SIMMS 2.1

Portable Online & InSitu Transformer Diagnostic System

Operational Manual

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Contents

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1. Introduction

Collecting one oil sample per year and processing it a lab, cannot provide the acurate data that is vital for avoiding failures and the subsequent management of the appropriate treatment program of the wet and/or aged transformer.

Generally are there two basic diagnostic problems:

- **moisture problem** – the standard reading based on the Karl Fisher method only shows very often the deep inconsistency between the predicted and real amount of removed water
- **dielectric problem** – the lab reading of the dielectric strength of aged oils is very often inconsistent with the water content in the oil acquired by the Karl-Fisher method.

Both problems can be very effectively solved by the implementation of the direct on-line reading of the relative humidity of the oil, the reading of the operational temperatures of the transformer and their proper evaluation.

The **ARS-Altmann** has therefore released the **SIMMS 2.1** , version 2015**,** a miniaturized portable oil sampler & evaluation system which enables the **in situ** of the correct samplings and corresponding relevant readings and evaluations of all above mentioned values. The SIMMS 2.1 can be easily used for the reading of any kind of a transformer.

The basic readings and diagnostic results achieved by the **SIMMS 2.1** system covers the following diagnostic areas:

⇒ water content in oil – Chapter 1.1.

⇒ water content in cellulose + ***determination of amount of water to be removed to meet norm-required water content in oil at requested temperature of transformer*** - Chapter 1.2.

⇒ TLC relation, the prediction of actual (theoretical) dielectric strenght of oil of oil (Ud-value) as the function of the temperature of the transformer + ***determination of amount of water to be removed to meet norm-required value of dielectric strength in oil at requested temperature of transformer*** – Chapter 1.3

The major advantages of the **SIMMS 2.1** are:

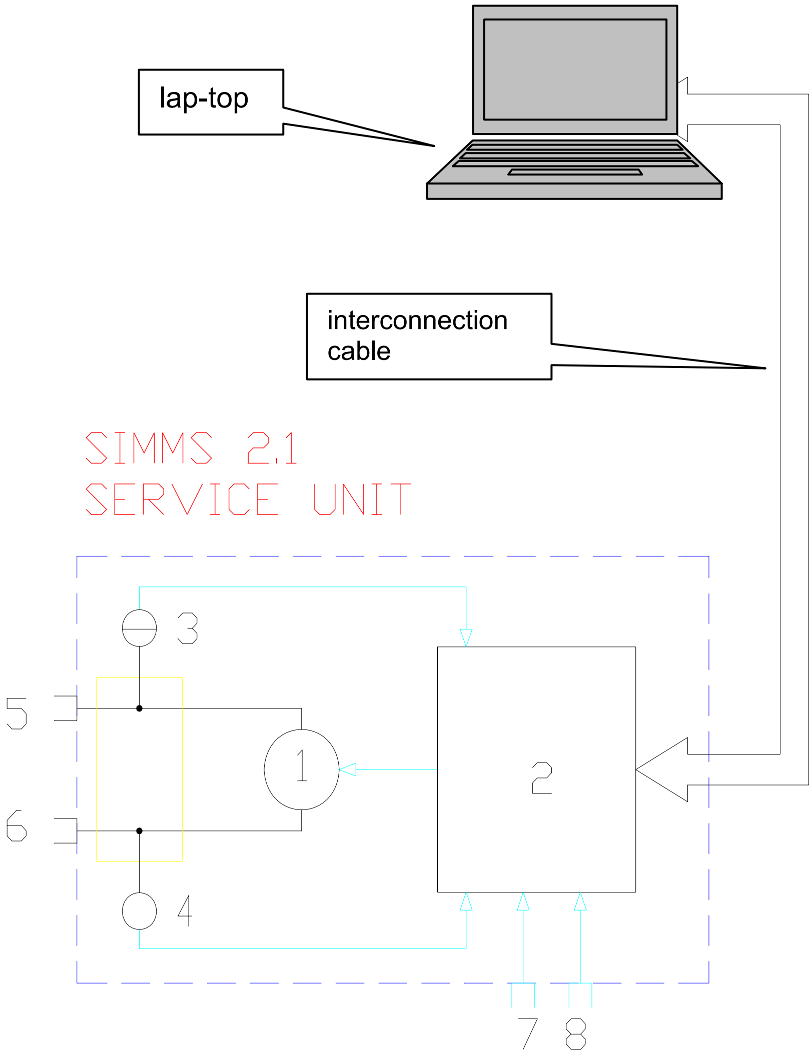
- **easy installation and commissioning**
- **on-line reading** – under normal operational conditions of a transformer
- **no contamination of oil within sampling & reading**
- **no loss of oil due to sampling**
- **first results are available in situ, in hours**

The **SIMMS 2.1 ,** See Fig. 1 consists of :

- **Service Unit** (**SU**), the hydraulical system See Fig. 2, 3 which samples the oil from the oil filling of a transfrormer, then reads the basic data giving the relative moisture of the oil and transformer temperatures, analyses and evaluates them and forces the oil back into the transformer.

The SU can always be used separately, but only for acquiring of elementary data of a transformer.

- **lap-top** interconnected to the **SU** via a data and control cable, then reads the information preprocessed by the **SU**, evaluates them in more detailed manner and offers their time-related visualization and interpretation.



1		Gear pump	6		Oil Inlet Quick coupling QC2
2		PCD Amit	7		Temp. sensor connector
3		Moisture sensor	8		Temp. sensor connector
4		Presure sensor			
5		Oil Outlet Quick Coupling QC1			

Fig. 1 The operating diagram of the SIMMS 2.1 system (version 2015)

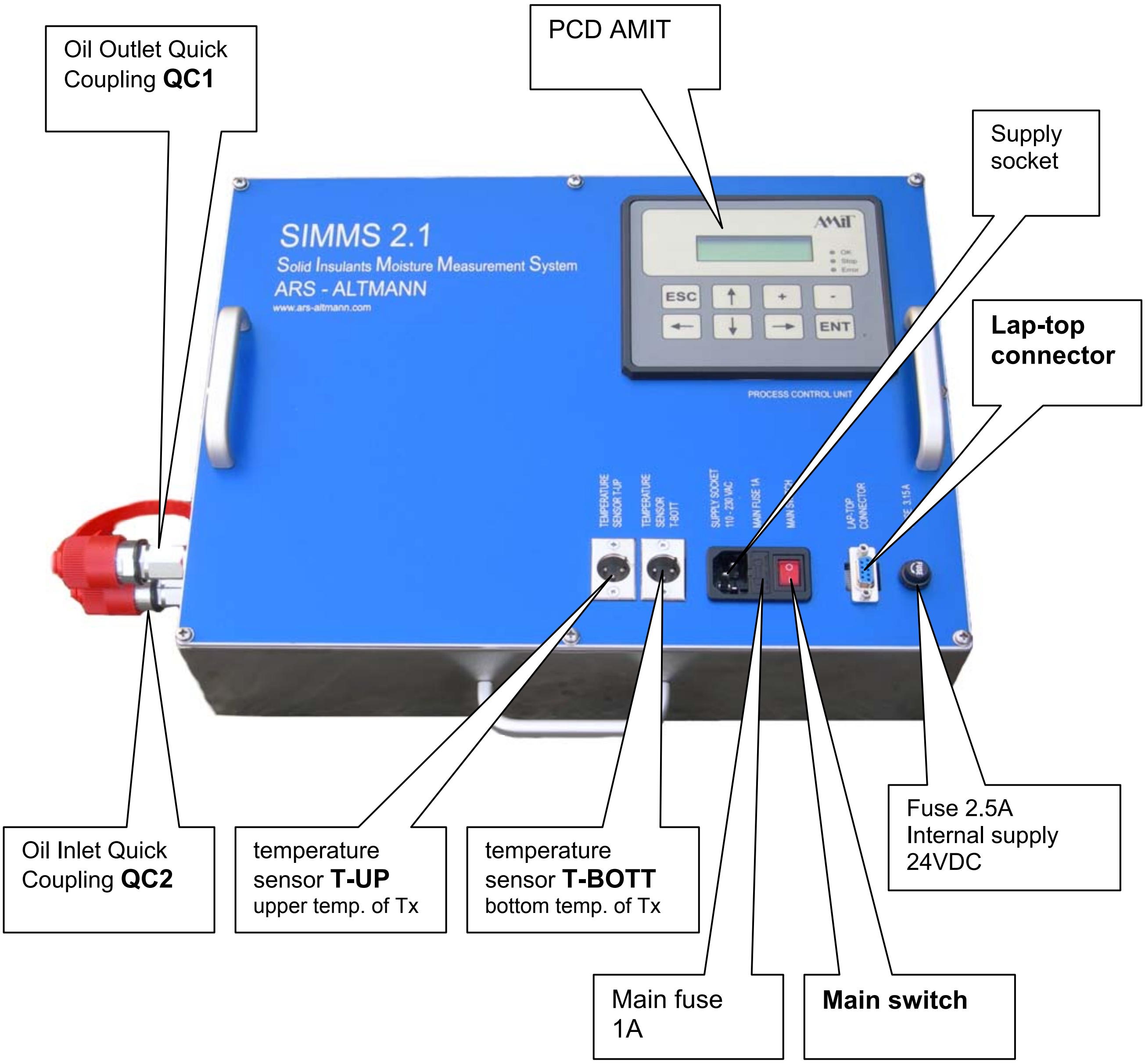


Fig. 2 The face-plate of the Service Unit (**SU**)

1.1. Water content in oil

The reading of the water content in the oil filling of a transformer is continuously performed by the humidity sensor Vaisala MT162 situated in the **SU** box. The oil is permanently being drained from the transformer via the first sampling cock and the first hose into the **SU ,** analyzed and then forced back via second hose and the second sampling cock into the oil filling of transformer – See Fig. 6.

The application of the precise humidity sensor eliminates the basic disadvantage of standard lab Karl Fisher readings:

- **the reading of water content in aged oils is to too high**, *the KF-methods reads not only relevant (diluted) water in the oil, but the bonded water in acids as well.*

But:

*between cellulose materials and oil filling migrates **diluted** water only*

it means

only diluted water is relevant for evaluation of the water contamination of a transformer

.

This basic disadvantage of KF-readings then inevitably leads to too high values of water content in **cellulose** materials

- **the discrepancy between the readings of water content and the Ud-readings of oil.**

The next advantage of the system is the total exclusion of all external contaminations. After the installation on a transformer, all hydraulical connections between the Service Unit (SU) and the transformer are at first vacuated to avoid an oil contamination and/or air ingress into oil inventory of transformer (potential Buchholz trip).

From the start of the operation, the sampled oil is in no way exposed to the atmosphere and therefore any kind of an external contamination is excluded.

The reading of the water content in the oil is the next part of the measuring procedure.

1.2 Water in cellulose

The evaluation of the water content in cellulose materials of a transformer performed by the **SIMMS 2.1** system is based on a time-related reading of :

- water content in the oil (the Qw-value) by a moisture sensor which reads the relative humidity of the oil
- the reading of the transformer temperature by means of two temperature sensors: the first is installed on its the upper part of the transformer and reads its upper temperature (the T-Up-value) and the second one is installed on its bottom part and reads its bottom temperature (the T-BOTT value).

