Risks assessment in terms of OHS for critical power infrastructures in context of industrial safety

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Abstract. The aim of occupational health and safety in the context of industrial safety is to provide the national industry with a proper operation state, an ergonomic, optimal and healthy work environment, safe workers and workplaces, safety of industrial processes, to limit and mitigate any unforeseen situation generated by events which might negatively affect the occupational health and safety level. The current paper approaches the risk assessment in terms of occupational health and safety within a cross-border 400/220 kV power substation interconnected to the European power grid, identified and assigned as European critical infrastructure. The assessment is carried out using the INCDPM Bucharest method, in order to establish the risk/safety levels in a quantitative manner, based on a systemic analysis and on the assessment of risks of accidents and professional diseases. The application of the method ends in a workplace assessment sheet which comprises the global risk level of the power substation and which sets the grounds for the plan for preventing accidents and professional diseases within the analysed power substation.

1 Description of the INCDPM Bucharest method for risk assessment in terms of OHS

The method developed by National Research and Development Institute of Occupational Safety "Alexandru Darabont" – INCDPM Bucharest, aims to determine the quantitative level of risk/safety for a workplace, sector, section or company, based on a systemic analysis and assessment of risks of injury and occupational disease, in terms of Occupational Health and Safety – OHS. The application of the method is finalised with a summary document – Assessment Sheet of Workplace, which includes the global risk level of the workplace. The developed assessment sheet of the workplace is the basis of the program for the prevention of accidents and occupational diseases for the workplace, sector, section or company analysis. The essence of the method is to identify all risk factors in the system analysis (workplace) on the basis of pre-established control lists and to quantify the risk dimension on the basis of the combination of the severity and frequency of the maximum foreseeable consequence. The level of security for a workplace shall be inversely

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proportional to the level of risk. The method comprises the following mandatory steps [1, 2, 8, 9]:

1) **The definition of the system to be analysis** (workplace);
2) **The identification of risk factors from the system**;
3) **Assessment of risks of injury and occupational disease**;
4) **Risk prioritization and prevention priorities**;
5) **Proposal for prevention measures**.

**Working tools:**

1) **List for identifying risk factors** (performer, work environment, work load, means of production);
2) **List of possible consequences of the action of risk factors on the human body** (possible consequences, location of consequences);
3) **Quotation scale of severity and probability of consequences** (severity class/consequences - severity of consequences, classes of probability/events - probability of consequences);
4) **Risk assessment scale** (severity class, probability class);
5) **Scale for the assignment of risk levels, respectively safety levels** (levels of risk - safety levels);
6) **Workplace assessment sheet – summary document** (general information, actual assessment);
7) **Proposed measures sheet** (record-keeping and follow-up of proposed measures).

The **global risk level** (Nr) per workplace shall be calculated as a weighted average of the risk levels established for the identified risk factors. In order for the result obtained to reflect as accurately as possible the reality, the risk factor ranking, which is equal to the level of risk, shall be used as a weighting element. In this way, the highest risk factor will also be the highest ranking. Thus, it is eliminated the possibility for the cross-compensation effect, involved by any statistical average, to mask the presence of the highest-risk factor.

The formula for calculating the **global risk level** is the following:

$$N_r = \frac{\sum_{i=1}^{n} r_i \cdot R_i}{\sum_{i=1}^{n} r_i}$$  \hspace{1cm} (1)

where:

- $N_r$ - the level of global risk in the workplace;
- $r_i$ - risk factor ranking „i‟;
- $R_i$ - level of risk for the risk factor „i‟;
- $n$ - number of risk factors identified at the workplace.

The **level of security** (Ns) at workplace is identified on the risk/security level mapping scale, built on the opposite proportionality of risk and security levels. Both the global risk level and the safety level are recorded in the workplace sheet. In the case of macro-systems assessment (sector, section, company), the weighted mean of the average safety levels determined for each workplace analysed in the macro-system component (similar workplace are considered as a single workplace) has to be calculated so that to obtain the **global level of safety at work** for the workshop/section/sector or enterprise under investigation – Ns:
where:
\[ r_p \text{ - the workplace ranking } "p" \text{ (equal to the risk level of the workplace);} \]
\[ n \text{ - number of workplaces analysed;} \]
\[ N_{sp} \text{ - average workplace safety level } "p". \]

\section*{2 The aim of critical power infrastructures in context of industrial safety}

For the purpose of industrial safety and societal security, the state must provide a series of facilities for people and companies, such as: access to drinking water and sewage, various fuels, natural gas, electricity, heat, resources, raw materials, etc., so that the economic development to be in continuous progress and in a secure environment. These very important facilities are provided by certain infrastructures, which fall into three main categories \[3, 10\]:

- **normal infrastructures** - a framework structure that ensures the construction and operation of a system;
- **special infrastructures** - with a consistent role in the operation of systems and processes and a high degree of stability and security in all the mechanisms of economic and social life of regional interest;
- **critical infrastructures** – are usually determinants of the instability, security and safety of systems and processes, with an important role in the development of economic-social, political and military processes.

The vulnerability of these infrastructures generates a number of risks and threats to them, thereby endangering industry and societal life, creating dysfunctionalities and causing extreme damage to the economy and society. Critical infrastructure is thus becoming indispensable for industry and society, without which the state and its mechanisms cannot operate and ensure industrial safety and societal well-being, and their protection and/or security becomes a major national and European objective, prompting the representatives of the member states of the EU to take action towards the identification, management and assessment of any risk or threat that could jeopardize the well-being of European citizens. Disruption or destruction of a critical infrastructure may have the following consequences on national and European security:

- **societal insecurity** – population affected by lack of facilities;
- **industrial insecurity** - industrial entities affected by the lack of facilities and stagnation of production;
- **economic insecurity** – economic loss;
- **medical insecurity** – population affected by a lack of public health care system;
- **ecological insecurity** – loss or destruction of the environment, etc.

