Improve Facility SIS Performance and Reliability

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"Solenoid Configurations: Selecting the Best Architecture for Your Application," ISA Tech99, ISA, Philadelphia, Pennsylvania, October 1999.
"Selecting the Best Solenoid Architecture for Your Application," Process Plant Reliability Symposium, Houston, Texas, October 1999.
"Improve Facility SIS Performance and Reliability," Hydrocarbon Processing, October 2002.

The safety instrumented system (SIS) standards, ANSI/ISA 84.01-1996 (1) and IEC 61511 (2), provide a new challenge for the process industry. One of the most difficult parts of complying with these standards is the testing interval often required for final elements, such as block valves. Most SIS block valves are function tested only at unit turnaround. Many refineries have reaped the benefits of good mechanical reliability programs, enabling them to extend unit turnaround to five to seven years. When SIL 2 or SIL 3 performance is required, five-year function tests are inadequate. Consequently, many users are looking for ways to supplement the off-line full stroke test, such as on-line full stroke testing or partial stroke testing.

Many users consider partial stroke testing (PST) as a cost effective alternative to on-line full stroke testing (FST). The use of PST often eliminates the need for full flow bypasses, reducing engineering, capital, and installation costs, as well as potentially removing a bypass that could be inadvertently left open.

Solenoid PST Methodologies

A PST can be accomplished by pulsing a solenoid valve. If the test solenoid is the same as the solenoid used for valve actuation, the PST will also test the actuating solenoid. Solenoid PST methodologies can employ simplex or redundant solenoids.

Simplex Solenoids

The Minerals Management Service, which oversees safety for oil and gas operations for US offshore waters provides one method for partial stroke testing. This method relies on the operator to pulse a single solenoid by turning a field-mounted switch, which de-energizes the solenoid for as long as the field operator holds the switch. The field operator monitors the valve position and releases the button when the operator confirms valve movement. When the valve moves, it can be inferred that the solenoid successfully vented. Of course, the main risk is that the operator may hold the switch too long, allowing the valve to close sufficiently to disrupt the process, resulting in unit shutdown.

It is also possible to automate the single solenoid test using a pulse timer is adjusted to achieve the desired valve travel. Valve travel confirmation is accomplished using a limit switch or position transmitter, allowing automatic documentation of test status. Since a failure of the solenoid or valve may result in excessive valve travel, the pulse timer should be voted with the limit switch or position transmitter. If the valve reaches its desired travel point before the pulse timer is finished, the solenoid valve is reset. The test can be programmed in the SIS logic solver with the test implemented automatically on a programmed cycle time or initiated by the operator per a maintenance schedule.

Another method is to use a single solenoid to partial stroke the valve and measures valve position as related to air pressure in the actuator. This results in a “fingerprint” of the breakaway pressure for valve closure, which can be compared with the original valve “fingerprint.” In order for this method to be effective, maintenance must have a specific procedure for examining the fingerprint to identify that the valve is degraded and to respond with corrective action. Depending on the specific implementation, this design may not allow on-line maintenance without taking the valve out-of-service, so full flow bypasses may still be required for maintenance.

When using simplex solenoids for valve actuation, spurious trips during normal operation can be a problem. Furthermore, when the simplex solenoid is being used to PST the valve, the solenoid is de-energized and then re-energized. If the solenoid valve does not reset, the test becomes a trip. Using redundant solenoids can essentially eliminate these problems.

Redundant Solenoids

When arranged in a 2oo2 configuration, redundant solenoids provide improved reliability during normal operation and reduce the probability of a spurious trip during the PST. The reduction in spurious trips is typically more than sufficient to justify the additional capital and installation costs.

ASCO offers a fully integrated solenoid package, providing on-line diagnostics of solenoid coil failure and facilitating on-line solenoid testing. During normal operation, the air signal passes through the package from the signal source to the valve actuator. When a trip occurs, the solenoid vents the air from the valve actuator and allows the valve to move to its fail-safe position.