All mentioned values have to be read under equilibrium conditions of a transformer, where the water migration between the cellulose and the oil filling is insignificant and the oil-cellulose equilibrium conditions for the relevant evaluation of the water content in the cellulose, is quaranted.

This is of course an ideal case. The “absolute equilibrium condition” in a real transformer, under continuous and inevitable change of its oil temperature, is unattainable under operational conditions.

The **SIMMS 2.1** system solves this specific “equilibrium” problem by the on-line reading and the subsequent evaluation of the time-variation of both values during the pre-defined time-period:

⇒ If the variation of values remain in predefined limits, this state is considered as the acceptable quasi-equilibrium, corresponding readings are therefore considered relevant and can be used for the subseqent evaluation via an equilibrium “chart”.

⇒ If this is not the case – the reading is potentially not correct and should be terminated

The outputs of both temperature sensors and the oil humidity sensor are processed by PCD AMIT of the **SU** (See Fig. 2). All time-related data are continuously loaded in the AMIT memory and are available for additional processing by laptop.

A good accurate snapshot can be made within ca 30 - 60mins, more accurately than using any other traditional methods. In order to follow the migratory patterns in seeking the equilibrium, more time is recommended to produce the snapshot. This is a simple, accurate and cost effective means for determining the level of water in the paper.

SIMMS 2.1 visualization software implemented in the lap-top gives us then the desired overall time-related profile - water content in oil Qw = Qw (t) and both temperatures Tu = Tu (t), Tb = Tb (t) – upper / bottom transformer temperatures, auxiliary temperature level of moisture transmitter TV = TV(t) and mean temperature level of transformer TTS = TTS (t).

After checking the proper equilibrium state of the measured transformer, the averaged (mean) Qw and TTS values are immediately used to calculate the water content in the cellulose Qp and Temperature Loading Curve (TLC) of the given transformer.

1.2. Transformer Equilibrium Check

The primary question after carrying out this specific measurement is : Are the adequate equilibrium conditions (approximately constant average temperature TTS and water content in oil Qw) in the transformer reached or not ?

This evaluation can be made:

- after the measurement of the water content in cellulose by the **SU** is finished
- simultaneously: the time-related values are on-line evaluated by the lap-top

If **YES** (the transformer is in an acceptable equilibrium), all the necessary calculations (average water content in cellulose, the Qp-value, Temperature Loading Curve - TLC …) can be made immediately by the laptop (and corresponding software).

If **NO**, the on-line measurement for a twenty-four-hour period (or a complete load cycle period) is usually necessary. That allows us to reach the desired accuracy in determining the average water content in solid insulants, and the temperature related to the temperature-related movement and time lag of the water movement between the paper and the oil.

1.2.4 The evaluation of the water content in cellulose

This procedure is performed by the connected lap-top and uses measured values of water in the oil the Qw-value (ppm) and upper temperature of the transformer, the T-UP-value and bottom transformer temperature, the T-BOTT-value, for the evaluation of the percentage of water in its cellulose insulation the Qp-value (weight %).

Subsequently, the amount of water is calculated which has to be removed from the insulating system to obtain the desired, or norm-requested, water content in oil and the actual (theoretical) dielectric strength of oil (the Ud-value).

The Qp -value is used for the condition evaluation because we know that:

The calculated Q_p value represents here not only the average water content of cellulose insulants in the transformer

but

<u>its temperature- invariant parameter</u>

because

the Qp-value of any transformer doesn´t substantially change by the temperature-driven water migration between oil and cellulose : the amount of water which migrates between the celluse insulants and oil filling is very low compared to amount of water absorbed in the cellulose .

In practical terms, if we take an oil sample from the transformer under any temperature we must (under equlibrium conditions) get approximately the same Qp-value.

The Qp-value as an almost temperature constant, represents the key value of a moisture related problems of any transformer.

which

enables <u>the prediction</u> of the most important (Qw, Ud) values <u>for the whole temperature range of the transformer</u>

For the easy interpretation the improved and experimentally verified Nielsen equilibrium chart (relation) is used.

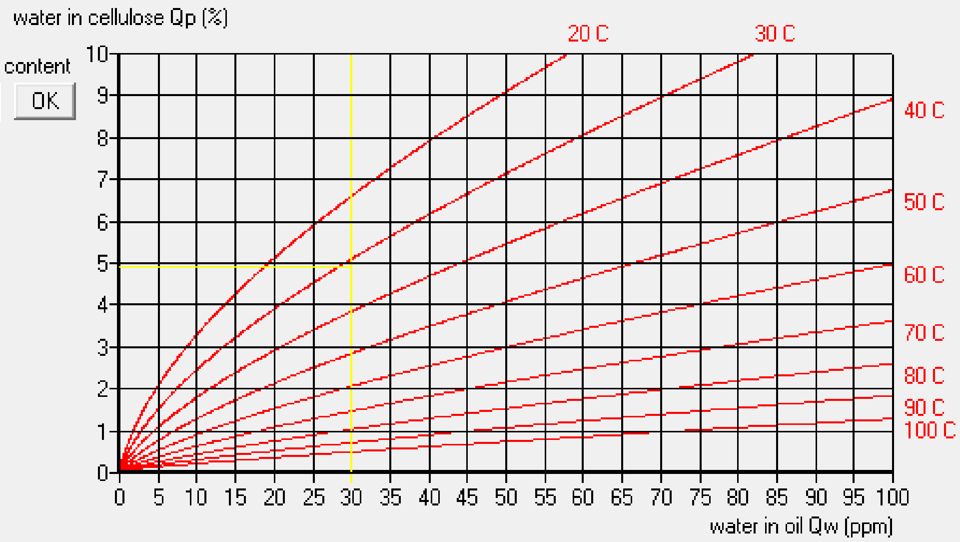
SIMMS 2.1 Print Return

Procedure: Nielsen Chart

Company: altmann
Location: shop

Date, time: 2.12.2015 11:51:00
Transformer Serial Number: 123

Insert max. allowed water content in oil Qwmax(ppm) 30 OK



DIAGNOSIS: Cellulose water content Qp=4,9 %
Flashover possible at 90 deg.C
For safe operation (Qwmax= **30** ppm) the main transformer temperature must not be higher than **31,6** deg.C

USER'S DEMAND: Up to which maximum temperature (TTSmax) do you wish the transformer will operate? Insert! 50 deg.C
Which water content in oil (Qwmax) must not be exceeded at the max.temperature? Insert! 20 ppm OK

PREDICTION: Solid insulants have to be dried at least to the value Qpmin=2,13 %.
ATTENTION! The mass of cellulose materials in the transformer is unknown!
The value K=0.08 and/or K=0.14 of the transformer cellulose materials mass/transformer oil mass ratio has been used for estimation of the minimum and/or maximum water removal from the transformer.
For K=0.08 : Minimum water removal Mw,p= 44,16 kg.
For K=0.14 : Maximum water removal Mw,p= 77,28 kg.

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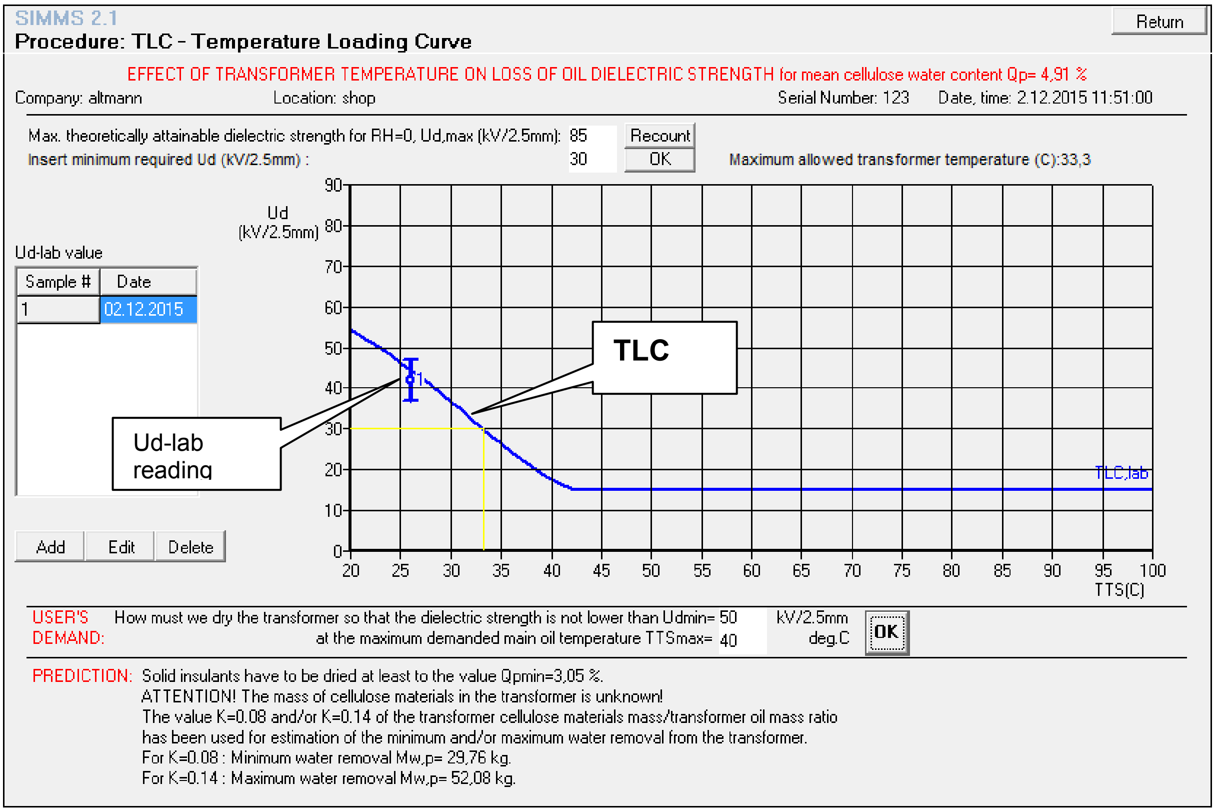
- o **Diagnosis** section then interprets the reading and calculates the averaged water content in cellulose (here Qp= 4.9%). Based on the entry of target value of water content in oil Qwmax = 30ppm and given water content in cellulose Qp = 4.9% then calculates the maximum allowed operating temperatures of the transfomer, here **31.6C** (indicated as the point of intersection of both yelow lines)
- o **User´s demands** section is interactive and allows clients to enter pre-demanded values of:
  - maximum operating temperature of transformer (50C)
  - maximum allowed water content in oil (20ppm)

  for further predictions.
- o **Prediction** section then calculates how much water has to be removed from this specific transformer to meet given demands (minimum ca 44 kg of water has to be removed in this case).

