Improving Process Reliability due to Electrical Interruptions Part II
(A Case Study, Delphi Saginaw Steering Systems Plant 2, Saginaw, MI)

Andy Hernandez, General Motors Delphi Steering Systems
and
Brian Prokuda, Keweenaw Power Systems, Inc.

Delphi Saginaw Overview

Delphi Saginaw Steering Systems (DSSS) supplies world class steering systems, driveline systems and steering columns to the world. Although a General Motors division, almost 50% of DSSS sales are to non-GM customers. These customers include companies such as Ford, Chrysler, Toyota, Nissan, Rolls Royce, Lamborghini, Jaguar, Maserati, John Deere, Mercury Marine and a host of other companies who utilize our systems and components. DSSS World Headquarters are in Saginaw, Michigan with Plants and Technical Centers in the U.S., Mexico, South America, Europe, India, the Far East and Australia. In all, DSSS has 24 manufacturing operations, 6 joint ventures, 5 global engineering centers, and 8 customer support centers utilizing some 7 million square feet in 17 countries.

Plant 2 Production Overview

Plant 2, in Saginaw, Michigan, was built in 1940 and started production in March, 1941. Plant 2 is a vital Plant producing components for the ever popular GM trucks and Sport Utility Vehicles (SUV). The Plant runs three (3) shifts, six to seven days per week. The great demand for trucks and SUV's makes up-time a very critical issue. Downtime means component shortages that could cause delays in just-in-time deliveries. During the period discussed in this paper, the Plant was operating three shifts, seven days per week.

Plant 2 Electrical Overview

Plant 2 gets its electrical power via the local Utility at 46 kV. This power is received at a primary substation, that interfaces the Plant and the Utility, and is transformed down to 13.2 kV. This power is supplied from the primary substation to each of six (6) plant substations where it is transformed down to 480 V, solidly grounded, feeding the Plant through electrical overhead bus.

Table 1 - Preventative Maintenance (PM) Activities

Monthly PM Activities	Yearly PM Activities	3 Year PM Activities	6 Year PM Activities
Read Meters	Includes Monthly PM	Includes Monthly & Yearly PM's with secondary injection tests of main breakers	Includes Monthly, Yearly, and 3 Year PM's
Check Batteries & Charging System	Infrared Inspections of cables, bus & controls	Test & Clean Liquid-filled Transformers & Switchgear	Complete De-energization of Substations for Cleaning & Testing
Visual Check & Repair of : Control Function, Pilot lights, Lighting, Cleanliness	Check Integrity of Insulators, Bushings and Check for Tracking	Test & Clean Oil Circuit Breakers	Perform Cable Hi-pot & Megger tests, Primary Switch Megger & Ductor Tests
Check Pressure, Temp and Oil levels (where necessary)	Check Operation of Fans, Pumps and other devices	Test & Verify Protective Relays	Check/Clean 13.8 kV fuses, fuse hardware, shutters, connections, electrical components and switchgear
	Exercise Tie-Breakers and perform secondary injection tests	Exercise primary switches at secondary substation level	Check, Clean and lube all Mechanical Parts, adjustment of racks, arms, clearances etc.

In, 1979, the Plant went through an electrical modernization adding electrical capacity. From, 1979 through 1991, only minimal maintenance was performed on the electrical system. In 1991, a Preventive Maintenance (PM) program was introduced that is still in place today. The PM program consists of monthly, yearly, three year and six year maintenance routines (see Table 1). In 1995, the Utility installed BMI meters at the service entrance. This aids

DSSS and the Utility when determining on which system (DSSS or Utility) a problem occurs and also to view interruptions and outages that occur on the utility service.

Chronology of Disruption/Interruption Events

Several events over a short time period raised concern as to the integrity of the DSSS and the Utility's system. Table 2 lists the events that triggered the efforts to eliminate the interruptions and minimize their effects.

Associated costs for each of the Utility events have an estimated range of, $5,000.00-$35,000.00. Costs include production losses, wages, broken tooling, lost time for set-up and programming, scrap and other miscellaneous costs. The costs depend on the severity and length of the outage, as well as, the effects to machinery in the Plant. For instance, the August 20, 1996, incident (Table 2) was at the higher end of the range while the April 4, 1997, incident (Table 2) would have been at the lower end. The costs associated with the grinder transient activity ranged from $20,000 - $30,000, for each instance. The majority of the costs were in-board repairs, damaged tooling and set-up.

