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EDS – Expert Diagnostic System for the continuous monitoring of substation devices

REVISION			**SUMMARY**	**VISA**
N	**PAGES**	**DATE**		
1	All	17/05/2007	Preliminary Issue	Lodi
2	All	11/07/2007	Complete revision of functionalities	Puricelli
3	All	31/07/2007	Definition of a monitoring system connected to the MRE system (Terna)	Puricelli
4	All	08/11/2007	Revision of the document as a function of the MRE system (Terna)	Puricelli

1 Foreword

The purpose of the on line monitoring system, model EDS – Expert Diagnostic System, is to highlight malfunctions before these can cause an inefficiency in the system, with the goal of better handling maintenance intervention. In order to achieve this goal it is necessary to set up a continuous monitoring system: any further monitoring with dedicated instruments can be programmed depending on the information received.

A pivotal design criterion of the system is that the collection of monitoring devices must not lower the overall system reliability.

As a consequence of this design criterion, the actual manufacturing follows guidelines of extreme reliability for the components used and of minimal connection to the controlled system.

In particular:
. Modules mounted outdoor are designed to work over an extended temperature range (from – 40 °C to + 85 °C);
. The central unit adopts industrial type components (from – 25 °C to +85 °C).

Since the station to be monitored adopts the MRE system by TERNA, all measures performed by the monitoring devices are transmitted via bidirectional optical fibre to a unit mounted in the line cubicle (U.S.) and there computed; the computed results will then be transferred to the MRE system by means of a monitoring unit (U.M.) placed in the line cubicle. The communication protocol between the monitoring unit (U.M.) and the computing unit is defined by the IEC standard 60870-5-101. The following analysis of the signals and the causes that raised alarms will be performed by dedicated units, by reading data from the MRE system.
By means of a dedicated line, separate from the MRE system, it will also be possible to modify parameters of the peripheral monitoring devices, and also to upgrade their firmware without the need of physically go in the field.

The physical construction of the EDS system devices allows mounting them on a variety of devices installed in the substation.

2 STANDARDS and REFERENCE REQUIREMENTS

The EDS instrument complies with CEE directives CEE relative to Low Voltage Electromagnetic compatibility.

2.1 Directives on Electromagnetic Compatibility

Directive no. 2004/108/EC. Applicable Standard : EN61326-1 + A1 + A2.

EMISSION
- CISPR16 (EN 55011, class A); Limits and methods of measurement of radio disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency.
Accepted limits for the conducted emission:
. 0.15-0.5 MHz: 79 dB pk; 66 dB av
. 0.5-5 MHz: 73 dB pk; 60 dB av
. 5-30 MHz: 73 dB pk; 60 dB av
Accepted limits for the radiated emission:
. 30-230 MHz: 40 dB (30 m)
. 230-1000 MHz: 47 dB (30 m).
- EN 61000-3-3: Fluctuations induces in the supply;

IMMUNITY
- EN 61000-4-2 Electrostatic discharge immunity: 8 kV in air, 4 kV contact.
- EN 61000-4-3 Radio-frequency immunity: f= 900 ± 5 MHz, field 10 V/m, AM modulated 80% 1 kHz.
- EN 61000-4-4 Electrical fast transients' immunity (burst): 2 kV peak; 5/50 ns.
- EN 61000-4-5 Surge immunity: 1kV differential mode, 2 kV common mode; 1.2/50 us.
- EN 61000-4-6 Conducted disturbances immunity: 0.15-80 Mhz, 3 Veff, 80% AM 1 kHz.
- EN 61000-4-8 Low frequency magnetic field immunity: 30 A(rms)/m.
- EN 61000-4-11 Supply voltage dip immunity: 20 ms with 100% dips.

2.2 Low-voltage directive

Directive n. 2006/95/EC.
- Applicable standard: CEI EN 61010-1. The class, pollution degree and installation category of the various module are summarized in the following table.
- Inputs and outputs protection: different for each module (see table), according to IEC EN 60529.
- Temperature and relative humidity: different for each module (see table).
- Altitude: less than 2000.

