Intrinsic Safety Protection for Explosive Atmosphere: A Review

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Abstract— **In the explosive atmosphere, there is always a high possibility of an explosion in the presence of electrical, electronic and non-electrical devices which in turn generate a spark or arc. Protection in the context of underground coal mines, oil mines, petrochemicals and refineries by intrinsic safety contributes to a design technique for explosion prevention by limiting electrical as well as thermal energy of circuit to such a level below which it cannot ignite an explosive atmosphere. For low power application like process data management and instrumentation intrinsic safety plays a significant role. In this article, a review of principles, design parameters and application are described.**

Index Terms— **Hazardous Area, Ignition Curve, Minimum Ignition Current, Minimum Ignition Energy, Safety Factor.**

I. INTRODUCTION

Electrical equipment that is used in the hazardous area is so designed, manufactured and operated that their existence does not contribute to causing an explosion. Predominantly the three approaches for electrical equipment design namely explosion confinement, ignition sources isolation and energy release limitation find use in the explosion-prone area for avoiding the explosion. Intrinsic safety (Ex i) concept being very old and popular for electronic products is based on the limitation of the energy of the circuit as well as stored energy in the components. Even having complex construction intrinsically safe devices have wide application in all zones (0, 1, 2). The main consideration of this concept is their appealing features to work on devices for re-equipment, maintenance and plant extension during operation and without 'gas clearance' certificate. Also in some cases, the designer can mix and match compatible intrinsic safe equipment with higher flexibility as suited for programmable process control and information transfer to make the circuit intrinsically safe with which even fault conditions are handled to be expectant and normal [1] [2][3].

II. WORLDWIDE CERTIFICATION BODY FOR INTRINSIC SAFETY

With the development of electrical equipment in underground coal mines until 1977 no appropriate certification body came into the picture. Thereafter in U.K. EECS/BASEEFA [4] and then CENELEC in European countries emerged as the certification and approval body and with the advancement in technology several standards were introduced with the help of the International Electrotechnical Commission (IEC) which are reviewed by EU commission's ATEX consultant which practically is European Norms (EN) version of IEC. Other certification bodies are Physicalisch Technische Bundesanstalt (PTB) in Germany and Canadian Standards Association (CSA) in Canada. In USA Factory Mutual (FM) and National Fire Protection Agency (NFPA)conducts compliance tests on the Ex equipment but the sole authority of certification lies with Labors of the U.S. Mine Safety and Health Administration (MSHA) department and Instrument Society of Measurement and Control (ISA). American National Standard Institute (ANSI), a non-profitable organization coordinates US standards with international Standards so as products can be accepted worldwide. In India, many laboratories for testing and certification of Ex equipment like Council of Scientific and Industrial Research-Central Institute of Mining and Fuel Research (CSIR-CIMFR) in Dhanbad, Central Power Research Institute (CPRI) in Bangalore, Electronics Regional Testing Laboratory (ERTL) in Kolkata, Intertek in Delhi and Karandikar laboratory in Mumbai etc. are active.

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III. STANDARDS FOR IS

With the advancement in time and technology upgradation of standards are made by the certification body by following the requirement, feedback and loopholes obtained from the previous standards. In European countries starting with BS1259 [5] (1958) standard with lacking in details of use of protection concept so failed to produce in national standard, thereafter SFA 3012[6] in 1972 produced by EECS/BASEEFA and then BS 5501, Part 7[7] in 1977 by CENELEC and then BS 5501, part 9 (1982) [8] with the help of standard IEC 79-11[9] by IEC. With the replacement of transistor and thermionic valve and the introduction of semiconductor and use of sophisticated monitoring and control of the complex process, the second edition of European standard BS/EN 50020(1995) [10] came. Other important standards for electrical equipment in the USA include NFPA no. 493 [11] by National Fire Protection Association, Instrument Society of America's RP 12.2 [12], Factory Mutual (FM3610) [13], Underwriters Laboratories (UL) Subject 913 [14]. Standard use in Canada under Canadian Standards Association CSA is CSA C22.2 NO 157.92-CAN/CSA [15]. Bureau of Indian Standards (BIS) is the National code laying body in India. All Indian standards except two codes relating to area classification and selection and installation of Ex equipment are identical to IEC standards [16-18].

