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Handling Low and High Demand Mode on Safety Instrumented Function

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Article Info	ABSTRACT
	In this paper, demand rate and hazardous event frequency considerations which effect to the error on the SIL calculation will be discused. The various value of hazardous event frequency and demand rate will be evaluated in this paper. The result of this paper is when hazardous event frequency 10E-06/year and PFD's safeguard 0.00002, with test interval 1 year, the SILs of low and high demand start showing different SIL at demand 5.1/year. At that point, engineer shouldn't use simplified formula for low demand, because it will provide different SIL target than simplified high demand formula or the original exponential formula. The required SIL targets are SIL 2 and SIL 1, for simplified low demand formula and simplified high demand formula, respectively. Therefore, it should be taken more attention and consideration for various value of hazardous event frequency with various demand rate.

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1. INTRODUCTION

Risk calculation taken as the combination of likelihood and severity of loss events. Exponential notation and order of magnitude help us grasp vast ranges such as those used in risk calculations [1, 2]. The order of magnitude of a specific risk could be reduced until tolerable level by implementing SIS (Safety Instrumented System) [3,4]. The specific control functions performed by SIS are called SIF (Safety Instrumented Function).

SIL target determination in safety instrumented function is very important. SILs are the fundamental concepts to maintain the system in safe condition. The SILs consist of four levels for make clasification of the safety integrity condition in the safety function. Safety cost consist of cost of capital, maintenance, operation and insurance are proportional with SIL target Level, higher SIL target will increase the cost and vice versa [1]. SIL-target values are calculated based on the hazardous event frequency which is one of the most important variables in SIL of SIF determination. Some researcher have been explored generic algorithms to estimate hazardous event frequency based on various model of demand mode [4]. There are two operation modes of SIF based on IEC 61508 standard, those are low demand and high demand mode [5]. The original basic equation for both modes that explain the relationship between hazardous event frequency (H), demand rate (D), and target failure rate (λ) is an exponential formula [6].

To simplified the calculation of demand rate in application, the engineer use formula from IEC 61508. In IEC 61508, to simplified the equation for each demand rate, the exponetial formula is converted to aritmetic formula using Maclaurin series. Recently, it has been found that simplified equation for low

demand will produce error in λ target if this equation is applied in high demand. Moreover, it could affect wrong SIL determination [1]. If practitioners use wrong approach or equation to determine SIL, the result will have different SIL value that affected to the safety cost. Safety cost include of capital cost, maintenance cost, operation cost and insurance cost will increase, if the SIL values are over estimate. This paper will discuss how to overcome this error and explore the regime or limit value of demand rate that affected SIL value. Various value of demand rate (D) will be used in this study and applied in the study case.

2.   INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC 61508)

IEC 61508 provides a method to determine safety requirements to achieve the required functional safety on electrical, electronic and programmable electronic systems. This standard distinguishes three modes of operation safety function. Those are low demand mode, high demand mode, and continuous mode. Every modes of operation are defined as follows in Table 1.

Table 1. IEC 61508 Ed 2 – Modes of operation

Mode	Description
Low Demand Mode	Safety Function demand rate is less than or equal to once a year
High Demand Mode	Safety Function demand rate is greater than once a year
Continuous Mode	Safety Function is operating as a continuous control function

The SIF could be applied in demand mode or continuous mode. It is not clear which modes of operation should be applied to Electric/Electronic/Programmable Electronic Safety-Related Systems (E/E/PE SRS(s)), reelated to the demand-state probability and the spurious demand frequency [4]. IEC 61508 applies different failure parameters for defining the safety integrity level. It depending on the mode of operation. For low demand mode, the failure measure is based on average probability of dangerous failure on demand (PFDavg), whereas for high demand mode is based on average frequency of dangerous failure per hour. Targeted failure for each mode are tabulated in Table 2.

