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SONGS - MEng-SEng. Report:

ASSESSMENT OF THE IMPACT OF THE DEGRADED CONNECTIONS BETWEEN BREAKER 2D201 AND BATTERY 2B008 ON THE FUNCTIONALITY-OPERABILITY OF THE BATTERY 2B008

Executive Summary:

During a weekly surveillance test of battery 2B008 and normal charger 2B002 carried out on March 25, 2008, two degraded connections (one per polarity) were discovered between the battery and breaker 2D201.

Subsequent investigations yielded the following conclusions:

1. The probable cause for the degraded connections is the under-torquing of the connection bolts during the replacement of the breaker (2D201) carried out on 3/17/2004.

2. There is reasonable assurance that the degraded connections did not compromise the capability of the battery to perform its design-function until the end of the normal charger test on 3/21/-08. From 3/17/08 thru 3/21/08 the swing-charger was in operation while the normal charger was out of service for testing. This conclusion is supported by plant data which indicates the connection resistance likely changed state upon completion of the 3/21/08 normal charger testing. This conclusion is supported by test data previous to this date which includes weekly battery surveillances, two successful Integrated ESF surveillance tests, two successful LOVS surveillance tests, as well as data from the four day period when the swing charger supplied 112 amps to the 2D2 bus through the degraded connections (from 3/17/08 to 3/21/08).

3. Although there is no plant data to evaluate the condition of the connections during the period from 3/21/08 until the failed surveillance test on 3/25/08, it is likely that the degraded connections would have been capable of performing their design function from 3/21/08 until the degraded condition of the connection was discovered on 3/25/08. This conclusion is based on the fact a very thin layer of oxidation across the joint and/or a small gap would have been readily breached by the 120 VDC applied to it during a real event. The degraded connections may have impacted battery capability for coping with Station Blackout (SBO) design basis. Due to the lack of plant data, SCE conservatively considers the battery to have been nonfunctional sometime during this period.

4. Seismic events would not have prevented the battery from meeting its design basis as a result of the degraded connections.

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Background:

On 03/25/2008 a weekly surveillance voltage test on 125 volt battery 2B008 failed its acceptance criteria. The test consists of verifying the battery voltage is at least 129 VDC when measured at the battery terminals. During the test, the measured voltage was approximately 121 VDC. During subsequent troubleshooting activities, degraded connections (one per polarity) were found on the battery side of the 2D201 breaker which connects the 2B008 battery to the 2D2 bus. Specifically, the bolts connecting the terminals of the 2D201 breaker to the aluminum buses leading to the battery were not fully tight. The battery terminal voltage recovered to 131 VDC when a voltage probe handled by the electricians was touched to one of the under-torqued connections during troubleshooting.

This report evaluates the impact of the under-torqued connections on the associated DC system, and the ability of the 2B008 battery to perform its credited safety functions during the period from 3/17/04 to 3/25/08. This report is not intended to address human factors, which are discussed in a separate RCE.

Definition of Terms:

LOVS:	Loss of Voltage Signal
ESF:	Engineered Safety Features
SIAS:	Safety Injection Actuation Signal
DGVSS:	Degraded Grid Voltage with SIAS Signal
SBO	Station Blackout
ADC	DC amperes
VDC	DC volts

Factual Information:

1. The surveillance test that failed was carried out on 03/25/08 (MO #080301117). The measured value was 121 VDC. The required minimum is 129 VDC.

2. Previous surveillance tests were carried successfully on 3/18/08 and every week before that. A complete table of weekly surveillance tests is included in Attachment 2.

3. Two Integrated ESF Surveillance Tests and two LOVS Surveillance tests were successfully completed during the four year period between 3/17/04 when the 2D201 breaker was replaced, and 3/25/08 when the weekly surveillance test was failed. These tests are designed to closely mimic the actual accident loading conditions on the battery bus. Successful completion of these tests provides a measure of confidence that the battery was capable of performing its design function. During approximately the first 15 seconds of these tests, the battery charger power is removed, so the battery is required to supply all required power to the bus through the impacted connection. The data below shows how the voltage decreased on the 125 VDC supply at switchgear 2A06 during the period of time when the battery charger was off. Graphs

obtained during the tests are included (Figures 1-3). To see where the voltage drop is measured, see Attachment 6.

Data is included from two ESF tests prior the 2D201 breaker replacement and two tests after the replacement. The data shows there was no significant change in voltage drop after the breaker was replaced. This supports a determination that the connection at the 2D201 breaker was sufficient to allow the battery to perform its safety function. Data is also included from one LOVS test prior to the 2D201 breaker replacement and two LOVS tests after the replacement. The data shows one case with a slight increase in voltage drop (0.7 to 2.3 VDC). This occurred after the breaker was replaced. The measurement is affected by inverter-noise and has an uncertainty of approximately +/- 1 volt, rendering the data inconclusive. It is judged that there would be sufficient margin in the battery design to accommodate a 1 to 2 volt change in voltage drop, based on the fact that the battery capacity test in 2008 determined a capacity near 100% while the calculation is based on a capacity of 80%. In the table below, all tests prior to the change of breaker 2D201 on March 2004 are noted as "TIGHT". Those after the breaker replacement are noted as "NOT TIGHT" (Refer to figure in Attachment 6).

MO	Date	Test	VDC Drop	Charger-off Time (sec)	Connection's Condition
06122943	11/29/07	ESF	11.04	13.7	NOT TIGHT
05081829	1/6/06	ESF	10.97	13.4	NOT TIGHT
03031098	2/11/04	ESF	11.42	14.5	TIGHT
01061449	5/24/02	ESF	11.26	14.6	TIGHT
08010611	1/9/08	LOVS	12.32	15.0	NOT TIGHT
06011546	1/21/06	LOVS	10.70	14.8	NOT TIGHT
03031098	2/20/04	LOVS	9.98	15.8	TIGHT

4. The breaker 2D201 was replaced on 03/17/04.

5. The last time the bolts on the impacted connection were disturbed was during the breaker replacement on 03/17/04 [8].

6. The affected bolts were tightened to their specified torque during the repair activities following the failed surveillance test of 03/25/08, and according to the maintenance personal involved, each bolt was tightened using a torque-wrench.

7. Each bolt is fastened with two flat washers and a lock-washer.

8. Interview with the two craftsman that tightened the bolts after the problem was discovered revealed the following facts:
    a. Each bolt was touched by hand while wearing insulated rubber gloves. Only one bolt was found completely loose.
    b. Two of four bolts on each connection were snug enough that they couldn't be moved without the application of torque with a wrench. The remaining bolts could be barely moved by hand.

c. No evidence of sparking or pitting of bolts, washers and buses (restricted visual access only permitted a limited view of the connection).
d. All eight nuts were fully threaded in their bolts.
e. The condition of the grease in the contact area was not inspected.
f. Did not count number of turns applied on the nuts to effectively apply the specified torque. The ratcheting torque-wrench requires a number of strokes to move the nut a full turn.
g. Bench tests previous to the interview show that it takes a full turn of the nut to flatten a lock-washer.
h. When asked what is the typical manner they will use to tighten the bolts, one of them said:
   - First by hand till the lock-washer is engaged,
   - Then with a regular wrench,
   - Finally with a torque-wrench.

9. Phone interview with the electrician that applied the Fluke probe to the degraded connection, revealed the following facts:
   a. Several minutes after the weekly surveillance test failed (battery voltage measured below acceptable limit), and following a phone call, he reached the charger room to perform troubleshooting tests.
   b. After taking a couple of readings on the charger side with satisfactory results, he touched the side of the head of one bolt of the degraded connection.
   c. He applied little pressure with the probe and cannot say for certain that the bolt moved, although he thinks he perceived a very minor movement.
   d. At the time the probe touched the head of the bolt, the sound from the charger or inverter changed, apparently indicating the loading changed.
   e. Then he returned to the battery and now the voltage readings were satisfactory.
   f. Looking at the busses and bolts with the panels removed, he could not see any signs of discoloration or other symptom related to high temperature on the busses and/or fasteners.
   g. At about the same time an operator came to say that there was a Trouble Alarm on 2D2. The alarm was gone immediately (likely caused by a momentary ground imbalance when the battery was reconnected to the circuit).

10. Breaker 2D201 has a magnetic trip circuit, rendering it insensitive to temperature rise of its terminals due to abnormal heat generated at the degraded connection (if any) (MO #04021613).

11. Swing charger 2B022 continuously fed 112 ADC thru the degraded connection between 3/17/2008 and 3/21/2008 (MO #08011467000).

12. The joint in question is designed for 1,200 continuous amperes of current (Reg. Dwg. SO23-302-5A-2). This is about four times the level of current this joint must carry continuously during an accident.

13. A *Ductor* test on the re-torqued connections upstream of 2D201 carried out on 7/15/08 (NMO #800117881), show acceptable contact resistance of no more than about 10 $\mu\Omega$.

Analysis:

The following questions are addressed in this section:

1. Most probable cause(s) for the degraded connection.
2. Was the degradation the result of a single event, or of a developing nature?
3. Did the degraded connection impact the ability of the DC System to perform its credited safety functions?
4. How would have a seismic event affect the integrity of the affected connections?

1. Most probable cause(s) for the degraded connection

A bolted connection can become loose over time by a number of mechanisms. The table in Attachment 1 identifies the most probable mechanisms for looseness, and their relevance to the present situation: As shown therein, SCE concludes that the most probable cause is that the bolts were not fully tightened during the breaker replacement of March 2004, as required by the relevant procedures.

2. Was the degradation the result of a single event, or of a developing nature

As explained in the previous section, the root-cause for the final onset of the degraded connection can be said to be due to a single event: the incorrect bolting activity on March 2004. However, due to the original oversight, there also was a potential for deterioration of the connection, given proper conditions; for instance, the drying out of the conductive grease applied between the busses during the breaker replacement. As explained below, a connection may lose pressure and still have a very low resistance. However, a connection which is not properly tightened may provide an opportunity for oxidation of the aluminum surfaces, suddenly increasing the contacts resistance to low voltage, which appears to be the case in the incident addressed herein.

<u>The following provides the most probable explanation for the final failure of the weekly surveillance test:</u>

During the March 2004 breaker replacement activity the electricians applied to the affected bolts enough torque to put some compression on the lock-washers, without fully tightening them. In doing so, they might have used a regular wrench, based on the fact at least two bolts per connection were found tight enough they could not be moved by hand (see item 8 under "Factual Information", above). The incomplete activity would have left the connections with a pressure less than required by the pertinent procedure. If a proper surface preparation was made, and anti-oxidant grease applied, this activity would have resulted in good contact (low contact resistance). In Figure 4, the anti-oxidant grease is visible on the edge of the bus joints. Also, as indicated in Item 12 under "Factual Information", the contact surface is designed with a current-carrying capacity of about four times the required under an accident, providing ample margin to carry the required current, even if torquing of all or some of the bolts did not meet existing procedures.

