Presenting
Proposed New Reference Document

Moisture Phenomena in Insulating Systems of Dry, Gas Insulated and Liquid Immersed Transformers & Reactors

Prof. Valery G. Davydov, Consultant
Melbourne, Australia

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valery.davydov@ieee.org

Proposal Made by the Author to IEEE/PES Transformers Committee in 2011

- **To develop a new reference document tentatively titled** *"Moisture Phenomena in Insulating Systems of Dry, Gas Insulated and Liquid Immersed Transformers and Reactors"*
- **To consider an IEEE/IEC dual logo status of the document proposed**

Current Status of the Proposal

- **At its Fall 2011 Meeting, the IEEE/PES Transformers Committee has considered the proposal**
- **Further consideration of the proposal has been assigned to the TF Moisture in Solid Insulation (IL SC)**

Statement of the Problem

- **The current approach is that each existing IEEE standard or guide contains its own solution to the moisture related phenomena it is dealing with**
- **The current approach is lacking benchmarking of the moisture state of insulation of transformers and reactors**
- **The proposed approach is unprecedented in the series of IEEE/PES Transformers Committee standard documents**

It Is Proposed:

- **To consider the issue of Moisture in Insulating Systems of Transformers and Reactors as a <u>whole</u>**
- **To develop a new document that would serve as a <u>single</u> knowledge base document for all IEEE (and IEC?) standards and guides dealing with moisture**
- **To consider the Insulation System of a transformer or reactor as <u>a physical complex</u>:**
  1. Solid-Gas (dry type, gas insulated & vacuum insulated units)
  2. Solid-Liquid (liquid immersed units without headspace), or
  3. Solid-Liquid-Gas (liquid immersed units with headspace)
- **To use the physical laws and mathematical equations for the <u>Solid-Gas Physical Complex</u> as the basis for all the three above listed physical complexes**

A Key Solution Proposed for Resolving the Moisture Issue

- **Let's consider two major types of moisture dynamics in the insulation system of a transformer or reactor:**
  1. Moisture exchange between the surface of solid insulation and the surrounding liquid or gaseous medium
  2. Moisture diffusion within the solid insulation
- **The key solution to the issue of moisture lays in proper addressing these two types of moisture dynamics**

Resolving the Issue of ‘Moisture Diffusion vs. Moisture Exchange’

- **The solution would lay in measuring or evaluating the two parameters:**
  1. Water content of surface of insulation
  2. Maximum water content of inner layers of solid insulation
- **It is proposed using the two parameters as the benchmarks**

Sections of New Document Proposed

1. Terminology and definitions
2. Measurement and evaluation of moisture-in-gas insulation parameters
3. Measurement and evaluation of moisture-in-liquid insulation parameters
4. Measurement and evaluation of moisture-in-solid insulation parameters
5. Evaluation of aging and end of life of solid insulation parameters
6. Factory/workshop application of knowledge on moisture; benchmarking
7. Field application of knowledge on moisture

Section 1: **Terminology and Definitions**

- **This section defines the terminology used in the document**

Section 2: **Measurement and Evaluation of Moisture-in-Gas Insulation Parameters**

- **This section describes general methods of moisture assessment in a gaseous medium**
- **Parameters of interest:**
  - Water vapor pressure
  - Saturation water vapor pressure
  - Total gas pressure
  - Absolute humidity
  - Relative humidity
  - Gas temperature
  - Dew point temperature
  - Other relevant parameters

Section 3: **Measurement and Evaluation of Moisture-in-Liquid Insulation Parameters**

- **Types of moisture assessments to consider:**
  - Sequential (not on-line):
    - **Assessments made one after the other (e.g. at the factory)**
    - **Periodic assessments (e.g. in the field)**
  - Continuous on-line moisture assessments
    - **At the factory and in the field**

Insulating Liquids to Consider

- **<u>All</u> insulating liquids used in modern transformers and reactors:**
  - Mineral oils
  - Natural esters
  - Synthetic esters
  - Silicon insulating liquids
  - Insulating liquids for high temperature applications
  - Other

