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[redacted]
Oneida, NY [redacted]
[redacted]

March 30, 2010

APR - 7 2010

U.S. Department of Transportation
NHTSA
Attn: Associate Administrator for Safety Assurance
1200 New Jersey Ave SE
West building
Washington, DC 20590

Dear Researchers:

I believe I have found the solution to the Toyota unintended acceleration issue.

In 1995, I published an article in Power Magazine (the world's largest trade publication for the electrical generating industry) about 'this issue'. 'This issue' involves high voltage transients (voltage spikes) generated by the collapsing magnetic fields of electromagnetic coils. All modern automobiles have many (10 to 40) electromagnetic coils incorporated into their electrical control system.

It is standard electrical design procedure to 'clamp', 'short out', or use some other means to prevent these high-voltage spikes from damaging sensitive electronic components in a DC control system. Please see the attached report from Tyco, a world leader in automotive relay manufacturing. Tyco clearly illustrates the need to add protective devices to their components to prevent overvoltage damage to nearby semiconductors.

Tyco reports that typical automotive relays can generate up to 1500 V. 1500 V voltage spikes of any duration are damaging to semiconductors. Damage accumulates until failure occurs. During the interval of the damaging period, but before failure occurs, research has shown there is an interim period where semiconductors (especially logic gates) can act unpredictably.

Many automobile manufacturers put some sort of overvoltage protection in parallel with their relays. A good example of this is shown below on the 2007 Buick Lacrosse. In addition to this type of protection, an overvoltage protection device such as a zener diode, I suspect, is added to the output transistor driving the relay inside the Engine Control Module (ECM). This provides double protection. Toyota and some other manufactures on the other hand do not provide an overvoltage protection device in parallel with their relays. A good example of this is shown below on the 2007 Toyota Camry. This strategy may improve relay life but if the ECM grounding point is compromised or the zener diode (or other overvoltage protection device) at the driving transistor fails, the ECM is subject to damaging high voltage transients. This is more like single protection.