Between 3/17/08 and 3/21/08, the swing charger was placed in-service on 2D2 which caused about 112 amps to be supplied through the degraded connections. This resulted in increased heating of the connections for about 4 days, followed by a cooling of the connections when the swing charger was removed from service. Increased heating can accelerate the rate of oxidation on an under-torqued joint allowing the formation of a very thin layer of oxidation on the aluminum surfaces (about 50-120 angstroms thick [5]). Increased heating can also accelerate the drying of the conductive grease, which can increase joint resistance. The normal charger output voltage is about 131 VDC and the open circuit battery voltage is 120 VDC, so a developing layer of oxide or dried grease at the breaker connections would be exposed to a maximum of 11 VDC. This voltage may not be high enough to puncture a developing surface layer of oxidation or grease. However, if a real safety event were to occur, the entire 120V DC would be applied to the oxide layer. This potential is sufficient to break the thin layer of insulation and/or small gap recreating the conducting joint. Contact theory indicates that there is a threshold voltage, called the "fritting" voltage, associated with the breakdown of surface oxides or other contaminants between conducting surfaces. Below the fritting voltage, the surface materials act as an electrical insulator preventing current flow. Above the fritting voltage, electrical stress causes an avalanche breakdown of the surface insulator and conductivity is restored [4]. The fritting voltage necessary to break contact resistance can vary from several volts to several hundred volts depending on the thickness of the surface buildup, the pressure between the surfaces, the materials involved and other environmental factors. From relay applications, contact surfaces with less than 24 volts across them are known to be susceptible to high contact resistance from surface oxidation or contamination.

Based on calculations and instrument tolerances, the joint resistance until the end of the swing charger test of 3/17-21/08 is calculated to be between 0 to 8 mΩ. The calculations are included in Attachment 3. The acceptable joint resistance value of 5.4 mΩ (Attachment 4) is statistically within the range 0-8 mΩ. A change in the total resistance of the circuit (attributable to the degraded connection) can be established as happening after 3/21/08. Using "as-left" data for the charger voltage and voltage measurements taken on the battery terminals, and conservatively assuming (based on the fact the battery was fully charged) a charging current of no more than 0.1 ADC, the calculation for the resistance of the degraded connection yields a value in the range of 0-5.7 Ω at the time the regular charger took over from the swing charger (See Attachment 3). Statistically, this resistance is orders of magnitude higher than the connection resistance of 3/17/08.

The change that happened with the reversal of current from the swing charger to the normal charger can be explained as follows:

Following the 4-day operation of the swing-charger (3/17/08 thru 3/21/08), the joint degraded. We believe the current flow thru the connection dried the grease on the contact surfaces and allowed the formation of an aluminum oxide layer. This layer of oxidation created enough resistance to withstand the very low potential differential between the charger and the battery. As explained above, this oxidation layer, and its corresponding fritting voltage would have been breached by the full battery voltage during a real event. A second possible cause (or in addition to the previous one), is that a small gap was created due to the geometry change following cool-down of the unloaded joint). The interview with the electrician that restored the circuit integrity by just lightly touching one bolt of the connection demonstrated that the oxidation layer or/and gap was indeed very weak/small.

3. Did the degraded connection impact the ability of the DC System to perform its credited safety functions?

The safety function of the 2B008 Battery is to provide power to the loads on the 2D2 Bus during three types of accident scenarios: Safety Injection Actuation Signal with Loss of Voltage Signal (SIAS/LOVS), Degraded Grid Voltage with SIAS Signal (DGVSS) and Station Blackout (SBO).

The design-basis bus loading during the various applicable scenarios is:

CONNECTION LOAD DURING SIAS/LOVS or DGVSS (normal charger on):

0–1 MIN = 474 ADC
1–90 MIN = 0 ADC

CONNECTION LOAD DURING SIAS/LOVS or DGVSS (swing charger on):

0–1 MIN = 474 ADC
1–90 MIN = 89 minutes of 193 ADC with one minute spike of 312 ADC

SBO:

0–1 MIN = 341 ADC
1–30 MIN = 193 ADC with one minute spike of 312 ADC
30–240 MIN = 155 ADC with one minute spike of 239 ADC

Evaluation of SIAS/LOVS and DGVSS scenarios (with normal charger in service):

During a SIAS/LOVS event or a DGVSS scenario, the battery is designed to provide adequate voltage to the 2D2 Bus loads for 90 minutes. Technical Specifications require periodic verification of the ability to supply the bus loads for 90 minutes by performing a Service Test on the battery.

During these scenarios, offsite power is lost and it takes approximately 10 seconds for Diesel Generator 2G003 to restore power to the 4KV system which will restore AC power to the battery charger. Once AC power is restored, the charger takes approximately 5 seconds to develop a DC output current due to the soft-start circuitry in the charger. Based on this, the 2B002 battery charger will be unable to support the 2D2 bus loads for approximately 15 seconds during SIAS/LOVS and DGVSS accident scenarios. During this 15 second period, the 2B008 battery would be required to supply the 2D2 bus loads through the 2D201 breaker with the degraded connections. During this 15 second period, the maximum design loading through the degraded connection is 474 amps for the first second and 340 amps for the remaining 14 seconds. Following this 15 second period, the battery charger will be restored to service. The charger is designed to carry 325 amps of load. The charger current supplied to the 2D2 bus will not pass through the degraded connections on 2D201 because the charger is connected to the 2D2 bus through a different breaker. All bus loading, up to 325 amps, will be supplied by the charger rather than the battery, once the charger recovers AC power. During the period from 15 seconds to 60 seconds, the maximum bus loading is 338 amps. Since the charger would assume 325 amps, only 13 amps would be supplied by the battery through the degraded connection. During the period from 1 minute to 90 minutes, the maximum bus loading is 245 amps so all of the current would be supplied by the charger and no current would be supplied by the battery through the degraded connection.

Based on this, the 2D2 DC System can perform its safety function if the degraded connections on the 2D201 breaker can carry the following current profile without adverse impacts: 464 amps for 1 second, followed by 340 amps for 14 seconds, followed by 13 amps for 45 seconds. Based on the short duration of this loading, it is concluded the degraded connection were capable of carrying the accident loading without significant degradation.

The connections passed all weekly surveillance tests (Ref Attachment 2) and four current-carrying tests [2] during the 4 year period of interest. The Integrated ESF tests and LOVS tests are designed to closely mimic the accident loading conditions on the bus This provides confidence that the degraded connections did not impact the ability of the battery to supply adequate voltage to the 2D2 loads during accident conditions.. From the list of tests indicated above, traces from three of the tests are presented herein:

- Figure 1 shows a trace from an ESF test carried out on 2/11/2004.
- Figure 2 shows a trace from an ESF test carried out on 11/29/2007, almost three years after the 2D002 breaker replacement.
- Figure 3 shows a trace from an LOVS test carried out on 1/28/2008, just a few weeks before the discovery of the degraded condition of the connections.

All three tests show time durations - when the battery charger was de-energized for approximately 15 seconds, and the degraded connections were conducting all of the 2D2 bus loads under simulated accident conditions. Item 3 in the Factual Information Section of this report contains a table which summarizes the results of the Integrated ESF Tests and LOVs tests. The data supports a determination that adequate voltage is being maintained on 2D2 when accident loading is being supplied through the degraded connections.

Satisfactory weekly surveillance tests from the time of the breaker replacement on 3/17/04 until the one on 3/18/08 (Ref Attachment 2) indicate the affected connections, although not fully torqued during the maintenance activity of March 2004, were able to carry charging current without any problem until the last satisfactory weekly battery surveillance test, on 3/18/08. This indicates that the battery remained fully charged during this 4 year period.

Evaluation of SIAS/LOVS and DGVSS scenarios (with swing charger in service):

There was a 4-day period between 3/17/08 and 3/21/08 when the 2D2 bus was being supplied by swing charger 2B022 rather than the normal charger 2B002. The swing charger is connected at the battery terminals, so its output current would have been supplied to the 2D2 bus through the degraded connections on the 2D201 breaker. In this alignment, if an accident were to occur, the degraded connections would have to carry the entire bus load for the full duration of the event because the charger current goes through the degraded connections. The load profile is 474 amps for 1 minute, followed by 193 amps for 89 minutes with a 1-minute spike to 312 amps during the second period (due to a consideration of random loads). It is noted that during the 4-day period between 3/17/08 and 3/21/08 when the swing charger was in-service, it was supplying approximately 112 amps through the degraded connections continuously. Subsequent inspections of the connections during re-torquing on 3/25/08 and subsequent ductor testing performed on 7/16/08, revealed no evidence of significant degradation of the connections. Although the average accident loading is about twice as high as the 112 amp loading carried over the 4-day period, the accident loading lasts only 90 minutes. Based on the above, it is concluded that the degraded connections were capable of carrying the accident loading without significant degradation.

Evaluation of SBO Scenario:

During an SBO event, the battery is designed to provide adequate voltage to the 2D2 Bus loads for 4 hours. Verification testing for this scenario is not required by Tech Specs. Analyses are performed to ensure the battery has adequate capacity to supply the 2D2 loads for 4 hours.

During this scenario, the battery charger (normal or swing) is not expected to be reenergized until the end of the 4 hour period so the battery would have to supply the bus loads for a 4 hour period. During this scenario the battery must supply the SBO load profile current (itemized above) through the degraded connection. Due to the 4 hour duration of this event, there is some possibility that heating of the connections would occur. It is concluded that this would not result in tripping of the 2D201 breaker within the four hour period given it has a magnetic trip not directly affected by the temperature at its terminals.

It is noted that during the 4-day period between 3/17/08 and 3/21/08 when the swing charger was in-service, it was supplying approximately 112 amps through the degraded connections continuously. Subsequent inspections of the connections during re-torquing on 3/25/08 and subsequent ductor testing performed on 7/16/08, revealed no evidence of significant degradation of the connections. During an SBO condition the average current through the degraded connections would be approximately 161 amps. Although this is about 45% higher than the current carried during the 4-day period, the SBO current lasts only for 4 hours. Based on the above, it is concluded that the degraded connections were capable of carrying the SBO accident loading without significant degradation.

