

## Substation Design Instruction

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# Acceptable purity limits for SF<sub>6</sub> gas

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## SUBSTATION DESIGN INSTRUCTION

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|------------------------|---------------------------------------------------------------|-------------------------------------------------|
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**SDI 545      Acceptable **purity** limits for SF<sub>6</sub> gas**

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## 1.0 PURPOSE

To set out in detail the minimum **requirements for** quality of sulphur hexafluoride (SF<sub>6</sub>) gas used in SF<sub>6</sub> equipment installed in transmission/zone substations and switching stations.

## 2.0 SCOPE

**This Standard** defines the requirement for SF<sub>6</sub> gas quality to be used in both high and low pressure GIS switchgear, gas insulated circuit breakers and switchboards installed at transmission/zone substations and switching stations.

**This Standard provides guidance on the maximum acceptable quality limits for the new, reclaimed, after-filling and in-service SF<sub>6</sub> gas installed equipment.**

**This Standard shall be read in conjunction with SDI 505 – minimum design and construction requirements for transmission and zone substations and switching stations. This standard shall also be read in conjunction with SMI 122 – Use and handling of sulphur hexafluoride (SF<sub>6</sub>)**

## 3.0 REFERENCES

- Company Policy 9.2.5 - Network Asset Design
- Company Policy 9.2.10 - Network Asset Ratings
- Substation Design Instruction SDI 505 – Minimum design and construction requirements for transmission and zone substations and switching stations
- Substation Maintenance Instruction **SMI 120 - Sulphur hexafluoride (SF<sub>6</sub>) emissions and inventory**
- SMI 122 - Use and handling of sulphur hexafluoride (SF<sub>6</sub>)
- Network Management Plan December 2013 Review
- Electrical Safety Rules
- ENA National Electricity Network Safety Code (Doc 01-2008)
- IEC 60376:2005 – Specification for technical grade sulphur hexafluoride (SF<sub>6</sub>) for use in electrical equipment
- IEC 60480:2004 – Guidelines for checking and treatment of sulphur hexafluoride (SF<sub>6</sub>) taken from electrical and specification for its re-use
- IEEE Std 1125 - IEEE Guide for Moisture Measurement and Control in SF<sub>6</sub> Gas-Insulated Equipment
- *Electricity Supply Act 1995 (as amended)*
- *Work Health and Safety Act 2011 (NSW)*

## 4.0 DEFINITIONS AND ABBREVIATIONS

### **Absolute pressure**

It is zero-referenced against a perfect vacuum, so it is equal to gauge pressure plus atmospheric pressure. A gas pressurised switchgear designed for an operating pressure of 7.5 bar gauge equates to an absolute pressure of 8.5 bar.

### **Atmospheric pressure**

Pressure caused by the weight of the atmosphere. At sea level it has a mean value of one atmosphere but reduces with increasing altitude.

The standard atmosphere (symbol: atm) is a unit of pressure equal to 101.325 kPa or 101.325 bars. It is equivalent to 760 mmHg (torr), 29.92 inHg and 14.696 psi.

|                                               |                                                                                                                                                                                                                                                                          |
|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Insulating gas</b> <sup>1</sup>            | Gas with negligible low electric conductivity, used to separate parts of different electrical properties.                                                                                                                                                                |
| <b>Low re-use pressure range</b> <sup>1</sup> | For equipment to be rated for absolute pressure less than 200 kPa.                                                                                                                                                                                                       |
| <b>Gauge pressure</b>                         | Gauge pressure is zero-referenced against ambient air pressure, and is equal to absolute pressure minus atmospheric pressure.                                                                                                                                            |
| <b>GC-TCD</b>                                 | Gas Chromatography                                                                                                                                                                                                                                                       |
| <b>High pressure range</b> <sup>1</sup>       | For equipment to be rated for absolute pressure greater than or equal to 200 kPa.                                                                                                                                                                                        |
| <b>New sulphur hexafluoride</b> <sup>1</sup>  | SF <sub>6</sub> gas complying with IEC 60376, and <b>not</b> used previously.                                                                                                                                                                                            |
| <b>Reclaiming</b> <sup>1</sup>                | Elimination of soluble and insoluble contaminants from an insulating liquid or gas by chemical adsorption means, in addition to mechanical means, in order to restore properties as close as possible to the original values or to the levels proposed in this standard. |
| <b>Reclaimed gas</b> <sup>1</sup>             | Gas that has been processed or recycled by a reclaimer.                                                                                                                                                                                                                  |
| <b>Re-use gas</b>                             | Use of reclaimed gas on-site for refilling installed electrical equipment                                                                                                                                                                                                |

