Transzformátorok

meghibásodása,

meghibásodások diagnosztikája,

a diagnosztika alapján

végrehajtható beavatkozások

CIGRE Working Group WG12.18

CIGRÉ

Conseil International des Grands Réseaux

Électriques á Haute Tension

(International Conference on Large High Voltage Electric Systems)

CIGRÉ célja: Megkönnyíteni és elősegíteni a műszaki tudás és információ áramlást az összes állam között a villamos energia termelés és a nagyfeszültségű átvitel területén

SC = Study Committee (Tanulmányi Bizottság)

SC12 = Study Committee : Transformers (A2)
Working Group WG 12.18
„Life Management Technique for Power Transformers”

Task Force = TF

GUIDE
for
Life Management Techniques
For Power Transformers

Prepared by
CIGRE WG 12-18

V. Sokolov (UKR) – Convenor
J. Lapworth (GBR), J. Harley (USA), P. Guuinic (FRA) – Task Force Leaders

G. Alcantara (ESP), B. Astrom (BRA), J. Aubin (CAN), P. Austin (AUS), R. Baehr (DEU), P. Balma (USA), C. Bengtsson (SWE), Z. Berler (USA), P. Boss (CHE), F. Cabezon (ESP), K. Carrander (SWE), V. Chorenogotsky (UKR), P. Christensen (BEL), **G. Csepes (HUN),** M. Dietrich (USA), T. Domzalski (POL), R. de Lhorbe (CAN), K. Eckholz (DEU), N. Fantana (DEU), H. Fujita (JPN), P. Goosen (ZAF), P. Griffin (USA), S. Hall (GBR), G. Jiroveanu (ROM), J. Isecke (USA), A. Kachler (DEU), J. Kanters (NLD), M. Kazmierski (POL), J. Kelly (USA), M. Lachman (USA), J. Lackey (CAN), P-G Larsen (NOR), P. Leemans (BEL), S. Lindgren (USA), S. Lizunov (RUS), A. Lokhanin (RUS), L. Magallanes (MEX), S. Manerikar (IND), A. McIntosh (GBR), O. Monzani (ITA), B.

Noirhomme (CAN), T. Noonan (IRL), B Pahlavanpour (GBR), B. Patel (USA), G. Polovick (CAN), L.J. Posada (MEX), V. Samoilis (GRC), L. Savio (USA), R. Sobocki (POL), C. Stefanski (USA), U. Sundermann (DEU), M. Svensson (SWE), M. Thaden (USA), L. Valenta (CZE), Y. Vachiratarapadorn (THA), S. Van Wyk (ZAF), G. Zafferani (ITA).

- 128 oldal, 7 főfejezet, 17 függelék, 7 ábra

1. Bevezetés

- jelentős érdeklődés tapasztalható élettartam menedzselés iránt
- egyre öregebb berendezések,
- közelednek „eredeti" élettartam vége felé
-egyre kevesebb szakértő áll rendelkezésre

- erős nyomás nehezedik karbantartási költségek csökkentése területén, az „idő” függő karbantartás helyett az állapot függő karbantartás felé elmozdulás tapasztalható

- Szervezeti változások, szétvált a „3” fő ágazat, fontos lett a maradék élettartam becslése,

- Új diagnosztikai és monitoring technikák váltak elérhetővé

Alapvetően az élettartam menedzselés:

minél többet kivenni a berendezésből

„to get the most out of an asset”

Biztosítani azokat a tevékenységeket amellyel leghosszabb élettartam vagy minimális élettartam költség keletkezik

Victor Sokolov (UKR) – Convenor

Using the existing body of knowledge and technologies, and looking into the future, develop guidelines with the objective to manage the life of transformers, to reduce failures, and to extend the life of transformers in order to produce a reliable and cost effective supply of electricity.

The work was organized into three task forces:

Task Force 1 - General Knowledge and Theoretical Issues (John LAPWORTH Leader)

Task Force 2 - Diagnostic and Monitoring Techniques (Jack HARLEY, Leader)

Task Force 3 - Operations on Transformers (Pieter GOOSEN/Victor SOKOLOV Leaders)

Task Force 4 - Application of Polarisation Techniques (Philippe GUUINIC Leader) was added to provide a review and report on the experience of users of recovery voltage and polarisation current techniques for determining insulation moisture levels. The work was performed within CIGRE WG 15-01-09, and the results have been published in Electra.[1]

S. Gubanski and co-authors, “Dielectric Response Methods for Diagnostics of Power Transformers”, Report CIGRE TF 15-01-09, Electric June 2002.