Table 2 - Chronology of Disruption/Interruption Events

DATE	EVENT	IMPACT
July 29, 1996	Lightning Strike	Momentary Outage: Plant down 20 min., Lights, Machines
August 20. 1996	Squirrel in Primary Yard	Service Disruption, Plt down 4 hr
August 22, 1996	Lightning Strike	Same as July 29
August 22, 1996	Lightning Strike	Same as July 29
August 28, 1996	Squirrel In Primary Yard	Momentary Outage: Plant down 20 min., Lights, Machines
September 5, 1996	Car Pole Accident	Same as August 28
September 7-23, 1996	Possible Transient Activity at grinders	Grinders "losing" cards and tooling
April 4, 1997	Power Interruption, Utility Fire	Lights Flicker, computers and machinery not affected
April 28-June 15, 1997	Possible Transient Activity at second grinder area	"Power Surges" cause loss of cards and tooling...Multiple machines affected
July 2, 1997	Storms & Tornadoes at Utility	No affect to either DSSS site
August 15, 1997	Utility Pole Fire	5 Sags Occur, Only One Sag (20% deep) Affects Plant, Other Sags (88.5%-67.9% deep) do not Affect Plant
August 18-16, 1997	Possible Transient Activity Third Grinder Area	Grinders Losing Cards And Tooling, Primarily Weekends
September 19, 1997	Lightning Strike	Momentary Outage: Lights & Machinery

Although the cause of many of the incidents were beyond our control (i.e. lightning strikes), management was concerned with the effect these events had on production. It seemed like the slightest "bump" raised havoc with the Plant and its machinery. Were the interruptions going to be part of the cost of doing business or could things be done to eliminate or reduce their effects? A reliability team was assembled consisting of personnel from DSSS, GM Worldwide Facilities, the Utility and our power distribution contractor. The team's primary function was to increase the reliability of the power feeding Plant 2.

Actions and Solutions to Increase Reliability

The first area the reliability team looked at was the primary substation. Anomalies in the Plant, such as problems with the grinders, had raised questions as to the integrity of the power provided by the Utility. The grinders, all new

Computer Numerical Controlled (CNC) equipment, seemed to be affected most by the interruptions. This was also the equipment that was purchased to eliminate one of the bottlenecks in the production required to supply our truck and SUV customers. In addition, there was still the question of why we lost complete power during the first squirrel incident (Table 2, Aug. 20). Was there a wiring problem, a relay problem or some other problem and did that problem reside on the DSSS side of the primary substation or the Utility side? Table 3 is a synopsis of the actions taken to increase reliability to Plant 2.

After investigating coordination studies and relay circuits and implementing minor repairs, we found the substation equipment to be functional. We then focused our energies on three major areas: supply voltage, machine voltage specifications and anomalies at the machine level. The most significant repair made, was raising the incoming Utility voltage. The Utility raised their incoming voltage at the primary substation approximately 3.5%. This resulted in approximately a 3.5% increase in-Plant distribution voltage. After some substation adjustments all substations were within 1.5% of nominal (480V) voltage. The individual benefit was that raising the voltage allowed the Plant to "ride through" disturbances that usually took the Plant down. This benefit was highlighted in the events of April 4, July 2 and August 15, 1997 (Table 2). The cost to implement this change was less than, $1,000.00, and has resulted in cost avoidance of several tens of thousands of dollars.

We also determined that, for an industrial facility, we had among the "cleanest" power available. We had several outside contractors, including the Utility, come in to perform bonded ground tests, harmonic tests, transient activity testing and a host of other tests that confirmed that the Plant had an excellent ground system from the substation to the machine level, low harmonic activity, low transient activity, and in general, a strong distribution system.

The second major area we investigated was that of machine equipment specification. The nominal Plant distribution voltage is, 480V. Many of the machine prints we saw during our investigations called out line voltages at, 460V. Complaints of "blown" boards and unexplained downtime were attributed to "bad power". In fact, we found most of those problems to be attributed to specifications that were not consistent with our nominal voltage.