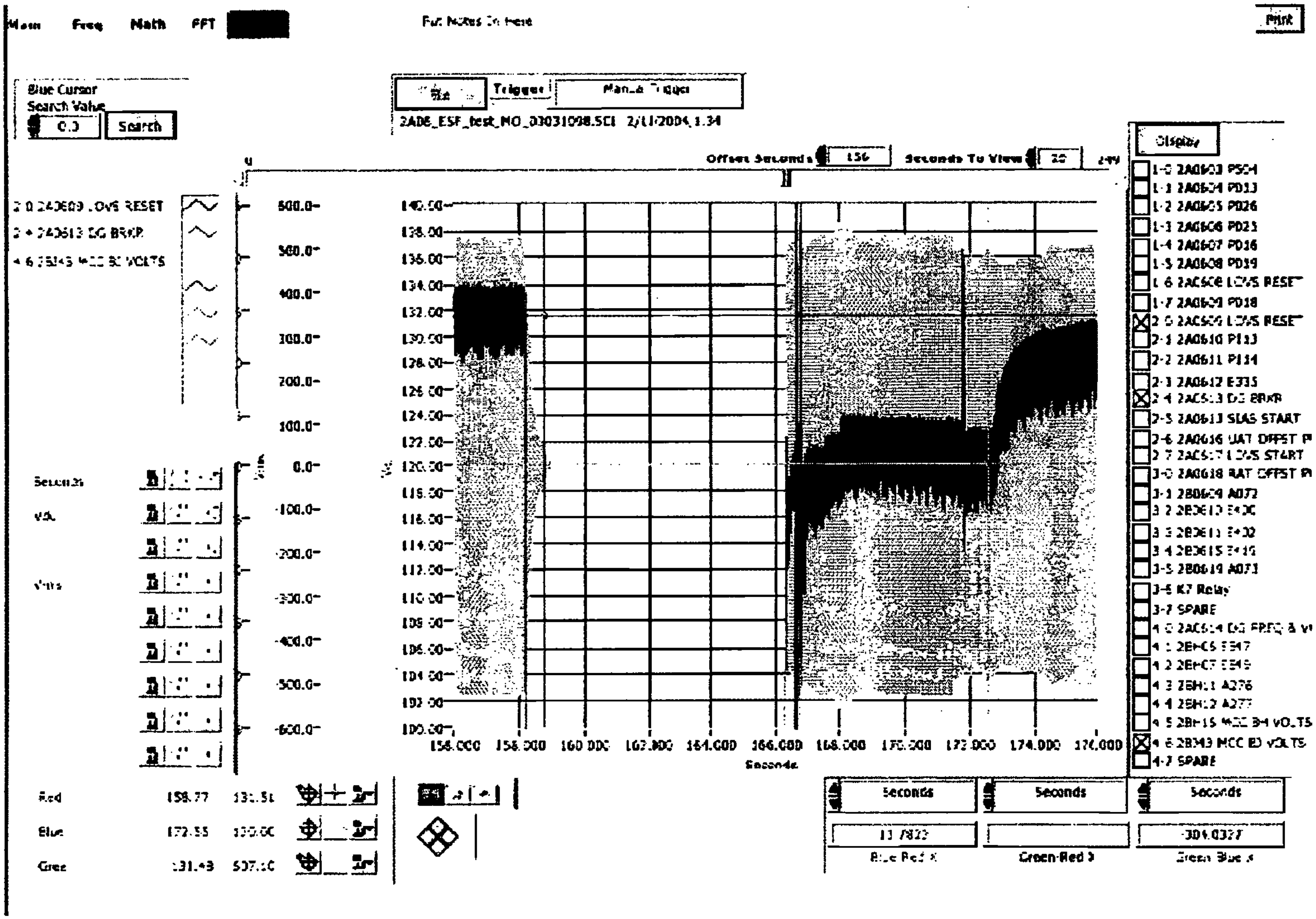

Figure 1 – ESF test on affected circuit on 2/11/2004 before the breaker replacement. Test duration of the test about 15 seconds.

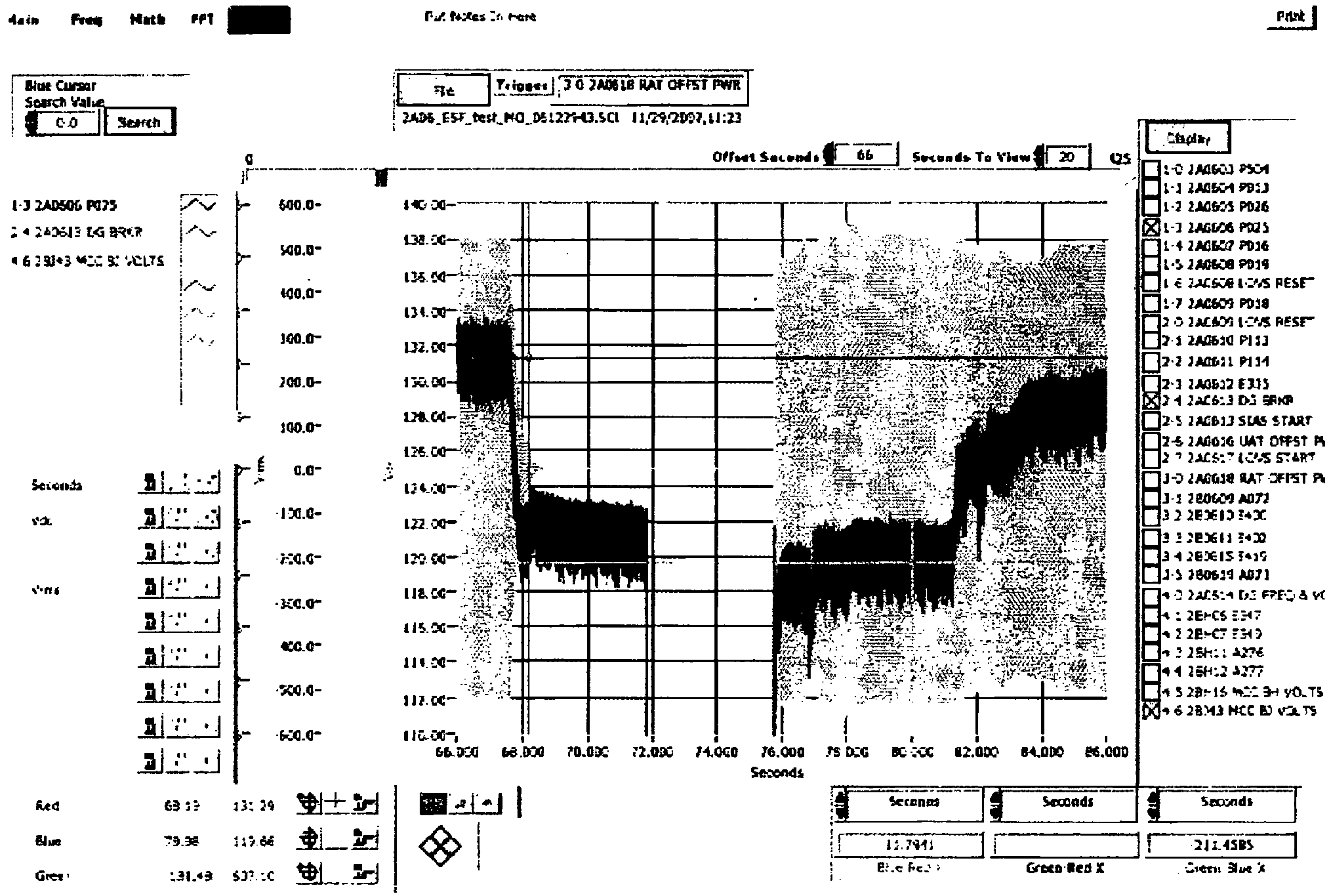

Figure 2 – ESF test on affected circuit on 11/29/2007 after breaker replacement. It is important to note no significant changes in the test results between this test after breaker replacement and the one in Figure 1, before breaker replacement. Test duration about 15 seconds.

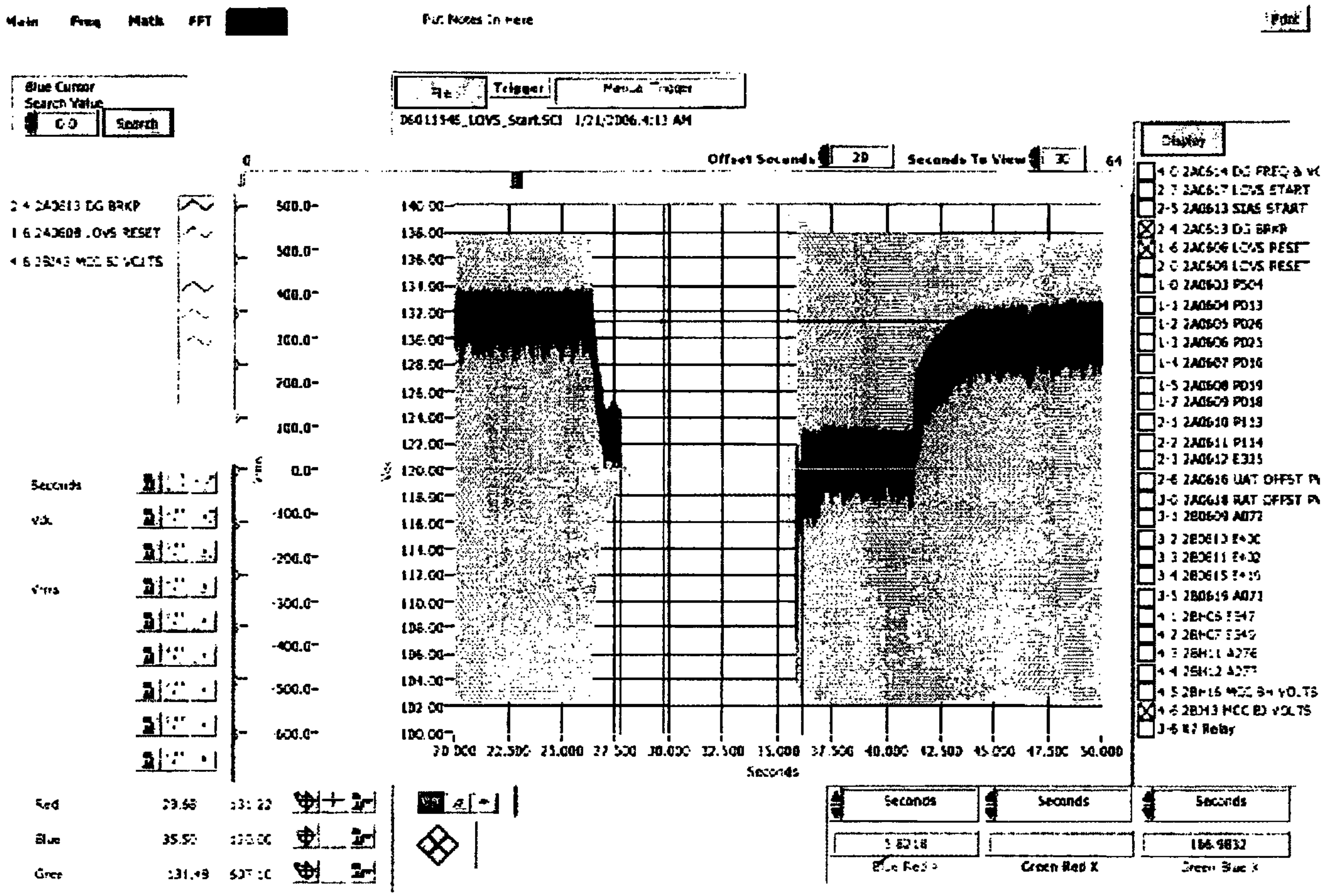

Figure 3 – LOVS test on affected circuit on 1/21/2008 performed a few weeks before the degraded condition of the connection was discovered. The test results were satisfactory. Test duration about 15 seconds.

