Reliability considerations for IS interfaces

The three types of reliability considered are: failures causing operational failure; failures which are self revealing, as used in the SIL approach to reliability, and failures that could lead to a possible explosive situation.

The example used in this analysis is the conventional 28V diode return barrier as illustrated in Figure 1, normally used with 4-20 mA transmitters. It is important to recognise that any analysis relating to SIL rating is related to a specific system and each system must be separately considered. The failure data of an apparatus is always relevant but SIL rating is a system concept.

Component failure rates

A significant difficulty in any reliability assessment is the establishment of credible component failure rates. This analysis uses figures derived from a combination of PD IEC TR 62380: 2004 and the 'BT Handbook of reliability data'. Some assumptions are necessary when deriving the figures used and a fairly conservative approach to factors such as ambient conditions has been used. However it is wise to treat the ensuing results as an indication of the order of things, rather than a precise analysis leading to irrefutable conclusions. The failure rates used in the calculations are specified in Table 1.

The zero failure rate of resistors to short circuit is in line with the 'infallible component' concept used in intrinsic safety and because of the derating of safety components is probably justified. Zener diodes used in the barrier are individually pulse tested and derated by a 1,5 factor and hence a lower figure for failure rate could be justified. However in this analysis the normal failure rate is used.

Operational failure rate

Open circuit of the series components and short circuit of the shunt components cause operational failure. Table 2 illustrates the analysis.

It might be thought that because we supplied several million barriers over the last 30 years that a fairly accurate failure rate would have been established. In practice, not all failures are returned or reported and the majority of 'failures' are caused by the application of excessive voltage to the safe area terminals. Under these circumstances the barrier has fulfilled its intended function and this should not be considered as a failure in the context of this document. It seems probable that the calculated failure rate of 0.1%/ annum is a pessimistic number but establishing these low failure rates with any degree of certainty from failures in the field is extremely difficult.

In practice, the design of barriers has evolved over time (as illustrated by Figure 2), the manufacturing and testing techniques have improved and component reliability increased. Consequently, the current reliability is probably higher than it was originally.

Component	Failure rate	Failure to short circuit	Failure to open circuit	Specification drift
Zener diode	10	7	2	1
Schotty diode	7,5	6	1,5	0
Resistor and fuse	10	0	10	0

Table 1: Component failure rates in FITS (1 FIT = 10^{-9}/hr)

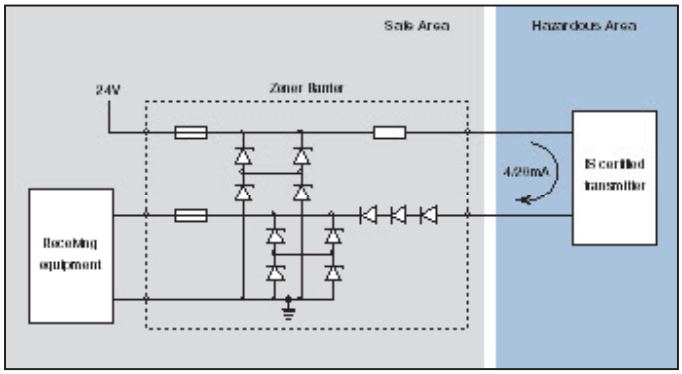

Figure 1: Typical intrinsically safe 4-20mA transmitter loop

Detected and undetected failure rates

Where a 4-20 mA transmitter loop is used in a situation requiring high integrity, the common practice is to monitor then alarm when the signal is outside the 4-20 mA range. Assuming this facility is in place, the only operational fault condition that would remain undetected is the failure of a Zener diode, creating a small leakage current. This would cause a measurement error.

An error can only be caused by leakage of the Zener diodes in the diode return section of the barrier. It can be argued that not all specification drift would cause a small leakage current but, for the sake of simplicity, the four relevant diodes are assumed to have a combined failure rate of 4 FITS in this mode. The figures - which are relevant to SIL calculations of a system incorporating out-of-range detection - are failure to danger of 4 and an overall failure rate of 98,5.

A SIL 3 system with an annual proof test has an acceptable failure rate on demand of 10^{-4} to 10^{-3} /annum. 4 FITS corresponds to 4 x 10^{-5}/annum which suggests that the use of this barrier would need to be taken into account in a SIL3 system. However, a single analogue transmitter loop would not normally achieve a SIL 3 level of integrity and for lower level of integrity systems the barrier failure rate is not likely to be significant. The low ratio of failures to danger to overall failure rate 4% means that the use of the figures from this barrier usually improves the safe failure fraction of most systems.

Failures creating an explosion risk

The failures which would render the barrier ineffective from an explosion risk viewpoint are a failure to open circuit of the two Zener diodes in the same section of the shunt diode chain, or alternatively that all three series diodes in the diode return channel should fail to short circuit.

