High voltage power supply

electrical equipments for electrostatic precipitators

technical leaflet

contents

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general

electrostatic precipitator operation

The gases carrying the particles to be eliminated flow between rows of earthed vertical collecting plates. Emitting electrodes at a negative DC high voltage are arranged half-way between these plates: by corona effect, gas ionisation takes place around these electrodes, and ions and electrons are created. The negative ions and the electrons move towards the collecting plates.

On their way, they charge the dust particles to a greater or lesser extent, the latter in turn being attracted to the plates by the electrical field. The particles are deposited on the plates from which they are regularly removed by rapping, collected in hoppers and finally evacuated from the electrostatic precipitator.

A large number of factors are involved in filtering efficiency, but the essential parameter is the electrical field established between the electrodes (fig. 1): the efficiency depends on the number of electrons and negative ions created per second, and on the migration velocity. This will therefore be higher the greater the field, therefore the more negative the voltage applied to the emitting electrode. This voltage is, however, limited: above a certain figure, brush discharges or sparks occur locally (sparking voltage). Above this voltage an arc is formed between the electrodes (flashover voltage).

The optimum voltage is the sparking voltage: the efficiency will be greater the closer the mean high voltage applied approaches this limit. Reaching flashover must, however, be avoided, as the filtering efficiency is nil during the arc and the latter may damage the electrodes by its repetition.

power supply principle

The sparking voltage is not constant, but varies according to the electrostatic precipitator operating conditions: density, nature and characteristics of dust, temperature, pressure, humidity of gases etc…

In order to achieve optimum efficiency, the high voltage power supply must be designed to "follow" the sparking voltage variations as closely as possible, avoiding arcs as far as possible.

Figure 2 illustrates the operating principle:

■ provided that the maximum permitted current is not reached, the high voltage supplied is constantly increasing.

■ as soon as a spark occurs, this voltage is reduced by a certain value ΔU_d , then continues increasing until the following spark.

■ if an arc forms, the voltage delivered by the power supply is brought down to zero and stays there for a certian time to enable the arc to be extinguished naturally.

■ after this blocking, the high voltage is raised to its previous level and the process of seeking the sparking voltage starts again.

■ if there is no arc, the high voltage therefore "follows" the sparking voltage, with a standard deviation by default equal to

$$\frac{\Delta U_d}{2}$$

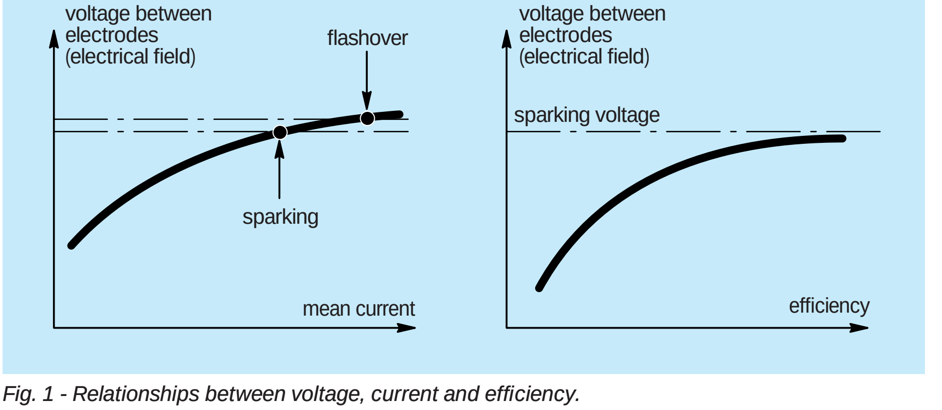

Fig. 1 - Relationships between voltage, current and efficiency.

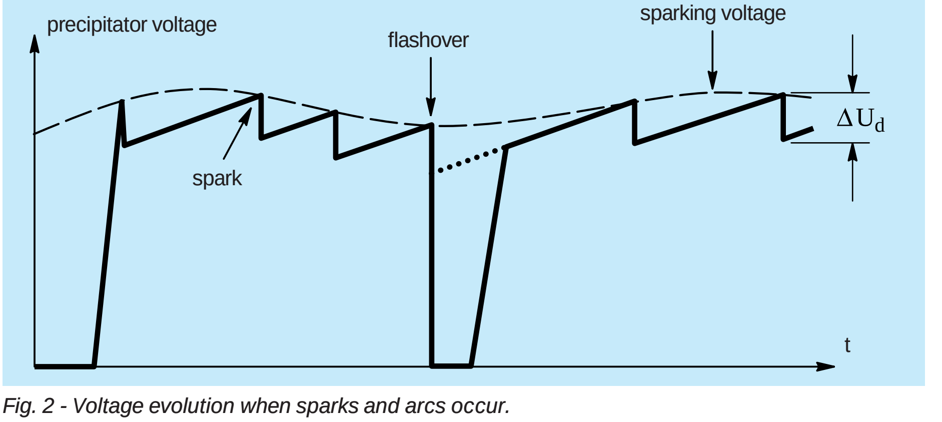

Fig. 2 - Voltage evolution when sparks and arcs occur.

general

power supply parameters

The block diagram of an electrostatic precipitator power supply is set out in figure 3.

The current supplied to the step-up transformer primary is controlled by an electronic variator. An inductance coil is inserted in the primary circuit to limit the current in the event of a short-circuit and to improve the form factor. The secondary voltage is rectified before being supplied to the emitting electrodes of the electrostatic precipitator.

