# PROPHYLACTIC AND THERMOVISION MEASUREMENTS OF ELECTRIC MACHINES AND EQUIPMENT

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*ABSTRACT:*

*High-voltage measurements of generators, unit and service transformers and some significant motor drives used at a nuclear power plant are described in this paper. Thermovision measurements of electric machines and distribution systems are dealt with in the second part of the paper.*
*Power electric equipment represent one of the most significant components of a nuclear power plant. Turbine mechanical energy is converted into the electrical energy within these equipment. Power generated by generators is transformed by transformers so that it can achieve appropriate parameters for both the transmission over the distribution system and the power plant service power supply. The service power supply switchboards and cables provide power supply to motors and other consumers necessary for the nuclear power plant technological process. The whole complex of equipment has to be maintained in good technical condition.*

*It is necessary to make thermovision and prophylactic measurements to identify and verify the electric equipment technical condition. The mentioned measurements warn the operation staff in advance against both gradual deterioration of power connection contact resistances, i.e. power connections overheating, and the machine insulation systems condition deterioration. The operation staff try to prevent the electric equipment operation accidents by early removing the detected failures, thus, improving the nuclear safety.*

*In order to provide the above-mentioned activities a special prophylactic measurement group was established at the NPP Bohunice in 1983. The group specialists make following types of measurements:*

***1. Prophylactic measurements of electric machines.***

*1. 1. Prophylactics of 220 MW generators and 6 MW service power generators,*
*1. 2. Prophylactics of both unit and service transformers and VHV bushings,*
*1. 3. Prophylactics of major 6 kV motor drives.*

***2. Thermovision measurements of current connections***

*Measurements enumerated in paragraph 1 are made on disconnected electric machines during refuelling outages, thermovision measurements are made under reactor unit full operation conditions, i.e. on equipment energised to the rated level.*

## 1.1. Prophylactics of 220 MW Generators and 6 MW Service Power Generators

A generator is disconnected from both encased conductors (in the points of bushings) routed to the respective unit transformer and connectors routed to the neutral point during measurements. The main generator stator winding must be dried up by means of pressure air so that water remaining in the winding can not distort measured values.

Phase-to-Earth Insulation Resistance Measurements

Measurements are made with the TETTEX HV-10 type 5430 megaohmmeter steplessly controllable up to 10 kV. Insulation resistance of a respective phase is measured against earth under voltage of 5 kV, the remaining phases being earthed. Measurements are made in function of time: readouts are taken after 15, 60 and 600 seconds. Polarisation indices $p_{i1}$ and $p_{i10}$ are calculated that equal to:

$$p_{i1} = R_{60} / R_{15} \qquad p_{i10} = R_{600} / R_{60}.$$

If polarisation index values exceed 1.3, the stator insulation condition is sufficient, if they range over 2.0, the condition is good. Polarisation index values depend on both moisture contents and pollution of the insulation system. The higher is the value, the drier is the insulation. The polarisation index is used for approximate review of the insulation condition. Subsequent measurements are only made if the winding insulation resistance equals to at least 700 MΩ.

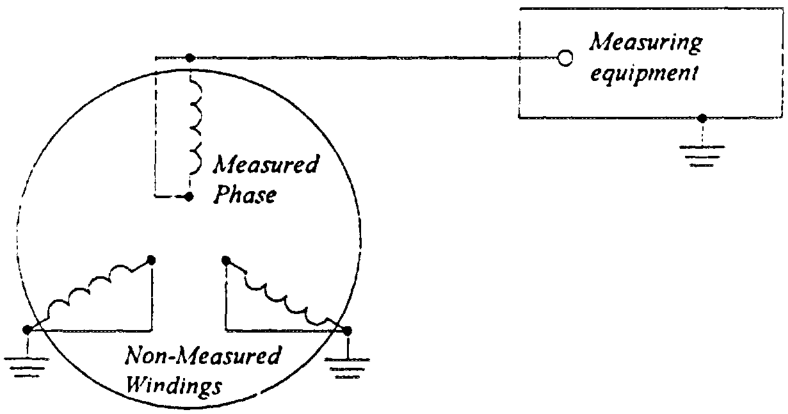


*Fig. 1: Interconnection between a measured winding and the measuring equipment*

**Capacity and Loss Factor Measurements**

The loss factor tg δ is defined as a ratio of active to reactive current. In case that measurements are made on an insulation material, it represents the extent to which electrical energy is converted into heat. Rise in the loss factor tg δ, as well as delta tg δ, is a generally accepted criterion of insulation material ageing. It is important to measure both loss factor and capacity against applied voltage if the ageing insulation material conductivity mechanism is being changed. Capacity C is measured in μF, loss factor tg δ is a dimensionless quantity.

