Guide for electrical design engineers

Leonardo ENERGY

Power Quality

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Designing an uninterruptible power supply

Example of a process production line

european COPPER institute

Power Quality

Scope of design

A company specialized in uninterruptible power supply systems developed and manufactured in 2006 a system comprising a 400kVA UPS unit. The system was installed in a production facility manufacturing food packaging equipment and foil, located in northern Poland. Frequent voltage dips and fluctuations were severely impairing the production process, causing downtimes of several-hour duration, which generated substantial losses. Restarting the production caused another losses resulting from the process specificity. Typically about 200 kg of material was lost until final product was compliant with standards.

The production plant is supplied directly from two-transformer substation 15/0.42 kV. The substation is not equipped with automatic stand-by switching system and is provided only with a manually operated power switch 1—0—2 (I_n=1250A). According to the design of electrical installation in the production line room, individual loads were supplied directly from LV switchboard in the transformer substation; a fire cut-off switch was not installed.

Since the commissioning of the uninterruptible power supply system the process line has been operating failure free. Supply interruptions, even of a several minute duration, do not cause the process breakdown. The transformer substation was provided with fire cut-off switch actuated by manually operated switches located at the main entrance to the production room and at the entrance to the UPS room. Actuation of the fire switch turns the UPS off and thus turns off all loads installed in the building. Photographs below show some elements of the uninterruptible power supply installation.

View of the uninterruptible power supply installation

Air-conditioning

The design of the uninterruptible power supply system installation involved some problems related with efficiently venting of hydrogen released during the UPS battery charging. The room intended by the investor for the UPS installation was very small what resulted in the necessity for design of ventilation and air conditioning installation.

Charging of lead-acid batteries involves hydrogen evolution due to water decomposition (even in a sealed battery there is no 100% recombination). This process is associated with the water decomposition voltage of ca. 0.23 V. Water decomposition process in lead-acid battery is indicated in figure 1.

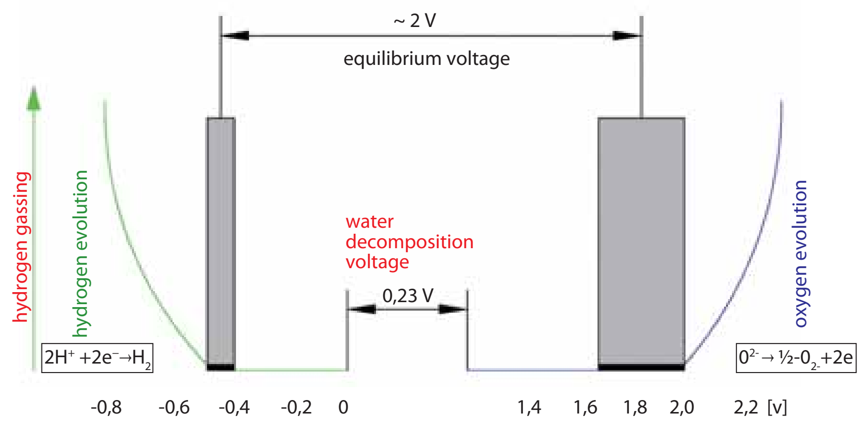


Fig. 1. Water decomposition in a lead-acid battery

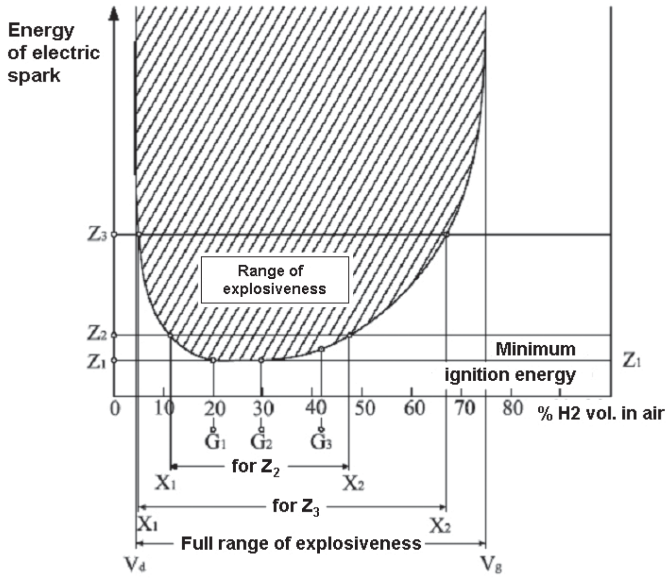


Fig. 2. The ignition energy of a hydrogen-air mixture vs. the hydrogen concentration

Z_1 – minimum ignition energy E_{min}=0,019 mJ,

V_d – lower explosive limit

V_g – upper explosive limit

Accumulating hydrogen gas mixes with air forming a mixture that at the concentration greater than 4.1% (lower explosive limit — LEL) becomes explosive. When the concentration exceeds the lower explosive limit even a small energy, e.g. that of an electrostatic discharge, is sufficient to initiate explosion. The floor in the battery room shall be of an antistatic material that enables an electrostatic charge accumulated on human body flow to earth. The floor resistance shall satisfy the condition: $50\ k\Omega \leq R \leq 1*10\Omega$. Fulfilling this condition provides for both: a proper workplace insulation, according to IEC 60364-4-41 requirements, and sufficient flow of static charge to earth. The dependence of ignition energy of a hydrogen-air mixture on the hydrogen concentration is shown in figure 2.

Hydrogen has a lighter density than air and tends to rise upward in air, forming under a ceiling a layer of mixture with concentration depending on the intensity of battery gassing and the air exchange rate in the battery room. In order to mitigate explosion hazards the UPS battery room ventilation is necessary.

The presented design employs a two-threshold explosive gases detection system. The detection system comprises a control panel, two detectors and an optical-audible signaling device. If the concentration exceeds 10% of the lower explosive limit (LEL) an exhaust fan with air exchange rate 6 times per hour is started. If the gassing is more intensive and the concentration exceeds 30% of LEL, the second exhaust fan is started. Both fans provide for air exchange rate 12 times per hour (the required rate is 4–8 air exchanges per hour).

When the concentration exceeds 30% of LEL the acoustic-optical signaling device is actuated which warns the staff to turn-on the ventilation with the manually operated switch located outside the UPS room.

Approximate air demand volume per hour in [m^3/h] can be calculated from the formula [1]:

$$Q_p = 0.05 * n * I_g * C_B$$

where: I_g – gassing current value:

- 1 mA – for sealed batteries at variable voltage
- 5 mA – or vented batteries at variable voltage
- 8 mA – for sealed batteries at constant charging voltage
- 20 mA – for vented batteries at constant charging voltage

n – number of cells

C_B – battery capacity.

It should be borne in mind that forced ventilation shall always be provided. A gravity (natural) ventilation may be applied if the ventilation openings fulfilling the following condition can be provided:

$$A_p = 28 * Q_p$$

where: A_p – total cross sectional area of the intake and outlet openings [cm^2].

In such case the ventilation openings shall be placed on the opposite walls. Where this is impracticable and ventilation openings have to be made in same wall, the distance between openings must not be smaller than 2 m. The same requirement applies to installation of exhaust fans whose distance must not be smaller than 2 m. These requirements shall be used solely for informative purposes. Design of battery room ventilation requires specialist knowledge and should only be made by a certified designer. The role of an electrical engineer is confined to the design of control and power supply systems for ventilating fans.

The design employs air conditioners in order to remove the surplus heat dissipated by equipment installed in the UPS room. The use of air conditioners also allows maintaining air humidity required by the UPS unit. Appropriate relative humidity air is an important factor for the generation of static charges and thus reduction of electrostatic discharge hazard. Specification for ventilators and air conditioners is provided by the HVAC part of design.

Specification and design calculations

The process equipment power supply switchboard is supplied from a two-transformer substation with two 800 kVA transformers. The substation is provided with a manual stand-by switching system. The process equipment power supply and control panel is fed directly from the two-transformer 15/0.42 kV substation main switchboard through a feeder cable 5x(3xYKY 1x150) {5x(3xH1VV1X150)}. The load current does not exceed 180 A in each phase of the feeder line.

Technical specification of the substation transformers:

- Rated power S_n = 800 kVA
- Connection group Dy5,

- Nominal voltage of primary side $U_{n1} = 15000$ V
- Nominal voltage of secondary side $U_{n2} = 420$ V
- Short-circuit voltage $u_k = 0.060$
- Nominal load losses $\Delta P_{obc\ zn} = 8.5$ kW.

Short-circuit capacity at the point of transformers connection to MV line: $S_{kQ} = 250$ MVA.

Air conditioner rating: P = 8 kW; $k_r = 4$; $U_n = 3x230/400$ V; cosφ = 0.9; η=0.9.

Ventilator rating: P = 1.0 kW; $k_r = 4$;U_n =3x230/400 V; cosφ = 0.9; η=0.9.

Technical description of installation

Since the second production line is planned to be installed, the process equipment power supply and control panel shall be supplied from UPS 400 kVA (a single production line could be supplied from a 200 kVA UPS that sufficiently fulfills the supply requirements).

Schematic diagram of the process equipment power supply is shown in drawing 3, diagram of the ventilation control circuits is shown in drawing 3A; diagram of the MD-2A control panel connections is shown in drawing 3B.

The separated part of production room shall be adapted to the UPS purposes. Equipment layout in the UPS room is shown in drawing 5. The layout of ventilation and air-conditioning installation in the UPS room is shown in drawing 6.

Diagrams of switchboards installed in the UPS room are shown in drawings 7, 7A, 7B, 8, 8A and 8B. Schematic diagram of the compressor and water treatment plant power supply switchboard is shown in drawings 9, 10A, 10B and 10C. Drawing 4 shows the layout of the uninterruptible power supply circuit.

The UPS room shall also be provided with two air conditioners; their selection and location is within the scope of mechanical and HVAC part of design.

The UPS room shall be separated from the rest of production room with a wire mesh fence not less than 3 m high. The fence design is outside the scope of this study. The UPS room is an electrical room therefore warning signs shall be placed on the fencing and access of unauthorized persons shall be prevented.

At the main entrance to the production room a fire cut-off switch shall be installed. Above the switch a sign shall be placed with information on its purpose and use.

Selection of the UPS unit

The peak load current under the process line normal operating conditions, measured in each phase is: $I_1=I_2=I_3 = I = 180$ A.

The process line shall be supplied with compressed air and process water in order to ensure continuity of its operation.

The peak power of additional equipment (of capacity sufficient for two process lines) is:

- compressor with a soft start system – $P_{sp} = 11$ kW,
- water treatment plant – $P_{SUW} = 41$ kW.

Calculated active power demand at the UPS output

$$P_1 = \sqrt{3} \cdot U_n \cdot I = \sqrt{3} \cdot 400 \cdot 180 = 124.71 kW \approx 125 kW$$

$$P_c = P_{wyjUPS} = 2 \cdot P_1 + P_{SUW} + P_{sp} = 2 \cdot 125 + 41 + 11 = 302 kW$$

$$\cos\varphi_z = 0.8$$

$$S_{wyjUPS} \geq \frac{P_{wyjUPS}}{\cos\varphi_z} = \frac{302}{0.8} = 377.5 kVA$$

Therefore the 400 kVA unit shall be selected

where: S_{wyjUPS} – reactive peak power at the UPS output [kVA]

P_c – active peak power at the UPS output [kW]

P_1 – active peak power of process line equipment (installation of second process line is planned as a target solution) [kW]

I – load current of the process line equipment under normal operating conditions and peak load (determined from measurement) [A]

$\cos\varphi_z$ – power factor of the process line equipment (calculated from the equipment manufacturer O&M instructions) [-]

U_n – nominal voltage of loads [V]

P_{wyjUPS} – UPS output active power [kW]

P_{SUW} – active peak power of water treatment [kW]

P_{sp} – compressor active peak power [kW].

