Fire Risk Assessment for Hydrogen at EDG/Battery Room

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1. Introduction

At the design stage of Nuclear Power Plant, the fire hazard analysis for the fire zone or compartment is implemented according to the fire protection requirement and the document is required for the licensing approval. On the basis of fire hazard analysis, the evaluation for the safe shutdown capability is preceded for each fire zone that contains safety-important systems and facilities. The primary philosophy for the fire safety is to secure fire defense-in-depth at Nuclear Power Plants that represents fire prevention, fire protection, and mitigation from fire damage.

One of the concerning fire zones that need quantitative fire hazard analysis as well as qualitative fire evaluation at Nuclear Power Plants is the battery room at Emergency Diesel Generator (EDG) Room. For an example, Emergency Power Supply System called as EPS at Wolsong Nuclear Power Plant generates emergency power and supply the electric power to the safety-related systems and essential facilities during the loss of on-site and off-site AC power.

For the start of emergency power generator, it needs DC power from the battery units inside the EPS room. For the emergency supply of DC power, the battery at EPS room should be recharged during the standby period to compensate the reduced chemical energy that was converted to the electric energy or depleted through the natural process. During the recharge process, especially at the time of charging current becoming greater than the nominal floating current or at the time of over-charging period, the hydrogen and the oxygen are generated from the positive plate and cathodic part respectively and escaped through the vent holes or crevices. In this context, the fire hazard assessment should be done for the EPS/battery room with quantitative approach and the fire safety evaluation for the explosion of hydrogen gas must be done under the specific fire protection program at Nuclear Power Plants.

2. Methods and Results

For the quantified fire risk assessment for the battery room, particularly at EPS room, the physical and combustible properties of the hydrogen were searched for the engineering calculation and the fire hazard assessment. For the engineering calculation, chapter 16 of NUREG-1805 [1] was referenced and NRC's spreadsheet was used to calculate the generation rate of hydrogen and the flammable gas buildup time in enclosed spaces.

By use of the result from the engineering calculation and the insight gained from the engineering approach, the fire risk assessment for the EDG/battery was implemented. For the safety demonstration of the flammable gas environment, the EPS/battery room at Wolsong Unit 1 was chosen for the detail fire hazard assessment

2.1 Physical and Combustible Properties of Hydrogen

During the recharge process of the lead-acid battery, the release of hydrogen gas is inevitable to fully charge the electric cells. It is estimated that the generation rate of hydrogen and oxygen at each overcharge ampere-hour and at standard temperature and pressure is about 0.42 liter and 0.21 liter respectively.

The following table shows the physical and combustible properties of hydrogen

Table 1: Properties of Hydrogen [2]

Physical Property	
1) Molecular weight	2.02
2) Gas density	0.0898 $kg.m^{-3}$
3) Viscosity	0.85E-5 $m^2.s^{-1}$
Combustible Property	
1) Lower Flammable Limit	4.1%
2) Upper Flammable Limit	74.2%
3) Minimum Ignition Energy	0.02~0.6mJ

2.2 Calculation of Hydrogen gas generation rate

The hydrogen gas generation rate was calculated by use the following equation suggested by Yuasa Inc. and incorporated into NUREG-1805.

$$H_{gen} = \frac{F_c}{1000} * \frac{A_h}{100} * K * N \quad \text{-------- (1)}$$

Where, Hgen: Hydrogen gas generation rate [ft^3/min]
Fc: floating current per 100AH [mA]
Ah: Ampere hour at nominal 8 hrs [AH]
K: Constant [0.000267 ft^3]
N: Number fo Cells [EA]

By use of the equation and site data, the hydrogen generation rate of EPS/battery room at Wolsong Unit 1 was estimated with the NRC spreadsheet calculation.