As the whole industry-economic environment depends on the facilities of the critical energy infrastructures (ultra-high-voltage and very high-voltage power substations and overhead lines - OHL), it makes the issue of which it is highly relevant and topical because the non-supply of electricity to industrial and domestic consumers generates national crises and societal imbalances with extreme effects on national security, the vulnerability of the final consumer and the safety of the citizen. In this context, the National Power Grid becomes a strategic objective of national and European importance, by being a generator of critical infrastructure and ensuring the health and safety at work for power substations staff.
(operation, maintenance or dispatching personnel), it is becoming an objective to ensure continuity of electricity processes and energy security. Each power substation listed as a national or European critical infrastructure (cross-border power substation) can generate risks which can jeopardize the safety of the workers through accidents or occupational diseases, therefore, the assessment of occupational health and safety risks has to become a major objective of every power critical infrastructure and must be carried out by highly skilled energy process specialists and specialists or experts in assessing occupational health and safety risks, in the context of securing the workplace and personnel [4, 13, 18].

3 The novelty of the study

OHS Management in terms of very high voltage installations (400 kV) for every power substation listed as critical infrastructure, is a very large area of inter-disciplinarity and multi-disciplinarity in the fields of electrical, medical, intelligence and safety, due to the multitude of sources of risks and threats to personnel, with the purpose of finding the most appropriate methods and means of preventing and protecting and ensuring the functionality of workplaces in complete safety, without disrupting the good functioning of national industry and economy.

The most effective way of protecting OHS for personnel from power substation is to eliminate electrical sources of danger, which is an action whose effects are maximum if it is carried out during the design and construction phase of work systems, but which is also beneficial thereafter, provided that a methodology is in place to analyze, identify and determine how to deal with these sources of danger and risk-related personnel.

Since OHS is a major problem for society with regard to national security and the well-being of the population, the authors come up with a proposal (novelty): every power substation listed as national or European critical infrastructure, built as a new objective, new or non-refurbished, must be assessed in terms of OHS at least twice a year or whenever the situation requires it (changes in operating systems and schemes or working conditions), with the active and pragmatic involvement of the Romanian state, in order to avoid, prevent and combat possible risks and threats to personnel and work places.

Finally, the role of OHS is to ensure that national industry is in a good working condition, an ergonomic, optimal and healthy working environment, secure personnel and work places, the safety and security of industrial processes, for the purpose of a smooth functioning of the national economy [5, 11, 17].

4 Risks assessment in terms of OHS at a cross-border 400/220 kV power substation within National Power Sector – European critical infrastructure

4.1 Program for assessing conformity with legal and other provisions in force

Within the 400/220 kV power substation exist the followings workplaces [6, 7, 12, 14]:

1) 400 kV and 220 kV Operational Service;
2) 20 kV Operational Service;
3) 400 kV and 220 kV Primary Circuit Maintenance;
4) 20 kV Primary Circuit Maintenance;
5) 20 kV Secondary Circuit Maintenance.
4.1.1 Risk level assessment for the activity: 400 kV and 220 kV Operational Service

The object of the activity is the operational service of the power installations:
- supervision;
- control;
- maneuver.

1. Means of production:

| 400 kV Power Substation | 220 kV Power Substation |
|-------------------------|-------------------------|
| busbars;                | busbars;                |
| OHL switchgears;        | OHL switchgears;        |
| 400/220 kV AT switchgears; | 220/110 kV AT switchgears; |
| coupling switchgears (transversal / longitudinal / longo-transversal); | coupling switchgears (transversal / longitudinal / longo-transversal); |
| compensating coil switchgears; | compensating coil switchgears; |
| busbar measuring switchgears; | busbar measuring switchgears; |
| discharge switchgears, etc. | discharge switchgears, etc. |

Risk factors specific to the means of production:
- mechanical risk (falling from the same level, slipping or tripping, explosions of equipment with a lifetime exceeded, falling from a height);
- electrical risk (direct contact with electrical installations);
- thermal risk (burns due to electric arc).

2. Work load:
According to the operating regulations, the duties of the operational staff are as follows:
- performing the handover-receiving operations of the work team;
- supervision activity;
- control activity;
- the activity of executing the electric maneuvers.

Risk factors specific to the work load:
- psychic stress in the 400 kV and 220 kV power substations, when installing short circuits by hand.

3. Performer:
The following staff works in the power substation:
- manager (s) of the power substations (electrical engineer);
- shift leaders;
- shift leaders aides.

Risk factors specific to the performer:
- wrong action:
  - incorrect identification of the installation and non-verification of the lack of voltage, when mounting the short circuits;
  - failure to respect the neighbouring distances with risk of electric shock by direct contact;
  - not checking the lack of voltage before mounting the mobile short circuits.
- omissions:
  - omissions of operations during manoeuvres, with risk of burns caused by electric arc, when closing grounding knives or mounting the mobile short circuits without checking the lack of voltage;
• non-use and/or non-verification of the personal protective equipment provided and/or of the electrical insulating means and devices.

4. Work environment:
The operating staff carries out the activity in the control room at the external power substations of 400 kV and 220 kV, where the specific nature of the work assignment requires operation and control activities regardless of climatic conditions and as a result the main risk factor specific to the working environment is the air temperature by exposure to high or low temperatures during the performances of the work assignment [15].