Cable sizing for continuous current-carrying capacity and thermal effects of overload current:

— UPS calculated power demand:

$$S_{wejUPS} = \frac{\left(\frac{P_{wyjUPS}}{\eta \cdot W} + \frac{0.25 \cdot P_{wyjUPS}}{W}\right)}{\cos\varphi_{UPS}} = \frac{\frac{302}{0.9 \cdot 0.9} + \frac{0.25 \cdot 302}{0.9}}{0.9} \approx\sim 507.50kVA$$

— UPS feeder cables and external bypass (protection: overcurrent power circuit breaker 800 A):

$$I_B = \frac{S_{wejUPS}}{\sqrt{3} \cdot U_n} = \frac{507500}{\sqrt{3} \cdot 400} = 732,50A$$

$$I_B = 732,50A \le I_n = 800A \le I_Z$$

$$I_Z \ge \frac{k_2 \cdot I_n}{1.45} = \frac{1,45 \cdot 800}{1.45} = 800A$$

where: $S_{wej\ UPS}$ – UPS apparent peak power [kVA]

W – UPS input current distortion factor determined from the manufacturer O&M instruction

η – UPS efficiency determined from the manufacturer O&M instruction [-]

$\cos\varphi_{UPS}$ – UPS power factor determined from the manufacturer O&M instruction [-]

I_B – load current [A]

I_n – nominal current of protective device [A]

I_Z – required continuous current-carrying capacity of a cable [A]

k_2 – multiple factor of a protective device rated current at which the protective device operates at the specified conventional time, equal [7]:

- 1.6- 2.1 – for fuse links
- 1.45 – for overcurrent circuit breakers
- 1.2 – for overcurrent selective circuit breakers and bimetallic relays

The selected cable 4x(2xYKXS 1x240) + YKXSżo 240 {4x(2xH1V4V1X240) + H1V4V1G240} satisfies the requirements of IEC 60364-45-523 standard regarding continuous current-carrying capacity and thermal effects of overload current:

$I_z' = k_p * I_z = 0.85 * 2 * 538 = 914.60$ A > 800 A.

Note: The main protection of RUPS feeder, installed in the transformer substation LV switchboard supplying the production room, is only a short-circuit protection. Since no overloads are expected the RUPS supply circuit the existing cable 5x(3xYKXS 1x150) {5x(3xH1VV1X150)} can be considered adequate for power supply of RUPS.

<u>- RS and UW feeder cable (protection: fuse 125 A):</u>

$$I_B = \frac{P_{RS\_i\_UW}}{\sqrt{3} \cdot U_n \cdot \cos\varphi_{RS\_i\_UW}} = \frac{52000}{\sqrt{3} \cdot 400 \cdot 0,8} = 93.82A$$
$$I_B = 93.82A \le I_n = 125A \le I_Z$$
$$I_Z \ge \frac{k_2 \cdot I_n}{1.45} = \frac{1,6 \cdot 125}{1.45} = 137.93A$$

The selected cable YKXSżo 5x50 {5xH1V4V5G50} satisfies the requirements of IEC 60364-45-523 standard regarding continuous current-carrying capacity and thermal effects of overload current:

$I_z' = k_p * I_z = 0.8 * 179 = 143.20$ A > 137.93 A.

<u>- Compressor feeder cable (protection: fuse 40 A):</u>

$$I_B = \frac{P_{SP}}{\sqrt{3} \cdot U_n \cdot \cos\varphi_{SP}} = \frac{11000}{\sqrt{3} \cdot 400 \cdot 0,8} = 19.85A$$
$$I_B = 19.84A \le I_n = 40A \le I_Z$$
$$I_Z \ge \frac{k_2 \cdot I_n}{1.45} = \frac{1,6 \cdot 40}{1.45} = 44.14A$$

The selected cable YKXSżo 5x6 {H1V4V5G6} satisfies the requirements of IEC 60364-45-523 standard regarding continuous current-carrying capacity and thermal effects of overload current:

$I_z' = k_p * I_z = 0.8 * 52 = 41.60$ A > 44.14 A.

<u>- Water treatment plant feeder cable (protection: fuse 80 A):</u>

$$I_B = \frac{P_{SUW}}{\sqrt{3} \cdot U_n \cdot \cos\varphi_{SUW}} = \frac{41000}{\sqrt{3} \cdot 400 \cdot 0,8} = 73.97A$$
$$I_B = 73.97A \le I_n = 80A \le I_Z$$
$$I_Z \ge \frac{k_2 \cdot I_n}{1.45} = \frac{1,6 \cdot 80}{1.45} = 88.28A$$

The selected cable YKXSżo 5x16 {H1V4V5G16} satisfies the requirements of IEC 60364-45-523 standard regarding continuous current-carrying capacity and thermal effects of overload current:

$I_z' = k_p * I_z = 1 * 96$ A = 96 A > 88.28 A

<u>- Ventilation fan feeder cable (protection: S303C4):</u>

$$I_B = \frac{P_W}{\sqrt{3} \cdot U_n \cdot \cos\varphi_{SUW} \cdot \eta} = \frac{1000}{\sqrt{3} \cdot 400 \cdot 0{,}9 \cdot 0.9} \approx 1.782A = 1.79A$$
$$I_B = 1.79A \le I_n = 4A \le I_Z$$
$$I_Z \ge \frac{k_2 \cdot I_n}{1.45} = \frac{1{,}45 \cdot 4}{1.45} = 4A$$

In addition: $I_r = k_r * I_B = 4 * 1.79 = 7.16 < k_4 * I_n = 5 * 4 = 20\ A$, therefore the selection of protection shall be considered appropriate with respect to starting currents.

The selected installation cable YDYżo 4x1.5 {H1VV4G1.5} satisfies the requirement of IEC 60364-45-523 standard regarding continuous current-carrying capacity and thermal effects of overload current:

$$I_z' = k_p * I_z = 1 * 17.5\ A = 17.5\ A > 4\ A$$

<u>- Air conditioner feeder cable (protection: S303C16):</u>

$$I_B = \frac{P_W}{\sqrt{3} \cdot U_n \cdot \cos\varphi_{SUW} \cdot \eta} = \frac{8000}{\sqrt{3} \cdot 400 \cdot 0{,}9 \cdot 0.9} \approx 14.26A$$
$$I_B = 14.26A \le I_n = 16A \le I_Z$$
$$I_Z \ge \frac{k_2 \cdot I_n}{1.45} = \frac{1{,}45 \cdot 16}{1.45} = 16A$$

In addition: $I_r = k_r * I_B = 4 * 14.26 = 71.30 < k_4 * I_n = 5 * 16 = 80\ A$, therefore the selection of protection shall be considered appropriate with respect to starting currents.

The selected installation cable YDYżo 4 x 1.5 [H1VV4G1.5] satisfies the requirement of IEC 60364-45-523 standard regarding continuous current-carrying capacity and thermal effects of overload current:

$$I_z' = k_p * I_z = 1 * 24\ A = 24\ A > 14.26\ A$$

where:
- P_{sp} – compressor active power [kW]
- P_{SUW} – water treatment plant active power [kW]
- $\cos\varphi_{sp}$ – compressor power factor determined from the manufacturer technical specification
- $\cos\varphi_{SUW}$ – water treatment plant power factor determined from the manufacturer technical specification
- k_4 – multiple factor of the rated current of the overload release lower operation limit of a miniature overcurrent electromagnetic circuit breaker [-].

Cable size checking for short-circuit conditions:

<u>- Power system impedance as seen from the point of transformer connection to the MV network reflected to the transformer low-voltage side:</u>

$$Z_{kQ} = \frac{c_{\max} \cdot U_{n1}}{S_{kQ}} \cdot \frac{(U_{n2})^2}{U_{n1}} = \frac{1.10 \cdot 15000^2}{250 \cdot 10^6} \cdot \left(\frac{420}{15000}\right)^2 = 0.000776\Omega$$
$$X_{kQ} = 0.995 \cdot Z_{kQ} = 0{,}995 \cdot 0.000776 = 0.000772\Omega$$
$$R_{kQ} = 0.1 \cdot X_{kQ} = 0{,}1 \cdot 0.000772 = 0.000772\Omega$$

where: Z_{kQ} – short-circuit impedance of the power system [Ω]

X_{kQ} – short-circuit reactance of the power system [Ω]

R_{kQ} – short-circuit resistance of the power system [Ω]

S_{kQ} – short-circuit capacity at the point of transformer connection to the power system, as determined by the utility company [MVA]

U_{n1} – nominal voltage of the transformer high-voltage side [V]

U_{n2} – nominal voltage of the transformer low-voltage side [V].

- Impedance of the transformer:

$$Z_{kT} = u_k \cdot \frac{U^2{}_{n2}}{S_T} = 0.06 \cdot \frac{0,42^2}{0.8} = 0.0132\Omega$$

$$I''_{k3} = \frac{U_{n2}}{\sqrt{3} \cdot Z_{kT}} = \frac{400}{\sqrt{3} \cdot 0.01323} \approx 17.50kA$$

$$i_p = \sqrt{2} \cdot \kappa \cdot I''_k = \sqrt{2} \cdot 1.4 \cdot 17.50 \approx 34.65kA$$

According to the catalogue specification the resistance and reactance of the 15/0.42 kV 800kVA transformer is, respectively:

R_T = 0.0023 Ω - resistance of the supply transformer

X_T = 0.0130 Ω - reactance of the supply transformer

$$R_k = R_{kQ} + R_T = 0.0000772 + 0.0023 = 0.0023772\Omega \approx 0.0024\Omega$$

$$X_k = X_{kQ} + X_T = 0.000772 + 0.0130 = 0.013772\Omega \approx 0.0133\Omega$$

$$Z_k = \sqrt{R_k^2 + X_k^2} = \sqrt{0.0024^2 + 0.0133^2} = 0.0135\Omega$$

$$\frac{R_k}{X_k} = \frac{0.0024}{0.0133} \approx 0.18$$

$$T = \frac{\frac{X_k}{R_k}}{\omega} = \frac{\frac{0.0133}{0.0024}}{2 \cdot 3.14 \cdot 50} \approx 0.0177s = 17.7ms$$

$$I''_{k3} = \frac{U_{n2}}{\sqrt{3} \cdot Z_{kT}} = \frac{400}{\sqrt{3} \cdot 0.0135} \approx 17.11kA$$

$$\kappa = 1.02 + 0.98 \cdot e^{-3\frac{R_k}{X_k}} = 1.02 + 0.98 \cdot e^{-3 \cdot 0,18} = 1.59$$

$$Z_{kT} = u_k \cdot \frac{U_{n2}^2}{S_T} = 0.06 \cdot \frac{0.42^2}{0.8} = 0.0132\Omega$$

$$i_p = \sqrt{2} \cdot \kappa \cdot I''_k = \sqrt{2} \cdot 1.59 \cdot 17.11 \approx 38.72kA$$

- Required minimum cross sectional area of the feeder cable:

RUPS protection: overcurrent power circuit breaker 1250 A with operating time setting:

T_k = 0.5 s (T_k= 0.5s > 10∗T = 0.18s) – thus the simplified relationship $I_{th} \approx I''_k$ can be used for calculation:

$$S \geq \frac{1}{k}\sqrt{\frac{I''^2_k T_k}{1}} = \frac{1}{135}\sqrt{\frac{17500^2 \cdot 0.5}{1}} = 91,67mm^2 << 450mm^2$$

Other UPS circuits protection: overcurrent power circuit breaker 800 A with operating time set T_k= 0.4 s – I_{cs} =40 kA s (T_k=0.5 s > 10∗T = 0.18 s) – thus the simplified relationship $I_{th} \approx I''_k$ can be used for calculation:

$$S \geq \frac{1}{k}\sqrt{\frac{I''^2_k T_k}{1}} = \frac{1}{135}\sqrt{\frac{17500^2 \cdot 0.4}{1}} = 82mm^2 << 480mm^2$$