In the 1oo1HS Mode, one solenoid is the primary solenoid and is confirmed on-line using a pressure switch. This primary solenoid is responsible for initiation of the shutdown action. The secondary solenoid is off-line and confirmed in the vented state (off-line state) by a pressure switch. If the second solenoid is in the incorrect position, an alarm is generated to notify maintenance for repair. The PLC is programmed so that if the primary solenoid goes to the vent state without being commanded (as detected by the pressure switch), the secondary solenoid is energized, preventing the spurious trip.

Solenoid testing is performed by cycling the solenoids and verifying that each solenoid successfully vents and resets using the pressure switches. The ASCO 2oo2D-SOV can be used for PST by incorporating a PLC timer to pulse the power to the solenoids for just long enough to achieve the partial stroke. To verify the movement of the valve, a position transmitter or limit switch is used. The position indication is also used to prevent over stroking of the block valve, i.e., if the valve moves too far during the timed stroke, the solenoids are re-energized. For preventative maintenance activities, over stroke or under stroke alarms can be configured to let maintenance know if the valve is moving too quickly or too slowly during the test.

Impact of PST on SIL and $MTTF^{spurious}$ for a SIS

SIL is defined by the average probability of failure on demand (PFD_{AVG}) for demand mode safety instrumented systems (SIS). In ANSI/ISA 84.01-1996, there are three SIL classes, while in IEC 61511 there are four SIL classes. Each SIL class provides an additional order of magnitude risk reduction as shown in Table 1.

The SIS standards require an examination of the PFD_{AVG} to ensure that the SIL assigned to the SIS is met. It is important to note that SIL is not a property of a specific device (3). It is a SIS property, encompassing the field sensors through the logic solver to the final elements (e.g. solenoid, valve, or pump motor control circuit).

SIL is an important concept for safe operation, but plant management demands that the process plant operate at a high utilization rate. If a SIS is installed which has a low mean time to failure spurious ($MTTF^{spurious}$), the project will be considered a failure, regardless of the SIL that the SIS achieves. Consequently, any SIS assessment should include an analysis of the $MTTF^{spurious}$.

Let's examine at a typical SIS, which includes transmitters, a redundant logic solver, solenoids, and block valves. In order to perform the PFD_{avg} and $MTTF^{spurious}$ calculations, failure rate data is required. Generic device failure rate data was selected based on industry published data, as shown in Table 2. The reader is cautioned to ensure that any data used during SIL verification is appropriate for their application. Additional data used in the analysis is as follows:

- For redundant transmitters, it was assumed that analog signal comparison is performed and a fault alarm is initiated when the transmitters deviate unacceptably. "D" at the end of the voting architecture indicates the use of diagnostic coverage. The diagnostic coverage is assumed to be 80% for dual redundancy and 90% for triplicated redundancy.
- The PST can detect 70% of the valve dangerous failures.
- Common cause factor is assumed to be 2%.
- Mean time to repair is assumed to be 24 hours.

For illustration purposes, the ASCO 2oo2D-SOV will be used for valve actuation and PST. Other PST methods can be assessed using similar techniques. The results for other PST methods may provide very different results for SIL and $MTTF^{spurious}$. Consequently, the results presented in this paper should not be generalized for all PST equipment.

Evaluation of Overall SIS Performance

The PFD_{AVG} for a SIS can be calculated using the failure data provided in Table 2. The individual bars provide a relative contribution of each device on the PFD_{AVG}.

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Single Block Valve Case

For the simplex solenoid cases shown in Figure 1, the SIS only achieved SIL 1 at annual function testing. When PST is used to supplement the full stroke test, the SIS achieves very high SIL 1 to mid-range SIL 2. The individual bars can be examined to determine the major contributors to the PFD_{AVG}. For the 1oo1 and 2oo2D cases, the transmitter is the major contributing cause to the PFD_{AVG}. The impact of the transmitter can be decreased by changing the voting to 1oo2D or 2oo3D, which results in the single block valve being the major contributor.

For the spurious trip rate calculation, the logic solver was not included in the calculation, because the spurious failure rate can vary so much dependent on the specific architecture. Some logic solvers have high spurious trip rates and their contribution to the overall $MTTF^{spurious}$ can overwhelm the other SIS components. For this paper, the logic solver was not included in this calculation to allow the examination of the field devices. For actual installations, the logic solver should be included in the calculation.