Measurements are made with a semi-automatic measuring bridge TETTEX 2809, supplied from HV power sources TETTEX 5281 and 5287. Voltage levels of 3.1,4.7, 6.3, 7.9, 9.0,9.4, and 10.0 kV are applied to respective phases when measurements are made. Non-measured phases are earthed. Values of tg δ are compared within ranges of 0.2 - 0.6 Un, 0.4 - 0.6 Un and 0.2 - 0.4 Un.

Values of tg δ must not exceed 2 %. If a higher value has been measured, it indicates that the stator winding is a geing and getting wet.

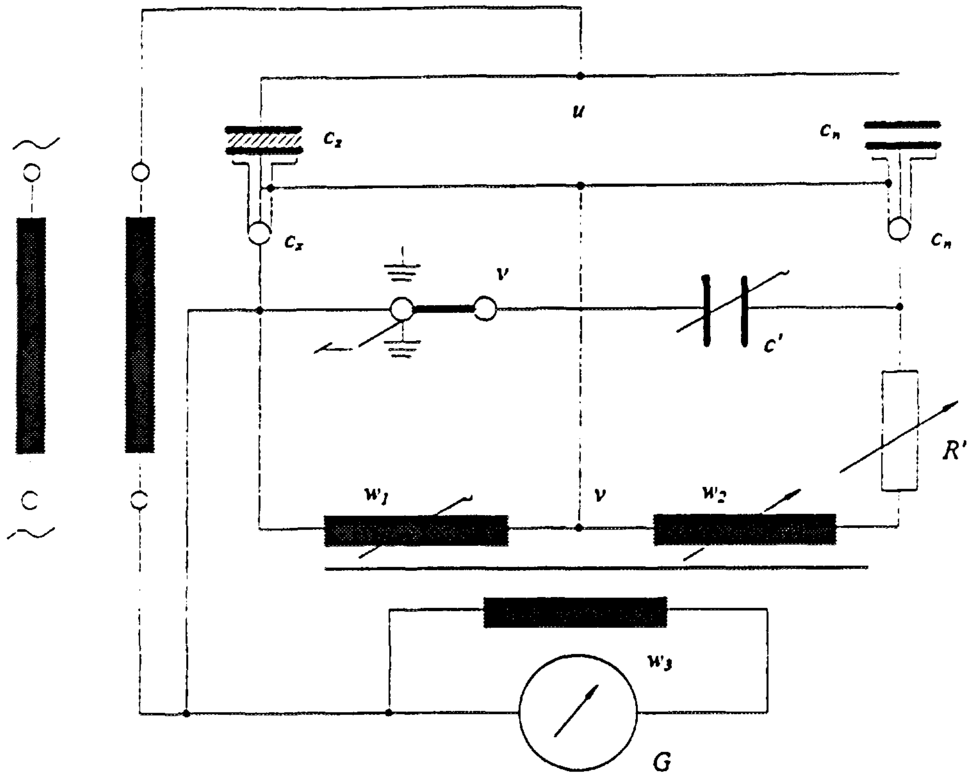


*Fig. 2: Principial Wiring Diagram of C and tg δ Measurements Made by Means of a Measuring Bridge*

**Charging Current Measurements**

Charging currents are measured with the BAUR PGK/45 DC power source. Measurements are made phase by phase, the non-measured phases being earthed. Charging current values are read out at voltage levels of 5, 8, 10, 12 and 15 kV in time periods of 60 and 300 seconds. $R_x$ resistance is calculated out of measured values:

$$R_X = U / I_{300} .$$

High - Voltage Test

A high-voltage test is made following each generator major overhaul involving winding repairs. DC voltage of 41 kV is applied to each of the phases for 60 seconds.
Measurements of windings are made with the BAUR PGK/45 DC power source. The -15,75 kV generator bushings high-voltage tests are also made by means of the application of 65 kV DC voltage supplied from the PGK/1OO DC power source.