Parameters of Interest

- **Water content of insulating liquid, ppm**
- **Water solubility limit of insulating liquid, ppm**
- **Relative saturation of insulating liquid, %**
- **Temperature of insulating liquid**
- **Distributions of moisture and temperature in the insulating liquid medium of a loaded unit**
- **Other relevant parameters**

Section 4: **Measurement and Evaluation of Moisture-in-Solid Insulation Parameters**

- **It is proposed that this section consists of the following three <u>sub-sections</u>:**
  1. <u>Measurement</u> of moisture in solid insulation using balance
  2. <u>Evaluation</u> of moisture in solid insulation using dielectric response methods
  3. <u>Inferring</u> of moisture in solid insulation from measurements conducted in liquid or gaseous medium

Sub-Section 4.1: **Measurement of Moisture in Solid Insulation using Balance**

- **This sub-section describes methods of moisture measurement using samples of solid insulation**
- **Parameters of interest:**
  - Water content of surface of insulation of a unit
  - Distribution of moisture inside solid insulation
  - And derived from the above – the water content of the wettest inner layer

Sub-Section 4.2: **Evaluation of Moisture in Solid Insulation using Dielectric Response Methods**

- **Parameters of interest:**
  - Distribution of moisture in solid insulation of unit
  - Distribution of temperature in solid insulation of unit during the moisture assessment

Sub-Section 4.3: **Inferring of Moisture-in-Insulation Parameters from Moisture-in-Gas and Moisture-in-Liquid Data**

- **This sub-section describes methods of inferring moisture in solid insulation from that measured in the liquid or gaseous medium**
- **Parameters of interest:**
  - Parameters to be measured
  - Parameters to be inferred
  - Distributions of moisture and temperature

What Can We Infer from Daily Moisture Fluctuations?

- **The water content of surface of solid insulation, %**

Notes regarding Inferring of Moisture Parameters in Solid Insulation

- **The existing inferring methods usually utilize:**
  - Measured parameters (e.g. RS, T, Load, other)
  - Equilibrium charts (vary for new and aged solids and liquids)
  - Intelligent algorithms (via utilizing moisture dynamics)

Section 5: **Evaluation of Aging and End of Life Parameters for Solid Insulation**

- **This section describes approaches for evaluation of parameters of end of life of solid insulation affected by moisture**
- **For the standard test procedures, the raw data is to be obtained from:**
  - Modified existing test models (e.g. Dual Temperature model, Lockie model, other), that would have new feature of:
    - **Moisture level control**
    - **On-line monitoring of data**
  - New test models featuring:
    - **Condition control – temperature, moisture, oxygen and chemicals**
    - **Monitoring of data – continuous on-line and periodic off-line monitoring**
- **For the field applications, the raw data is to be obtained from both periodic and continuous on-line assessments in the field**

Materials and Parameters of Interest

- **It is proposed that consideration is given to the following types of solid insulating materials:**
  - Cellulose materials:
    - **Kraft paper**
    - **Thermally upgraded paper**
    - **Pressboard**
    - **Compressed wood**
    - **Other (e.g. cotton)**
  - Polymer materials:
    - **Aramid fiber materials**
    - **Other**
- **Aging and end of life parameters of interest:**
  - Degree of polymerization (DP) – for cellulose materials
  - 50% tensile strength – for both cellulose and polymer materials
  - Life expectancy
  - Loss of insulation life

Notes regarding Aging of Solid Insulation

- **It is proposed that aging of solid insulation is considered under the combined effect of the following parameters:**
  1. Temperature only – assuming that insulation is dry – for the reference purpose
  2. Temperature and moisture – for units that are properly preserved against the ingress of atmospheric air
  3. Temperature, moisture and oxygen – for units that feature some exposure to atmospheric air
  4. Temperature, moisture and aggressive chemicals – for old or contaminated units

Section 6: **Factory/Workshop Application of Knowledge on Moisture; Benchmarking**

- **This section describes a factory/workshop approach to the <u>benchmarking</u>**

Benchmarking of New and Repaired Units

It is proposed introducing the factory/workshop benchmarking of the following parameters:

1. Water content of solid insulation, characterized by the two values:
   a. **Water content of insulation surface**
   b. **Maximum water content of inner layers of insulation**
2. Water Solubility Limit parameter – for insulation liquid immersed units
3. Aging parameters of solid insulation:
   a. **DP and 50% tensile strength for cellulose materials**
   b. **50% tensile strength for polymer materials**

