ANALYSIS OF SEL-100/200 SERIES RELAYS' YEAR END ROLLOVER OPERATION

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OVERVIEW

This paper addresses the issues surrounding Y2K and SEL-100/200 series relays. General SEL relay operation is discussed and the relay software clock is described in addition to the usage of EEPROM for storage of relay settings and maintaining year information. From this several scenarios involving year rollover and relay operation are outlined. Finally fault tree analysis is used to evaluate the unavailability of the protective relay for several options that are proposed for Y2K concerns.

GENERAL RELAY OPERATION

SEL-100/200 series relays operate on a periodic interrupt. During each interrupt the relay evaluates its protection algorithms using measured system currents and voltages to determine if an abnormality is present on the power system. If an abnormality exists, the relay initiates protection operations based on user customized settings (CTR, 51P, etc.). The relay settings are optimized by each user to match the relay to their system. The SEL-100/200 relays store settings in non-volatile EEPROM memory so that they are retained during a power loss.

RELAY SOFTWARE CLOCK OPERATION

All SEL relays use an internal software clock. The software clock in the relay is updated on the same interrupt schedule as the protection algorithms, every ¼ cycle. The software clock in 100/200 series relays is only active while the relay is powered; therefore the relay loses its date and time if there is a loss of power. Because of this loss of date and time information upon loss of power, as well as a need to maintain correct time-stamped data in the protective relay, many users connect a demodulated IRIG-B time code source to the relay. The relay automatically re-synchronizes its internal clock to the IRIG-B time code every few minutes. A limitation of IRIG-B time code is that it does not contain year information. Because of this limitation of IRIG-B time code, SEL modified most of its 100/200 series relays to save the year to EEPROM on midnight of New Year's so a loss of power would not require the user to set the date in the relay even if attached to an IRIG-B time code source.

DESCRIPTION OF THE 12-CYCLE DISABLE

From the above discussion the relay stores both the protection settings and the clock year in EEPROM. EEPROM, like most memory chips, only allows one access at a time, so the memory cannot be read and written to at he same time. This means that while the relay reads settings associated with its primary function of power system protection, the system clock cannot write the year to the EEPROM. The reverse is also true: when the system clock is writing the year to EEPROM, the protection algorithms cannot read the settings from EEPROM.

In order to prevent relay misoperation and a read/write conflict when writing a value to the EEPROM, the relay must disable the protection functions until the write is complete. This can be seen following modification of relay settings. While the relay is saving the settings, the relay disables itself and closes its alarm output contact. The amount of time the relay disables itself depends on the amount of data written to the EEPROM plus additional operations that the relay may be doing.

In an identical fashion, the system clock writes the year to EEPROM just after midnight on New Year's Eve each year. While performing this write, the relay disables itself for exactly 12 cycles. This operation can be seen in most 100/200 series devices except the BFR/2BFR and the 151/251.

HOW THE 12-CYCLE DISABLE AFFECTS PROTECTION

The 12-cycle disable causes the relay to suspend nearly all operations. This suspension affects relay protection tripping times assuming that the relay is called on to operate due to a system fault on or near midnight New Year's Eve. For ease of explanation, consider a relay with an overcurrent condition timing towards a trip with a trip time setting of 25 cycles. Consider four possible scenarios:

1. The relay detects the overcurrent condition greater than 25 cycles prior to midnight. The disable occurs following the trip and therefore has no impact, so the total trip time is 25 cycles.

2. The relay detects the overcurrent condition less than 25 cycles prior to midnight and the relay disables before the trip. This causes the trip to be delayed by 12 cycles, for a total trip time of 37 cycles.

3. The relay is disabled when the overcurrent condition occurs. The relay detects the overcurrent condition following the 12-cycle disable and times to trip. The trip time is increased between 0 and 12 cycles depending on when the fault is applied relative to the start of the disable time. Total trip time is between 25 and 37 cycles.

4. The overcurrent condition occurs immediately following the 12-cycle disable. The disable has no impact on the trip so the total trip time is 25 cycles.

Another Y2K question involves the 100/200 series relay calculated memory voltage. The memory voltage is used to maintain phase distance element directional polarization for zero voltage three-phase faults. Because the relay disables for *exactly* 12 cycles and the voltage sampling begins at the same relative system angle or point on wave, the memory voltage maintains correct directional polarization. If a fault happens during the 12-cycle window, the relay will behave the same as a switch-on-to-fault condition.

FAULT TREE ANALYSIS

An analysis of the relay unavailability was performed using the fault tree method (refer to the appendix). The fault tree method allows an engineer to evaluate the possible problems that could cause the system to be unavailable to the user. The unavailability due to different problems can be combined to find the overall unavailability for the system.

In the analysis of the 100/200 series SEL relays, we considered the following possible causes for relay unavailability.

Relay Failure – The relay fails and it reported to the user via the ALARM contact.

Year Write Once per Year – The relay is disabled while the relay is writing the year to EEPROM. This situation is considered over the course of one year because the relay only writes to EEPROM at midnight on New Year's Eve.