Symbols used:

- low voltage side:

U_L : rms value of mains supply voltage

I_L : rms value of primary current

P_a : transformer apparent power

K : transformation ratio

- high voltage side:

U_v : rms value at transformer secondary

U_d : mean value of DC high voltage

U_p : peak value of DC high voltage

I_d : mean value of DC high voltage current

I_v : rms value of secondary current

- an index may accompany these symbols:

0 : value on no-load

1 : value on rated load

No-load peak high voltage, U_{p0}

This is the parameter which is generally used to define the power supply voltage: is it essentially determined by the distance between the electrodes of the filter. In some cases, it is the peak value on a resistive load which is specified: considering the value of the primary inductance coil generally adopted and the total losses, we have the following relation:

$$U_{p1} \# \ 0.92\ U_{p0}$$

The power supply can also be defined by the mean high voltage value on a resistive load.
We then have:

$$U_{d1} = \frac{U_{v1}}{1.11} \# \frac{0.92\ U_{p0}}{\sqrt{2 \times 1.11}}$$

$$U_{d1} \# \ 0.586\ U_{p0}$$

Mean rectified current, I_d

This is the second parameter for defining the power supply. It is mainly linked with the surface of the electrodes. As the current in the electrostatic precipitator is generally pulsed (fig.4), the mathematical expression of the mean current is:

$$I_d = \frac{1}{T}\int_0^T i_d\ dt$$

Current form factor, FF

The form factor FF is the ratio of the rms current value to its mean value:

$$FF = \frac{I_v}{I_d}$$

This ratio is a function of:

- the nature of the load (inductance, capacity, resistance),
- the value of the total equivalent inductance of the primary circuit,
- the conduction angle of the thyristors.

It is better the smaller it is and the closer to 1.11, the theoretical value for a conduction angle of 180° on a resistive circuit.

Figure 5 shows the influence of the instantaneous current shape on the form factor, for the same value of I_d.

The primary inductance coil contributes to reduce the value of the form factor, thus favouring the operating stability of the electrostatic precipitator.

This parameter is characterized by determining its maximum value, obtained when the power supply output is short-circuited (minimum conduction angle).

The form factor is determinant in dimensioning the installation power. Our power supplies are designed for a maximum FF value of 1.4.

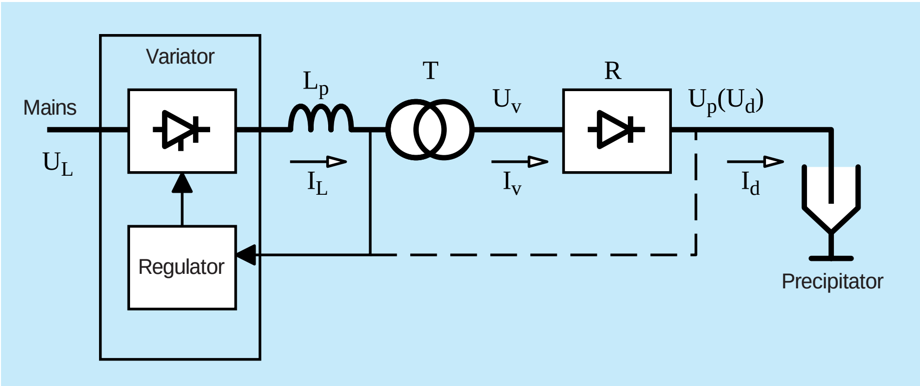

Fig. 3 - Block diagram of a power supply.

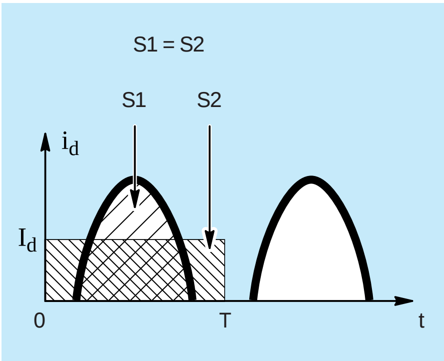

Fig. 4 - Mean rectified current.

Apparent power, P_a

The maximum primary side apparent power P_a is determined by the relation:

$$P_a = U_{L1} \times I_L$$

with

$$U_{L1} = U_{L0} = \frac{U_{v0}}{K} = \frac{U_{p0}}{K\sqrt{2}}$$

and

$$I_L = K \times I_v = K \times FF \times I_d$$

whence

$$P_a = \frac{U_{p0}}{K\sqrt{2}} \times K \times FF \times I_d$$

$$P_a = 0.71 \times FF \times U_{p0} \times I_d$$

For a form factor of 1.4, we have:

$$P_a \# U_{p0} \times I_d$$

Rms value of primary current, I_L

$$I_L = \frac{P_a}{U_{L1}} = 0.71 \times FF \times I_d \times \frac{U_{p0}}{U_{L1}}$$

and with $FF = 1{,}4$

$$I_L \# I_d \times \frac{U_{p0}}{U_{L1}}$$

Maximum active power

Maximum actual power supplied to a resistive load:

$$P_u = U_{v1} \times I_{v1}$$

$$P_u \# \frac{0.92\ U_{p0}}{\sqrt{2}} \times 1.11 \times I_d$$

$$P_u \# 0.72 \times U_{p0} \times I_d$$

The maximum active power drawn from the mains supply is therefore:

$$P_{act} = P_u + \text{losses} \# 0.75 \times U_{p0} \times I_d$$

$$P_{act} \# 0.75\ P_a$$

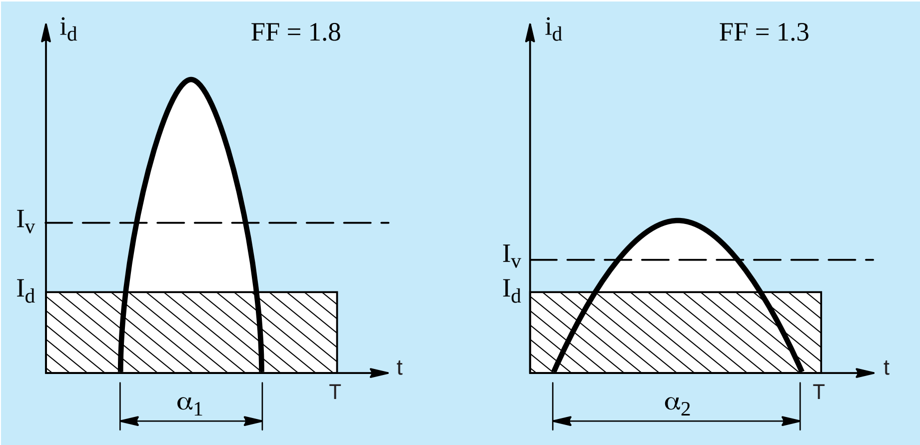

Fig. 5 - Conduction angle and form factor.

output voltage	peak value on resistive load	$U_{p1} \# 0.92\ U_{p0}$
	mean value on resistive load	$U_{d1} \# 0.586\ U_{p0}$
power	apparent (kVA)	$P_a \# U_{p0} \times I_d$
	actual on resistive load (kW)	$P_u \# 0.72\ U_{p0} \times I_d$
	maximum active (kW)	$P_{act} \# 0.75\ U_{p0} \times I_d$
primary current	maximum rms value	$I_L \# I_d \times \frac{U_{p0}}{U_{L1}}$

operation

block diagram

As shown in block diagram form in fig. 3, an electrostatic precipitator power supply essentially comprises a transformer T controlled by a variator via a reactance L_p and delivering to a rectifier R.

Fig. 6 shows the operating principle of the power supply with the UHT 4 regulator.

The variator control device comprises two thyristors Th fitted “head-to-tail”. Their conduction angle, controlled by an electronic regulator operation of which is described below, makes it possible to adjust the transformer primary current, and therefore the rectified secondary voltage as well.

The low voltage reactance L_p has a value such that the transformer-rectifier unit short-circuit voltage is 33 % : this is the voltage, expressed in % of the rated supply voltage, which has to be applied to the unit input to make the rated secondary current I_d flow in a short-circuited load. This reactance therefore limites the maximum primary current of the unit supplied at rated voltage to $3\ I_L$.

Powering on or off in the event of a fault occuring is by means of a contactor K.

The transformer secondary winding is connected to a rectifier bridge the positive pole of which is grounded via a measuring shunt if this is the case.

The negative pole, protected by a surge inductance coil L_S, is connected to the output HV terminal. A resistive divider bridge (HV probe) can be used to measure the rectified high voltage or to detect arcs and sparks directly on the HV output.

Apart from this optional detection on the secondary, the electronic regulator uses:

■ the line current I_L, detected by a current transformer (CT).

■ the transformer primary voltage which, after it has been rectified, is the image on the voltage on the electrostatic precipitator.

conventional operation (UHT 4 regulator)

To control the high voltage value according to the principle set out in the chapter “General” (cf. fig. 2), the variator controls the transformer primary current by acting on the conduction angle of the thyristors.

The latter are controlled by phase converters piloted by a regulating amplifier. The thyristors can also be blocked by a locking circuit.

Regulation to maximum current displayed

The current setpoint displayed I_d max can be reached and maintained, if no sparks, arcs or short-circuits are detected, by a first control loop.

To do this, the primary current measured by the CT is compared with this setpoint: the resulting error signal is input to the regulating amplifier.

High voltage reduction during rapping

The HV supplied to the precipitator can be reduced during rapping by changing the setpoint value I_d max by means of an external contact. This reduces disturbances due to dust reentrainment.

Sparking feed-back

When the electrostatic precipitator sparking voltage is reached, the sparks create fleeting current pulses which are detected by deriving the rectified primary voltage. Each spark generates a voltage step which is subtracted from the setpoint signal I_d max, thus bringing about a reduction ΔI_d, thus bringing about a reduction ΔI_d of the mean current called feed-back rate. This voltage step is followed by a slow rise which increases the setpoint again until the following spark occurs, unless the current I_d max is reached.

The feed-back rate is adjustable according to two possible operating modes:

■ “fixed” mode: the rate ΔI_d is constant

■ “adjusted” mode: the rate ΔI_d is proportionnal to the current value when the spark occurs.

