Functional system for experimentation and testing of products for professional use - Professional risk management tool for workers performing industrial activities

Anca Elena Antonov1*, Georgeta Buică1, Constantin Beiu1 and Remus Dobra2

1 INCDPM “Alexandru Darabont”, 35A Blvd Ghencea, 6th county, Bucharest 062692, Romania
2 University “1 Decembrie 1918” Alba-Iulia, Romania

Abstract. The products intended for professional use must guarantee the fulfilment of the safety and health requirements from the design phase; they are being tested in the experimentation and “zero series” stage to validate the series production. The work equipment for professional use, the industrial product prototype’s functional, operating and protection properties must be defined to establish the necessary conditions for their experimentation. In this sense, it is necessary to develop specific tools for the management of professional risks in order to take the decision at the managerial level to protect the workers who carry out industrial activities. The study presents research results regarding establishing security and compliance conditions to develop a methodology for experimentation, testing and validation of product prototypes intended to protect workers and prevent occupational risks in electrical installations. As part of the research study, a managerial tool for managing professional risks was developed in order to ensure the protection of people who carry out industrial activities and the prevention of occupational risks in the energy sector, which consisted of an intelligent decision support tool necessary for designing, experimenting the product prototype, the testing of the upgraded product model and its validation, to introduce it into series production.

1 Introduction

Ensuring the safety of workers is achieved from the design and manufacturing phase of work equipment, both through intrinsic design and through complementary and tertiary protection measures. The state-of-the-art analysis of the risks that can lead to manufactured/industrial disasters is based on identifying aspects related to disasters and the importance of risk identification and assessment in disaster risk management. Identifying and preventing the causes that can endanger and establishing in time what needs to be done in case of necessity can limit possible losses or damages.

Activities are a dynamic situation because they are constantly changing in terms of operations and technological processes, and other work requirements. Potential hazards

* Corresponding author: anca.antonov@gmail.com

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related to human, organizational and environmental factors must be recognized, quantified and controlled [1, 2]. Knowing the aspects related to risk management in the field of electrical installations, respectively the types of electrical installations and work equipment in use, the work environment through the prism of the activities carried out by workers based on the workload, is necessary for the establishment and development of risk structures - causes - consequences - preventive measures [1]. The starting point in optimizing work accident and occupational disease prevention activity in a system is the assessment of the risks in that system. The prevention of work accidents due to the use of work equipment has as its primary objective the safety of the use of work equipment by observing the instructions provided in the Technical Books and the technical training of workers. Through the research study, the specific requirements necessary for developing safe tools were identified to comply with work equipment intended to prevent occupational risks and to ensure the protection of people who carry out activities in electrical installations [1, 2].

2 Aspects related to risk factors and measures to prevent danger in electrical installations

In the framework of the research study, the analysis of statistical data related to work accidents that occurred at the national level between 2010 and 2020, in electrical sector, was carried out, which indicates that there was an increase in accidents resulting in temporary incapacity for work between 2014 and 2019 and a slight decrease of fatal accidents in recent years, according to the National Institute of Statistics (INS) registration in the section Production and supply of electricity and thermal energy, gas and water presented in fig.1.

![Fig. 1. Total work accidents in Romania in the period 2010-2020. Source: INS - TEMPO program 2022 section Production and supply of electricity and thermal energy, gas, and water [1, 3]](image)

The number of people injured at work represents the number of people who were injured at work (electrical installations), regardless of gender, the nature of the accident and the consequences produced by it. Traffic accidents are not included in the number of casualties [1, 3]. Figure 2 shows statistically the total number of victims (workers) registered in collective occupational accidents (where at least 3 persons were injured at the same time and for the same reasons within the same incident) and the number of fatalities. In recent years, the number of workers involved in collective accidents has decreased and the number of victims who died in these accidents has increased.
The analysis of the statistics on occupational accidents registered at the national level in the field of generation and supply of electricity and thermal energy, gas and water were carried out in order to analyse the causes of occupational accidents, identify, and establish some safety measures and adopt some technical solutions for the safety of workers at work.

The analysis was carried out based on data collected and recorded at national level by INS and presented within the framework of the project “Partnership for the transfer of knowledge and the development of research relations” funded by European funds. As part of the research study, the structure Risk - Causes - Consequences - Preventive Measures was created, taking into account the results of the statistical analysis of accidents, their causes and the risks identified in electrical installations (electrical plants, overhead power lines, underground power lines, low-voltage electrical installations), a specific OSH ontology was developed at the level of the beneficiary company to ensure the safety and health of workers, the protection of the environment and the assets defined as means of production, taking into account the main elements of the concepts related to OSH [1, 4, 5].