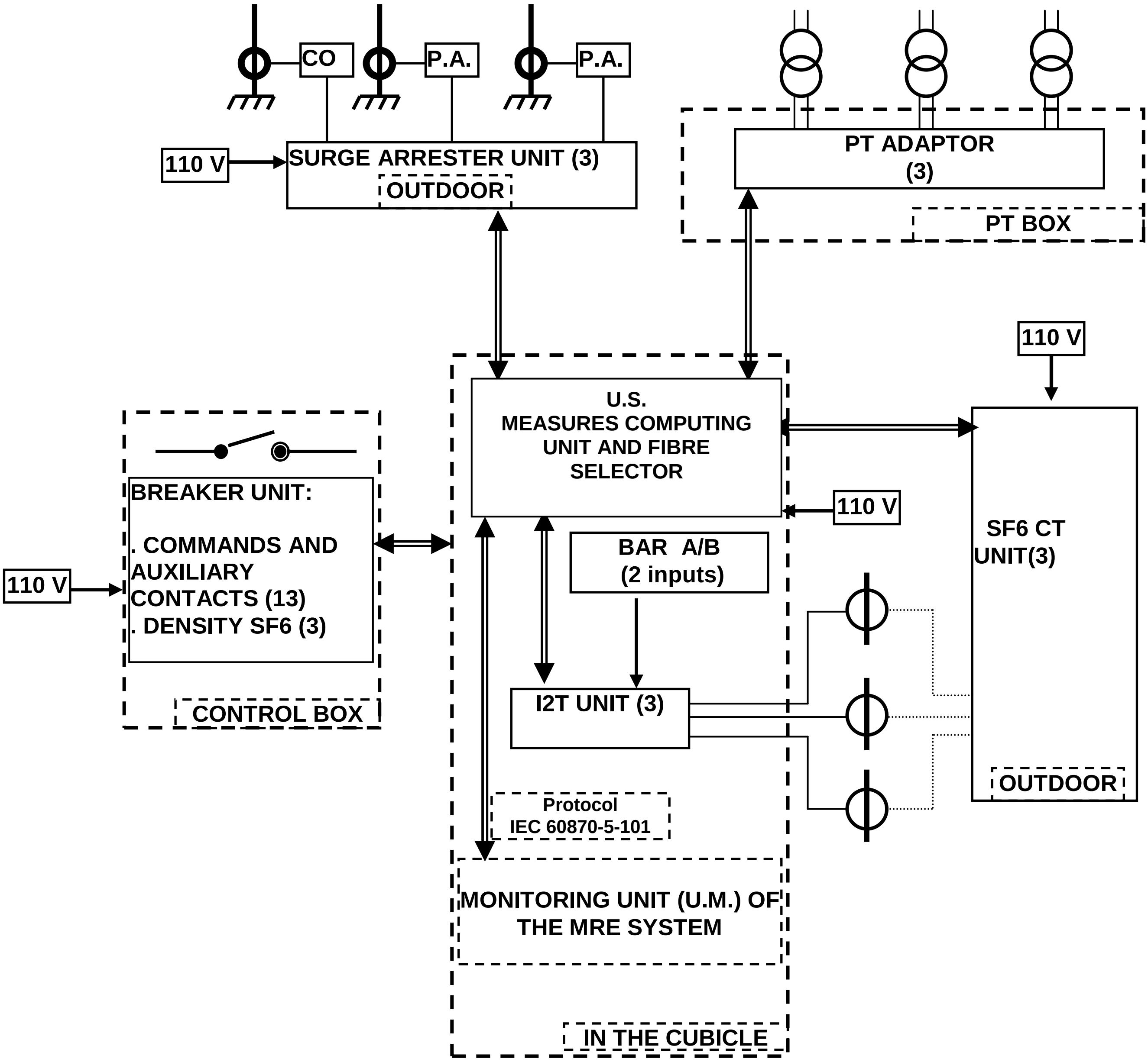
MODULE	**SENSOR POSITION**	**TEMPERATURE**	**IP**	**RH**
Breaker	CB control box	- 25 °C a + 65 °C	20	10 – 90%
I2T	In the cubicle	- 10 °C a + 50 °C	20	10 – 90%
SF6 TA	Outdoors	- 25 °C a + 65 °C	65	10 – 90%
Discharger	Outdoors	- 25 °C a + 65 °C	65	10 – 90%
PT	PT box	- 25 °C a + 65 °C	20	10 – 90%
Line unit	In the cubicle	- 10 °C a + 50 °C	20	10 – 90%
Central unit	Substation- control room	0 °C a + 50 °C	20	20 – 80%

3 UNIT CHARACTERISTICS

3.1 General notions of the monitoring system in association with MRE system

This chapter summarizes the characteristics and the performances of the EDS components:

. Peripheral units, that perform the monitoring signal conversion, and transmit them upon request on bidirectional optical fibre to the computing unit of the line (U.S.);
. Computing unit in the line cubicle (U.S.), that continually controls the peripheral units, receive measurements via optical fibres through a fibre selector, computes the measurements, confronts results with alarm thresholds and sends messages to the monitoring unit (U.M.) of the MRE system via standard IEC 60870-5-101.