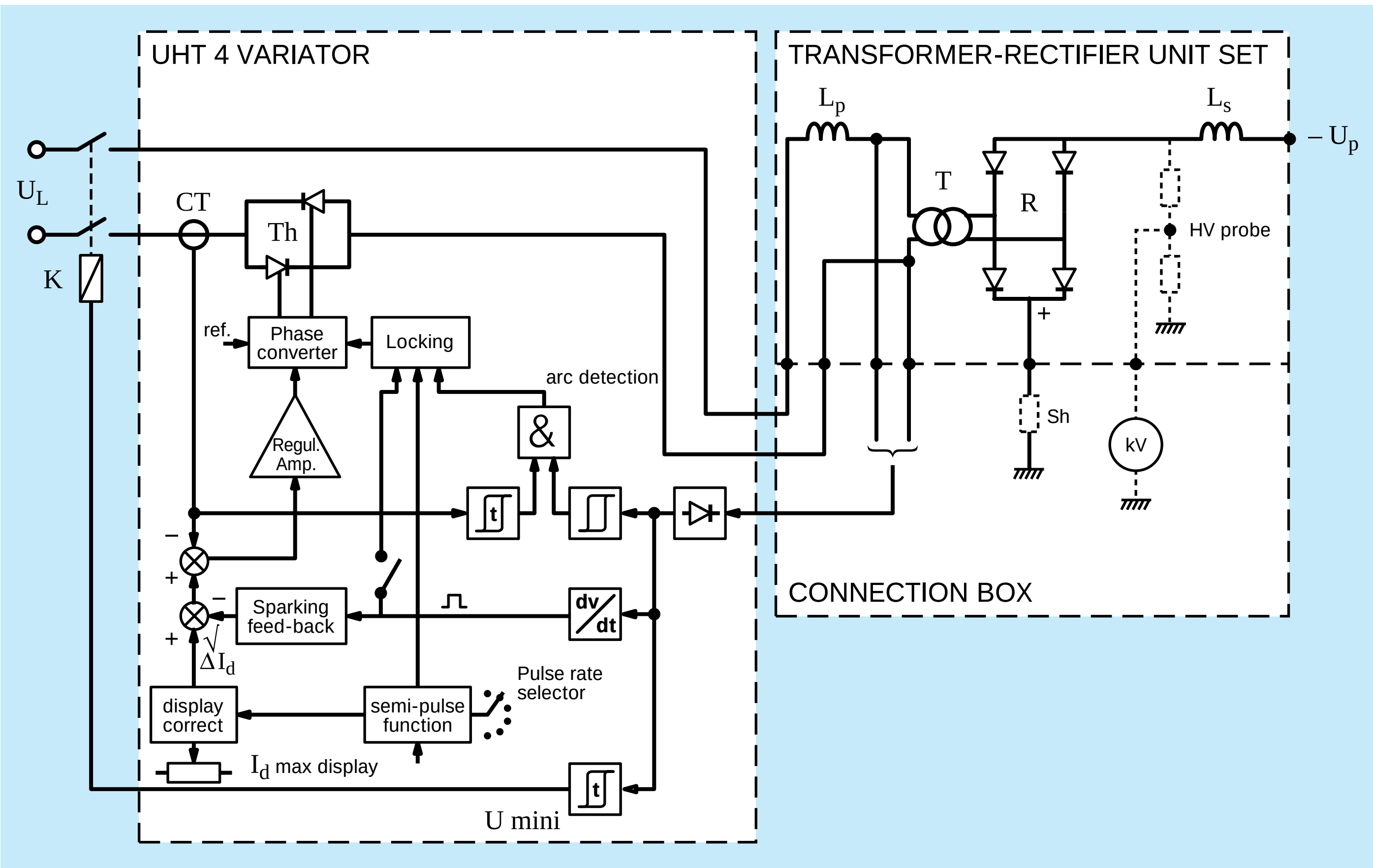

Fig. 6 - Operating principle with UHT 4 regulator.

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Arc detection and extinction

An arc in the electrostatic precipitator brings about a sudden voltage decrease and a large current increase: two trip releases simultaneously detecting a primary voltage which is too low and a primary current exceeding a preset threshold for at least 30 ms leads to locking of the thyristors for the time required for the arc to be extinguished.

After locking, the current is progressively reestablished until the setpoint value defined by the sparking feedback is reached.

This arc extinguishing sequence can also be triggered each time a spark occurs (“1 st arc”).

semi-pulsed energization operation (UHT 4 regulator)

The UHT 4 regulator enables conventional operation or semi-pulsed energization to be selected by means of a selector switch with selection of impulse rate.

In the latter operating mode, a single mains halfwave is used to supply power to the electrostatic precipitator during an adjustable time cycle corresponding to 3, 5, 7… 17 mains half-waves, the pulse rate being the ratio of the number of useful halfwaves to the total number of cycle half-waves (1/3, 1/5, 1/7… 1/17). The rate 1/1 therefore corresponds to the conventional operating mode.

Fig. 7 illustrates this operating mode. Its main advantage lies in reducing the power consumption, without appreciably decreasing the efficiency of the electrostatic precipitator. Fig. 8 shows how the power consumption can be halved: if the conduction angle is reduced in conventional mode, the mean voltage and current are appreciably reduced, whereas the choice of semi-pulsed operation at 1/3 makes it possible to maintain a high mean voltage. This is important, for the efficiency of the electrostatic precipitator is to a large extent dependent on the maximum value of the electrical field.

