Explosion on a low-pressure chlorine system

ARIA 40197- 23/07/2009 - Allemagne - Ibbenbüren
20.14 - Production of other basic organic chemicals

A lightning strike caused a voltage drop on the power supply of a chlorine-alkali plant using the mercury process. The emergency electrical system was activated, though restoring the external supply voltage in less than 200 ms rendered the entire system inconsistent; some units were operating normally, but all units connected to the emergency devices (including the mercury pump) remained idle. An explosive mix of 500 kg of chlorine and an unknown amount of hydrogen accumulated inside the low-pressure chlorine treatment circuit and, upon exploding, injured two employees and destroyed the whole circuit (damage: 237 000 euros).

This accident demonstrates the need to surpass a simple binary approach (i.e. on/off) in order to incorporate short-duration voltage drops (electrical disturbances) into the safety reports. An installation’s emergency power supply must be designed by integrating a SIL 2 safety integrity level (according to the Standards IEC 61508 / 61511). The site operator extended personnel training modules to include the facility’s operating details, in a step to better cope with unidentified defects.
Lightning : Direct and indirect effects

Lightning is a natural phenomenon involving a disruptive electrostatic discharge following static electricity build-up between storm clouds or cumulonimbus and the earth. The difference in electrical potential between the two points, which is capable of reaching 100 million volts, produces a plasma at the time of the discharge along with a heat release and explosive expansion of the air. Upon dissipation, the plasma creates a lightning bolt and thunder.

This violent phenomenon may be at the origin of many accidents. The high-frequency atmospheric electrical discharge is capable of causing severe physiological effects on humans (death, burns, blindness, electrification specifically due to step voltage, ARIA 36096), as well as many other induced effects: breakdown of electrical equipment resulting from significant potential differences, ignition of materials due to the Joule effect, electromagnetic and electrodynamical effects, and acoustic phenomena caused by the pressure surge.

The "direct effects" arising during a lightning strike on structures are able to: penetrate, or even rupture, metal envelopes such as pipelines (ARIA 5678) or tanks (ARIA 18325, 25617); spark a fire like that on floating roof tanks in joint zones where flammable vapours accumulate (ARIA 6277, 12229, 12231, 20819). The shell/roof equipotential bonding might actually prove inadequate in ensuring safe current flow while avoiding equipment breakdown.

"Indirect effects" can lead to a voltage surge that propagates by means of either conduction or radiation once a lightning impact has occurred at a relatively distant point from a building or installation (ARIA 11262, 32624, 37499, 40197).

Of the 130 accidents due to lightning recorded in France within the ARIA database, 60% resulted from direct effects, 30% related to indirect effects and the remaining 10% could not be classified due to a lack of sufficient information (ARIA 33544). Fire is the most commonly observed type, with 65% of cases involving industrial facilities to the same extent as farm buildings or barns (ARIA 3707, 6277, 7168, 7664, 8885, 12937, 15215, 15849). Explosions have also been cited (ARIA 18325, 40197).

While lightning serves as the initiating external trigger of the recorded incidents and accidents, their deep-rooted causes are often associated with electrical problems, design flaws, operating mishaps or site management issues.

Many accident sources lie in electrical defects (ARIA 37499, 38617) subsequent to a lightning impact:

- rupture of a 225-kV electrical cable (ARIA 19539);
- formation of an arc, with ignition of a flammable gas (ARIA 5675);
- electrical voltage surge (ARIA 20844);
- poorly-protected electrical devices or circuits (ARIA 1200, 2715, 26577, 32016...);
- loss of electrical power supply (ARIA 1884, 5874, 40197).

Whether partial or total, the loss of electrical power supply can affect all equipment and related instruments, thereby leading to deficiencies in alarms, sensors (ARIA 26577), ancillary equipment (ARIA 4507) or, more generally, any servo control system, while at the same time causing accidental discharges and spills.

Design flaws, operating mishaps and site management problems have been related to:

- an undetected or insufficiently evaluated lightning risk (ARIA 3707, 27506, 33544);
- poor management of unexpected shutdowns (ARIA 15749) or unit restarts (ARIA 26503, 26579) during thunderstorm events, without an appropriate verification of the equipment and instrumentation potentially damaged;
- electronic information transmission systems rendered inoperable (ARIA 32016).

Various prevention and protection measures are typically employed to mitigate the effects of lightning by means of:

- routing the electrical flow towards a lower-risk zone;
- ensuring sufficient electrical conduction to the ground in order to avoid equipment overheating or destruction (equipotentiality, adequately-sized metal sections, proper and regularly-tested grounding, etc.);
- paying close attention to equipment seals so as to avoid leaking flammable or combustible materials;
- protecting electrical and electronic equipment, particularly when such equipment is part of the safety system.

With respect to electrical supply deficiencies or disturbances caused by lightning, besides checking for weather alerts, several prevention measures may be suitable for implementation, namely:

- switch to regularly-inspected electric generating sets (ARIA 30199 / generating set malfunction due to poor controls);
- switching of power supply onto a protected line (backup power supply line, inverter, electric generating set);
- unit shutdown or reset in safe operating mode;
- temporary interruption of any operations presenting a special risk;
- protection of sensitive or risk-prone equipment in the event of a lightning impact (ARIA 6277);
- redundancy of systems and all electrical circuits vital to maintaining site safety (above/belowground electrical line).

As a violent natural phenomenon with potentially serious consequences, lightning deserves special attention from industrial site operators. Maintaining a "steady" power supply to units is key for the means of production and constitutes an essential strategic component in installation safety. The frequency of electrical installation damage, coupled with such potentially serious impacts, requires efficient management of both technical and organisational measures in order to ensure installation integrity.