Year Write around Midnight – The relay is disabled while the relay is writing the year to EEPROM. This situation is considered over the one minute around midnight because there is higher concern that more problems may arise on the system at this time.

Firmware Replace – The relay is unavailable while the firmware is being upgraded.

In addition to the difference in the EEPROM writes mentioned above, five different scenarios are considered:

1. Both primary and backup are 100/200 series and are synchronized to IRIG.
2. Primary relay synchronized to IRIG and Backup relay offset by greater than 2 minutes.
3. Neither relay synchronized to IRIG.
4. Replace firmware in both relays so they do not save the year. It is assumed that this will not be done during the one minute around midnight, so the unavailability due to replacing the firmware is not included in this calculation.
5. Replace firmware in both relays so they save the year at an offset time after midnight. It is assumed that this will not be done during the one minute around midnight, so the unavailability due to replacing the firmware is not included in this calculation.

Details of the analysis are in the appendix. The main item to consider in the table below is the relative difference in the unavailability for each scenario. The larger the number, the greater the unavailability of the system. All numbers are normalized to an exponential factor of 10^{-8} to make the comparison easier.

Relay Unavailability (10^{-8})	Primary and backup synchronized	Primary with IRIG, backup offset by more than 2 minutes	Neither relay synchronized to IRIG	Replace firmware to remove write to EEPROM	Replace firmware to offset write to EEPROM
One minute spanning midnight	333333	12	0.1	0.1	0.1
Any one minute during the year	0.1	0.1	0.1	1	1

Items to consider about the table:

a. The relay disable at midnight is a significant factor if we are only considering the one minute around midnight on New Year's Eve and the relays are synchronized to an IRIG source.

b. Simply offsetting the time of the backup relay greatly improves the unavailability.

c. Replacing the firmware does not improve the unavailability over simply not having the relays synchronized to each other.

d. Over the course of one year, the unavailability is actually worse when replacing the firmware than even having the relays synchronized.

SUMMARY

This paper has presented the internal workings of the SEL-100/200 series relays and how the EEPROM usage and the year rollover affect protection. It was written to help each customer make a well-informed decision regarding whether any action is necessary for year-end rollover, and, if so, the appropriate action. If any action is taken, it should be individually tailored to each power system protection application.

DEFINITION OF TERMS

100/200 Series Device – Family of SEL relays. The devices that differ only in the first digit (e.g., 121G and 221G) share firmware but use different hardware platforms.

Cycle – One hertz or a single power system cycle. For a 60 Hz system this amounts to 1/60th of a second or 16.7 milliseconds.

Disable – State of a device when it not available to perform its regular functions.

EEPROM – Electrically erasable memory chip. These chips can be read from and written to many times while in the circuit. EEPROM chips retain their memory when external power is removed.

Embedded System – An intelligent electronic device that is self-contained. As a minimum, the device includes a microprocessor, memory, and the system program. Examples of embedded systems are protective relays, copiers, and remote controls.

Firmware – Software used in an embedded device. Typically, firmware is stored in memory chips and upgrades to firmware require changing the memory chips.

Interrupt – Input signal to a microprocessor causes the current program to halt and start another task. An example is the reset button on a PC. Pressing the reset button interrupts the current operation and causes the PC to run the initialization code.

Non-Volatile – Device that retains its memory when power is removed.

Protection Algorithms – Software functions that run each interrupt in a relay.

Task – A logical grouping of software functions. A system typically contains several tasks.

APPENDIX: FAULT TREE ANALYSIS

To understand fault trees and unavailability analysis, consider the following calculator example.

Possible calculator failures: bad key or bad display.
Assume each failure has an unavailability factor of 0.01.

Either the key (0.01) OR the display (0.01) can cause the calculator to fail and thus make the calculator unavailable for the user. An OR function adds the unavailability for the two failures together for a total unavailability of 0.02.

Now suppose you have a backup calculator. Then you must experience at least one failure in the primary calculator (0.02) AND at least one failure in the backup calculator (0.02).   An AND function multiplies the unavailability for the two calculators for a total unavailability of 0.0004. The unavailability of the calculator due to a failure is small and the unavailability due to a failure occurring in both calculators at the same time is significantly smaller.

In the fault tree analysis we considered the following possible causes that could make the relay unavailable:

a. Relay is disabled while writing the year to EEPROM. This is evaluated over the course of a year.

b. Relay is disabled while writing the year to EEPROM. This is evaluated over the one minute at midnight on New Year's Eve.

c. Relay has failed.

d. Relay is out of service during the firmware upgrade process. We used one hour for the out-of-service time. We also assumed that the upgrade would not be done during the one minute at midnight on New Year's Eve.