1.3 TLC-relation

This procedure uses the given Qp-value (%) for the calculation of the TLC-relation. The TLC(Temperature Loading Curve) then **predicts the dielectric strength of oil, the Ud-value**, **for the whole temperature range (here 20 – 100C) of this specific transformer.**



Simultaneously, based on the calculated TLC and allowed dielectric strength of oil (30 kV/2.5mm , horizontal yelow line), the maximum allowed temperature of the transformer (vertical yellow line : ca 33.4 C) is determined.

The next calculation (Prediction) shows how much water must be removed from the insulating system (at the given temperature of the transformer) to meet the pre-determined miminum (e.g. norm-requested) dielectric strength of oil in its oil filling.

User´s demands section is interactive again and allows the entry of values:

- (minimum-requested) dielectric strength of oil

- requested operating temperature of transformer

for further predictions.

Prediction section then calculates how much water has to be removed from this specific transformer to meet these demands.

Verification of diagnostic results by Ud-lab value(s) based on the comparison of theoretical Ud-value (TLC-curve) with the Ud-lab value (See point **1** with error bars) at the same sampling time and the same temperature of the transformer.

2. SIMMS 2.1 Service Unit Specification

2.1 Technical data

Power supply voltage	80 – 250 VAC
Power supply frequency	50 - 60 Hz
Power consumption:	max 80W
Oil throughflow	max 100l per hour
Measuring range	
Water content in the oil	5 – 100 ppm (diluted water)
Temperature	0 – 100 C
Outlet /inlet filtering grade of preliminary filter	40 µm
Weight – inclusive lap-top, alu transport box and accessories	22 kg
Dry weight of the measuring unit only (without oil)	5 kg
Hydraulical connection	2 x flexible hose
Communication:	lap-top connector

2.2 Operational conditions

The **SIMMS 2.1 Service Unit** is focused on the **quick and precise reading** of three basic time-related values of the transformer:

- Water content in the oil
- Upper (operational) temperature of the transformer
- Bottom (operational) temperature of the transformer

The interconnected lap-top evaluates directly in situ:

- o Desired equilibrium condition of a transformer
- o An averaged water content in cellulose materials
- o TLC (Temperature Loading Curve) – predicts the relation between the dielectric strength of oil and transformer temperature

The reading of the TGC-value is performed, under standard conditions, after the basic reading of the water content is finished.

Please never forget

SIMMS 2.1 system is designed for a quick reading and evaluation of basic parameters of a transformer in situ

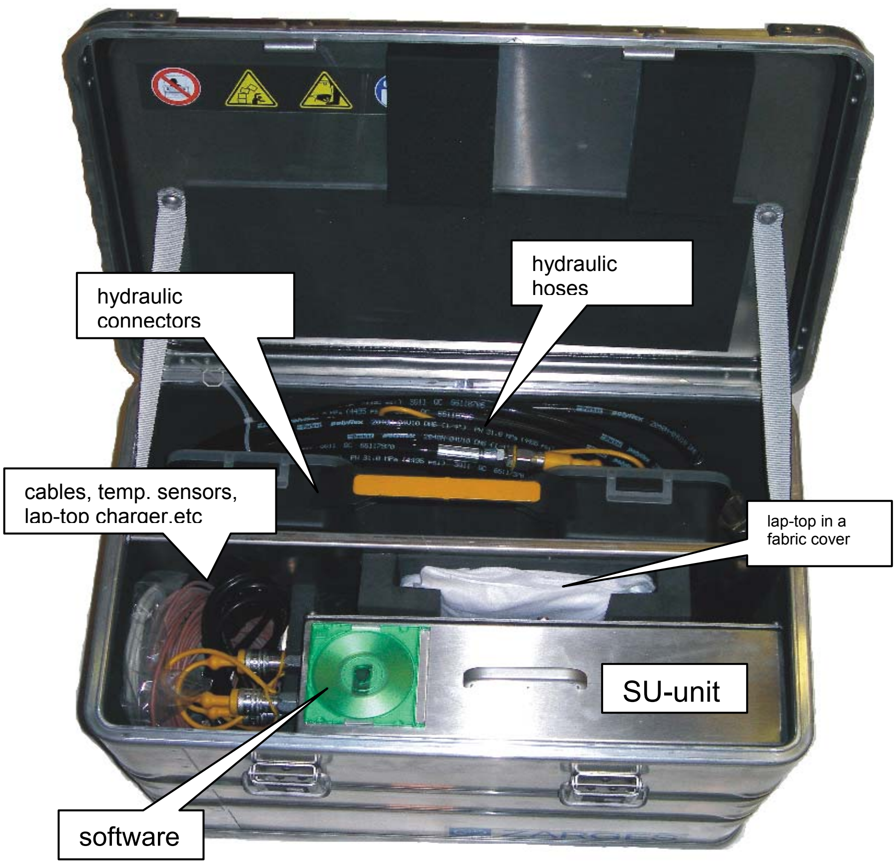
SIMMS 2.1 Service Unit is not designed for daily or weekly readings – customers need to have results in hours

The recommended reading period of a transformer should not exceed 1 – 2 hours, or in a extreme situation ca 24 hours.

3. Transportations

SIMMS 2.1 Service Unit is always transported, inlusively the lap-top and all accessories in:

- high resistant alu box intended for all-day operations under very heavy conditions



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ATTENTION

Check the functionality of SIMMS 2.1 Service Unit before taking it to the client.

To avoid delays and problems by the installation, always ask the client before, what potential connection points are available in situ.

4. Installation

Preparation for the installation of the SU

All possible connection points of the transformer(s) suitable for the **SU** installation should be properly checked before the installation.

Call the customer first and check all possible connection alternatives to their transformer(s)

Every transformer has at least, one of five accessible connection points:

- sampling cock (s)
- filter press valves
- drain valve (s) of main tank
- air cock of Buchholz relay
- discharge cock of conservator

ATTENTION

If a transformer tank isn´t equipped with standard sampling cocks (representing the ideal, direct connection to its oil filling) and filter press valves, drain valves etc. (we will call them generally <u>main</u> valves here) have to be used then so-called the detrimental space between main valve and sampling cock always exists and has to be deaerated (and subsequently rinsed by oil) before reading procedure begins.

<u>any air intrusion into oil filling of transformer within reading procedure has to be avoided</u>.

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Installation of the SU in situ

Hydraulic interconnection of a transformer and the SU is performed in three steps:

1. the **inlet hose H1** (3 m long hose marked with **green** band) is connected to **first (bottom) sampling cock** of the transformer and its opposite end is via quick coupling QC2 connected to the **inlet section** of SU. The exhaust hose **H3** (2 m long marked with **red** band) is via quick coupling QC1 connected to outlet section of SU and its opposite end is situated into oil-resistant bucket See Fig.4 .The **inlet hose H1** is then by gear pump deaerated and after sampling cock is opened, subsequently flushed by oil from transformer. The inlet hose **H1** is then disconnected from quick coupling QC2.

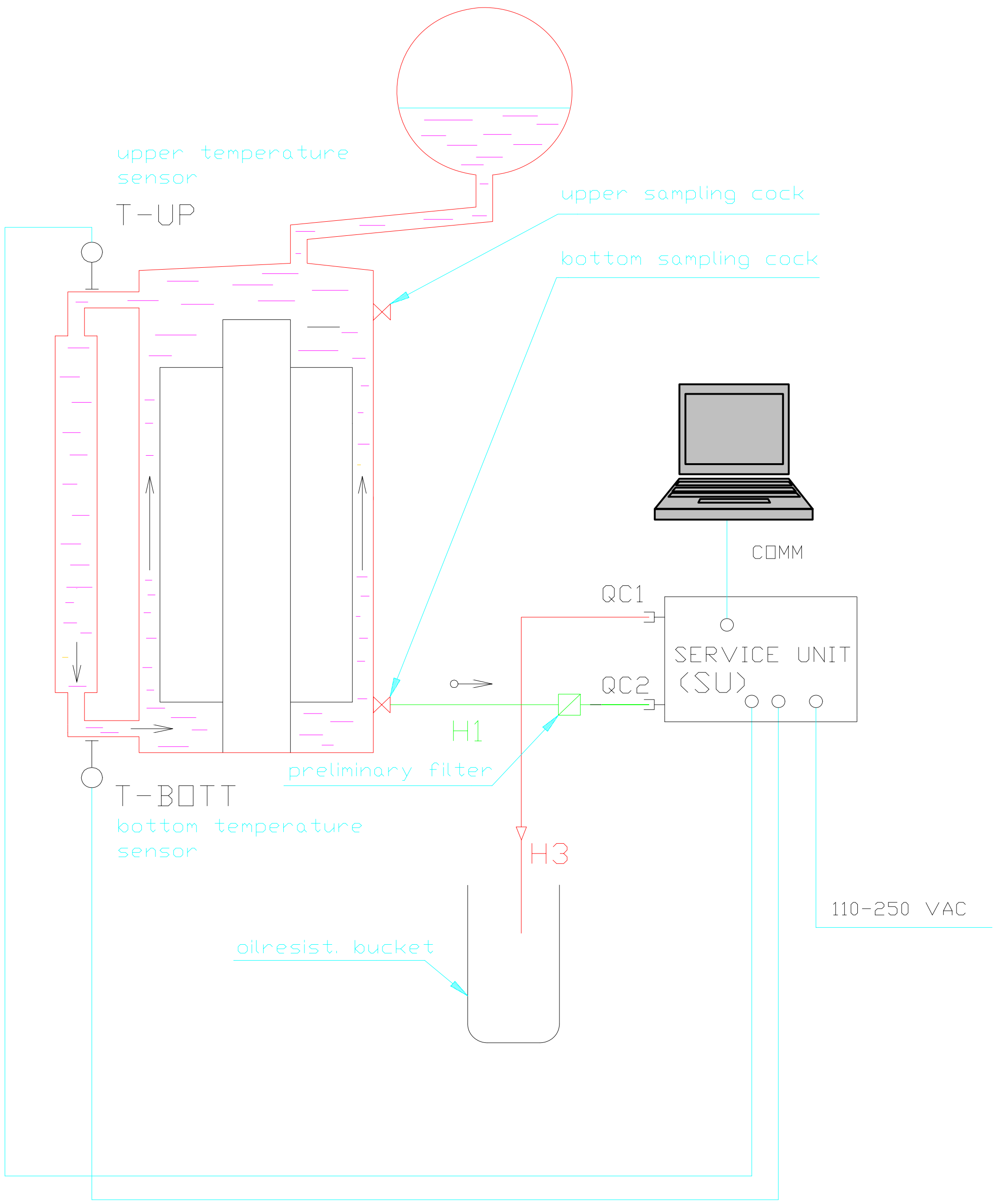

Fig. 4 Deaeration and flushing of inlet hose H1

2. the **outlet hose H2** (10m long hose marked with **blue** band) is connected **to second (upper) sampling cock** of the transformer and its opposite end is via quick coupling QC2 connected to the **inlet section** of SU. The exhaust hose H3 is, as before, via quick coupling QC1 connected to outlet section of SU and its opposite end is situated into oil-resistant bucket See Fig.5 .The oulet **hose H2** is then by gear pump deaerated and after sampling cock is opened, subsequently flushed by oil from transformer. The outlet hose H2 is then disconnected from quick coupling QC2.