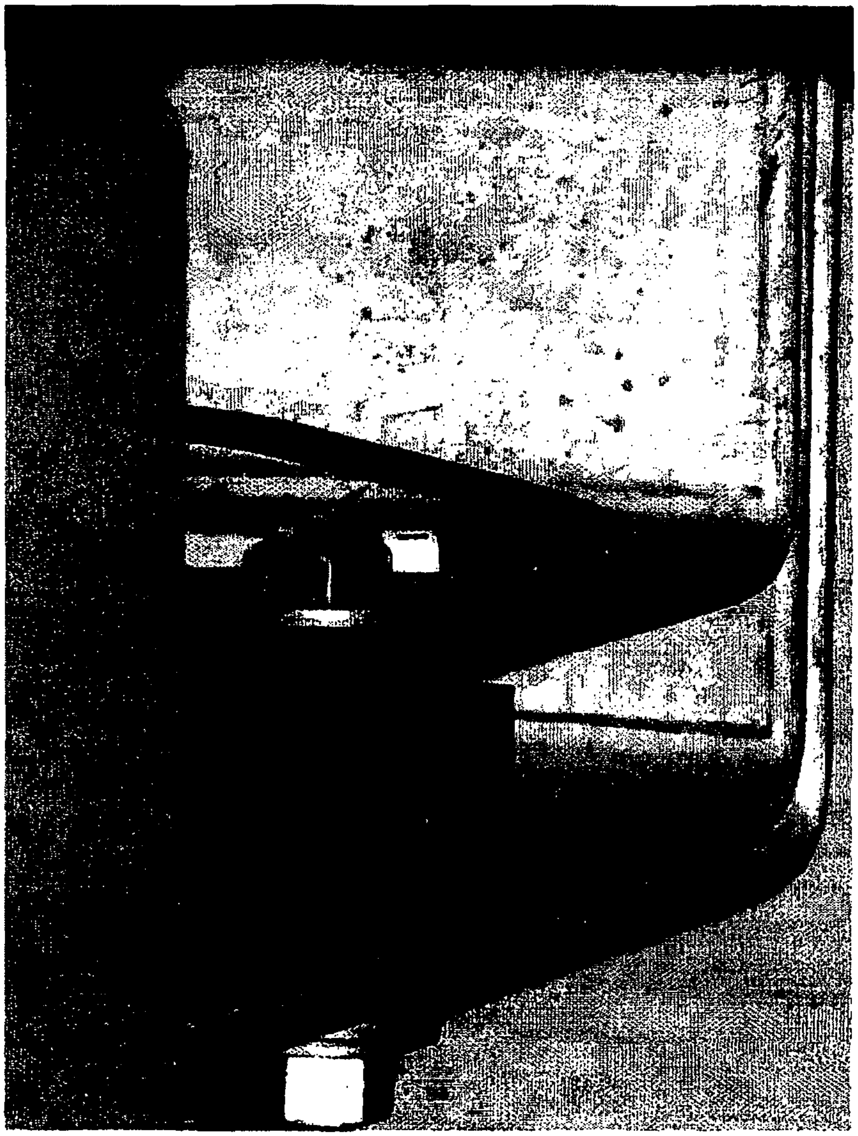

Figure 4: One bolt on the affected connection.

All the aforementioned are in accordance with the assumption based on existing knowledge (as shown graphically in Figure 5), that once a clean contact was established on March 2004, losing pressure did not immediately result in an increase of contact resistance. This only happened after the 4-day period of swing-charger current flowing thru the impacted joint.

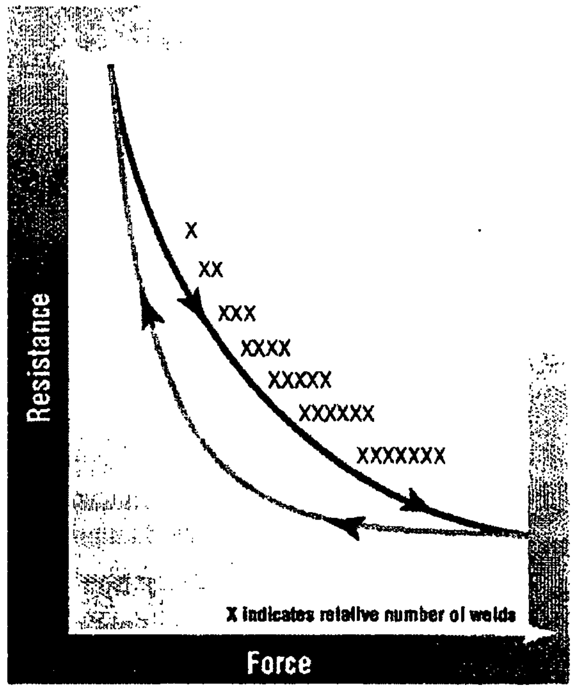

Figure 5 [4] – Contact theory says that contact points are actually cold welds. If the high contact force is decreased, the contact resistance remains constant and does not increase until a much lower force is reached.

4. <u>How would have a seismic event affect the integrity of the affected connections</u>

A seismic event would have no adverse impact on the integrity of the connection [9].

First of all, from inspection of Vendor's drawings and Bill of Material, the breaker is attached by dedicated bolts and channels to the panel. The connections to the buses upstream and downstream are not designed for support purposes, but to provide electrical continuity to the rest of the circuit. From an electrical point of view, all the bolts belonging to the two affected connections are fully threaded into their nuts and some of them quite tight (from interview with the craftsman that tightened the bolts – Item 8 under "Factual Evidence" above). This means that there was little or no increase in risk that a seismic event would separate the buses breaking the physical continuity of the circuit. Second, the violent shaking of the connection would have help in breaching the very thin layer of oxidation between the busses further reducing (perhaps to zero) the fritting voltage of the connection. Once a DC current starts, it is well known that current flow will be maintained over small gaps due to the lack of zero-current crossing inherent to DC circuits. This is particularly true in an inductive circuit, such as the one being fed by 2B008.

The following statement results from seismic calculations performed specifically to address the situation on hand [9]:

"The connections will not lose contact because there will be very little differential movement between the breaker tabs and the bus bars. Since the bolts have sufficient strength to withstand the seismic loads, lateral movements will be limited to about 1/16 inch which is the difference between the 3/8 inch diameter holes and the 5/16 inch bolt diameters. As shown in the figures (Figure 6 below), the breaker tabs are sandwiched top and bottom by the bus bars. Due to the out-of-plane flexibility of the bus bars and having at least two tight bolts per connection, the bus bars will move with the tabs vertically and thus, existing gaps would not be expected to become greater in a seismic event."

Figure 6: Physical support of breaker 2D201

Conclusions:

1. The cause for the degraded bus connections between 2D201 and 2B008 was insufficient torque applied to the eight bolts (four per polarity) holding the buses and breaker terminals together, during 2D201 replacement in March 2004.
2. Reasonable assurance is provided by surveillance tests and data from the normal-charger test period that the connections were able to perform their design function for the entire period starting with the replacement of 2D201 until the last successful surveillance test a week before the failed one.
3. Based on the physics of aluminum-to-aluminum contact and fritting voltage, it is likely that the 120 DC-volts circuit would have exceeded the fritting voltage during a real event allowing the connections to carry current without abnormal voltage drop from 3/21/08 up to the time of the failed surveillance test.
4. As shown by calculations [9], a seismic event would have no deleterious effect on the physical integrity of the breaker or in the capability of the connections discussed herein to perform their design-duty.

5. For a LOVS/SIAS or DGVSS event with normal charger 2B002 in service, there is high confidence that the 2B008 battery would have supplied the required power to the 2D2 loads, even with the degraded connections at the 2D201 breaker. This is based on the following facts:

   a) The 120 VDC available at the battery would be expected to be above the fritting voltage for the connection so it would punch through any surface buildup of oxidation.

   b) Once DC current begins to flow, it tends to be self sustaining as there is no zero crossing of the current & voltage,

   c) The battery would need to support the loads for only 15 seconds until the EDG starts, and then 2B002 charger recovers, so there would not be any significant heat buildup at the connection that would impact the connection or the breaker

   d) Two successful ESF tests and two successful LOVS tests were performed between 2004 and 2008. This corroborates the conclusions above.

6. For a LOVS/SIAS or DGVSS event with the swing charger 2B022 in service, there is reasonable confidence that the 2B008 battery would have supplied the required power to the 2D2 loads, even with the degraded connections at the 2D201 breaker. This is based on the following facts:

   a) The 120 VDC available at the battery would be expected to be above the fritting voltage for the connection so it would punch through any surface buildup of oxide or contaminants,

   b) Once DC current begins to flow, it tends to be self sustaining as there is no zero crossing of the current & voltage,

   c) The battery would need to support the loads for 90 minutes, however during a recent (3/2008) normal charger test, the swing charger supplied 112 ADC thru the under-torqued connections for approximately four days.

7. For an SBO event, the degraded connection would have to support the 2D2 bus loads for a 4 hour period and there is some possibility that heating of the connections would occur. But, this would not result in tripping of the 2D201 breaker within the four hour period given it has a magnetic trip not directly affected by the temperature at its terminals. Calculations from data obtained during the swing charger test of 3/17/08 to 3/21/08 indicate the resistance before the current reversal was no more than 0-8 mΩ. For an 8 mΩ resistance, a current of 170 ADC (SBO average current) will produce a loss in the connection of about 250 watts – not enough to cause any deleterious heating over a four hour period. The calculations in Attachment 3 and 4, independent from all the above, show the resistance of the joint prior the end of the 4-day normal charger test is statistically within the maximum allowable value, i.e.: the connection would have allowed the battery and swing charger to deliver their charger/load as required.