In calculating the unavailability, we used the following process:

a. Define a time period of interest. For example 0.2 seconds/years for the EEPROM write, or in the case of the relay failure the unavailability is 2 days/150 years because it generally takes 2 days to repair a relay and we are using a mean time to failure of 150 years.

b. Convert the number described in step a into a unitless number. Simply canceling units does this.

$$\frac{0.2\ \text{sec}}{\text{year}} \cdot \frac{1\ \text{year}}{31536000\ \text{sec}} = 6 \cdot 10^{-9}$$

$$\frac{2\ \text{days}}{150\ \text{year}} \cdot \frac{1\ \text{year}}{365\ \text{days}} = 3.5 \cdot 10^{-5}$$

c. Apply a consistent exponent magnitude to the number. This is done to make comparisons easier. For this paper we will use 10^{-8}.

Scenarios used in the analysis:

1. Both primary and backup are 100/200 series and are synchronized to IRIG.
2. Primary relay synchronized to IRIG and backup relay offset by greater than 2 minutes.
3. Neither relay synchronized to IRIG.
4. Replace code in both relays, do not save the year.
5. Replace code in both relays, save year at offset time after midnight.

As mentioned above, we investigated the scenarios at any random minute in a year, and at the one minute spanning midnight.

The calculations below show the unavailability for each situation. These are the values used in the table at the end of the appendix. Each unavailability is converted to a unitless number so that we can perform the multiplication and addition calculations from the fault tree analysis.

$$W1 = \frac{0.2\ \text{sec}}{1.0\ \text{min}} = 333333 \cdot 10^{-8}$$

$$W2 = \frac{0.2\ \text{sec}}{1.0\ \text{year}} = 0.6 \cdot 10^{-8}$$

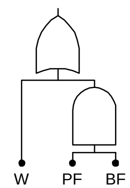
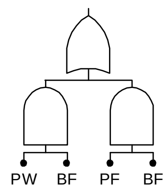
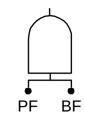
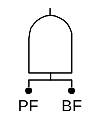
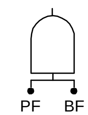
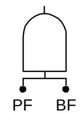
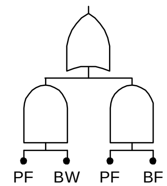
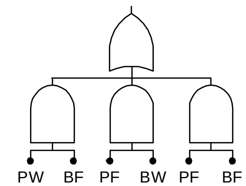
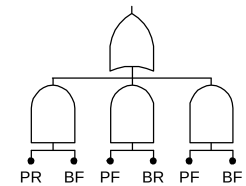
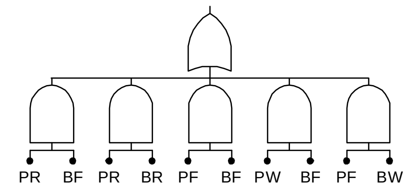
$$R = \frac{1.0\ \text{hour}}{1.0\ \text{year}} = 11400 \cdot 10^{-8}$$

$$F = \frac{\text{MTTR}}{\text{MTBF}} = \frac{2\ \text{days}}{150\ \text{years}} = 3600 \cdot 10^{-8}$$

Legend

P – Primary
B – Backup

F – Failure of Relay
W – Write to EEPROM
R – Replace Firmware

	Both primary and backup sync to IRIG.	**Primary relay sync to IRIG, backup relay offset at > 2 minuets.**	**Neither relay sync to IRIG offset > 2 minutes.**	**Replace code in both relays. Do not save year.**	**Replace code in both relays. Save year at offset time after midnight.**
Unavailability during minute spanning midnight.					
$W = 333{,}333\cdot 10^{-8}$ $F = 3600\cdot 10^{-8}$	W + (PF)(BF) $= 333{,}333\cdot 10^{-8}$ $20{,}000{,}000\cdot 10^{-8}$ sec/min	(PW)(BF) + (PF)(BF) $= 12\cdot 10^{-8}$ $= 720\cdot 10^{-8}$ sec/min	(PF)(BF) $= 0.1\cdot 10^{-8}$ $= 6\cdot 10^{-8}$ sec/min	(PF)(BF) $= 0.1\cdot 10^{-8}$ $= 6\cdot 10^{-8}$ sec/min	(PF)(BF) $= 0.1\cdot 10^{-8}$ $= 6\cdot 10^{-8}$ sec/min
Unavailability during a year of any random minute					
$W = 0.6\cdot 10^{-8}$ $F = 3600\cdot 10^{-8}$ $R = 11400\cdot 10^{-8}$	(PF)(BF) $= 0.1\cdot 10^{-8}$ $= 6\cdot 10^{-8}$ sec/min	(PF)(BW) + (PF)(BF $= 0.1\cdot 10^{-8}$ $= 6\cdot 10^{-8}$ sec/min	(PW)(BF) + (PF)(BW) + (PF)(BF) $= 0.1\cdot 10^{-8}$ $= 6\cdot 10^{-8}$ sec/min	(PR)(BF) + (PF)(BR) + (PF)(BF) $= 1\cdot 10^{-8}$ $= 60\cdot 10^{-8}$ sec/min	(PR)(BF) + (PF)(BR) + (PF)(BF) + (PW)(BF) + (PF)(BW) $= 1\cdot 10^{-8}$ $= 60\cdot 10^{-8}$ sec/min

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