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Roxtec Ltd

Humidity Effects in Substations

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Humidity Effects in Substations

by

Tony Byrne

Summary

Roxtec Ltd requested EA Technology Ltd to produce a report on the causes and effects of humidity within indoor substation environments and methods of mitigating these factors.

This report briefly explains relative humidity and partial discharge, and the effect of high relative humidity on the inception or level of partial discharge.

The report covers the environmental factors in switchgear design standards and the manufacturer's literature.

The report covers best practice for the design of substations and internal environment control, the factors affecting the environment within a substation and methods of mitigating these factors.

This report demonstrates why it is extremely important to control the substation environment and this can be achieved by minimising moisture ingress into substations and controlling the temperature and humidity within the building.

Contents

1 Introduction

Roxtec is aware of the of the potential for equipment failure resulting from high humidity within high voltage substations.

Roxtec Ltd requested EA Technology Ltd to produce a report on the causes and effects of humidity (namely equipment insulation failures due to partial discharge) within indoor substation environments and methods of mitigation.

This report covers relative humidity and the effect it has on the inception or level of partial discharge. The factors affecting the environment within a substation and methods of addressing these factors are discussed.

Best practice for the design of substations and internal environment control is discussed.

2 Relative Humidity and Partial Discharge

2.1 Description of relative humidity

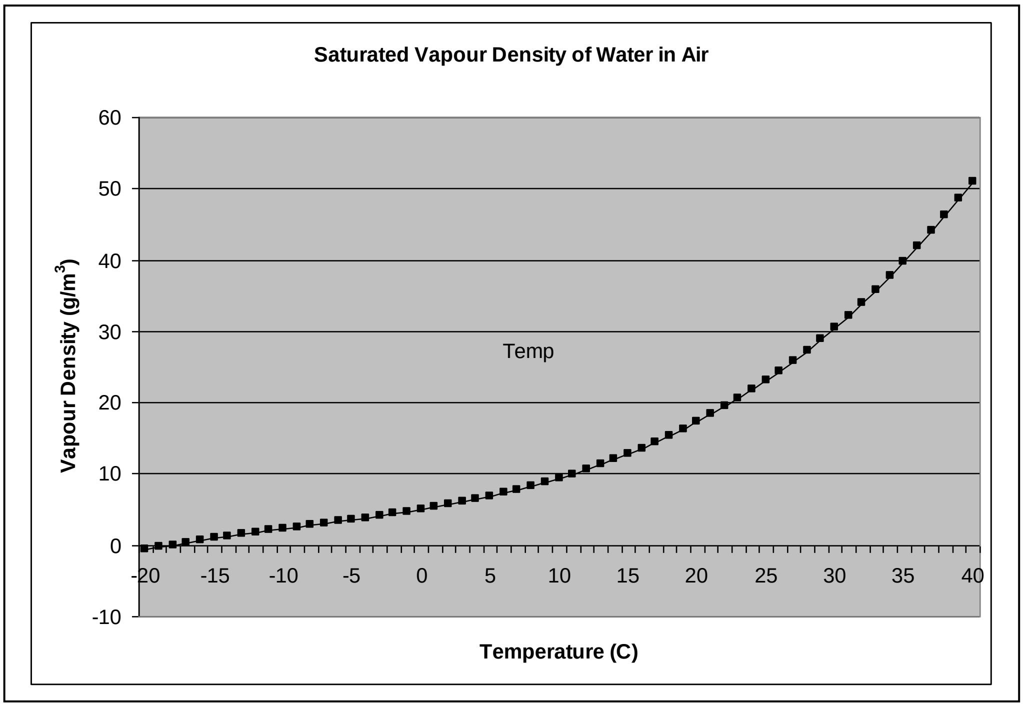
The following is a simplified description of relative humidity and how it is affected by temperature.

The amount of water contained in air depends on the temperature and pressure. When air is holding the maximum possible amount of water it is said to be saturated.

For the purposes of this report it is assumed that substations are not hermetically sealed so that air pressure inside and outside the substation, and consequently all equipment in the substation, is equal at all times. The description of actual and relative humidity assumes that standard air pressure (0^{o}C and 1 atmosphere at sea level) applies throughout the substation and its environment, so air pressure can be ignored for practical purposes.