References:

1. Attached *Timeline*. (Attachment 5)

2. Graphs obtained during the ESF and LOVS tests noted in Item 3 of the section titled "Factual Information", below.

3. *Engineering Report: Bolting Techniques and Practices Aluminum / Copper*, by Columbia MFG, LLC, Astoria, Oregon.

4. *Creating Reliable Electrical Connections*, by Norman Shackman, P.E., Maintenance World, Posted on Internet on 8-25-03.

5. *Conductive Grease and Electrical Contact Lubricant "NO-OX-ID A-Special Electric Grade;* The Sanchem Company.

6. *SONGS - Calculation No. E4C-017.1 Rev. 3,* sheet # 83.

7. *MO #07042009000* (battery charger 2B002 test).

8. *MO #03100406* (2D201 replacement).

9. SONGS Seismic study of degraded connections – July 2008.

10. *Ductor* test on re-torqued connections performed on 7/15/08 (NMO #800117881).

11. Notification 200055175 (As found test of 2EYD2 computer readout for 2D bus voltage).

ATTACHMENTS

ATTACHMENT 1

Potential Cause(s) for the Marginal Connection Found on 3/25/08

Cause	Relevance
Corrosion of the bolts' threads	External surfaces of bolts found not corroded (1).
Over-tightening (taking the bolt material beyond its yield point)	The looseness found on some of the bolts is more than it would have been found if the bolts were torqued over their yield point (1).
Vibration	Equipment is not subject to severe and continuous vibration.
Deformation of the bolted buses	There is no visible indication of deformation (1).
Continuous lateral movement of the bolt wearing the bus and/or washer	No such wearing of the buses/bolts/washers was found on their outside surface (1).
Under-tightening	**Most probable cause.** Possible scenario: Maintenance personnel tightened the bolts with the common wrench, but forgot to finalize the torquing activity with the torque wrench. This conclusion is based on the interview with the craftsmen (see Item 8 under "Factual Information," above.

Note (1): The degraded connections have not been disassembled and inspected.

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ATTACHMENT 2

Weekly Battery (2B008) Test Data – 2004-2008

Date	Battery Volts	SpGr Cat A Limits Met? (>= 1.202)	Pilot Cell A Corr SpGr	Pilot Cell B Corr SpGr	MO	Remarks
06/10/08	131.76	Yes	1.229	1.224	08060144	
06/03/08	131.75	Yes	1.225	1.218	08052367	
05/27/08					08051932	MO not imaged
05/20/08	131.75	Yes	1.232	1.224	08051182	
05/13/08					08050425	MO not imaged
05/06/08	131.87	Yes	1.224	1.218	08042805	
04/29/08	131.46	Yes	1.234	1.225	08042026	
04/22/08	131.80	Yes	1.236	1.223	08041266	
04/15/08	131.86	Yes	1.234	1.225	08040720	
04/08/08	131.86	Yes	1.225	1.223	08040112	
04/01/08	131.74	Yes	1.237	1.231	08031922	
03/25/08	131.88	Yes	1.223	1.225	08031473	**2D201 Event**
03/18/08	131.52	Yes	1.237	1.225	08030752	
03/11/08	131.85	Yes	1.240	1.224	08030184	
03/04/08	131.73	Yes	1.225	1.219	08022321	
02/26/08	131.60	Yes	1.226	1.219	08021808	
02/19/08	131.94	Yes	1.225	1.217	08020977	
02/12/08	131.91	Yes	1.226	1.220	08020457	
02/05/08	131.85	Yes	1.225	1.217	08012307	
01/29/08	131.84	Yes	1.227	1.220	08011542	
01/22/08	131.82	Yes	1.226	1.209	08011162	
01/15/08	131.93	Yes	1.227	1.218	08010585	
01/08/08	131.76	Yes	1.234	1.228	08010076	
01/01/08					07121685	MO not imaged
12/25/07	131.40	Yes	1.227	1.221	07121328	
12/18/07	131.22	Yes	1.226	1.221	07120824	
12/11/07	131.29	Yes	1.229	1.224	07120307	
12/04/07	131.37	Yes	1.226	1.223	07111436	
11/27/07	131.50	Yes	1.230	1.223	07112430	
11/20/07	131.35	Yes	1.227	1.221	07110810	
11/13/07	131.62	Yes	1.227	1.221	07110397	
11/06/07	131.45	Yes	1.225	1.220	07101717	
10/30/07	131.61	Yes	1.227	1.221	07101477	
10/23/07	131.69	Yes	1.229	1.223	07101022	
10/16/07	131.37	Yes	1.229	1.224	07100642	
10/09/07	131.31	Yes	1.226	1.225	07100110	
10/02/07	131.23	Yes	1.229	1.217	07091415	

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09/25/07	131.27	Yes	1.229	1.226	07091049
09/18/07	131.45	Yes	1.228	1.223	07090784
09/11/07	131.33	Yes	1.229	1.223	07090267
09/04/07	131.41	Yes	1.230	1.223	07081640
08/28/07	131.36	Yes	1.231	1.226	07081180
08/21/07	131.48	Yes	1.229	1.225	07080810
08/14/07	131.44	Yes	1.220	1.222	07080393
08/07/07	131.41	Yes	1.223	1.218	07080101
07/31/07	131.42	Yes	1.223	1.218	07071141
07/24/07	132.04	Yes	1.212	1.214	07070851
07/17/07	131.99	Yes	1.223	1.220	07070424
07/10/07	131.99	Yes	1.224	1.220	07070128
07/03/07	132.00	Yes	1.223	1.222	07061477
06/26/07	131.87	Yes	1.223	1.219	07061065
06/19/07	131.86	Yes	1.224	1.223	07060693
06/12/07	131.81	Yes	1.223	1.222	07060287
06/05/07	131.80	Yes	1.222	1.222	07051854
05/29/07	131.74	Yes	1.222	1.217	07051514
05/22/07	131.81	Yes	1.222	1.213	07051093
05/15/07	131.49	Yes	1.220	1.215	07050550
05/08/07	131.58	Yes	1.210	1.208	07050145
05/01/07	131.77	Yes	1.215	1.213	07041721
04/24/07	131.57	Yes	1.219	1.218	07041298
04/17/07	131.60	Yes	1.221	1.217	07040841
04/10/07	131.67	Yes	1.215	1.209	07040377
04/03/07	131.66	Yes	1.217	1.212	07033435
03/27/07	131.66	Yes	1.215	1.211	07032955
03/20/07	131.69	Yes	1.210	1.213	07032416
03/13/07	131.64	Yes	1.212	1.210	07030537
03/06/07	131.65	Yes	1.212	1.211	07022492
02/27/07	131.60	Yes	1.220	1.218	07021801
02/20/07	131.18	Yes	1.219	1.209	07021348
02/13/07	132.05	Yes	1.209	1.217	07020750
02/06/07	131.54	Yes	1.228	1.225	07011942
01/30/07	131.96	Yes	1.214	1.218	07011363
01/23/07	131.06	Yes	1.221	1.216	07011107
01/16/07	131.14	Yes	1.219	1.213	07010592
01/09/07	131.21	Yes	1.218	1.212	070100097
01/02/07	131.15	Yes	1.218	1.213	06121575
12/26/06	131.16	Yes	1.218	1.213	06121303
12/19/06	131.12	Yes	1.222	1.215	06150848
12/12/06	131.13	Yes	1.218	1.215	06120337
12/05/06	131.21	Yes	1.217	1.214	06111608
11/28/06	131.23	Yes	1.223	1.222	06111257
11/21/06	131.30	Yes	1.230	1.217	06110903
11/14/06	131.27	Yes	1.222	1.218	06110429
11/07/06	131.27	Yes	1.223	1.217	06110184
10/31/06	131.29	Yes	1.223	1.216	06101425
10/24/06	131.28	Yes	1.223	1.216	06100933
10/17/06	131.31	Yes	1.223	1.217	06100741

10/10/06	131.28	Yes	1.218	1.214	06100111	
10/03/06	131.27	Yes	1.218	1.214	06091284	
09/26/06	132.22	Yes	1.222	1.216	06090865	
09/16/06	131.79	Yes	1.218	1.216	06090189	
09/12/06	131.91	Yes	1.226	1.219	06090189	
09/05/08					06081588	MO not imaged
08/29/06	131.60	Yes	1.222	1.217	06081261	
08/22/06	131.59	Yes	1.225	1.217	06080908	
08/15/06	131.58	Yes	1.220	1.217	06080586	
08/08/06	131.59	Yes	1.229	1.218	06080107	
08/01/06	131.68	Yes	1.224	1.219	06071235	
07/25/06	131.76	Yes	1.223	1.219	06070854	
07/18/06	131.66	Yes	1.224	1.219	06070606	
07/11/06	131.61	Yes	1.219	1.218	06070160	
07/04/06	131.64	Yes	1.226	1.220	06062026	
06/27/06	131.63	Yes	1.224	1.221	06061477	
06/20/06	131.59	Yes	1.223	1.219	06060926	
06/13/06	131.49	Yes	1.223	1.219	06060596	
06/06/06	131.57	Yes	1.224	1.219	06060174	
05/30/06	131.53	Yes	1.222	1.221	06051947	
05/23/06	131.29	Yes	1.223	1.222	06051339	
05/16/06	131.47	Yes	1.226	1.221	06050784	
05/09/06	131.45	Yes	1.228	1.225	06050300	
05/02/06	131.48	Yes	1.218	1.217	06041634	
04/25/06	131.46	Yes	1.227	1.223	06041324	
04/18/06	131.34	Yes	1.228	1.222	06040718	
04/11/06	131.36	Yes	1.226	1.222	06040424	
04/04/06	131.41	Yes	1.227	1.223	06032246	
03/28/06	131.37	Yes	1.227	1.224	06031753	
03/21/06	131.35	Yes	1.220	1.218	06031102	
03/14/06	131.24	Yes	1.229	1.223	06030667	
03/07/06	131.44	Yes	1.233	1.225	06021785	
02/28/06	132.56	Yes	1.220	1.223	06021408	
02/21/06	131.44	Yes	1.238	1.230	06020927	
02/14/06	131.65	Yes	1.220	1.217	06020532	
02/07/06	131.66	Yes	1.221	1.218	06020011	
01/31/06	131.67	Yes	1.218	1.217	06011826	
01/24/06	131.74	Yes	1.219	1.216	06011303	
01/17/06	131.58	Yes	1.220	1.217	06010560	
01/10/06	131.71	Yes	1.221	1.218	06010091	
01/03/06	131.54	Yes	1.218	1.215	05121705	
12/27/05	131.56	Yes	1.220	1.217	05121316	
12/20/05	131.63	Yes	1.219	1.217	05120898	
12/13/05	131.63	Yes	1.220	1.218	05120406	
12/06/05	131.59	Yes	1.222	1.219	05111528	
11/29/05	131.64	Yes	1.220	1.219	05111259	
11/22/05	131.72	Yes	1.221	1.218	05110868	
11/15/05	131.62	Yes	1.219	1.217	05110596	
11/08/05	131.68	Yes	1.221	1.218	05110066	
11/01/05	131.71	Yes	1.222	1.218	05102804	

