A	269A7235-020	08/09/01	OH - 2376564	AS FOUND	66	78.7	64.1	69.8
2ENANS05B	3000A	269A7241-021	06/19/97	I/A - 771152	AS FOUND	63	78.1	66	48.9
1ENANS06H	3000A	269A7241-021	10/03/01	OH - 2376574	AS FOUND	85	98.8	94	97.4
1ENANS06K	3000A	269A7236-024	10/14/96	OH - 738065	AS FOUND	49	86.1	62	55.5
1ENANS06K	3000A	269A7236-024	10/20/99	I/A - 881711	AS FOUND	67	87.4	60	52.2
3ENANS02A	3000A	269A7243-020	10/22/98	I/A - 839490	AS FOUND	51.1	73	64.7	47.4
1ENANS06K	3000A	269A7243-020	01/01/02	OH - 2414276	AS FOUND	44	76.5	57	51.7
2ENANS03A	1200A	269A7238-007	5/23/00	OH - 923521	AS FOUND	>130	>100	79	66.6
2ENANS03A	1200A	269A7238-007	10/31/03	I/A - 2565528	AS FOUND	63.4	70	69	57
2ENANS04A	1200A	288A3669-004	4/18/99	I/A - 864222	AS FOUND	42	73	82.3	60.2
1ENANS02J	1200A	288A3669-004	4/26/02	OH - 2489845	AS FOUND	38	71.9	90	97.7
1ENANS01H	1200A	288A3669-005	2/9/99	I/A - 862454	AS FOUND	52	65.6	63	53.2
2ENANS04A	1200A	288A3669-005	2/25/02	OH - 2414095	AS FOUND	46	71.7	72	80.7
2ENANS05B	3000A	269A7235-021	03/17/98	I/A - 825861	AS FOUND	58	37.4	51	48.3
2ENANS05B	3000A	269A7235-021	06/21/01	OH - 2365410	AS FOUND	36	75.3	66	72.3
1ENANS06K	3000A	269A7236-024	10/20/99	I/A - 881711	AS FOUND	67	87.4	60	52.2
2ENANS05D	3000A	269A7236-024	01/07/03	OH - 2552118	AS FOUND	58	82.3	76	56.8
2ENANS06A	3000A	269A7233-021	03/03/97	I/A - 769115	AS FOUND	34	65.3	57	41.3

ATTACHMENT B
Offsite Power Breaker As-Found Condition Data

BREAKER LOCATION	BREAKER RATING	BREAKER S/N	DATE	WORK MECH	DATA	CLOSE COIL P/U VOLTAGE (<90V)	CLOSE TIME (<91.3MS)	TRIP COIL P/U VOLTAGE (<70V)	TRIP TIME (<55MS)
2ENANS06A	3000A	269A7233-021	07/26/00	OH - 234021	AS FOUND	45	71.7	53	46.8
2ENANS03B	3000A	269A7240-020	03/01/95	OH - 690499	AS FOUND	68.4	77	58.9	61.4
2ENANS03B	3000A	269A7240-020	10/09/97	I/A - 798178	AS FOUND	89	87.5	58	45.7
2ENANS06C	3000A	269A7240-020	01/16/01	OH - 2342065	AS FOUND	86	99.7	75	60.9
3ENANS03A	1200A	269A7239-009	3/17/00	OH - 907785	AS FOUND	33.5	71.9	59.5	46.6
3ENANS03A	1200A	269A7239-009	4/20/03	I/A - 2508462	AS FOUND	21	70.9	41.2	70.3
3ENANS04A	1200A	269A7239-003	6/30/98	OH - 836718	AS FOUND	43	72.2	64	51.8
3ENANS04A	1200A	269A7239-003	10/16/01	I/A - 2366316	AS FOUND	41	69.1	47	46.4
3ENANS03B	3000A	269A7244-021	03/12/97	I/A - 769115	AS FOUND	58	59.5	62	43.8
3ENANS05B	3000A	269A7244-021	06/13/00	OH - 922359	AS FOUND	59	75.2	81	67
1ENANS05D	3000A	269A7236-023	04/30/95	I/A - 701115	AS FOUND	91.2	88.3	90.9	76.3
3ENANS05D	3000A	269A7236-023	01/20/99	OH - 863842	AS FOUND	101	100	98	146
1ENANS04B	3000A	269A7245-023	03/15/99	OH - 864571	AS FOUND	96	87.4	99	93
3ENANS05D	3000A	269A7245-023	10/24/02	OH - 2552116	AS FOUND	59	85.6	74	>99
3ENANS06A	3000A	269A7245-021	10/03/95	OH - 724618	AS FOUND	54	77.4	49	47.5
3ENANS06A	3000A	269A7245-021	06/16/00	I/A - 917631	AS FOUND	>90	>100	48	51
3ENANS06C	3000A	269A7245-022	10/26/92	I/A - 549856	AS FOUND	77.3	70.9	62.2	41.5
3ENANS06C	3000A	269A7245-022	11/03/95	OH - 724620	AS FOUND	47	73.3	65	58.2
3ENANS06C	3000A	269A7245-022	11/29/99	I/A - 889441	AS FOUND	79	75.5	71	56.7
3ENANS05D	3000A	269A7245-022	02/20/04	OH - 2627369	AS FOUND	88	81	84	76