## 5.0 ACTIONS

### 5.1 General

New SF<sub>6</sub> gas can contain impurities such as air (O<sub>2</sub> and N<sub>2</sub>), CF<sub>4</sub> (tetrafluoromethane), moisture, mineral oil and HF (hydrofluoric acid). Due to the presence of these impurities, the acceptable level of purity of the new SF<sub>6</sub> gas shall not be less than 99.7% by weight (measured in liquid phase)<sup>2</sup> in cylinders. Annexure 1 – Origin of SF<sub>6</sub> impurities, summarises the main impurities and their sources for rectification.

SF<sub>6</sub> gas recovered from electrical equipment in operation can contain impurities due to ageing and electrical stresses. The expected additional impurities in SF<sub>6</sub> gas taken from equipment can come from both gas handling and the operation of the equipment.

Equipment containing SF<sub>6</sub> must be reclaimed and must not be released into the atmosphere. Acceptable purity levels for SF<sub>6</sub> for re-use in equipment are detailed in this standard and require certification approval by the Network Substations Manager prior to acceptance for re-use.

For correct handling of SF<sub>6</sub> gas, refer to SMI 122 - Use and handling of sulphur hexafluoride (SF<sub>6</sub>).

All portable SF<sub>6</sub> gas sampling and testing devices for on-site testing shall be approved for use by Primary Systems Engineering and of a pump back or gas return design. The test device shall be capable of testing the percentage volume or mass of Air (O<sub>2</sub> and N<sub>2</sub>), Moisture (H<sub>2</sub>O), Acidity (HF) and reactive gaseous decomposition by products (CF<sub>4</sub>, SO<sub>2</sub>, SOF<sub>2</sub>). Instruments with measurement capability of SO<sub>2</sub>F<sub>2</sub>, SF<sub>4</sub> and WF<sub>6</sub> are preferred but optional.

<sup>1</sup> IEC 60480:2004 – Guidelines for checking and treatment of sulphur hexafluoride (SF<sub>6</sub>) taken from electrical and specification for its re-use

<sup>2</sup> IEC 60376:2005 - Specification for technical grade sulphur hexafluoride (SF<sub>6</sub>) for use in electrical equipment

The sampling and testing of the SF<sub>6</sub> gas in SF<sub>6</sub> filled equipment shall be site based. However, for SF<sub>6</sub> gas that is of critical nature such as samples collected from GIS or CBS performing capacitor switching suspected for high arcing; by-products shall be tested in a laboratory for precision testing.

## 5.2 Acceptable impurity limits

As a minimum, the quality of SF<sub>6</sub> gas for new, reclaimed, pre-commissioning and in-service SF<sub>6</sub> gas shall comply with the acceptable limits set out in this standard unless the manufacturer's specifications are more stringent than these requirements.

Endeavour Energy's minimum requirement for new SF<sub>6</sub> gas, supplied in green collared cylinders by the manufacturer shall have a purity of 99.7%<sup>2</sup> as detailed in Table 1. This applies unless the manufacturer/supplier of SF<sub>6</sub> electrical equipment stipulates a higher level of purity for the supplied equipment. In this circumstance the higher purity standard shall apply.

Tables 1, below specifies the maximum allowable levels for various impurities that can be contained in SF<sub>6</sub> gas and equipment in new, reclaimed, after-filling and for in-service gas and equipment to meet Endeavour Energy's minimum requirements.

Table 1 – Maximum acceptable impurity limits for SF<sub>6</sub> gas and their origin (volumetric measurements at 100kPa & 20°C unless stated otherwise)