- The process equipment power supply and control panel protection:

400 A fuse – I_{cs} = 100 kA:

$$S \geq \frac{1}{k}\sqrt{\frac{I^2 t_w}{1}} = \frac{1}{135}\sqrt{\frac{1600000}{1}} = 9.37mm^2 << 480mm^2$$

- RS and UW feeder protection: 125 A fuse – I_{cs}=100kA:

$$S \geq \frac{1}{k}\sqrt{\frac{I^2 t_w}{1}} = \frac{1}{135}\sqrt{\frac{104000}{1}} = 2.39mm^2 << 50mm^2$$

- Air conditioners power supply (protection: S303C16 –I_{cs} = 6 kA)

$$S \geq \frac{1}{k}\sqrt{\frac{I^2 t_w}{1}} = \frac{1}{115}\sqrt{\frac{8000}{1}} = 0.78mm^2 < 4mm^2$$

- Ventilation fans power supply (protection: S303C4 –I_{cs} = 6 kA)

$$S \geq \frac{1}{k}\sqrt{\frac{I^2 t_w}{1}} = \frac{1}{115}\sqrt{\frac{5000}{1}} = 0.62mm^2 < 1.5mm^2$$

where:

I^2t_w	– fuse link operation Joule integral [A^2∗s]
k	– one-second short-circuit current permissible density [A/mm^2]
I_{cs}	– rated service short-circuit capacity [kA]
S	– required minimum cross sectional area of a conductor [mm^2]
I''_k	– initial short-circuit current [kA]
T	– time constant of short-circuit loop [s]
ω	– angular frequency
I_{th}	– thermal equivalent short-circuit current [kA].

Checking the RS and UW feeder cable for permissible voltage drop:

Note: Due to the distance of RS and UW to the power source, only the feeder line is to be checked for voltage drop. Distances of other circuit elements to the power source are negligible thus they could be disregard in design calculations; calculation of these voltage drops is left to the interested reader.

$$\Delta U \geq \frac{P \cdot L \cdot 100\%}{\gamma \cdot S \cdot U_n^2} = \frac{52000 \cdot 60 \cdot 100}{55 \cdot 50 \cdot 400^2} = 0.71\% < 1.0\%$$

The condition is satisfied.

Required cross sectional area of protective conductors PE with regard to the effectiveness of electric shock protection in the case the installation is supplied from UPS:

- RS and UW:

$$R_{PE} \leq \frac{U_L}{I_a} = \frac{50}{1475} = 0.033\Omega$$

$$S_{PE\_\min} \geq \frac{L_{PE}}{R_{PE} \cdot \gamma} = \frac{60}{0.033 \cdot 55} = 33.06mm^2 < 50mm^2$$

The selected cable satisfies the conditions for protection against electric shock.

- The process equipment power supply and control panel:

$$R_{PE} \leq \frac{U_L}{I_a} = \frac{50}{5280} = 0.0094\Omega$$

$$S_{PE\_\min} \geq \frac{L_{PE}}{R_{PE} \cdot \gamma} = \frac{50}{0.0094 \cdot 55} = 29.02mm^2 << 240mm^2$$

The selected cable satisfies the conditions for protection against electric shock.

- Other elements of the uninterruptible powers supply system

$$R_{PE} \leq \frac{U_L}{I_a} = \frac{50}{6400} = 0.0078\Omega$$

$$S_{PE\_\min} \geq \frac{L_{PE}}{R_{PE} \cdot \gamma} = \frac{15}{0.0078 \cdot 55} = 35mm^2 << 240mm^2$$

The selected cable satisfies the conditions for protection against electric shock.

where: S_{PE_min} – required minimum cross sectional area of the protective conductor [mm^2]

L_{PE} – length of the protective conductor [m]

R_{PE} – maximum resistance of the protective conductor [Ω]

I_a – operating current of the protective device [A], within the time required by IEC 60364-4-41 standard, determined from the current-time characteristic provided by a manufacturer (here: for T=0.4s)

γ – conductivity of the conductor [m/(Ω·mm^2)].

Checking the automatic disconnection of supply in the case the installation is not supplied from the UPS system:

- RUPS switchboard

According to the catalogue specification the resistance and reactance of the 15/0.42 kV 800kVA transformer is, respectively:

R_T = 0.0023 Ω – resistance of the supply transformer

X_T = 0.0130 Ω – reactance of the supply transformer

Resistance of the RUPS feeder line:

$$R_{L1} = \frac{L}{\gamma \cdot S} = \frac{20}{55 \cdot 450} = 0.00081\Omega$$

Reactance of RUPS feeder line:

$$X_{L1} = \frac{(x' \cdot L)}{3} = \frac{(0.08 \cdot 0.02)}{3} = 0.00053\Omega$$

The impedance of short-circuit loop:

$$Z_{k1} = \sqrt{\left(R_{kQ} + R_T + 2 \cdot R_{L1}\right)^2 + \left(X_{kQ} + X_T + 2 \cdot X_{L1}\right)} =$$
$$\sqrt{(0.0000772 + 0.0023 + 2 \cdot 0.00081)^2 + \left(0.000772 + 0.0130 + 2 \cdot 0.000530^2\right)} = 0.0146\Omega$$

Line-to-earth fault current at RUPS

$$i_{k1} = \frac{0.8 \cdot U_0}{Z_{k1}} = \frac{0.8 \cdot 230}{0.0146} = 12603A >> I_{aIT_k=0,5s} = 10000A$$

where:

L	– length of the feeder line [km]
R_L	– resistance of the feeder line [Ω]
X_L	– reactance of the feeder line [Ω]
U_0	– voltage between the phase conductor and earthed protective conductor PE [V]
Z_{k1}	– impedance of the short-circuit loop for line-to-earth fault [Ω]
I_a	– operating current of the protective device within the time required by IEC 60364-4-41 standard, determined from the characteristic t =f(I_k), provided by the protective device a manufacturer [A]
x′	– reactance per unit length of cable (assumed 0.08 Ω/km)
γ	– conductivity of the conductor [m/(Ω·mm²)].

Other calculation results are listed in Table 1.

No.	Item	Z_k [Ω]	I_{k1} [A]	Protection	I_a [A]	Condition $I_{k1} \geq I_a$
1	UPS unit	0.015	12266.66	NS800N	5600/T_k=0.4 s	+
2	External Bypass	0.015	12266.66	NS800N	5600/T_k=0.4s	+
3	Air conditioner I	0.110	1672.72	S303C16	160/T_k=0.1s	+
4	Air conditioner II	0.130	1415.38	S303C16	160/ T_k=0.1s	+
5	Fan I	0.260	707.69	S303C4	40/ T_k=0.1s	+
6	Fan II	0.360	511.11	S303C4	40/ T_k=0.1s	+
7	RS and UW	0.060	3006.66	WTN00gG125	1475/ T_k=0.4s	+
8	Process RG	0.020	9200.00	WTN2gG400	5280/ T_k=0.4s	+
9	CSW	0.130	1415.38	S301C2	20/ T_k=0.1s	+
10	Water treatment plant	0.080	2300.00	WTN00gG80	776/ T_k=0.4s	+
11	Compressor	0.075	2453.33	WTN00gG40	300/ T_k=0.4s	+

Table 1. The effectiveness of automatic disconnection of supply for other elements of the uninterruptible power supply system — calculation results

Therefore the designed installation provides effective protection against electric shock.

Note: In these calculations the reactance of conductors with cross sectional area $S_{Cu} \leq 50$ mm^2 or $S_{Al} \leq 70$ mm^2 can be neglected.

Concluding remarks

1. The part of the production room adapted for the UPS purposes shall be separated and signed with warning safety signs; an access of unauthorized persons shall be prevented.
2. Installation and assembly of the UPS unit shall be exclusively made by the manufacturer service or an authorized person.
3. All accessible conductive parts shall be bonded to the main earthing bar. The bonding shall be made with installation cable LgYżo 35 {H1V-K1G35}.
4. The UPS room floor shall be covered with insulating mats.
5. Upon completion of installation works all necessary tests and measurements shall be carried out according to the requirements of IEC 60364-6-61 standard and the manufacturer's specification.
6. The selected UPS unit meets the power demand of the planned second process line. The installation of the uninterruptible power supply system is designed to meet these requirements.
7. Operators shall receive an adequate training prior to the system commissioning.
8. Before the second process line commissioning the MV/LV 2 x 800 kVA transformer substation should be provided with automatic stand-by switching with electrical and mechanical interlocks.
9. Cables in the battery circuits are sized according to the UPS manufacturer's specification.

Specification of basic materials

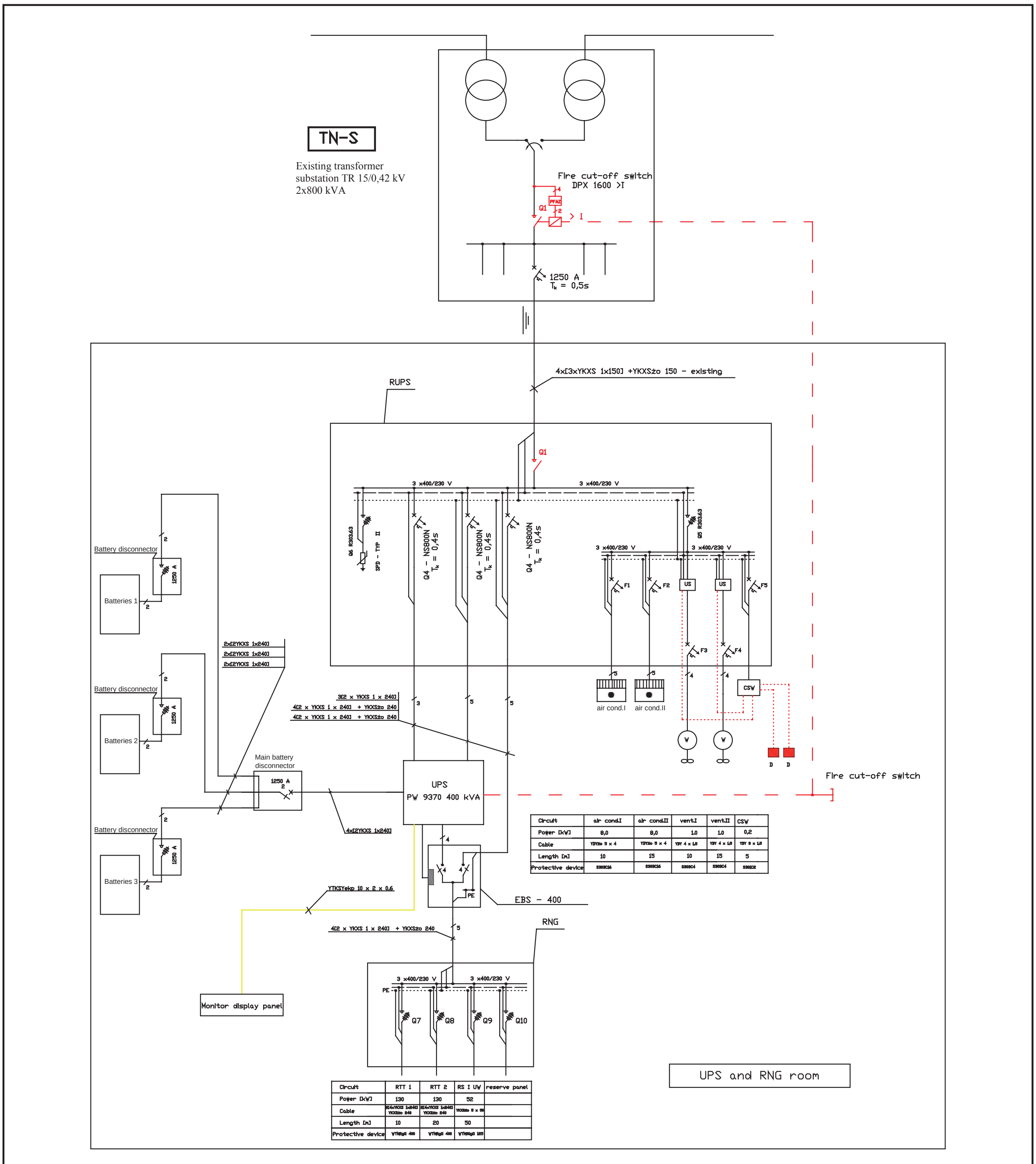
1. UPS unit	1 set
2. Battery banks (90 Ah)	3 sets
3. Battery rack	3 pcs
4. Battery disconnector 1250 A, wall mounted enclosure	3 sets
5. External bypass	1 pc
6. Pushbutton operated emergency-stop switch	1 pc
7. Switchboard RUPS acc. to dwg. 7; 7A; 7B	1 pc
8. Switchboard RNG acc. to dwg. 8; 8A; 8B	1 pc
9. Switchboard RS and UW acc. to dwg. 10; 10A; 10B	1 pc
10. Cable YKY 1 x 240 {H1VV1X240}	180 m
11. Cable YKYżo 5 x 50 {H1VV5G50}	60 m
12. Cable YKYżo 5 x 6 {H1VV5G6}	10 m
13. Cable YKYżo 5 x 16 {H1VV5G16}	10 m
14. Installation cable LgYżo 25 {H1V-K1G35}	50 m
15. Cable trays	30 m
16. Installation cable NKGx 2x2.5 or equivalent	40 m
17. Control panel	1 pc
18. Optical-audible signaling device	1 pc
19. Hydrogen concentration detectors	2 pcs
20. Power supply 17 Ah	1 pc
21. Other installation fitting, accessories, materials	as required.