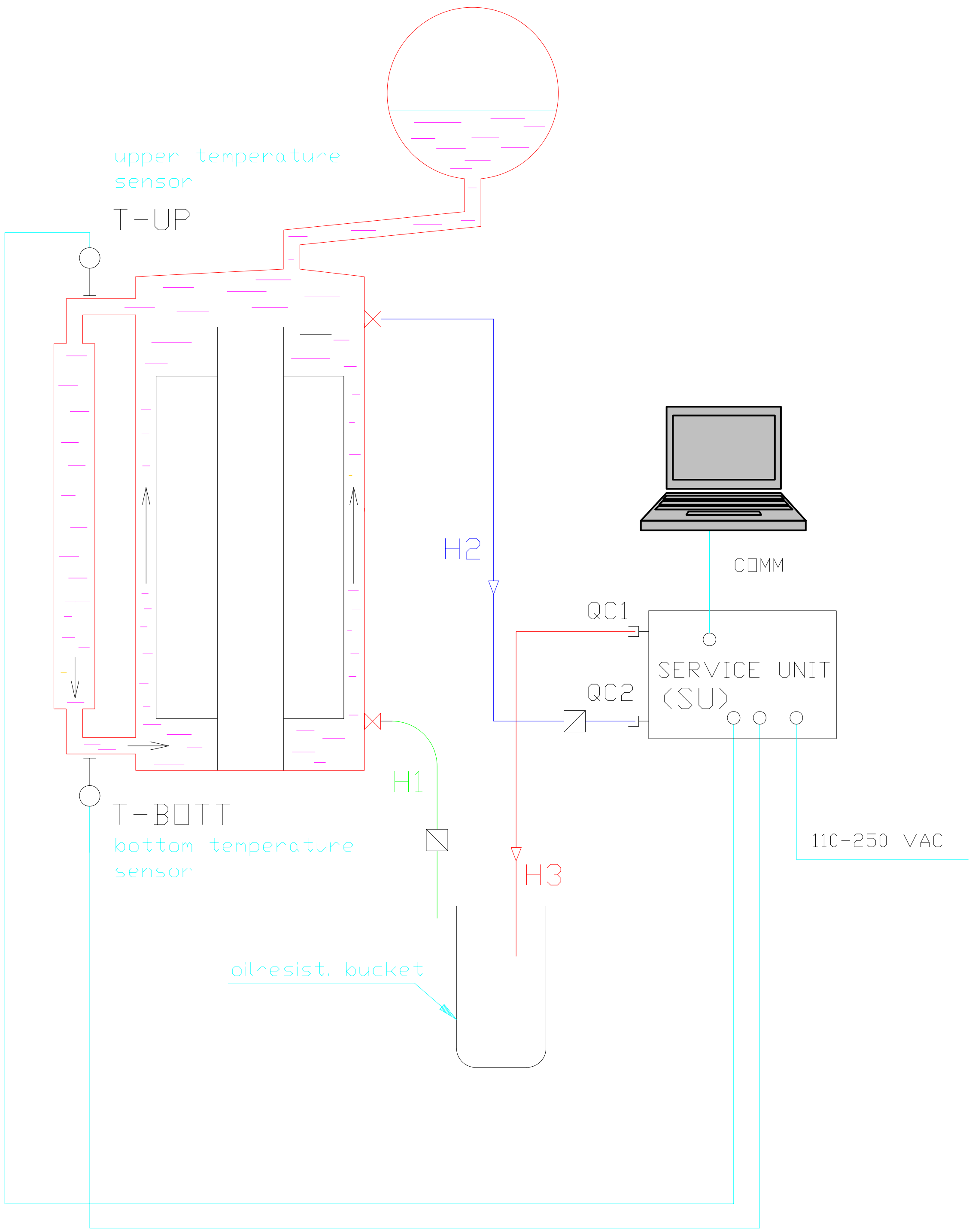

Fig. 5 Deaeration and flushing of outlet hose H2

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3. final step of interconnection of oil filling of a transformer and the SU - inlet hose H1 (**green** band) is connected via quick coupling QC1 to inlet section of SU, exhaust hose H3 (red band) is disconnected, and oulet hose H2 (**blue** band) is via quick coupling QC2 to outlet section of SU.

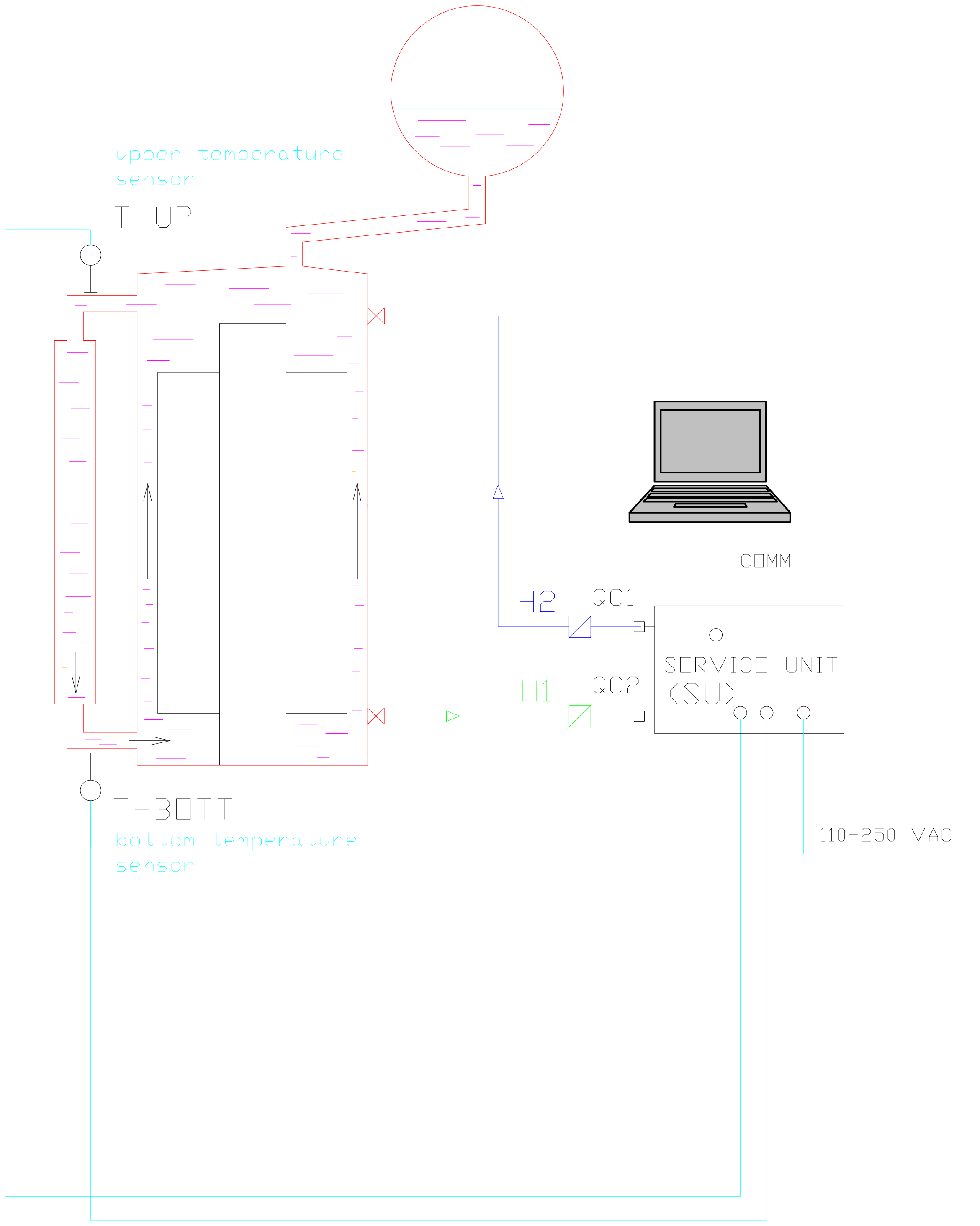

Fig. 6 Finalization of hydraulic interconnections of transformer and SU

Rem.: The oil is under standard conditions always sampled from bottom sampling cock via inlet hose H1 (**green** band) and forced back via outlet hose H2 (**blue** band) and upper sampling cock. to upper part of transformer

Attention !!

to avoid damage of gear pump never operate SU without particle filters

Measuring of transformer temperatures

For a precise evaluation of equlibruim conditions of the transformer and consequently the precise evaluation of the averaged water content its cellulose materials, it is necessary for a " long-term " reading of:

- upper temperature of the transformer
- bottom temperature of the transformer

Both temperatures are measured by means of enclosed cylindrical temperature sensors RAWET PT30, Ni 1000.

The optimal location of sensors is:

- upper tube (sleeve) of the radiator, which feeds the hottest oil representing the temperature of the upper part of the windings into a radiator.
- bottom tube (sleeve) of the radiator, which feeds the cold oil from the radiator into the bottom part of transformer which will satisfactorily represent the temperature of the bottom part of the windings.

The reading of both sensors is inevitably indirect, because sensors read not the oil temperature directly, but the temperature of surfaces of tubes which lead the oil in/out the radiator.

It is always necessary not only to perform the proper mechanical fixation of a sensor at the given tubing, moreover the sensor and the tube on its both sides should be thermally insulated as well.

The standard solution is that the temperature sensor is fixed at the tube by an enclosed rubber band or a suitable tape.

The pre-loaded rubber band safisfactorily fixes the sensor at the tube and simultaneously acts as a sufficient thermal barrier, which effectively eliminates the temperature difference between the throughflowing oil and the outer surface of the tube (and the sensor).

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To meet plug & play features of SIMMS 2.1, the inherent part of the delivery is pre-programmed lap-top to avoid any communication and evaluation problems.

ATTENTION :

TO AVOID COMMUNICATION PROBLEMS USE DETERMINED USB PORT ONLY

Fig.6 The example of interconnection of **SU** and lap-top for a data transfer.

5. Start-Up

ATTENTION

The SIMMS 2.1 reading should always be performed on transformers under operational conditions.

For the desired precision reading of the water content in the oil, the precise evaluation of the water content in oil (the Qw-value), the relevant evaluation of the water content in cellulose (the Qp-value) and the theoretical dielectric strength of oil (the Ud-value.

the average temperature of a transformer during a reading should always be over 30 C.

To avoid the loss of data or diagnostic results the check of the full charge of the lap-top battery is highly recommended before any start-up.

The substantial advantage of the advanced time-related approach is an eventual and direct intervention from the lap-top into all processes :

- to evaluate the equilibrium conditions of the transformer (Tx)
- to improve or change of conditions of data flow
- to improve the precision of diagnostic results .

To start the **SU** following steps are necessary:

- to provide hydraulical connection between Tx and **SU**
- to connect the unit to the suitable power supply (See Specification)
- to connect the **SU** to delivered lap-top with the SIMMS 2.1 software
- to switch on the main switch QM1 ON.