Section 7: **Field Application of Knowledge on Moisture**

- **This section describes:**
  - The risks associated with moisture in operating transformers and reactors
  - Approaches to mitigate the risks
  - Tracing the changes in moisture conditions in the field against the factory/workshop benchmarks

Moisture Risks for Liquid Immersed Units

1. **Bubble emission and water drops release from winding insulation:**
   a. During a short term emergency loading above the nameplate rating
   b. During a cold start following a long-term (years) storage
2. **Formation of oversaturated (foggy) insulating liquid:**
   a. During a sudden drop of load after a period of high load
   b. During a rapid cooling of the insulating liquid in the cooler (e.g. due to a sudden heavy rain on a hot summer day)
   c. During load removal in sub-zero winter weather
3. **Formation of water drops at the main tank's inlet of the conservator during a cooling period**
4. **Risk of loss of life of solid insulation**
5. **Risk of loss of life of insulating liquid**

Moisture Risks for Gas-Insulated Units

- **Risk of loss of life of solid insulation due to moisture**
- **For dry-type units, the risk of dielectric breakdown due to the high moisture content when the unit was de-energized for a prolonged period and then must be re-energized**
  - This is more of an installation / maintenance issue rather than loading

Tracing Changes in the Field against Benchmarks

- **Parameters to be evaluated in the field:**
  1. Two values of the water content of solid insulation:
     a. **Water content of insulation surface**
     b. **Maximum water content of inner layers of insulation**
  2. Water Solubility Limit parameter – for insulation liquid immersed units
  3. Aging parameters of solid insulation:
     a. **DP and 50% tensile strength for cellulose materials**
     b. **50% tensile strength for polymer materials**

Proposed Future Direction of this TF to Present at the IL SC Meeting

- **It is proposed that the status of the Task Force "Moisture in Solid Insulation" is upgraded to the status of a Working Group**
- **It is also proposed that the new Working Group develops a guide for the interpretation and benchmarking of the moisture related phenomena**
- **The intended draft Title, Scope and Purpose for the PAR (Project Authorization Request) are suggested in the next slides**

Intended Title (Draft)

- **Guide for the Interpretation and Benchmarking of Moisture and Moisture Related Parameters in Dry, Gas Insulated and Liquid Immersed Transformers and Reactors**

Intended Scope (Draft)

This guide applies to dry, gas insulated and liquid immersed transformers and reactors and addresses:

1. The theory of moisture dynamics and methods of assessment of moisture and moisture related parameters in solid-gas, solid-liquid and solid-liquid-gas insulating physical complexes
2. The interpretation of measurements and evaluations of moisture and moisture related parameters
3. The risks associated with moisture in operating transformers and reactors, and approaches to mitigate the risks
4. The benchmarking of moisture and moisture related parameters
5. Tracing the changes against the benchmarks through the life of the transformer or reactor
6. A bibliography of related literature

Intended Purpose (Draft)

- **There is a need for a new reference guide, written in a proper scientific and engineering manner, which would serve as a single knowledge base for other standards and guides dealing with moisture and moisture related phenomena in dry, gas insulated and liquid immersed transformers and reactors. After such a reference guide is developed, each existing guide or standard could refer to it and, if needed, build a higher level moisture related application on the basis of the comprehensive and up-to-date information presented in it.**
- **This guide, therefore, recommends the ways of comprehensive assessment of moisture and moisture related parameters of transformers and reactors, their benchmarking at the factory or workshop, tracing the changes against the benchmarks throughout the life of the units in the field, and mitigating the risks associated with moisture.**

Closing Remarks

- **If the proposal for the establishment of a new WG is supported, it is suggested that an initiative group consisting of the WG Chair, WG Secretary and the author is formed at this TF meeting for tuning the intended Title, Scope, and Purpose**
- **The initiative group will collect comments from the TF Members during the period from March to October 2012, and present the tuned intended Title, Scope, and Purpose to the F12 TF meeting**
- **The Title, Scope, and Purpose for the PAR are to be discussed and finalized at the F12 TF meeting**

Questions?