Risk factors specific to the work environment:
- physical risk factors:
  • exposure to adverse weather conditions (low/high temperatures, rain, snow, air currents) during installations’ control.

Table 1. Workplace assessment sheet 400 kV and 220 kV Operational Service

| NATIONAL POWER SECTOR | RESPONSIBLE NATIONAL COMPANY | ASSESSMENT SHEET OF WORKPLACE | NUMBER OF EXPOSED PERSONS |
|-----------------------|-----------------------------|--------------------------------|---------------------------|
| 400 kV and 220 kV OPERATIONAL SERVICE | The composition of the work system | Identified risk factors | CONCRETE FORM OF MANIFESTATION OF RISK FACTORS |
| | | | Maximum foreseeable consequence | Class of severity | Class of probability | Risk level |
| MEANS OF PRODUCTION | Mechanical risk factors: - falling from the same level | 1. Falling due to distraction when moving through outside power substations | Temporary Work Incapacity 3-45 days | 2 | 1 | 1 |
| | Electrical risk factors: - electrical shock hazard | 2. Not using two mobile short circuits in the working area | DEATH | 7 | 2 | 4 |
| | | 3. Not using in working area of capacitive load damper (in case of capacitive currents) | DEATH | 7 | 2 | 4 |
| | Thermal risk factors: - explosion hazard | 4. Explosion of power, voltage, and current transformers, discharge | DEATH | 7 | 1 | 3 |
| PERFORMER | Wrong actions: - omission of present operations; - not using means of protections | 5. Not checking the lack of voltage before mounting the mobile short circuits | DEATH | 7 | 2 | 4 |
| | | 6. Failure to use or verify personal protective equipment, tools and electro-insulating devices provided | DEATH | 7 | 1 | 3 |
7. Exposure to adverse weather conditions (high, low temperatures), when operating in outdoor power substations

The global risk level at workplace: 400 kV and 220 kV Operational Service

\[
N_{400kV-220kV} = \frac{\sum_{i=1}^{7} R_i \cdot r_i}{\sum_{i=1}^{7} r_i} = \frac{2 \cdot (1 \cdot 1) + 2 \cdot (3 \cdot 3) + 3 \cdot (4 \cdot 4)}{2 \cdot 1 + 2 \cdot 3 + 3 \cdot 4} = \frac{68}{20} = 3.4
\]  

Table 2. Proposed measures sheet – 400 kV and 220 kV Operational Service

| No. | RISK FACTOR                                      | RISK LEVEL | PROPOSED PREVENTION MEASURES                                      |
|-----|--------------------------------------------------|------------|-------------------------------------------------------------------|
| 1.  | Not using two mobile short circuits in the working area | 4          | Training and unannounced and regular control by the management    |
| 2.  | Not using in working area of capacitive load damper (in case of capacitive currents) | 4          |                                                                   |
| 3.  | Not checking the lack of voltage before mounting the mobile short circuits | 4          |                                                                   |

4.1.2 Risk level assessment for activity: 20 kV Operational Service

The object of the activity is the operational service of the power installations:
- supervision;
- control;
- maneuver.

1. Means of production:
20 kV Power Substation:
- busbars;
- OHL switchgears;
- 110/20 kV AT switchgears;
- coupling switchgears (transversal / longitudinal / longo-transversal);
- compensating coil switchgears;
- busbar measuring switchgears;
- discharge switchgears, etc.

Risk factors specific to the means of production:
- mechanical risk (falling from the same level, slipping or tripping, explosions of equipment with exceeded lifetime, falling from a height);
- electrical risk (direct contact with electrical installations);
- thermal risk (burns due to electric arc).

2. Work load:
According to the operating regulations, the duties of the operational staff are as follows:
- performing the handover-receiving operations of the work team;
- supervision activity;
- control activity;
- the activity of executing the electric maneuvers.
Risk factors specific to the work load:
- psychic stress in the 20 kV power substations, when installing short circuits by hand.

3. Performer:
The following staff works in the power substation:
- manager(s) power substations (electrical engineer)
- shift leaders;
- shift leaders aides.

Risk factors specific to the performer:
- wrong action:
  - incorrect identification of the installation and non-verification of the lack of voltage, when mounting the short circuits;
  - failure to respect the neighbouring distances with risk of electric shock by direct contact;
  - not checking the lack of voltage before mounting the mobile short circuits.
- omissions:
  - omissions of operations during maneuvers, with risk of burns caused by electric arc, when closing grounding knives or mounting the mobile short circuits without checking the lack of voltage;
  - non-use and/or non-verification of the personal protective equipment provided and/or of the electrical insulating means and devices.

4. Work environment:
The operating staff carries out the activity in the control room at the external power substations of 20 kV, where the specific nature of the work assignment requires operation and control activities regardless of climatic conditions and as a result the main risk factor specific to the working environment is the air temperature by exposure to high or low temperatures during the performances of the work assignment [16].

Risk factors specific to the work environment:
- physical risk factors:
  - exposure to adverse weather conditions (low/high temperatures, rain, snow, air currents) during installations’ control.