Furthermore, the reduction of the current density due to semi-pulsed energization can in some cases attenuate the back-corona phenomenon and improve the filtering efficiency. In this operating mode, the pulse rate can be chosen by means of a selector switch via a device acting on the thyristor locking circuit. The maximum current setpoint is modified according to the pulse rate, the mean current being reduced but in a lower ratio than this rate, so that the current pulses are greater than in conventional operation.

Sparking feed-back normally acts to optimize the mean high voltage value. Arc detection is on the other hand inhibited in semi-pulsed energization, for in this mode systematic locking for several half-waves after each pulse is sufficient to extinguish any arc which might occur.

protective and testing devices

Tripping on faults

The main power supply contactor cuts the power input if faults occur:

- short-circuit in the electrostatic precipitator: an undervoltage release detects abnormally low voltages on the transformer primary, and delivers a “fault” signal after an adjustable time.
- overloads: tripping by thermal relay on the power supply line.
- variator fault: blown fuses on the low voltage power supply to the electronic circuits, or thyristor temperature too high, or regulator fault.
- transformer-rectifier unit fault: gas presence in the tank, oil temperature too high, and oil pressure too high (DGPT 2 relay).

Testing device (UHT 4 regulator)

A spark occuring can be simulated by means of a push-button in order to test the behaviour of the regulator.

Arc and short-circuit detection can be inhibited by means of change over switches for the purposes at the tests.

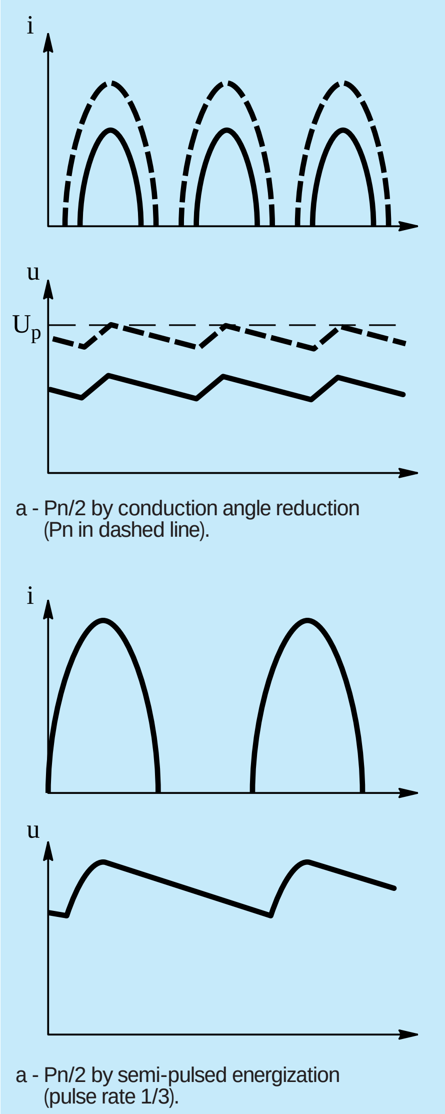


Fig. 8 - Reduction of power consumed.

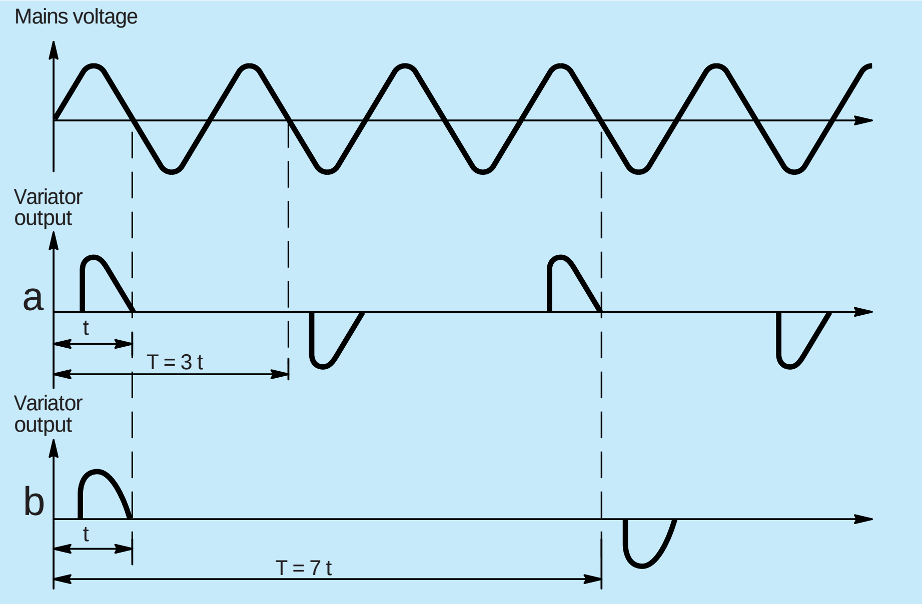


Fig. 7 - Semi-pulsed energization operation (pulse rate 1/3 in a, 1/7 in b).

high voltage power supply

electrical equipments for electrostatic precipitators

description

general presentation

The electrostatic precipitator power supply comprises a transformer-rectifier unit, designed for outdoor installation, and a control cabinet located indoors. The latter is usually integrated in an electrical switchboard which groups together all the control cabinets and the low voltage distribution for the other electrostatic precipitator components. The transformer-rectifier unit is connected to the control cabinet by cables carrying the power (single-phase low voltage) and monitoring and protection information (variable in number according to the options).

transformer-rectifier unit

The transformer-rectifier unit is made up of hermetically sealed tank completely filled with mineral oil in which the single-phase voltage step-up transformer, the rectifier, the primary inductance coil and the overvoltage damping choke are immersed. It is a sealed type and completely immersed unit.