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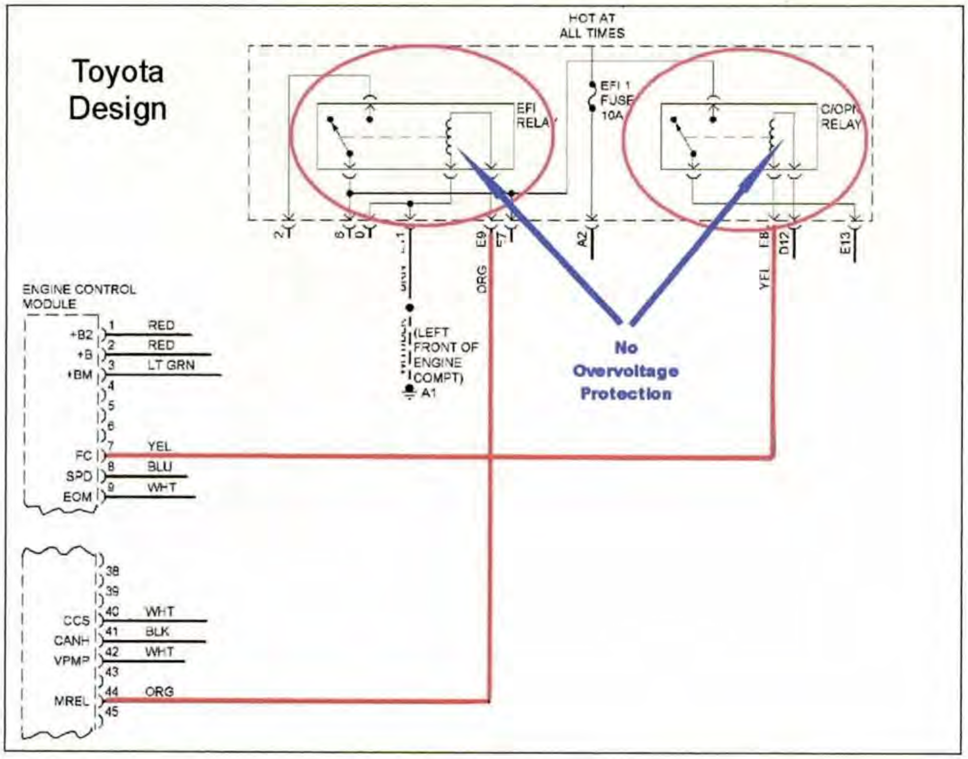
Toyota
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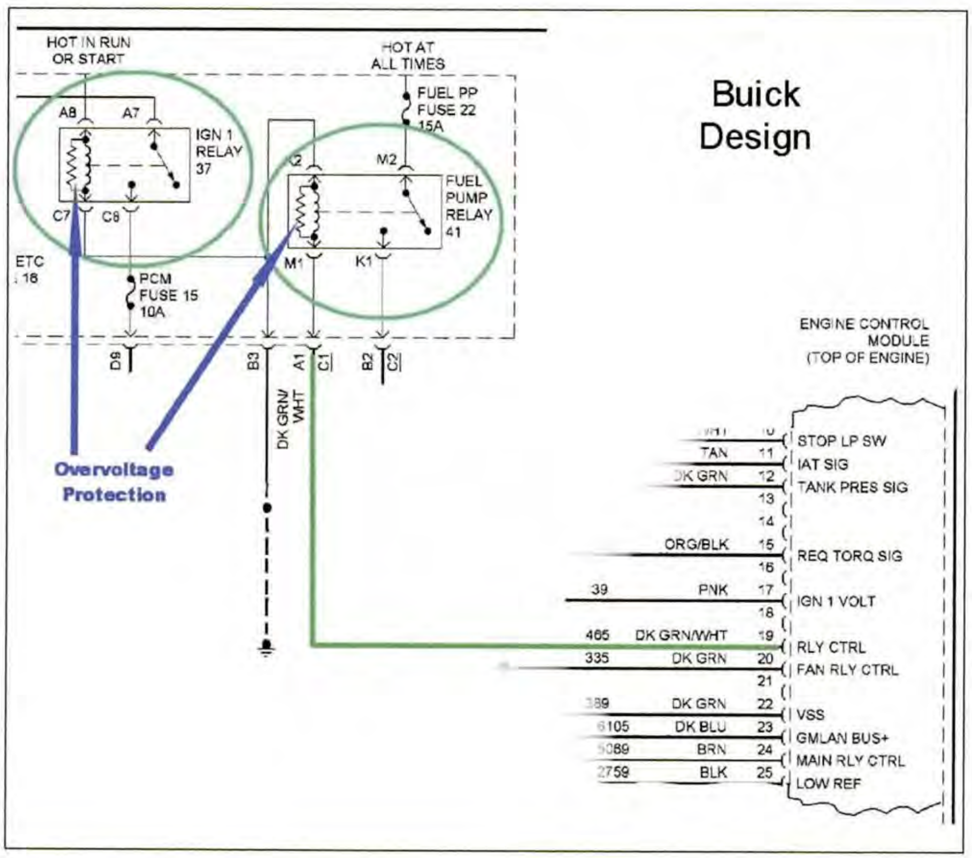
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DK GRN
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Voltage spikes are invisible, non-intuitive, and usually don't cause a component to fail immediately. They are like "sinister ghosts" that strike randomly, accumulating damage in various components. This is why they are so hard to diagnose. A component in one system may fail today and a component in a completely different system may fail next week, all because of one source of voltage spikes. Automobiles have many, many sources of voltage spikes. Exacerbating this problem is the fact that I have not been able to find any reference to checking the validity of the "noise filters" utilized by Toyota in their Service Manuals. My recommendation is that any time a semiconductor component fails or acts unpredictably, part of the troubleshooting procedure should involve checking for voltage spikes and ensuring the validity of noise filters.

I assisted NASA with a similar problem. NASA was having a difficult time with their engine cutoff sensors (ECO) on the Shuttle Discovery back in 2005. This problem went on for over four months and NASA had assigned over 120 engineers to come up with a solution for their intermittent and unpredictable failures. Four hours after I sent them the article I wrote in 1995, they resp[redacted] "we are finding sources of EMI that we didn't previously suspect" and "it looks like [redacted] may have called it". Within days their problem was solved.

I have some ideas on how this can be proved, but the cost to me personally would be prohibitive. I can assist your engineers in this endeavor.

I am a retired power plant maintenance manager, marine engineer by training and have been involved in a power plant business for 15 years before retiring. I was a specialist in troubleshooting difficult electrical control system problems.

Please feel free to give me a call at any time for more information.

Sincerely, [redacted]

Attachments:

Tyco Document
1995 Power Magazine article
Letter to Toyota Management

[redacted]
Oneida, NY [redacted]

February 11, 2010

Yoshimi Inaba
Toyota Motor North America, Inc.
9 W. 57th St.,
Ste. 4900
New York, NY
10019