IV. Basics of design of IS

Product's design is influenced by the standards applied. Intrinsically safe devices being only permissible device to be used in zone 0 and hence all zone, have to be of the higher level of security and thus is more complex and expensive. The maximum power theorem governs the circuit conditions that need to be protected. The two-basic feature which determines the addition of the protective component to the IS design is the maximum energy transferred to intrinsically safe device must lie below the safe ignition curves and the device must satisfy de-rating criteria of IS standard under fault conditions. The intrinsic safe circuits are examined under the faults which are defined by the standard as follows:

- Fault: Fault is considered as defect in any part of the components or insulation or inter-connection between components, which does not come under infallible as per the standard or there may be cases where even components meet the enhanced specification as per the protection concept but is subjected to risk of danger if disturbance occurs elsewhere in the circuit upon which intrinsic safety depends within the scope of the standards.
- Countable Fault: This fault occurs in that part of electrical apparatus or interconnection which are at par with the constructional requirements of the standard of protection concept. Also, this fault may even occur in apparatus having enhanced specification with safety factors which ensures full safety
- Non-countable fault: This fault occurs in that part of electrical components or assembly or interconnection which do not conform with the constructional requirements of protection concept. In case some non-compliance occurs then the cause of fault may be due to same disturbance alone.
- Infallible: This is not subject to fault modes as per specified in the standard, also care is taken such that connection point condition is same as rest of the circuit.

Standards also define rules on what criteria component is distinguished as faulted and infallible. In fault conditions, most unfavourable single fault or subsequent related faults having afactor of safety of 1.5 applied to energy is also mentioned. Also, the most unfavourable combination is when more than one fault followed by subsequent faults with no additional factors of safety is present. In the case of the highest-level of intrinsic safety, the voltage that is applied to the circuit must be incapable of causing ignition in any of these conditions during spark generation in case of an interruption in an inductive circuit, discharge of a capacitive circuit, make-break of a resistive circuit. Also, not only an actual spark but also the transfer of heat to the gas from incandescent particles of metal must also be taken into consideration [19-21].

The location classification and the suitability of the intrinsically safe (IS) system for that classification are verified depending on the category of IS i.e. ia (applicable for all zone) and ib (for zone 1 and zone 2) and ic for zone 2 only. This also includes verifying the class, group, and temperature ratings of the intrinsically safe apparatus as well as associated apparatus which agree with the actual classification of the location. Prior to energizing an intrinsically safe system inspections are done to ensure the following,

- Voltage and current are kept low so no spark can occur, if occurs must possess negligible energy incapable of igniting an explosive atmosphere.
- Zener diode's safety factor during calculation of rating.
- Creepage, as well as clearance distances, must follow values specified in the standards [22].
- Diodes which are often connected in series with the output of a particular part of the circuit is used for blocking and preferably are duplicated for redundancy.
- Resistors are used to reduce/restrain the instantaneous discharge of charge from capacitors and are operated with safety factor which is calculated at maximum power dissipated also include tolerance at a maximum ambient temperature as mentioned by the manufacturer. One such type of resistor used is wire wound resistor which gets open circuit when current exceeds the limited value.
- Capacitors used to block direct current voltage as a safety measure. The electrolytic and tantalum capacitors are not being used.
- Fuses of high breaking capacity ~ 1.5KA generally cartridge type fuses are connected if used in a hazardous area, rewireable fuses are not accepted.
- Transformers and optocouplers are used to set apart intrinsically safe from non-intrinsically safe circuits.
- Capacitance and inductance of cables connecting to the circuit is also included in energy calculation
- The inductive and resistive value of the cable is considered for L/R ratio.
- The maximum temperature of the faulty component must be within the limit of the faulty board.
- Use of sensor/actuator to monitor various technical physicalvariables (temperature, pressure, flow, vibrations, etc.) [23-25].

A. *Minimum Ignition Energy and Minimum Ignition Current*

The basic principle that lies behind intrinsic safety is to limit, under normal and predictable fault conditions, in the circuit present in the hazardous area, the amount of electrical energy that will ignite the most easily ignited atmosphere concentration (MEIC) of gas or vapour. This amount of energy required is called as Minimum Ignition Energy (MIE). Design of electrical equipment present in hazardous area as well as the interconnected equipment in safe area is such that they reduce the open circuit voltage as well as short circuit current to values unable to cause ignition even in case of open circuit, short circuit or by heating of any parts of the circuit [26]. The Lowest Explosion Limit (LEL) and Upper Explosion Limit (UEL) as provided in the MIE graph is expressed as the percentage are in the normalized ratio form of volumes of flammable gas or vapor to volume of air. Relation between maximum safe open-circuit voltage and short-circuit current is nearly inversely proportion and must lie below 'safe curve' at place of the spark as given in the particular standard for intrinsic safety. MIE is influenced by volume of gas, temperature, humidity and atmospheric pressure [27].

Minimum ignition Current(MIC) is that current at which incentive spark may occur.The source of the spark may be due to the discharge of capacitive circuit, interruption in an inductive circuit, making and breaking at an irregular interval of a resistive circuit and hot wire fusing.

Based on the equation MIE=0.5LI^2, under standardized, optimal conditions for ignition, being more constrained than the standard experimental curves for all values of currents and for inductance. So, to obtain the conservative curve in the resistive circuit an empirical formula had been derived given in equation(1).

$$I = 15000 \times MIE^{0.45} \times \frac{1}{V^2} --- (1)[28]$$

Where I in ampere, MIE in joule, and V in volts.

B. Components of IS System

The intrinsically safe system consists of simple apparatus, intrinsically safe apparatus, all components of associated apparatus and the interconnecting cables [29].