PERIPHERAL UNITS OF THE LINE AND COMPUTING UNIT

The peripheral units are mounted:

- Breaker unit: in the CB control box; the transducers for the monitoring of the SF6 gas are positioned outdoors, on the pressure gauges column.
- I2T unit: in the line cubicle, connected via small transformers with core that can be opened at the CT secondary side wiring cables;
- PT unit: in the PT box;
- Surge arrester unit: outdoors, in a box positioned on the central discharger. Each transformer includes a pre-amplifier (P.A);
- SF6 CT unit: outdoors, in a box positioned on the central CT.
- various transducers (CT, VT and so on.. , depending on the use)

The remote units, those not positioned in the line cubicle, are connected via bidirectional optical fibres to a concentrator (U.S.) placed in the cubicle (total of four fibres). In the same module (U.S.) is also placed a computing unit, that handles the communication with the various remote units, processes the results obtained and communicates via IEC 60870-5-101 protocol with the MRE monitoring unit placed in the cubicle.

3.2 Breaker Unit

The breaker peripheral unit includes the following circuits:
. Monitoring of the auxiliary contacts;
. Density of the SF6 gas.

3.2.1 Circuits for the Monitoring of the auxiliary contacts

- Number of inputs: 16.
- Type of monitored inputs: wet.
- Inputs voltage: from 93,5 to 121 V CC.
- Threshold voltage: 77 V ± 5 V.
- Recognition criteria: an input is acknowledged as closed if it passes the threshold for a time longer than 200 µs.
- Precision of the timing measure: ± 100 µs.
- Input circuits are isolated; voltage withstand 500 V ac.
- Absorbed current by the input circuits: 2 mA nominal.
- Input impedance: greater than 20 kOhm.
- In case of fault of one component of the measuring circuit, the minimum impedance of the input is 10 kOhm. The resulting current does not further damage the circuit.

3.2.2 Circuits for the Monitoring of the SF6 gas density

- Number of inputs: 3.
- Type of transducers: density meters WIKA GD-10 , or equivalent.
- Range of densities to be measured: from 0 to 60 kg/m3, or from 30 to 60 kg/m3 .
- Transducer output: dc current on the supply, useful to be measured by the monitoring circuit, with a fireproof cable respecting standard CEI 20-22, with maximum length 20 m.
- Precision of the density measure: ± 2% of the measure ± 2% of the full range.

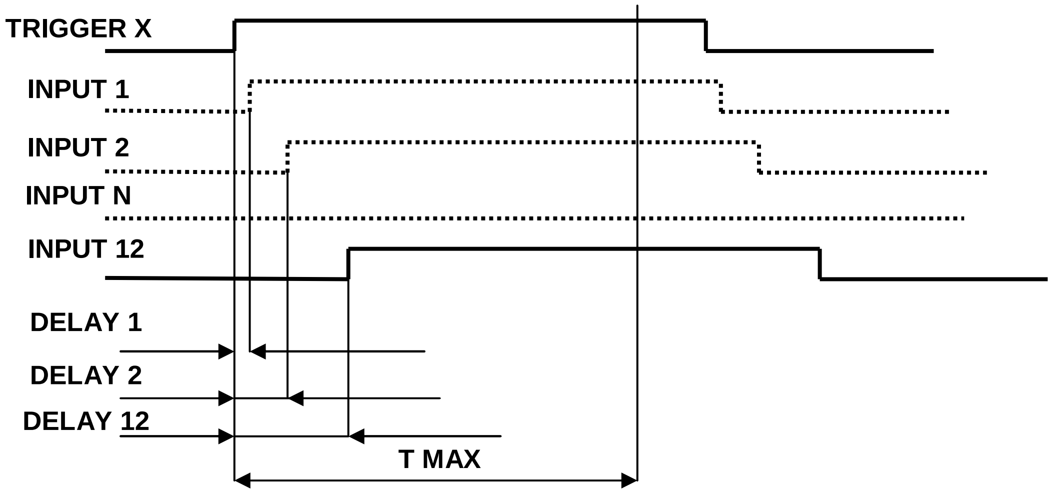
3.2.3 Computations of the peripheral unit for the timings

- At installation, it is necessary to program the trigger inputs for the timing measures (trigger, total of seven) and the inputs matching the CB position and not matching the CB position (total of six).