| Contents                                                           | Maximum acceptable impurity levels:                       |                                                                 |                                                                      |                                          | Main Origin                                                 |
|--------------------------------------------------------------------|-----------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------------------|------------------------------------------|-------------------------------------------------------------|
|                                                                    | New SF <sub>6</sub> gas<br>(In accordance with IEC 60376) | Reclaimed SF <sub>6</sub> gas<br>(consideration with IEC 60480) | After-filling SF <sub>6</sub> gas (in equipment) - <i>see note 1</i> | In-service limit for SF <sub>6</sub> gas |                                                             |
| Air (O <sub>2</sub> and N <sub>2</sub> )                           | 1% volume in total<br>[2000 mg/kg]                        | 1% volume in total                                              | 1.5% volume in total                                                 | 3% volume in total                       | Air (O <sub>2</sub> and N <sub>2</sub> ) from gas handling  |
| CF <sub>4</sub>                                                    | 4000 ppmv<br>[2400 mg/kg]                                 |                                                                 |                                                                      |                                          | CF <sub>4</sub> from switching arcs                         |
| H <sub>2</sub> O<br>ppmv (dew point)<br><br><i>See note 2</i>      | 200 ppmv (- 36 °C)<br>[25 mg/kg]                          | 200 ppmv (-36 °C)<br>[25 mg/kg]                                 | Interrupting chambers:<br>200 ppmv (-36 °C)<br>[25 mg/kg]            | For absolute pressure<br>< 200 kPa       | Absorption from surfaces and polymers                       |
|                                                                    |                                                           |                                                                 | Non-interrupting chambers:<br>350 ppmv (-31 °C)<br>[45 mg/kg]        | 750 ppmv<br>(- 23 °C)<br>[95 mg/kg]      | 470 ppmv<br>(- 28 °C)<br>[60 mg/kg]                         |
| Mineral oil                                                        | Nil                                                       | 2 ppmw                                                          | 2 ppmw                                                               | 10 ppmw                                  | During gas handling - introduced from pumps and lubrication |
| Total acidity expressed in HF                                      | 6 ppmv<br>[0.8 mg/kg]                                     | 6 ppmv<br>[0.8 mg/kg]                                           | 6 ppmv<br>[0.8 mg/kg]                                                | 2000 ppmv<br>(combined value)            | Sparking, Corona, partial discharge or internal arc         |
| SO <sub>2</sub> + SO <sub>2</sub> F <sub>2</sub>                   | Nil                                                       | 12 ppmv                                                         | 12 ppmv                                                              |                                          | Internal arc, switching                                     |
| Total reactive gaseous decomposition by-products <i>See note 3</i> | Nil                                                       | 50 ppmv<br>Note 4                                               | 50 ppmv<br>Note 4                                                    |                                          | Sparking, Corona, partial discharge Switching arc erosion   |
| SF <sub>4</sub> and WF <sub>6</sub>                                | Nil                                                       |                                                                 |                                                                      | 100 ppmv                                 | Arcing with toxicity impact                                 |

**Note 1:** The gas shall be tested after 24 hours of filling equipment.

**Note 2:** Dew point measured / corrected at 100 kPa (1 Bar) and 20 C (refer annexure 2 for conversion)

**Note 3:** Combined SO<sub>2</sub>, SOF<sub>2</sub>, HF, SO<sub>2</sub>F<sub>2</sub>, SF<sub>4</sub> and WF<sub>6</sub>

**Note 4:** this implies the maximum of 50 ppmv of SO<sub>2</sub>, SOF<sub>2</sub>, HF, SO<sub>2</sub>F<sub>2</sub>, SF<sub>4</sub> and WF<sub>6</sub> or 12 ppmv of SO<sub>2</sub>+ SOF<sub>2</sub> whichever value is reached first

Table 2 – On-site and laboratory SF<sub>6</sub> gas analytical methods

| Contents                                                                                                        | Analytical methods<br>(for indication only, not exhaustive) |                            |
|-----------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|----------------------------|
|                                                                                                                 | On-site test methods (devices)                              | Laboratory methods         |
| Air<br>(O <sub>2</sub> and N <sub>2</sub> )                                                                     | Infra-red absorption                                        | Infrared absorption        |
|                                                                                                                 | Portable GC-TCD                                             | Gas-chromatographic        |
|                                                                                                                 | Density meter (for the % of SF <sub>6</sub> )               | Density                    |
| CF <sub>4</sub>                                                                                                 | Portable GC-TCD                                             | Gas-chromatographic        |
|                                                                                                                 | Infrared absorption                                         | Infrared absorption        |
| H <sub>2</sub> O                                                                                                | Infra-red absorption                                        | Infrared absorption        |
|                                                                                                                 | Chilled mirror hygrometer                                   | Gravimetric method         |
|                                                                                                                 | Electronic hygrometer                                       | Electrolytic method        |
|                                                                                                                 | Electrochemical sensor                                      | Dew point method           |
| Mineral oil                                                                                                     | Tube of mineral oil                                         | Infrared absorption method |
|                                                                                                                 |                                                             | GC-FID                     |
| Reactive gases<br>SO <sub>2</sub> , SOF <sub>2</sub> , SO <sub>2</sub> F <sub>2</sub> , SF <sub>4</sub> ,<br>HF | Portable GC-TC                                              | Electrochemical sensor     |
|                                                                                                                 | Electrochemical sensor                                      | Titration                  |
|                                                                                                                 | Infra-red absorption                                        | Infrared absorption method |

## 6.0 AUTHORITIES AND RESPONSIBILITIES

The **Chief Engineer** has the authority and responsibility for approving this instruction.