Attention:

- **if you use only the SU (without lap-top connection) reading data are shown only on the display of PCD AMIT.**
- **if you use only the SU (without lap-top connection) all procedures should be properly finished to the end of the program – it means that the measuring should be finished without any interuptions until the preprogramed parameter TD (Test Duration) expires.**

In the case that the last measuring is interrupted – e.g. before the **TD** parameter (Test Duration) expires, the **SU** will always evaluate the switching OFF/ON as a supply outage / supply recovery and after **60 sec** will try to continue the last stage of measuring.

This “automatic restart” can be easy interrupted by the click on an arbitrary button of the AMIT PLC in the beginning of a new job of the **SU**.

The old data remaining in the **SU** can then be downloaded into the lap-top.

On the other hand, if the interconnection of the **SU** and a lap-top exists, the corresponding data can be downloaded into the lap-top for the evaluation and are simultaneously visualized in the corresponding windows.

The “old” data remains in the **SU** till a new On-line Measurement of the Transformer begins. The begining of a new job is always defined by the selection and the confirmation of 1-P or 2-P regime. Up to this confirmation it is always possible to download the “old” data into the lap-top. After the confirmation all data are erased from the AMIT memory.

After switch-up of main switch See Fig.2 the PSD AMIT of the **SU** asks at first for the specification of **TD**-value (**T**est **D**uration) parameter, if the **TD** is not defined, the display will automatically show the preset parameter TD = 20 (min):

TD = (min)
+/- PUSH ENTER

This parameter can be altered by pushing (+) / (-) buttons, the TD-value will be changed in time-periods of 10 min. (min. duration of the test is 20min, max. 1550 min) or, under operation conditions, the TD-value can be arbitrary changed in the Parameter Table (See 5.1).

But never forget – your SIMMS 2.1 Service Unit is the apparatus for the quick, reliable reading and evaluation of the status of a transformer and not for its quasi-on-line measurement (e.g. more days) !

By pushing ENTER, the **SU** proceeds to commissioning procedure.

Rem. Should any malfunction happen, simply shut-down the **SU** by the main switch QM1 and restart the whole operation again.

5.1 Date & Time Setting of SU

For the change of Date and Time click on ESCAPE and the display shows the last Date and Time e.g.

25.11.2015
11.33.00

To change Date (25.11.2015) click on (+). To select the number click on (→) or (←) and change this number by click on (↑) or (↓).

To changeTime (11.33.00) click on (-). To select the number click on (→) or (←) and change this number by click on (↑) or (↓).

To load the change in the SU memory click on ENTER and then click on ESCAPE for return back to former procedure.

5.2 STARTUP Procedure

In the first step of startup procedure See Fig. 4 the SU asks if the inlet hose **H1** (**green**) is properly connected to sampling cock of a transformer and its opposite end by quick coupling **QC2** (bottom coupling) to SU

CONNECT H1 (GREEN)
TO QC2 <ENTER>

and the exhaust hose H3 (**red**) has to be properly connected via **QC1**(upper coupling) to SU and its opposite end is situated into oil resistatnt bucket

CONNECT H3 (RED)
TO QC1 <ENTER>

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Immediately after the pushing ENTER , the **SU** starts the deaeration of hose H1 and the display shows

VACUUM BUILDING
ON P = xxx **kPa**

the pressure P in inlet section gradually descreases and if the condition **P ≤ Pminvac** is fulfiled, the system is considered tight.

The SU then asks if the sampling cock is **directly connected** (via sampling cocks) to oil filling of a transformer or not (See please page 12 - ATTENTION)

DIRECT CONNECTION?
YES PUSH (+) NO (-)

For direct connection **+** the SU displays demands

OPEN SAMPLING
COCK, PUSH ENTER

after opening of sampling cock the hose H1 and the whole SU is rinsed our by the oil from the transformer and oil is forced by running gear pump via hose H3 into oil-resistant bucket.

The SU asks if the inflow into oil-resistant bucket proceeds without bubbles (the hose H1 has to be completely fulfilled by oil before its disconnection !!)

NO BUBBLES ?
PUSH ENTER

After confirmation by ENTER is deaeration of hose H1 finished and gear pump stops.

If the detrimental space betwenn the main valve and sampling cock exists is necessary to push (**-**) and the SU at first shows the same display as before

OPEN SAMPLING
COCK, PUSH ENTER

but now, the deaeration of detrimental space between main cock and sampling cock is performed. The display reads again

VACUUM BUILDING
ON P = xxx **kPa**

if a detrimental space is properly deaerated (**P ≤ Pminvac** again) the SU displays .

OPEN MAIN COCK
PUSH ENTER

and the **detrimental space and the hose H1** is rinsed out by oil from the transformer again and by gear pump is forced via QC2 and hose H3 into the bucket as before.

The SU asks

NO BUBBLES ?

PUSH ENTER

After confirmation by ENTER is deaeration of detrimental space and hose H1 finished and the gear pump stops.

In the next step the hose H1 has to be disconnected from QC2 to make this connector available for the connection of hose H2 and its deaeration.

The SU asks:

DISCONNECT H1
FROM QC2 <ENTER>

and after pushing ENTER the check of proper H2 (**blue**) connection is performed (hose H3 was already properly connected to QC1 and oil-resistant bucket before)

CONNECT H2 (BLUE)
TO QC2 <ENTER>

the gear pump is started again and the deaeration of hose H2 begins

VACUUM BUILDING
ON P = xxx **kPa**

the pressure P in inlet section gradually descreases and if the condition **P ≤ Pminvac** is fulfiled, the system is considered tight.

The SU asks the same way as before if this sampling cock is **directly connected** to oil filling of a transformer or not

DIRECT CONNECTION?
YES PUSH (+) NO (-)

For **+** the SU displays

OPEN SAMPLING
COCK, PUSH ENTER

after opening of sampling cock the hose H2 and the whole SU is rinsed out by oil from transformer and the oil is forced by running gear pump via hose H3 into oil-resistant bucket.

The SU asks if this procedure proceeds without bubbles (the H1 has to be completely fulfilled by oil before its disconnection !!)

NO BUBBLES ?
PUSH ENTER

After confirmation by ENTER the deaeration of hose H1 is finished and gear pump stops and the begin of main procedure (the reading) is repoested by corresponding display.

If the detrimental space between the main valve and sampling cock exists it is necessary to push (**-**) and the SU shows the same display as before

OPEN SAMPLING

COCK, PUSH ENTER

and via opening of sampling cock the deaeration of detrimental space between main cock and sampling cock begins. The display reads again

VACUUM BUILDING
ON P = xxx **kPa**

if a detrimental space is properly deaerated (**P ≤ Pminvac** again) the SU demands

OPEN MAIN COCK
PUSH ENTER

and **detrimental space and the hose H2** is rinsed out by oil from the transformer again and by gear pump is forced via QC2 and hose H3 into bucket as before.

The SU asks

NO BUBBLES ?
PUSH ENTER

After confirmation by ENTER the deaeration and rinsing of detrimantal space and hose H1 is finished and the gear pump stops.

This way both hoses H1 and H2 and both potential detrimental spaces are deaerated and rinsed by oil.

In Fig. 6 the recommended **bottom-up** sampling procedure is shown:

⇒ hose H1 (3 m long is connected to bottom sampling cock and its opposite end is connected to SU via inlet connector QC2 (bottom connector)

⇒ hose H2 (10m long) si connected to uppper sampling cock and its opposite end is connected to the SU via outlet connector QC1 (upper connector).

The B-U interconnection is regarded as the optimal especially when a Tx-temp is low (about 20C) because relatively short hose (3m) means a low hydraulic resistance and small decrease of P-level.

The display demands

CONNECT H1 (GREEN)
TO QC2 <ENTER>

and

CONNECT H2 (BLUE)
TO QC1<ENTER>

and after confirmation the SU goes into on-line reading procedure.

6. ON-LINE Measurement of Transformer

During the on-line reading (in the bottom-up regime in this case) the gear pump permanently drains the oil from Tx- oil inventory via bottom sampling cock and hose H1 into SU, where its humidity is measured and the oil is forced via hose H2 and upper sampling cock back into Tx.

The SU permanently reads the pressure P in inlet section to avoid a undesired release of gases induced by a low absolute pressure and subsequent intrusion of gas bubbles into Tx.

The initial rotational speed of pump is therefore set at a pre-set low level and PCD gradually increases this specific level according to measured P-value. If P-value decreases under allowed Pr-niveau (See Parameter Table) PCD automatically stops the increase of r.p.m. to avoid a potential gas release from the oil. If P-level increases again the PCD increases r.pm. as well.

The overpresure problem is solved indirectly by monitoring of P-value again. Under standard condition the P-value is dominantly defined by the hydraulic resistance of inflow section. If the output is hydraulicky blocked, magnetic driven gear pump stops, the throughflow of oil in inlet section becomes null and void and P-value abruptly increases at the hydrostatic pressure of Tx..

The display shows it as warning:

OVERPRESSURE
P = xxxx kPa

When a source of the overpressure is identified and removed, the **SU** continues automatically.

The basic values Qw, TV, TU, TB are periodically loaded in the PCD AMIT memory and actual values appear on the display.

QW = ... (ppm)
AW = ... (1)

where: QW .... water content in oil (in the ppm at time t)
Aw .... relative humidity of oil directly measured by Vaisala sonde (1)

The remaining data are available by another ↓

TU = … TB = …. (C)
TTS = … (C)

and the next rolling of display ↓ shows

P = xxx **kPa**
Qpv = xxx **%**

where: TU .... upper temperature of transformer at time t
TB .... bottom temperature of transformer dtto
TTS .... main temperature of transformer dtto
P ... actual pressure in inlet section (kPa)
Qpv .... virtual water content in cellulose (%)

All measured data from the beginning are available at any time by means of laptop, which can be connected to the serial connector of the **SU**.

For proper data evaluation, the equilibrium operating environment of the transformer must meet the necessary criteria.