Table 2. Target failure: low demand and high demand mode

Safety Integrity Level (SIL)	Low Demand Mode Average PROBABILITY of Dangerous Failure on Demand (PFDavg)	High Demand Mode Average FREQUENCY per hour of a Dangerous Failure
1	$\geq 10^{-2}$ to $< 10^{-1}$	$\geq 10^{-6}$ to $< 10^{-5}$
2	$\geq 10^{-3}$ to $< 10^{-2}$	$\geq 10^{-7}$ to $< 10^{-6}$
3	$\geq 10^{-4}$ to $< 10^{-3}$	$\geq 10^{-8}$ to $< 10^{-7}$
4	$\geq 10^{-5}$ to $< 10^{-4}$	$\geq 10^{-9}$ to $< 10^{-8}$

2.1. SIL (Safety Integrity Level)

The IEC 61508 assumes that over all system comprise of Equipment Under Control (EUC) that protected by EUC control system(s), an E/E/PE SRS(s), another technology based SRS(s) and an External Risk Reduction Facility (ERRF). The EUC control system(s) controls EUC to avoid specific hazardous event that may be happened [4]. The hazardous event is well-defined as an event that arise consequence in harm, i.e. injury, fatalities, and affect to the property and/or environment [7]. The SRSs and ERRF are redundant of the sub-system preventing hazardous event when EUC control system fails to control EUC under safety condition. SIL should be determined to answer the question whether instrumented protection is needed to achieve the required level of safety.

IEC 61508 provides various methods from that enginee may choose it. These methods are statements in the section of the standard and are not obligatory. Level of SIL for high demand is determined by λ (Average Frequency per hour of a Dangerous Failure), whereas It is determined by PFDavg of SIF for low demand. The value of λ is calculated in order to matched with PFDavg of high demand and low demand.

2.2. The Mathematical Formula to Calculate SIL

The exponential form is a basic formula to calculate SIL for single channel SIF, as shown in Equation 1 [6]:

$$H = \lambda(1\text{-exp}(- DT/2)) \tag{1}$$

where::
H = Hazardous event frequency stated the probability of hazard may occur (year^{-1})
λ = The required dangerous failure rate of a SIF (year^{-1})
D = The rate at which a protective system is called on to act (year^{-1})
T = The time between successive test (year)
The equation could be multiply by others PFD of ERRF, if there is existing pasive guard in plant safety system. Equation (1) could be represent as Equation (2) and could be used to calculate the required dangerous failure rate (λ) of a SIF.

$$\lambda = \frac{H}{\left(1 - \exp^{\left(\frac{-DT}{2}\right)}\right)} \tag{2}$$

The demand rate (D) of SIF could be vary depend on estimation of specific hazardous event that may occur in the plant. The demand rate could be very small or very large. If the demand rate so small considered as low demand, hence Equation (1) could be derived as follows:

$$H = \lambda \left(1 - \left(1 - \frac{DT}{2} + \cdots\right)\right)$$
$$H = \lambda \left(\frac{DT}{2}\right) \text{ or } Dx\frac{\lambda T}{2} \text{ or } DxPFDavg$$
$$PFDavg = \frac{H}{D} \tag{3}$$

In another hand, if the demand rate of a SIF is large, it is considered as high demand, therefore the value of exponential form is near to zero. Therefore the Equation (1) will be represent as Equation (4) :

$$H = \lambda (1 - 0)$$
$$H = \lambda \tag{4}$$

It shows that Equation (4) doesn't consider D. It makes the required dangerous failure rate as an constant at any demand rate value. It provides different result compare to the original equation in Equation (2). Finally, the affect of simplified equation provides error in SIL determination for specific demand rate case.

2.3. Formation of ERRF
ERRF could be arranged such as a parallel or series stuctures. The concept for calculating PFDavg of ERRF is very important, because it can affect to the SIL of the system. The value of ERRF could be multiply or added to Equation (1) depend on the formation used between SIF and ERRF. If the connecton between SIF and ERRF is in series structure, hence "add" operator is used, and the "multiply" operator is used if the connecton between SIF and ERRF is in parallel structure. For examples, in Figure 1 there are two relief valves or two high level trips system in parallel structure.
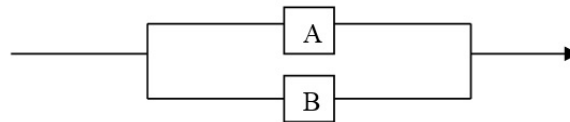