Table 3. Workplace assessment sheet 20 kV Operational Service

| NATIONAL POWER SECTOR | RESPONSIBLE NATIONAL COMPANY | 20 kV OPERATIONAL SERVICE | ASSESSMENT SHEET OF WORKPLACE | NUMBER OF EXPOSED PERSONS |
|------------------------|-------------------------------|-----------------------------|-------------------------------|---------------------------|
|                        |                               |                             | CONCRETE FORM OF MANIFESTATION OF RISK FACTORS | EXPOSURE TIME: hours/shift |
| The composition of the work system | Identified risk factors | Maximum foreseeable consequence | Class of severity | Class of probability | Risk level |
| Mechanical risk factors: | 1. Short circuit breaker explosions | DEATH | 7 | 1 | 3 |
### MEANS OF PRODUCTION

| Hazard movements: - movement under propulsion | 2. Discharging explosions during operation | DEATH | 7 | 1 | 3 |
| --- | --- | --- | --- | --- | --- |
| Electrical risk factors: - electric current | 3. Touching of unmarked terminals and installations | DEATH | 7 | 1 | 3 |
| | 4. Touching live installations when connecting short circuits | DEATH | 7 | 1 | 3 |
| | 5. Touching the 20 kV busbars during maneuvers | DEATH | 7 | 1 | 3 |
| Thermal risk factors: - flames, flame | 6. Burns due to short circuits caused by insulation breaks and explosions | DEATH | 7 | 1 | 3 |

### WORK LOAD

| Inadequate work load content relative to requirement s security | 7. Mounting short circuits by hand | DEATH | 7 | 1 | 3 |

### Wrong actions

| 8. Failure to respect the neighbouring distances with risk of electric shock by direct contact. | DEATH | 7 | 1 | 3 |
| 9. Failure to verify the position and/or condition of the components to be operated when maneuvering | DEATH | 7 | 1 | 3 |

### PERFORMER

| - omission of operations present in the Maneuver Sheet | 10. Not checking the lack of voltage before installing mobile short circuiting or closing the grounding knives | DEATH | 7 | 1 | 3 |
| - not using of means of protection | 11. Failure to use or check personal protective equipment, tools and electro-insulating devices | DEATH | 7 | 1 | 3 |

The global risk level at workplace: 20 kV Operational Service

\[
N_{20kV} = \frac{\sum R_i \cdot r_i}{\sum r_i} = \frac{11 \cdot (3 \cdot 3)}{11 \cdot 3} = \frac{99}{33} = 3.00
\]  \hspace{1cm} (4)
Table 4. Proposed measures sheet – 20 kV Operational Service

| No. | RISK FACTOR | RISK LEVEL | PROPOSED PREVENTION MEASURES |
|-----|-------------|------------|------------------------------|
| -   | -           | -          | -                            |

4.1.3 Risk level assessment for activity: 400 kV and 220 kV Primary Circuit Maintenance

The purpose of maintenance and repair of primary equipment is the following types of work:
- servicing primary equipment;
- mechanical activities;
- welding and painting activity;
- masonry repair;
- dismantling of appliances.

1. Means of production:
   400 kV Power Substation:
   - busbars;
   - OHL switchgears;
   - 400/220 kV AT switchgears;
   - coupling switchgears (transversal / longitudinal / longo-transversal);
   - compensating coil switchgears;
   - busbar measuring switchgears;
   - discharge switchgears, etc.
   
   220 kV Power Substation:
   - busbars;
   - OHL switchgears;
   - 220/110 kV AT switchgears;
   - coupling switchgears (transversal / longitudinal / longo-transversal);
   - compensating coil switchgears;
   - busbar measuring switchgears;
   - discharge switchgears, etc.

Risk factors specific to the means of production:
- mechanical risk factors:
  - hazardous movements;
  - cutting edges and sharp corners when replacing broken insulators;
  - explosion of molten metal particles or electric shock to electric welding;
  - explosions at transformers.

2. Work load:
   Work load of the service and repair team is to:
   - technical revisions (TR) – annually on all equipment in the power substations;
   - current revisions (RC) – changes in sub-assemblies, replacement of power substation components;
   - accidental interventions – in the event of faults or failures in primary equipment;
   - maintenance of auxiliary installations;
   - maintenance work on the power substation;
   - changes of lighting fittings.

Risk factors specific to the work load:
- failure to properly prepare and/or failure to comply with the required steps in the performance of maintenance activities;
- failure to comply with measures to ensure the working area;
- oversized physical effort when removing the cutting-off switches from the switchgears.

3. Performer:
   The service-repair team the primary equipment is composed of electricians who are led by a master.
Risk factors specific to the performer:
- **wrong action:**
  - misidentification of the installations in which work is being carried out;
  - wrong maneuvers when performing operational tests;
  - exceeding proximity distances when transporting materials to the work area and during work;
  - displacement, stationing in hazardous areas outside the working area;
  - falling from the same level by unbalancing, during the transport of materials within the area of the power substation,
- **omissions:**
  - non-use of personal protective equipment as provided or use of non-certified personal protective equipment.

4. Work environment:
Service activity – primary equipment repair is carried out in the external power substation and very rarely in the mechanical room.

Risk factors specific to the work environment:
- **physical risk factors:**
  - inhalation of noxious in paint work;
  - bad weather conditions (high/low temperature, wind).