The benefit of using the 2oo2D-SOV is evidenced in Figure 2. In each case, the spurious trip rate was reduced significantly when the 2oo2D-SOV is used instead of a simplex solenoid. The single SOV cases had a spurious trip rate of 10 years for the 1oo2D transmitter case and 15 years for the other transmitter cases. When the 2oo2D-SOV is used, the $MTTF^{spurious}$ exceeds 45 years for the 1oo2D transmitter case and exceeds 420 years for the 2oo2D and 2oo3D transmitter cases. If the plant life is 20 years, the single solenoid cases yield an average of 1.5 trips during the life of the plant. Even if a spurious trip costs only $100,000, the simplex solenoid will result in the loss of $150,000 over the life of the plant. For the 2oo2D-SOV cases, the $MTTF^{spurious}$ is greater than the plant life expectancy, yielding substantial savings.

Dual Block Valve Case

Dual block valves are used in many installations to provide greater assurance that the process is isolated. When dual block valves are used, it is common for test intervals to be extended to unit turnaround. Consequently, for the analysis, a five-year full stroke function test was assumed for the logic solver, solenoid, and block valves, while annual testing was used for the transmitters.

For the simplex solenoid cases shown in Figure 3, the SIS achieved high SIL 1 to the borderline between SIL 1 and SIL 2, when annual device testing. When PST is used to supplement the full stroke test, the SIS achieves mid range SIL 2 with 1oo1 and 2oo2D transmitter voting. For 1oo2D and 2oo3D voting, the PST makes it possible to achieve SIL 3. Again, the individual bars can be examined to determine the major contributors to the PFD_{AVG}. As seen in the simplex block valve SIS, the transmitter is the major contributing cause to the PFD_{AVG} for the 1oo1 and 2oo2D transmitter cases. The contribution of the transmitter is seriously reduced when the voting is change to either 1oo2D or 2oo3D. In these latter cases, the major contributors to the PFD_{AVG} are the dual block valves.

Again, the benefit of using the 2oo2D-SOV is evidenced in Figure 4. The $MTTF^{spurious}$ for the simplex solenoid cases is an average of 7 years. When the 2oo2D-SOV is used for valve actuation, the $MTTF^{spurious}$ is more than 40 years for the 1oo2D transmitter case and more than 210 years for 2oo2D and 2oo3D transmitter cases. If the plant life is assumed to be 20 years, the single solenoid cases yield an average of 2.8 trips during the life of the plant. Again, if a spurious trip costs $100,000, the plant will lose more than $280,000 over the life of the plant due to spurious trips.

Conclusion

Users operating continuous processes are finding that on-line testing is necessary for achieving SIL 2 and SIL 3. The manpower costs associated with manual testing is a major issue for many companies. Further, operations management is extremely concerned about spurious trips during testing, since these can seriously impact production.

There are a number of PST methods available to the user. Each method has different components to facilitate testing, so each method must be analyzed for its specific impact to the SIS SIL. This analysis was based on the use of the ASCO 2oo2D-SOV in the 1oo1-HS mode. The analysis showed that there is a significant reduction in the SIS SIL when PST is used to supplement FST. Since testing is performed automatically, manpower costs are minimized, enabling the user to achieve the desired SIL without maintenance cost impact. Finally, the fault tolerance of 2oo2D-SOV resulted in significantly reduced SIS spurious trip rates, improving plant reliability.

References

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Table 1. Relationship between SIL, PFD_{AVG}, & Risk Reduction

SIL	PFD_{AVG}	Risk Reduction
4	0.0001 to 0.00001	10,000 to 100,000
3	0.001 to 0.0001	1,000 to 10,000
2	0.01 to 0.001	100 to 1,000
1	0.1 to 0.01	10 to 100

Table 2. Failure rate data used in the analysis

Device	$MTTF^{D}$ (Years)	$MTTF^{spurious}$ (Years)	Data Sources *
Transmitters	100	100	OREDA data for various transmitters
Redundant Logic Solver	5,000	Not included in analysis	Vendor data for 1oo2D, 2oo3D, or 2oo4D logic solvers
Solenoid	60	15	TR84.00.02 data
Pressure Switch	75	60	CCPS data
Block Valve	40	455	OREDA data

* Due to the nature of the analysis presented in this paper, values were selected to represent generic devices rather than specific devices. For an actual SIS, values representing the specific devices should be used.

