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:

$$N_r = \frac{\sum_{i=1}^{n} r_i \cdot R_i}{\sum_{i=1}^{n} r_i} \tag{1}$$

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:

$$N_g = \frac{\sum_{p=1}^{n} r_p \cdot N_{sp}}{\sum_{p=1}^{n} r_p} \quad (2)$$

where:
r_p - the workplace ranking "p" (equal to the risk level of the workplace);
n - number of workplaces analysed;
N_{sp} - average workplace safety level "p".

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:
- *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* (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		**ASSESSMENT SHEET OF WORKPLACE**	**NUMBER OF EXPOSED PERSONS**			
RESPONSIBLE NATIONAL COMPANY			**EXPOSURE TIME: hours/shift**			
400 kV and 220 kV OPERATIONAL SERVICE			**ASSESSMENT TEAM:**			
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 of 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

WORK ENVIRONMENT	**Risk factors:** - air temperature	7. Exposure to adverse weather conditions (high, low temperatures), when operating in outdoor power substations	Temporary Work Incapacity	2	1	1

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

$$N_{400kV\text{-}220kV} = \frac{\sum_{i=1}^{7} R_i \cdot r_i}{\sum_{i=1}^{7} r_i} = \frac{2\cdot(1\cdot 1)+2\cdot(3\cdot 3)+3\cdot(4\cdot 4)}{2\cdot 1+2\cdot 3+3\cdot 4} = \frac{68}{20} = 3{,}4 \qquad (3)$$

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		**ASSESSMENT SHEET OF WORKPLACE**	**NUMBER OF EXPOSED PERSONS**			
RESPONSIBLE NATIONAL COMPANY			**EXPOSURE TIME: hours/shift**			
20 kV OPERATIONAL SERVICE			**ASSESSMENT TEAM:**			
The composition of the work system	Identified risk factors	**CONCRETE FORM OF MANIFESTATIO N OF 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 PRODUCTIO N	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
PERFORMER	**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
	Omissions: - 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

$$N_{20\,kV} = \frac{\sum_{i=1}^{11} R_i \cdot r_i}{\sum_{i=1}^{11} r_i} = \frac{11 \cdot (3 \cdot 3)}{11 \cdot 3} = \frac{99}{33} = 3{,}00 \quad (4)$$

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		**ASSESSMENT SHEET OF WORKPLACE**	**NUMBER OF EXPOSED PERSONS**			
RESPONSIBLE NATIONAL COMPANY			**EXPOSURE TIME: hours/shift**			
400 and 220 kV PRIMARY CIRCUIT MAINTENANCE			**ASSESSMENT TEAM:**			
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
MEANS OF PRODUCTION	**Mechanical risk factors:** - functional movements of technical machinery	1. Displacement by means of transport to the workplace – road accident;	DEATH	7	1	3
		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

	Electrical risk factors - indirect touch	4. Touching of metal parts accidentally under voltage, in conditions of: - damage to insulation from the metal housing; - failure of the protective connection	DEATH	7	2	**4**
WORK LOAD	Improper content in relation to security requirements	5. Improper preparation and/or non-compliance with mandatory steps and measures to secure the work area	DEATH	7	1	3
	Under/oversized workload in relation to the capacity of the performer	6. Dynamic, static effort, forced working positions at ground and height when handling and replacing subassemblies and components of primary equipment, insulators replacement	Temporary Work Incapacity 45-180 days	3	2	2
WORK ENVIRONMENT	**Physical risk factors**	7. Inhalation of toxic dust and gases in the while performing painting operations	Temporary Work Incapacity 45-180 days	3	2	2
PERFORMER	Wrong actions	8. Incorrect identification of the installations in which they work, wrong maneuvers when performing functional tests	DEATH	7	1	3
		9. Entering the work area unprepared in terms of work safety	DEATH	7	1	3
		10. Incomplete work permit without specifying all working area insurance conditions	DEATH	7	2	**4**
		11. Exceeding neighbouring distances of	DEATH	7	1	3

		materials to the work area and during the works				
		12. Displacement, stationing in hazardous areas outside the working area	DEATH	7	1	3
		13. Falling from the same level through imbalance during the transport of materials to the power substation	Temporary Work Incapacity 3-45 days	2	1	1
	Omissions	14. Not using the personal protective equipment provided or use of non-certified personal protective equipment	DEATH	7	1	3