This amount of water in air is usually expressed in grammes per cubic metre (g/m^3). The graph in Figure 1 shows how the saturated vapour density of water in air varies with temperature. This clearly shows that the higher the temperature the larger the amount of water that air can hold.

Figure 1 Variation of saturated vapour density of air



The actual amount of water in air will vary constantly depending on weather conditions, e.g. raining, sunny, freezing, etc...

The Relative Humidity (RH) expressed as a percentage is a measure of the actual amount of water in air compared to the maximum amount of water air can hold (saturated) at the same temperature.

It the temperature falls then as the actual amount of water vapour in air is unchanged, the RH will increase. Conversely if the temperature rises then the RH will decrease.

The dew point of air is the temperature to which air must be cooled to make it saturated. Any further cooling, or the air coming into contact with a cooler surface, will cause the moisture to condense out of the air.

If further information on humidity and its measurement is required then reference should be made to the following standards:

- BS 1339-1:2002 Humidity. Terms, definitions and formulae
- BS 1339-2:2009 Humidity. Humidity calculation functions, tables and user guide
- BS 1339-3:2004 Humidity. Guide to the measurement of humidity.

2.2 Effect of changes in environmental and operational conditions

2.2.1 Environmental conditions

The environment inside substations depends largely on the ambient external conditions and the type of building construction.

Solar radiation will heat the external surfaces of the substation structure and the internal effects will depend on the thermal conductivity of the materials used in the construction. Walls and roofs having materials of low thermal conductivity will smooth out the temperature variations inside the substation. Walls and roofs having materials of high thermal conductivity will transfer heat to the inside of the substation during the day but will also radiate heat at night leading to large temperature variations within the substation.

Metal doors are often used in substations for security reasons and this will exacerbate the effect of solar radiation due to their higher thermal conductivity. The orientation of doors relative to the sun will also affect the amount of solar gain. For example an east facing door will be heated by the rising sun, and on a cold clear winter's day the temperature rise on a dark painted metal door can be considerable, and this heat is transferred to the inside of the building resulting in temperature variations in the room.

Rain falling on the substation will cause internal cooling through walls as the water evaporates from the walls. Badly maintained roofs, gutters, downspouts and drains will exacerbate the effects.

Where there are cable trenches or basements then consideration needs to be given to the height of the water table and the direction of run-off from the surroundings in periods of high rainfall. Whilst the sealing of cable entries may be adequate in moderate conditions the increased pressure of water as the ground saturates may cause leaks in inadequate or incorrectly installed seals. Poor construction or materials in the structure will also allow water to seep into trenches and basements.

Local flooding is an obvious problem. Within the UK the Environment Agency[1] maintains flood risk maps and it is a simple matter to determine the risk at a particular site. The owner must determine whether the risk of flooding and the impact on their business is acceptable and if not then they should implement measures to protect the substation.

The ambient RH changes constantly depending on local weather conditions. In the UK it is typically between 65% and 95%. This means that without any environmental control the air inside the substation will be at a similar level of RH.

2.2.2 Operational conditions

Electrical loading on equipment generates heat so any changes in load current will have an impact on the overall temperature in the substation, although this obviously may be small.

The impact of changes in load on cables will cause small amounts of expansion and contraction. The passage of fault current can cause considerable movement in cables. These movements will impact on any duct sealing system and may eventually lead to failure of the seal.

[1] Environment Agency website: www.environment-agency.gov.uk

Equipment such as batteries and the associated chargers, electronic components in protection and control panels, computers, etc that are routinely installed in substations generate heat which will also affect the temperature in the substation, and therefore the RH.

2.2.3 Effects on substation environment

Water ingress through walls or badly fitted doors and via wet or flooded cable trenches or basements will increase the level of water vapour in the air.

The temperature in an enclosed space is invariably warmer at the top than at the bottom. The amount of heat transfer through the structure of the substation and any heat from the equipment will cause temperature variations inside the substation in addition to the variation with height.

As the RH is dependent on the temperature this also implies that the RH will vary dependent on the height and distance from heat sources across the space. The RH will be higher in those areas, especially at the bottom of the space, where the temperature is lower.

2.3 Description of PD and how it leads to insulation system failure

Partial Discharges (PD) are electrical discharges occurring inside or on the surface of electrical insulation materials caused by high-voltage electrical stressing of the insulation system when equipment is energised.