Note: Items 1—6 are covered by the order placed at the UPS supplier.

Since the transformer substation is supplied via two independent overhead lines outgoing from the same main feeding point (MFP), an engine generating set (EGS) shall be installed in order to improve the reliability of supply. Its rated power shall be sufficient to cover the peak power of all equipment installed in the production room. In addition a manually operated power switch 1—0—2 shall be replaced with an automatic stand-by switching system as an explicit redundancy.

References:

1. M. Miegoń, A. Przasnyski; J. Wiatr - Systemy zasilania gwarantowanego Powerware. Poradnik projektanta i wykonawcy. [Uninterruptible power supply systems Powerware. Designer's and contractor's guide] (in Polish) – the EATON QUALITY Company Poland 2006.
2. IEC 60364 Standard: Electrical installations of buildings.
3. EATON POWERWARE products catalogue.
4. www.elektro.info.pl



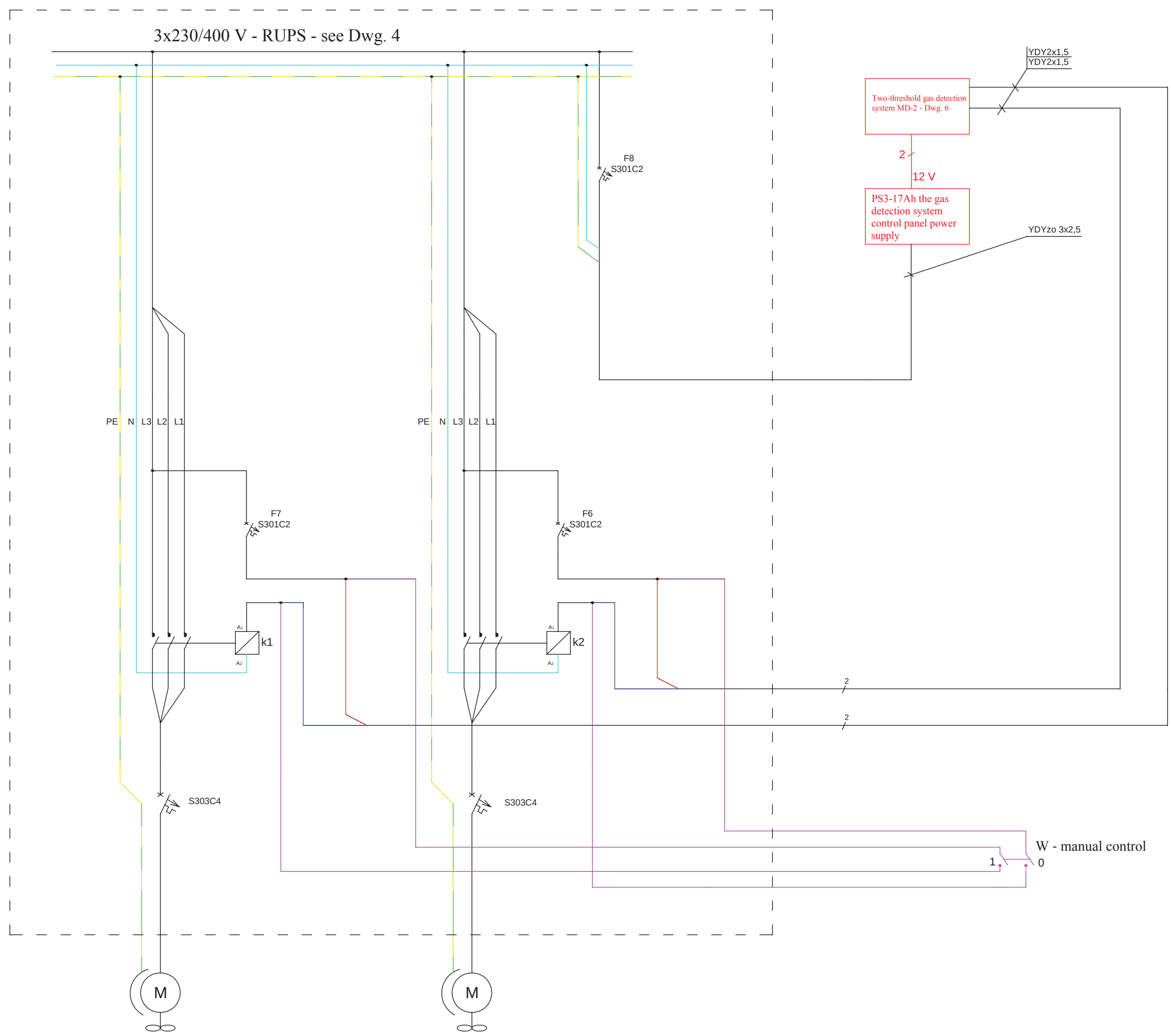
Circuit	air cond.I	air cond.II	vent.I	vent.II	CSW
Power [kW]	8,0	8,0	1,0	1,0	0,2
Cable	YDYżo 5 x 4	YDYżo 5 x 4	YDY 4 x 1,5	YDY 4 x 1,5	YDY 3 x 1,5
Length [m]	10	15	10	15	5
Protective device	S303C16	S303C16	S303C4	S303C4	S301C2

Circuit	RTT 1	RTT 2	RS I UW	reserve panel
Power [kW]	130	130	52	
Cable	2[4xYKXS 1x240] YKXSżo 240	2[4xYKXS 1x240] YKXSżo 240	YKXSżo 5 x 50	
Length [m]	10	20	50	
Protective device	WTN2gG 400	WTN2gG 400	WTN00gG 125	

Note:
US - Ventilation control system, type MD-2 manufactured by "GAZEX".
CSW - Ventilation control panel
D - Explosive gas detector manufactured by "GAZEX"
Transformer substation is not equipped with automatic stand-by switching system. It supplies only the loads installed in the production room. The production building has no cable joint; feeding cables are brought directly into switchboards installed in the production room.

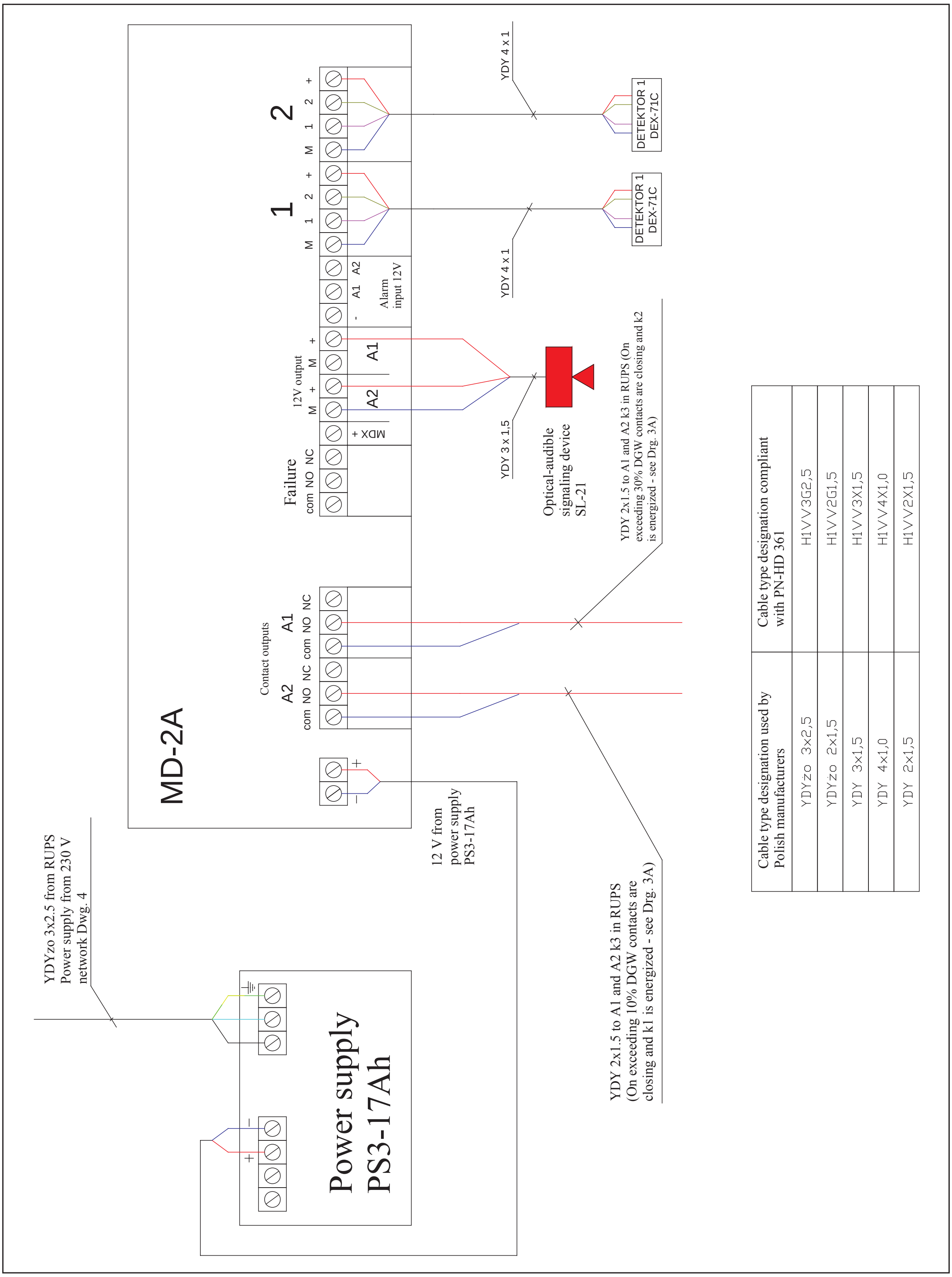
Cable type designation used by Polish manufacturers	Cable type designation compliant with PN-HD 361
4x(3xYKXS 1x150) + YKXSżo150	4x(3xH1V4V1X150) + H1V4V1G150
2x[2xYKXS 1x240]	2x(2xH1V4V1X240)
3x[2xYKXS 1x240]	3x(2xH1V4V1X240)
4x(2xYKXS 1x240) + YKXSżo240	4x(2xH1V4V1X240) + H1V4V1G240
2x(4xYKXS 1x240) + YKXSżo240	2x(4xH1V4V1X240) + H1V4V1G240
YKXSżo 5x50	H1V4V5G50
YDYżo 5x4	H1VV5G4
YDY 4x1,5	H1VV4X1,5