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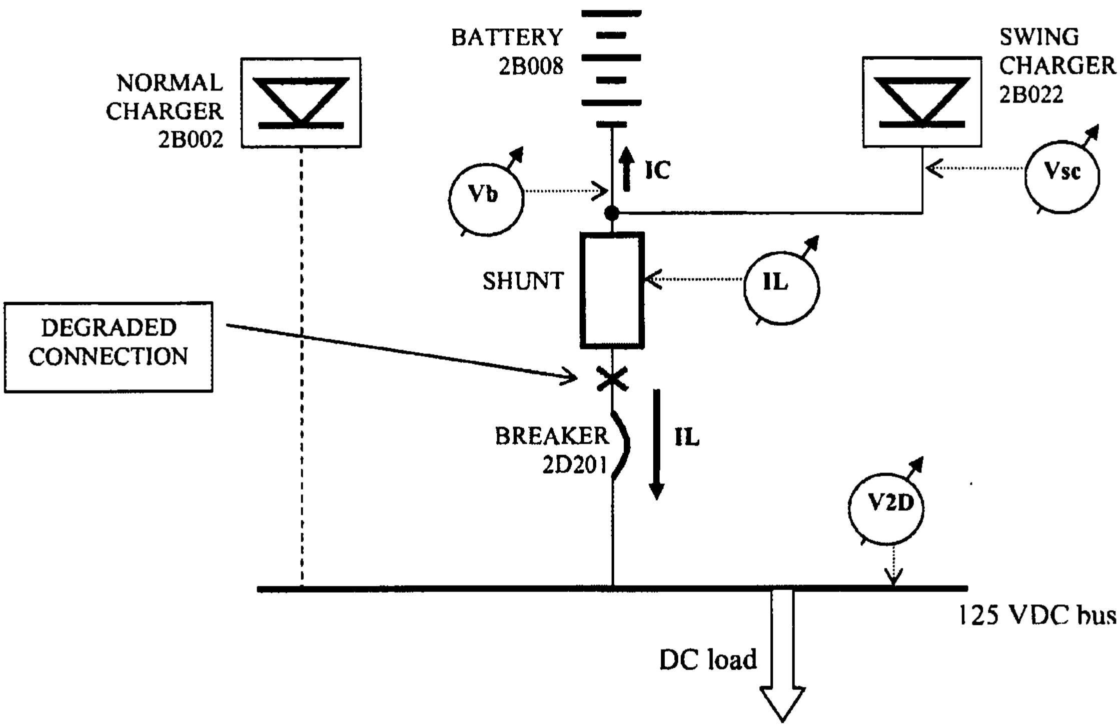
10/25/05	131.67	Yes	1.221	1.219	05102429
10/18/05	131.67	Yes	1.223	1.219	05100637
10/11/05	131.71	Yes	1.221	1.218	05100194
10/04/05	131.67	Yes	1.218	1.217	05091712
09/27/05	131.67	Yes	1.220	1.218	05091222
09/20/05	131.70	Yes	1.219	1.217	05090683
09/13/05	131.70	Yes	1.223	1.219	05090306
09/06/05	131.71	Yes	1.219	1.218	05082109
08/30/05	131.82	Yes	1.221	1.217	05081531
08/23/05	131.78	Yes	1.221	1.216	05081047
08/16/05	131.73	Yes	1.220	1.217	05080627
08/09/05	131.79	Yes	1.220	1.218	05080126
08/02/05	131.79	Yes	1.220	1.219	05071506
07/26/05	131.87	Yes	1.220	1.218	05070985
07/19/05	131.66	Yes	1.220	1.217	05070626
07/12/05	131.68	Yes	1.217	1.217	05070246
07/05/05	131.63	Yes	1.217	1.216	05062441
06/28/05	131.59	Yes	1.218	1.216	05061796
06/21/05	131.50	Yes	1.217	1.217	05061234
06/14/05	131.61	Yes	1.219	1.218	05060690
06/07/05	131.61	Yes	1.220	1.216	05052313
05/31/05	131.63	Yes	1.218	1.216	05052099
05/24/05	131.63	Yes	1.222	1.218	05051459
05/17/05	131.76	Yes	1.214	1.214	05050915
05/10/05	131.63	Yes	1.220	1.217	05050250
05/03/05	131.58	Yes	1.220	1.217	05041899
04/26/05	131.62	Yes	1.217	1.218	05041362
04/19/08	131.56	Yes	1.221	1.216	05040766
04/12/05	131.57	Yes	1.219	1.217	05040467
04/05/05	131.54	Yes	1.217	1.215	05032192
03/29/05	131.61	Yes	1.218	1.217	05031618
03/22/05	131.56	Yes	1.219	1.216	05031095
03/15/05	131.52	Yes	1.217	1.215	05030661
03/08/05	131.60	Yes	1.222	1.216	05030091
03/01/05	131.56	Yes	1.219	1.216	05022033
02/22/05	131.59	Yes	1.220	1.217	05021455
02/15/05	131.52	Yes	1.219	1.216	05020661
02/08/05	131.54	Yes	1.220	1.216	05020116
02/01/05	131.55	Yes	1.220	1.216	05012154
01/25/05	131.63	Yes	1.218	1.219	05011488
01/18/05	131.67	Yes	1.218	1.216	05011156
01/11/05	131.64	Yes	1.219	1.217	05010189
01/04/05	131.42	Yes	1.219	1.216	04123087
12/28/04	131.76	Yes	1.221	1.218	04122690
12/21/04	131.76	Yes	1.220	1.215	04122402
12/14/04	131.63	Yes	1.220	1.215	04120542
12/07/04	131.57	Yes	1.221	1.216	04112002
11/30/04	131.49	Yes	1.222	1.217	04111735
11/23/04	131.45	Yes	1.222	1.218	04111198
11/16/04	131.56	Yes	1.220	1.215	04110704

11/09/04	131.51	Yes	1.222	1.216	04110222	
11/02/04	131.62	Yes	1.220	1.215	04102097	
10/26/04	131.63	Yes	1.216	1.216	04101499	
10/19/04	131.66	Yes	1.215	1.214	04100924	
10/12/04	131.60	Yes	1.219	1.218	04100488	
10/05/04	132.00	Yes	1.217	1.216	04091788	
09/28/04	131.83	Yes	1.217	1.219	04091336	
09/21/04	131.78	Yes	1.217	1.215	04090929	
09/14/04	131.92	Yes	1.219	1.219	04090272	
09/07/04	131.89	Yes	1.216	1.217	04082120	
08/31/04	131.81	Yes	1.220	1.222	04081618	
08/24/04	131.80	Yes	1.220	1.222	04081084	
08/17/04	131.84	Yes	1.217	1.218	04080658	
08/10/04	131.87	Yes	1.221	1.223	04080244	
08/03/04	131.83	Yes	1.218	1.221	04072035	
07/27/04	131.85	Yes	1.220	1.219	04071416	
07/20/04	131.89	Yes	1.218	1.218	04070933	
07/13/04	131.86	Yes	1.219	1.219	04070422	
07/06/04	131.82	Yes	1.219	1.220	04062326	
06/29/04	131.72	Yes	1.216	1.219	04061791	
06/22/04	131.77	Yes	1.215	1.220	04061223	
06/15/04	131.76	Yes	1.218	1.219	04060698	
06/08/04	131.76	Yes	1.217	1.220	40600810	
06/01/04	131.75	Yes	1.218	1.221	04052007	
05/25/04	131.70	Yes	1.218	1.219	04051494	
05/18/04	131.79	Yes	1.218	1.220	04050904	
05/11/04	131.74	Yes	1.218	1.218	04050260	
05/04/04	131.90	Yes	1.213	1.221	04042120	
04/27/04	131.31	Yes	1.224	1.216	04041552	
04/20/04	132.28	Yes	1.227	1.229	04041001	
04/13/04	131.93	Yes	1.225	1.225	04040483	
04/06/04	131.87	Yes	1.222	1.221	04032496	
03/07/04						**2D201 Breaker Replacement**
03/30/04	131.48	Yes	1.220	1.224	04031814	
03/23/04	131.25	Yes	1.226	1.227	04031252	
03/16/04	131.28	Yes	1.227	1.225	04030721	
03/09/04	131.57	Yes	1.230	1.228	04030178	
03/02/04	131.10	Yes	1.216	1.221	04021740	
02/24/04	131.35	Yes	1.218	1.218	04021295	
02/17/04	131.32	Yes	1.221	1.227	04020785	
02/10/04	131.57	Yes	1.219	1.222	04020282	
02/03/04	131.39	Yes	1.220	1.227	04011819	
01/27/04	131.38	Yes	1.219	1.224	04011327	
01/20/04	131.63	Yes	1.219	1.226	04010936	
01/13/04	131.50	Yes	1.220	1.226	04010242	
01/06/04	131.42	Yes	1.219	1.227	03121961	

ATTACHMENT 3

Calculation of joint resistance of degraded connections during the normal charger test of 3/17-21/08

1) Calculation of contact resistance while the swing charger is working:



On 3/17/08, when the normal charger (2B002) was removed from service and the swing charger (2B022) was placed in service, the swing charger voltmeter read 131.52 (+/- 0.15) VDC and 112 ADC. Based on plant computer data, the 2D2 bus voltage under these conditions was between 130.7 and 131.8 VDC. Based on this information, the 2D201 connection resistance at this time would be 0 to 8 mΩ.

IL = 112 ADC (from MO #08011467)
Vsc = 131.52 +/- 0.15 VDC = 131.67-131.37 VDC
V2D = 130.7-131.8 VDC (RTime reading of 132 VDC and calibration data from Notification #200055175).

