# Substations equipment inspection and periodic maintenance

## Improving the reliability of HV and EHV equipment

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**A preventive maintenance program is a powerful tool to assure the quality and continuity of grid operation and an important contribution to personnel and installations safety**


## ABSTRACT

In this article we analyse frequency, actions regarding preventive maintenance frequency and inspections that must be carried out when dealing with 60-800 kV equipment (insulators, circuit breakers, isolator switches, instrument transformers and surge arresters), in order to keep them working properly, within manufacturers' instructions, and to avoid premature ageing of the equipment, namely busbar system and insulators, circuit breakers, isolator switches, instrument transformers and surge arresters.



## KEYWORDS

maintenance frequency, preventive maintenance, inspection and tests, substations equipment

## 1. Introduction

EHV/EHV and EHV/HV substations are an important element of the electricity transmission network of a country or of a large area of a country and their functions are:

- Interconnection of power plants within the national or area electrical grid.
- Stepping up and stepping down voltage of the distribution network to suitable values for network's operating conditions.
- Spreading of HV and EHV overhead lines and underground cables along the country or along an area of a country.
- Electrical power supply of HV/MV distribution substations.

Figure 1 shows a schematic diagram of the electrical grid in which power plants, substations, transmission lines and distribution lines (MV and LV) are represented.

Some consumers (industry, shopping malls, casinos, etc.) that require high power supply are connected to EHV, HV or MV networks and have their own substations (private substations).

Voltage levels change from country to country. In Table 1, the standard voltages according to IEC 60038 [6] are indicated, and they correspond to the highest voltage for equipment and the most common voltages used in networks and equipment.

## 2. EHV and HV equipment

Main EHV and HV equipment in substations, apart from busbars and insulators, are:

- Power transformers – used to step down or to step up the voltages of the network.
- Circuit breakers – used for the interruption of service currents and short-circuit currents and to extinguish electric arc that is formed when an electrical current is interrupted.
- Isolator switches or disconnectors – used to isolate a part of the installation, ensuring that isolation is visible, which is vital for personnel safety.
- Instrument transformers (voltage transformers – VT – and current transformers – CT) – used to provide an overview of voltage and current to metering equipment, protection units and control and monitoring systems.
- Surge arresters – used for the protection of equipment against overvoltage (lightning and switching overvoltage).
- Neutral-earthing reactors – used for neutral grounding of transformers and networks to limit the phase-to-earth short-circuit current.
- Current-limiting reactors – used to limit three phase and phase-to-phase short circuit currents, allowing the

**Substation owners used to establish their own preventive maintenance plan, which included the frequency of maintenance actions regarding the substation's equipment**

**LEGEND**

Transmission network (solid red line)

Distribution network (dashed black line)

**PS** – Power station
**A** – Generator
**B** – MV/EHV or MV/HV substation (power station)
**C** – EHV or HV overhead line/underground cable (transmission network)
**D** – EHV/EHV, EHV/HV, HV/HV or EHV/EHV/HV transmission substation
**E** – EHV/HV/MV or HV/MV private substation
**F** – HV/MV (EDP) distribution substation
**G** – MV overhead line/underground cable (distribution network)
**H** – MV/LV distribution substation
**I** – MV/LV private substation
**J** – LV overhead line/underground cable (distribution network)