The rectifier is formed by a fullwave single-phase bridge make up of controlled avalanche silicon diodes whose safety coefficient V_{RRM}/U_p is equal to #2.

The tank hood supports:

■ the HV output terminal (vertical),

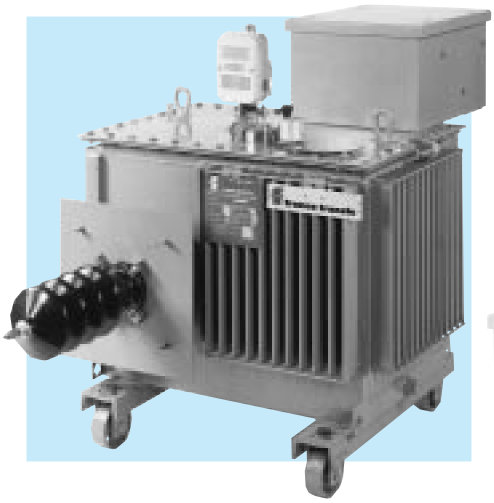
■ a protecting device DGPT 2 (pressure and gaz detector, thermostat with 2 contacts and dial type thermometer),

■ an enclosure housing the low voltage terminals and the electrical connections,

■ the lifting lugs.

The unit is also equipped with rollers, filling and drain plugs and an earth terminal.

Standard treatment, anticorrosion treatment and final painting: GREY RAL 7033.



Optionally:

■ the HV terminal can be fitted horizontally on the side of the tank. It can be centered or not,

■ in case of a half-field electrostatic precipitator, we can quote transformers equipped with two horizontal bushings and two grounding switch sets,

■ the transformer primary winding can be equipped with taps enabling the high voltage to be reduced up to 30 % of its rated value,

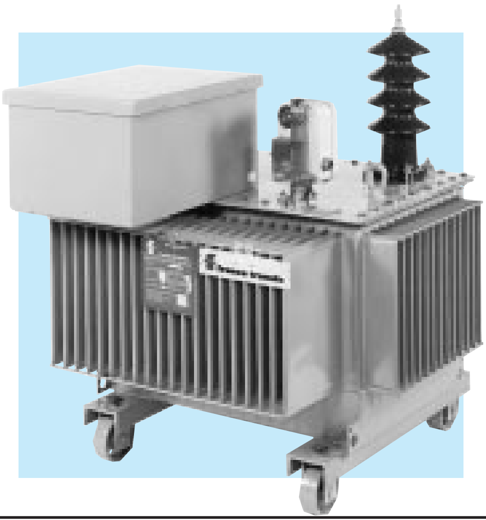
■ the unit can be equipped with a direct high voltage measurement probe immersed in the oil,

■ 2 rectified current measurement shunts can be fitted in the connection enclosure,

■ a switch immersed in the oil, with an observation window, makes it possible to ground the high voltage outcoming,

■ a grounding switch device entirely automatic (MALTAUTO). This apparatus allows to earth the output of the transformer-rectifier and to discharge the electrostatic precipitator in case of explosive or ignitible mixture presence,

■ other types of dielectrics, paintwork, etc. can also be offered.



control cabinet

The control cabinet houses the thyristor variator and all the equipment required for monitoring and protection of the high voltage power supply.

The components are installed in a “front” compartment, accessible once the door has been opened. The compartment has a protection index of IP 31.

A rear duct, with a protection index of IP 20, evacuates the calories given off by the variator by means of free air circulation allowed by the air vents.

The paintwork is of RAL 7032 colour.

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description

Thyristor variator

The thyristor variator is comprised of a mounting plate on which the circuitry and components necessary for primary current monitoring are fitted. The UHT 4 electronic regulator is fitted on the variator mounting plate.

The thyristors are mounted on a heat sink equipped with a thermostat. Cooling is perfomed either by natural convection or by forced ventilation depending on the rated current. The heat sink, with the fans if it is equipped with any, is located at the rear of the mounting plate so that when the latter is in place in the compartment, these components protrude into the rear duct.

The following are also fitted on the mounting plate:

- the thyristor firing circuit,
- the measurement transformers and their shapping circuit,
- the protective circuits (RC, fuses),
- the electrical connection terminal.

The assembly is protected by a plexiglass cover.

UHT 4 regulator

The UHT 4 regulator is comprised of a single printed circuit, electrically connected to the mounting plate by means of a connector, which makes it easy to replace. This card supports all the setting and test devices:

- “rated current” setting (I_d max.),
- spark detection sensitivity setting,
- sparking feedback rate setting (ΔI_d),
- post-sparking gradient setting,
- “fixed” or “adjusted” mode selection for ΔI_d,
- “1 st arc” or “3 rd arc” mode selection for the arc extinction sequence,
- minimum arc detection voltage threshold setting,
- thyristor locking time setting,
- minimum short-circuit detection voltage threshold setting (U min.),
- short-circuit tripping time delay setting,
- semi-pulse rate selector switch (semi-pulsed energization operation),
- current display selector switch in the case of a transformer with primary taps,
- changeover switch for short-circuit test,
- changeover switch inhibiting tripping on short-circuit,
- “sparks” test push-button,
- “sparks” indicator lamp,
- “arcs” indicator lamp.