In practice, this means the following :

- time variation of the mean temperature (TTS) of the transformer

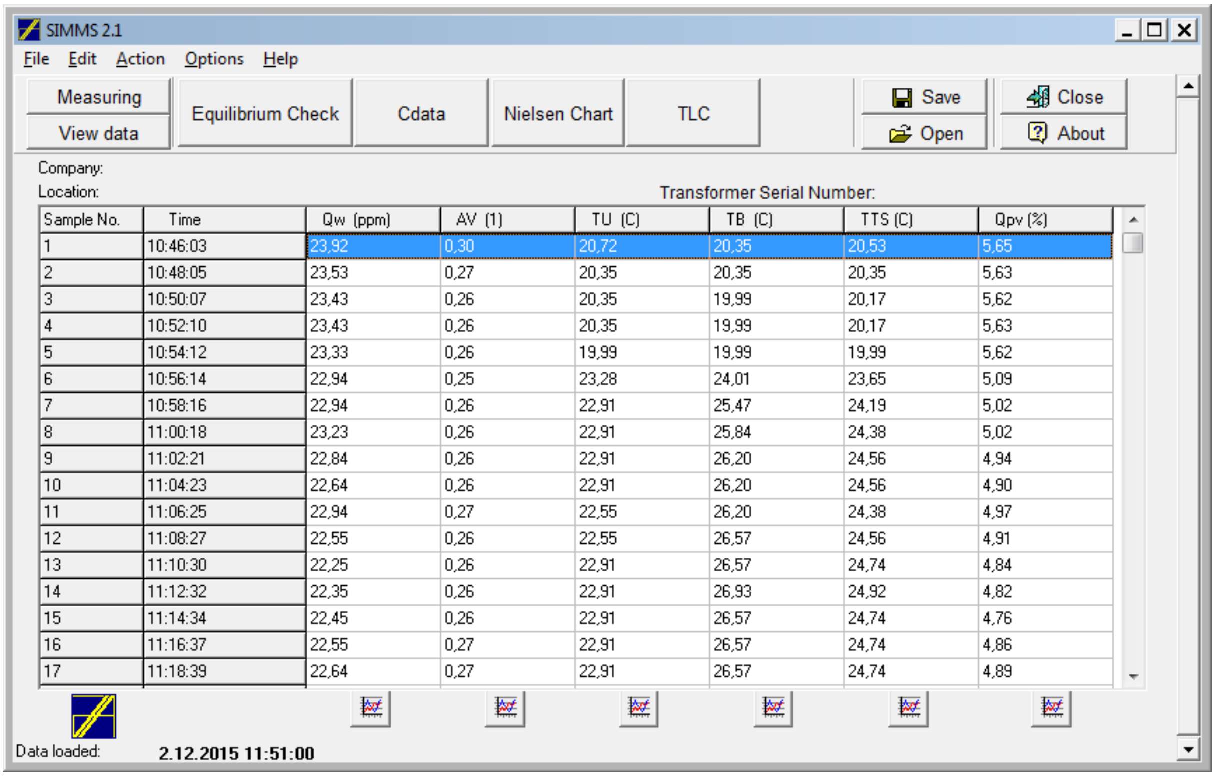
and

- time variation of the water content in the oil (Qw)

must be simultaneously lower then predefined limits.

The **SIMMS 2.1** software solves the problem in the following steps:

- the program is started by clicking on the **SIMMS 2.1.exe** icon at the Main window of the lap-top and we get the main SIMMS 2.1 window. By click on the **Measuring** button are data transferred into the lap-top and visualized in the form of the Data Table.



Sample No.	Time	Qw (ppm)	AV (1)	TU (C)	TB (C)	TTS (C)	Qpv (%)
1	10:46:03	23,92	0,30	20,72	20,35	20,53	5,65
2	10:48:05	23,53	0,27	20,35	20,35	20,35	5,63
3	10:50:07	23,43	0,26	20,35	19,99	20,17	5,62
4	10:52:10	23,43	0,26	20,35	19,99	20,17	5,63
5	10:54:12	23,33	0,26	19,99	19,99	19,99	5,62
6	10:56:14	22,94	0,25	23,28	24,01	23,65	5,09
7	10:58:16	22,94	0,26	22,91	25,47	24,19	5,02
8	11:00:18	23,23	0,26	22,91	25,84	24,38	5,02
9	11:02:21	22,84	0,26	22,91	26,20	24,56	4,94
10	11:04:23	22,64	0,26	22,91	26,20	24,56	4,90
11	11:06:25	22,94	0,27	22,55	26,20	24,38	4,97
12	11:08:27	22,55	0,26	22,55	26,57	24,56	4,91
13	11:10:30	22,25	0,26	22,91	26,57	24,74	4,84
14	11:12:32	22,35	0,26	22,91	26,93	24,92	4,82
15	11:14:34	22,45	0,26	22,91	26,57	24,74	4,76
16	11:16:37	22,55	0,27	22,91	26,57	24,74	4,86
17	11:18:39	22,64	0,27	22,91	26,57	24,74	4,89

At first, the Equilibrium Check of the SU reading has to be performed.

In order to achieve the first rough estimation of dynamic change during the reading in the graphical form simply click on the icone under the columns Qw, AV, TU, TB, TTS. or Qpv (virtual water content in cellulose in %)

If there exists a substantial and obvious change of both values, the transformer doesn´t most probably reach the requested equilibrium in given TD time-period and the TD-parameter has to be extended.

The change of TD-parameter can be performed:

- o any time during the reading-period in the Parameter Table
- o at the end of given TD-period.

The exhaustion of TD-period is then reported by the display

CONTINUE ?
+ YES / NO -

By click on (+) the next display asks for requested time-extension

TD = (min)	
+/-	**PUSH ENTER**

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This parameter can be altered in this specific case by pushing (+) buttons, the TD-value will be extended in time-periods of 10 min.

This extension procedure can be arbitrarily repeated till either the requested equilibrium is met or the dynamic of a Tx excludes any relevant evaluation of its moisture problem.

The expiration of last-defined TD period reports the AMIT by the display

CONTINUE ?
+ YES / NO -

By click on (-) is the reading finished and the next display reports the begin of next procedure the return of oil from bucket back into transformer (See Section 8).

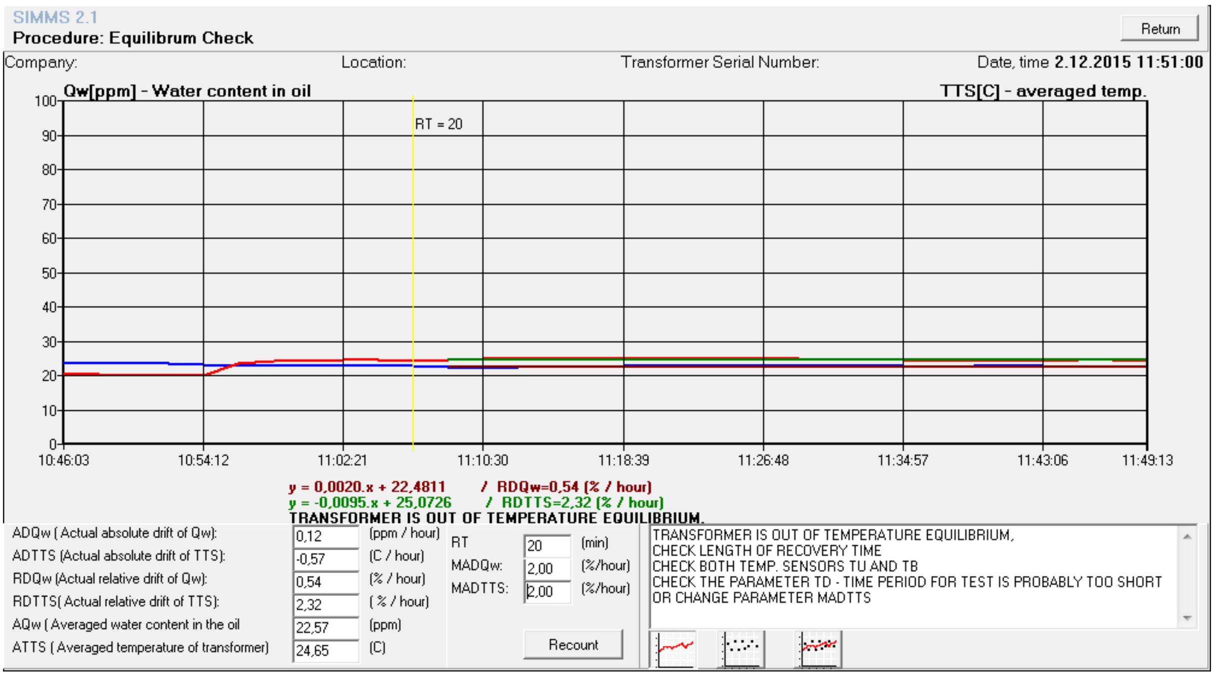
A proper evalution of moisture problem of the given transformer is always based on more detailed check of equilibrium of given transformer See Section 7.

Ca 10 minutes after beginng of the reading the click on Equilibrium Check button give us the first information concerning time-related changes of both main values:

- o .Qw … water content in oil
- o TTS … averaged temp. of diven transformer

7. Transformer Equlibrium Check

By click on the button Equlibrium Check the time-related diagram of Qw- and TTS-value (transformer average temperature) is shown.



then chose in the bottom part of the window:

- what **R**ecovery **T**ime (**RT**) will be used for data evaluation (in this way, we can “cut out” the undesired dynamical variation of the initial data (which can be caused by SIMMS 2.1 alone). In the picture RT=5 min is used.
- what **M**aximal **A**llowed **D**rift:
  - o MADQW – for water content in the oil Qw (%/hr), here 1.5%/hr
  - o MADTTS – for main transformer temperature TTS (%/hr), here 0.5% /hr

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The value of the relative concentration drift of Qw (RDQW = 4.00%/hour) looks high.

Therefore computer evaluates this state as: TRANSFORMER IS OUT OF CONCENTRATION EQUILIBRIUM and subsequently offers : CHECK ………

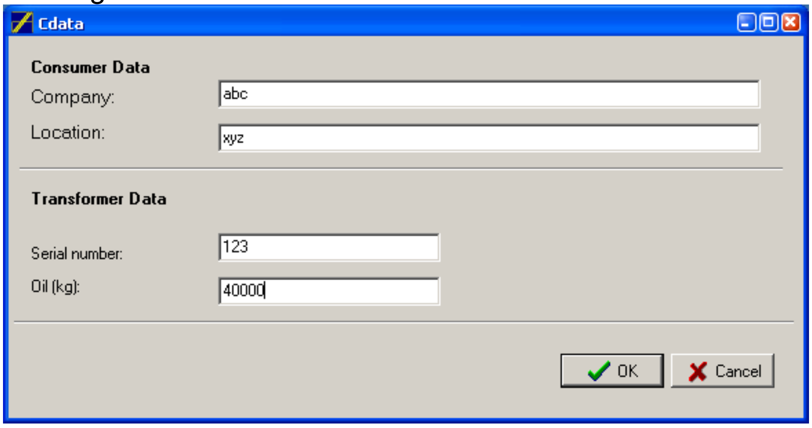
Yet, when considering the relative temperature drift (RDTTS = 0.62 %/hour) the transformer **is** in the acceptable quasi-equilibrium.

This slightly diverges from the overall equilibrium of the transformer, but the absolute value of Qw, as well as the absolute drift ADQW = - 0.27 ppm/hr are relatively very low as well and near the calibration precision of the Vaisala transmitter. Thus, both AQW and ATTS values can be accepted for the following evaluation.

The conclusion is simple: the RT-value is too low and the MADQW and MADTTS values were set too low as well – acceptable quasi-equilibrium MADQW value ranges between 3-5 % /hour. On the other hand, the preset MADTTS values should never exceed 5-7% /hour. Therefore we will set both values on 5%/hour and the RT on 10, then, by click on button Recount we get a new evaluation of the current state of the transformer.