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The failure rate to open circuit of two Zener diodes in parallel is non-linear, increasing with time. An approximation of failure rate of the combination, which is frequently used, is 2 x (component failure rate)^2 x time. If a conservative approach is used and it is assumed that the failure rate after 10 years is appropriate then the failure rate can be calculated as follows:

Failure rate/hr of one section of two Zener diodes in parallel to open circuit after ten years	= 2 x [2x 10^{-9}]^2 x 10^{5}	= 4 x 10^{-13}
Failure rate of one of two sections in series	= 2 x 4 x 10^{-13}	= 8 x 10^{-13}
Failure rate of one of two channels	= 2 x 8 x 10^{-13}	= 1,6 x 10^{-12}

The equivalent approximation for the failure rate to short circuit of all three series diodes is given by 3 x (component failure rate)^3 x (time)^2. At the 10 year point the series diode failure rate becomes 3 x (6 x10^{-9})^{3}x (10^5)^2 = 6,5 x 10^{-15}/hr. Consequently only the shunt Zener diode failure rate of 1,6 x 10^{-12} is relevant.

For there to be an ignition-capable level of energy available the power supply to the transmitter or the equipment monitoring the return signal would also have to develop a fault. Additionally for an explosion to occur there has to be a flammable mixture of gas present and a spark or hot spot present at the same time. These additional factors further decrease the possibility of an explosion but are arguably more difficult to quantify. This type of analysis does not take into account common mode failures, which at these predicted low failure rates should be taken into consideration. However because they are almost impossible to quantify the possibility of common mode failures is not usually taken into account. Such failures are usually caused by mistakes in the manufacture or assembly of components

This calculation suggests that if a statistical approach is adopted then possibly the design requirements of intrinsically safe equipment could be relaxed. For example the possibility that the requirement to use a 1.5 factor of safety on the rating of safety components could be removed would need to be considered.

Maintenance and inspection

Probably the major effect of this type of analysis is on the attitude to inspection and routine test procedures. Provided that some means of recognising that the 4-20 mA signal is out of range there is little point in checking the operational integrity of the barrier since almost all failures are self revealing. Where accuracy of measurement is very important a calibration check of the field instrument would also check for the remote possibility of diode leakage (4 FITS).

There is no point in checking the barrier for intrinsic safety integrity since the probability of failure to danger of an explosion risk is negligible (less than 1,6 x 10^{-12}). An effective check can only be carried out by removing the barrier and the probability of making a mistake in this operation far outweighs the risk of a barrier failure. An occasional check to ensure that there has been no incorrect substitution of the barrier and that the earth connection is still present could be justified but even this is not a probable risk.

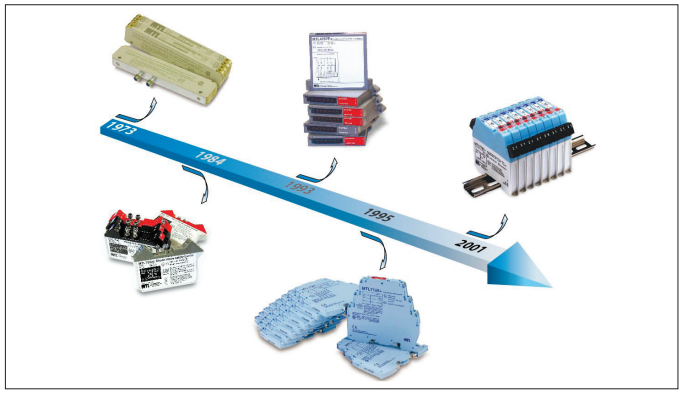

Figure 2: The evolution of the Zener barrier

Conclusion

The calculated operational failure rate - using this data - of this shunt diode barrier is 0,1%/annum (98,5 FITS). This is probably pessimistic, but this analysis enables the failure rate of different failure modes to be compared effectively. A similar calculation for the whole loop would probably result in a failure rate in excess of 1%/annum and consequently inserting a barrier has only a marginal effect on the operational reliability.

There is always a problem in specifying the failures to danger of an apparatus used in a SIL system because, inevitably, they are decided by the particular system. In this case, provided that the system is the commonly used system discussed, the analysis is straightforward. The resultant failure to danger rate of 4 FITS corresponds to 4 x 10^{-5}/annum, which means that the rating of a SIL3 system may be slightly affected, but that that the more probable SIL2 and SIL1 systems are not appreciably affected by the insertion of a barrier.

The figures determined for explosion risk show that the apparent risk is negligible. It can be argued that by the accepted standards for other methods of explosion protection the barrier is over designed. Whether at some future time a change is made to the statistical approach, or whether the current policy of making things as 'safe as is practicable' is continued, is a question for the intrinsic safety committee? Compliance with the IEC intrinsic safety standard dictates the current design.

It can be argued that all intrinsically safe interfaces should be subject to this type of analysis. The particular Zener barrier used in this loop was deliberately chosen as an easy example so as to illustrate the process. Almost all other applications contain situations, which are more difficult to quantify, and their analysis is less conclusive. Generally the results of such an analysis are more speculative but usually edifying.

The author, Chris Towle, has been involved with intrinsic safety since the mid 1950s and subsequently as a founder of MTL product line in 1971. He was secretary of the IEC (1988-2007) and CENELEC (1987-2009) committees for many years and is currently retained as a consultant to CCH-MTL.

Component	Failure mechanism	Failure rate (FITS)
Fuses - x 2	open circuit	20
Resistors - x 1	open circuit	10
Diodes - x 3	open circuit	4,5
Zener diodes - x 8	short circuit + drift	64
	Total	98.5

Table 2: Operational failure-rate analysis

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