Dwg. 3. Schematic diagram of the uninterruptible power supply system



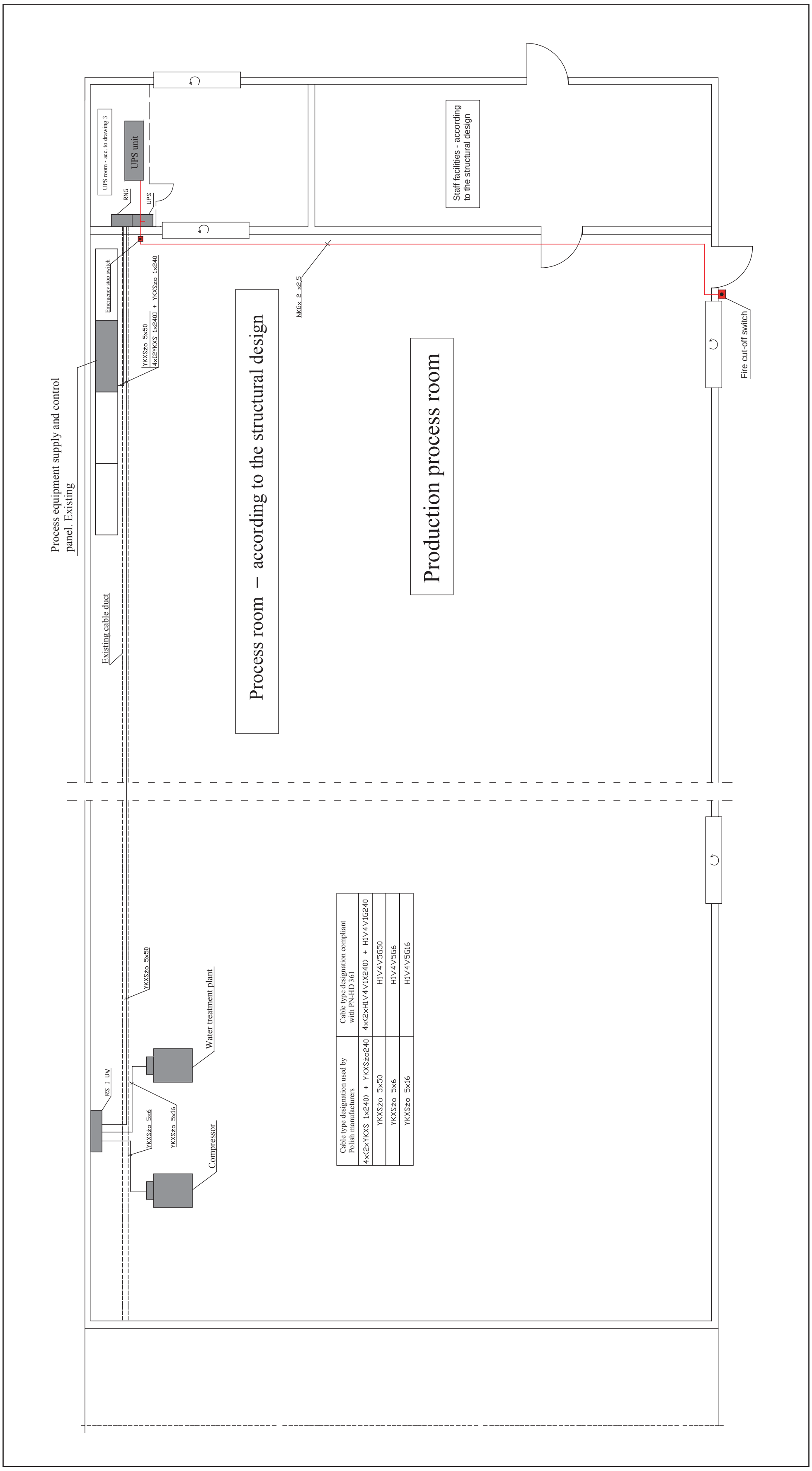
Cable type designation used by Polish manufacturers	Cable type designation compliant with PN-HD 361
YDYżo 3x2,5	H1VV3G2,5
YDY 2x1,5	H1VV2X1,5

Dwg. 3A. Schematic diagram of the ventilation system control

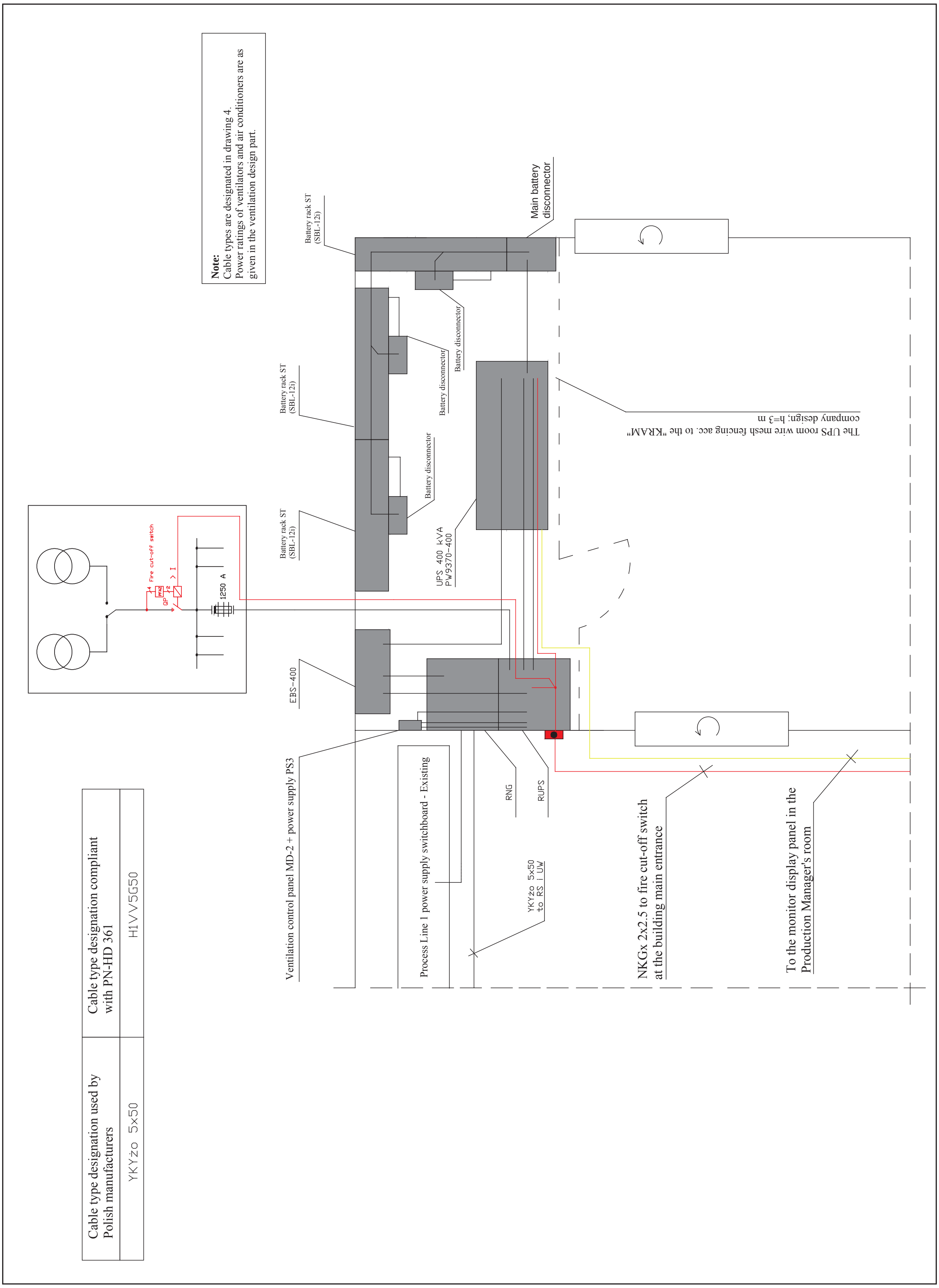


Cable type designation used by Polish manufacturers	Cable type designation compliant with PN-HD 361
YDYżo 3x2,5	H1VV3G2,5
YDYżo 2x1,5	H1VV2G1,5
YDY 3x1,5	H1VV3X1,5
YDY 4x1,0	H1VV4X1,0
YDY 2x1,5	H1VV2X1,5

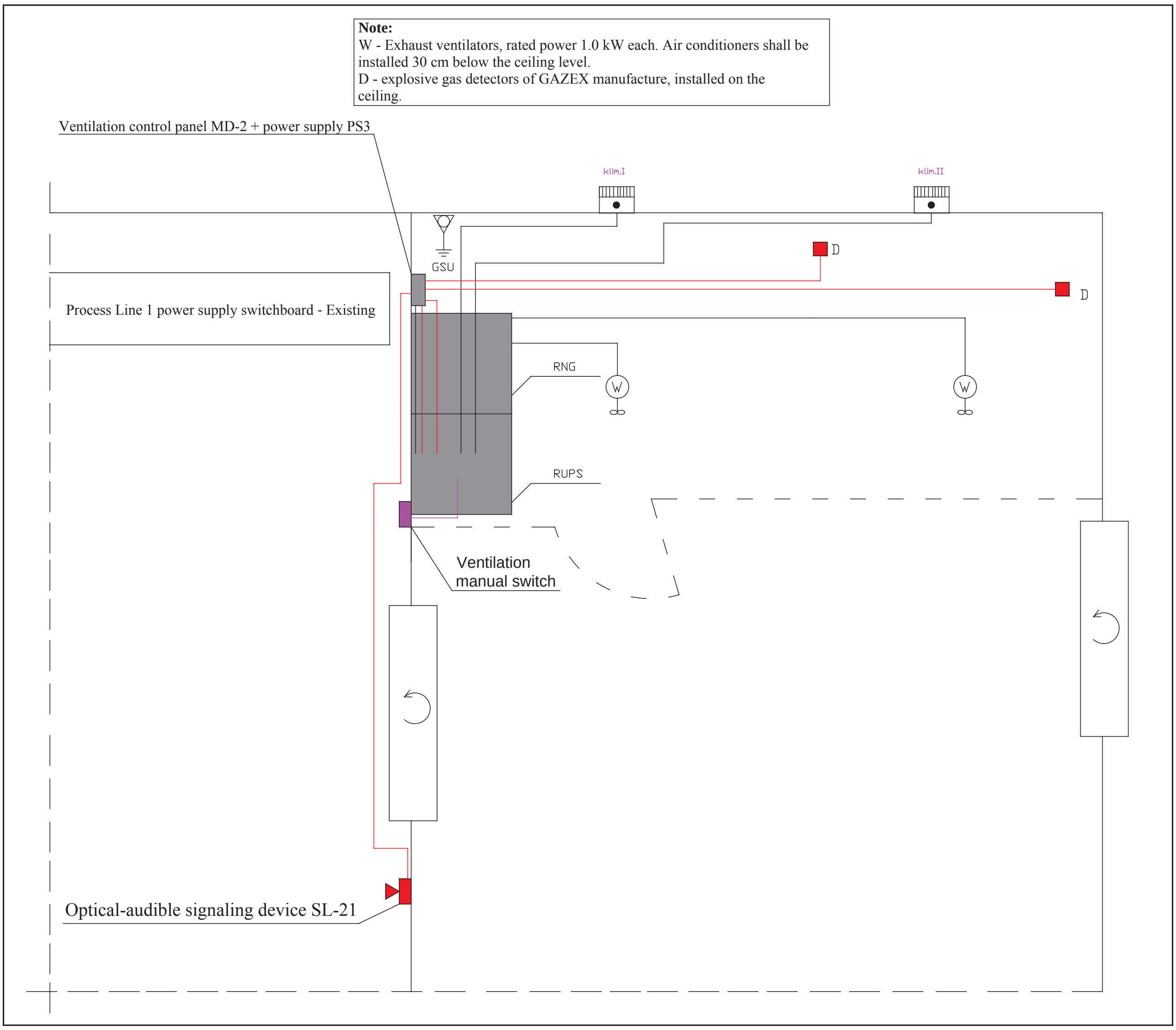
Dwg. 3B. Connection diagram of the hydrogen detection panel