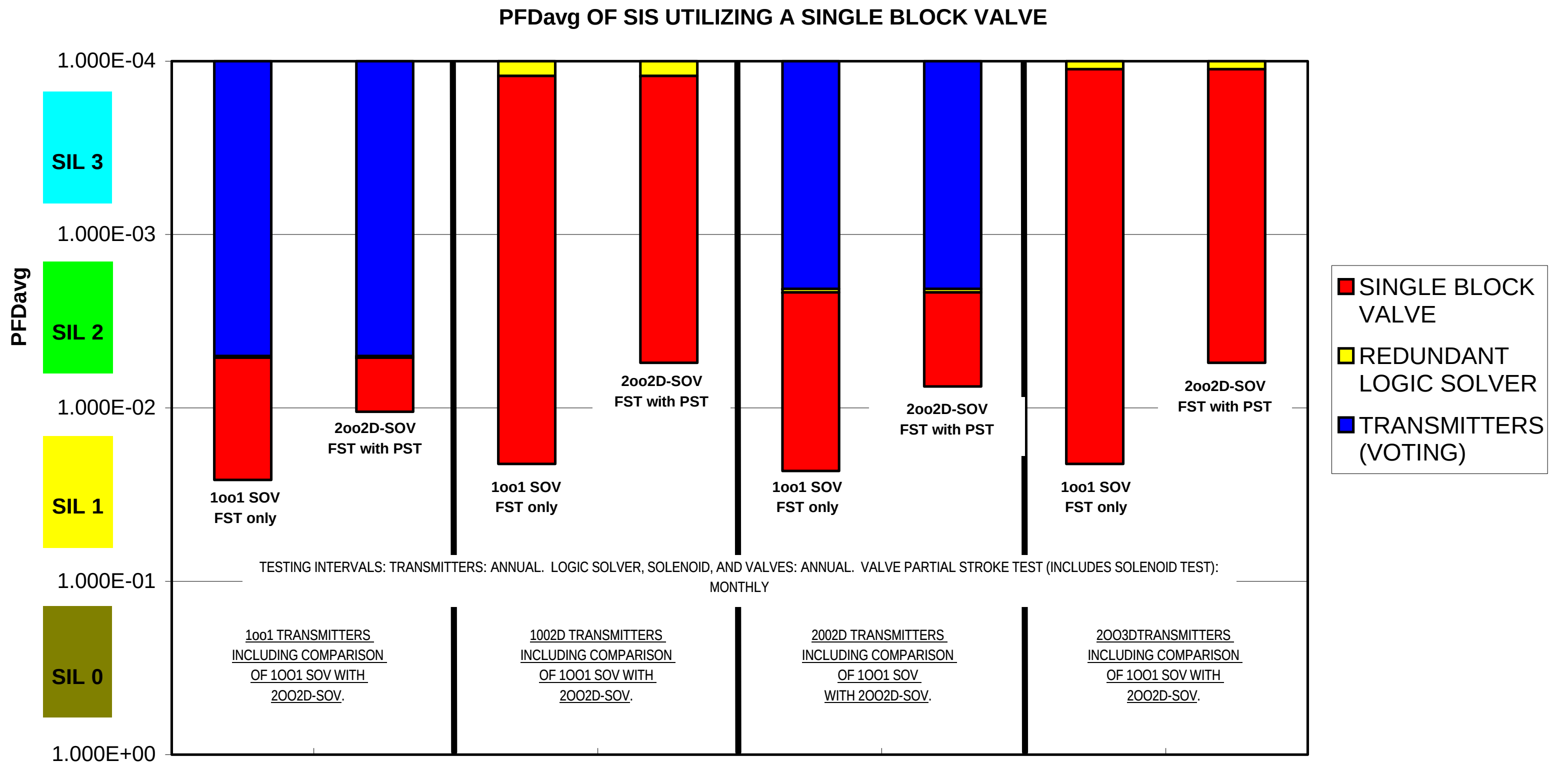

Figure 1. Plot of PFD_{AVG} showing the benefit of using PST of a single block valve