Certain setting and the test push-button are accessible through a window drilled in the plexiglass cover. Access to the other setting and test devices and to the test points can only be reached after this cover has been removed.

monitoring and protective devices

In addition to the thyristor variator and its regulator, the standard control cabinet equipment comprises:

- a disconnecting switch with fuses,
- a main power supply contactor,
- a thermal relay with current transformer,
- a unit primary voltage measurement transformer,
- a control and signalling circuit supply transformer,
- the control and signalling relays,
- the ouput current in manual control display potentiometer, which enables the high voltage current to be varied from zero to its preset maximum value (I_d max),
- the “automatic-manual” selector switch associated with output current monitoring: the “manual” position enables adjustement to be made by means of the above potentiometer, the “automatic” position allows the current to reach the value I_d max, the UHT 4 regulator functions remaining operational in both cases.

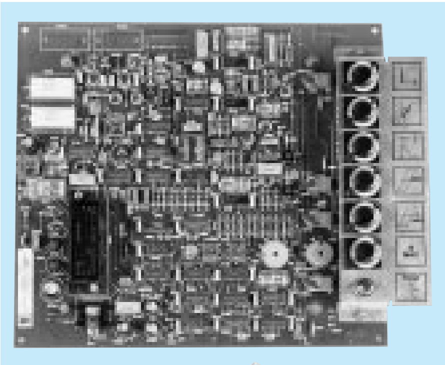
The control and protective circuits combine the following malfunctions in a single “fault” signal: thermal relay and thyristor thermostat trip, regulator fault, short-circuit detection at transformer-rectifier unit output, gas detection in the unit and excessive oil temperature. The “fault” signal causes the main power supply contactor to open, a contact (remote signalling) to close, and the “fault” indicator lamp (local signalling) to light up.

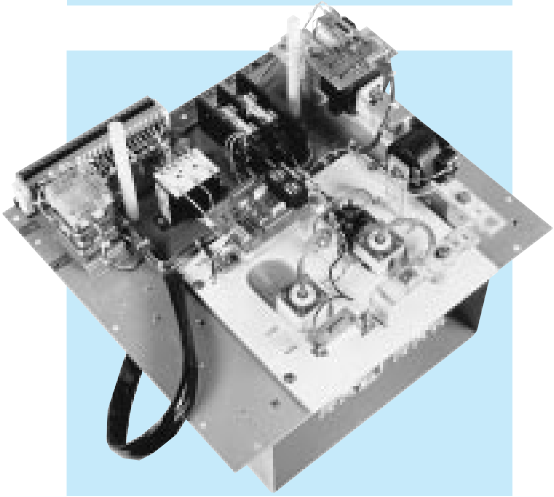
The following are fitted on the door:

- 3 control push-buttons (“on”, “off”, “off-reset”),
- 2 “on”, “off” indicator lamps,
- 1 “fault” indicator lamp,
- 1 transformer primary voltage display voltmeter,
- 1 primary power supply current display ammeter,
- 1 HV current display ammeter (measurements by shunt in earth return of HV positive).

To meet specific installation requirements, the control cabinet can be fitted with **optional extras**, for example:

- specific “fault” processing circuit, with individual signalling of each fault,
- I_d max during rapping display potentiometer,
- remote measurement transmission (0-20 mA or 4-20 mA transmitters with galvanic insulation),
- secondary voltage indicators from probe on the transformer-rectifier unit,
- higher cabinet protection index,
- integration of auxiliary functions,
- etc…





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technical data

general characteristics

output

U_{p0}	no-load peak voltage	50, 60, 70, 78, 90 or 111 kV
I_{d1}	mean current	100, 200, 400, 600, 800, 1000, 1200, 1600 or 2000 mA

power supply

U_L	mains voltage	220, 380, 440, 500, 550 V single-phase 50 - 60 Hz
	permitted voltage fluctuations	+ 5 %, – 15 %
P_a	apparent power	from 10 kVA to 180 kVA
I_L	primary current	from 30 A to 420 A

Note: on request, other output or power supply characteristics can be supplied: high voltage up to 150 kV, mean current up to 3000 mA, mains voltage up to 660 V, primary current up to 580 A, rated power up to 330 kA, etc.

transformer-rectifier unit

short-circuit voltage	33 %
maximum form factor	1.4
maximum operating temperature - short duration - daily mean - annual mean	from 10 kVA to 180 kVA 40 °C 30 °C 20 °C
maximum operating altitude	1000 m
dimensions and masses	see table page 9

control cabinet

control and signalling circuits supply voltage	220 V
maximum operating temperature	40 °C
dimensions	see table page 9
approximate mass	200 kg

Note: consult us for different operating characteristics or conditions.