2. Közös célok és előnyök

- lásd előbbieket, és még
- egyik legdrágább berendezés, de nehéz a költségeket becsülni (direkt, indirekt költségek)
- nehéz igazi univerzális útmutatót adni

- bizonyos mértékben gazdaságossági aspektusok is találhatók a tanulmányban, de főleg műszaki témakörök szerepelnek

A WG 12.18 Munka Bizottság fő céljai:

Egy gyakorlati segédeszköz közreadása, amelyet mindenki, aki transzformátorok menedzselésével foglalkozik használhat, amely képes figyelembe venni a helyi körülményekből, gyakorlatból és szükségletekből adódó különbözőségeket.

Concepts for Life Management of Power Transformers:

- Improvements over traditional time-based maintenance, e.g. - - Condition based or Reliability Centered Maintenance.
- Maintaining a transformer in service
- Continuity of supply. How to operate a defective unit
- Priority of in-field repair and on-line processing
- Minimizing the remedy actions. Making the most effective remedial actions
- Comprehensive life assessment and/or extension program

A major benefit of the work was to provide formalised and unified descriptions of processes and methodologies, to ensure a complete coverage of all relevant aspects.

In this way users should be able to answer important questions such as:

Do I need to do anything?
What should I do?
Why am I doing it?
What are the consequences?

To develop cooperation and communication between parties and to facilitate such communication, a vocabulary ***(Appendix 1)*** of commonly used terms was agreed upon and used consistently to avoid confusion and ambiguity.

Appendix 1: Vocabulary

Failure: **The IEC 60050 definition of failure is:**

The termination of the ability of an item to perform a required function.

Notes on this definition state:

1- After failure the item has a fault.

2- "Failure" is an event, as distinguished from "fault," which is a state.

Defect

Any non-conformance to normal condition requiring some investigative or remedial action.

Reliability

The probability that the equipment will remain in service without a failure occurring.

End of life

The point at which a transformer should no longer remain in service because of an actual or potential failure of function which is uneconomic to repair or because it is no longer sufficiently reliable.

Failure mode

A description of a failure which illustrates what actually happened when the failure occurred.

Continuous monitoring

On-line monitoring carried out as frequently as possible, i.e. as soon as one cycle of measurements is complete the next is started, or triggered by some event.

3. Általános ismeretek és elméleti kérdések

The first task was to improve the knowledge and general theory of degradation processes and end of life failures.

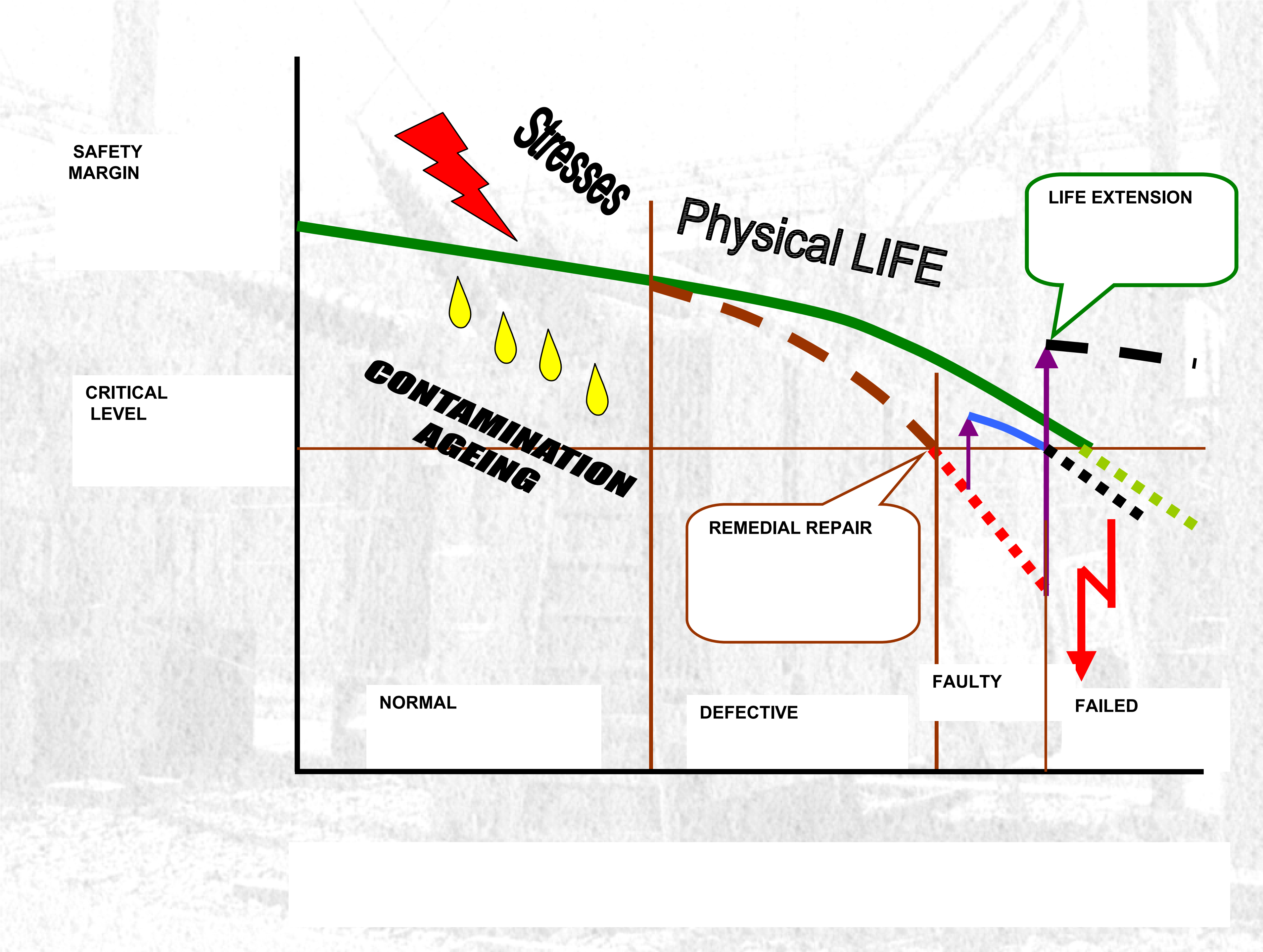
An overriding need is to unify and build onto previous work on the subject, most notably by bodies such as IEC, IEEE and CIGRE. The overall goal was to provide a practical Guide to the main types of problems suffered by transformers and means of managing these to optimise asset life and usability.