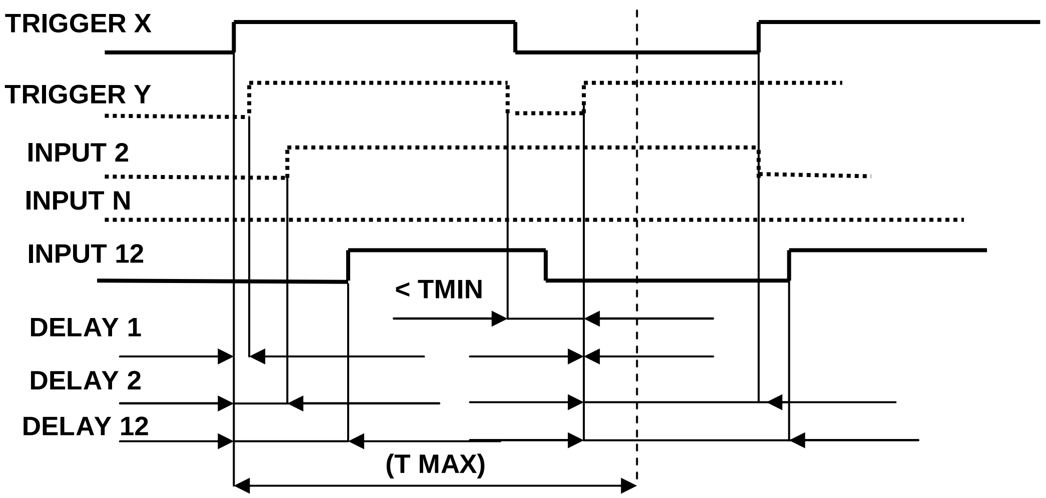
- When one of the trigger inputs becomes positive (for more than 200 µs), the unit records all the timings of the other 12 inputs (see picture).

- The maximum duration of the measure is TMAX (programmable). If one input does not change within this time, the result is “not changed”.

- The measure of the timings ends if:
. TMAX is reached; or
. One of the trigger inputs opens (for more than 200 µs) and closes (for more than 200 µs) after a time TMIN (programmable), meaning that a new command has been raised.
. Notice that if a command is present at the time of the trigger, the resulting delay is zero.



A) MEASURE OF THE TIMINGS UNTIL TMAX IS REACHED



B) SECOND TRIGGER WITHIN TMAX

- All measures, identified by the trigger channel and measured channel, are sent to the central unit for subsequent processing.

3.2.4 Computations of the peripheral unit for the SF6 gas density

- The transducer current, that measures the gas density, is converted into a density measure; the value is transmitted via optical fibre.

3.2.5 General characteristics of the unit

- Supply voltage: 110 V CC nominal; voltage range from 93,5 to 121 V CC.
- Absorption: 10 W.
- In case of fault, the supply is protected by a fuse, 0,2 A.
- Inputs connection:

. Commands and breaker contacts: by means of clamps
. SF6 gas density: by means of clamps.
- Connection to the output: by means of connector for optical fibre type ST multimodal 62.5 / 125 micron
- Malfunction signalling:
. Fault on the SF6 transducers supply; transmitted via optical fibre;
. Fault on the internal supply; transmitted via optical fibre;
- Production: box to be mounted inside the breaker control box.
- Weight: 2 kg.
- Dimensions: 200 x 200 x 100 mm.

3.3 I^2T peripheral unit

3.3.1 Circuits for the Measure of the current

- Number of inputs: 3.
- Measure connections: toroidal transformers placed on the CT secondary sides.
- Toroidal transformers characteristics:
  . Description: Resin coated toroidal transformer, to be screwed on a base, with output connector.
  . Internal hole: 12 mm diameter.
  . Transformer ratio: 1000//1.
  . Primary current: 5 A; surge 150 A (30*IN) for 1 s, 2*IN to time indefinite.
- Global precision: transformer, converter, rms measure: ± 5% of measure ± 2% of range.

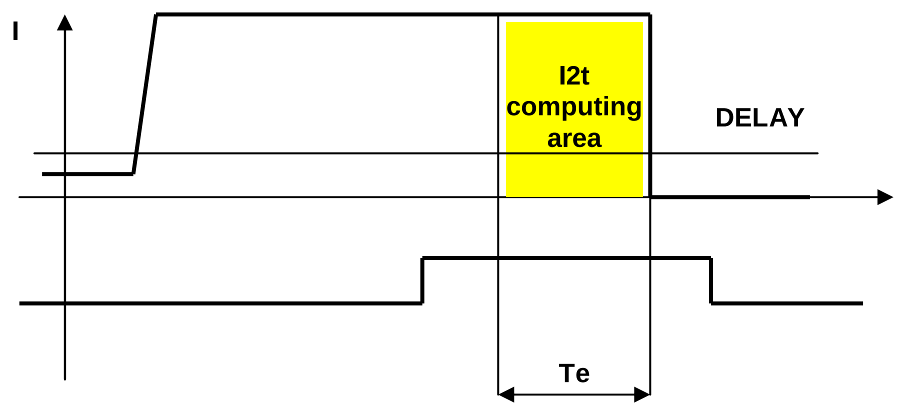
3.3.2 Circuits for the monitoring of A/B Bars

Number of inputs: 2.
- Type of monitored inputs: wet.
- Inputs voltage: from 93,5 to 121 V CC.
- Threshold voltage: 77 V ± 5 V.
- Recognition criteria: an input is acknowledged as closed if it passes the threshold for a time longer than 200 µs.
- Precision of the timing measure: ± 100 µs.
- Input circuits are isolated; voltage withstand 500 V ac.
- Absorbed current by the input circuits: 2 mA nominal.
- Input impedance: greater than 20 kOhm.
- In case of fault of one component of the measuring circuit, the minimum impedance of the input is 10 kOhm. The resulting current does not further damage the circuit.