UHT 4 regulator setting ranges

	parameter	UHT 4 regulator
I_d max	maximum output current	50 to 100 % of I_{d1}
	maximum output voltage	100 % of U_{p0}
	blocking time on powering on	fixed - 220 ms
	rise time on powering on	fixed - 100 ms
Δ Id	sparking feedback rate - fixed mode - adjusted mode	 2 to 20 % of I_d max 2 to 20 % of I_d
	rise gradient after spark (slow)	6 to 600 s for 100 % I_{d1}
	rapid rise gradient after arc or spark	fixed - 100 ms for 100 % I_{d1}
	locking time after arc	10 to 250 ms
	semi-pulse rate (semi-pulsed energization)	1/3, 1/5, 1/7 … 1/17
U mini	minimum voltage (short-circuit detection)	0 to 40 % U_L
	short-circuit tripping time delay	1 to 30 s

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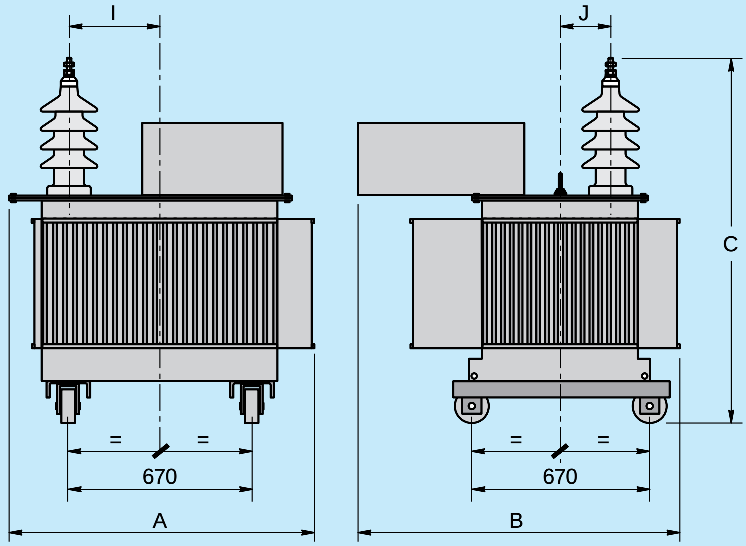
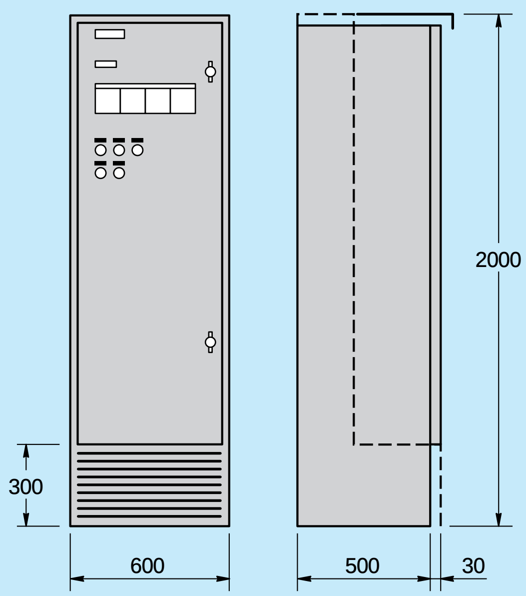
dimensions and masses (basic version without options)

transformer-rectifier unit

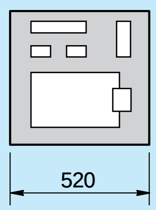


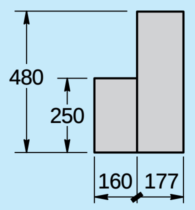
	Upo ≤ 90 kV					Upo ≥ 90 kV				
Pa (kVA)	**12**	**24**	**47**	**84**	**144**	**18**	**32**	**47**	**84**	**144**
A (mm)	1100	1100	1100	1260	1410	1100	1100	1100	1210	1410
B	1100	1100	1100	1160	1220	1090	1090	1090	1120	1230
C	1240	1290	1340	1390	1490	1510	1510	1510	1510	1560
J	150	150	150	150	150	150	150	150	150	150
I	300	300	300	300	300	300	300	300	300	300
mass (kg)	580	640	700	840	1140	685	745	792	910	1120

control cabinet



UHT 4 variator





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defining an HV power supply

■ general characteristics

Rectified secondary voltage kV — Value { peak / mean — no-load / on R load

Rectified current, mean value on precipitator: mA

Single-phase power supply: voltage: V — Frequency: 50 Hz — 60 Hz

■ transformer-rectifier unit

HV output terminal: vertical — horizontal — centered — left — right

Intermediate primary taps: –10% — –20% — –30%

Dielectrics : mineral oil — silicone — ....

Accessories : manual earthing switch (with observation window)
automatic grounding switch (MALTAUTO)
HV current measurement shunt
HV measurement probe
DGPT 2 protection

Special environment and protection:

max temperature: short duration °C — daily mean °C — annual mean °C

operating altitude m

special paintwork: ....

If an outgoing "High Voltage Busduct" has to be forseen, thank you to inform us, at the order, about dimensions and orientation of fixings (studs, flange, …).

■ control cabinet

cabinet: complete — variator only — to be installed by yourself in the control cabinet

Regulator: UHT 4 — digital

supply voltage:

- control circuits V — DC — AC — internal — external
- signal. circuits V — DC — AC — internal — external

Individual fault signalling:

HV display indicator

High voltage reduction during rapping

Analog signal transmitters: Nr — 0-20 mA — 4-20 mA

Special environment and protection:

max temperature: °C

front compartment protection index: IP

special paintwork: ....

Important: The hereover description corresponds to a standard unit. Non described functions may be supplied, as addition of supplementary order devices HV outgoings for auxiliary electrostatic precipitator, etc… Please consult us.

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Due to the evolution of standards and materials, the present document will bind us only after confirmation from our technical department.

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