Transformers are generally very reliable equipment with expected ***service lives of 40 years or more,*** so it is difficult for individual engineers to build up sufficient first hand experience of problems and how best to deal with them.

3.1 Basic failure concepts

The basic **failure model** proposed for consideration assumes that there are a number of key functions or parameters, such as dielectric and mechanical strength, and that:

failure occurs when the **withstand strength** of the transformer with respect to one of these key properties is exceeded by **operational stresses** (Figure 1).



SAFETY MARGIN
Stresses
Physical LIFE
LIFE EXTENSION
CRITICAL LEVEL
CONTAMINATION
AGEING
REMEDIAL REPAIR
NORMAL
DEFECTIVE
FAULTY
FAILED

3.2 Condition classification

Table 3-1 Definitions of condition classifications
Condition/Definition

Normal:No obvious problems, No remedial action justified. No evidence of degradation.

Aged? Normal in service? Acceptable, but does not imply defect-free

Defective: No significant impact on short-term reliability, but asset life may be adversely affected in long term unless remedial action is carried out.

Faulty: Can remain in service, but short-term reliability likely to be reduced. May or may not be possible to improve condition by remedial action.

Failed: Cannot remain in service. Remedial action required before equipment can be returned to service (may not be cost effective, necessitating replacement).

remedial actions

3.3 Recommendations on failure identification

3.3.1 Failure causes

A failure is usually a "tuning fork" of Life Management procedures.

Many failures occur due to aging phenomena:

Shortened life due to accelerated deterioration of components particularly bushings and OLTCs

Overheating of the HV winding coils due to poor cooling or excessive circulating current

Change in the condition due to ingress of water, particle contamination, aging of oil, loosening of contacts and clamping forces, vibration, unusual stresses, etc.

3.3.2 Failure reports

Appendix 2

3.3.3 Failure code

Appendix 3: Catalogue of Defects and Faults

It is envisaged that for each important problem an

Identity Card (Appendix 5)

would be produced to include a complete description in a standardised format of how to manage the problem in question.

An **Example** of a filled-in card is in (Appendix 6).

In particular, this will describe the likely consequences of each particular problem, recommendations on when to act (with suggested Caution and Critical levels) and recommended remedial action.