PD leads to progressive deterioration and often plays a significant part in subsequent failures, affecting all types of high-voltage assets critical to the operation of the network including switchgear, cables and transformers.

A partial discharge emits energy in the following ways:

- Electromagnetic: radio, light, heat
- Acoustic: audio, ultrasonic
- Gases: ozone, nitrous oxides.

The most practical techniques for non-intrusive testing are based on the detection of the radio frequency part of the electromagnetic spectrum and ultrasonic emissions.

2.3.1 Solid insulation internal discharge

Within all insulation material, however well manufactured, there are small voids, often microscopic. In use, these voids to become charged like small capacitors within the voltage field applied to the insulator. When sufficiently charged, they discharge with a small spark.

These sparks produce heat, light, smoke, noise and electromagnetic radiation just like surface discharge, but because they are embedded deep in the insulation only the electromagnetic radiation can escape. During this process, the insulation is eroded making the voids larger, the sparks stronger and the degradation faster. Carbonisation of the internal surface of the void also occurs, progressively making the voids conductive. This increases the electrical stress on the next voids and the process is cumulative. Eventually, there are sufficient conductive voids throughout the insulation to cause insulation failure.

2.3.2 Surface discharge

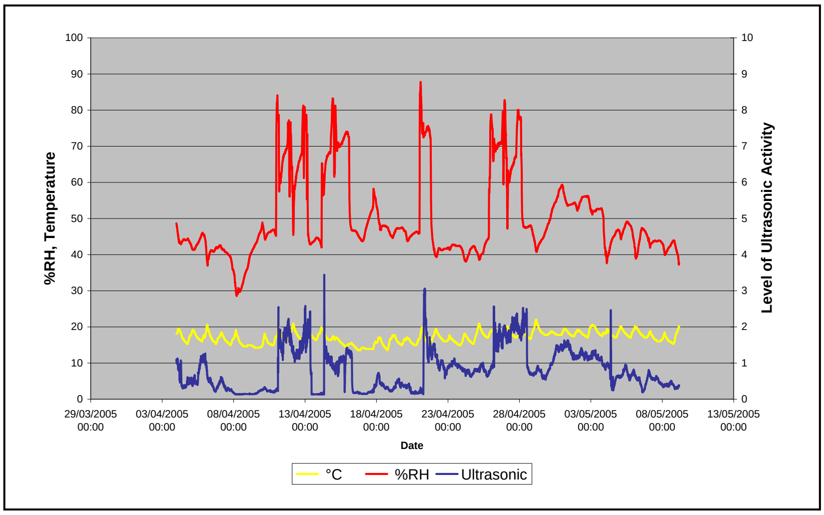
Surface discharges tend to initiate between particles of contamination (typically dust), especially in conditions of high humidity, producing heat, light, smoke, sound, electromagnetic radiation, ozone and nitrogen gases.

Surface discharges can be both phase to phase and phase to earth, although the electromagnetic radiation produced tends to be small in the early stages and does not induce much signal activity in neighbouring metalwork. In the early stages of this type of degradation process, sound waves in the ultrasonic frequencies are produced. When surface discharge occurs, the nitrogen gases produced combine with atmospheric moisture to produce nitric acid. This attacks the bushing surface to produce a substrate on which tracking may occur. The damaged surface also becomes conductive due to carbonization caused by the breakdown of the cast resin. This effectively reduces the electrical clearances of the insulation, causing the PD process to accelerate to eventual flashover. The acid also attacks the surrounding metalwork, which becomes characteristically rusty.

2.4 How high relative humidity in combination with other contaminants contribute to insulation failure

Research was carried out at EA Technology Ltd to investigate the effects of varying RH on the level of PD in switchgear that had been removed from an electricity distribution network due to issues with PD. This showed that RH has an impact of the levels of existing PD. Figure 2 shows the variation of PD with RH and it can be seen that there is a short term correlation between the RH and the level of discharge.

Figure 2 Results of measuring PD and RH



(Source EA Technology Report No T5853 (Confidential))

High RH is known to promote the initial development of partial discharge on the surface of insulation materials. The most important factor is to avoid rapid variations in temperature, which in conditions of high humidity may drop below the dew point causing condensation. It is also known that the air inside lightly loaded switchgear is at the same temperature and RH as the ambient air in the substation. Condensation would therefore occur within and outside the switchgear, leading to corrosion that would not be apparent until invasive maintenance is carried out.