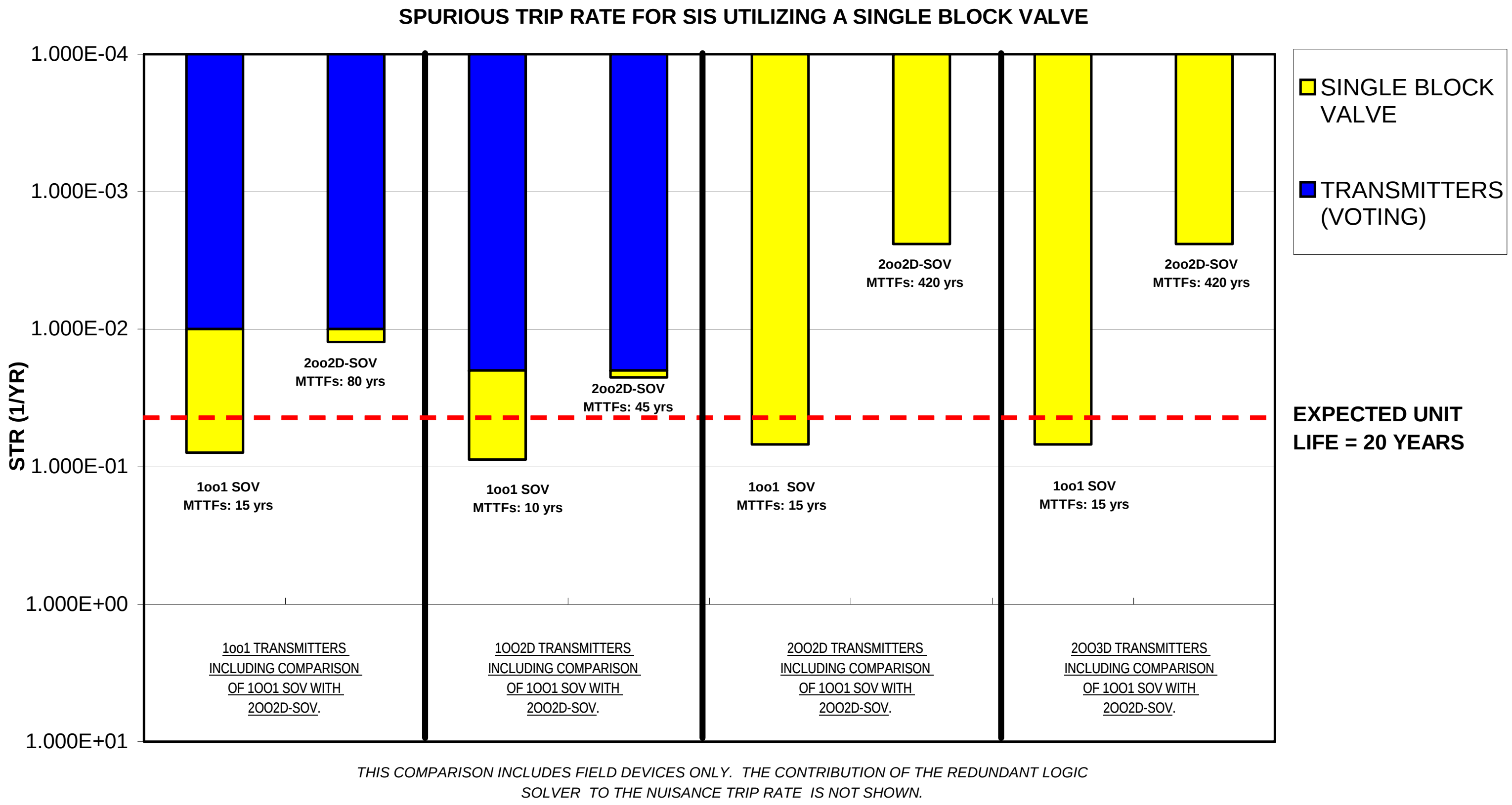

Figure 2. Plot of $MTTF^{spurious}$ showing the benefit of using PST of a single block valve