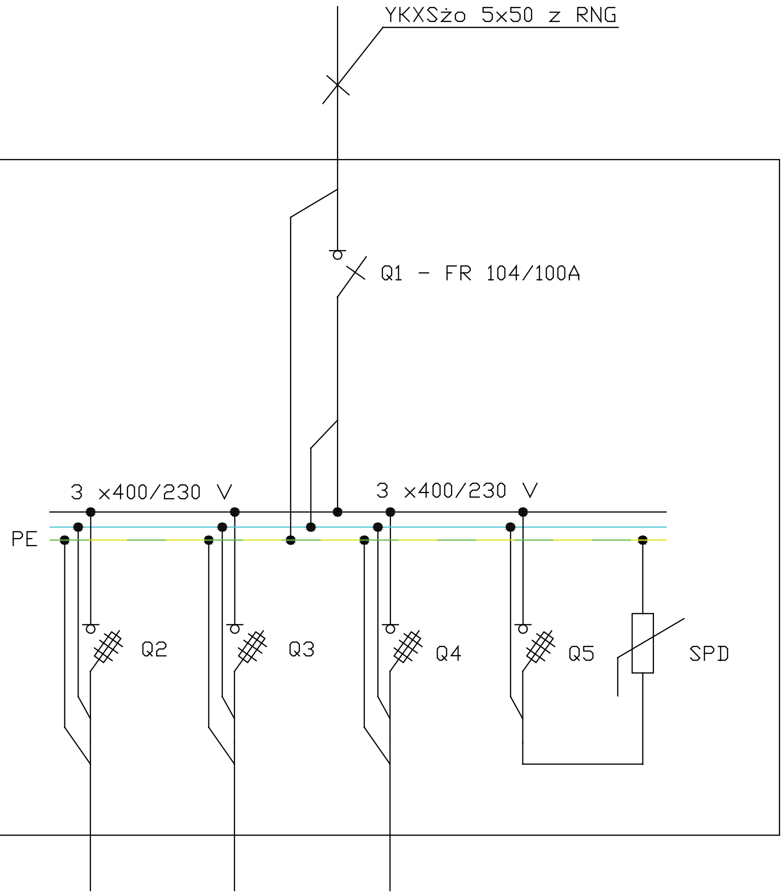
Dwg. 4: Layout of uninterruptible power supply cable lines



Dwg. 5: UPS installation layout



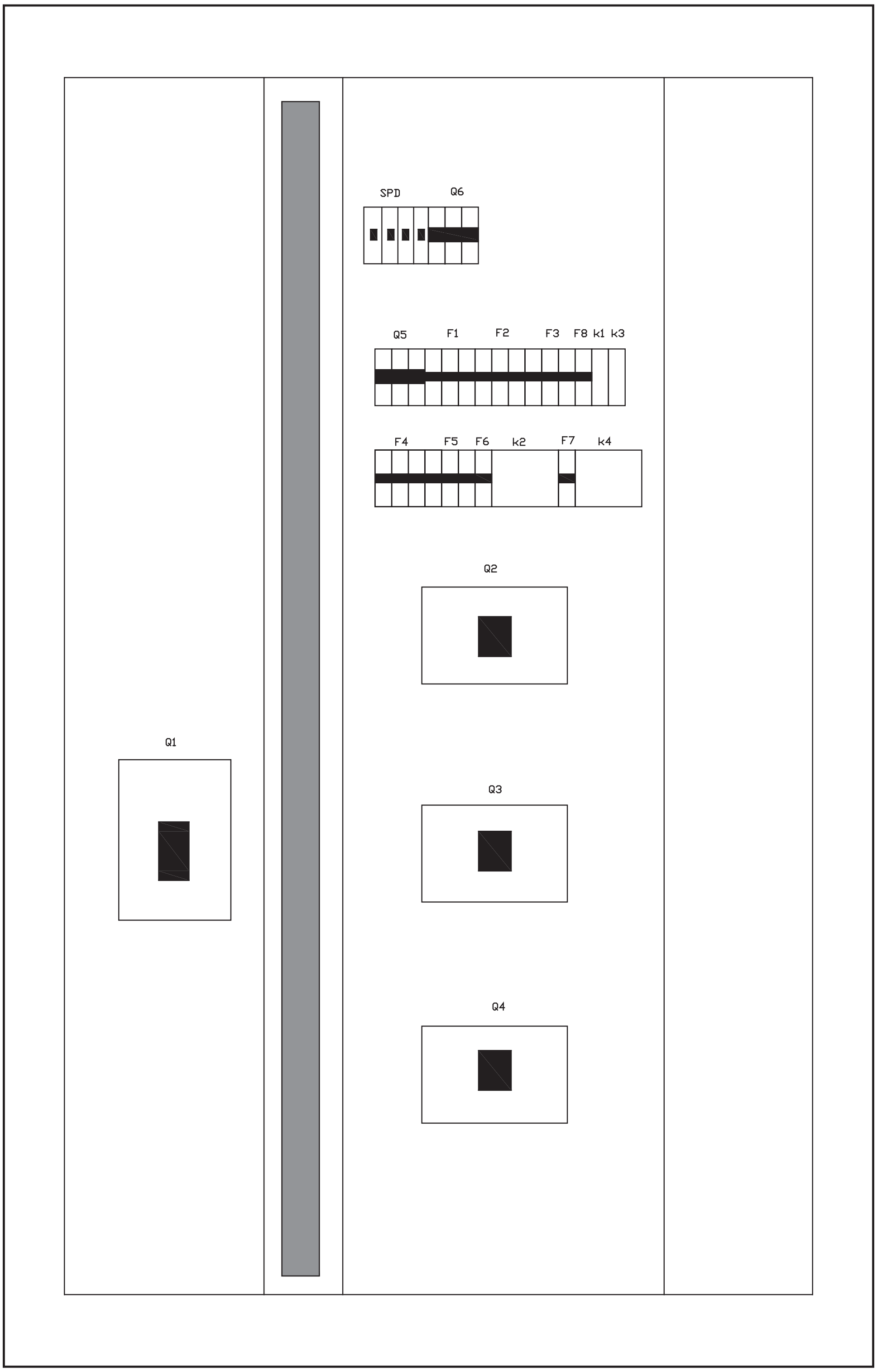
Dwg. 6: Layout of ventilation and air conditioning installation



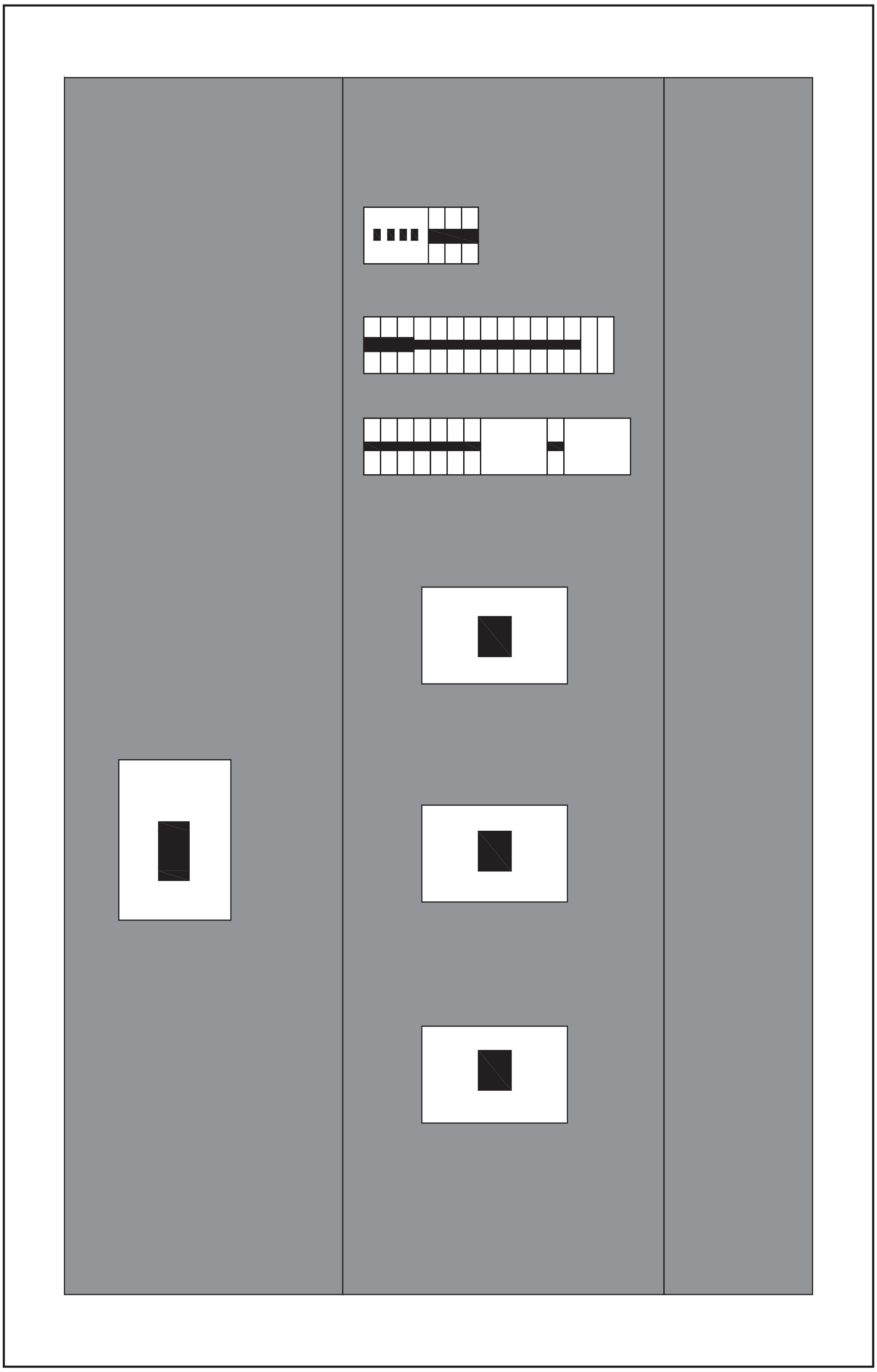
Circuit	Compressor	S U W	reserve panel	SPD TYP II
Power [kW]	11	41		————
Cable	YKYżo 5 x 6	YKYżo 5 x 16		LgY 10
Length [m]	10	10		
Protective device	NH0WTN00gG40	NH0WTN00gG80	NH00	R303.63

Cable type designation used by Polish manufacturers	Cable type designation compliant with PN-HD 361
YKXSżo 5x50	H1V4V5G50
YDYżo 5x6	H1VV5G6
YDYżo 5x16	H1VV5G16
LgY 10	H1V-K1X10