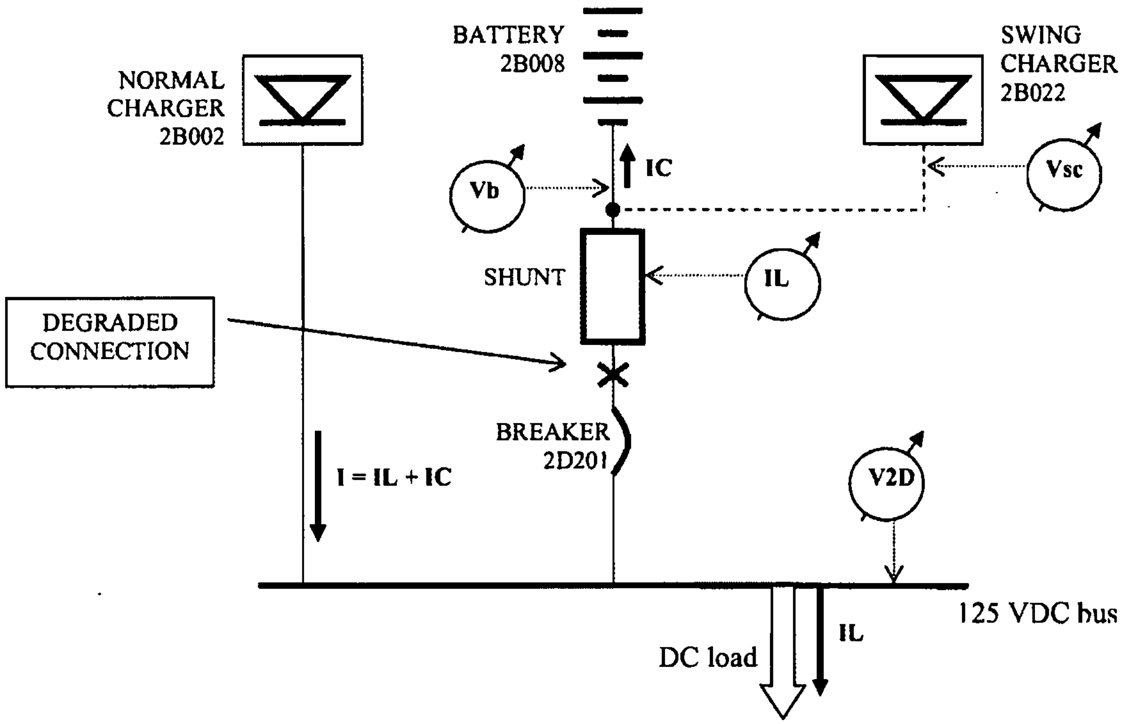
$R_{max} = (Vsc_{max} - V2D_{min})/IL = (131.67 - 130.7)/112 = \mathbf{8\ m\Omega}$

$R_{min} = (Vsc_{min} - V2D_{max})/IL$

However, V2D can only be as high as the swing-charger's voltage, otherwise current would flow in the "wrong" direction, thus:

$R_{min} = (131.37 - 131.37)/112 = \mathbf{0\ m\Omega}$

2) Calculation of contact resistance when the normal charger resumed operation:



On 3/21/08, when the normal charger (2B002) was returned to service, the 2D2 bus voltage was 130.7-131.8 VDC. The battery terminal voltage under these conditions was 131.38 (+/- 0.15) VDC. Assuming a typical float current of 0.1 amps into the battery, the corresponding connection resistance at this time would be equal to 0-5.7 Ω. Statistically, this resistance is orders of magnitude higher than the connection resistance on 3/17/08.

IC =	0.1 ADC
Vb =	131.38 +/- 0.15 VDC = 131.53-131.23 VDC
V2D =	130.7-131.8 VDC

$R_{max} = (V2D_{max} - Vb_{min})/IC = (131.8 - 131.23)/0.1 = \mathbf{5.7\ \Omega}$

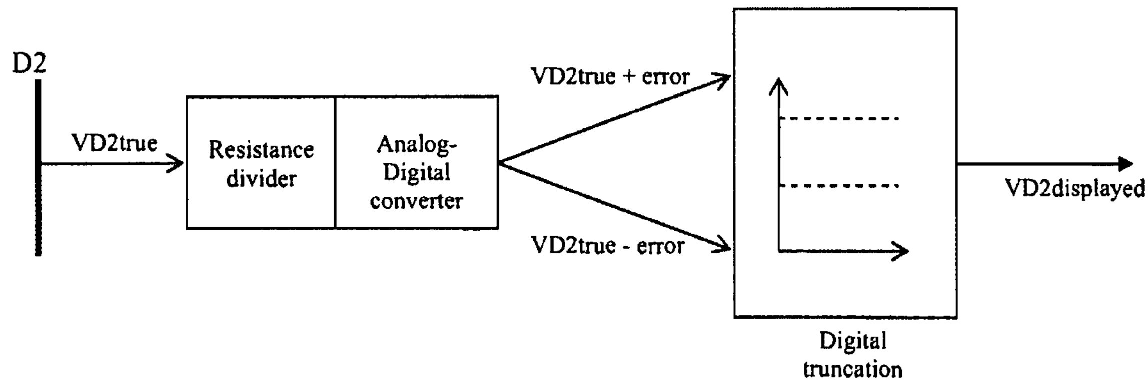
$R_{min} = (V2D_{min} - Vb_{max})/IC$

However, V2D can only be as high as the -charger's voltage, otherwise current would flow in the "wrong" direction, thus:

$R_{min} = (131.53 - 131.53)/0.1 = \mathbf{0\ \Omega}$

3) Calculation of VD2 based on measured value

As shown on the schematic below, the value of VD2 is measured on a computer, after it is affected by the error of the resistance divider, analog-digital converter, and truncated at the computer. Thus, if the value displayed in the computer for VD2 is 132 VDC, then the true value at the bus is as shown below.



In order to measure the relation between the true value of VD2 and the value displayed on the computer, a careful "as-found" test performed on 7/15/08 (Ref. 11) yielded the following.

$$VD2_{displayed} = 132\ VDC \rightarrow \text{true value of } VD2 = 130.8\text{-}131.7\ VDC$$

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ATTACHMENT 4

Calculation of voltage values during analyzed accidents and maximum acceptable resistance in degraded connection

Microsoft Excel - LOVSSIAS = B008 = TEST = (GN-15).xls

File Edit View Insert Format Tools Data Window Help R*TIME

Arial 10 75%

M44 BOUNDING CASE

	F	G	H	I	J	K	L	M	N
10			CONDUCTOR			MINUTE TIME PERIOD			
11	TO	LENGTH	SIZE	OHM/1000'	TOTAL RES (OHM)	0-1	1-30	30-89	89-90
12	2D2	82	500 MCM	0.026	0.0088	463.90	165.07	165.21	244.[illegible]
13	2D2P1	132	250 MCM	0.061	0.0080	401.92	34.87	35.01	35.01
14	2A06	240	3/0 AWG	0.077	0.0184	167.79	7.78	7.78	7.78
15	2B06	180	3/0 AWG	0.077	0.0138	82.70	2.85	2.85	2.85
16	2L-33	724	2 AWG	0.203	0.1470	8.95	0.31	0.31	0.31
17	2L-71	648	6 AWG	0.498	0.3227	13.81	13.81	13.95	13.95
18	2L-421	408	12 AWG	1.972	0.8046	2.64	2.64	2.64	2.64
19	2L-345	232	12 AWG	1.972	0.4575	0.85	0.85	0.85	0.85
20	2L-71	574	12 AWG	1.972	1.1319	2.00	2.00	2.00	2.00
21	2L-161	1982	4/0 AWG	0.131	0.2596	123.18	4.63	4.63	4.63
22	P492(2L375)	156	12 AWG	1.972	0.3076	31.00	0.00	0.00	0.00
23	P493(2L373)	340	12 AWG	1.972	0.6705	26.90	0.00	0.00	0.00
24	P496(2L375)	152	12 AWG	1.972	0.2997	31.10	0.00	0.00	0.00
25	P497(2L373)	340	12 AWG	1.972	0.6705	26.90	0.00	0.00	0.00
26	2Y002	68	3/0 AWG	0.077	0.0052	128.66	128.66	128.66	128.66
27	2MS4706	1152	500 MCM	0.026	0.0297	41.71	0.85	0.85	78.87
28	2TB07	44	2 AWG	0.203	0.0089	0.54	0.54	0.54	0.54
29	2L-71	610	12 AWG	1.972	1.2029	0.54	0.54	0.54	0.54
30	2L-345	324	12 AWG	1.972	0.6389	0.00	0.00	0.00	0.00

	O	P	Q	R	S	T	U	V	W
10	MINUTE TIME PERIODS				MINUTE TIME PERIOD				
11	0-1	1-30	30-89	89-90	PANEL/LOAD	0-1	1-30	30-89	89-
12	4.09	1.45	1.46	2.15	2D2	106.11	113.85	113.15	110.
13	3.23	0.28	0.28	0.28	2D2P1	102.89	113.57	112.87	110.
14	3.08	0.14	0.14	0.14	2A06	99.80	113.43	112.73	110.
15	1.14	0.04	0.04	0.04	2B06	101.75	113.53	112.83	110.
16	1.32	0.05	0.05	0.05	2L-33	101.57	113.52	112.83	110.
17	4.46	4.46	4.50	4.50	2L-71	98.43	109.11	108.37	106
18	2.12	2.12	2.12	2.12	2L-421	100.76	111.45	110.75	108
19	0.39	0.39	0.39	0.39	2L-345	102.50	113.18	112.48	110.
20	2.26	2.26	2.26	2.26	2L-71	100.62	111.31	110.61	108
21	31.98	1.20	1.20	1.20	2L-161	70.81	112.37	111.67	109
22	9.64	0.00	0.00	0.00	P492(2L375)	61.27	112.37	111.67	109
23	18.04	0.00	0.00	0.00	P493(2L373)	62.87	112.37	111.67	109
24	9.32	0.00	0.00	0.00	P496(2L375)	61.58	112.37	111.67	109
25	18.04	0.00	0.00	0.00	P497(2L373)	52.87	112.37	111.67	109
26	6.67	0.67	0.67	0.67	2Y002	105.44	113.18	112.48	110.
27	1.24	0.03	0.03	2.34	2MS4706	104.87	113.82	113.13	108
28	0.00	0.00	0.00	0.00	2TB07	106.11	113.85	113.15	110.
29	0.64	0.64	0.64	0.64	2L-71	106.46	113.20	112.50	110.
30	0.00	0.00	0.00	0.00	2L-345	106.11	113.85	113.15	110.