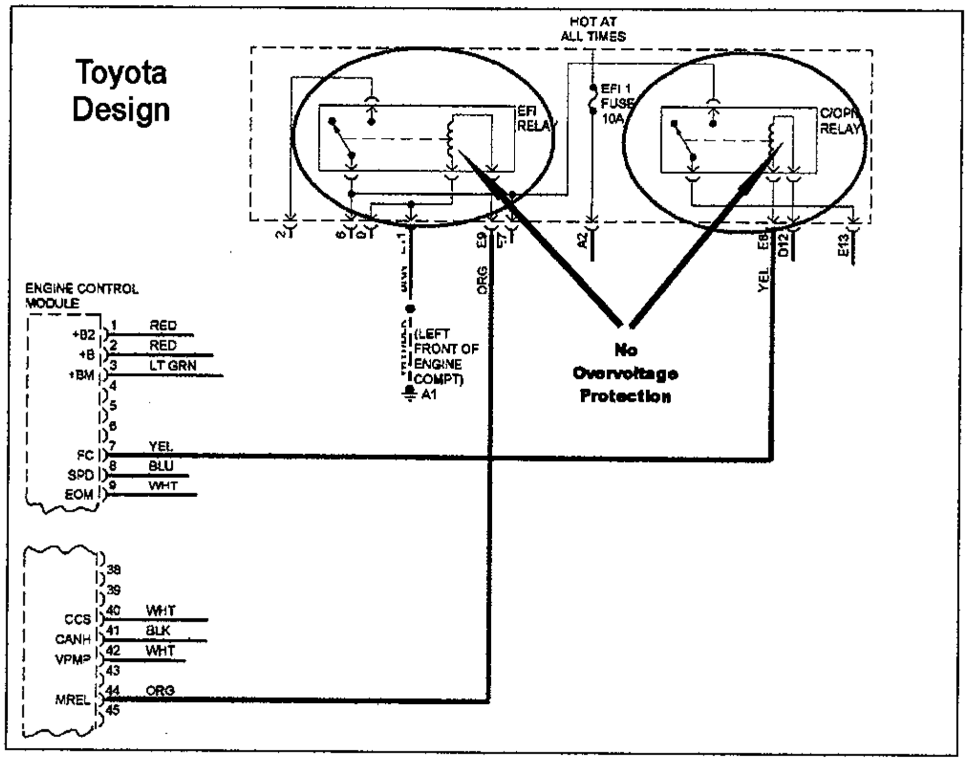
Dear Yoshimi Inaba,

I believe I have found the solution to the unintended acceleration issue.

Relays are a common component found in all modern automobiles. As per the manufacturer Tyco, the world's leader in automotive relay manufacturing, 12 V DC relays need to have some sort of over-voltage suppression due to the "substantial voltage transient" generated upon relay deactivation. Failure to do so can create EMI and semiconductor breakdown. Your engine control modules are comprised of semiconductors. In the interval between a "good semiconductor" and a "bad semiconductor", semiconductors can create an anomalous output. In Toyota's case, the anomalous output could be to open the throttle.

I know what I'm talking about. I authored a feature article in Power Magazine in 1995 titled "Finding, curing dangerous voltage spikes boosts reliability". I also assisted NASA in 2005 in solving their engine cut off sensor (ECO) problem, which by the way, was a problem that had stumped them for nearly 4 months and had cost millions of dollars, and at one point had over 120 engineers working on it. NASA's problem was related to the same phenomenon that now challenges Toyota; extremely short duration, extremely high voltage transients.

To illustrate my point, please notice the comparison in system design philosophy when it comes to relays and voltage transient suppression between a Toyota and a Buick.