The mentioned measurements helped us to detect insufficient insulation condition of the NPP V 1 generator bushings. Insulation resistance must be always measured by means of 5 kV DC voltage prior to and following each high-voltage test.

## 1.2. Prophylactics of both Unit and Service Transformers and VHV Bushings

Oil represents an essential component of transformer insulation. The special prophylactic measurement group specialists have no chromatographic analysis equipment of their own available. That is why they co-operate with the Diagnostic Center Križovany in this field.

The transformer must be disconnected at both primary and secondary sides during measurements and its bushings must be cleaned up.

Winding Insulation Resistance Measurements

Insulation resistances of the windings are measured with the TETTEX HV-1O type 543O megaohmmeter by means of 2.5 kV DC voltage application. Readouts are taken after 15 and 6O seconds. Polarisation indices are calculated out of the measured values in a way similar to the generator insulation resistance measurements. Following winding and support connection combinations are used for the measurements:

| | | | | | |
|---|---|---|---|---|---|
| I. | VHV | : | HV | | |
| II. | VHV | : | HV | + | S |
| III. | VHV | : | S | | |
| IV. | HV | : | VHV | | |
| V. | HV | : | VHV | + | S |
| VI. | HV | : | S | | |

Note: VHV - very-high-voltage side
HV - high-voltage side
S - Winding support

Capacity and Loss Factor Measurements

10 kV/50 Hz voltage is applied to different connection combinations as mentioned above. If the major overhaul takes place in winter, measurements must be done immediately following disconnecting the transformer from the grid, i.e. before the transformer temperature drops below 20° C, because the loss factor value is temperature-dependent.

Magnetising Current Measurements

Magnetising currents are measured with digital multimeters by means of 380 V 50 Hz AC voltage application. Windings of lower voltage are only measured on unit transformers, as the windings are wound over each other (HV, VHV).

If any higher-voltage winding displacement or short circuit, etc. occurred, this would always be transformed into the lower-voltage winding, too. Both VHV and HV sides are measured on the plant service transformers. Transformer taps No. 1, 9 and 19 are measured on the VHV side, whereas tap No. 9 is measured on the HV side.

Winding Ohmic Resistance Measurements

Measurements are made by means of the TETTEX 2285 computer system running under special transformer ohmic resistance measurement software.

The measurement system provides following measurement possibilities:

- single current source I = 1 - 50 A,
- two current sources for separate measurements, i.e two objects can be measured at a time,
- a couple of current sources connectedin parallel, current supply up to 100 A.

The measuring system measures either ambient temperature or oil temperature by measurement probes. Measured values are subsequently used for ohmic resistance correction in relation to selected reference temperature (20°C is the selected value). The measuring system provides remote switching over of plant service transformer taps.

Following the measuring system start up it takes the power source (or power sources) several seconds to supply the selected current to the winding. The ohmic resistance value should be stabilised. It is important to observe whether the value only drops or fluctuates, i.e. it can not be stabilised. The stable value is logged and next transformer tap of a higher number is switched over by the measuring system. All 19 taps of the plant service transformer are measured in this manner. The higher-voltage side is supplied with current of 100 A, the lower-voltage side with 50 A.

A trend line connecting measured value points must form a straight line in case of the NPP V 1 plant service transformers, whereas that of the NPP V 2 plant service transformers must form a parabola. The difference consists in different types of change-over switches. In case that some values are not located on the straight line or parabola or they fluctuate, a definite conclusion can be drawn that there is a defective current connection inside the transformer. Practice indicates it is just this type of measurements that gives the best idea of the transformer current connections condition. It has enabled early identification of severe failures inside transformers at both the NPP Bohunice and Dukovany several times.

400 kV (220 kV) bushings represent very important components of unit transformers. Their insulation resistance is measured by means of 2,5 kV voltage application between the measured point and the transformer frame. Besides, both their capacity and loss factor are also measured.

Capacity $C_1$, as well as loss factor tg $\delta_1$, are measured by means of 10 kV voltage applied to the bushing outlet (top). The measuring cable is connected to the measured point of a bushing and the earthing cable is connected to the transformer frame. The measuring bridge is connectedin UST wiring scheme, i.e. VHV:HV.

