Oleksandr Matusevych, Viktor Sychenko, Andrzej Białoń

Continuous improvement of technical servicing and repair system of railway substation on the basis of FMEA methodology

The article shows the ways of solving the problem of upgrading and efficiency of the technical servicing and repair of railway substation of electrified railways in operation. Proposed to use of FMEA methodology to continuous improvement the technical servicing and repair process of electrical equipment throughout the life cycle. By the given method, the calculation of critical violations operations of subprocess maintenance work of the supply transformer and subprocesses criticality of maintenance of power electric equipment of railway substations is carried out.

Keywords: Railway substation; method FMEA; electric equipment; technical servicing and repair; system; service life; engineering status

Increasing of efficiency of the process of operation organization of power equipment of the railway substations (RS) can reached when receiving optimum technical condition of the equipment in relation to initial and ensuring reliability of the equipment at the set level. At present time, the organization of operation process of electric equipment of RS of divisions of railway power supply of Ukraine carried out according to industry-specific regulatory documents. According to basic provisions of these documents maintenance of necessary level of reliability of RS electric equipment in use is provided, on the one hand at the expense of considerable coefficient of a stock of the service life put at its creation, and on the other hand, system of technical servicing and repair (TS and R).

This system based on carrying out the scheduled preventive maintenance (ShPM) after the operating certain time (system of scheduled preventive maintenance). However, sometimes such service leads to unjustified expenses as real technical condition of RS electric equipment at the work moment cannot demand maintenance, and the replaced details have not reach critical degree of wear yet. Besides, at present time, practically there is no necessary financial and technical ensuring carrying out ShPM to the fullest extent, and gradual aging of equipment stock of RS and decrease in assurance coefficient put a problem point-blank of risk level assessment of its operation outside the target life (for example, on the Ukrainian railways 82,9 % of RS and the basic hardware work with service life more than 30 years) [Matusevych, Myronov 2015; Sychenko, Matusevych, Kyrychenko 2014].

On the assumption of existing operational conditions of RS - the main objective of system improvement of TS and R of power equipment RS for today are ensuring necessary level of reliability, safety and efficiency of electric equipment functioning at the minimum costs for operation. Improvement of technical servicing and repair system concerns generally control methods of parameters in the course of technical condition inspection and calculation methods of the appointed resource: existence of the models allowing defining function of error-free running time of the RS equipment taking into account its specific features.

However, efficiency of the RS equipment operation of TP of the electrified railways increasing degree becomes dependent on activity of the repair services urged to provide process of maintenance of processing equipment in operating state with the minimum repair expenses. However, despite an important role of repair services in providing qualitative TS and R equipment, the level of technical equipment of distances divisions of power supply, their organization and management for the present don't conform to modern requirements of regulations and standards. A deep basis of problems is not only the equipment itself, but system of operation makes not so much it at all stages of life cycle: from design, installation and its input in action before operation, maintenance and utilization.

The analysis of modern methods of increase of efficiency of functioning of the enterprises shows [IEC/FDIS 31010:2009(E); Matusevych 2015; MIL-STD-1629A 1980; PTC Windchill FMEA] that the solution of the problem of maintenance system improvement and repair of processing equipment can be carried out also on the basis of achievements of modern science management.

Contemporary technologies of maintenance and repair of technical equipment are also being developed and used at the other railway transport enterprises, for example, in freight and passenger sector [Melnychuk, Myamlin, S. Isopenko, Myamlin, V. 2010; Myamlin, V., Bosov, Myamlin, S. 2011; Myamlin, V., Myamlin, S. 2011; Myamlin, S., Kutko, Kebal, Myamlin, V. 2011], including the usage of flexible in-line technologies [Myamlin, V., Myamlin, S. 2011; Myamlin, S., Kutko, Kebal, Myamlin, V. 2011; Myamlin, V., Myamlin, S. 2012].

Development of the technique of FMEA of technical servicing and repair of the equipment of railway substation

Increasing requirements for the reliability and safety of railway traffic led to the application of new methods of system analysis of the technical condition of traction energy objects. As one of such methods can be proposed the method of modes analysis and effects of potential inconsistencies of - Failure Mode and Effects Analysis, hereinafter referred to as - the method FMEA as well as its variant, called FMECA (Failure Modes, Effects and Criticality Analysis) extends the capabilities of the method by ranking the severity of the consequences of violations (failure), allowing you to prioritize preventive actions. In the world, almost 25 years' experience of development and successful application of the FMEA analysis is the best practice. The main task of FMEA/FMECA, for system TS and R, RS, the quality management of system processes and continuous improvement when ensuring detection of potential discrepancies (defects) and prevention of their emergence at all stages of life cycle the electro technical equipment of RS is. Currently, analysis of species and the effects of potential inconsistencies (FMEA-methodology) [FMEA; McDermott, Mikulak, Beauregard 1996; NASA/SP-2000-6110; Rich 2001; Rozno 2000] carry out at least 80% of the technical development of products and technologies.