3.4 Insulation deterioration: Theoretical issues

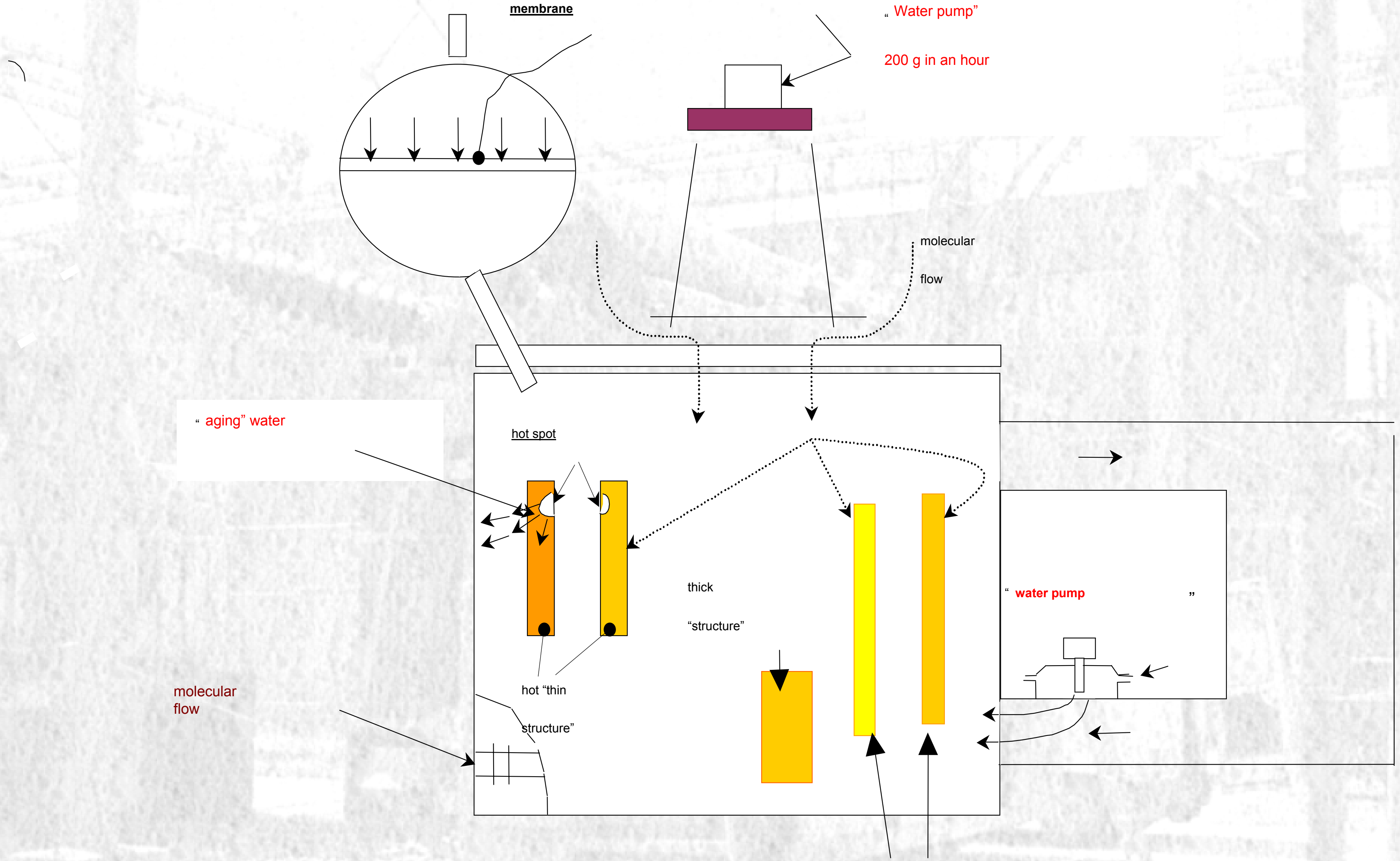
3.4.1 Aging factors

Water, oxygen, oil aging products (acids particularly) and particles of different origin are agents of degradation, that can shorten transformer life significantly under impact of thermal, electric, electromagnetic and electrodynamics stresses.

3.4.2 Water contamination

There are three sources of excessive water in transformer insulation: Residual moisture in the "thick structural" components not removed during the factory dry out, ingress from the atmosphere, and aging (decomposition) of cellulose and oil.

A transformer moisture model suggested by the WG12.18 [3] is shown in Figure 2.



membrane
„ Water pump"
200 g in an hour
molecular
flow
" aging" water
hot spot
thick
"structure"
" water pump "
hot "thin
structure"
molecular
flow

3.4.3 Particle contamination

The origins of particles are manifold. Cellulose fibres, iron, aluminum, copper and other particles resulting from the manufacturing processes, are naturally present in the transformer oil.