Considering the complexity of electrical installations depending on their role, the diagnosis of the technical and security condition of electrical installations, and the identification of risk factors, the cause-consequence analysis was carried out by types of installations: electrical stations, overhead power lines, underground power lines and electrical installations of low voltage [1, 4, 5]. The documentation of the risks in the users’ low-voltage electrical installations was carried out in the current configurations of the electricity networks. We say current because “at some point”, depending on the agreement, the configuration could be changed given that the constraints could be time-varying: security constraints, cost constraints, or reliability constraints [6, 7].

Table 1 presents an extract of the risk structure - causes-consequences for the risks identified in the installations. The risks presented in Table 1 are common risks identified in approximately 65% of the activities analyzed ((electrical transformation stations and electrical networks of 110 kV, 6 kV, 0.4 kV).
Table 1. Risk structure - causes and consequences for the risks identified in electrical installations (electrical transformation stations and electrical networks of 110 kV, 6 kV, 0.4 kV) (excerpt) [1, 4, 5]

<table>
<thead>
<tr>
<th>Risk</th>
<th>Causes</th>
<th>The maximum foreseeable consequence</th>
<th>Preventive measures</th>
<th>Obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric (electrocution, arc flash effects)</td>
<td>Carrying out work with non-certified work/protective equipment from the point of view of occupational safety and health;</td>
<td>Death</td>
<td>Technical measures: ensuring equipment and means of protection and individual protective equipment compliant/certified; performing periodic checks of personal protective equipment (PPE); replacement of equipment whose technical life span is exceeded; Organizational measures: prohibiting the execution of works without using PPE and protective equipment; verification by permanent control; training the workers; awareness of workers regarding responsibilities, risks and dangers.</td>
<td>-</td>
</tr>
<tr>
<td>Electric (electrocution, arc flash effects)</td>
<td>Carrying out work with regularly unchecked work/protective equipment</td>
<td>Death</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Electric (electrocution, arc flash effects)</td>
<td>Carrying out work with work/protective equipment whose technical service life has expired</td>
<td>Death</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Electric (electrocution, arc flash effects)</td>
<td>Non-compliance with the order of application of all technical measures for the creation of the work area</td>
<td>Death</td>
<td>Technical measures: provision and use of PPE and protective equipment; Organisational measures: verification by continuous control; compliance with technical and H&amp;S regulations, internal documents; training of workers on the execution of manoeuvres, work areas; awareness of responsibilities, risks and dangers.</td>
<td>-</td>
</tr>
<tr>
<td>Electric (electrocution, arc flash effects)</td>
<td>Overcoming neighbourhood distances in the preparation and execution of works</td>
<td>Death</td>
<td>Technical measures: maintain the permissible distances from live installations; the provision and use of electrically insulating barriers; the marking of the danger zone; the disconnection of the equipment on which work is to be carried out, or equipment in the vicinity, if the minimum permissible distances from live equipment cannot be guaranteed; the use of PPE Organisational measures: the observance of one's own safety instructions for carrying out work on electrical installations in operation; instructing workers on the work to be carried out.</td>
<td>-</td>
</tr>
</tbody>
</table>
The developed ontology aimed to define the classes and subclasses regarding work equipment (EM) intended to prevent occupational risks in order to ensure the protection of people who carry out industrial activities in order to develop the security requirements regarding product prototypes, the specific evaluation and testing methods necessary for the development, testing and validation of product prototype experimentation procedures.

Thus, the work equipment has been classified according to its role in the work facilities, the work environment in which it can be used, the risks it can generate, the maximum foreseeable consequences, the remaining risks, respectively the security measures necessary to be adopted during use. On the other hand, the subcategory of protective equipment has been classified according to the type of electrical installation/workplace where it is used, the protective role provided, the work environment in which it can be used.