Table 5. Workplace assessment sheet 400 kV and 220 kV Primary Circuit Maintenance

| NATIONAL POWER SECTOR | RESPONSIBLE NATIONAL COMPANY | ASSESSMENT SHEET OF WORKPLACE | NUMBER OF EXPOSED PERSONS |
|-----------------------|-----------------------------|-------------------------------|--------------------------|
|                       |                             | CONCRETE FORM MANIFESTATION OF RISK FACTORS | EXPOSURE TIME: hours/shift | ASSESSMENT TEAM: |
|                       |                             | Maximum foreseeable consequence | Class of severity | Class of probability | Risk level |
|                       |                             |                               |                         |                         |            |
|                       | The composition of the work system | Identified risk factors | 1. Displacement by means of transport to the workplace – road accident; | DEATH | 7 | 1 | 3 |
|                       | Mechanical risk factors: - functional movements of technical machinery | | | | | |
|                       | 2. Hazardous surfaces | Temporary Work Incapacity | 2 | 2 | 2 |
|                       | Thermal risk factors | 3. Injury by the thermal effect of the electric arc for service and repair personnel when traveling on the area of power substations for fulfilling the work load | 1st degree Disability | 6 | 1 | 3 |
|                       | | | | | |

11
| Electrical risk factors | WORK LOAD | Physical risk factors | PERFORMER |
|-------------------------|-----------|-----------------------|-----------|
| - indirect touch        | Under/oversized workload in relation to the capacity of the performer | Inhalation of toxic dust and gases in the while performing painting operations | Wrong actions |
| 4. Touching of metal parts accidentally under voltage, in conditions of: | 5. Improper preparation and/or non-compliance with mandatory steps and measures to secure the work area | 6. Dynamic, static effort, forced working positions at ground and height when handling and replacing subassemblies and components of primary equipment, insulators replacement | 8. Incorrect identification of the installations in which they work, wrong maneuvers when performing functional tests |
| - damage to insulation from the metal housing; | | | 9. Entering the work area unprepared in terms of work safety |
| - failure of the protective connection | DEATH | Temporary Work Incapacity 45-180 days | DEATH |

| 7. | WORK ENVIRONMENT |
|-----------------------------------|------------------|
| 7. | Inadequate preparation and/or non-compliance with mandatory steps and measures to secure the work area |
| DEATH | 7 | 1 | 3 |

| 8. | Under/oversized workload in relation to the capacity of the performer |
| Insertion of toxic dust and gases in the while performing painting operations |
| DEATH | 7 | 2 | 2 |

| 9. | Incorrect identification of the installations in which they work, wrong maneuvers when performing functional tests |
| DEATH | 7 | 1 | 3 |

| 10. | Inadequate preparation and/or non-compliance with mandatory steps and measures to secure the work area |
| DEATH | 7 | 2 | 4 |

| 11. | Exceeding safety distances |
| DEATH | 7 | 1 | 3 |
| No. | RISK FACTOR | RISK LEVEL | PROPOSED PREVENTIVE MEASURES |
|-----|-------------|------------|-------------------------------|
| 1   | Touching of accidentally live metal parts under the conditions ok: - damage to the insulation from the metal housing; - failure of the protective connection | 4           | Making connections to the earthing of all technical equipment. Measurements of touch voltages. Compliance with the deadlines for technical revisions. |
| 2   | Incomplete work permit without specifying all working area insurance conditions | 4           | Starting of work only on the basis of a work permit specifying all the conditions for securing the work area. |

### 4.1.4 Risk level assessment for activity: 20 kV Primary Circuit Maintenance

The purpose of maintenance and repair of primary equipment is the following types of work:

- servicing primary equipment;
- mechanical activities;
- welding and painting activity;
- masonry repair;
- dismantling of appliances.
1. Means of production:
20 kV Power Substation:
- busbars;
- OHL switchgears;
- 110/20 kV AT switchgears;
- coupling switchgears (transversal / longitudinal / longo-transversal);
- compensating coil switchgears;
- busbar measuring switchgears;
- discharge switchgears, etc.

Risk factors specific to the means of production:
- mechanical risk factors:
  - hazardous movements;
  - cutting edges and sharp corners when replacing broken insulators;
  - explosion of molten metal particles or electric shock to electric welding;
  - explosions at transformers.

When assessing the severity and probability of manifestation of these risk factors, the age of 20 kV power substations is also taken into account, an age that amplifies the accidental potential of electrical equipment.

2. Work load:
Work load of the service and repair team is to:
- technical revisions (TR) – annually on all equipment in the power substations;
- current revisions (RC) – changes in sub-assemblies, replacement of power substation components;
- accidental interventions – in the event of faults or failures in primary equipment;
- maintenance of auxiliary installations;
- maintenance work on the power substation;
- changes of lighting fittings.

Risk factors specific to the work load:
- failure to properly prepare and/or fail to comply with the required steps in the performance of maintenance activities;
- failure to comply with measures to ensure the working area;
- oversized physical effort when removing the cutting-off switches from the switchgears.

3. Performer:
The primary service-repair team for equipment is composed of electricians who are led by a master.

Risk factors specific to the performer:
- wrong action:
  - misidentification of the installations in which work is being carried out;
  - wrong maneuvers when performing operational tests;
  - exceeding proximity distances when transporting materials towards the work area and during work;
  - displacements, stationing in hazardous areas outside the working area;
  - falling from the same level by unbalancing, during the transport of materials within the area of the power substation.
- omissions:
  - non-use of personal protective equipment as provided or use of non-certified personal protective equipment.
4. Work environment:
Service activity – primary equipment repair is carried out in the external power substation and very rarely in the mechanical room.

**Risk factors specific to the work environment:**
- **Physical risk factors:**
  - inhalation of noxious during in paint work;
  - bad weather conditions (high/low temperature, wind).