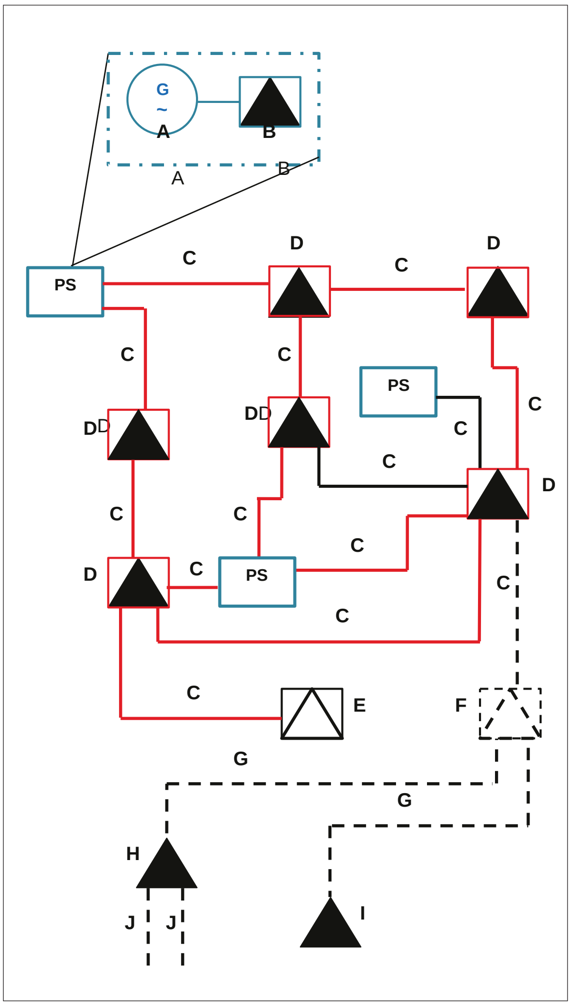


Figure 1. Schematic diagram of an electrical grid

Table 1. Standard voltages according to IEC 60038

| Voltage level | Highest voltage for the equipment (kV rms) | Common networks voltages (kV rms) | Standard withstand voltage | |
|---|---|---|---|---|
| | | | Short-time power-frequency (kV rms) | Lightning impulse (kV peak) |
| Low Voltage (LV) | ≤ 1 (AC)<br>≤ 1.5 (DC) | 0.11-0.19;<br>0.127-0.22;<br>0.23-0.4; 0.5; 0.6; 0.66 | ≤ 2 | ≤ 12 |
| Medium Voltage (MV) | 3.6 | 3.3 | 10 | 40 |
| | 7.2 | 6; 6.6 | 20 | 60 |
| | 12 | 10; 11 | 28 | 75 |
| | 17.5 | 13.8 | 38 | 95 |
| | 24 | 22 | 50 | 125 |
| | 36 | 30; 33 | 70 | 170 |
| | 52 | 49.5 | 95 | 250 |
| High Voltage (HV) | 72.5 | 60; 66; 69 | 140 | 325 |
| | 123 | 110; 115 | 230 | 550 |
| | 170 | 132; 138 | 325 | 750 |
| Extra High Voltage (EHV) | 245 | 150; 154 | 395 | 950 |
| | 300 | 220; 230 | 460 | 1050 |
| | 420 | 345; 400 | 630 | 1425 |
| | 550 | 500 | 740 | 1675 |
| | 800 | 765 | 830 | 2100 |

**Maintenance frequencies must be defined by taking into account the real conditions of equipment utilization, their criticality, the required reliability and their failures history**

reduction of the short circuit withstand values of equipment and busbars.

- Shunt reactors – used to compensate capacitive currents that have an origin in long underground cables and long not loaded overhead lines.
- Capacitor banks – used to compensate inductive currents that have an origin in long loaded overhead lines.

## 3. Frequency of preventive maintenance actions

Utility companies and major industrial plants (cement, steel, paper, etc.) used to establish their own preventive maintenance plan, which included the frequency of maintenance actions regarding the substation equipment.

Frequency of maintenance shall be established taking into account equipment reliability and substation service's continuity requirements, environmental conditions (temperature, relative humidity, degree of pollution, etc.) and manufacturers' maintenance manuals and recommendations.

ANSI/NETA[1] Standard MTS[2]-2019 Appendix B [5] is commonly used in several countries[3], such as USA, Canada and Saudi Arabia, to determine the frequency of maintenance, which is shown in Table 2 for circuit breakers, isolators, instrument transformers and surge arresters; and a coefficient matrix, which is recommended to be applied to the defined maintenance frequency, taking into account equipment condition and the required reliability, as shown in Table 3.

[1] **ANSI**: American National Standards Institute.
**NETA**: InterNational Electrical Testing Association.
[2] **MTS**: Maintenance Testing Specifications.
[3] There are no relevant applications of this standard in Europe and they do not have similar recommendations. The experience of the author, taking into account his experience in this field and working with several electrical utility companies, is to recommend the use of this standard.