3.3.3 Computations of the I2T

- The module receives the actual open command raised by the breaker unit, from the computing unit in the line cubicle (U.S), and such command orders the unit to start the measurement. The sampling frequency for each phase is 1 kHz.

On the measured currents, the module will compute the following functions:
. Verifies if the current is greater than the programmed threshold;
. Calculates I2Te by integration of the current values of the last part of the phenomenon, corresponding to the arc extinction time Te programmed (average arc time).



. The picture shows the computations performed by the instrument.

- The I2Te computed value is transmitted to the central unit for further processing. The total error on the measure of I2Te is less than 10% for currents greater than 15 IN.
- The module detects and transfers the A/B bar selection, which will be used by the MRE system for the monitoring of the PT.

3.3.4 General characteristics of the unit

- Supply voltage: 110 V CC nominal; voltage range from 93,5 to 121 V CC.
- Absorption: 5 W.
- In case of fault, the supply is protected by a fuse, 0,1 A.
- Connection of the inputs from the transformers: via connectors or clamps.
- Connection of the output: via connector for the computing unit in the line(U.S).
- Malfunction signalling:

. Fault on the internal supplies; transmitted to the computing unit in the line (U.S).

- Production: box to be mounted inside the line cubicle.
- Weight: 2 kg.

3.4 SF6 CT peripheral unit

The unit includes three circuits for the measure of the SF6 gas density.

3.4.1 Characteristics of the circuits for the monitoring of the SF6 gas density

- Number of inputs: 3.
- Type of transducers: density meters WIKA GD-10, or equivalent.
- Range of densities to be measured: from 0 to 60 kg/m3, from 15 to 45 kg/m3 or from 30 to 60 kg/m3, depending on the installed transducer .
- Transducer output: dc current on the supply, useful to be measured by the monitoring circuit, with a fireproof cable respecting standard CEI 20-22, with maximum length 20 m.
- Precision of the density measure: ± 2% of the measure ± 2% of the full range.

3.4.2 Computations of the peripheral unit for the SF6 gas density

- The transducer current, that measures the gas density, is converted into a density measure; the value is transmitted via optical fibre.

3.4.3 General characteristics of the unit

- Supply voltage: 110 V CC nominal; voltage range from 93,5 to 121 V CC.
- Absorption: 10 W.
- In case of fault, the supply is protected by a fuse, 0,2 A.
- Connections from inputs to the transducers: by means of connectors or clamps.
- Connection to the output: by means of connector for optical fibre type ST multimodal 62.5 / 125 micron
- Malfunction signalling:

. Fault on the SF6 transducers supply; transmitted via optical fibre;
. Fault on the internal supply; transmitted via optical fibre;

- Production: stainless steel box to be mounted outdoors.
- Weight: 2 kg, plus the contained weight.
- Dimensions: 300 x 300 x 130 mm.

3.5 Surge arrester peripheral unit

3.5.1 Foreword

The module serves the purpose of verifying the discharger efficiency of the metal oxide surge arresters installed on the HV transport lines, according to IEC standards 60099-5 A1 ED. 1.0 Section 6: Diagnostic indicators of metal-oxide surge arresters in service (method B1).

The control is executed with the surge arrester in service, by analyzing through a current transformer the current discharged in the grounding connection. This current normally has values in the range between fractions of mA and a few mA, and is characterized by a deformation of the 3rd harmonic, whose value is an indication of the degradation of the surge arrester itself.

The instrument amplifies the current measured by the clamp, measures the real rms value of the total current, filters the 3rd harmonic component by means of a pass-band filter and measures the resulting rms value. This value is confronted with the maximum accepted value; when it gets higher than the threshold an alarm is generated.

The measure environment is characterized by the presence of very high electrical and magnetic fields. In order to minimize their effect on the measurement, the transformer is shielded against magnetic fields; furthermore the signal pre-amplification is done on the transformer itself. The cable that connects the transformer to the peripheral unit is therefore much less sensitive to the electrical field.