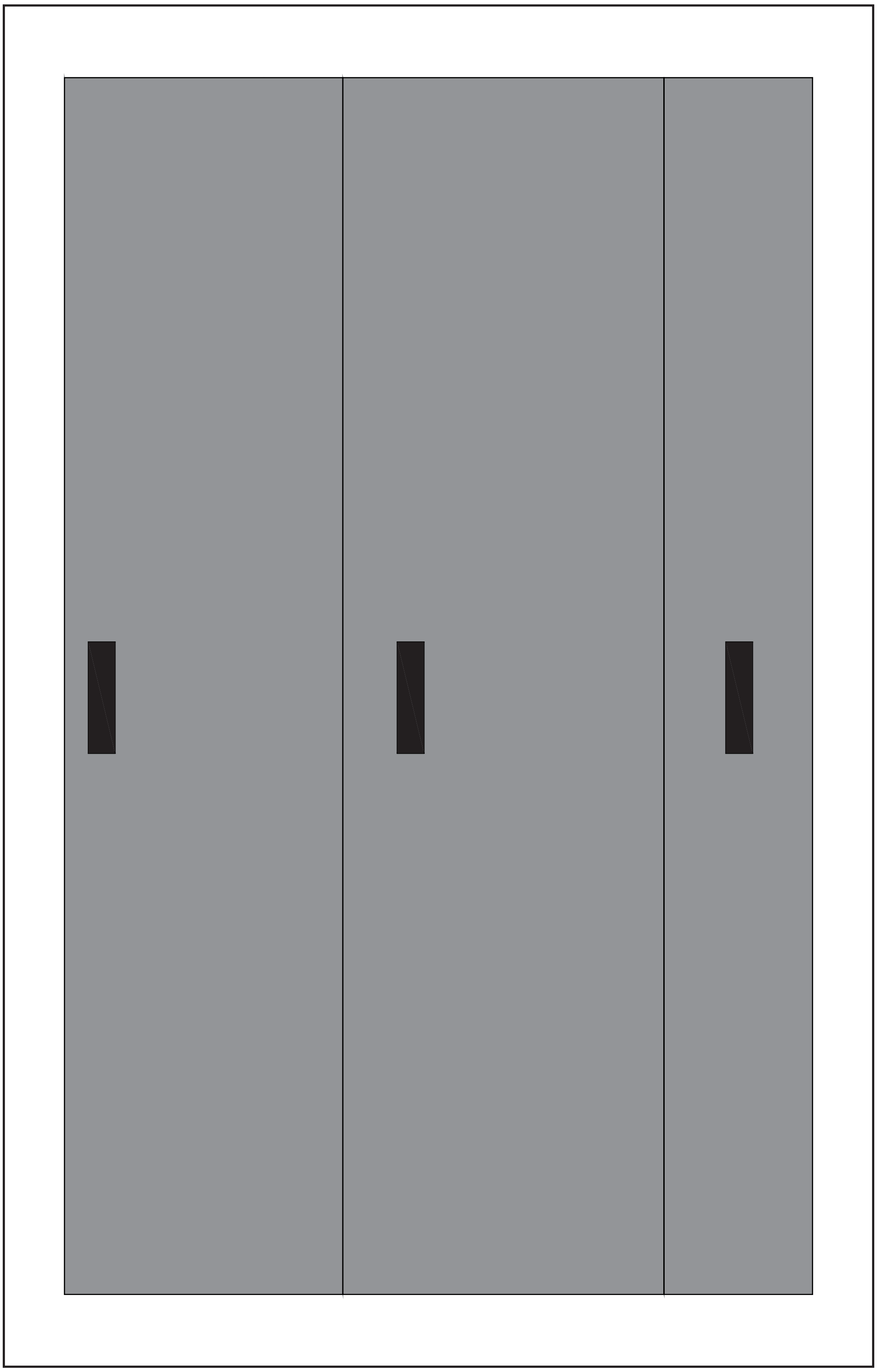
Dwg. 9. Schematic diagram of RS and UW



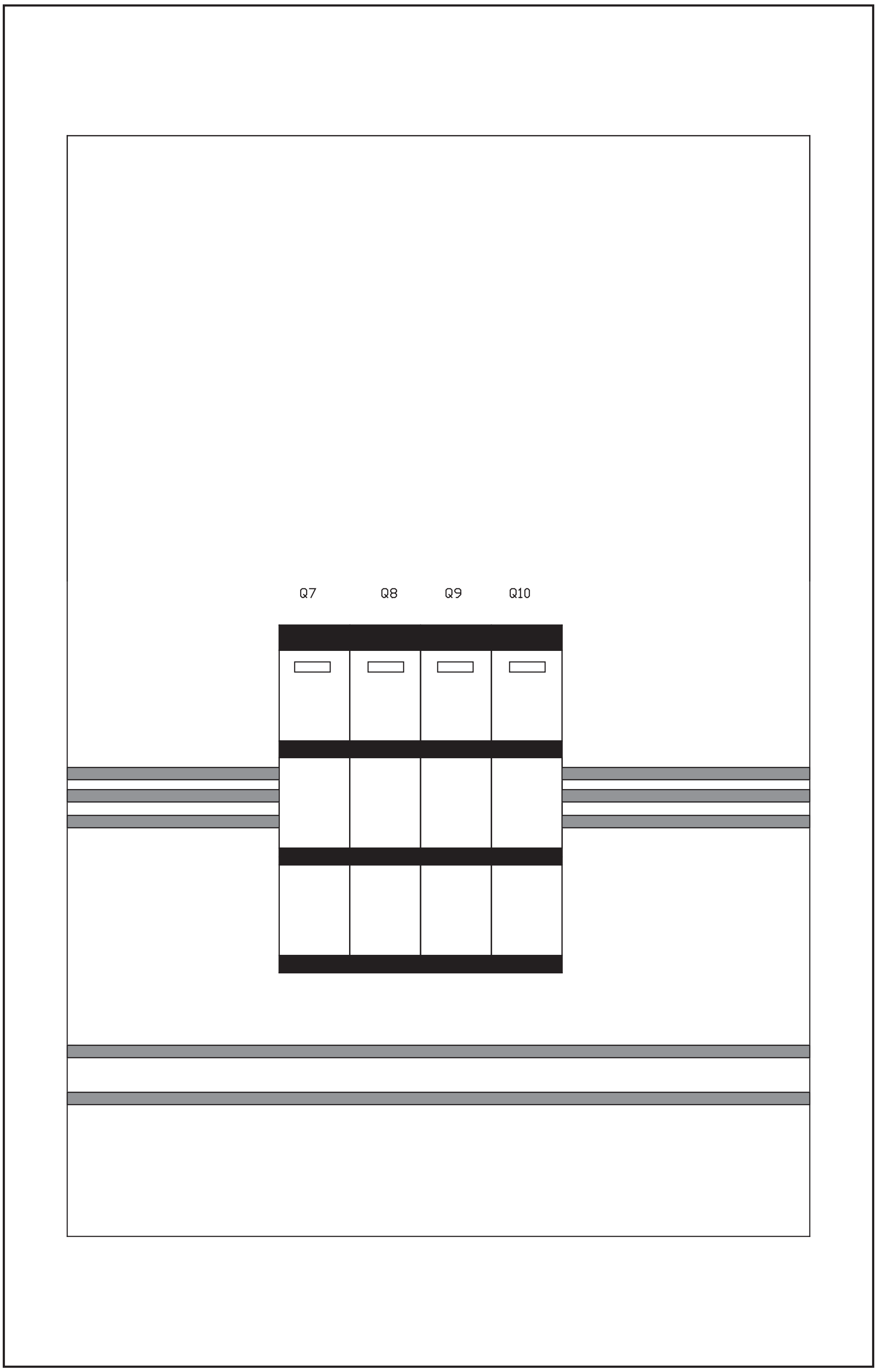
Dwg. 7: View of RUPS cabinet without covers



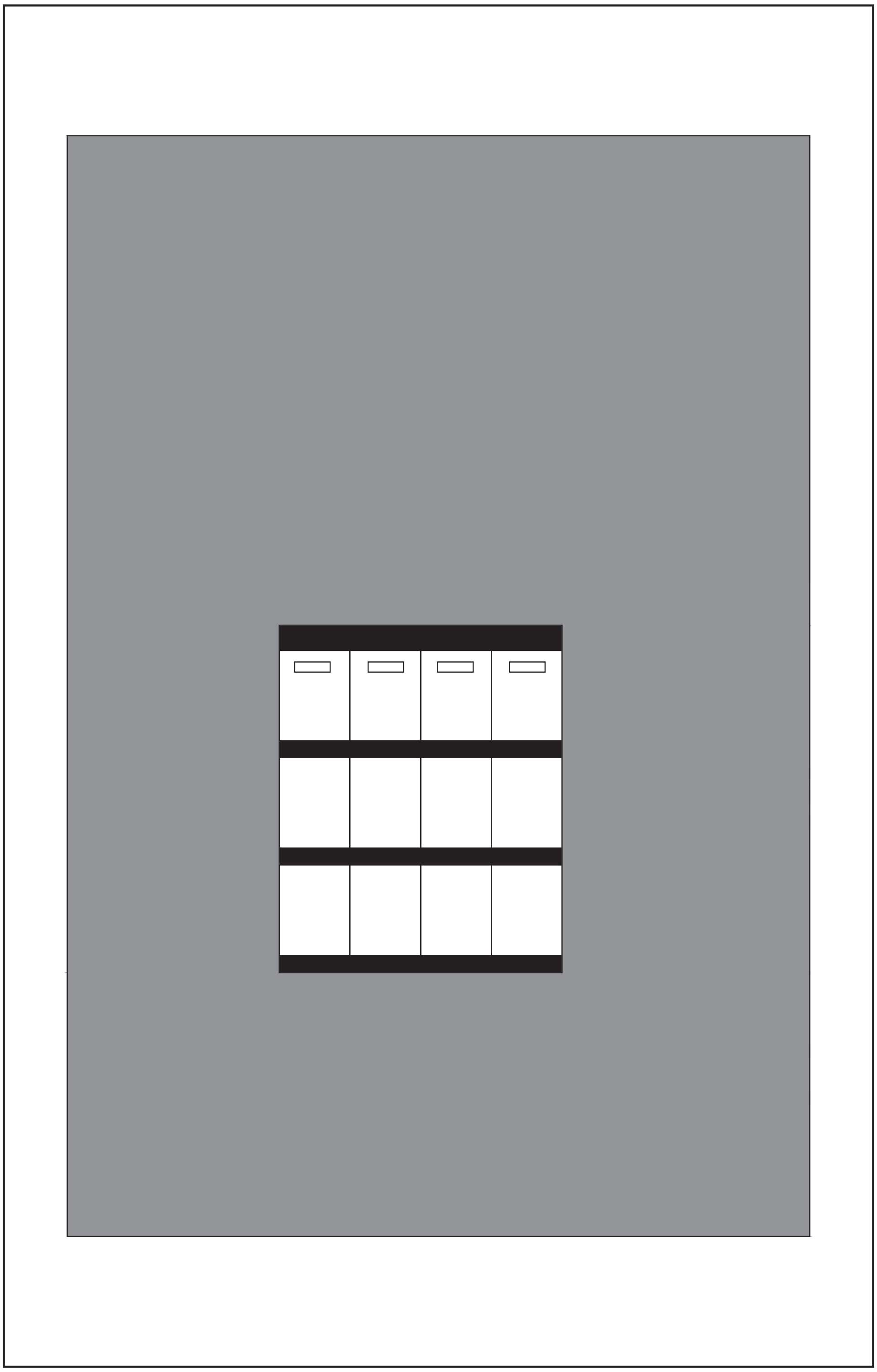
Dwg. 7A: View of RUPS cabinet with covers