Table 2. Standard inspection and maintenance frequency of substation equipment

| Equipment | Inspection and maintenance tasks – months | | |
|---|---|---|---|
| | Visual | Visual and mechanical | Visual, mechanical and electrical |
| Isolator switches | 1 | 12 | 36 |
| Circuit breakers | 1 | 12 | 12 |
| Instrument transformers | 12 | 12 | 36 |
| Surge arresters | 2 | 12 | 24 |

Table 3. Coefficient matrix to apply to maintenance frequency

| | | Equipment condition | | |
|---|---|---|---|---|
| | | Bad | Average | Good |
| Equipment reliability requirement | Low | 1.0 | 2.0 | 2.5 |
| | Medium | 0.5 | 1.0 | 1.5 |
| | High | 0.25 | 0.5 | 0.75 |

**The aim of general inspection is to identify externally any type of malfunctions without shutting down the substation and it includes visual and thermography tests and measurements**

Both frequencies and coefficients shown in Tables 1 and 2 should be considered as a guide only. Maintenance frequencies must be defined by taking into account the real conditions of equipment utilization, their criticality, the required reliability and their failures history.

Some utility companies consider two types of interventions – general inspection and integrated maintenance. These two interventions constitute what is usually designated as Systematic Preventive Maintenance (SPM).

General inspection includes visual and thermography tests and measurements, without shutting down the substation. The aim of this inspection is to identify externally any type of malfunction.

To perform integrated maintenance, it is necessary to shutdown the substation (totally or only the bays under intervention, but in compliance with all the safety procedures). Tasks for this type of intervention include those of general inspection and revision and operating tests for manoeuvre equipment.

Table 4 summarizes SPM tasks for the equipment that is within the scope of this article.

Maintenance activities (visual and mechanical inspection, electrical tests, tests values) for each piece of equipment are defined under ANSI/NETA standard MTS-2019.

Table 4. SPM tasks

| Interventions | Tasks |
|---|---|
| General Inspection | Visual inspection of all equipment. |
| | Thermography tests of all equipment and connections, including busbars. |
| | Check the functioning of protection, control and monitoring systems. |
| | Check all earthing connections. |
| Integrated Maintenance | Visual inspection of all equipment. |
| | Adjustment, lubrication and functioning test done on operation devices of EHV and HV circuit breakers and isolators. |
| | General revision of all EHV and HV equipment and busbar system. |
| | Check the functioning of protection, control and monitoring systems. |
| | Check all earthing connections. |

# 4. EHV and HV equipment preventive maintenance

## 4.1. General procedures

This article will cover insulators, circuit breakers, isolator switches, instrument transformers and surge arresters.

General procedures regarding preventive maintenance include visual inspection and infrared thermography, which must be done regularly, in order to detect eventual problems in advance and to correct any possible failures thus avoiding large and costly repairs.

Infrared thermography is a non-destructive and contactless test done by special equipment (thermography camera) that allows detecting equipment's hot spots, as shown in Figure 2, which can be a symptom of fault or malfunction.

Figure 2. Hotspot detected by infrared thermography

Thermography inspection must be carried out every two to three years, but severe working conditions and/or environment may require doing this inspection each year or even more frequently.

According to the above referred ANSI/NETA standard, the suggested actions to be undertaken based on the temperature rise are indicated in Table 5.

Table 5. Suggested actions according to temperature rise

| Temperature difference (ΔT) based on comparisons between similar components under similar loading | Temperature difference (ΔT) based upon comparisons between component and ambient air temperatures | Recommended actions |
|---|---|---|
| 1 ºC – 3 ºC | 1 ºC – 10 ºC | Possible deficiency; warrants investigation |
| 4 ºC – 15 ºC | 11 ºC – 20 ºC | Indicates probable deficiency; repair as time permits |
| ------------ | 21 ºC – 40 ºC | Monitor until corrective measures can be accomplished |
| > 15 ºC | > 40 ºC | Major discrepancy; repair immediately |

General procedures regarding maintenance of EHV and HV equipment include the following actions:

- Replacement of equipment, pieces and components that are worn or damaged due to normal use or that show premature ageing, when the defined time of use and/or the number of manoeuvres for those pieces and components is exceeded.
- Check the tightening of all busbars and EHV and HV equipment connectors as well as the control and monitoring cables connections, in order to avoid contact resistance increase and the resulting overheating.
- Check all earthing connections of EHV and HV equipment.
- Check cleanliness of substation outdoor yard to avoid the contamination of insulating materials, what would decrease creepage distance and therefore the insulation distance.
- Check the condition of supporting metallic structures to detect any corrosion points, and the respective concrete slab (tightening of rag-bolts, bolts and nuts; eventual concrete disaggregation).

## 4.2. Insulators and connectors

EHV and HV insulators, as shown in Figure 3, whether included in EHV and HV equipment or used as the support of rigid busbar and/or in suspension and tension springs, must be carefully inspected in order to detect if any crack and/or chip exists and if the metallic components show any trace of rust.

In these situations, dielectric losses of the insulator must be measured to detect if there is any reduction of dielectric properties of the damaged insulator. Usually, it is less expensive and easier to replace the faulty insulator than to repair it, an operation that in the majority of cases, namely in insulator strings, requires the insulator to be sent to the manufacturer's facilities.

One of the common practices for insulators maintenance is to wash

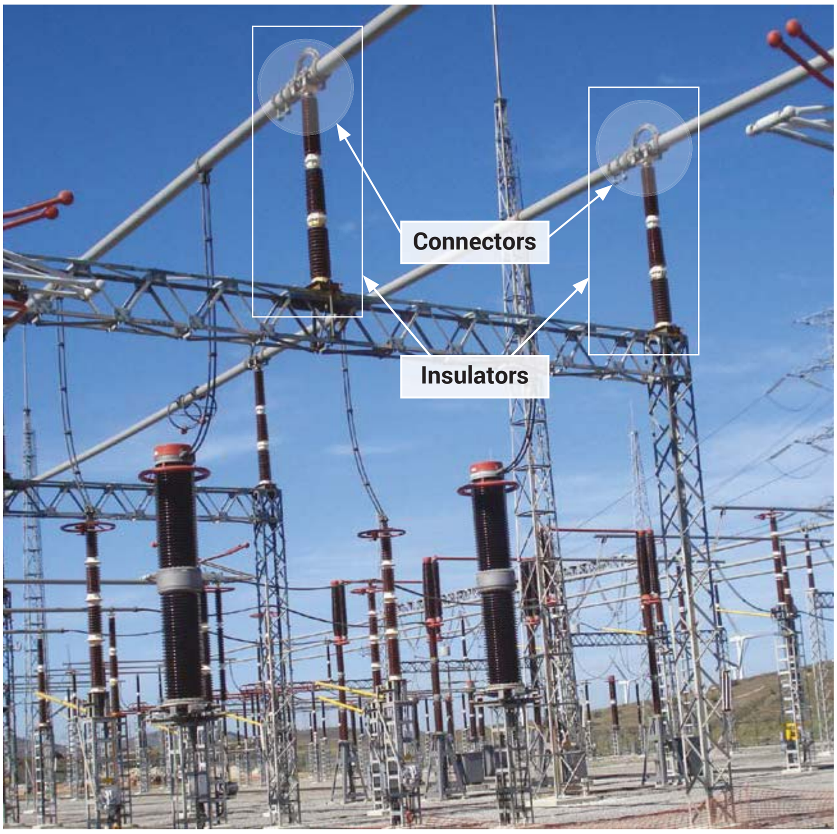


Figure 3. Insulators and connectors for rigid busbar

Figure 4. Circuit breaker

> **Integrated maintenance requires shutting down the substation and includes general inspection, revision and operating tests for manoeuvre equipment**

them with water jet. This requires the installation to be without voltage while the washing process is done.

If metallic components of ceramic and glass insulators get contaminated due to electric discharges, insulation degradation and environment aggressiveness, it is recommended to apply a silicone-based product which vulcanizes at ambient temperature. This operation increases dielectric properties of the insulator and allows the repair of small cracks and chips. It is usually not included in preventive maintenance and it requires the shutdown of the substation's bays (one by one).