The **Manager Primary Systems** has the authority and responsibility for making recommendations to the Chief Engineer in respect to this instruction.

The **Network Substations Manager, Primary Systems** has the authority and responsibility for maintaining that the content of this instruction is kept up to date based on industry best practice.

The **Regional Transmission Managers** have the authority and responsibility for verifying that the purity and quality of SF<sub>6</sub> gas and gas in equipment is maintained in accordance with the limits in this instruction and associated SMI 120 - **Sulphur** hexafluoride (SF<sub>6</sub>) emissions and inventory.

All **Endeavour Energy employees and/or contractors** have the authority and responsibility for:

- maintaining that requirements of this instruction and SDI 505 are met;
- working in accordance with local and statutory requirements;
- maintaining that public safety is not compromised; and
- working in accordance with Endeavour Energy's Electrical Safety Rules.

All **Project Managers** have the authority and responsibility for:

- meeting the requirements of this instruction within their area of responsibility;
- verifying that Endeavour Energy employees and/or contractors engaged to perform the work have appropriate qualifications; and
- maintaining that appropriate equipment details are entered into the Ellipse database as part of the work.

## 7.0 DOCUMENT CONTROL

**Documentation content coordinator:** **Network Substations Manager**

**Documentation process coordinator:** **Standards** Process Coordinator

Annexure 1 – Origin of SF<sub>6</sub> impurities

| SF <sub>6</sub> situation and use | Sources of impurities                         | Possible impurities                                                                                                                                                                                                                                      |
|-----------------------------------|-----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| During handling and in service    | Leaks and incomplete evacuation<br>Desorption | Air, Oil, H <sub>2</sub> O                                                                                                                                                                                                                               |
| Insulating function               | Partial discharges: corona and sparking       | HF, SO <sub>2</sub> , SOF <sub>2</sub> , SOF <sub>4</sub> , SO <sub>2</sub> F <sub>2</sub>                                                                                                                                                               |
| Switching equipment               | Switching arc erosion                         | H <sub>2</sub> O, HF, SO <sub>2</sub> , SOF <sub>2</sub> , SOF <sub>4</sub> , SO <sub>2</sub> F <sub>2</sub> , CuF <sub>2</sub> , SF <sub>4</sub> , WO <sub>3</sub> , CF <sub>4</sub> , AlF <sub>3</sub>                                                 |
|                                   | Mechanical erosion                            | Metal dusts, particles                                                                                                                                                                                                                                   |
| Internal arc                      | Melting and decomposition of materials        | Air, H <sub>2</sub> O, HF, SO <sub>2</sub> , SOF <sub>2</sub> , SOF <sub>4</sub> , SO <sub>2</sub> F <sub>2</sub> , SF <sub>4</sub> , CF <sub>4</sub><br>Metal dusts, particles, AlF <sub>3</sub> , FeF <sub>3</sub> WO <sub>3</sub><br>CuF <sub>2</sub> |