Capacity $C_2$, as well as loss factor tg $\delta_2$, are measured under the voltage of 2 kV after both voltage and measuring cables have been interchanged. The measuring bridge is connectedin GST wiring scheme, i.e. VHV:HV+S.

### 1.3. Prophylactics of major 6 kV motor drives

The scope of measurements has been extended nowadays to cover also some major motor drives at the NPP. Both 4.8 MW cooling water pump motor drives and 2.1 MW steam generator feedwater pump motor drives are included. Both motors are of the three-phase asynchronous type, their stators being connectedin Y or 2Y-connection. Unlike the cooling pump motor drives, neutrals of the feedwater pump motor drives Y-connection are not connected to terminal boxes. Thus, it is not possible to make measurements on each respective phase. Following motor drive parameters are measured:

- insulation condition - by means of 5 kV voltage application,
- capacity and loss factor at voltage levels of 2, 4, and 6 kV,
- partial discharges.

Insulation condition, capacity and loss factor are measured in the way described in paragraph 1a).

Partial Discharges Measurements

Insulation systems of electric machine stator windings are never perfectly homogenous. They contain lots of tiny cavities arisen during the machine manufacture and operation. The relative permittivity of gases inside the cavities is er times as low as that of the insulation material. This results in a fact that gases inside the cavities are subjected to er times higher gradient than the insulation material. Moreover, electric strength of an insulation material is higher than that of a gas. That is why breakdowns occur inside cavities at a voltage level much lower than the insulation material breakdown voltage. Discharges occurring inside the cavities are called partial discharges, as they do not span the whole distance between electrodes, but only a short section.

The TETTEX 9126 measuring device is available for partial discharge measurements. It is equipped with its own measuring, processing and recording device and an oscilloscope. The TETTEX 5287 and TETTEX 5281 control transformers are used as HV power sources. The wiring diagram is depicted in Figure 3. The coupling capacitor compensating the partial discharge power must be located as close to the measured machine as possible so as to eleminate the condenser - machine connection interfering effects as far as possible. The aim is to measure both the voltage level at which the discharges start to be displayed on the oscilloscope screen and capacity and current levels of the discharges. Measurements are made at selected voltage levels (e.g. 4, 5, 6 kV).

It is of high significance to eliminate interfering effects of the environment as far as possible during measurements. Following interfering effects are among the most dangerous ones: close located conductive objects without fixed potential, electromagnetic waves of radio transmitters, coupling capacitor, (wrong earthed), tips near both the measuring and HV cables connecting points.

The group specialists have only been making this type of measurements from less than two years. The measured values data bank is, therefore, not very large. Yet, the specialists unambiguously detected insufficient insulation conditions of four feedwater pump motor drives on the basis of both partial discharge and capacity and loss factor measurements.