8. Advanced Evaluation

Clicking on the **Cdata** button in the SIMMS 2.1 main window opens the Basic Data logger

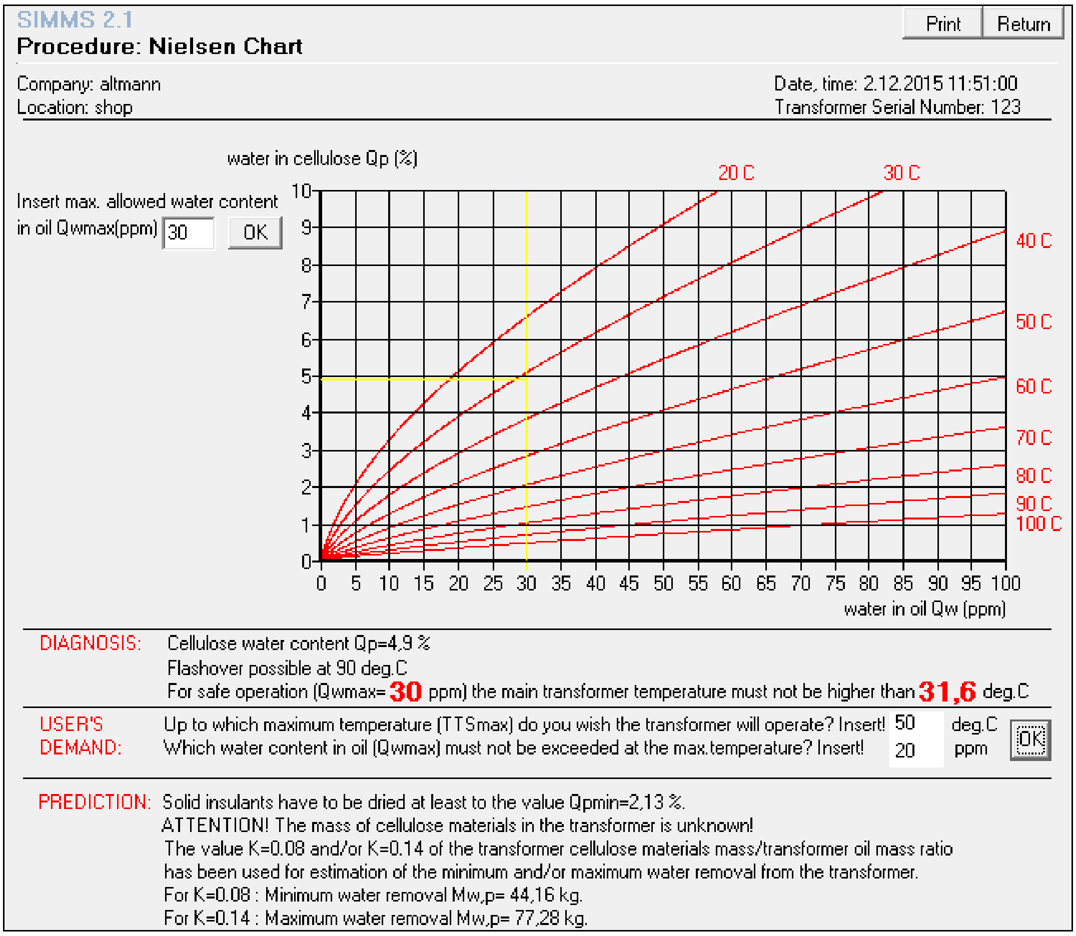


consisting from Consumer Data and Transformer Data.

All data have to be properly entered to avoid problems concerning:

- o proper indentification of the transformer
- o quantitative evaluation of the amount water which should be removed according to client ´s demand via Nielsen and LTC procedure

After clicking on the Nielsen Chart button the evaluation of water content in the cellulose is shown.



The Nielsen chart then enables in the **Diagnosis** section :

- quantitative evaluation of the average water content in hard insulants of the transformer (Qp = 4.9% in this case) based on the SU-reading of:
  - o water content in oil
  - o upper and bottom temperature of the transformer
  - o equilibrium conditions
- the first determination of operation conditions is focused on evaluation of the ***maximum allowed temperature level of this transformer where*** **the water content in oil** ***doesn´t exceed allowed limit.*** See an example: the horizontal yelow line represents the calculated Qp-value (4.9%), the vertical yellow line represents the entered maximum allowed Qwmax-value (30ppm) and their intersection then determines the requested maximum allowed temperature of this transformer (**31.6** degC).
- evaluation of the amount of water which has to be removed, by given averaged temperature of the transformer, to achieve the desired water content in oil

The **USER´S DEMAND** section then enables to enter target values of this specific transformer:

- ➢ the requested water content in oil (20ppm):
- ➢ at requested (averaged) temperature of its oil-cellulose system (50C):

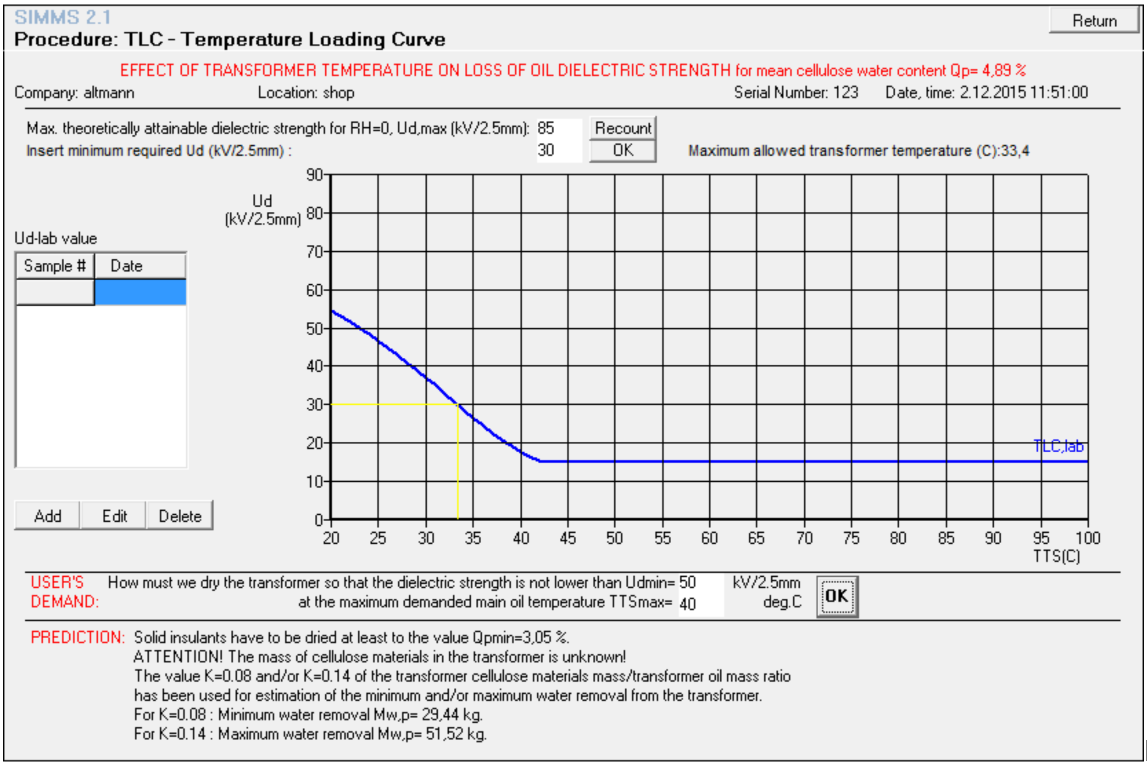
After clicking on the OK button, the calculation of the amount of water which has to be removed from this transformer is performed and shown in the **PREDICTION**:

To fulfil input conditions (10 ppm, 50 C,) and after click on OK, the PREDICTION give us following results:

o the water content in cellulose has to be reduced from 4.9% at 2.13%,

o the minimal amount of water which has to be removed is ca 44 kg

o the maximum amount of water which has to be removed is ca 77 kg



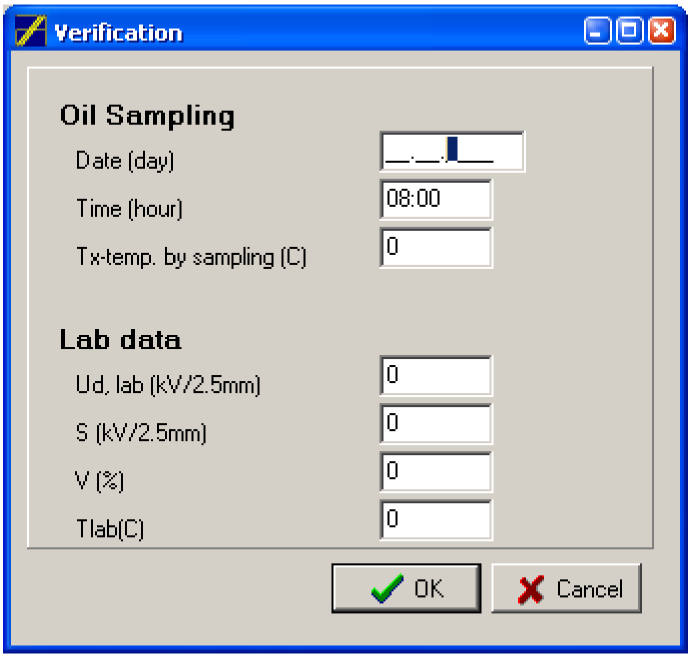
In the next diagnostic step, started by the click on TLC-button, the next very important relation between the theoretical dielectric strength of oil (Ud-value) and the averaged temperature of this specific transformer is established.

This step is extremely important especially for the determination of IEC-requested operation conditions of the transformer (the Ud-value has to be, under operation condition, always higher than IEC-given limit).

In contrast to standard diagnostic which gives us only **single Ud-value** at a sampling temperature and nothing else, the TLC-relation (Temperature Loading Curve) gives us substantially better insight because **describes the change of the Ud-value of oil within the whole temperature range of the given transformer .**

This approach enables us the another, extremely important step: the easy verification of the veracity of our TLC-relation (and therefore veracity of the whole diagnostics inclusive lab reading(s))) by **by the <u>independent</u> Ud,lab-measured value(s):**

The Ud,lab-value can be entered by the clicking on the Add- button under the Ud-lab Table (Sample #, Date] which opens window



where the **Oil sampling** data (Date, Time, Tx-temp by sampling) and the **Lab data** (Ud,lab-value, S.. Ud-deviation, V-deviation, Tlab-temp) can be easily entered.

The clicking on the OK button, then implements all data in the TLC-diagram and simultaneously shows the corresponding sample.

Verification results :

1. the lab Ud,lab-value at the sampling temperature is near enough of the TLC-relation: it means that the difference between Ud,t-value (maximum attainable dielectric strength corresponding TLC) and the Ud,lab is ca + - 10 kV/2.5mm $\Rightarrow$ **The acceptable accuracy of the TLC-relation and the Ud,lab-reading.**

2. the Ud,lab-value is substantially lower (the Ud-lab value is vertically more than 20 kV/2.5 mm under the corresponding Ud,t-value (TLC): this difference indicates the potential presence of particles in oil (or a wrong reading of course). Should therefore be confirmed/disproved in the next diagnostic step (e.g.amount and size of particles has to be checked or a new Ud, lab -reading should be performed).