The three most common sources of humidity within substations leading to the onset of partial discharge are:

- Ambient air with high humidity
- Water leaks into the substation
- Water in cable trenches (Figure 3).

Figure 3 – Flooded cable trench

Dust can cause partial discharge when found in considerable quantities in all substation rooms. Where possible, switchgear chambers should be designed to prevent contamination inside various chambers. Precautions should be taken to prevent contamination ingress via the following routes:

- Openings in walls
- Cable entry points through walls and roofs which may not be sealed
- Duct entries to cable trenches or basements
- Trunking entry points through walls which may not be sealed
- Leaving auxiliary compartment covers open.

2.5 Effects of Partial Discharge

The physical effects of long term Partial Discharge will typically lead to the eventual catastrophic failure of the insulation. The examples below in Figures 4 and 5 show the effects of advanced partial discharge activity. This activity would have required replacement of the damaged insulation components and typically could not be rectified through cleaning or minor refurbishment.

Figure 4 - Discharge in a cable box caused by PVC phase tape left installed following installation

Figure 5 - Discharge on a circuit breaker caused by high humidity and a design flaw

Further information on partial discharge and instruments for its detection can be found at the EA Technology website http://www.eatechnology.com/partial-discharge.

3 Switchgear Specification and Design

3.1 Environmental requirements in IEC standards

The relevant switchgear standard above a 1000V is IEC 62271-1:2007 +A1:2011 High-Voltage Switchgear and Controlgear. Common Specifications, which is identical to BS EN 62271-1:2008.

Clause 2.1.1 in IEC 62271-1 gives the normal service conditions for indoor switchgear and controlgear. This is reproduced below.

a) the ambient air temperature does not exceed 40°C and its average value, measured over a period of 24 h, does not exceed 35°C.

d) The ambient air is not significantly polluted by dust, smoke, corrosive and/or flammable gases, vapours or salt. The manufacturer will assume that, in the absence of specific requirements from the user, there are none.

e) The conditions of humidity are as follows
  - *the average value of the relative humidity, measured over a period of 24 h, does not exceed 95 %*
  - *the average value of the water vapour pressure, over a period of 24 h, does not exceed 2.2 kPa*
  - *the average value of the relative humidity, over a period of one month, does not exceed 90 %*
  - *the average value of the water vapour pressure, over a period of one month, does not exceed 1.8 kPa."*

  For these conditions, condensation may occasionally occur.

  NOTE 1 Condensation can be expected where sudden temperature changes occur in periods of high humidity.

  NOTE 2 To withstand the effects of high humidity and condensation, such as breakdown of insulation or corrosion of metallic parts, switchgear designed for such conditions should be used.

  NOTE 3 Condensation may be prevented by special design of the building or housing, by suitable ventilation and heating of the station or by the use of dehumidifying equipment.

It should be noted that IEC 62271-1 states that condensation may occasionally occur and that it can be expected where there are sudden temperature changes.

Note 3 identifies that the user may use environment control to prevent condensation.

It should be noted that type tests are carried out over a relatively short time period. The effects of long term (i.e. several years) exposure to the levels of RH stated in the standard have not been tested.

3.2 Environmental requirements in manufacturer's literature

All HV switchgear is stated as complying with the requirements of IEC 62271-1. Manufacturers recognise the information in the notes by the use of qualifying statements in the equipment manuals, as the following extracts indicate:

- "When the area is free of moisture and abrasive substances (i.e. a satisfactory environment for normal operation of the switchgear when commissioned)…"[2]

- "CAUTION: Relative humidity must not exceed 80 % and the combination of temperature and humidity must be such that condensation, in or on the equipment, will not occur. Where relative humidity exceeds 80 %, take special precautions to prevent

[2] Alstom Installation, Operation and Maintenance Manual for the HWX Form A Switchgear (2002) Clause 2.6.3.

condensation. These may include operating the unit heaters via a humidistat and, preferably, equipping the substation with de-humidification equipment."[3]

- "If the average air humidity exceeds 75%, we recommend that appropriate remedies are adopted."[4]

