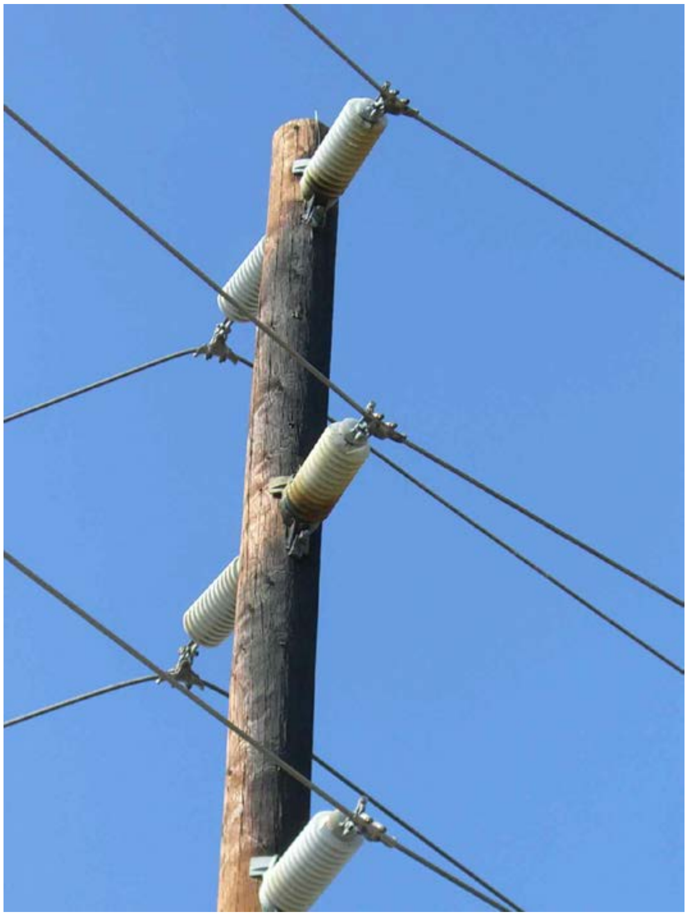
Appendix 1

Incident Report
Fault on 46 kV Power System near the Boeing Facility

What Happened?
On 4 October 2006 at 7:18 pm a fault occurred on the pole structure outside the Boeing manufacturing plant in North Salt Lake. This is about half way along the Gadsby - Wasatch Springs 46 kV line (SL15).

The fault occurred on the center pole shown in the photo on the left. The fault was witnessed by persons at Boeing, and appeared to be lightning-caused. It caused some surface blackening of the pole and damage to the insulators. This blackening and damage are shown in the closeup of the insulators in the second photo below. In this second photo the damage to the insulators is evident in the brown discoloration at the base of the upper two insulators.



Effect on Chevron Refinery
In addition to the interruption at Boeing, this fault caused a shutdown of the Chevron-Texaco Refinery, fed by Wasatch Springs substation a few miles up the line. This also caused Chevron-Texaco to suffer damage and briefly emit pollutants into the air. Of course, all of this cost Chevron-Texaco a significant amount, and Rocky Mountain Power regrets that this occurred.

Digging Deeper
While such lightning-caused faults occasionally occur and are not preventable at reasonable expense, a few aspects of this particular incident bear further investigation. These were primarily brought to light by the Nexus 1252 power quality monitor (PQM) located at Wasatch Springs on Transformer #1. For detail on these please refer to the figures in the attached Appendix. Discussion of each of these issues begins on the following page. Underlying each issue is the question, "Did the system operate normally and correctly to restore service?"

Issue 1—Pre-fault Voltage Question

Figure 1 shows the earliest record of the event. It indicates that phase B voltage (red) is depressed prior to the fault inception recorded about 1/3 second later near the end of Figure 2. This is not common. Usually a lightning stroke will establish a low-impedance arc, and this arc will quickly cause major fault current to flow, allowing the protective relays to quickly detect the fault and trip the breaker.

At a meeting of the relay support manager, area engineer, account manager, maintenance manager, account manager, and power quality engineer on 19 October 2006, such issues were discussed in detail. It was concluded that this was, indeed, an uncommon fault that began as a B-phase-ground fault that caused the B-phase voltage as seen at Wasatch Springs substation to be depressed, but not as depressed as a solid fault to ground would have. A fault study indicated that the voltage on the faulted phase at Chevron for a solid (normal) fault at Boeing would have been about 45% of nominal; whereas this fault was measured at 87% of nominal.