The global risk level at workplace: 400 kV and 220 kV Primary Circuit Maintenance

$$N_{MENT.EP400/220kV} = \frac{\sum_{i=1}^{14} R_I \cdot r_i}{\sum_{i=1}^{14} r_i} =$$

$$= \frac{1 \cdot (1 \cdot 1) + 3 \cdot (2 \cdot 2) + 8 \cdot (3 \cdot 3) + 2 \cdot (4 \cdot 4)}{1 \cdot 1 + 3 \cdot 2 + 8 \cdot 3 + 2 \cdot 4} = \frac{101}{39} = 2{,}58 \quad (5)$$

Table 6. Proposed measures sheet – 400 kV and 220 kV Primary Circuit Maintenance

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 gasis 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			**EXPOSURE TIME: hours/shift**			
20 kV PRIMARY CIRCUIT MAINTENANCE			**ASSESSMENT TEAM:**			
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
MEANS OF PRODUCTION	**Mechanical risk factors:** - functional movements of technical machinery - hazardous surfaces	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**
	Thermal risk factors	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**

		- damage to insulation from the metal housing; - failure of the protective connection				
WORK LOAD	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	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	10. Incorrect identification of the installations in which they work, wrong maneuvers when performing functional tests	DEATH	7	4	**6**
		11. Entering the work area unprepared for work safety	DEATH	7	4	**6**
		12. Incomplete work permit without specifying all working area insurance conditions	DEATH	7	4	**6**
		13. Exceeding the distances of materials to the work area and during the works	DEATH	7	3	**5**
		14. Journeys, stationing in hazardous areas	DEATH	7	3	**5**

		outside the working area				
		15. Falling to the same level through imbalance during the transport of materials to the power substation	Temporary Work Incapacity 3-45 days	2	3	2
	Omission	16. Not using the personal protective equipment provided or use of personal protective equipments non-certified	DEATH	7	3	**5**

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

$$N_{MENT.EP20kV} = \frac{\sum_{i=1}^{16} R_I \cdot r_i}{\sum_{i=1}^{16} r_i} =$$

$$\frac{3\cdot(2\cdot 2)+2\cdot(3\cdot 3)+2\cdot(4\cdot 4)+4\cdot(5\cdot 5)+5\cdot(6\cdot 6)}{3\cdot 2+2\cdot 3+2\cdot 4+4\cdot 5+5\cdot 6} = \frac{342}{70} = 4{,}8 \quad (6)$$

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: - damage to insulation from the metal housing; - failure of the protective connection	6	Making connections to the ground of all technical equipment. Measuring touch voltages. Compliance with the deadlines for technical revisions
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, wrong maneuvers when performing functional tests	6	The preparation of appropriate working instructions and the training of personnel on operating conditions in the power substation

7	Entering the work area unprepared for work safety	6	Compliance with the work and safety instructions. Respect for discipline in the workplace.
8	Incomplete work permit without specifying all working area insurance conditions	6	Start work only under the work authorization in which all conditions for securing the working area shall be specified
9	Exceeding the distances of materials to the work area and during the works	5	Withdrawal from service of installations which are below the limit of neighbourhood
10	Journeys, stationing in hazardous areas outside the working area	5	Following the internal instructions for power substation travel
11	Not using the personal protective equipment provided or use of personal protective equipments non-certified	5	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 ao 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			**EXPOSURE TIME: hours/shift**			
20 kV SECONDARY CIRCUIT MAINTENANCE			**ASSESSMENT TEAM:**			
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
MEANS OF PRODUCTION	**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
	Electrical risk factors - direct touch	3. Touching unmarked terminals and installations	DEATH	7	1	3
		4. Touching 20 kV busbar during revisions or repairs	DEATH	7	1	3
	- indirect touch	5. Touching of accidentally energized metal parts under the conditions of: - insulation failure; - damage to the protective circuit by grounding;	DEATH	7	1	3