- "Ideal conditions - Humidity below 40%
  Standard / Normal Conditions - Humidity below 60% RHD (Optional anti condensation heaters may be fitted where RHD exceeds this value)" [5]

- "In case of stations installed in areas with a high relative humidity or in areas with a high groundwater level, prevention of condensation will have to be given special attention. This also applies to switchgear installed in areas abounding in water."[6]

- "Ideal conditions - Humidity below 40% and no dripping water
  Standard conditions - Humidity below 60%."[7]

One switchgear manufacturer has described allowable climate conditions in terms used in BS EN 60721-3-3:1995 Classification of environmental conditions. Classification of groups of environmental parameters and their severities. Stationary use at weatherprotected locations. This standard classifies groups of environmental parameters and their severities. The following is an extract from Table 1 in BS EN 60721-3-3

Table 1 Environmental parameters

Environmental parameter	Unit	Class	
		3K3	3K5
Low air temperature	°C	+5	–5
High air temperature	°C	+40	+45
Low relative air humidity	%	5	5
High relative air humidity	%	85	95

Source: BS EN 60721-3-3 Table 1

"with class 3K5 the installation of additional heating devices is required"[8]

As can be seen from the above extracts ideal conditions for relative humidity (RH) can be as low as 40% and standard / normal conditions for RH less than 60%. Where the average RH is greater than 60% it is normally recommended that some form of environment control is used in the switchroom. When classifications from BS EN 60721-3-3 are used the recommendations are similar.

[3] AREVA Visax S Installation and Commissioning Manual Technical Handbook MA611(a) Rev 5 (2004) Clause 1.1.1
[4] AREVA PIX Installation, Operation and Maintenance Manual No AMT NoT 060-02 (2006) Clause 2.3
[5] Hawker Siddeley Switchgear Eclipse Operation and maintenance instructions, Instruction Manual No 55/4154 (2009) Clause 4.1.1
[6] Eaton Holec Innovac SVS/08 Technical User Manual Ref 991.137 H, Clause 3.1.1
[7] Schneider Electric Genie Range Installation, Operation and Maintenance Instructions Version 002 (2000). Clause on Maintenance.
[8] Siemens NXAIRM Supplement 2000 to Catalog HA 25.71 Section 5.

3.3 Switchgear arrangements

3.3.1 Insulation materials

Historically switchgear insulators were either glazed porcelain or materials such as synthetic resin bonded paper (SRBP). Polymeric and resin materials were introduced around 30 years ago and their use has become almost universal. These modern materials have proven much more prone to partial discharge than did porcelain and SRBP.

3.3.2 Cable entries and terminations

Historically cables entered substations through curved ducts cast into the concrete floor and were terminated in compound filled cable boxes. The shape of the ducts, which were often filed with bentonite, prevented water entering the substation. Cables were terminated in compound filled boxes which completely sealed the cables and terminations.

Modern switchgear, especially the fixed pattern design, has the cable entry virtually at floor level so it is essential to have a cable trench or basement under the switchgear to provide access for the cable to the area where it is terminated.

Modern cable termination boxes are air insulated. BS 2562:1979 Cable Boxes for Transformers and Reactors Clause 7.3 states for Unfilled Boxes "To minimise condensation, ventilation shall be provided." It is known that in unfilled boxes that do not breathe there will be a build up of moisture leading to corrosion and discharge on the terminations. It also means that the RH of the air inside the cable box is the same as the ambient air.

3.3.3 Switchgear chambers

There is free exchange of air between the switchroom and the various chambers in the switchgear. This means that the temperature and RH in the switchgear is essentially the same as in the switchroom.

4 Transformer Rooms and Bays

Transformers are usually placed in separate rooms or bays in substations entirely separate from switchgear and protection/control equipment due to the requirement to provide ventilation for cooling.

As with all other high voltage equipment transformers are susceptible to partial discharge. Whilst any discharge inside the transformer should not be influenced by the external environment, the same cannot be said for the high voltage insulators, cable boxes and the associated connections.

Whilst ventilation is required the ingress of water should be minimised. A standard that may be useful in determining the requirements to limit the ingress of water is IEC 60529 Degrees of Protection Provided by Enclosures (IP Code). The second characteristic numeral is the requirement for protection against the ingress of water. If the transformer room / bay is considered as an enclosure then this standard can be applied to the design of the ventilation openings to minimise the ingress of water.