Tightening of all connectors of busbars and equipment terminals must be executed and checked with a calibrated torque wrench.

### 4.3. Circuit breakers

Apart from visual and insulators inspection mentioned above, maintenance of circuit breakers, as shown in Figure 4, must include adjustment, lubrication and functioning test of the equipment, control devices and mechanical interlocking, if any. All connections' tightening (power and control) must be checked.

Spring charge motor must be tested (measurement of insulation resistance and checking the functioning, connections and rotation direction).

Charging conditions of operation springs (opening and closing) must be checked to assure that the energy stored in the springs allows the circuit breaker to open, since the last manoeuvre must always be the opening of the circuit breaker.

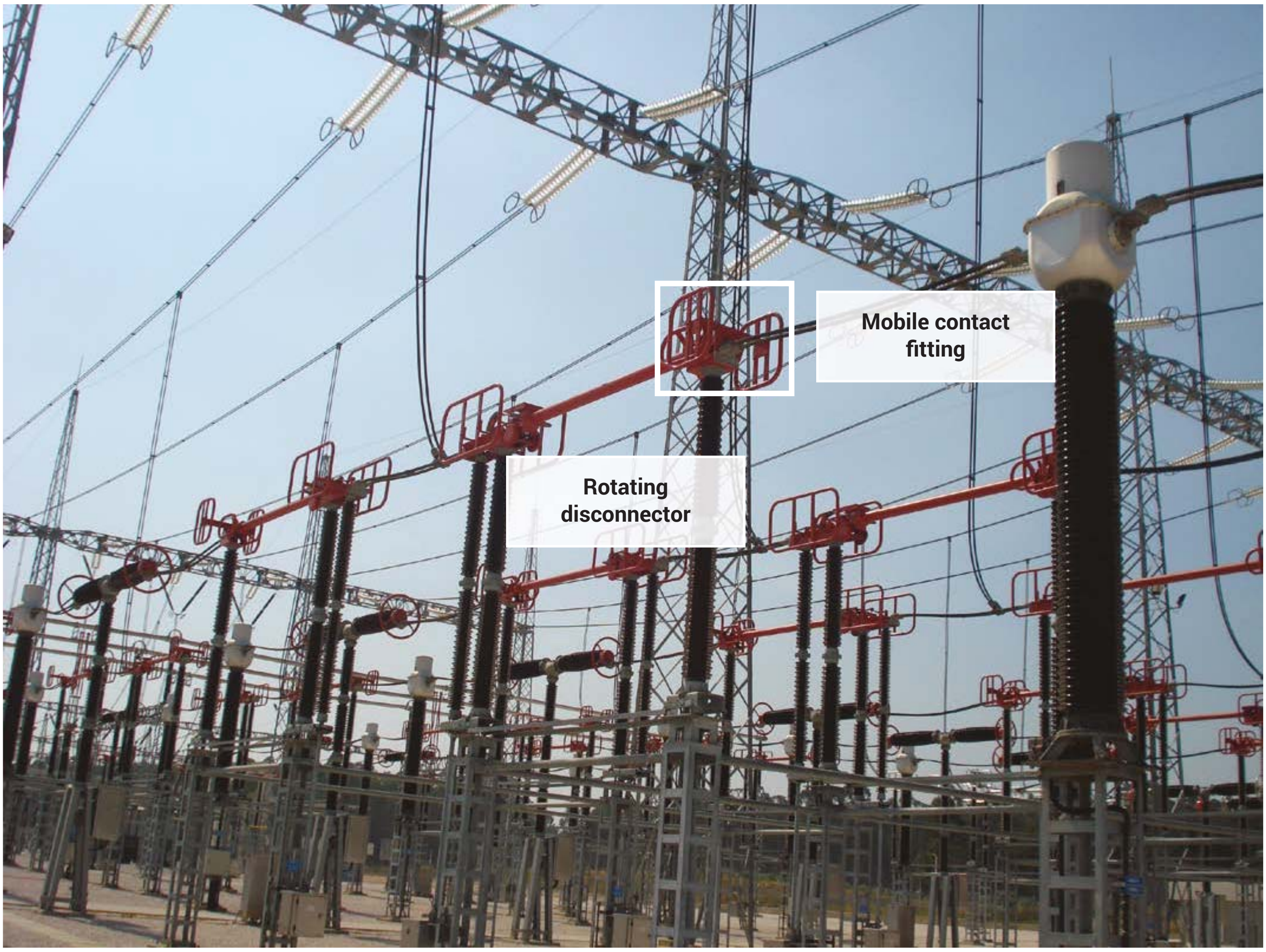


Figure 5. Rotating disconnector fitting

### 4.4. Isolator switches

Similar to circuit breakers, preventive maintenance of EHV and HV isolators includes visual inspection and adjustment, lubrication and functioning test involving equipment, control devices and mechanical interlocking, if any. All connections tightening (power and control) must be checked.