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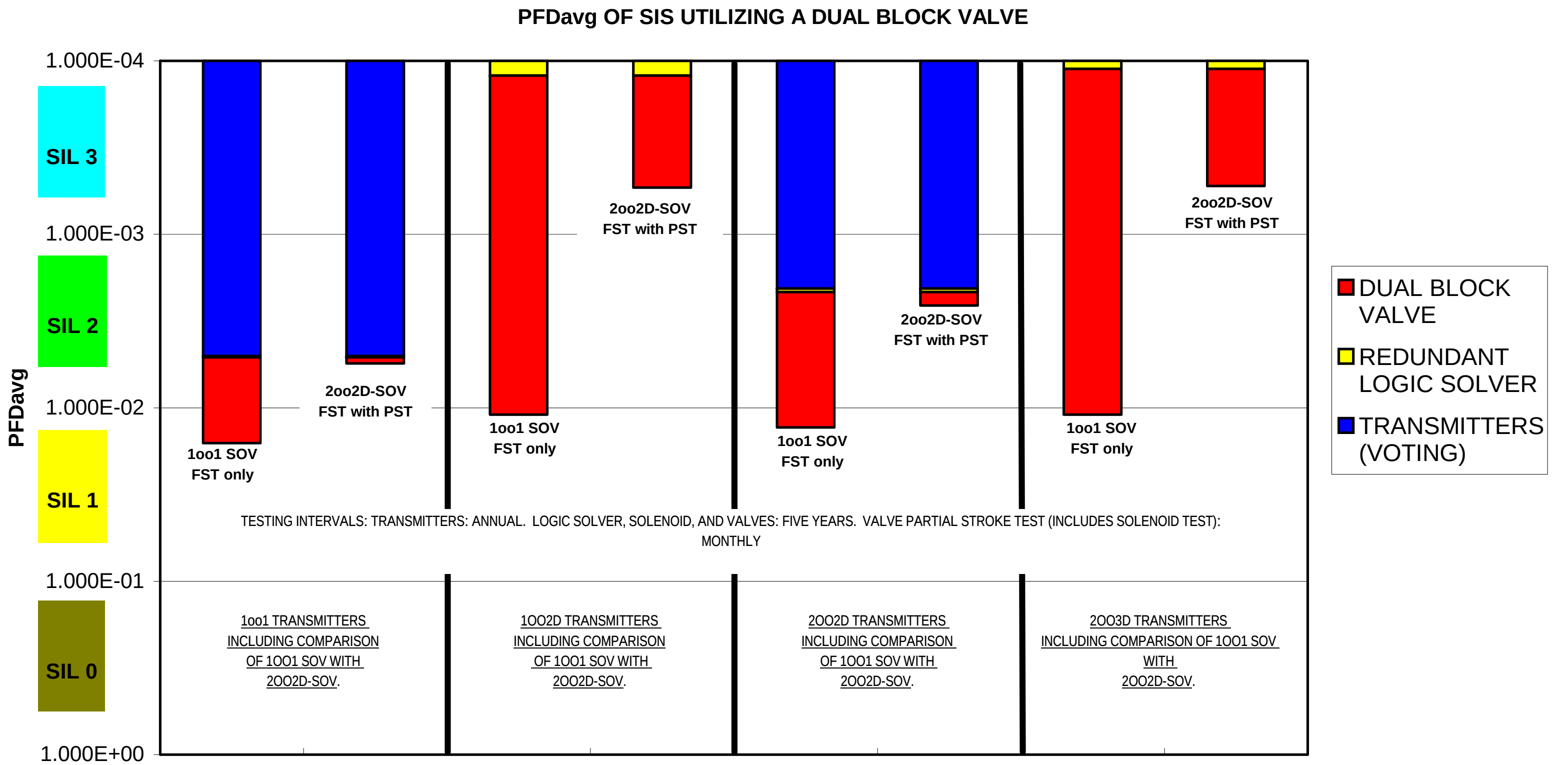