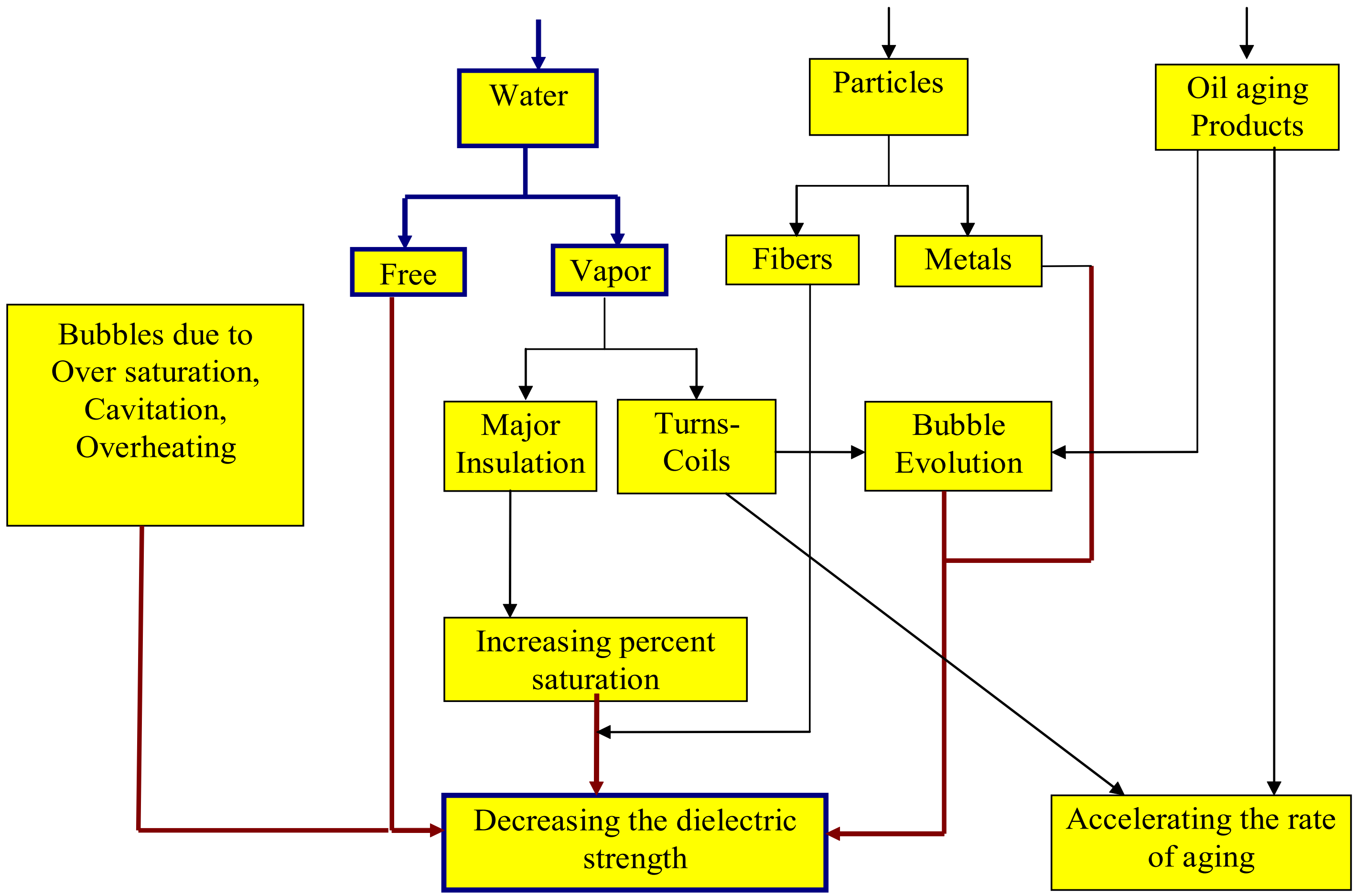
Aging during utilization at normal and overload temperatures slowly forms sludge particles. Localized overheating over 500 °C could be a symptom of forming carbon. The carbon particles produced in the OLTC diverter may migrate by leakage, accidents or human error into the bulk oil compartment to contaminate the active part. A typical source of metallic particles is wear of bearings of the pumps.

Particle contamination is a major factor of degradation of dielectric strength of transformer insulation and, accordingly, elimination of particles is the most important objective of oil processing.

The most dangerous particles are conductive mode particles (metals, carbon, wet fibers). CIGRE Working Group WG 12.17 Particles in Oil [4] has collected and evaluated a significant number of HV transformer failures being attributed to particles. Particle identification and counting were found to be necessary procedures of condition monitoring. Typical contamination levels, including possible dangerous levels, have been advised.

3.4.4 Paper aging decomposition

Insulation decomposition is a chemical phenomenon. Three mechanisms of degradation: hydrolysis, pyrolysis and oxidation act simultaneously. Hydrolysis is the decomposition of a chemical compound by reaction with water. Pyrolysis is the decomposition or transformation of a compound caused by heat. And oxidation is the combination of a substance with oxygen. Temperature, water and oxygen are the main agents of cellulose degradation as well as oxidation of the oil. Figure 3 shows the Model of Aging of oil-paper transformer insulation.