The section on cable entries and terminations in the section on switchgear applies equally well to transformers.

5 Consequences of Equipment Failure

The consequences of equipment failure can vary depending on the severity of the failure and the impact on the systems supplied from the equipment. The following sections discuss the factors that should be taken into account when assessing the possible consequences of equipment failure and the consequent loss of electricity supplies. It is the responsibility of the owner of the equipment to carry out such an assessment.

5.1 Network / plant shutdown costs

For electricity Distribution Network Operators (DNO) in the UK the loss of supplies to customers incurs costs for Customer Minutes Lost (CML) and Customer Interruptions (CI). These costs are part of the Regulatory framework and the DNOs have targets set during the 5 year price control review with the Regulator. In addition there will be a decrease in the reliability of supply for customers not affected by the immediate fault.

With generating companies a failure can prevent the generated energy being exported from the generating station. This causes an immediate and substantial loss of income until the failed equipment can be rectified or replaced. For a large generator these costs can be greater than £500,000 per day.

For manufacturing plants the failure may cause an immediate shutdown in the manufacturing process. This can result in loss of product passing through the production process, damage to the manufacturing equipment, down time for process staff, etc., all of which will incur costs for the company. In a prolonged outage additional costs may be incurred for late or missed deliveries.

5.2 Operational costs

In any failure there will be considerable costs incurred in the immediate response to make the site safe, to carry out any environmental cleaning and to restore electricity supplies as far as possible.

In addition it is good practice to investigate the cause of the failure to determine whether it is an isolated incident or if there is an issue which could affect similar plant. In the latter case it will be necessary to develop a plan to carry out remedial actions on similar equipment to prevent further failures.

Temporary work may be required to restore supplies to critical areas.

5.3 Consequential damage

The failure of any electrical equipment can cause damage to adjacent equipment that is otherwise healthy, power and control cables, building structures and connected equipment.

All equipment connected to the failed equipment will need to be assessed and tested to ensure that it has not been damage by voltage surges or overcurrents during the fault.

In a manufacturing plant the loss of supply may require that the production process equipment must be cleaned or maintained before it can be put back into operation.

5.4 Safety

In any failure there is a danger to staff and public from the immediate explosion, collapse of structures, any resultant fire and the possible release of noxious or toxic compounds into the atmosphere.

The failure will require a review of the risk management procedures to determine whether the causes and consequences of the failure require the procedures to be revised.

5.5 Repair or replacement

A technical assessment will need to be made of the failed equipment to determine whether it can be repaired or will need replacement.

If repairs are to be carried out it is essential to ensure that competent personnel are used to ensure the repairs are safe and effective.

If equipment needs to be replaced then consideration needs to be given to the following factors

- the lead time for new equipment, which may be considerable in the case of specialist items
- the arrangement of power, control and telecommunication cables in new equipment may require re-design of the existing installation.
- new equipment may be designed to different standards requiring assessment and re-design work on other equipment, which may itself have to be replaced
- phasing of the replacement work to minimise the time requirement and the disruption to normal operations.

6 Substation Environment

The external environmental and operation conditions that have an impact on the substation environment have been discussed previously in this report.

6.1 Ingress of moisture to substations

6.1.1 Substation structure

The main sources of moisture ingress through the substation structure are leaking roofs and doors.

In addition virtually all building materials are permeable to moisture. It is worth noting that many substations constructed pre-1940 often used semi-glazed brick on the inside walls, which is impermeable to moisture. It s not known whether this was for aesthetic purposes or they were attempting to minimise the ingress of moisture.

The amount of water on the walls will be exacerbated if the gutters, downspouts and drains are damaged or blocked, which will cause a flow of water over the walls.

6.1.2 Cable trenches and cable entries

Wet trenches can be due to local ground conditions but can also be subject to temporary rise in the water table during prolonged wet weather. Ground conditions can be affected by external landscaping groundwork which can affect ground levels and the direction of water run-off.

Where the seals on cable entries to trenches or basements are inadequate or not installed correctly the movement of cables and changes in the external water pressure due to the rise and fall of the water table can lead to failure of the seal allowing the ingress of water.

6.2 Effects of high relative humidity within substations

As has already been described high RH within substations will increase the likelihood of partial discharge on high voltage electrical insulation.