32 g currents and panel voltages associated with motor starting

34	
35	68°F
36	1
37	1
38	
39	0A
40	
41	0.0054 Ω
42	

Voltage Drop from battery to inverter	4.75
Minimum Inverter Voltage	105.414
[illegible]	[illegible]
VPC	1.90

Cells	56.00	
Inter Cell Connector	54.00	
Feeders IN & OUT Connector	2.00	
3-Jumper Cables Connector	6.00	
Total Connectors	62.00	
Average Inter Cell Connector's Resistance	1.200E-05	12μΩ
Total Connectors Resistance	7.440E-04	Ω
Shunt Resistance with Terminating Plates	1.657E-04	165.7μΩ
2D201 Breaker Connector's Resistance	0.0054	Ω
3-Jumper Cables Resistance	3.830E-04	383μΩ
(B008 = 20R = 4-1/C # 3/0)		
Total Resistance	6.693E-03	
(Added to the NF Resistance)		

BOUNDING CASE

Table 8.3.1B-B008 Sizing=1.86 / Table 8.3.1B-B008 Sizing=1.90 / Table 8.4.1B-B008 TV=GN-15 / Table 8.4.1B-U2VR=GN-15 / Table 8.4.1B-U3VR

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Microsoft Excel - SBO = B008 = TEST = (GN-15).xls

File Edit View Insert Format Tools Data Window Help R*TIME

D5

	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
17	648	6 AVG	0.498	0.3227	15.81	15.81	15.81	15.78	15.78	5.10	5.10	5.10	5.09	5.09	2L-71	102.56	108.05	104.81
18	408	12 AVG	1.972	0.8046	2.64	2.64	2.64	2.64	2.64	2.12	2.12	2.12	2.12	2.12	2L-421	105.54	111.03	107.79
19	232	12 AVG	1.972	0.4575	0.76	0.76	0.76	0.76	0.76	0.35	0.35	0.35	0.35	0.35	2L-345	107.32	112.81	109.56
20	574	12 AVG	1.972	1.1319	2.00	2.00	2.00	2.00	2.00	2.26	2.26	2.26	2.26	2.26	2L-71	105.40	110.89	107.65
21	1382	[illegible] AVG	0.131	[illegible]	77.22	17.51	17.51	17.51	95.18	20.05	4.55	4.55	4.55	24.71	[illegible]	[illegible]	[illegible]	105.36
22	[illegible]	12 AVG	1.972	[illegible]	31.00	0.00	0.00	0.00	0.00	9.54	0.00	0.00	0.00	0.00	P492(2L373)	78.08	[illegible]	105.36
23	340	12 AVG	1.972	0.6705	26.90	0.00	0.00	0.00	0.00	18.04	0.00	0.00	0.00	0.00	P493(2L373)	69.58	108.61	105.36
24	152	12 AVG	1.972	0.2997	31.10	6.30	6.30	6.30	6.30	9.32	1.89	1.89	1.89	1.89	P496(2L375)	78.29	106.72	103.47
25	340	12 AVG	1.972	0.6705	26.90	6.30	6.30	6.30	6.30	18.04	4.22	4.22	4.22	4.22	P497(2L373)	69.58	104.39	101.14
26	68	[illegible]	0.077	0.0052	128.66	128.66	128.66	90.66	90.66	0.67	0.67	0.67	0.47	0.47	2Y002	108.93	112.91	109.66
27	1152	[illegible]	0.026	0.0297	41.71	0.85	0.85	1.01	1.01	1.24	0.03	0.03	0.03	0.03	2MS4706	108.36	113.55	110.30
28	44	2 AVG	0.203	0.0089	1.39	1.39	1.39	0.74	0.74	0.01	0.01	0.01	0.01	0.01	2TB07	109.59	113.56	110.31
29	610	12 AVG	1.972	1.2029	1.31	1.31	0.66	0.66	0.66	1.58	1.58	0.79	0.79	0.79	2L-71	108.01	111.98	109.53
30	324	12 AVG	1.972	0.6389	0.08	0.08	0.08	0.08	0.08	0.05	0.05	0.05	0.05	0.05	2L-345	109.54	113.51	110.26

32 ...l panel voltages associated with motor starting.

Voltage Drop from battery to Inverter	3.59
Minimum Inverter Voltage	105.414
[illegible]	[illegible]
VPC	1.88

Cells	58.00	
Inter Cell Connector	54.00	
Feeders IN & OUT Connector	2.00	
3-Jumper Cables Connector	6.00	
Total Connectors	**62.00**	
Average Per Cell Connectors Resistance	**1.200E-05**	**12μΩ**
Total Connectors Resistance	**7.440E-04**	Ω
Shunt Resistance with Terminating Plates	1.657E-04	165.7μΩ
2D201 Breaker Connector's Resistance	**0.0854**	Ω
3-Jumper Cables Resistance (B008 = 20ft = 4-1/C # 3/0)	3.830E-04	383μΩ
Total Resistance (Added to Cable Resistance)	[illegible]	Ω
Minimum Inverter Voltage	**105.414V**	

Table 8.3.3B-B008 Sizing=1.85 / Table 8.3.3B-B008 Sizing=1.88 / Table 8.4.3B-B008 TV=GN-15 / **Table 8.4.3B-U2VR=GN-15** / Table 8.4.3B-U3VR / T

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Start | Degradation of DC conn... | > Azzi Files - Lotus Notes | Microsoft Excel - SBO ... | MMINetApp | 5:30 PM

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ATTACHMENT 5

Breaker 2D201 and Battery 2B008 Sequence of Events

05/02/2002	**MO 01061449** completed 5/27/02 **connect monitoring equipment (2A04, Train B ESF test)**
02/11/2004	**MO 03031098** completed 9/30/04 **Support various Operations procedures. Completed the DG tests "Train B" 2A06. (ESF)**
02/20/2004	**MO 03031098 Support various Operations procedures. Completed the DG tests "Train B" 2A06. (LOVS)**
02/27/2004	MO 04021613 retested new breaker for long time trip on 2/20/04 per ECP 031200986-9. On 2/10/04 obtained new breaker and trip tested per SO123-I-4.7.
03/17/2004	**MO 03100406 completed changing the Short Time Delay Settings and installing new breaker 2D201 per Calc E4C-109.** (ECP 001000280-05, ECN A20785)
10/11/2005	CWO 05050813 preliminary testing of new battery charger per procedures 2B022.
01/06/2006	**MO 05081829** completed 3/28/06, **the DG tests "Train B" 2A06.** (ESF)
01/21/2006	**MO 06011546 support Operation's procedure for 2G003 DG.** (LOVS)
02/25/2006	MO 05011306 completed 5-year Battery Performance Test (2D201 breaker operated per WAR 2-R4D2BAT)
07/15/2006	MO 06041451 completed quarterly battery surveillance on B008 battery.
10/03/2006	MO 06070800 completed quarterly battery surveillance on B008 battery.
12/28/2006	MO 06100206 completed quarterly battery surveillance on B008 battery.
01/30/2007	MO 06070902 Annual Battery Performance test after reaching 85% service life in October 2006 and performance of Thermography (2D201 breaker operated per WAR 2-0601303)

03/27/2007	MO 07010094 completed quarterly battery surveillance on B008 battery.
06/13/2007	MO 07033365 completed quarterly battery surveillance on B008 battery.
09/17/2007	MO 07060901 completed quarterly battery surveillance on B008 battery.
11/29/2007	**MO 06122943 completed the ESF tests "Train B" 2A06.**
12/08/2007	MO 07091048 completed quarterly battery surveillance on B008 battery.
12/27/2007	MO 07020582 Perform pre-weekly quarterly battery performance test.
12/28/2007	MO 07100767 aligning DC BUS 2D5 to its Swing Charger, 2B022, alarm window 63A57 "2D5 Charger Trouble" comes in and then resets frequently.
01/09/2008	**MO 08010611 support for ESF tests** (LOVS)
01/302008	MO 07020585 Weekly 1E battery inspection completed - sat.
02/05/2008	MO 08020402 aligned Swing Charger 2B022 to 2D5
02/19/2008	MO 08020977 Weekly 1E battery inspection completed - sat.
	MO 08011261 Perform pre-weekly quarterly battery performance test.
02/22/2008	MO 07120476 Connect 2/3B00X to 2D206 (2B008). This temp ECP to connect battery 2/3B00X to bus 2D2 to support 2B008 battery bank performance testing. (Temp ECP 070900092-3) (2D201 operated per MO with In-test)
	MO 08011236 contingency MO to connect Swing Charger (no work performed)
02/25/2008	MO 08011292 31-day post test weekly/quarterly inspection
02/27/2008	MO 07020581 Annual Battery Performance test after reaching 85% service life in October 2006 and performance of Thermography. (2D201 operated per WAR 2-0702901 via an In-test)
	MO 07020584 Perform Physical inspection of battery
03/03/2008	MO 08010255 completed quarterly battery surveillance on B008 battery.
03/11/2008	MO 08030184 Weekly 1E battery inspection completed – sat

03/17/2008 MO 08030095 31-day post test weekly/quarterly inspection

03/21/2008 MO 06100929 B002 Battery Charger performance test and thermography inspection.
(2D201 not operated per WAR 2-0702504)

MO 08011467 2B002, Bus D2 Normal Charger, placed in service and 2B022, Swing charger removed from service by soft transfer operation. (Operations)

MO 07042009 Charger Performance Test, perform Operability readings on 2B008 while on the Swing Charger 2B022.

03/25/2008 MO 08031473 completed weekly battery surveillance which discovered low voltage on battery 2D2.

Operations declared 2D2 battery inoperable.

Electricians discovered eight loose bolts on the battery side of breaker 2D201.

ACE 080301117 generated to determine cause of loose bolts on bus bars of 2D201.

MO 08031721 Tighten and torque the loose bus bar bolts.

MO 08031738 Perform weekly/quarterly inspection for declaring batteries operable

03/28/2008 MO 07101740 perform annual energization testing on swing charger 2B022.
(2D201 not operated per WAR 2-0702931)

04/01/2008 MO 08031922 Weekly 1E battery inspection completed - sat.

04/02/2008 MO 07101741 Swing Battery Charger 2B022 Perform 12-hour Full Load Test - sat

04/10/2008 OE 26600 Operating Experience generated on loose Bus Bars bolts causing low battery voltage.

05/19/2008 MO 08030494 completed quarterly battery surveillance on B008 battery.

NOTE: all dates are MO completed dates unless noted.

rev.08

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ATTACHMENT 6