Whenever the operation motor is disconnected from power supply and reconnected later, it is necessary to check the motor rotation direction to assure that both rotation directions are in accordance with manual and automatic closing and opening controls.

Special attention must be given to mobile contacts fittings of rotating disconnectors as shown in Figure 5 and busbar counter contact of pantograph disconnectors as shown in Figure 6 to detect abnormal wear, which is the source of overheating.

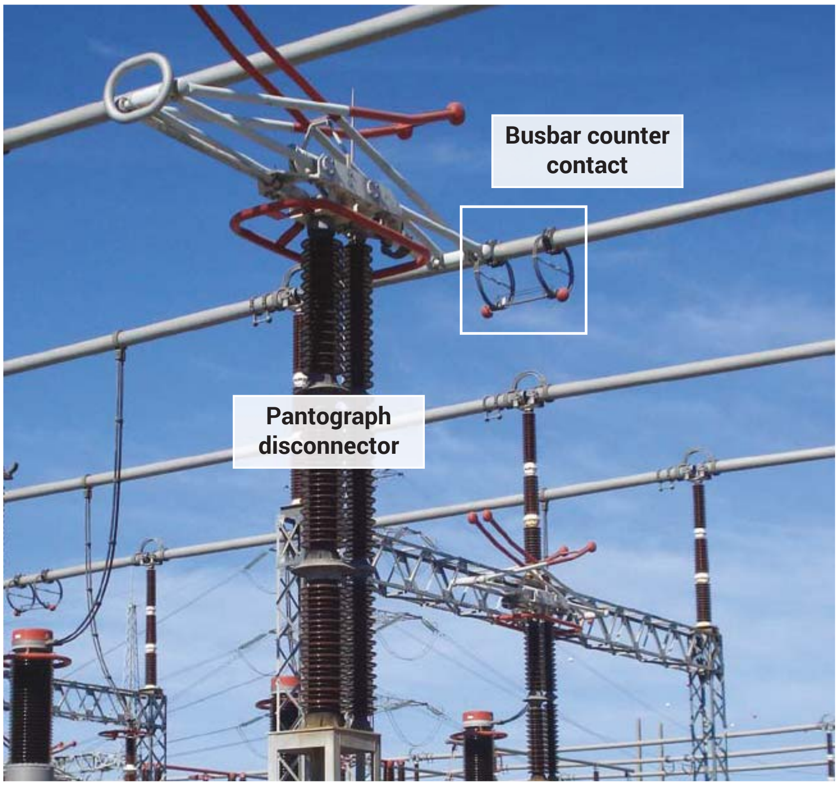


Figure 6. Pantograph disconnectors' busbar counter contact

**Records of equipment's historic faults are a key element in establishing a realistic preventive maintenance program**

(a) (b)

Figure 7a and 7b. Current transformer (left) and voltage transformer (right)

### 4.5. Instrument transformers

Apart from visual inspection, as mentioned above, instrument transformers maintenance should include insulation resistance test, dielectric tests, ratio test, tests of measurement accuracy class and measurement error. These tests are performed by primary current injection (for CT) or primary voltage injection (for VT), using a proper test equipment.

Instrument transformers are represented in Figure 7.