		- failure to operate the protection or within the time period before the protection is activated.				
	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	1st degree Disability	6	1	3
WORK LOAD	**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	2	2	2
	- physical stress	8. Physical strain, forced working positions during check at the clamp strings.	Temporary Work Incapacity 3-45 days	2	2	2
WORK ENVIRONMENT	- lighting	9. Lighting level in the 20 kV power substation	Temporary Work Incapacity 3-45 days	2	3	2
PERFORMER	**Wrong actions:** - 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	7	1	3
		11. Touching of current paths-conductors, clamps or test machine	DEATH	7	1	3

		busbars during high voltage tests, electrical shock hazard				
		12. Not short circuit of secondary windings at current transformer for carrying out works related to low voltage circuit – hazard of electric shock	DEATH	7	1	3
		13. Touching the terminals of devices, clamps, relays, during voltage checking of secondary circuits under the use of damages personal protective equipment	DEATH	7	1	3
		14. Not short circuit of the secondary terminals of current transformer when opening current circuits for mounting / dismounting measuring devices	DEATH	7	1	3
	Parking, hazard movings	15. Parking or moving outside the work area or outside normal routes	DEATH	7	1	3
	Omission	16. Non use and/or non verification of personal protective equipments.	DEATH	7	1	3

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

$$N_{EP} = \frac{\sum_{i=1}^{17} R_I \cdot r_i}{\sum_{i=1}^{17} r_i} = \frac{13 \cdot (3 \cdot 3) + 3 \cdot (2 \cdot 2)}{13 \cdot 3 + 3 \cdot 2} = \frac{129}{45} = 2,87 \quad (7)$$

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

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

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:

$$N_{rg} = \frac{\sum_{p=1}^{n} r_p \cdot N_{rp}}{\sum_{p=1}^{n} r_p} =$$

$$\frac{(3,4 \cdot 3,4) + (3 \cdot 3) + (2,58 \cdot 2,58) + (4,8 \cdot 4,8) + (2,87 \cdot 2,87)}{3,4 + 3 + 2,58 + 4,8 + 2,87} = \frac{49,48}{16,65} = 2,97 \quad (8)$$

$$\mathbf{N_{rg\text{-}station} = 2,97}$$
$$\mathbf{N_{rg\text{-}power\ substation} = 2,97}$$

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

7 → 1	7 → 3	7 → 2	7 → 5	7 → 2
	8 → 3	8 → 3	8 → 3	8 → 2
	9 → 3	9 → 3	9 → 2	9 → 2
	10 → 3	10 → 4	10 → 6	10 → 3
	11 → 3	11 → 3	11 → 6	11 → 3
		12 → 3	12 → 6	12 → 3
		13 → 1	13 → 5	13 → 3
		14 → 3	14 → 5	14 → 3
			15 → 2	15 → 3
			16 → 5	16 → 3
Work environment 14%	Work environment 9%	Work environment 7%	Work environment 6%	Work environment 6%
Performer 29%	Performer 36%	Performer 50%	Performer 43%	Performer 43%
Mean of Production 57%	Mean of Production 55%	Mean of Production 29%	Mean of Production 38%	Mean of Production 8%
		Work load 14%	Work load 13%	Work load 13%
Risk level 3,4 Unacceptable	**Risk level 3 Low**	**Risk level 2,58 Very Low**	**Nivel risk 4,8 Unacceptable**	**Nivel risk 2,87 Very low**
GLOBAL LEVEL RISK 2,97 → RISC LEVEL LOW – VERY LOW				

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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