Table 3 - Actions & Solutions to Increase Reliability

Date	Action	Findings	Corrections	Impact
August 29 - 30 1996	Animal mitigation	Animal trespass	Installed Lexan on perimeter fence and poles, Lexan discs installed on service wire and guy wires, 30ft path cleared around perimeter fence, gravel fill	No further animal trespass to date
September 2, 1996	Substation relay testing for 8/20/96 disruption	Relays check OK	None	Need to trace wiring to find cause
September 7-23, 1996	Monitor Anka #2 & #7 grinders	Low voltage condition at grinders; Some transient activity present; Existing suppression not effective (location & lead length)	Suppression installed at each grinder; existing suppression removed;	Transient activity reduced, machine operation acceptable Pursue investigation of Plant low voltage condition

Table 3 - Actions & Solutions to Increase Reliability (Continued)

Date	Action	Findings	Corrections	Impact
September 8, 1996	Investigate Substation relay circuits for 8/20/96 disruption	Plunger on tie-breaker not making full travel causing aux. contacts to remain open. Contact closure activates 67N	Added shim allowing plunger to make full travel; Prints sent to Engineering firm to identify need for auxiliary contact	Directional 67N relays energized to allow proper operation of switchgear in the event of a fault

		relays	block	traveling through a closed tie system
October 6, 1996	Plant voltage raised at Primary Substation	Voltages ranging from 455V - 470V	Raised Utility voltage 3.5%, range 475V - 495V; Taps on 3 xfrms (4A, 6A, 6D) adjusted down	Plant voltage at nominal 480V resulting in higher control voltage
December 3, 1996	System ground testing, Control Voltage testing at E-Mag grinders	2 point bonding tests from Sub to machine floor	System ground excellent, E-Mag control voltage low (98.5V - 107.1V)	Removed ground problems variable, Recommend that plant raise control voltage
December 9-13, 1996	Bus Survey of equipment connections	No significant findings, Anka #2/#7 fed from same sub, different bus, having different transient activity, Transient activity does not travel far from source	Recommend suppression installation, OEM's consulted to upgrade equipment to meet 480V nominal instead of specified 460V	Distribution system is sound
February 12 - March 7, 1997	Monitor secondary voltages at Substation	Lowest recorded voltages at Subs 4A, 6A&D (4.5% below Nom. (480V±10%)	Recommend to Adjust xfrms back to center tap, Operation on 10/6 (Sun.) gave false high reading	All Plant voltage within 2% of nominal
March 3, 1997	Engineering P.O. issued from 9/8 investigation	Aux. contacts not necessary for closed tie system	Remove aux. contacts from control circuit	67N relays will be energized at all times
March 10-13, 1997	Substation power quality analysis	Analysis revealed no significant findings	None	Distribution system is sound
April 13, 1997	Transformer tap adjustments: 4A, 6A&D	Subs @ 4.5% below nominal (480V ±10%)	Adjust xfrms to center tap	Subs 6A&D slightly above nominal, 4A (E-Mags) 0.75% below nominal; All subs less than 1.5% below nominal
April 28 - June 15, 1997	Investigate E-Mag grinder "power surges"	Distribution system sound no "power surges" found, Monitoring revealed problem in control circuit (E-Stop), Wrong Voltage card in power supply	Replace Voltage card, Previous card tolerance at ± 1% instead of ±10%	Grinder operation back to normal, operation no longer a bottleneck

Table 3 - Actions & Solutions to Increase Reliability (Continued)

Date	Action	Findings	Corrections	Impact
May 24-26, 1997	6 yr Substation PM Phase 1	2nd time around less costly due to ongoing PM activities	Breaker testing, Xfrm testing, switch testing	Significant cost reduction from first PM (1/3), Up-time and reliability at near maximum levels
August 18-26, 1997	Investigate power problem at Huffman &	Grinders kicking out during weekends and	Re-tap control transformers at 480v	Grinders operating normally, Board

	Walters grinders	evenings, Primary voltage 475V - 495V, Control voltage too high (prints call for 460V input)	input	repair & tooling costs dropped significantly ($20 - 30,000 per machine), Request to revise machine spec. sent to Controls Eng.
August 22, 1997	Received Eng. changes for substation aux. contacts	Aux. circuit bypassed, circuit left intact for future changes	Rewire aux. circuit during phase 2 PM (July 98')	67N relays directly wired in control circuit avoiding possible failure point

The event of August 18-26, 1997 (Table 3) exemplified that specifications were not consistent with Plant nominal voltages. Complaints of "blown" boards and interruptions at night and weekends were first thought to be due to transient activity. A week of line monitoring found line voltage to be, 475-495V, transient activity to be minimal and no machine interruptions. Print specifications called for input voltage at 460V instead of the nominal 480V. The control transformers for the grinders were re-tapped to accommodate the nominal voltage. This change has enabled the grinders to operate normally and without interruption due to high voltage. The cost of an electrician's time to change the taps resulted in a savings of $20,000 - $30,000, for each machine on board repairs and other associated costs.