Analysis of the types and effects of potential nonconformities is widely used by many international companies for the development of new designs and technologies, as well as for analysis and planning of production processes and products. FMEA methodology allow evaluating risks and potential damage caused by the potential discrepancies design and production processes in the early stages of designing and creating the finished product or its components. Application of the method covers all stages of the life cycle product and any technological processes. The greatest effect is the use of FMEA in the design, development stages of the process, however, and in the current production method can effectively applied to the analysis of non-conformities, and their causes are not identified in the development of equipment or due to factors of variability during the operation.

The purpose of this analysis is detection and an assessment of potential defects (refusals) of the equipment or process, definition of actions that can eliminate or reduce probability of emergence of potential refusals and documenting of all these actions for the purpose of achievement of reliable, effective operation of the equipment. At a completion stage, for example, of technological process of system of TS and R RS or at its improvement by the FMEA method it is necessary to solve the following tasks:

- detection of critical places of technological processes of TS system and R and taking measures to their elimination when planning productions of power supply divisions;
- making decisions on suitability of the offered and alternative processes of TS and R when developing technological processes of service system;
- creation of a ranked list of species and the reasons for discrepancies of TS and R for planning corrective and preventive actions;
- definition of corrective and preventive actions of TS and R, which could eliminate or reduce the risk of critical processes (non-compliance);
- completion of technological process to the most acceptable from various points of view, namely: reliability, safety for the personnel, detection of potentially defective technological operations etc.;
- data documenting on results of the analysis for accumulation in the knowledge base.

For definition of area operative treatment in process TS and R power equipment's of RS, it is possible to offer carrying out the FMEA analysis of process at the level of the main subprocesses of service [Matusevych 2015; Matusevych, Myronov 2015]: scheduling on maintenance, preventive check (survey), maintenance, between-repairs tests, capital repairs of the equipment, financing of works on maintenance (fig. 1).

According to the offered technique (fig. 1), for each operation element of the chosen level of structuration it is necessary to make the list of potential violations then influence of each violation on functioning of subprocess and process of TS and R in general, and technical condition of the equipment of RS is studied.

In order to establish critical operations of TS and R – an analysis of possible hazards causes of potential consequences of irregularities in the organization of maintenance of electric power transformer substation RS ECh-2. Results of the analysis (excerpt) [Dolin, Pershina, Smekalov 2000; Matusevych 2015; Matusevych, Myronov 2015] submaintenance of power converter TDTN-25000/150-70 U1 TA DC shown in table 1.

The technique FMEA is to identify all potential errors or system failures (process or equipment) [FMEA and FMECA; Rozno 2000; Wang, Moczygemba 2015].

For any potential violation of TS and R, defect or failure of equipment, according to the methods FMEA, determined by three indicators based on three criteria (scale from 1 to 10):

- *coefficient of gravity of the infringement* (K_S),takes into account the importance of the consequences of the breach of the *i*-th operation TS and R (the severity of the symptoms causes of the violation (failure)). Probability P_S that, that the equipment of RS will fail (it is improbable =1; almost for certain =10);
- *frequency factor of operation dysfunction* (K_O), evaluation of frequency (probability P_O failure) violations i-th operation TS and R. Danger of violation (influence is insignificant =1; extraordinary influence = 10);
- *coefficient* (K_D), take into account probability P_D, assessment of probability not of detection of violation *i*-th operation TS and R before manifestation of its consequences (at early stages). Possibility of violation identification (detection is probable = 1; detection is improbable = 10).

For the first two criteria this scale increasing i.e. the higher the importance or frequency of emergence of violation, the corresponding estimates are higher. For the third criterion the scale decreases – the higher possibility of this violation detection is, the corresponding assessment is lower.

To calculate the critical violation of operation TS and R may use the integrated estimation of criticality of the given violation (K_R), so-termed (Risk Priority Number – RPN) – the priority risks