Water
Particles
Oil aging Products
Free
Vapor
Fibers
Metals
Bubbles due to Over saturation, Cavitation, Overheating
Major Insulation
Turns-Coils
Bubble Evolution
Increasing percent saturation
Decreasing the dielectric strength
Accelerating the rate of aging

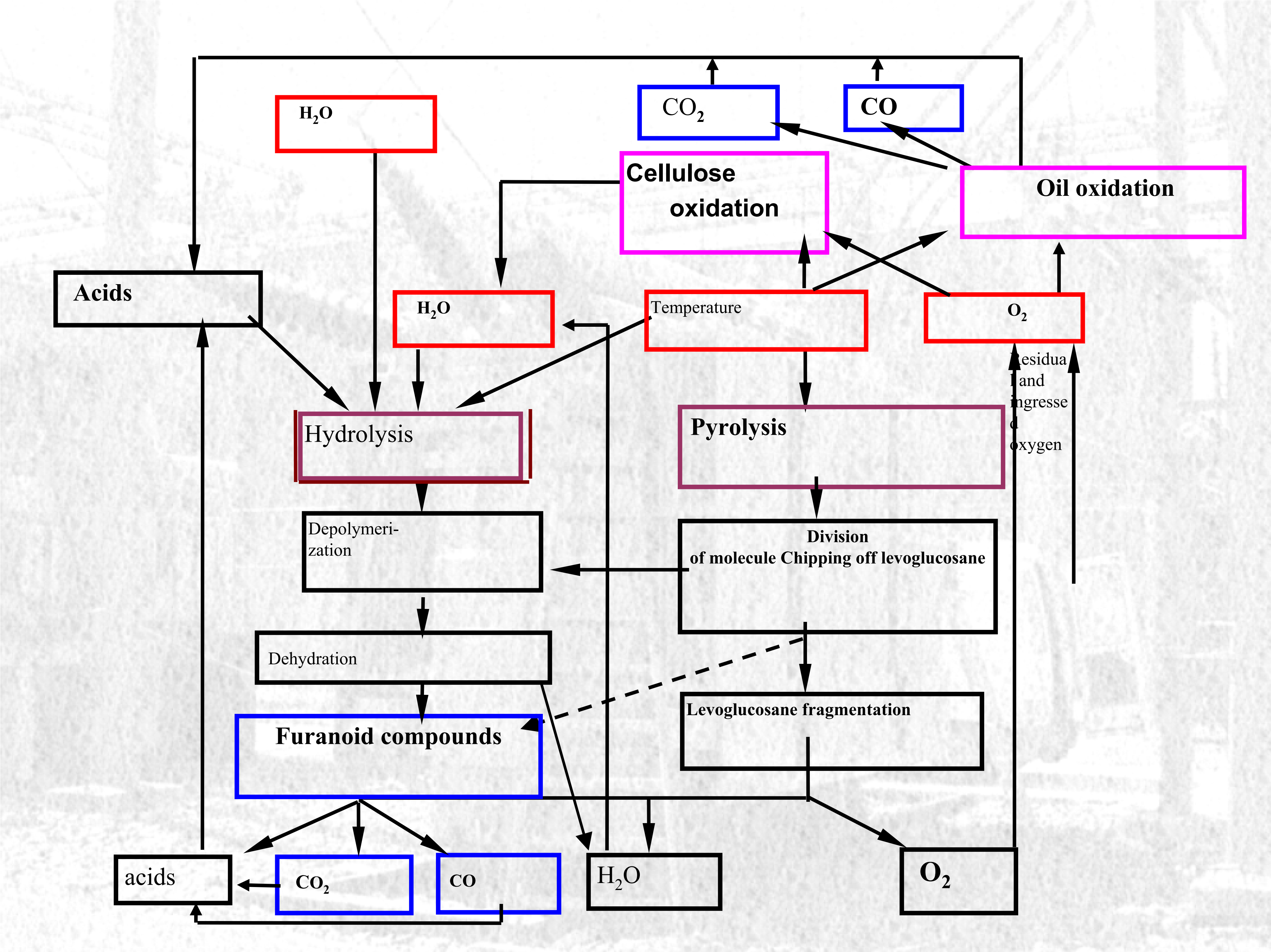
3.4.5 Summary: Dangerous effect of degradation factors

A Model "Dangerous effect of degradation factors" suggested by the WG12.18 is shown in Figure 4. The dielectric safety margin of both major and minor insulation contaminated with water is determined by the dielectric withstand strength of the oil.

Note: Hydrolysis is the decomposition of a chemical compound by reaction with water. Pyrolysis is the decomposition or transformation of a compound caused by heat. The levoglucosanes are the source of furans.

The presence of bubbles may cause critical partial discharge (PD) to occur even at rated voltage. Bubble evolution is a problem of a "hot transformer". This involves not only high temperature and elevated water content, but also presence of air and decreasing interfacial tension of the oil due to its aging.