Toyota Design
HOT AT ALL TIMES
EFI RELAY
EFI 1 FUSE 10A
C/OPN RELAY
ENGINE CONTROL MODULE
+B2
+B
+BM
FC
SPD
EOM
RED
RED
LT GRN
YEL
BLU
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(LEFT FRONT OF ENGINE COMPT)
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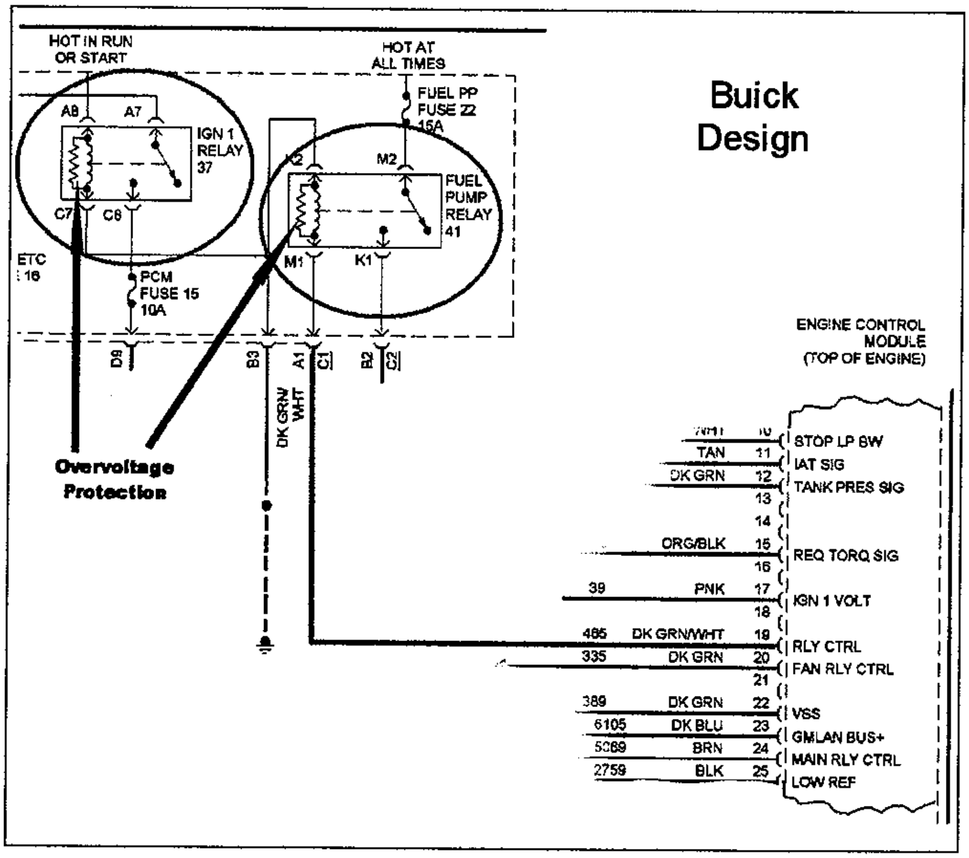

HOT IN RUN OR START
HOT AT ALL TIMES
FUEL PP FUSE Z2 15A
Buick Design
IGN 1 RELAY 37
FUEL PUMP RELAY 41
PCM FUSE 15 10A
ENGINE CONTROL MODULE (TOP OF ENGINE)
Overvoltage Protection
DK GRN/WHT
STOP LP SW
IAT SIG
TANK PRES SIG
REQ TORQ SIG
IGN 1 VOLT
RLY CTRL
FAN RLY CTRL
VSS
GMLAN BUS+
MAIN RLY CTRL
LOW REF
TAN
DK GRN
ORG/BLK
PNK
DK GRN/WHT
DK GRN
DK GRN
DK BLU
BRN
BLK

I am extremely concerned about this, for not only the general public but my daughter, 18 years of age and attending college. My daughter recently purchased a 2003 Toyota Matrix. She has been experiencing random dashboard light activity. I have reviewed the wiring diagrams and her dashboard lights are controlled by the "Integration Relay" or otherwise known as the "Body Control Module". It appears that the lack of relay over-voltage suppression on any of the relays in her Matrix has caused damage to her Integration Relay. There is no way of telling how much damage has been done to her engine control module. I fear that her car is a good candidate for unintended acceleration.

I write to you as a public service and as a friend of Toyota. I not only own a Toyota, but everyone in my large family either owns a Toyota or Lexus (by my recommendation). I do not want to see Toyota punished or run out of business. I want you to explain to me how Toyota engineers have found some other way (not shown on your wiring diagrams) to address relay over-voltage transients and/or add relay related over-voltage suppression in future models and address what to do for Toyotas already on the road.

I trust that you will act quickly, research and resolve this issue.

I have attached the document from Tyco addressing the need for relay suppression.

Respectfully,

[redacted]

The application of relay coil suppression with DC relays

This application note has been written in response to the numerous application problems resulting from improper relay coil suppression. The typical symptom is random "tack" welding of the normally-open contacts when switching an inductive load or a lamp load with high inrush current.

The Need for Transient Suppression
When an electromechanical relay is de-energized rapidly by a mecanical switch or semiconductor, the collapsing magnetic field produces a substantial voltage transient in its effort to disperse the stored energy and oppose the sudden change of current flow. A 12VDC relay, for example, may generate a voltage of 1,000 to 1,500 volts during turn-off. With the advent of modern electronic systems, this relatively large voltage transient has created EMI, semiconductor breakdown, and switch wear problems for the design engineer. It has thus become common practice to suppress relay coils with other components which limit the peak voltage to a much smaller level.

Types of Transient Suppression Utilized with Relays
The basic techniques for suppression of transient voltages from relay coils are shown in Figure 1. As observed here, the suppression device may be in parallel with the relay coil or in parallel with the switch used to control the relay. It is normally preferred to have the suppression parallel to the coil since it can be located closer to the relay (except in the case of PC board applications where either may be used).

When the suppression is in parallel with the relay coil, any of the following may be used.