Figure 3. Plot of PFD_{AVG} showing the benefit of using PST of a dual block valve

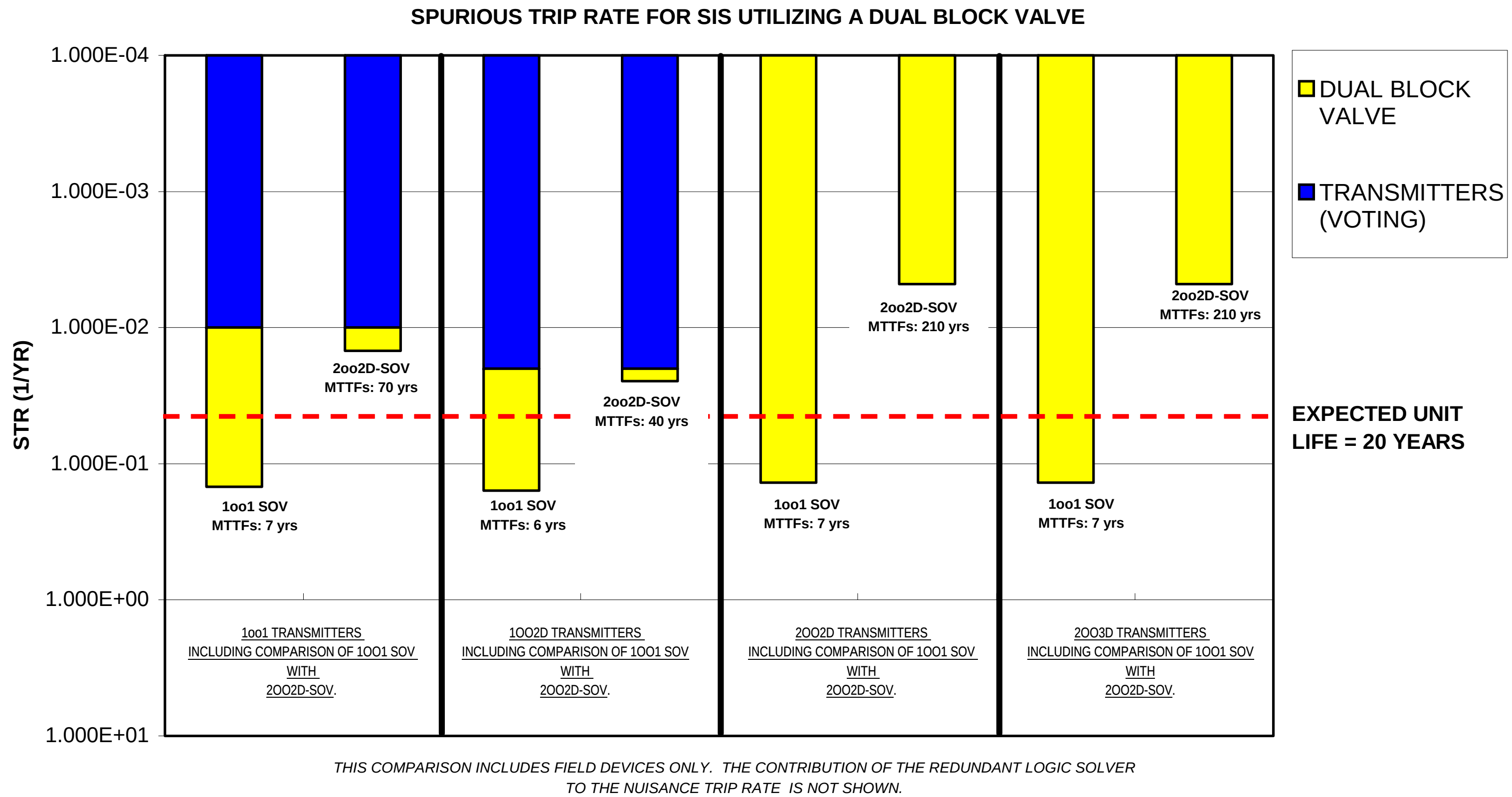

Figure 4. Plot of $MTTF^{spurious}$ showing the benefit of using PST of a dual block valve

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