**Table 7. Workplace assessment sheet 20 kV Primary Circuit Maintenance**

| NATIONAL POWER SECTOR | ASSESSMENT SHEET OF WORKPLACE | NUMBER OF EXPOSED PERSONS |
|-----------------------|-------------------------------|---------------------------|
| RESPONSIBLE NATIONAL COMPANY | 20 kV PRIMARY CIRCUIT MAINTENANCE | EXPOSURE TIME: hours/shift |
| The composition of the work system | Identified risk factors | ASSESSMENT TEAM: |
| Mechanical risk factors: - functional movements of technical machinery - hazardous surfaces | CONCRETE FORM MANIFESTATION OF RISK FACTORS | |
| 1. Traveling by means of transport to the workplace – road accident | DEATH | 7 | 2 | 4 |
| 2. Accidents caused by the tension of the MR spring during the adjustment operation The MRI actuator of the IO 20 kV circuit breaker | 3st degree Disability | 4 | 2 | 3 |
| 3. Cutting edges, sting when replacing broken insulators, TT, TC and damaged discharge devices | Temporary Work Incapacity 3-45 days | 2 | 4 | 2 |
| 4. Hazard of explosion TIRBO transformers | DEATH | 7 | 2 | 4 |
| 5. Injury by the thermal effect of the electric arc of service and repair personnel when traveling on the territory power substations of the work load | 1st degree Disability | 6 | 4 | 6 |
| Electrical risk factors - indirect touch | 6. Touching of accidentally live metal parts under the conditions: | DEATH | 7 | 4 | 6 |
| WORK LOAD | Physical risk factors | Deceased cause |
|-----------|-----------------------|----------------|
| Inadequate content in relation to security requirements | 7. Adequate preparation and/or non-compliance with mandatory steps and measures to secure the work area | DEATH 7 3 5 |
| Under/oversized workload in relation to the capacity of the performer | 8. Dynamic, static effort, forced working positions at ground and height when handling and replacing subassemblies and components of primary equipments, insulating replacement | Temporary Work Incapacity 45-180 days 3 4 3 |
| WORK ENVIRONMENT | Physical risk factors | Deceased cause |
| Inadequate content in relation to security requirements | 9. Inhalation of toxic dust and gases in the execution of the operations of painting | Temporary Work Incapacity 45-180 days 3 2 2 |
| PERFORMER | Wrong actions | Deceased cause |
| Incorrect identification of the installations in which they work, wrong maneuvers when performing functional tests | 10. Incorrect identification of the installations in which they work, wrong maneuvers when performing functional tests | DEATH 7 4 6 |
| Entering the work area unprepared for work safety | 11. Entering the work area unprepared for work safety | DEATH 7 4 6 |
| Incomplete work permit without specifying all working area insurance conditions | 12. Incomplete work permit without specifying all working area insurance conditions | DEATH 7 4 6 |
| Exceeding the distances of materials to the work area and during the works | 13. Exceeding the distances of materials to the work area and during the works | DEATH 7 3 5 |
| Journeys, stationing in hazardous areas | 14. Journeys, stationing in hazardous areas | DEATH 7 3 5 |
### Table 8. Proposed measures sheet – 20 kV Primary Circuit Maintenance

| No. | RISK FACTOR                                                                 | RISK LEVEL | PROPOSED PREVENTIVE MEASURES                                                                                                                                 |
|-----|------------------------------------------------------------------------------|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Traveling by means of transport to the workplace – road accident             | 4          | Preparation of instructions for maneuvering and working instructions for vehicle in the power substation. Compliance with traffic rules.                     |
| 2   | Hazard of explosion TIRBO transformers                                       | 4          | Wearing personal protective and work equipment.                                                                                                               |
| 3   | Injury by the thermal effect of the electric arc of service and repair personnel when traveling on the territory power substations of the work load | 6          | Wearing personal protective and work equipment.                                                                                                               |
| 4   | Touching of accidentally live metal parts under the conditions:              | 6          | Making connections to the ground of all technical equipment. Measuring touch voltages. Compliance with the deadlines for technical revisions                  |
|     | - damage to insulation from the metal housing;                               |            |                                                                                                                                                             |
|     | - failure of the protective connection                                       |            |                                                                                                                                                             |
| 5   | Adequate preparation and/or non-compliance with mandatory steps and measures to secure the work area | 5          | Preparation of specific working instructions regarding the delimitation of the area work and the execution and observance of the work                      |
| 6   | Incorrect identification of the installations in which they work,            | 6          | The preparation of appropriate working instructions and the training of personnel on operating conditions in the power substation                            |
|     | wrong maneuvers when performing functional tests                             |            |                                                                                                                                                             |
Entering the work area unprepared for work safety

Compliance with the work and safety instructions. Respect for discipline in the workplace.

Incomplete work permit without specifying all working area insurance conditions

Start work only under the work authorization in which all conditions for securing the working area shall be specified.

Exceeding the distances of materials to the work area and during the works

Withdrawal from service of installations which are below the limit of neighbourhood

Journeys, stationing in hazardous areas outside the working area

Following the internal instructions for power substation travel

Not using the personal protective equipment provided or use of personal protective equipments non-certified

Instructions on the use of the personal protective equipment and the certified personal protective equipment

4.1.5 Risk level assessment for activity: 20 kV Secondary Circuit Maintenance

The team of revisions-repairs of equipments and secondary circuits and prophylaxis have as object of activity:

- revision;
- maintenance;
- repair of secondary protection and circuits;
- prophylaxis of power installations.

1. Means of production:
20 kV Power Substation:
- busbars;
- OHL switchgears;
- 110/20 kV AT switchgears;
- coupling switchgears (transversal / longitudinal / longo-transversal);
- compensating coil switchgears;
- busbar measuring switchgears;
- discharge switchgears, etc.