A. A bilateral transient suppressor diode that is similar in V-I characteristics to two zener diodes connected cathode to cathode (or anode to anode).

B. A reverse-biased rectifier diode in series with a zener diode such that their anodes (or cathodes) are common and the rectifier prevents normal current flow.

C. A metal-oxide-varistor (MOV).

D. A reversed-biased rectifier diode in series with a resistor.

E. A resistor, when conditions permit its use, is often the most economical suppression.

F. A reversed-biased rectifier diode.

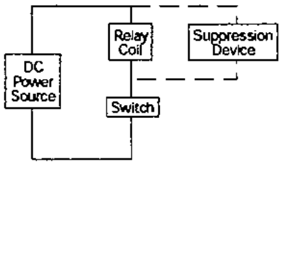
G. A resistor-capacitor "snubber". Generally the least economical solution and no longer considered a practical solution.

H. A bifilar wound coil with the second winding used as the suppression device. This is not very practical since it adds significant cost and size to the relay.

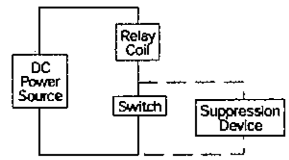
Suppression used in parallel with the switching element is likely to be either a zener diode or a resistor-capacitor "snubber". The comments associated with the "parallel to coil" application are also applicable to this circuit.

Figure 1 - Schematic for Relay Coil Suppression

Suppressor Parallel to Coil



Suppressor Parallel to Switch



Effects of Coil Suppression on Relay Dynamics and Life
Even though the use of coil suppression is becoming more significant, relays are normally designed without taking the dynamic impact of suppressors into account. The optimum switching life (for normally-open contacts) is therefore obtained with a totally unsuppressed relay and statements of rated electrical life are usually based on this premise. The successful "breaking" of a DC load requires that the relay contacts move to open with a reasonably high speed.

A typical relay will have an accelerating motion of its armature toward the unenergized rest position during drop-out. The velocity of the armature at the instant of contact opening will play a significant role in the relay's ability to avoid "tack welding" by providing adequate force to break any light welds made during the "make" of a high current resistive load (or one with a high in-rush current). It is the velocity of the armature that is most affected by coil suppression. If the suppressor provides a conducting path, thus allowing the stored energy in the relay's magnetic circuit to decay slowly, the armature motion will be retarded and the armature may even temporarily reverse direction. The reversing of direction and re-closing of the contacts (particularly when combined with inductive loads) often leads to random, intermittent "tack welding" of the contacts such that the relay may free itself if operated again or even jarred slightly.

Based upon the impact on armature motion and optimizing for normally-open contacts, the best suppression method is to use a silicon transient suppressor diode. This suppressor will have the least effect on relay drop-out dynamics since the relay transient will be allowed to go to a predetermined voltage level and then permit current to flow with a low impedance. This results in the stored energy being quickly dissipated by the suppressor. Transient suppressor diodes are available as bi-directional components and permit the relay to be non-polarized when installed internally. Note that if a uni-directional transient suppressor is used, a rectifier diode must be placed in series with it to block normal current flow and it has little advantage over the use of a zener diode. The transient suppressor should be selected such that its pulse energy rating exceeds any anticipated transient such as coil turn-off or motor "noise" found in the application.

A metal-oxide-varistor will provide results similar to those of transient suppressor diode, but will have a higher "on-state" impedance and will thus allow a higher voltage to be developed. As an example, a 33 volt transient suppressor diode may have a "clamping" voltage between 30 and 36 volts. In comparison, a 33 volt MOV will likely clamp the relay at 45 to 55 volts (based on a typical automotive relay with 130 mA coil current). When the additional voltage is no problem, an MOV may save cost over the transient suppressor diode and will also provide a non-polarized relay.

The use of a reversed-biased rectifier diode in series with a zener diode will provide the best solution when the relay can be polarized. This suppression is often recommended by Siemens Electromechanical Components (SEC) for use in automotive circuits. The impact on release dynamics is minimal and poses no loss of reliability. This is normally a low-cost method and the only design precaution is to select a zener with an appropriate breakdown voltage and impulse power specifications adequate for the relay in its application. In printed circuit board applications with transistors used as relay drivers, the zener diode can be placed "across" the transistor; that is, for a common emitter circuit, cathode connected to collector and anode connected to the emitter (the series rectifier diode is not used in this type of circuit).

A reversed-biased rectifier in series with a resistor may be used successfully with some relays when maximum load switching capacity is not required. Care must be taken to use a resistor large enough in value to quickly dissipate the relay's stored energy but yet stay within the desired peak voltage transient. The required resistor value may be approximated from the following equation:

$$R = V_{peak}/I_{coil}$$

where;

R = resistor value in Ohms
V_{peak} = peak transient voltage permitted
I_{coil} = steady-state relay coil current

The actual voltage peak observed will be lower than calculated by this formula due to energy losses in the resistor. When using this type of suppression it is best to consult the relay manufacturer for recommended values.