ATTACHMENT C
Offsite Power Circuit Breaker Failures

Cause: Degraded Lubrication and Dust				
Location	**Failure**	**Date**	**Corrective Action Document**	**Corrective Action**
1ENANS05A	No remote/local elect open/trip	7/6/1988	EER 88-NA-021	To maintain PMs
1ENANS05A	No remote/local elect open/trip	3/5/1989	EER 89-NA-012	GE - 2 yr CB lube cycle
1ENANS05D	No remote elect open/trip	10/7/1998	CRDR 1-8-0494	Revised PM – cycle bkrs
3ENANS06A	No remote elect close	4/21/2004	CRDR 2700714	PM revision under evaluation

Cause: To be Determined				
Location	**Failure**	**Date**	**Corrective Action Document**	**Corrective Action**
1ENANS06K	No remote elect close	6/14/2004	CRDR 2716019	Under evaluation
3ENANS05D	No remote elect close	6/14/2004	CRDR 2716019	Under evaluation

Cause: Degraded Contacts (oxidation and carbon)				
Location	**Failure**	**Date**	**Corrective Action Document**	**Corrective Action**
1ENANS05B	No remote elect close	10/27/1992	CRDR 1-2-0543	Maint Proc revision

Cause: Trip Coil Mechanism Binding (coil misalignment and dust)				
Location	**Failure**	**Date**	**Corrective Action Document**	**Corrective Action**
2ENANS05D	No remote elect open/trip	10/22/1992	CRDR 2-2-0325	Maint Proc revision

Cause: Circuit Breaker Not Racked Up Completely				
Location	**Failure**	**Date**	**Corrective Action Document**	**Corrective Action**
2ENANS06A	No remote elect close	11/16/1998	CRDR 2-8-0290	Operator training

ATTACHMENT D
Offsite Power Circuit Breaker Maintenance History

Breaker ID	Status	Overhaul Work Order Date	Installation Work Order Date	Comments
1ENANS05A	AC	WO 2627363 2/4/04	WO 2611671 4/29/04	S/N 269A7236-020
1ENANS05B	NC	WO 00901601 12/14/99	WO 00896473 4/2/00	S/N 288A3669-001 scheduled for OH, WO 2586992, 12/14/04
1ENANS05D	NO	WO 2589646 5/6/03	WO 2503899 6/16/03	S/N 269A7241-020
1ENANS03A	AC	WO 2627373 4/23/04	WO 2611670 4/29/04	S/N 269A7242-009
1ENANS06F	NO	WO 2376564 8/9/01	WO 2372704 8/14/01	S/N 269A7235-020
1ENANS06H	NC	WO 2376574 8/9/01	WO 2388117 12/17/01	S/N 269A7241-021
1ENANS06K	AC	WO 2414276 1/1/02	WO 2484968 11/18/02	S/N 269A7243-020
1ENANS04A	AC	WO 00870287 10/26/99	WO 00881785 10/26/99	S/N 269A7247-010 – Last breaker inspection and adjustment completed under WO 2484885 on 10/20/02
2ENANS05B	NO	WO 2365410 6/21/01	WO 2372930 8/2/01	S/N 269A7235-021
2ENANS05D	NC	WO 2552118 1/7/03	WO 2391131 1/16/03	S/N 269A7236-024
2ENANS03A	AC	WO 00923521 5/23/00	WO 00926621 10/24/00	S/N 269A7238-007
2ENANS06A	NO	WO 234021 8/4/00	WO 232447 8/18/00	S/N 269A7233-021
2ENANS06C	NC	WO 2342065 1/24/01	WO 2321950 1/29/01	S/N 269A7240-020
2ENANS04A	AC	WO 2414095 2/25/02	WO 2389492 4/2/02	S/N 288A3669-005
3ENANS05B	NO	WO 2489843 4/23/02	WO 2427319 7/2/02	S/N 269A7240-021
3ENANS05D	NC	WO 2627369 4/1/04	WO 2716870 6/19/04	S/N 269A7245-022 Note: Failed breaker S/N 269A7245-023 was removed under WO 2716870 and replaced with newly overhauled breaker S/N 269A7245-022 on 6/19/04. Breaker -023 was overhauled under WO 2552116 on 11/04/02 and installed in 3ENANS05D under WO 2454572 on 12/24/02.
3ENANS03A	AC	WO 00907785 3/20/00	WO 00905830 4/18/00	S/N 269A7239-009 – Last breaker inspection and adjustment completed under WO 2508462 4/20/03
3ENANS06A	NO	WO 00720396 11/3/95	WO 00724618 11/3/95	S/N 269A7245-021 - scheduled for OH, WO 2391149, 6/14/04. Replacement reschedule required due to 3-unit trip.
3ENANS06C	NC	WO 2489844 3/12/03	WO 2391086 2/13/04	S/N 256A9814-001
3ENANS04A	AC	WO 00836718 6/30/98	WO 00838168 10/10/98	S/N 269A7239-003

AC = Always closed NC = Normally closed NO = Normally open