- the Ud,lab.-value is substantially higher than Ud,t-value: is higher than the maximum attainable dielectric strength of oil $\Rightarrow$ wrong lab reading or the wrong Qw-reading:

- oil temperature before the BDV (Break Down Voltage)-test was probably substantially higher than the norm-requested 20C+/- 5C-level.
- the Qw-reading is wrong : the Vaisala sensor has to be calibrated

ATTENTION.

According to IEC Norm the reading of Ud-value in a lab has to be performed under strictly defined conditions. One of most important parameters is the temperature of oil in the measuring vessel : the temp. has to be 20C +- 5C !!

For a proper evaluation and verification of data by means of the TLC, the Tlab-value (the temp. of the oil) is absolutely crucial: higher temp. of the oil means higher Ud-value of the oil and vice versa. The oil protocol without this specific temp. is therefore worthless.

- **Determination of operation conditions**: the Ud-value must never be lower then e.g. IEC limit (say 30 kV/2.5mm)

  insert (in the left, upper part of the TLC-window):

  - minimum required Ud-value (here 30 kV/2.5mm),

  and the clicking on the OK button then gives you requested results : the maximum allowed (averaged) temperature of the transformer (ca 34 C)

corresponding relation is smultaneously shown in the diagram (30kV/2.5mm = horizontal yelow line, resulting 34 C = vertical yellow line)

The **USER´S DEMAND** section enables to enter target Ud-values of this specific transformer:

- the required Ud-value (say 50kV/2,5mm):

This target value of the oil has to be always substantially higher than the IEC-limit (mostly 30 kV/2.5mm)

- at requested (averaged) temperature of its oil-cellulose system (40C)

To fulfil input conditions (50kV/2.5mm, 40 C in this case), the PREDICTION give us following results:

- o the water content in cellulose has to be reduced from 4.9% at 3.05 %,
- o minimal amount of removed water is ca 29.44 kg
- o maximum amount of water which has to be removed is ca 51.52 kg

8. Return of oil from oil resitant bucket back into transformer

The oil discharged into oil-resistant bucket (during deaerating of both hoses H1 and H2) should be safely returned back into transformer.

The PCD Amit asks if the oil return should to be performed or not

OIL RETURN ?
Yes + / No -

If **No** the **SU** measuring campaign is definitely finished and display shows

READING
FINISHED

If **Yes** , the SU asks if discconection of hose H1 from connector QC1 was performed

H1 DISCONNECTED ?
YES <ENTER>

if Yes the SU requires connection of hose H3 to connector QC1 (hose H2 remains connected to connector QC2)

H3 CONNECTED ?
YES <ENTER>

by clicking on Yes the SU asks for confirmation of proper positioning of opposite end of hose H3 under oil level in oil-resistant bucket

UNDER OIL LEVEL?
YES <ENTER>

click on Yes starts gear pump and the oil is sucked via hose H3 from the bucket and via hose H2 is transported back into oil inventory of transformer.

If the hose H3 isn´t properly placed under oil level, the PCD switch the gear pump immediately off and PCD asks again

UNDER OIL LEVEL ?
YES <ENTER>

and after confirmation the removal of the oil continues

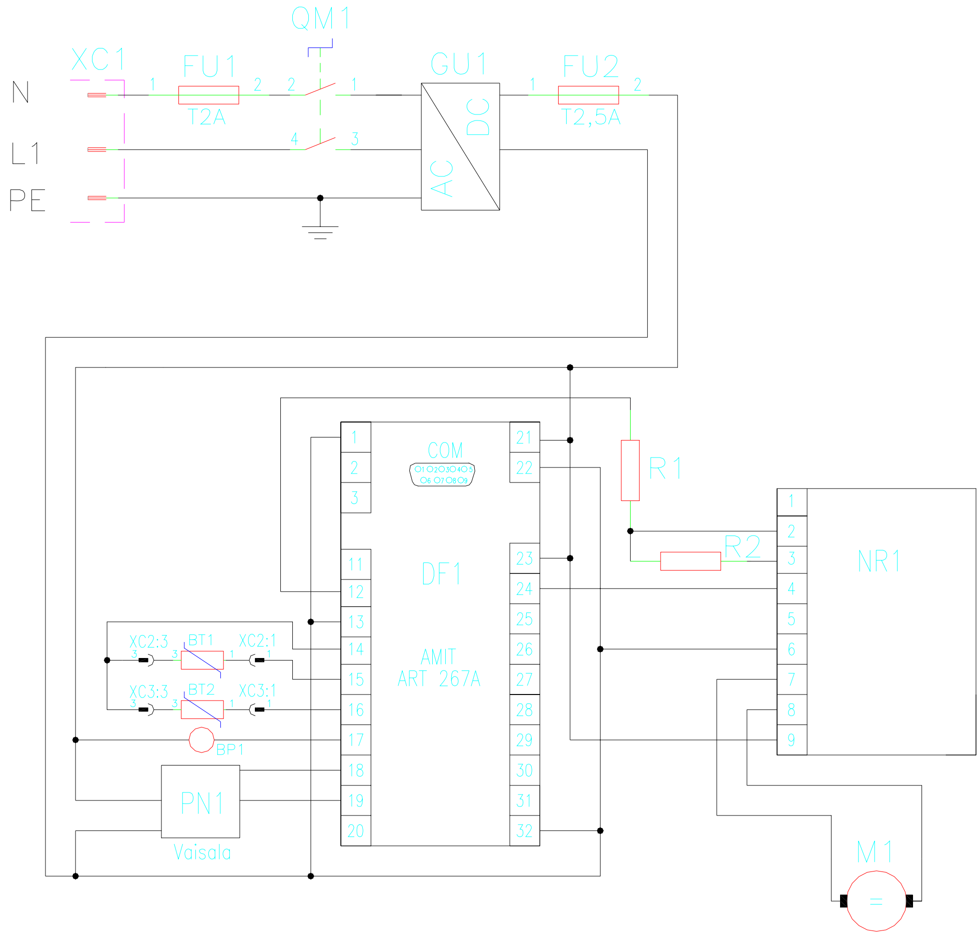
OIL REMOVAL ON
WAIT PLEASE

till the bucket is fully emptied

OIL REENTRY
FINISHED

9 . Electrical circuits .

Power Circuit diagram of the SU is shown on Fig.6, components location is shown on Fig.7



Name	Function	Designation	Qty	Producer
QM1	Main switch 10A, 240V	Best.Nr. 5016 38-50	1	Conrad
XC1	Power supply connector	2RMD18B4S5V1	1	EMS
XC2,3	Temp. sensor connector	XLR 3	2	CANON
XC3	Data connector	F09	1	D-SUB
GU1	Power supply	TXL 070-24S	1	Traco Power
FU1	230 (110)VAC T 2A tube fuse	FST01	1	GES Electronics
FU2	24 VAC T 2,5A tube fuse	FST02	1	GES Electronics
DF1	Proces Control Unit	ART 267 A	1	AMiT
BT1, BT2	Temperature sensor	PT30, Ni 1000	2	Rawet
BP1	Pressure sensor	DMP 331, 0-6bar	1	BD Sensors
PN1	Humidity sensor	MMT 162	1	Vaisalla
M1	Gear Pump	M42x30/I	1	Maprotec
NP1	Pulse control converter	DRN 4225	1	Bel
R1, 2	Rezistor 1.5kΩ, 0.6W		2	

Fig. 6 **SU** Circuit diagram

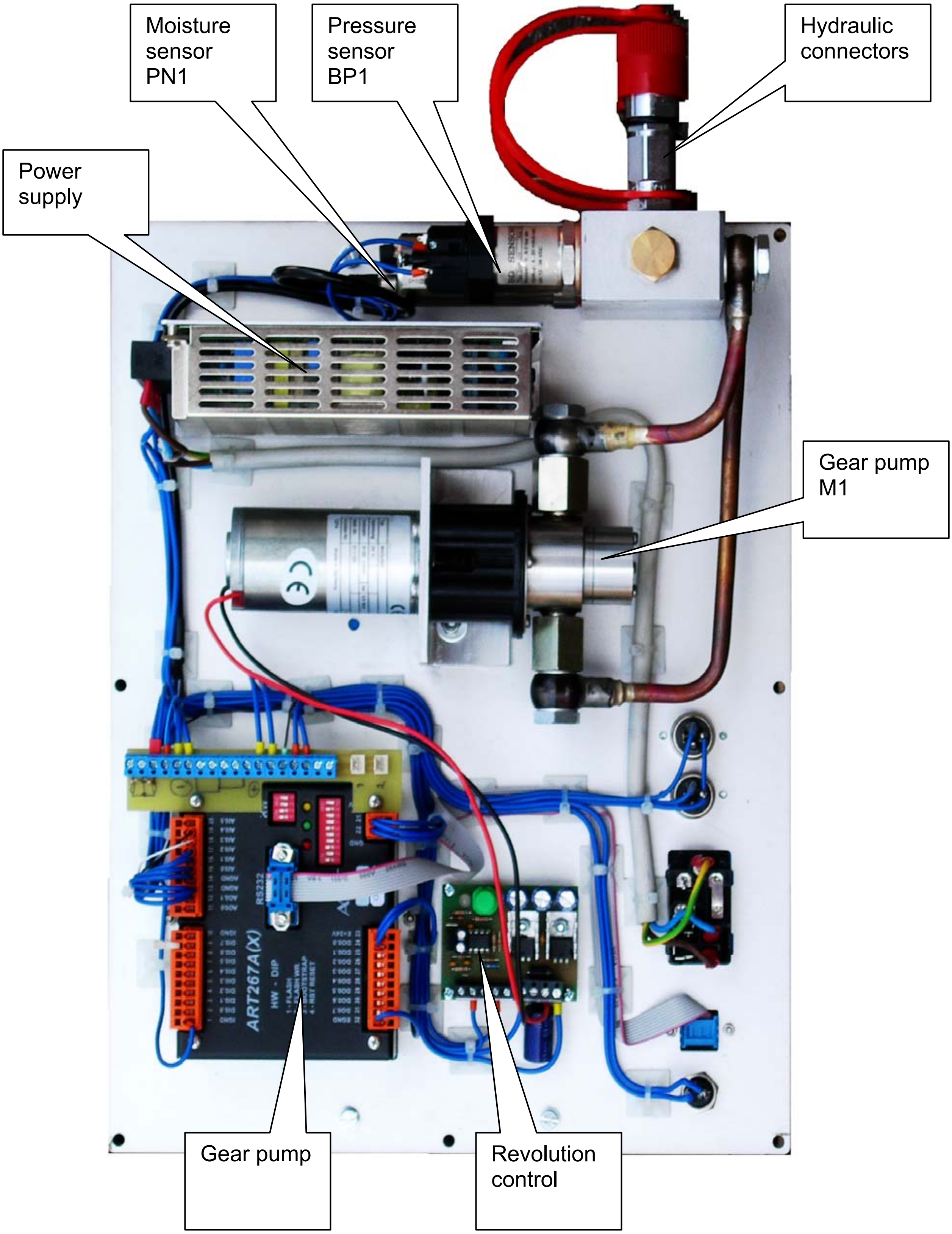


Fig. 7 **SU** Component location

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