Figure 1. Two ERRF in parallel

Let the A has PFDavgA and B has PFDavgB, then the PFDavg of the system is
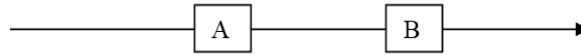
$$PFDavg = PFDavgA * PFDavgB \tag{5}$$

Figure 2. Two ERRF in series

For the system in series formation (Figure 2), if the A has PFDavgA and B has PFDavgB, and subsequently the PFDavg of the system is

$$PFDavg = PFDavgA + PFDavgB - (PFDavgA * PFDavgB)$$

Or   (6)

$$PFDavg = PFDavgA + PFDavgB \quad \text{(IF PFDavgA and PFDavgB are small)}$$

There should be considered if the system/equipments are arrarenged in in series, the PFD of each components should have small value or in another word reliability of component should be high value.

3.   RESULTS AND DISCUSIONS

3.1. SIL Determination in a Case Study

The case study of process plant described below is knockout drum separator that it is taken from [1]. The schematic or process flow diagram is shows in Figure 3.
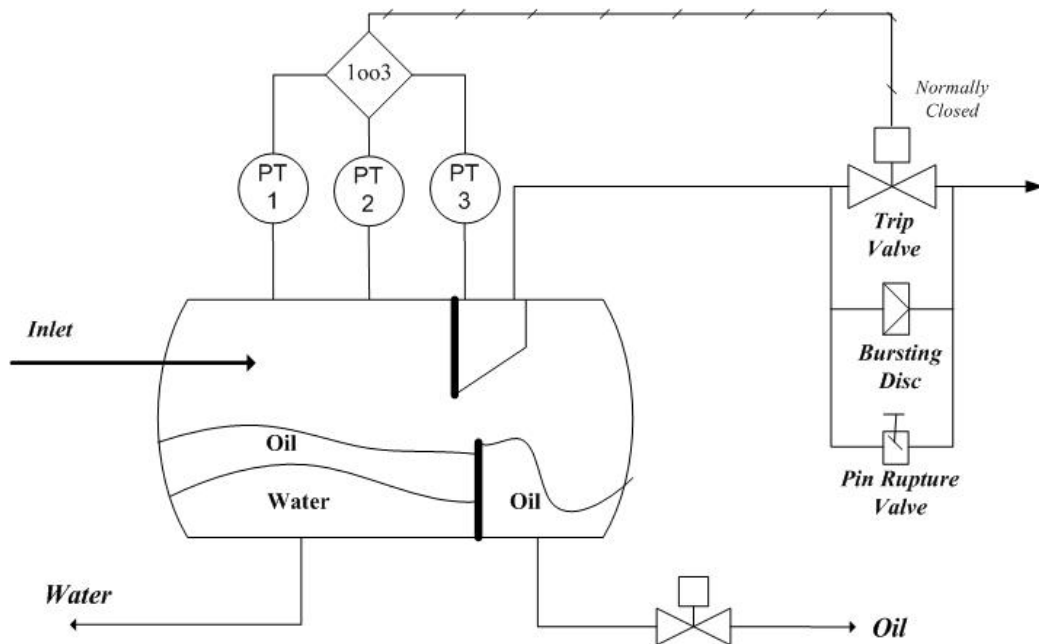

Figure 3. Process flow diagram of the system under study [1]

Hydrocarbon gas stream from various section of the upstream plant is flows into the separator three phase and it is separated into water, oil and gas based on the phase of hydrocarbon molecule. If the gas flow rate enter into the separator three phase in exceeds capacity of separator, it will lead to the hazardous event due to overpressrue condition. Releasing of the hydrocarbon to the environment/air due to overpressure separator could lead to an explosion. The explosion could harm people, environment, and cause equipment damage, hence overpressure SIF would be installed.