3.5.2 Measure of the currents

- Number of inputs: 3.
- Connection: on the surge arrester grounding cable.
- Characteristics of the measuring transformers:
. Description: Resin coated toroidal transformer, with output connector.
. Transformer ratio: 1000//1.
. Ratio error from 0,1 mA to 10 mA: 5% ± 0,05 uA.
. Internal hole diameter: 50 mm.
. Connection: with connector.
. Connection cable: shielded, 5 pins, maximum length 10 meters.
- Measure performed on the current measured by the clamp:
  . True rms value of the total current;
  . 3rd harmonic rms value;
  . Digital conversion of these voltages for the transmission on optical fibre.
- Range of the total current: 19.99 mA.
- Range of the 3rd harmonic: 1999 uA.
- 3rd harmonic filter response:
  . < - 60 dB at 50 Hz;
  . 0 dB at 150 Hz;
  . < - 20 dB at 250 Hz and greater frequencies.
- Errors:
. Measure at 50 Hz, rms value: ± 5 % of the measure ± 1 % of the range.
. Measure at 150 Hz, rms value: ± 10 % of the measure ± 2 % of the range.
- External fields insensitivity. In presence of the following disturbances:

. Electric field: < 10 kV/m;
. Uniform magnetic field: < 50 uT;
. Non-Uniform magnetic field, create by the circulation of a 20 A current in a conductor placed 50 mm away from the current transformer,
the measure will be maximum 2 mA rms at 50 Hz.

3.5.3 Measure of the number of discharges

- Number of inputs: 3.
- Connection: on the surge arrester grounding cable.
- The number of discharges will be increased if the current value is greater than the programmed threshold (500 A, 2000A, 5000A, > 5000A)
- Error on the measure of the current pulse amplitude: < 30%

3.5.4 Computations of the surge arrester units

- Upon command issued by the computing unit in the line cubicle (U.S) , the measures of the fundamental current and those of 3rd harmonic are executed and transmitted to the computing unit (U.S) itself.
- Always upon command, the number of discharges is transferred, together with dates, hour and minute of the single events.

3.5.5 General characteristic of the unit

- Supply: Voltage 110 V CC nominal; voltage range from 93,5 to 121 V CC.
- Absorption: 5 W.
- In case of fault, the supply is protected by a fuse, 0,1 A.
- Connection of the inputs from the transformers and the discharger sensors: via connectors or clamps.
- Connection to the output: by means of connector for optical fibre type ST multimodal 62.5 / 125 micron
- Malfunction signalling:
. Fault on the internal supply; transmitted via optical fibre;
- Production: stainless steel box to be mounted outside
- Weight: 2 kg , plus the container weight
- Dimension: 300 x 300 x 130 mm

3.6 PT Peripheral unit

3.6.1 Foreword

Purpose of this unit is to provide an accurate measure of the PT secondary voltage, and to highlight anomalies in the functioning of the transformer itself by confronting the value at the secondaries of the other PT in the plant, operation carried out by the MRE system.

Each module includes three measuring signal conversion circuits.

3.6.2 Circuits for the voltage measure

- Number of inputs: 3.
- Connection: on the PT secondaries, by means of isolation transformer.
- Range: 100 V CA.
- Global precision: transformer, measure true rms and converter, from 65 V CA:

. Temperature from 25 °C: ± 0,1% of the measure ± 0,02% of the range.
. Complete range of temperatures (from -25°C to + 60 °C): ± 0,5% of the measure ± 0,1% of the range;
. Differences between two units, whose temperature difference is lower than 10 °C: ± 0,2% of the measure ± 0,04% of the range.

3.6.3 Computations of the PT peripheral unit

- Upon command issued by the central unit, the peripheral for each phase:

. Samples the voltage with rate 10 kHz for a period of 10 s;
. Computes the true rms value of the measured voltage;
. Transmits the measures to the computing unit of the line (U.S).

3.6.4 General characteristics of the unit

- Supply: from the secondaries of the PT. Voltage range: from 40 to 100 V CA.
- Load on the supply: type resistive (power factor greater than 0,9); maximum 3 VA per phase.
- In case of fault of a component in the measuring circuit, the minimum impedance of the input becomes 1 kOhm (load on PT of 3,3 VA). The subsequent current does not further damage the circuit.
- Connection from the inputs to the transformers: by means of connectors of clamps.
- Connection to the output: by means of connector for optical fibre type ST multimodal 62.5 / 125 micron
- Malfunction signalling:

. Fault on the internal supply; transmitted via optical fibre;

- Production: box to be mounted in the PT box
- Weight: 2 kg.
- Dimensions: 200 x 200 x 100 mm.

3.7 Computing unit in the line cubicle of the monitoring system when the MRE system is present

3.7.1 Inputs from the peripheral units

The computing unit in the line cubicle collects the measures from the various remote units, to be more precise those not positioned in the line cubicle, by means of optical fibres. The computing unit reads the measures at specific times from the remote units; typical measure times are summarized in the table.

Unit	**Typical measure period**	**Answer within**
Breaker:		
- Timing.	10 s	10 s
- I2Te	10 s	10 s
- Breaker SF6	From 10 s to 24 h	10 s
CT SF6	From 10 s to 24 h	10 s
SURGE ARRESTER	1 day	10 s
PT	1 day	60 s

The measure polling period is programmable for each type of unit. The peripheral unit makes the measurements available within the times indicated. At confirmation of the measure successful message, the unit stores the measurement in the local memory; otherwise it repeats the transmission of the measure.