Additional references (detailed data sheets, summaries):

- ARIA 18325: Explosion of an alcohol tank within a sugar refinery / distillery
- How industry copes with the risks caused by lightning - Face au Risque, Issue no. 451 - March 2009

Accidents whose ARIA number has not been underlined are reported on the Website:

www.aria.developpement-durable.gouv.fr

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Within a distillery, a 5,000 m³ tank containing 1,000 m³ of ethanol at 96% concentration exploded when lightning struck and then ignited. The raised roof fell into the reservoir, which remained intact. However, the tank foot valve cracked upon impact. An emulsifier delivered 2 hours later enabled preventing the fire from spreading to the 1,000 m² retention basin. The blaze was extinguished in 3 hours and the firefighters for over 5 hours cooled 3 adjacent 2,500 m³-tanks exposed to the intense heat. Their structural condition would be controlled prior to resuming facility operations. During the emergency response, 23,000 l of emulsifiers stored onsite and a total of 7,000 m³ of water (including cooling water) were used. An Internal Response Plan drill conducted 2 months earlier and based on a comparable scenario involving one of these tanks served to facilitate the actual intervention. The loss was valued at 30 MF (including 2.5 MF of alcohol destroyed and 3 MF of emulsifier). The extinction water (1,500 m³) collected in the retention basins could be observed. The accident was noticed by a train conductor (in witnessing a brushfire), who promptly sounded the alert.

Property damage was appraised at 2.2 MF.
The general station circuit-breaker, turned off at the time, was responsible for the accident. Once it had been turned back, normal operations could be restored. This malfunction would have been due either to vandalism (signs of forced entry into the electrical cabinet) or to the intense heat. Moreover, network remote monitoring was running in a degraded mode: a thunderstorm a few days prior had destroyed the remote transmission equipment at the pumping station, with information on system flaws not being relayed to the monitoring station. These safety devices could not be replaced due to an inventory shortage in the maintenance workshop, and many equipment replacements had to be carried out since the beginning of the month due to the frequent occurrence of thunderstorms.

Several hypotheses were forwarded to explain the symptoms: lightning, electrical short in the depot, faintness due to cardiac troubles. The immediate measures adopted were: restricted access to the incident zone for the remainder of the night, disconnection of all electrical outlets located near where the short circuits occurred, and remote monitoring by the site security company. On the next day, the fire automation systems on the manifold were tested under remote control conditions and revealed no anomaly. These safety devices could not be replaced due to an inventory shortage in the maintenance workshop, and many equipment replacements had to be carried out since the beginning of the month due to the frequent occurrence of thunderstorms.

The classified facilities inspectorate noted that the preliminary lightning assessment was inadequate and requested that the site operator conduct a new study as quickly as possible. Moreover, the operator was required to assemble a spare parts inventory for all site safety equipment.

The “CMP” workshop was continuously producing 2 types of PS: “crystal” (DC1 and DC2 lines), and “shock” (DC3 line). The “EPS” shop was producing in batch mode “expandable” PS in 6 non-synchronised reactors: 2 at the beginning of the cycle, 2 at the intermediate stage, and 2 at the end of the reaction. In order to minimise the impacts of micro-outages (due to electrical storms) on the quality of PS produced, the plant operator typically switched the shop power supply onto the 4 electric generating sets of the site’s “EJP” power unit. This switch took place at 10:46 pm, with 3 of the generating sets being available at the time. At 10:43 pm, the storm knocked out the first set; since the 2 other sets proved insufficient, the “EJP” power unit tripped into safe mode at 10:46 with a loss of utility services. A technician attempted to restart the EJP unit; a bit later, at 10:53, the on-call maintenance electrician, who was the only person actually certified to switch the power supply back onto the EDF grid, was called. The internal alarm was sounded at 11:01 pm, which in turn activated a crisis management unit and notified both an on-call team and external first responders.
At 11:05, pressure in the first DC1 reactor began to rise. In accordance with the plant's emergency procedure, gyro monitors were turned on at 11:15 so as to contain vapours that may have been vented from reactor 1 / DC2 line. Given the process employed and in contrast with what was happening on the other 2 lines, a pressure surge might have ruptured the disc. The site was connected to the grid network at 11:18 pm, though the units started up following a short time lapse. At 11:20, the disc of reactor 1 (DC2) burst at 5.8 bar, splattering a liquid mix containing 10 tonnes of PS and 3 tonnes of styrene. At 11:40, a peripheral water curtain was activated to control the vapours. Both reactors from the EPS workshop at the beginning of the polymerisation process were emptied into an emergency pit as a precautionary measure. At 12:25 am, styrene concentrations around the pit and in 4 neighbouring municipalities had returned to zero. The state of alert was lifted at 2 am. The efficiency of these gyro monitors, along with the degree of polymerisation (smaller quantity of styrene) and the confinement of aqueous discharges within a basin, all helped limit the consequences to operating losses; neighbouring residents were nonetheless inconvenienced by foul odours. An emergency order was issued and the units allowed to restart on 19 July. The reactor's runaway response was due to the loss of utility services. Since the technician had not completed the manoeuvre to contain the pressure surge, the emergency vent on the CMP unit's line 2 reactors had not opened early on during the incident, as indicated in the procedure. During a thunderstorm, electrical power is provided by the EDF company incorporating positive safety features, which remain independent of available utility services or of inverter backup on key safety equipment, as needed to control a runaway reactor. The emergency procedure adopted for the DC2 line was modified: open vent valve, and start-up of gyro monitors upon initiation of the emergency shutdown procedure. The cooling of this line was also modified in order to limit disc ruptures during runaway reactions.