A resistor may also be used by itself as a transient suppressor when the additional power dissipation and resulting heat generated by the resistor can be tolerated. In most situations, this will provide the least expensive suppression method (assuming the resistor value can be properly sized to minimize its impact on relay performance). This method is normally recommended by SEC when the application requirements permit.

Many engineers use a rectifier diode alone to provide the transient suppression for relay coils. While this is cost effective and fully eliminates the transient voltage, its impact on relay performance can be devastating. Problems of unexplained, random "tack welding" frequently occur in these systems. In some applications, this problem is merely a minor nuisance or inconvenience and the controller or operator will cycle the relay until the proper response is obtained. In many applications; however, the first occurrence may cause a complete system failure or even present a hazardous situation. It is important that these systems be designed with another method of relay suppression.

To illustrate the impact of various coil suppression on the relay response time, consider the following data that was recorded using an automotive ISO type relay with a 55 ohm coil and with 13.5VDC applied to the coil.

Suppression Technique	Drop-out Time (ms)	Theoretical Transient	Recorded Transient
Unsuppressed	1.5		-750
Diode & 24V Zener	1.9	-24.8	-25
680Ω Resistor	2.3	-167	-120
470Ω Resistor	2.8	-115	-74
330Ω Resistor	3.2	-81	-61
220Ω Resistor	3.7	-54	-41
100Ω Resistor	5.5	-24.6	-22
82Ω Resistor	6.1	-20.1	-17
Diode	9.8	-0.8	-0.7

Suggested Methods for Relay Coil Suppression

From the standpoint of physics, the suggested technique for relay coil transient suppression is to use a reversed-biased rectifier diode and series zener diode in parallel with the relay coil. This permits the relay to have optimum release dynamics and normally-open contact life. Such suppression may be incorporated easily into the circuitry for printed circuit board relays; however, when specifying suppression for a socket-mounted relay, this method may be less practical than using a resistor.

When the permissible transient voltage is large enough and power dissipation tolerable, the relay may be suppressed with a resistor. From the standpoint of a Failure Mode and Effects Analysis (FMEA), the resistor will provide less added risk of failure than the two diodes suggested above (provided that its value is high enough to avoid detrimental effects to the relay's release dynamics). It must be noted that the optimum resistor value for one type of relay will not necessarily be the right value for another type.

Now that we have provided suggested suppression techniques based on normally-open contact performance, we must add a qualifying comment concerning the normally-closed contacts. When the primary load is on the normally-closed contacts (and a small load or none on the normally-open), it may be desirable to use a rectifier diode alone as the relay suppression (or perhaps a rectifier diode and a lower value of series resistor). The retarded armature motion that adversely impacts normally-open contact performance will typically improve normally-closed contact performance. The improvement results from less contact bounce during closure of the normally-closed contacts. This results from the lower impact velocity created by the retarded armature motion and has been utilized in the past to improve normally-closed contact performance on certain relays.

Finding, curing dangerous voltage spikes boosts reliability

Inductive voltage spikes left unchecked in a control system can spell high maintenance costs and chronic system failures. Powerful diagnostic tools can help pinpoint the causes

By [redacted], Sithe Energies Inc, Sterling Energy Facility

In today's quest for ever-increasing performance and profitability, yesterday's reactive maintenance approach is not good enough. Predictive maintenance (PDM) is called for, especially the proactive testing of powerplant control systems containing direct-current (dc) relays and solenoids (see box below).

If the relays or solenoids are not protected properly, voltage spikes may damage the control system—damage that is cumulative over time and very difficult to diagnose once it has occurred (see box, p 50). Yet, the cost of the diagnostic equipment is small compared to the damage these high-voltage spikes can wreak. Routine testing can increase reliability and save money.

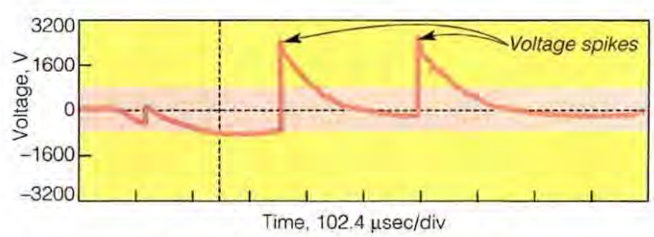
Examples from the field. During a 1993 outage at the Sterling Energy Facility (SEF, see box, p 50), maintenance personnel discovered a high-voltage spike on a steam-turbine admission/extraction-valve trip coil. When the 125-V-dc coil was de-energized during a test after plant shutdown, a 2895-V spike was shown to originate at the coil and pass through the system (Fig 1). Further inspection revealed that no shunt had been installed on the coil. (This omission was determined to be the root cause of an earlier failure of a steam-turbine governor circuit board.) A metal oxide varistor (MOV) type of shunt was installed. The test was repeated, which then showed a satisfactory result—a spike of less than 300 V.