3.7.2 Software of the computing unit

The operating system of the computing unit is based on the Windows CE platform, therefore the software will be developed with Microsoft programming tools. The basic characteristics are:

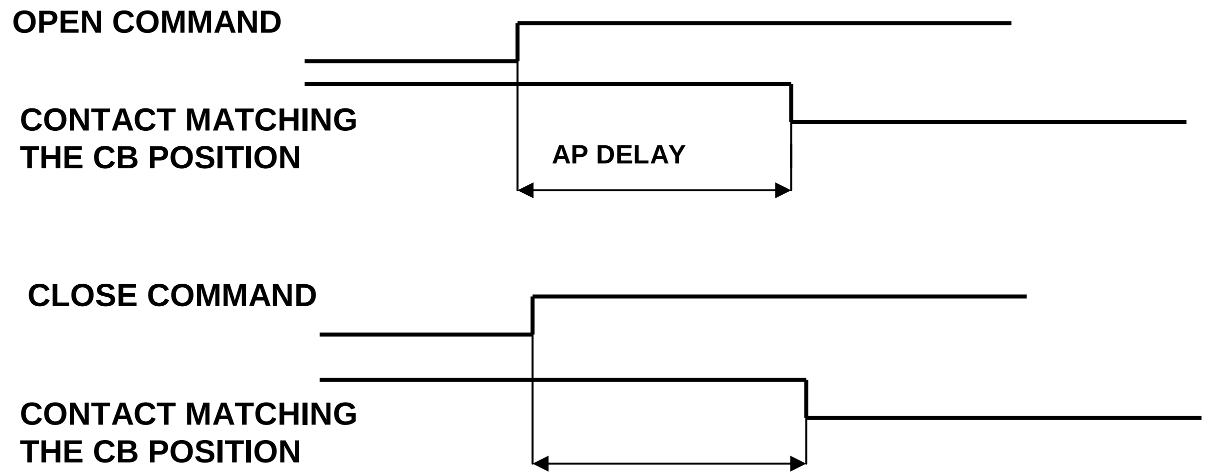
- Execution of the monitoring of the various peripheral units
- Storage of the results in daily/weekly/yearly database that can be simply consulted
- Trend analysis of the SF6 density.
- Possibility to modify the threshold parameters.
- Possibility to remotely configure thresholds, zeroing measurements and so on.
- Firmware Upgrade of the various peripheral units
- Remote interrogation from another PC via static IP (with password)
- Transmission of the measurements and the alarms to the monitoring unit (U.M.) of the MRE system

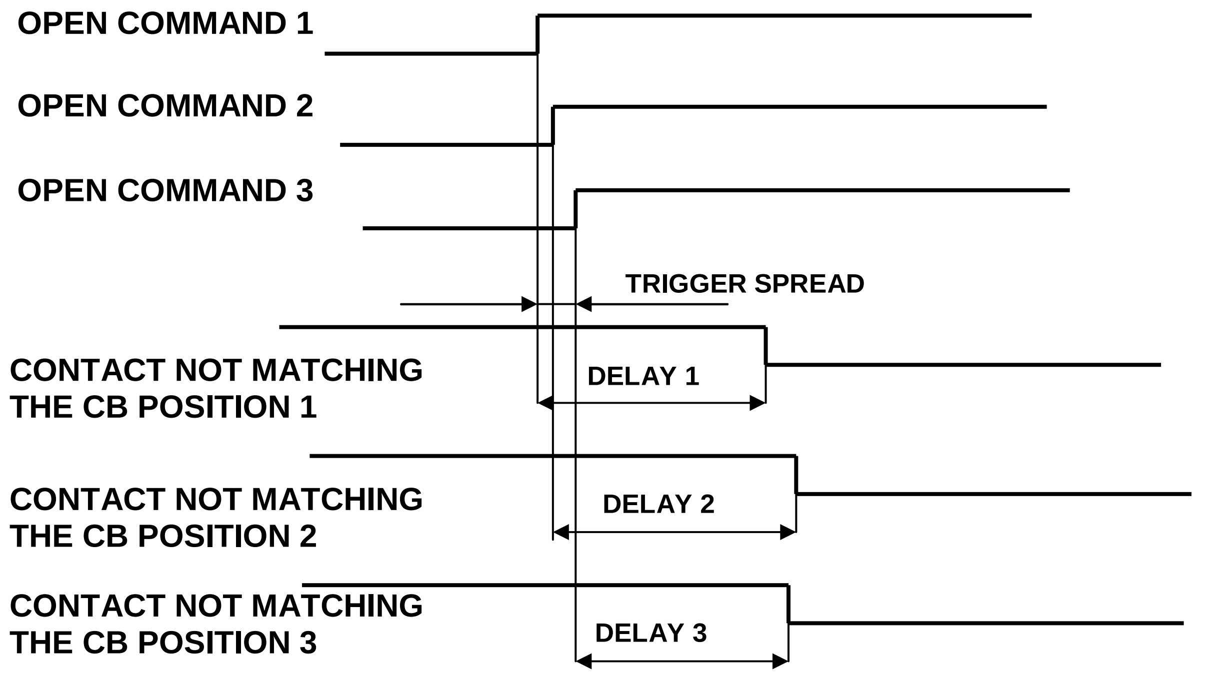
In the following subheadings a greater detail of the performed measures is found.