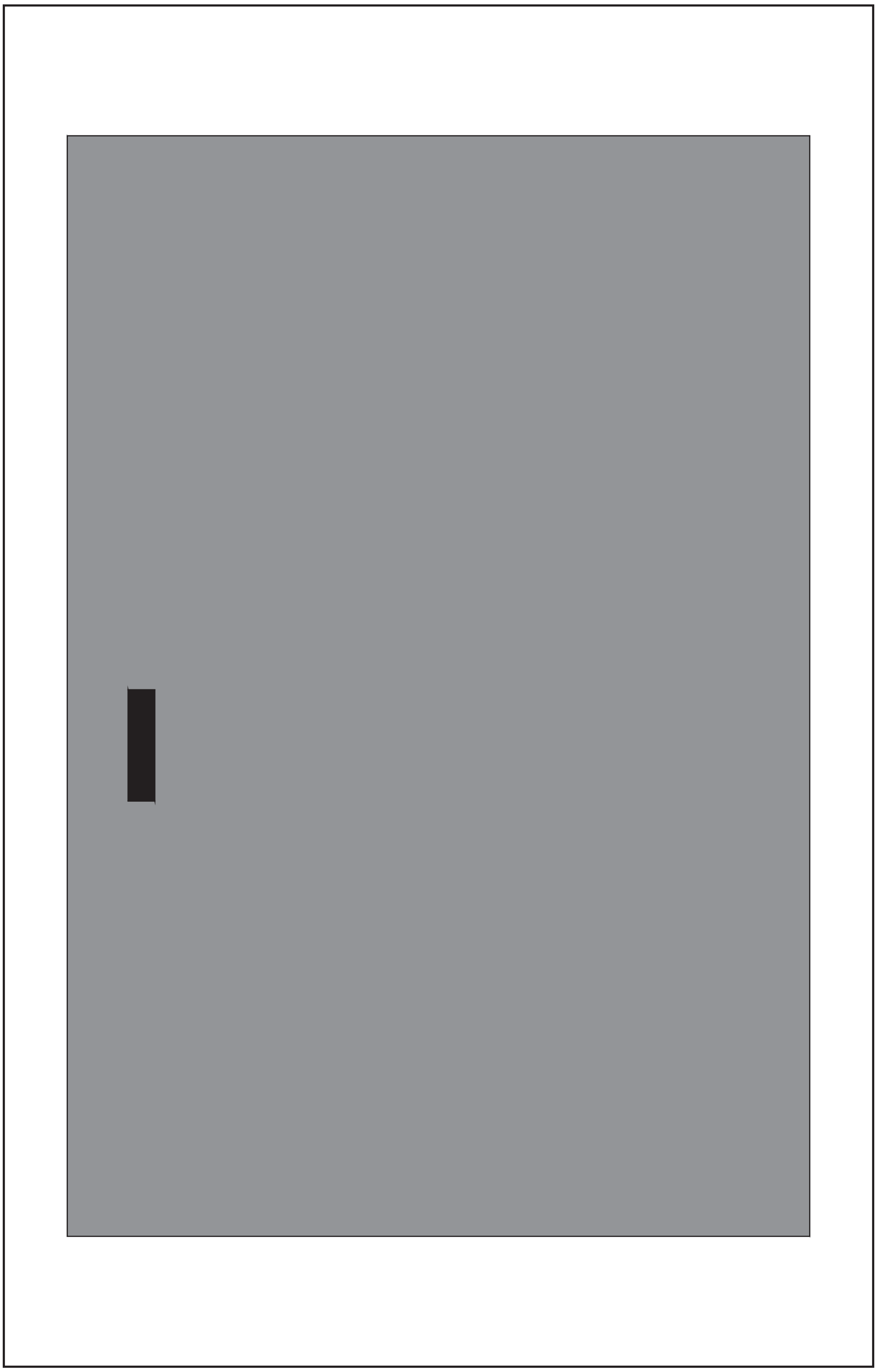
Dwg. 7B: View of RUPS cabinet with doors



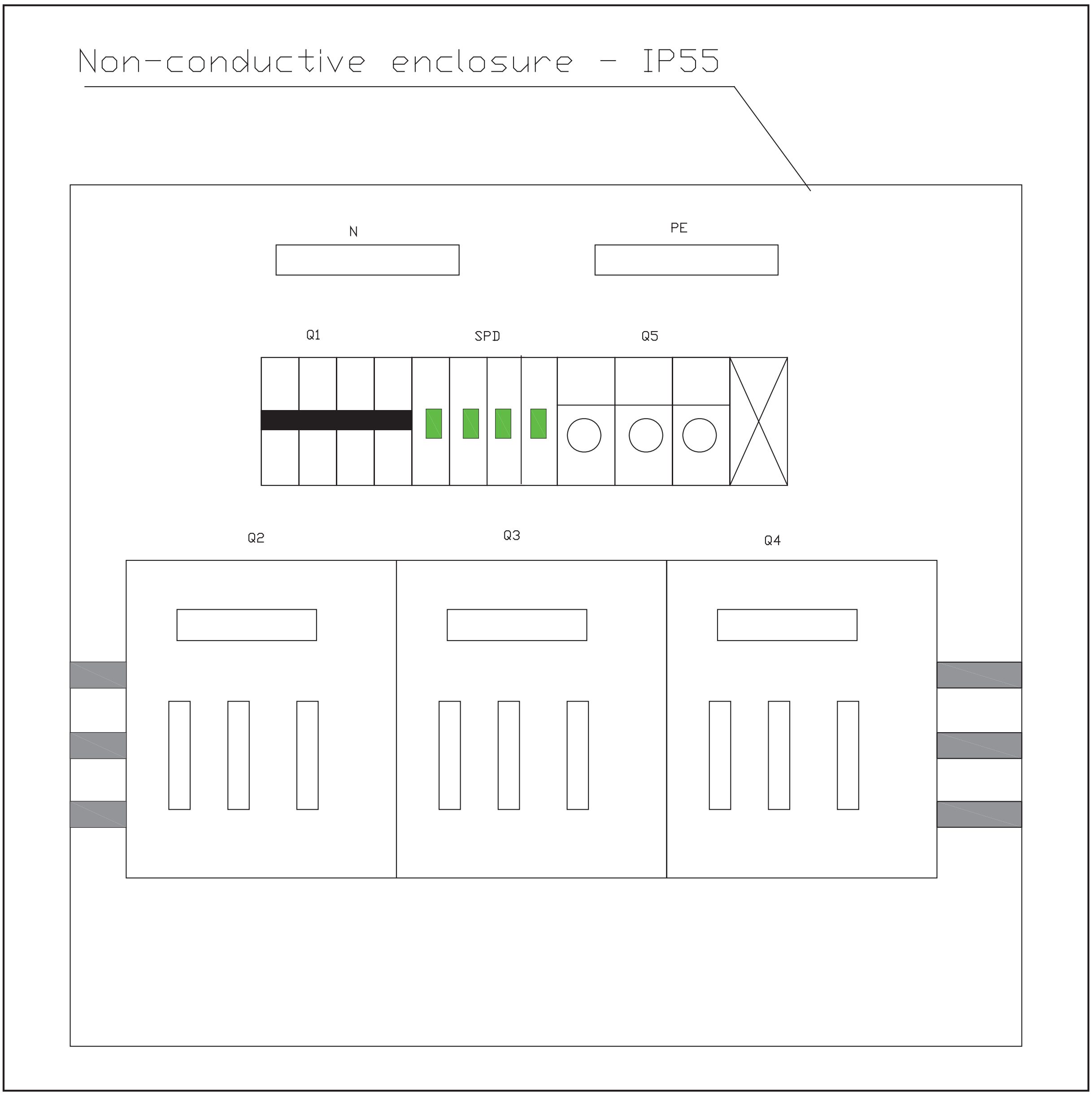
Dwg. 8: View of RNG cabinet without covers



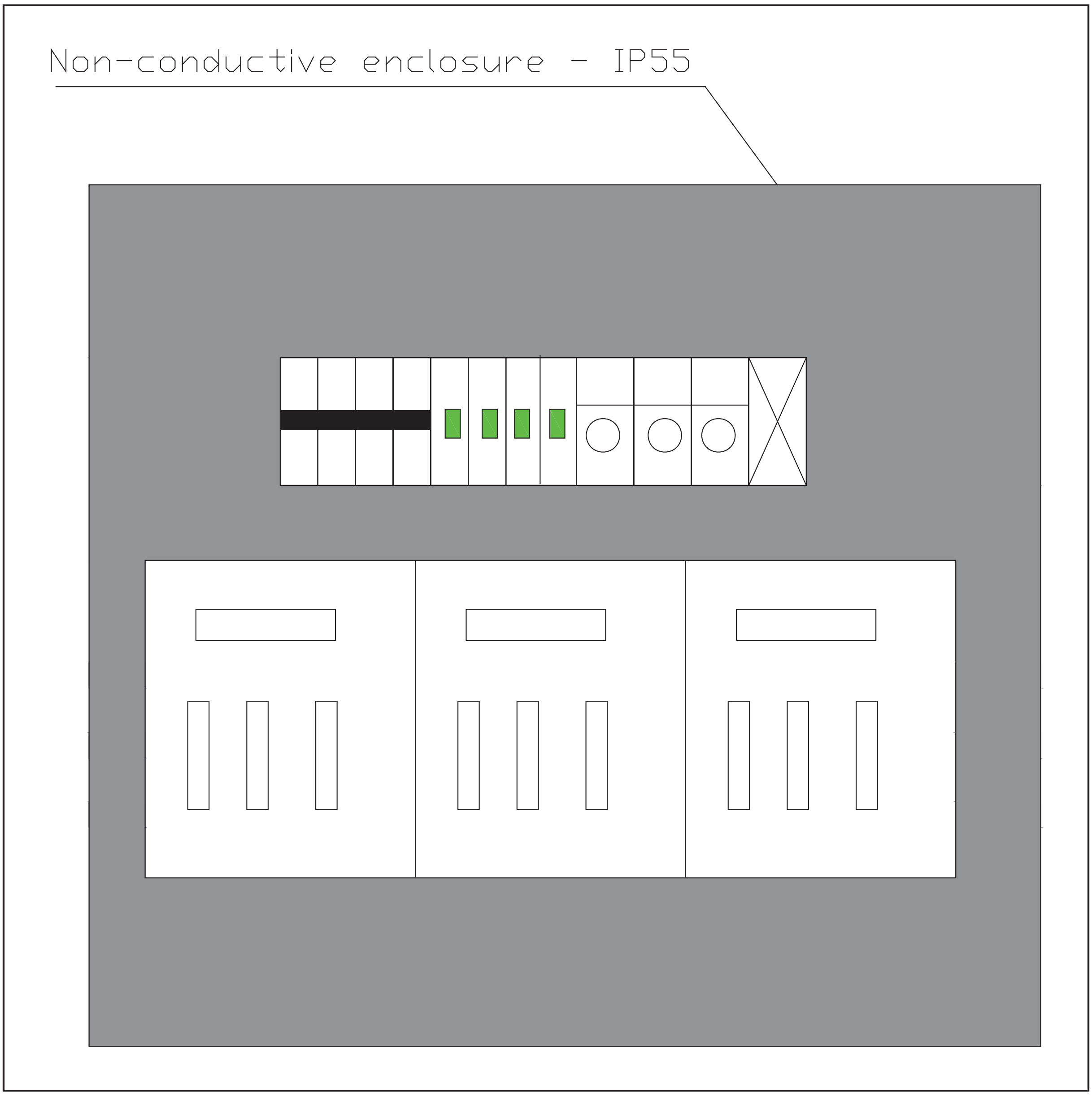
Dwg. 8A: View of RNG cabinet with covers



Dwg. 8B: View of RNG cabinet with doors



Dwg. 10: Assembly diagram of RS and UW



Dwg. 10A: View of RS and UW with covers