Other anomalies at the machine level were also investigated. The Anka grinders (Sept. 7-23, 1996, Table 3) and E-Mag grinders (Apr. 28 - June 15, 1997, Table 3) were two of the more interesting cases. In both instances, claims of poor power quality were causing machine down time, lost tooling and board failures. These failures not only contributed to the slowing of already bottlenecked operations but also to sky rocketing repair costs for board repairs and associated equipment failures. In both instances, as with most of the investigations, a RPM digital meter monitored incoming power, control power and other power points. Transient activity was a problem with the Anka grinders, both self generated transients and transients generated from other machines. The bus system itself was not a factor due to the fact that two of the grinders were on different 800 amp bus, both being supplied by the same 3000 amp bus. This fact also leads to the theory that transients do not travel very far from their source. The bus plugs and connecting points would tend to dampen transients as they traveled. Rather than try to find the source of the transient activity the affected equipment was treated by installing a suppression device. Since the installation of the suppression unit operation has been normal. The cost avoidance of $20,000 - $30,000, for board repairs and associated equipment was eliminated by the installation of a $1,500 suppression device.

The E-Mag grinders were another problem that started out as complaints of "power surges". These "surges" were causing board failures, lost tooling and interrupted production. A RPM digital meter monitored several power points. E-Mag and General Electric (GE) representatives also worked with DSSS personnel. A power problem was the only consideration when the investigation began. Monitor data along with data from the two point bonding tests and the Plant power quality analysis showed that power quality was not a problem and that the problems stemmed from within the machine. After lengthy analysis, with the help of the machine OEM, we found the cause to be at the GE servo power supply. After more investigation, GE found that the power card in the power supply was rated for a, $\pm$ 1% tolerance instead of the +10%/-15% tolerance stated in the literature. This was replaced with the correct card and no other "power problems" have occurred since that time.

What has been interesting about our year-plus of investigations in Plant 2 has been the fact that only one real power quality problem existed, that with the Anka grinders. The most productive changes were the raising of voltage at the Utility entrance and the adherence to correct specifications. In relating these experiences to other Plants in the Corporation, we have found the single most effective change in increasing reliability was getting distribution voltage as close to nominal as possible. Lightning strikes and car-pole accidents are beyond the Plant's control but minimizing their effects were accomplished by this inexpensive adjustment.

As different situations were monitored it was important for us to establish base lines for power quality at the machine (i.e. % distortion, % harmonics, etc.). This means that OEM suppliers must be cognizant of the environment to which their equipment is being installed. Monitor data must be complete and must include both voltage and current data. Without both pieces of data it was difficult to ascertain whether the event seen was an actual anomaly or the start up after the anomaly. Even though there were perceived voltage problems voltage data alone was not enough to see the entire picture.

Finally, the cost to implement the solutions were minimal when compared to the return. A case in point would be the suppression on the Anka grinders. For $1,500, the Plant has avoided costs to repair boards and tooling, and were able to gain more up-time in production schedules. In addition, the Plant is not so quick to name every problem a power quality problem and they do understand that their power quality is very good. This bodes well for a good working relationship and the ability to solve problems more quickly. This is not to say that power problems do not exist or will not exist in the future, but more investigation into machine problems take place before we are called in to solve a problem. When called upon, most repair alternatives have been exhausted and our expertise is required.

Conclusions

There are lessons learned that can be gleaned from this case study. Power quality can be enhanced by simple, inexpensive actions. These actions can reduce downtime, costs and make Plant power more reliable. The following are some of the more significant findings:

- Animal mitigation activity can help increase reliability
- Preventative Maintenance activities can deter problems before they start
- Plant PM activity should include function tests of primary substation relays and protection circuits
- Plant nominal voltage and equipment specification should work together (440V vs. 460V vs. 480V)
- Basic power control and relay logic/wiring may not always be correct
- Control voltages should be checked to specified voltage and tolerances
- System baselines for grounding, harmonics, and transients should be established and checked
- Suppression installation practices are critical (location, lead length)

These activities have helped DSSS Plant 2 improve process reliability by reducing electrical interruptions. Plant production has increased and maintenance costs have been reduced as a result of the work stated within. As a result, Facilities Engineering is now looked upon as a critical resource in helping Delphi Saginaw Steering Systems maintain their goals of providing world class steering systems, driveline systems and steering columns to the world.