Risk factors specific to the means of production:
- electrical risk:
  - direct contact (unprotected terminals, unprotected heating elements);
  - indirect contact (housing, metal parts).
- mechanical risk:
  - functional movements of technical equipments;
  - displacements under the effect of propulsion.
- thermal risk:
  - flames, explosion of molten metal particles.

2. Work load:
- protection checks:
  - during the revisions, all the verifications provided by the technical books of protection are performed
  - the monitoring of the protection system parameters is done from the 20 kV control room.
- measurements and verifications performed by the secondary equipments revisions-repair team:
  - at the internal service panels:
    - checking the electrical connections;
    - measurements at internal service cables;
    - measurements at internal service transformers;
    - checking switching devices and current transformers;
    - calibration of fuses on all circuits;
    - checking the ground connections.
  - within the prophylaxis program of the primary equipment from the 20 kV power substations, the following verification are performed:
    - measurements and checks performed on voltage measuring transformers are:
      - measuring the insulation resistance of the windings;
      - measuring the tangent of the dielectric loss angle at the main insulation;
      - measuring the ohmic resistance of the windings;
      - raising the idling characteristic;
      - measuring the secondary load.
    - measurements and checks performed on the current measuring transformers are:
      - measuring the insulation resistance of the windings;
      - measuring the tangent of the dielectric loss angle at the main insulation;
      - measuring the ohmic resistance of the windings;
      - raising the idling characteristic;
      - measuring the secondary load.
    - checking the polarity of the windings.
    - measurements and checks performed on the circuit breakers are:
      - measuring the insulation resistance;
      - checking the contact resistance;
      - checking the ohmic resistance of the triggering and triggering coil;
      - low voltage operation of the control and automation installation;
      - checking the dielectric strength of the oil.
    - measurements and checks performed at power cables are:
      - checking the continuity and identifying the phases;
      - measuring the insulation resistance.

Risk factors specific to the work load:
- psychic stress on decisions in circuit and scheme modification operations in relation to the consequences of mistakes in performing these operations;
- physical strain, forced working positions during check at the clamp strings.

3. Performer:
The team consists of electricians and a team leader or foreman who are authorized in terms of OHS (groups I, II, III, IV, V).

Risk factors specific to the performer:
- wrong actions:
  - touching the current paths during the high voltage tests;
  - touching a point of the current paths;
  - touching the terminals of devices, strings of clamps, relays;
  - parking, hazardous movements.
- omissions:
• non short circuiting of the secondary windings at the current transformers for carrying out works related to low voltage circuits;
• non short circuiting of the secondary terminals of the current transformers when opening the current circuits for mounting or dismounting the measuring devices;
• omission of the connection to the null busbar of the internal services of a conductor from the protection circuit to the own busbar;
• non use and/or non verification of personal protective equipments.

4. Work environment:
Revisions – repairs of primary equipments and secondary circuits.

Risk factors specific to the work environment:
- physical risk factors:
  • lighting.

Table 9. Workplace assessment sheet 20 kV Secondary Circuit Maintenance

| NATIONAL POWER SECTOR | ASSESSMENT SHEET OF WORKPLACE | NUMBER OF EXPOSED PERSONS |
|------------------------|-------------------------------|---------------------------|
| RESPONSIBLE NATIONAL COMPANY | 20 kV SECONDARY CIRCUIT MAINTENANCE | EXPOSURE TIME: hours/shift |
| The composition of the work system | Identified risk factors | CONCRETE FORM MANIFESTATION OF RISK FACTORS | Maximum foreseeable consequence | Class of severity | Class of probability | Risk level |
| Mechanical risk factors: - movement under dynamic effect | 1. Traveling by means of transport to the intervention area – road accident | DEATH | 7 | 1 | 3 |
| | 2. Explosions of primary equipment, during the movement on the 20 kV substation territory to perform service attributions | DEATH | 7 | 1 | 3 |
| MEANS OF PRODUCTION | Electrical risk factors: - direct touch | 3. Touching unmarked terminals and installations | DEATH | 7 | 1 | 3 |
| | - indirect touch | 4. Touching 20 kV busbar during revisions or repairs | DEATH | 7 | 1 | 3 |
| | 5. Touching of accidentally energized metal parts under the conditions of: - insulation failure; - damage to the protective circuit by grounding; | DEATH | 7 | 1 | 3 |
|        | **WORK LOAD** | **WORK ENVIRONMENT** | **PERFORMER** |
|--------|---------------|----------------------|--------------|
| **Thermal risk factors:** | - flame, flame, explosion of molten metal particles when producing an electric arc | 6. The capture of personnel by the thermal effect of the electric arc at failure of insulation of primary equipment |  |
| **Oversize load in relation to performer's capacity:** | - psychic stress | 7. Psychic stress on decisions in circuit and scheme modification operations in relation to the consequences of mistakes in performing these operations | **Territorial Labour Inspectorate** 3-45 days |
| **WORK ENVIRONMENT** | - lighting | 9. Lighting level in the 20 kV power substation | **Temporary Work Incapacity** 3-45 days |
| **PERFORMER** | - defective execution of operations | 10. Confusion when working on the clamp string in the protection system, resulting in loss of the current transformer secondary circuit, clamp and current transformer terminal overvoltage, electrical shock hazard, transformer failure and untimely equipment tripping | **DEATH** |
|        |              | 11. Touching of current paths-conductors, clamps or test machine | **DEATH** |

| Failure to operate the protection or within the time period before the protection is activated. |  |  |
| --- | --- | --- |
| 1st degree Disability | 6 | 1 | 3 |
| Territorial Labour Inspectorate 3-45 days | 2 | 2 | 2 |
| **Temporary Work Incapacity** 3-45 days | 2 | 3 | 2 |
| **DEATH** | 7 | 1 | 3 |
| **DEATH** | 7 | 1 | 3 |
12. Not short circuit of secondary windings at current transformer for carrying out works related to low voltage circuit – hazard of electric shock