The 1oo3 voting of the sensors can be considered to overcome the common cause failure at this stage, hence it is sufficient part to treat the system as a single channel safety function. Plant designer should install pasive protection such as a bursting disc and rupture pin valve and calculate PFDavg of ERRF from

PFD of bursting disc, rupture pin valve and probability of ignition. The ERRF is composed as parallel design, therefore the PFDavg of (ERRF) = 0.01*0.01*0.2 = 0.00002.

Demand rate that use in this research is 22/year, and the hazardous event frequency is determined about 1E-06/year. Using high demand approach in Equation (5), the failure rate will be shown as follow:

λ x 0.01 x 0.01 x 0.2 = 10-6 per year

$\lambda = 5.7 \times 10^{-6}$ per hour

Refer to the Table 2 (high demand column), the λ is categorized as SIL 1. However, If using the low demand approach in Equation (4), the failure rate will be shown as follow:

$$PFDavg = \frac{10^{-6}}{22 \, x \, 0.00002} = 0.0023$$

Refer to the Table 2 (low demand column), the λ is categorized as SIL 2. It could be concluded that using high demand approach the SIF of this system is SIL 1 that sufficient to achieve safety requirement. However. If the SIF use SIL 2 as a safety requirement due to using low demand formula, it increases cost of capital, operation and maintenance.

3.2. The Development of SIL Calculator for Various Demand Rate

The case shows that calculations using low and high demand formula provided in IEC 61508 have potential error or wrong SIL target in SIF when the demand rate is high. Therefore, to help engineer in determine SIL target in various demand, the SIL calculator in Matlab environment was developed as shown in Figure 4. This calculator output is a graph that it can estimate λ when use high demand approach or low demand approach with at different demand rate.
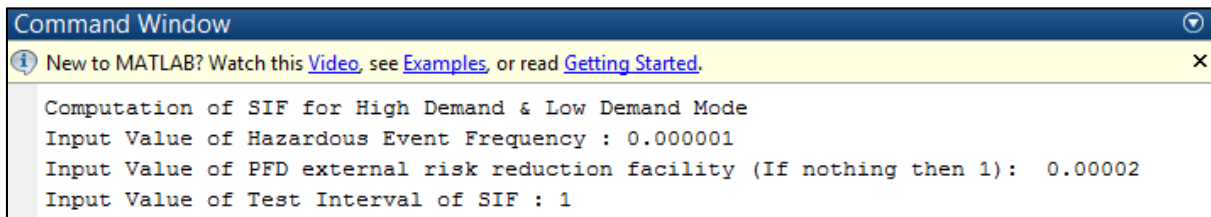

Figure 4. The simulation code for SIL calculator

The input of the calculator are the hazardous event frequency (H), PFD of ERRF (PFDavg ERRF), and test interval (T). At the end of simulation, the maximum demand rate that engineer should consider will provide by the calculator. Using the case that has described before, The result of calculator is an plot between λ or PFDavg and demand rate as shown in Figure 5 below:
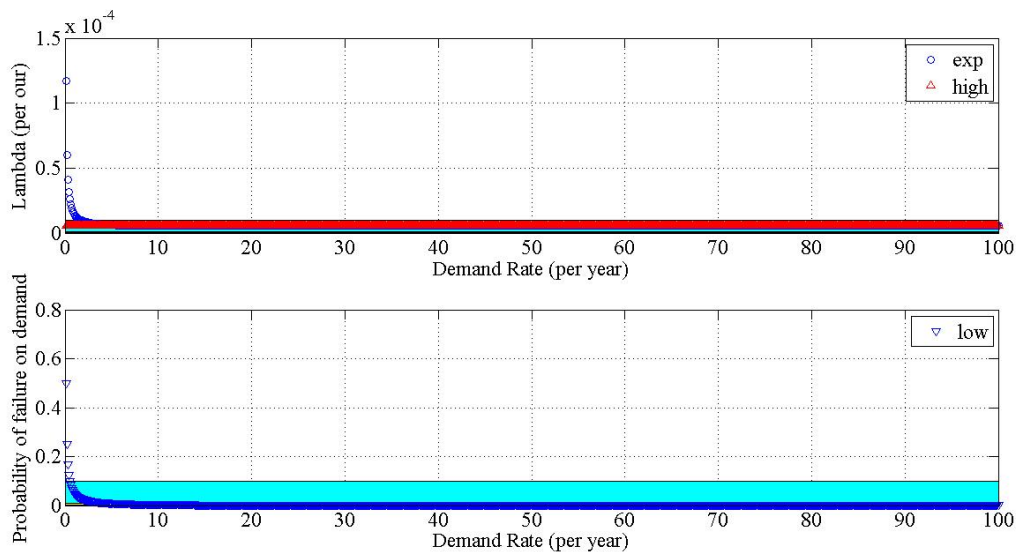