Table 2: Specification of EPS/Battery Units

Specification		Ref.
Room Size (W*L*H)	19.7*41.3*20[ft^3]	Each EPS
Floating Current (Fc)	600 [mA]	For Series
Ampere Hours (Ah)	190 [AH]	@20hr
Number of Cells (N)	12	For Series
Constant (K)	0.00267 [ft3]	
Charge Voltage(V)	26.75 [V]	

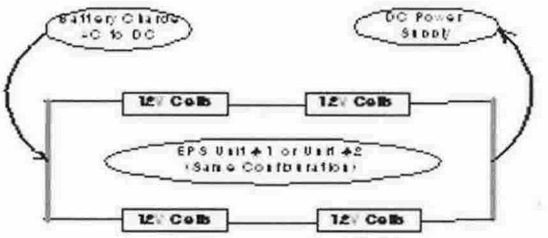

Figure 1: EPS Battery Configuration

As a result, hydrogen is generated at $0.0365ft^3/min$ for each series and the total amount for one EPS/Battery room is 0.073 ft^3/min. The product rate of hydrogen can be used to calculate the required time for the EPS/Battery room to reach at lower flammable limit of hydrogen. With the given volume ($16,272ft^3$) and the lower flammable limit (4.1%), it takes about 152 hours with conservative assumption that the hydrogen is generated constantly and there is no air exchange at the fire zone.

2.3 Hydrogen gas buildup time in enclosure

The other concerning is the fire prevention at the hazard zone from the hydrogen gas buildup. Before the gas reaches at the explosive limit, the hydrogen concentration must be detected and controlled. This alarming value should be quite lower than the lower flammable limit. Normally it is recommended around the range of 1.0% to 2.0%. For the EPS/Battery room, the alarming point was selected at 1.0% for the buildup time calculation. The equation at NFPA 69 [3] is used to estimate the flammable gas buildup time and it reveals about 342 hours.

$$\ln\left(1 - \frac{C * Q}{G}\right) = -K * N \qquad (2)$$

$$t = \frac{V * N}{(Q + G)} \qquad (3)$$

Here, C: Combustion gas concentration (alarm point)
Q: Volume of air in enclosure [ft^3/min]
G: Combustible gas leakage rate [ft^3/min]
K: Mixing efficiency [no dimension]
N: Number of theoretical air change
t: the flammable gas buildup time to alarm point
V: the volume of EPS/Battery room [[ft^3]

The relevant values at the equation are achieved as shown on the table 3.

Table 3: Specific values for the buildup time calculation

Relevant Variables	Value
C : Combustible gas control (alarm) point	0.01
G : Combustible generation rate [ft^3/min]	0.073
Q : Air exchange rate for fire zone [ft^3/min]	7.227
K : Mixing efficiency	0.5

It should be noted that air exchange rate for the fire zone is corresponding to 99% of total exchange volume rate while the combustible gas generation rate amounts to 1% to control the flammable gas concentration at the fire zone. In addition, the time to build up to set point is derived from the relation, $(Q+G)* t = V*\lambda *t = V*N$. At the relation, λ means the air exchange rate per unit hour.

3. Conclusion

For the hazard zone with the flammable gas, the generation rate of explosive gas can be quantified with the spreadsheet at NUREG-1805. This program was made by NRC for the regulative inspectors to evaluate and verify the safety status of the fire zone. In addition, the gas buildup time can be achieved at this program with the technical knowledge [4] for the engineering judgment.

For the safety assessment of the flammable gas zone, the EPS/Battery room was targeted. The time to reach at the lower flammable limit without ventilation is about 152 hours and it means that the zone is quite stable and safe even under the conservative limitations. When it considers the natural ventilation through the openings, the time to reach at the alarming set point of 1% takes about 342 hours. It also means the zone can be easily manageable under the fire protection program.

It should not be neglected, though, there are several flammable gas zones at Nuclear Power Plants. At the quite low ignition energy, the flammable gas can be deflagrated and there are so many ignition sources around the fire zone. In this context, the fire zone with flammable gas must be assessed with both qualitative and quantitative approach [5] under the specific fire protection program.

REFERENCES

[1] NUREG-1805 Volume 1 and 2, Fire Dynamics Tools Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program, NRC, June 2003

[2] Junggi Moon et al., Development of Protection and Prevention Technology for Hydrogen Explosion Hazards (I)

[3] NFPA-69, Standard on Explosion Prevention Systems, 2002

[4] SFPE, Fire Protection Engineering Handbook, 2nd Edition

[5] Guidance for Implementing a Risk-informed, Performance-based Fire Protection Program Under 10CFR 50.48 (c), NEI, July 2004