13. Touching the terminals of devices, clamps, relays, during voltage checking of secondary circuits under the use of damages personal protective equipment

14. Not short circuit of the secondary terminals of current transformer when opening current circuits for mounting / dismounting measuring devices

Parking, hazard movings
15. Parking or moving outside the work area or outside normal routes

Omission
16. Non use and/or non verification of personal protective equipments.

| No. | RISK FACTOR | RISK LEVEL | PROPOSED PREVENTIVE MEASURES |
|-----|-------------|------------|------------------------------|
| -   | -           | -          | -                            |

The global risk level at workplace: 20 kV Secondary Circuit Maintenance

\[ N_{EP} = \frac{\sum_{i=1}^{17} R_i \cdot r_i}{\sum_{i=1}^{17} r_i} = \frac{13 \cdot (3 \cdot 3) + 3 \cdot (2 \cdot 2)}{13 \cdot 3 + 3 \cdot 2} = \frac{129}{45} = 2.87 \]  

(7)

Table 10. Proposed measures sheet – 20 kV Secondary Circuit Maintenance

4.2 Global risk level assessment of the 400/220 kV power substation

The risk levels, determined for each workplace in the 400/220 kV power substation are generally the followings:
Table 11. Workplace from 400/220 kV power substation

| No. | WORKPLACE                                      | LEVEL RISK (N_{rp}) |
|-----|-----------------------------------------------|---------------------|
| 1   | 400 kV and 220 kV OPERATIONAL SERVICE         | 3,4                 |
| 2   | 20 kV OPERATIONAL SERVICE                     | 3                   |
| 3   | 400 kV and 220 kV PRIMARY CIRCUIT MAINTENANCE | 2,58                |
| 4   | 20 kV PRIMARY CIRCUIT MAINTENANCE             | 4,8                 |
| 5   | 20 kV SECONDARY CIRCUIT MAINTENANCE           | 2,87                |

The global risk level of the 400/220 kV power substation is:

\[
N_{rg} = \frac{\sum_{p=1}^{n} r_p \cdot N_{rp}}{3,4 + 3 + 2,58 + 4,8 + 2,87} = \frac{49,48}{16,65} = 2,97
\]

\[\text{N}_{rg\text{-station}} = 2,97 \]
\[\text{N}_{rg\text{-power substation}} = 2,97\]

5 Conclusions

The results of the assessment of risks of industrial injury and illness specific to activities carried out in a 400/220 kV power substation. The assessment of the risks of injury and occupational disease was carried out for five activities that were highlighted at the station:

1) 400 kV and 220 kV Operational Service;
2) 20 kV Operational Service;
3) 400 kV and 220 kV Primary Circuit Maintenance;
4) 20 kV Primary Circuit Maintenance;
5) 20 kV Secondary Circuit Maintenance.

and are as follows (table 12).

Table 12. Risk factors / Risk levels per workplace / Global risk level of the Power Substation 400/220 kV

| 400 kV and 220 kV Operational Service | 20 kV Operational Service | 400 kV and 220 kV Primary Circuit Maintenance | 20 kV Primary Circuit Maintenance | 20 kV Secondary Circuit Maintenance |
|---------------------------------------|---------------------------|---------------------------------------------|----------------------------------|----------------------------------|
| number risk factor → risk level       | number risk factor → risk level | number risk factor → risk level             | number risk factor → risk level | number risk factor → risk level |
| 1 → 1                                 | 1 → 3                     | 1 → 3                                       | 1 → 4                            | 1 → 3                            |
| 2 → 4                                 | 2 → 3                     | 2 → 2                                       | 2 → 3                            | 2 → 3                            |
| 3 → 4                                 | 3 → 3                     | 3 → 3                                       | 3 → 2                            | 3 → 3                            |
| 4 → 3                                 | 4 → 3                     | 4 → 4                                       | 4 → 4                            | 4 → 3                            |
| 5 → 4                                 | 5 → 3                     | 5 → 3                                       | 5 → 6                            | 5 → 3                            |
| 6 → 3                                 | 6 → 3                     | 6 → 2                                       | 6 → 6                            | 6 → 3                            |
These risk factors must be the focus of those who coordinate the activities of the 400/220 kV power station, as they can always be manifested in an event that can result in human casualties. The conclusion is that those who lead and coordinate the work are not influenced by the global value of the level of risk (which is a weighted average of the risk levels and risk factors identified), but take account of these risk factors with the maximum possible consequence of DEATH for which existing preventive measures must be maintained and the adoption of additional preventive measures. Given the risk factors identified for each assessed activity, specific to the elements of the work system and taking into account the level of risk corresponding to each risk factor, a number of preventive measures have been proposed. After the analysis, it was concluded that the 400/220 kV power substation should enter full retechnologization, for the following reasons:

- the age of apparatus and equipments in the primary circuits of the 400 kV, 220 kV and 20 kV power substations,
- the age of apparatus in the secondary circuits of the 400 kV, 220 kV and 20 kV power substations.

Due to these very old apparatus and equipment, the hazard of incidents is very great, which would endanger the good functioning of the National Power Grid. The risk of injury and occupational disease is particularly high in the 20 kV power substation, which is also a reason for the power substation to go into full retechnologization.

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