Issue 2—What really happened at Boeing?

So if the fault in its early stages only sagged the B phase voltage at Chevron to 87% of nominal, what could have happened to cause the unbalanced voltage seen in Figure 1? There are two possibilities: (1) some kind of major load imbalance on the system, or (2) the fault did not develop a solid arc (fully ionized path) to ground. The first possibility is extremely unlikely with no supporting evidence, but the second possibility, though uncommon, has occurred in the past and is likely the best explanation.

While we will likely never know exactly how it happened, it is possible that the grounding conductor for the pole was somehow severed or vaporized by the lightning or the follow-on fault current before the relays at each end of the line could operate. Another possibility is that tracking to ground provided a higher impedance path between B phase and the grounding conductor than is normally seen in faults.

However the fault started, it soon evolved into a 3-phase fault (shown in Figure 2) with voltages at Wasatch Springs more in line with what would be expected for a "normal" fault as indicated in a fault study. Figure 3 then shows a breaker (likely at Chevron) tripping about six cycles later. At some point Gadsby CB45 also trips (not captured by the PQ monitor at Wasatch Springs substation) and the fault is interrupted.

Issue 3—Why didn't the Wasatch Springs Breaker Trip?

One thing that was difficult to explain was that, even though SCADA showed that Gadsby CB45 tripped, no SCADA record was received indicating that Wasatch Springs CB53 also cleared the fault. This left the question open as to how the fault cleared. Which circuit breaker tripped? Did the fault just "blow itself out?" Was Wasatch Springs fed from both ends in normal looped mode prior to the fault?

The answer to this question remained difficult until the relay technician queried the digital SEL321 distance relay at Chevron and found that it clearly tripped the Chevron breakers for this event. This is a distance relay that sends trip signals with no intentional delay when it detects a fault within its zone. So this relay merely beat the Wasatch relays to the punch. This still left open the question as to why there was no SCADA record of their operation. This is being investigated.

Issue 4—Why did the Chevron sub relay operate at all?
In this case it was fortunate that the Chevron sub relay operated when it did so its breakers could clear the fault just a bit earlier, clearing the Chevron – Wasatch Springs line instead of the Wasatch Springs – Gadsby line. This clearing issue was traced to coordination between the relays for these two line sections. This issue has been identified and is now corrected.

Restoration
Just over a second after the Chevron breakers tripped, service was restored. This is shown in Figure 4. Also note in this figure that the currents are not sinusoidal at first. This is transformer charging current for the Chevron transformer. This distorted current also distorts the voltage, as can be seen especially in C phase. This is a normal restoration phenomenon and lasts less than one second.

The final state of restoration is indicated by Figure 5. This shows normal voltages and currents with the plant fully operational.

Normal Voltages
Inasmuch as Chevron management was concerned at our last meeting about continuous voltage levels, these voltages were obtained. Average 15-minute rms voltages delivered to Wasatch Springs substation on the 46kV bus were recorded by Rocky Mountain Power's SCADA system and stored in its PI historian database. These are shown in Figures 5 and 6 for the August—Early October 2006 periods. They show that the normal voltage was generally around 47 kV (102.1%) with occasional excursions as high as 48.2 kV (104.7%) and as low as 45.5 kV (98.9%). The 107% range we discussed at our last meeting was based on a quick calculation from the unfaulted C phase voltage seen in Figure 1. Subsequent detailed analysis showed it to be affected by the fault and somewhat high. This often happens during faults, and therefore these levels are not to be trusted.

Conclusions
Rocky Mountain Power regrets that faults occur on its system and that these faults sometimes cause process interruptions to its customers. Such a fault occurred on 4 October 2006 at 7:18 pm near the Boeing plant, due to lightning. This fault was odd in that it started as a high-impedance fault on B phase that lasted for about half a second and likely caused the process interruptions that Chevron experienced. It then evolved into a more normal 3-phase fault and was promptly cleared by protective equipment.

A detailed examination of this incident was greatly aided by the existence of data from digital recording equipment (PQ monitor and digital relay) at Wasatch Springs and Chevron substations. No design, construction or maintenance errors were found in the power system, itself. However, inadequate relay coordination was found in the relay settings protecting the Wasatch Springs – Chevron line, causing it to overtrip. Even if this overtripping had not occurred, Chevron would have experienced the same low, sustained, and imbalanced voltage from the Boeing fault, likely causing the same outcome. The relay settings have since been changed to fully coordinate, minimizing network impact due to system faults.