In the case of VT, the functioning of LV circuit breakers in the junction box must be verified as shown in Figure 8.

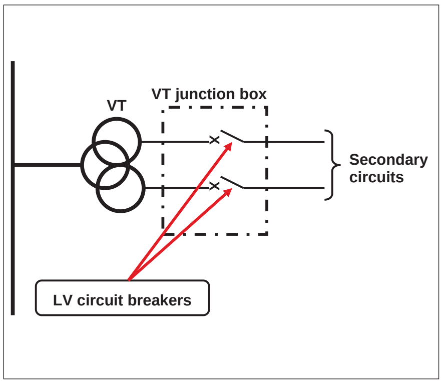


Figure 8. Voltage transformer junction box

When it is necessary to disassemble a CT for repair or replacement, a special care must be taken when assembling the equipment, in order to assure that both primary (P1 and P2) and secondary (S1 and S2) terminals are properly connected so that current direction is correct, as shown in Figure 9, in order to assure the proper functioning of the devices that are connected to the secondary CT terminal.

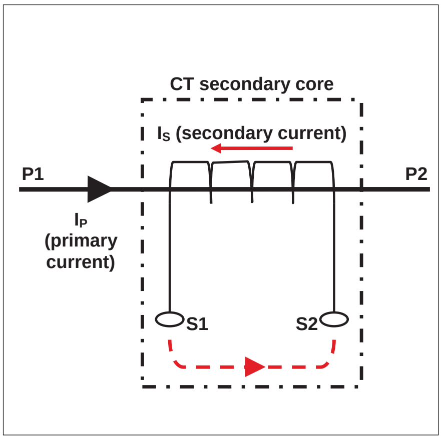


Figure 9. Current transformer connection

With this connection primary ($I_P$) and secondary ($I_S$) currents are:

$$P1 \rightarrow P2$$

$$S1 \rightarrow S2 \quad \underline{(Externally)}$$

### 4.6. Surge arresters

With surge arresters, as shown in Figure 10, it is important to record values shown in discharge counters (one per phase) with the aim to analyse the number of discharges that each arrester has been subjected to.

This information will allow us to decide if surge arrester needs a more in-depth inspection (usually at manufacturer's facilities) or if it must be replaced because it reached the end of its useful life, as recommended by the manufacturer.

## Conclusion

Establishment of a preventive maintenance program, based on international standards, manufacturers' instructions and historic faults of HV and EHV substations equipment, together with accurate records and trained and qualified personnel, is a powerful tool to assure the quality and continuity of service of electrical networks and an important contribution to personnel and installations safety.

Records of equipment's historic faults are a key element in establishing a realistic preventive maintenance program.

## Bibliography

[1] ANSI/NETA MTS-2019, *Standard for Maintenance Testing Specifications for Electrical Power Equipment and Systems*, 2019 Edition

[2] M. Bolotinha, *Basics of HV, MV and LV Installations*, Editora Ómega, January 2017

[3] M. Bolotinha, *Subestações: Projecto, Construção, Fiscalização*, Quântica Editora/Engebook, 2nd edition, January 2019

[4] M. Bolotinha, *Subestações – Uma Abordagem à Manutenção Preventiva*, Hotmart, Brazil, December 2018, available at : https://pages.hotmart.com/a10550825y/subestacoes-uma-abordagem-a-manutencao-preventiva/

[5] ANSI/NETA Standard MTS-2019

[6] IEC Standard 60038


Figure 10. Surge arrester

## Author

**Manuel Bolotinha** completed his Licentiate Degree in Electrical Engineering (Power Systems) in 1974 at the Instituto Superior Técnico, Lisbon University, where he was an auxiliary professor and his Master's Degree in Electrical and Computers Engineering in April 2017 at the Faculty of Sciences and Technology, Nova University of Lisbon. His career includes design, site supervision and contract management of electrical installations works in Portugal, Africa, Asia and South America. He is now an independent consultant on substations, a senior fellow of the Portuguese Engineers Association (Ordem dos Engenheiros) and a certified professional instructor, conducting training courses and writing course books, in Portugal, Africa and Middle East.