When the RH is high there is a risk of condensation if the temperature falls below the dew point of the air. Condensation will also occur if the temperature of a surface is below the dew point, irrespective of the temperature of the air, e.g. metal or glass containers taken from a fridge into a warm kitchen.

This effect can cause condensation both externally and internally as the RH is the same throughout the room and the equipment.

7 Mitigation measures

7.1 Best practice for new substation design

The substation building should be of sound construction and adequately water tight.

Where the substation is in a location of extreme weather or flooding extra measures to prevent water ingress may be required. Substations can be designed so that the switchroom floor level is raised above the most likely flood level. The risk of flooding at a specific location in the UK can be found on the Environment Agency website referenced above.

Substation roofs should be designed so that water will run off easily. It should be constructed for ease of maintenance and the use of materials that would be attractive to thieves (e.g. lead flashing) should be avoided.

Gutters and downspouts should be designed for the maximum level of rainfall prevalent in the location. Drains should be sized for the expected amount of water and allow for easy cleaning.

The substation building should be adequately insulated to prevent large temperature variations.

Substation doors should be well fitted to minimise the passage of the external ambient air into the substation. A weather strip should be fitted over the door to prevent rainwater from collecting on the top of the door. The bottom edge of the door should have a spill fitted to ensure that water is dispersed clear of the bottom opening.

The orientation of doors relative to the sun, the material of which they are constructed and the paint finish can have an impact on the heat that they will transmit into the substation. All personnel access doors should be fitted with self closing mechanisms to prevent them being left open to minimise the ingress of moisture and contaminants in the air.

The use of entry lobbies for normal personnel access doors can provide a barrier to minimise the effect of both heat and moisture on the more sensitive areas of the substation, i.e. high voltage switchrooms.

Substation floors should be sealed to minimise dust and to simplify cleaning.

All cable entries to the substation should be sealed to prevent the ingress of water and, where they are above ground level, airborne contamination. This has the additional effect of preventing vermin from entering the substation. Seals on underground cable entries must be adequate for the expected underground conditions and be installed correctly.

Transformers require ventilation for cooling so the RH in that space will be the same as the external ambient air. The heat from the transformer is normally sufficient to minimise the effects of RH.

There should be no exchange of air between transformer rooms / bays and rooms containing switchgear or protection and control equipment.

Any rooms containing switchgear, batteries or protection and control equipment should be designed to include the mitigating techniques described below as required.

7.2 Techniques and equipment for maintaining internal substation environment

There are several measures that can be used address the control of the environment in the switchrooms and substations as described in the following sections.

7.2.1 Switchroom environment control

The following secondary measures can be implemented to improve the substation environment, these can be implemented where substation environmental conditions fall outside of the above bounds:-

a) Fitting heaters in the switchgear (e.g. in the cable compartments) in cases where humidity is high over a long period of time.
b) Installation of substation heating.
c) Installation of dehumidifiers or air conditioning.

Anti-condensation heaters can be fitted inside the switchgear cable compartments and <u>must</u> operate continuously to prevent condensation forming. They are designed to prevent condensation in that chamber but they do have several disadvantages:

a) They can only be checked during invasive maintenance requiring a circuit outage.
b) They do not remove moisture from the air, but keep the temperature of the compartment above the dew point, thus preventing condensation.
c) They have little beneficial effect on other chambers in the switchgear.
d) If they fail this may lead to condensation and rapid failure of the switchgear.

Substation heaters can be installed to reduce temperature swings within the substation. If fitting heaters in the substation they should be temperature regulated to avoid large temperature swings or be left on continuously. The heating should be checked regularly as if they fail it may lead to condensation and rapid failure of the switchgear. If the switchroom is wet with standing water in a cable trench then substation heaters can contribute to humidity by increasing evaporation rather than getting rid of it.

The options for positively controlling the environment in a substation are air conditioning, heating and dehumidification controlled by room mounted thermostats and humidistats.

The best option depends on the local climate especially temperature variation. The most important factor is to avoid rapid variations in temperature, which in conditions of high humidity may drop below the dew point causing condensation. It is also known that the air inside switchgear is at the same temperature and RH as the ambient air in the substation. Condensation would therefore occur within and without the switchgear, leading to corrosion that would not be apparent until invasive maintenance.