Figure 4 Dangerous effects of degradation factors



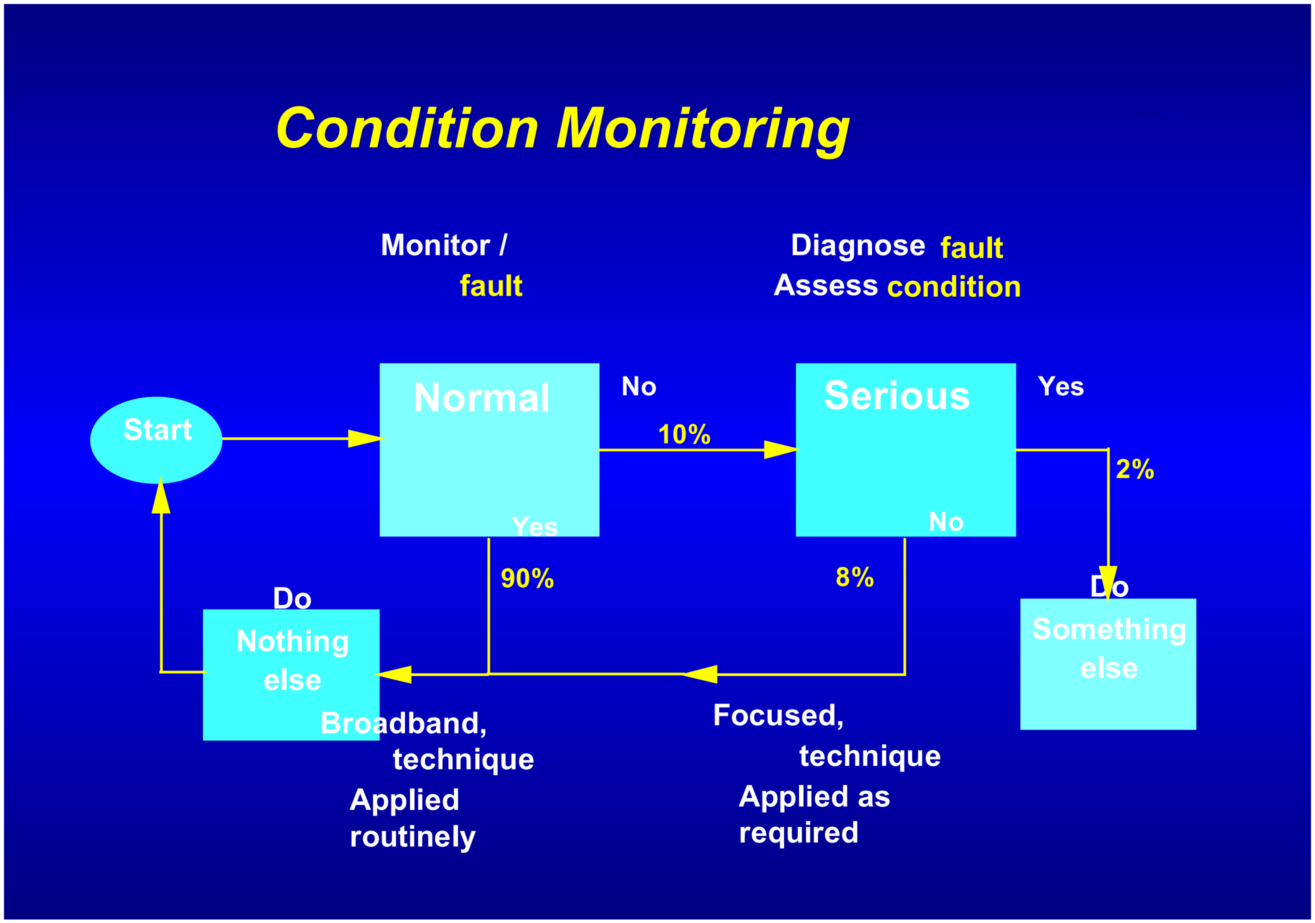
H_2O
CO_2
CO
Cellulose oxidation
Oil oxidation
Acids
H_2O
Temperature
O_2
Residual and ingressed oxygen
Hydrolysis
Pyrolysis
Depolymeri-zation
Division of molecule Chipping off levoglucosane
Dehydration
Levoglucosane fragmentation
Furanoid compounds
acids
CO_2
CO
H_2O
O_2

4.1 Condition-based methodology

Although the ideal is to base the assessment of the **condition** of a transformer on the relevant withstand strengths or spare margins, in practise this is not an option at the moment because the necessary tools are not available.

Nevertheless, there is a pressing need for some interim methodology to enable important decisions on life management to be made by utilities.

Therefore, to enable efforts to be concentrated where they are most needed and will bring the best benefit, and to provide a framework against which a consistent approach can be applied over a population of equipment, a pragmatic two stage condition based methodology has been proposed (Figure 5)


Condition Monitoring
Monitor / fault
Diagnose fault
Assess condition
Start
Normal
No
10%
Serious
Yes
2%
Yes
90%
No
8%
Do Nothing else
Do Something else
Broadband, technique Applied routinely
Focused, technique Applied as required

Life management of transformers naturally follows the same process for the resolution of problems as for the management of human health, with the progression