C. Simple Apparatus

Simple apparatus are parts of an intrinsically safe circuit which do not contribute to any energy which is available for sparking or heating as they are essentially inert in nature.

D. Intrinsically Safe Apparatus

All components of this apparatus are intrinsically safe. Apparatus such as transmitters, solenoid valves, I/P converters, switches, thermocouple, RTD, light emitting diode (LEDs), solenoid, IS solenoid, fire detectors, strain gauge, potentiometer, audible alarms, serial communication and any other type of energy storing device used in hazardous area underground mines is to be certified by the certification body as intrinsically safe apparatus. The frequency of fault decides security of apparatus as the possibility of faults are repeatable in this apparatus.

E. Associated Apparatus

Barriers or Isolators, which act as an interface between control room equipment (non IS) and field(IS), limit voltage and current in case of normal as well as faults condition thereby, protect the circuits in hazardous area. The energy is diverted from control room equipment, and thus are not allowed to pass through circuits in the hazardous area, this defines maximum allowable parameters of the circuits for safety and can be safely connected to the hazardous area terminals of the barriers.

F. FISCO

The Fieldbus Intrinsically Safe Concept (FISCO) is specified in the IEC 60079-27 standards which receives a significant boost with an increase in its use in hazardous areas. This standard initially started with experimental evidence and theoretical analysis based on the PTB, a German certification body, and thus named as the Fieldbus Intrinsically Safe COncept(FISCO). Its first full edition of the standard (IEC 60079-27) issued in April 2005. As all standards related to underground explosion protection is becoming more constraining and complex with the passage of time.

V. Zener Barrier and IS Power Supply

The problems related to intrinsic safety can be simplified to a great extent by installing 'power transfer limiters' at the juncture where the hazardous area loop is connected to equipment in the safe area. Depending on the input (digital or analogue) or the bit rate or transmitted power, barrier device can be chosen from optocouplers, zener diode circuits, saturable transformers or the simple electric relay. They are installed generally in a safe area or in a suitable protective enclosure.

A. Zener diode barriers

Zener diode barrier is an associated apparatus which is used to limit the energy in the hazardous area to such a level which can prevent ignition of a specific air-gas mixture. This is achieved by protecting against the faults like a short circuit of wires or grounding of wires which is connected to the hazardous area side of the or failure of the power supply thus granting an unsafe voltage to be applied directly to the safe side of the barrier.

Despite zener diode barrier have proper protection operation and are cost effective but there are some shortcomings also in its inherent characteristics which is to be closely analyzed during the installation.

B. Controlling the power supply

The controlled power source using SMPS (Switched Mode Power Supply) techniques can also be converted into intrinsically safe power supply. Using this technique ac supply taken as input and is converted to DC with the switch mode power conversion technique which allows minimum losses. To check the electromagnetic interference and the power factor distortion in the ac side of the supply, waveform is passed through the electromagnetic induction (EMI) filter and boost power factor correction(PFC) device accompanied in the conversion stage including rectifier operation converting ac supply to unregulated dc supply followed by dc dc conversion device to obtain the regulated dc voltage. The regulated DC supply is then fed to the zener barriers which limit the voltage and current and deliver the desired intrinsically safe output power to intrinsically safe equipment for hazardous area [30-31].

VI. Test Type for IS

There are many types of tests are conducted after design evaluation of the Ex i product. The spark test, insulation test, impact test, weatherproof test, drop test, temperature class test etc. are carried out on the Ex i product after successful design evaluation as per suitable standards. To check the intrinsic safety protection, circuit intentionally is subjected to random sparks which are capable of igniting an explosive atmosphere. In presence of spark, circuit conditions are varied by varying the or variable source impedance to obtain demarcation line between non-ignition and ignition value as specified in the particular standard.

VII. Entity Parameters

The intrinsically safe field device is connected to the intrinsically safe barrier which must agree on safety parameters, or at times known even as entity parameters. The entity parameters are assigned to hazardous area instrument which is based on the worst-case scenario and the value of voltage, current, power, capacitance and inductance. The introduction of FISCO specification, which makes clear the use of constant power supplies to intrinsically safe equipment.

VIII. Applications of IS systems

As IS protection is for equipment with low power and for extremely low voltage, thus all or some part of equipment can even be used in Zone 0 of the hazardous area of all gas group I, IIA, IIB and IIC. The IS equipment mainly deals in the explosion protection, telemetering and electronic process control. Further attempts have been made to include more of electrical equipment certified and designed as IS system with the use of solid-state technology along with IS techniques.

IX. Conclusions

The intrinsically safe concept is very popular for electronic equipment in the hazardous area industry. It is need to understand the basics of this protection method and certification and concerned approval process before use in hazardous area to enhance the safety level of the industry. making connection between IS equipment with other IS and or non-Is equipment is also very difficult task sometimes in the field if necessary information is not available of entity parameters.

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