## Annexure 2 – Conversion between dew point and moisture volume concentration with various gas filling pressures

| ppmv      |     | SF <sub>6</sub> rated filling pressures (kPa) – absolute pressure |      |      |      |      |      |      |      |      |
|-----------|-----|-------------------------------------------------------------------|------|------|------|------|------|------|------|------|
|           |     | 100                                                               | 150  | 200  | 300  | 400  | 500  | 600  | 700  | 850  |
| Dew point | -41 | 115                                                               | 76.4 | 57.3 | 38.2 | 28.6 | 22.9 | 19.1 | 16.4 | 13.5 |
|           | -40 | 128                                                               | 85.5 | 64.2 | 42.8 | 32.1 | 25.7 | 21.4 | 18.3 | 15.1 |
|           | -39 | 144                                                               | 95.8 | 71.8 | 47.9 | 35.9 | 28.7 | 23.9 | 20.5 | 16.9 |
|           | -38 | 161                                                               | 107  | 80.3 | 53.5 | 40.2 | 32.1 | 26.8 | 22.9 | 18.9 |
|           | -37 | 179                                                               | 120  | 89.7 | 59.8 | 44.9 | 35.9 | 29.9 | 25.6 | 21.1 |
|           | -36 | 200                                                               | 133  | 100  | 66.7 | 50.1 | 40   | 33.4 | 28.6 | 23.6 |
|           | -35 | 223                                                               | 149  | 112  | 74.4 | 55.8 | 44.7 | 37.2 | 31.9 | 26.3 |
|           | -34 | 249                                                               | 166  | 124  | 82.9 | 62.2 | 49.8 | 41.5 | 35.5 | 29.3 |
|           | -33 | 277                                                               | 185  | 138  | 92.3 | 69.2 | 55.4 | 46.1 | 39.6 | 32.6 |
|           | -32 | 308                                                               | 205  | 154  | 103  | 77   | 61.6 | 51.3 | 44   | 36.2 |
|           | -31 | 342                                                               | 228  | 171  | 114  | 85.5 | 68.4 | 57   | 48.9 | 40.3 |
|           | -30 | 380                                                               | 253  | 190  | 127  | 95   | 76   | 63.3 | 54.3 | 44.7 |
|           | -29 | 421                                                               | 281  | 211  | 140  | 105  | 84.3 | 70.2 | 60.2 | 49.6 |
|           | -28 | 467                                                               | 311  | 233  | 156  | 117  | 93.4 | 77.8 | 66.7 | 54.9 |
|           | -27 | 517                                                               | 345  | 258  | 172  | 129  | 103  | 86.2 | 73.9 | 60.8 |
|           | -26 | 572                                                               | 381  | 286  | 191  | 143  | 114  | 95.3 | 81.7 | 67.3 |
|           | -25 | 632                                                               | 422  | 316  | 211  | 158  | 126  | 105  | 90.3 | 74.4 |
|           | -24 | 698                                                               | 466  | 349  | 233  | 175  | 140  | 116  | 99.8 | 82.2 |
|           | -23 | 771                                                               | 514  | 385  | 257  | 193  | 154  | 128  | 110  | 90.7 |
|           | -22 | 850                                                               | 567  | 425  | 283  | 213  | 170  | 142  | 121  | 100  |
|           | -21 | 937                                                               | 625  | 468  | 312  | 234  | 187  | 156  | 134  | 110  |
|           | -20 | 1032                                                              | 688  | 516  | 344  | 258  | 206  | 172  | 147  | 121  |
|           | -19 | 1140                                                              | 757  | 568  | 378  | 284  | 227  | 189  | 162  | 134  |
|           | -18 | 1250                                                              | 832  | 624  | 416  | 312  | 250  | 208  | 178  | 147  |
|           | -17 | 1370                                                              | 914  | 686  | 457  | 343  | 274  | 229  | 196  | 161  |
|           | -16 | 1510                                                              | 1000 | 753  | 502  | 376  | 301  | 251  | 215  | 177  |
|           | -15 | 1650                                                              | 1100 | 826  | 551  | 413  | 330  | 275  | 236  | 194  |
|           | -14 | 1810                                                              | 1210 | 905  | 604  | 453  | 362  | 302  | 259  | 213  |
|           | -13 | 1980                                                              | 1320 | 992  | 661  | 496  | 397  | 331  | 283  | 233  |
|           | -12 | 2170                                                              | 1450 | 1090 | 724  | 543  | 434  | 362  | 310  | 255  |
|           | -11 | 2380                                                              | 1580 | 1190 | 792  | 594  | 475  | 396  | 339  | 279  |
|           | -10 | 2600                                                              | 1730 | 1300 | 866  | 649  | 519  | 433  | 371  | 306  |
|           | -9  | 2840                                                              | 1890 | 1420 | 946  | 709  | 567  | 473  | 405  | 334  |
|           | -8  | 3100                                                              | 2060 | 1550 | 1030 | 774  | 619  | 516  | 442  | 364  |
|           | -7  | 3380                                                              | 2250 | 1690 | 1130 | 845  | 676  | 563  | 483  | 398  |
|           | -6  | 3680                                                              | 2460 | 1840 | 1230 | 921  | 737  | 614  | 526  | 433  |
|           | -5  | 4010                                                              | 2680 | 2010 | 1340 | 1000 | 803  | 669  | 574  | 472  |

Legend:

|                                                                                     |                                  |                                                                                     |                               |
|-------------------------------------------------------------------------------------|----------------------------------|-------------------------------------------------------------------------------------|-------------------------------|
|  | - New and reclaimed gas          |  | - Equipment pre-commissioning |
|  | - Gas suitable for continued use |  | - Gas unsuitable for use      |