Where positive environment control is installed it should be fitted with an alarm system to report failures in the environment control system, high humidity and low temperature. These alarms should ideally be connected to the SCADA system and highlight faults in the local control room.

7.2.2 Protection and control equipment environment control

Modern electronic protection and control equipment can generate considerable amounts of heat, which may require separate environment control.

If it is situated within the high voltage switchroom care must be taken to ensure that it is taken into account when considering the overall heating requirements.

The comments on switchrooms apply equally to protection and control equipment.

7.2.3 Cable entry points

Cables can enter substations through the roof, walls, or from cable trenches and basements.

Cable entries above ground should be sealed and care should be taken to ensure the exterior finish will not trap water or cause water ingress to the substation.

Cable entries below ground should be sealed preventing water ingress to the trench or basement.

All cable entry seals should be adequate for the expected conditions and correctly installed

Cable trenches should be covered. If the trench contains water this will minimise the exchange of air between the room and the trench and reduce the amount of moisture that will enter the room by evaporation.

In extreme circumstances cable trenches and basements can be sloped to create a sump to collect water that can be pumped clear using a level activated sump.

Cable ducts need to be sealed in such a way as to remain effective taking into account such factors as the thermal cycling of power cables during changes in load, the electromechanical forces on power cables during fault conditions and the modern multicore nature of 33kV and 11kV power, protection and control cables and earth wires.

Where the substation is elevated it is still necessary to seal the cable entries from the cable space to the rooms containing equipment to prevent moisture from entering the substation.

7.3 Maintenance

It is essential that the substation structure and internal environment control is subject to regular inspection and maintenance.

The roof, gutters, downspouts and drains should be inspected prior to known periods of adverse weather and maintained where necessary.

Any environmental control and its associated alarm system should form part of the scheduled inspection and maintenance activity and the frequency should be determined by the severity of the local conditions.

7.4 Monitoring switchroom environment

Temperature / RH surveys using dataloggers should be carried out in substations to confirm that there are no wide variations over a long time period. In carrying out this survey dataloggers should be placed at low and high level at each end and the centre of the room, with one datalogger external to the building to record the ambient conditions.

As the local climate varies considerably throughout the year in each country this survey is repeated to record data during extremes of weather conditions.

The results of any survey should be reviewed and to establish if the switchroom environment is satisfactory and to identify ay areas for remedial work. It should be noted that unacceptable conditions could be due to failure of the environment control equipment or ingress of moisture through lack of maintenance or the failure of inadequately or incorrectly installed cable entry seals.

7.5 Existing substation improvements

The structure and condition of existing substations may give cause for concern.

A survey of the structure should be carried out to determine its condition based on the best practice information above and any deficiencies rectified.

A temperature and humidity survey should be carried out in high voltage switchrooms to determine the actual conditions and if unsatisfactory then the complete substation should be assessed in light of the best practice given above. Simply retrofitting positive environment control will not be cost effective if the substation structure is unsatisfactory.

8 Conclusions

It is known that the internal environment of a substation, especially humidity, can have a significant effect on the development of partial discharge in polymeric components.

The design of the substation can have a major impact on the internal environmental conditions.

Cable entry points are one of the main sources of water ingress to substations and they should be effectively sealed.

The use of positive environment control in substations will maintain the humidity at an acceptable level and prevent sudden temperature swings which can lead to condensation. The environment should be controlled by thermostats and humidistats, with alarms to highlight failure of the environment control system.

It is essential that routine inspection and maintenance is carried out on the substation structure and environment control.

9 Documents Referenced

- BS EN IEC 62271-1:2007 +A1:2011 High-Voltage Switchgear and Controlgear. Common specifications
- IEC 60529 Degrees of Protection Provided by Enclosures (IP Code)
- BS 1339-1:2002 Humidity. Terms, definitions and formulae
- BS 1339-2:2009 (CD-ROM) Humidity. Humidity calculation functions, tables and user guide
- BS 1339-3:2004 Humidity. Guide to the measurement of humidity
- BS 2562:1979 Cable Boxes for Transformers and Reactors
- BS EN 60721-3-3:1995 Classification of environmental conditions. Classification of groups of environmental parameters and their severities. Stationary use at weatherprotected locations (identical to IEC 60721-3-3:1994)

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