Figure 5. Output of calculator as λ/PFD in various demand rate

Figure 5 shows the output of calculator as λ/PFD in various demand rate. From the output of calculator, low demand approach just sufficient if used in the range of demand less than 0.5 /year. It could be seen in Figure 6 as enlargement view from Figure 5.
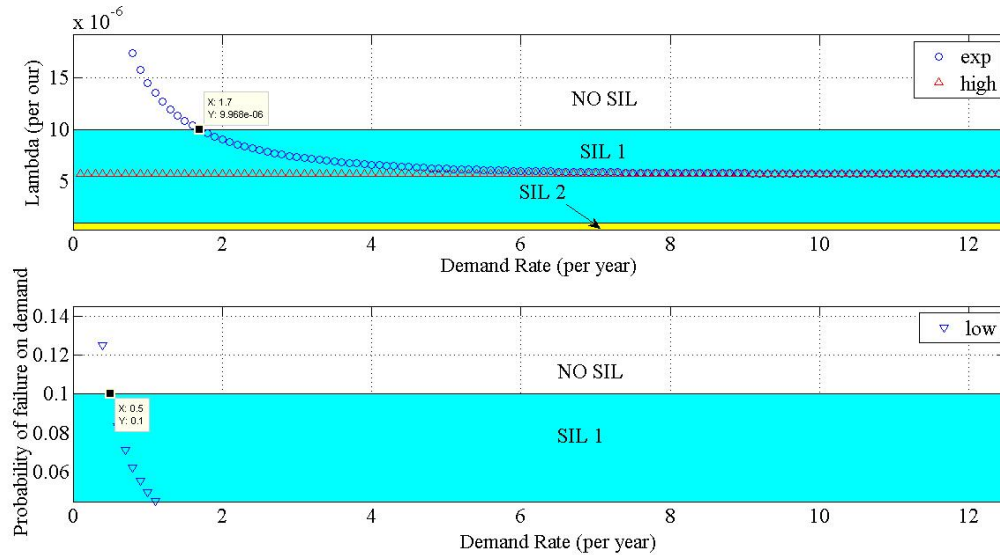

Figure 6. The range of demand rate sufficient for low demand

The different value of λ between high demand and low demand approach will be occured at demand rate 5.1/year. In another word if low demand approach is used, start from the demand rate 5.1/year, the low demand approach will provide higher SIL target than high demand approach.