3.7.3 Breaker timings

When polled for interrogation, the breaker unit transmits 12 measures. The computing unit in the line cubicle gets the following measures:

. Time between the open command and the contact not matching the CB position(one or three measures, depending on single-phase or three-phase open).
. Delay between the close contact and the contact matching the CB position(three measures);
. Trigger spread time (three-phase open command);
. Open pole discrepancy (none or one measure, depending on single-phase or three-phase open);
. Close pole discrepancy (none or one measure, depending on single-phase or three-phase open).





Pole discrepancy = MAX ((DELAY1 – DELAY2); (DELAY2-DELAY3); (DELAY3– DELAY1)).

The algorithm for the open pole discrepancy takes into account the possible discrepancy between the open commands on the various phases.

For each type of timing there is a defined tolerance. The central unit checks the values against the tolerances and if surpassed, an alarm message is sent to the MRE system (total of 9 alarms).

3.7.4 SF6 gas density (breaker and CT)

When polled for interrogation, the breaker unit (or CT SF6) transmits the density measures. The computing unit in the line, having received the density for each phase, computes the density variation speed, as per the following algorithm:
- Rapid variation, fault: an average over a programmable number of measures is performed (for instance 10 measures, equivalent to 100 s) If the average of two averages varies of a value greater than the fault threshold (programmable), the event is immediately raised;
- Slow variation. The derivative measure is performed once a day, overnight, when the temperature is more stable, at the programmed time; the time is synchronized by means of the clock input. The derivative is calculated on the average of a programmable number of values (for instance 100), as a difference of the readings over two or more days.

In total, two alarms for each phase can be raised.

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3.7.5 I^2T

When polled for interrogation, the I^2T unit transmits the I^2T values for each phase measured for each interruption to the computing unit; therefore:
- it adds up, for each phase, the measured value to the previous ones, and stores the total;
- checks the total against the programmed threshold value, and transmits an alarm when the threshold is surpassed. Two thresholds are defined: pre-alarm, and alarm (total of six thresholds).

When the device is installed, the operator can program the actual I^2Te value of the breaker since it has likely been in service for some time.

3.7.6 Surge arresters

The computing unit receives, by polling the surge arresters peripheral unit, for each phase:

a) The value of the total current and of the 3^{rd} harmonic current; then it checks the values against the programmed thresholds, and raises an alarm when the maximum programmed threshold is surpassed. Two thresholds are defined: pre-alarm and alarm. The measure of the total current is stored together with that of 3^{rd} harmonic, to complete the event information.

b) The number of discharges, along with the timing of the various events

3.7.7 PT monitoring

The algorithm for the monitoring of the PT serves to the purpose of highlighting anomalies in the transformer, despite the line voltage variations and the unavoidable measure errors.

The algorithm works on the measures coming from at least three PT connected to the same phase.

If during the measure there is a switching on the line the measured values are discarded, and the measure is repeated 15 minutes after the line is restored back to normality.

The algorithm is the following.
. The three measures are recorded in a table;
. The differences between the measures are computed, by taking as a reference the values of the various transformers;
. The differences are added up together;
. The differences with respect to the PT with lower total are considered, and checked against the maximum of the standard, which is double the sum of the maximum error of the PT + that of the measure.

Time will prove the efficacy of this approach.

Implementation of the monitoring algorithm for PTs, given the presence of the MRE system, is to be performed by a substation computer, which is not object of this supply.

3.7.8 General characteristics of the computing unit in the line

The fibres coming from the various remote units are connected to a fibre selector placed in the line. In the same module is placed the computing unit, that manages also the communication protocol with the MRE system.
- Connections to the line cubicle: by means of connectors for optical fibre type ST multimodal 62.5 / 125 microns
- Function: measures computing unit and handling of the communication protocol IEC 60870-5-101.
- Service port for the maintenance and programming local functions handled by PCs supplied with diagnostic and programming software
- Ethernet port, with TCP/IP protocol, for the configuration of the monitoring system, and in general for the maintenance and querying of the system itself.
- Supply: voltage 110 V CC nominal; voltage range from 93,5 to121 V CC.
- Absorption: maximum 50 W.
- In case of fault, the supply is protected by a 1 A fuse.
- Production: 19” rack module.