3 Development of an expert decision support system for product prototype testing

3.1 Aspects related to work equipment used in electrical installations with the role of protection against professional risks

The prototypes were tested and evaluated as part of the research study carried out in the project, are equipment with a protective role, which is part of the category of work equipment specific to activities in electrical installations [1]. The equipment and means of protection used in electrical installations are to protect the workers and the people in the area from the dangers generated by electricity. They have a security function, but failure/damage during use or improper operation may endanger the safety or health of exposed persons and/or produce unforeseen events leading to disasters [1, 4, 5, 8]. In this sense, the information related to the fields of use of the equipment and means of protection is essential for the development of prototype experimentation procedures, establishing the technical conditions and security requirements necessary for the evaluation and diagnosis of the prototypes, respectively, the technical characteristics, operation and security quality of the prototypes. In the framework of the research study, the safety and health conditions that must be met by five product prototypes designed to prevent occupational risks and ensure the protection of people who carry out activities in electrical installations have been developed. The prototypes were chosen based on the importance, the role of protection and the degree of use, and the risks identified during the evaluations.

3.2 Development of the functional system for product experimentation and testing - SQTEST

The development of the functional decision support system for the testing and inspection of the prototype products of the “zero series” and the improved product with a view to “series production” aims to develop an intelligent decision support system/product to avoid occupational risks and ensure the protection of persons performing activities in electrical installations [1]. The knowledge base was developed within the project in partnership with the company SC NAKITA PROD COMIMPEX SRL Tg. Mureș and included the elements of knowledge necessary to implement the security requirements applicable to products intended to prevent occupational risks and ensure the protection of people who carry out activities in electrical installations, experimentation product prototypes, the application of the product prototype evaluation and testing method with the legal and technical provisions in force regarding the conformity assessment of products for professional use. The developed knowledge base included the necessary knowledge elements for testing product.
prototypes, the “zero series”, and the upgraded product for “series production”. To this end, the logic schemes for representing the technical knowledge related to the design and development of new products to prevent occupational risks and to ensure the protection of persons performing activities in electrical installations were developed and used as a representation model. The functional logic diagrams were developed and adapted for the case studies and cover the phases of prototype testing, “pilot production” and product improvement with a view to “series production”. The functional logic schemes were developed for the case studies and covered the phases of prototype experimentation, “zero series”, and upgraded product with a view to “series production”. The case studies were conducted for the development of 5 new products used as work equipment in electrical installations to protect against occupational risks [1]: mobile grounding and three-phase short-circuit device for medium-voltage overhead power lines (LEA), equipped with electro-insulating elements; modular electrical insulating rod, with multiple uses for electrical installations, with nominal voltage over 1 kV – 2 developed and upgraded products; bipolar phase correspondence indicator for use in electrical installations with nominal voltage 6-35 kV; portable electric field detector for use in low and medium-voltage electrical installations. Functional logic schemes were developed in order to establish and develop the technical conditions of safety and health at work regarding the design and realization of product prototypes intended to prevent occupational risks, the experimentation of prototypes, the testing of the “zero” series and the upgrading of the product (type of model).

In figure 3 is the present overall structure of technical conditions and safety and health requirements for the prototype Mobile grounding, and three-phase short-circuit device for medium-voltage overhead power lines (LEA) equipped with insulating elements. In order to experiment and validate the product prototypes, including the technical documentation, the logical scheme of the prototype experimentation and validation stages was developed, which was tested, validated and applied within the project.

![Diagram](https://example.com/diagram.png)

**Fig. 3.** Overall structure, technical conditions and safety and health requirements, product prototypes - Mobile three-phase grounding and short-circuit device for medium-voltage overhead power lines (LEA), equipped with electro-insulating elements [1]

The functional logic schemes for the case studies formed the basis for developing the functional model of the expert decision support system for the following areas:

a) Logical schemes regarding the identification of occupational risks to design and make prototypes of products intended for the prevention of occupational risks in order to ensure the protection of people who carry out activities in electrical installations [1]. For this
purpose, the logical scheme was established regarding integrating the risks generated by the product prototypes in the general decision support system (DSS), presented in Figure no. 4 within the framework of developing the functional system for product experimentation and testing - SQTEST. Identifying and assessing workplace risks allow the elimination of risk factors through appropriate working conditions, limited risk exposure, adequate personal safety equipment, medical investigations, and ergonomic workplace design when the elimination of risks is not possible, reducing them to the level of residual risks is mandatory, which must be adequately controlled to ensure healthy workplaces for all workers [9, 10].

b) Logical schemes for the occupational risks identified in electrical installations in order to establish the technical conditions/requirements for safety and health at work regarding the design and realization of product prototypes intended for the prevention of occupational risks in order to ensure the protection of people who carry out activities in electrical installations [1].

c) Logical schemes for evaluating and testing product prototypes intended to prevent occupational risks to ensure the protection of people who carry out activities in electrical installations [1].