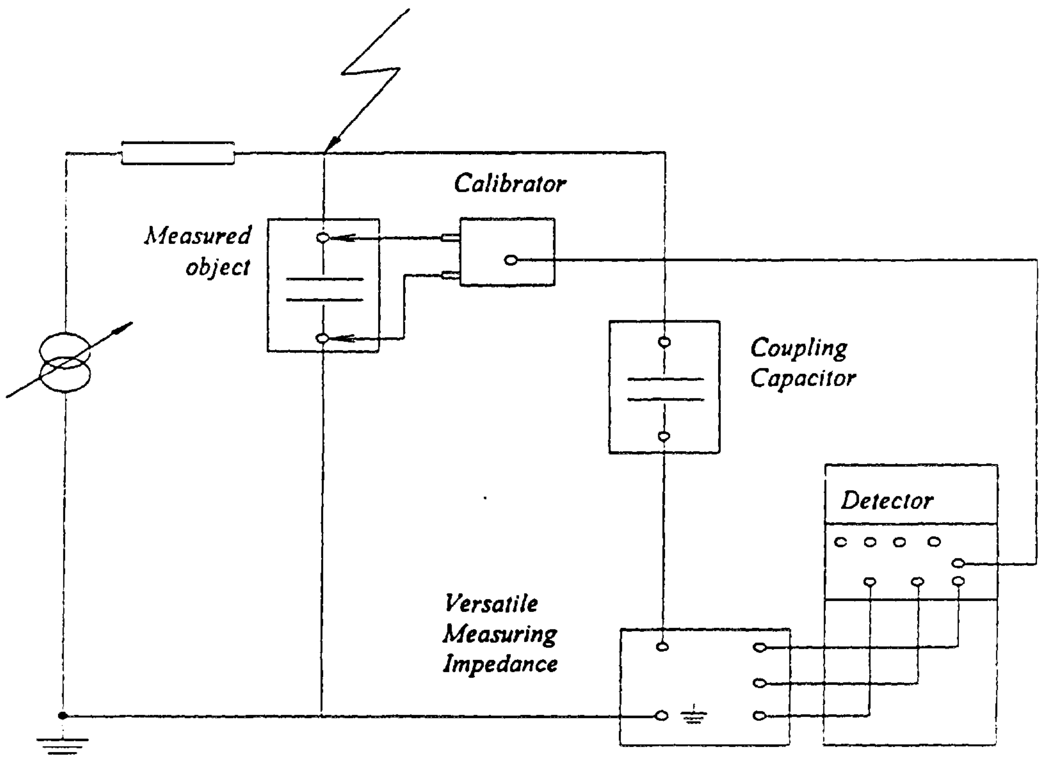


*Fig. 3: Partial Discharge Measurements Principal Diagram*

The results of all the mentioned prophylactic measurements are logged. Thus, an accurate idea of the nuclear power plant electric equipment present-day insulation condition is available. Ten years experience in generators and transformers measurements provides a serious basis for possible measured anomalies review. Each machine has its own „curriculum vitae". It makes it possible to observe annually either a slightly deteriorating insulation condition or a step change in it; this indicates a possible failure of the machine. Copies of measurement logs are handed over to both the equipment owner and Maintenance Division engineers. If the group specialists give recommendations to repair a machine, the maintenance staff will do it. Following each repair work, the machine is subjected to repeated complex measurements prior to putting back into service.

In 1992 the TETTEX INSTRUMENTS Co. mounted the capacity, loss factor, ohmic resistance and partial discharge measuring devices into an AVIA FURGON truck, subjected the devices to certification tests, and connected them to a processing and evaluation computer. Thus, a mobile measurement center was completed that enables to make the mentioned HV measurements reliably and promptly both on and off the NPP site.

## 2. THERMOVISION MEASUREMENTS OF CURRENT CONNECTIONS

Thermal defects, especially in cable corridors. both indoor switching stations and outdoor switchyards and in electric machines themselves. represent dangerous factors. Above all. the fire risk may occur. as well as major electric equipment may fail to operate which results in the NPP nuclear safety violation. Current connections in electric equipment represent a basic source of thermal defects. The connections are made by means of different technologies: pressed connection. screwed connection, contacts of switches, circuit breakers. contactors, etc. The current connections are inspected by means of a thermovision system which operates within the infrared section of the electromagnetic spectrum. Thermovision measurements are made in 110. 220, and 400 kV switchyards, unit transformers. generator outlets. generator switches. generator collecting equipment, 6 kV, 0.4 kV switching stations and 6 kV. 0.4 kV power cable current joints. The above-mentioned equipment are inspected once a year. prior to the reactor unit major overhaul. VHV equipment are inspected twice a year. In addition to the regular measurements, generator stator windings are measured during an inductive warm up and measurements are made on some non- electric technological equipment.

The electric equipment inspection periods are specified by directions. Detected failures are removed by the maintenance staff during reactor unit major overhauls. more severe failures are removed as soon as possible. The value of temperature difference between the current connection and its incoming feeder is the criterion of a thermal defect occurrence. If both the current connection and its incoming feeder are of equal temperature under the conditions of both a steady thermal state and a constant current flow, there is no thermal defect in the connection. If the current connection is warmed up in relation to the incoming feeder. i.e. the temperature difference is not equal to 0° C, the current connection is considered to be defective. In practice, the defect is in most cases identified reliably due to thermal gradient detected along the current route in the neighbourhood of the connection, even if the defect is small. The group specialists are able to detect a warm up by means of the thermovision set. The accuracy of detection is ± 0.1° C for materials with a defined emittivity the value of which does not drop too deep below „1" (this condition is met in practice). The extent of a defect is defined by the warm up value (°C). This value is approximately kept even if the ambient temperature fluctuates. That is why if a defect is observed in function of time, we can judge by the warm up value whether the defect remains unchanged or expands, while the ambient temperature can even drop.