Figure 7 shows the different colour for SIL 1 (ligth blue) and SIL 2 (yellow). It seem that λ value from high demand approach always lay at SIL 1. However, λ value from low demand approach lay at SIL 1 and SIL 2. In this case, engineer should use high demand approach strat fro His more sufficient to use high demand equation that result in SIL 1 lower than high demand approach demand rate 5.1/year.
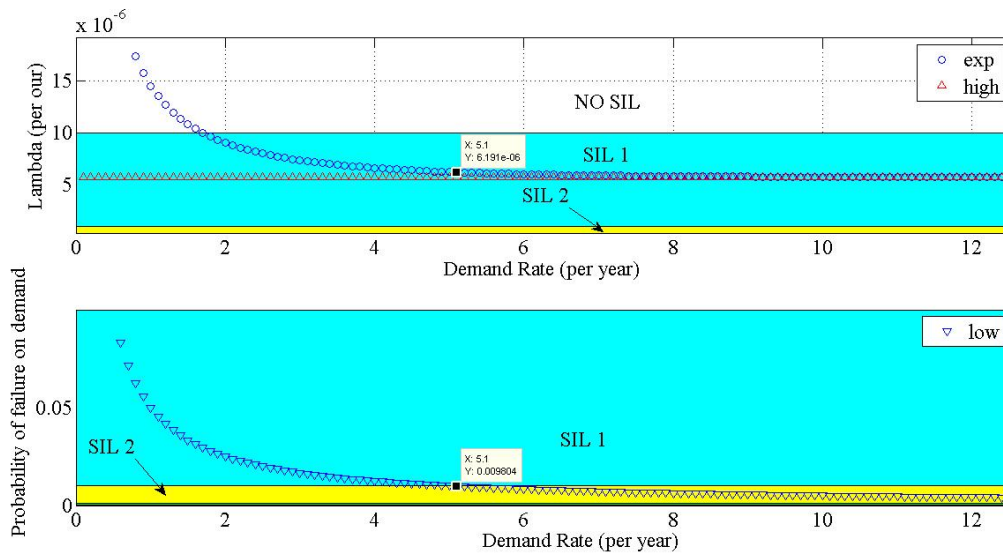

Figure 7. Error between high demand and low demand approach (different result of SIL)

Using the same case mentioned above and the demand rate 22/year, the different SIL target from both approach are shown in Figure 8. The higher SIL will achieved if the calculation of SIL use low demand equation in high demand application. The starting poin of different value of lamda or SIL depends on hazardous event frequency (H), PFDavg of ERRF and test interval (T).

As metioned before higer SIL increases safety cost. Since, the high demand isue is new isue in recent time, the engineer should be carefull to determined SIL target for various plant demand by recording the plant trip or shutdown event per year for each equipments.
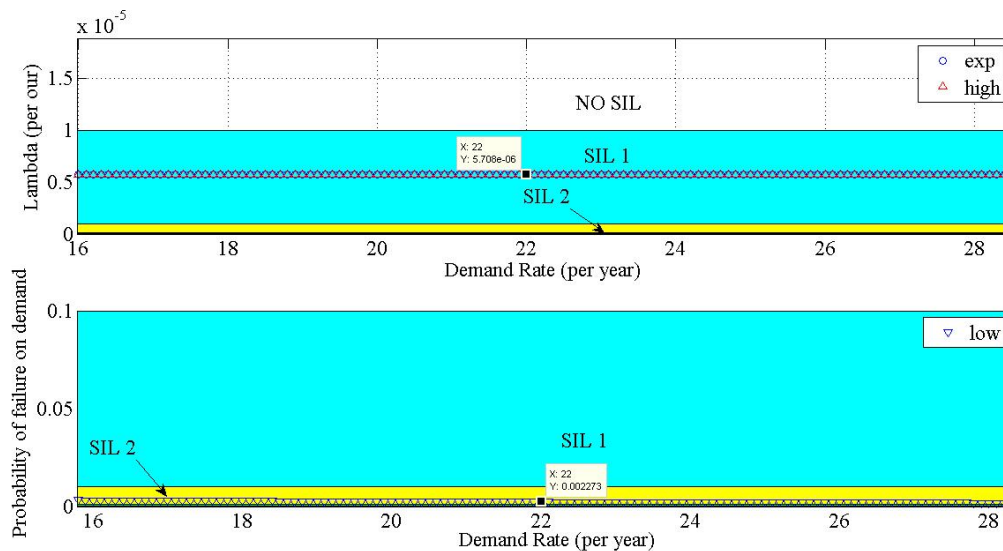

Figure 8. Different result of SIL on demand rate 22/year

4.   CONCLUSION

The value of demand rate should be determined first based on plant maintenance planing and activity data. The different value of lamda or SIL depends on demand rate (D), hazardous event frequency (H), PFDavg of ERRF and test interval (T). From the study case, it can be concluded that at the demand rate lower than 0.5/year it will sufficient to use low demand approach, and at demand rate above 5.1/year the low and high demand approach will provide diffrent SIL target.

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