In the framework of the research study, activities were carried out related to developing technical and security conditions to create product prototypes intended to prevent occupational risks and ensure the protection of people who carry out activities in electrical installations. Tests were carried out to evaluate the technical and security characteristics of the prototype produced for the equipment mentioned above, including after their upgrade.

In the framework of the research study, activities were carried out related to the simulation and testing of product types for the case studies - product types intended to prevent occupational risks to ensure the protection of people who carry out activities in electrical installations.

Appropriate testing techniques for evaluating the quality of product prototypes must be found and implemented. In an ideal world, testing techniques would perfectly duplicate the conditions that occur in practice; however, this is not feasible, so testing of these hazards is done by replicating real-world impacts as closely as possible [11].

Insulation resistance measurement is one of the main tests performed to ensure the safety of workers and the safety of electrical installations. The reason these tests are performed is to prevent accidents caused by electric shock and equipment damage [12].

A chemical risk analysis is necessary because electrical insulating materials can release toxic vapours and/or corrosive by-products in the event of a short circuit, which can irritate the eyes and respiratory system [13].

Microclimate conditions can also decisively influence the safety of the produced prototype, and the degradation of the insulation, which leads to a high risk for workers [14].

Also, accidental releases of toxic/flammable/explosive substances can have serious consequences for workers or the neighbouring population, but also the need to identify and evaluate risks of a chemical nature must be taken into account in terms of the impact on the safety characteristics of the prototypes product. [15, 16, 18].
The implementation of the assessment technique validates that the technical functions' requirements are met while keeping the operational indicators’ values within the prescribed limitations [17]. The information collected by applying the evaluation technique can be used to verify that the objective of a safe prototype product is achieved, as well as to strike a balance between technical and safety criteria, as well as reliability and cost considerations [16, 17].

Following the risk analysis and test results, technical solutions/measures (e.g. choice of another material, other design, other components) can be adopted to be adopted by the manufacturer (e.g. taking into account criteria such as durability, ergonomics of construction, lower cost) [16, 19]. To ensure the goal of ensuring product prototypes are safe and to find a balance between technical and safety needs, reliability and economic requirements, the data produced from the application of SQTEST's risk analysis can be used [1, 16 - 19].
4 Conclusion

Within the framework of the European-funded research project PROC, research studies were carried out during the period 2018-2023 to develop a decision management tool to help beneficiary companies develop new products to prevent occupational risks in order to ensure the protection of people carrying out industrial activities. The novelty consists in the new tools developed for the identification of occupational risks, for the design of products for the prevention of occupational risks and for the evaluation and testing of product prototypes.

Following the implementation of the research project PROC, a decision support system for product trials and testing - SQTEST - was developed, which is used by both companies and the certification body within the INCDPM in the testing and certification processes of work equipment.

The decision/product support system for the evaluation and testing of product prototypes for the prevention of occupational hazards to ensure the protection of persons performing activities in electrical installations, for prototype testing and verification, pilot production testing, product improvement, evaluation and testing of product types for the prevention of occupational hazards to ensure the protection of persons performing activities in electrical installations, has been developed within the framework of a research project in partnership with a beneficiary company.

The decision/product support system also included the component developed for decision/product support in the identification of occupational risks to design and create product prototypes to prevent occupational risks to ensure the protection of persons performing activities in electrical installations for the technical conditions/requirements of occupational safety and health in relation to the design and realisation of 5 product types developed, tried and tested in the framework of experimental and industrial research.

The decision/product support system also included the component developed for decision/product support in the identification of occupational risks to design and create product prototypes to prevent occupational risks to ensure the protection of persons performing activities in electrical installations under the conditions/technical requirements of occupational safety and health about the design and realisation of the five product types.

The decision/product support system also includes the component developed for decision/product support is a necessary tool for conformity assessment, technical diagnosis, and EM certification, as well as for EM manufacturers aiming to prevent accident risks and ensure the protection of workers in electrical installations.

5 Future Prospective

Based on the results of the industrial and experimental research activities carried out under the European-funded project PROC, two new products have been launched in the period 2018-2023, for which patent applications have been filed, and in the next period three new products will be launched to prevent occupational risks in order to ensure the protection of people carrying out industrial activities.

The research studies conducted aimed to promote sustainable development through the decision support system developed to assess and avoid risks that may lead to disasters, as well as through the methods and procedures developed as part of the research project.

The management tools developed are made available to companies to increase their competitiveness in the market and ensure a high level of safety for people carrying out industrial activities.
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