In another example, while performing a voltage stability test on a gas turbine's 125-V-dc control-system bus, a voltage spike greater than 1600 V was detected. This spike was generated by the collapsing magnetic field in the windings of an emergency 10-hp (dc) lube-oil pump motor (Fig 2). It impressed a measured 834-V spike on the main power-supply bus feeding critical computer systems, even though this bus was protected by a nearby MOV and suppressor assembly.

The 1600-V spike at the motor is detrimental to motor winding life, while the 834-V spike on the control-system bus far exceeds manufacturer recommendations. SEF personnel installed MOV at the motor contactor. Subsequent tests indicated that the spike was reduced to 279 V.

Enter the technician, properly equipped. The foregoing case histories required qualified technicians and leading-edge instruments to track down voltage spikes. A top technician treats every failure with extreme skepticism, always suspecting an underlying cause of failure. Heat, vibration, rapid thermal changes, and voltage instability (including spikes) are typical causes of component failure.

The technician working with a set of basic tools—plus accurate schematics and wiring diagrams—can make intelligent deductions. Basic tools include



1. High-voltage spikes reach 2895 V on a steam-turbine admission/extraction-valve trip coil (above)

2. Technician tests an emergency dc lube-oil pump motor on a gas turbine (right)

Dc relays, solenoids are common powerplant control devices

Powerplant control systems often use relays and solenoids for equipment control. Relays see service for ladder-logic building, controlling a large current with a small control signal, circuit isolation, and physically opening or closing an alarm or trip circuit. A majority of these relay systems rely on dc electrical power.

Dc power is commonly selected for several reasons: (1) It is easier to use with battery backup systems; (2) solid-state digital-control circuits often rely on dc; (3) several types of sensors and feedback devices work best with dc; and (4) dc relays have better operating characteristics. It is not uncommon for a gas turbine, steam turbine, large refrigeration machine, or other highly controlled industrial equipment to have up to 100 dc relays in their control systems.

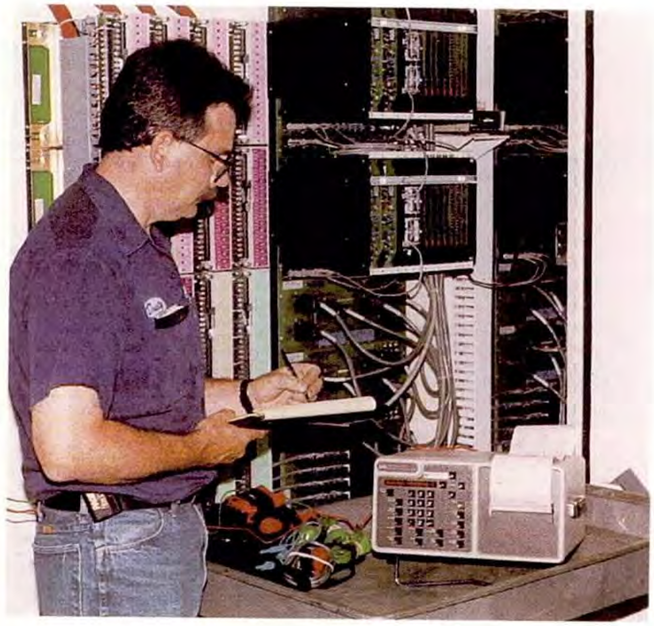
All dc relays and solenoids must have high-voltage shunts, clamps, or suppressors installed in parallel with the relay or solenoid to prevent extremely high voltage spikes (transients) from damaging the control system, which includes solid-state components, wiring insulation, and the relay and solenoid coils themselves.

Voltage spikes and the damage they can cause

Voltage transients or spikes are primarily caused by switching disturbances—the source usually being the stored energy in the inductive components of the system. When a dc coil is energized, it stores energy in the form of a magnetic field surrounding the coil. When de-energized, this field collapses, inducing a voltage transient. This voltage is much higher than the original energizing voltage, often thousands of volts. It is impressed on all wiring and components from the coil and the point of circuit opening through the remainder of the circuit.