The special prophylactic measurement group has a couple of thermovision measurement workplaces available. One of them is specialised in the NPP V 1 electric equipment inspections. It is equipped with the AGEMA 782 SW thermovision set that comprises: a thermovision camera. a monitor, accumulator batteries. a videorecorder and photocameras for both thermal and real photographs. This set is of older design. Isothermic degrees must be calculated into degrees of Celsius by means of a programmable calculator. The other workplace is specialised in the NPP V 2 electric equipment inspections. It is equipped with the AGEMA 880 LWB thermovision set that comprises similar components to the AGEMA 782 set. Its sensitivity is, however higher and isothermic degrees are calculated into degrees of Celsius by means of the HUSKY computer. The computer is connected to a monitor. It runs in the real-time mode. Moreover. the camera can be controlled remotely. This is especially appreciable when measurements are made near strong current fields. e.g. in case of the generator inductive warm up.

Both the workplaces are operated in the following way:
equipment that have already been enumerated are inspected by means of the mobile thermovision set in compliance with their significance. The group specialists have recorded and registered data on all the power plant switchboards. as well as all 6 kV and 0.4 kV power cable joints. The latter. situated in cable corridors. have been labelled to facilitate their later use.

If a defect is detected. it is recorded by the videorecorder with the accompanying audio explanations. involving both a more detailed defect description and the date of the defect detection. Both thermal and real photographs are taken. because a thermal picture differs much from a real one which makes the orientation more difficult. The measurement results are further processed. More complex thermal pictures are processed by means of the TIC 8 000 computer code providing a very large scale of measured picture processing including historical defect data collection.

The group specialists hand the log of reactor unit equipment thermovision measurements over to both the maintenance staff and the equipment owner two weeks prior to commencing the reactor unit major overhaul. The log involves both a list of measured equipment and a list of defects; each defect item includes either a thermal picture photograph or a colour picture generated by TIC 8 000, e real defect photograph, date of the defect detection, a measured value of the defective current connection temperature difference, temperatures of surrounding properly operating connections, and, finally, a value of current flowing through the connection.

There are two basic measurement techniques: direct temperature measurements and temperature measurements by means of a reference source.

The reference source technique has proved to be better for the group specialists. If an accurate reference temperature source is available, both temperature and warm up can be measured with a high accuracy of ± 0.1° C. Either the switchboard structure or the related equipment are used as the reference temperature source. The object temperature value is not measured with a high accuracy (the ambient temperature referred to as a reference source can fluctuate by ± 1° C), but the value of warm up that is decisive for the measurement purposes does not lose its accuracy, especially at lower temperatures.

The advantage of this measurement technique consists in a good accuracy with which the warm up can be determined and smaller amount of efforts needed to make measurements, because lower number of measurements are to be made to determine the value of warm up. This results in both shorter defect recording time by the videorecorder, as well as less time needed to process the defect records (an advantage with respect to a large number of recorded defects).

If a more severe defect occurs, e.g. a high warm up of a disconnecting switch in a 0,4 kV panel, this results in a remarkable warm up of the switchboard construction that is considered to be a reference source with a constant temperature. In such a case, if possible, the direct technique of both the construction and the faulty object temperature measurement is used. The measurement accuracy still complies with the measurement purpose.

The thermovision measurements have been made since 1986. A sufficiently wide overview of the electric equipment current connection condition has been got at the NPP during this time period. While 120 to 130 thermal defects were detected at one reactor unit annually during the first years, this number dropped to one half nowadays. In 1992 110 kV switchyards thermovision measurements were made to order of Vodné elektrárne Trenčín Company. More than 10 defects were detected in each of inspected switchyards that are identical to the NPP Bohunice VHV switchyards, the warm up values being relatively high - up to 25° C. 1 thermal defect per a switchyard is detected during the inspection in the NPP Bohunice at the most at present. This proves doubtlessly the significant contribution of the thermovision measurements to the nuclear safety.