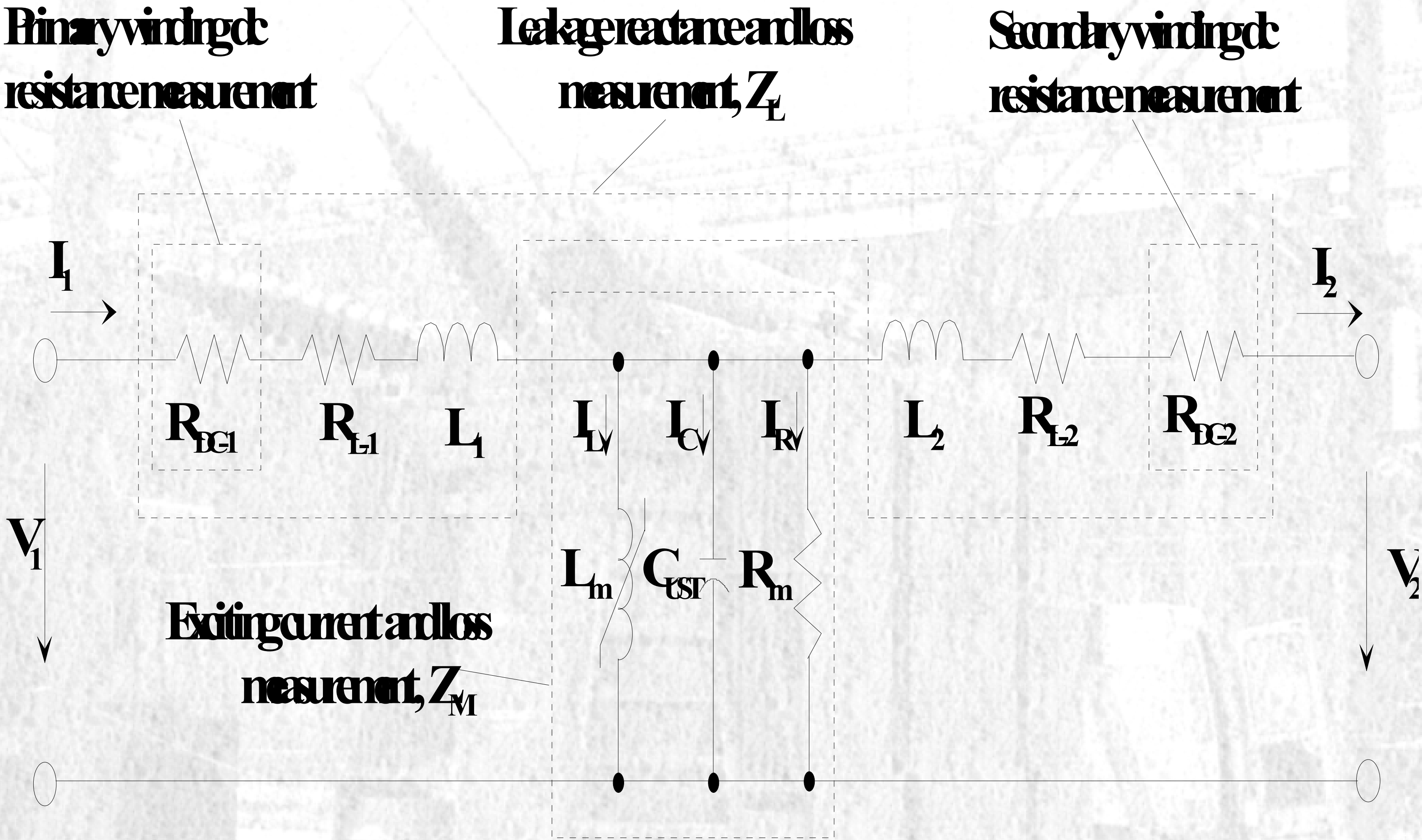
Symptoms → **Diagnosis** → **Cure**

once a problem is suspected.

The difference is that a human being is usually able to recognise when he or she is ill and a doctor should be consulted, but for the management of transformer health it is necessary to employ some form of **monitoring** to provide an indication of when to initiate the above process.

In this first step, which may be described as **monitoring** or **detection**, the fundamental question to be answered, expressed in its simplest terms is :

Is it **NORMAL**? i.e. **is there a fault** ?


Primary winding dc resistance measurement
Leakage reactance and loss measurement, Z_L
Secondary winding dc resistance measurement
I_1
I_2
R_{DC-1}
R_{L-1}
L_1
I_L
I_C
I_R
L_2
R_{L-2}
R_{DC-2}
V_1
L_m
C_{UST}
R_m
V_2
Exciting current and loss measurement, Z_M

The most dangerous particles are conductive mode particles (metals, carbon, wet fibers). CIGRE Working Group WG 12.17 Particles in Oil [4] has collected and evaluated a significant number of HV transformer failures being attributed to particles. Particle identification and counting were found to be necessary procedures of condition monitoring. Typical contamination levels, including possible dangerous levels, have been advised.