The high-voltage spike actually jumps across the switch while it is opening, not only damaging the switch but momentarily impressing its extremely high voltage on the entire circuit. Altogether, high coil-induced voltage transients can cause arcing and burning of relay and switch contacts, insulation damage, and damage to the originating coil itself. All solid-state and especially the newer electronic components are extremely susceptible to high-voltage transients.

Many times, the damage sustained by an electronic component is not instantly fatal. More commonly, the damage is cumulative, causing failure after many high-voltage "hits." This characteristic makes the problem difficult to diagnose and is subsequently overlooked for the type of problem it really is.



3. Power-disturbance analyzer (on bench) is a diagnostic instrument for finding voltage spikes—besides other applications

the volt/milliamp meter and the oscilloscope. More sophisticated tools for speedy diagnosis of obscure problems include the infrared camera, harmonic-distortion and power-factor analyzers, and the power-disturbance analyzer. The latter is of special interest, since it helped pinpoint the SEF voltage spikes noted above.

Power-disturbance analyzer. This powerful diagnostic instrument has several applications (Fig 3). In addition to finding voltage transients, it can detect intermittent loose wires. If the analyzer is a multiple-channel type, it can also act as a portable "first-out" panel.

The typical power-disturbance analyzer has what is called a pre-trigger or dynamic ram feature. Signal information is continuously stored in memory for a specific period of time. This enables the unit to print out what happened just before, during, and after the trigger event or voltage disturbance. Input impedance is very high and response time is in the millisecond range, enabling precise readings.

Trigger points are set to activate a printout. Voltage transients can be automatically applied across a resistance to derive the voltage spike's energy. When a problem is found, this information can be useful for indicating the size of the clamp needed. Typically, a trigger level of 600 or 800 V for a 125-V-dc relay is applied. This voltage level is too high to produce a printout of every relay opening caused by electrical "noise," but not too high to detect an unclamped relay's inductive voltage spike.

A typical test period using the analyzer is during shutdown and startup of equipment. In addition, scheduling protective circuit checks will enhance system reliability.

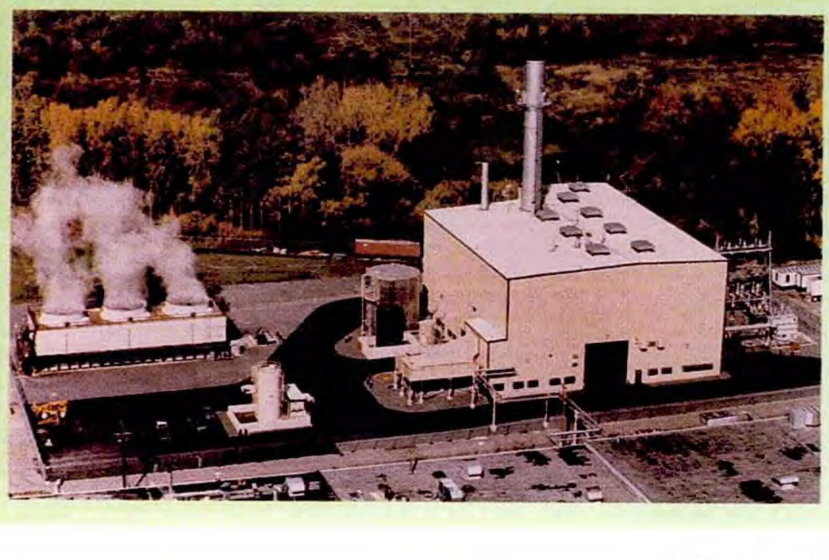
Analyzer as PDM tool. As noted, SEF has used a power disturbance analyzer to detect several electrical and electronic faults before total failure was experienced, which has increased plant reliability. In fact, routine testing with the analyzer has been added to the PDM program at Sterling. The program is composed of a data base listing all the plant's dc relays, solenoids, and pumps, including their terminal numbers and locations. Also included in the data base is "when to test" information. This provides a quick and simple procedure to check for voltage spikes during plant shutdowns and startups.

Edited by Tom Elliott

Cogeneration plant has record of high availability

Sterling Energy Facility, Sherrill, NY (photo), began commercial operation in 1991. Owned and operated by Sithe Energies Inc, New York, NY, this cogeneration plant has a General Electric Co (Schenectady, NY) Frame 6 42-MW gas turbine and 16.5-MW steam turbine, a Zurn Industries Inc (Erie, Pa) heat-recovery steam generator, and a Leeds & Northrup Co (North Wales, Pa) distributed control system.

For its first three years in operation, the facility has logged a cumulative total availability in excess of 98%, including all outages and shutdowns (scheduled and nonscheduled). Reliability for this period has exceeded 99.8%. There have been zero lost-time accidents by plant or contractor personnel since the 1991 plant commissioning.



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