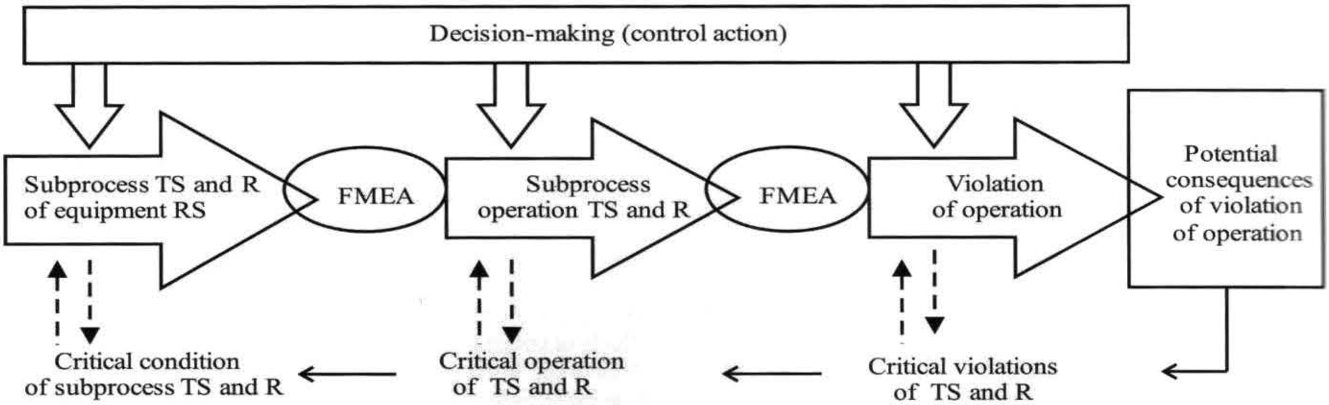

Fig. 1. *Process FMEA technique TS and R equipment of RS*

Tab. 1. On-line maintenance power converter TDTN - 25000/150-70 U1

No.	Name of subprocess / operation	Critical violation	Potential causes	Potential consequences
On-line maintenance power converter				
Operations				
1	Preparatory work and permit to work	Failure to comply with the time limits for data submission	Human factor	Failure to deliver on time of RS
		Bad preparation of the tool	Human factor	Increase in time of RS, poor quality of works
		Low quality of repair materials (or its absence)	The lack of analysis and monitoring of current inventory	Reduction of service life of the equipment (Repair failure to meet time constraints)
		Unsatisfactory performance records	Human factor	Low-quality planning of terms of RS
2	Exterior check of power converter	Grounding bolt clamps of aren't tightened	Default of maintenance requirement card	Deformation of contact joint
3	Coil resistance test of insulant	Poor quality of check	Lack of the measurement modern equipment	Operating life reduction
4	The analysis of oil from a power converter tank	Unsatisfactory quality of the analysis	Lack of the modern equipment of diagnosing	Operating life reduction, power converter fault
5	Check of gas protection	Unsatisfactory quality of check	The contractor is badly trained	Lack of the alarm system (probability is not of shutdown of power converter)

number (RPN), which is calculated as the intersection of the above three factors:

$$K_R(RPN) = K_S \cdot K_O \cdot K_D \quad (1)$$

Criticality *j*-th operation is counted based on criticality *i*-th violation of the operation, taking into account its importance (weight):

$$RPN_j = \sum_{i=1}^{m} RPN_i \cdot K_i \quad (2)$$

where RPN_j – criticality *j*-th operation, K_i – weight factor of the violations importance *i*-th operation. The weight coefficient is defined by the expert way, where $\sum K_i = 1$.

Criticality *q* subprocess calculated based on criticality *j*-th operation taking into account its significance:

$$RPN_q = \sum_{j=1}^{n} RPN_j \cdot K_j \quad (3)$$

where K_j – weight factor of the violations importance *j*-th operation, where $\sum K_j = 1$.

The value of RPN can take values from 1 to 1000, and provides estimation of the risk level of the given failure. One of the main objectives of FMEA – failure detection with the highest RPN and their steady decline. A predetermined maximum acceptable value of the RPN on the potential failure (usually not more than 100 ... 125) is the critical value of the RPN.

Calculation of operations risk and subprocesses of technical servicing and repair of railway substation

Consider the example of the practical application of FMEA methodology for risk analysis of operations of TS and R of railway substations, in order to prevent critical situations and to improve the reliability of traction energy.

At the first stage using the results of the analysis of subprocess of online repair of the power convertor TDTN-25000/150-70 U1 TP of a direct current (table 1) the coefficient considering weight of refusals is defined – *S* Criteria of the importance with the indication of points of consequences coefficients are given in table 2.

At the second stage of carrying out the FMEA analysis, defined the potential reasons for each of possible discrepancies (table 1). For convenience and completeness of identification the reasons expediently application of the Isikava's charts, a fault tree, structural, functional models, etc.

For each potential reason we define the coefficient considering probability of defect emergence – *O*. This involves expert assessment of the frequency of reasons occurrence – the coefficient of frequency operation violations (K_O). The coefficient changes from 1 (very rare defects) to 10 (constantly arising defects) and is specified in table 3.

At the third stage for each defect and each separate reason of its emergence, define coefficient, for each operation of subprocess of the power convertor on-line maintenance, considering probability of refusal detection before emergence of its consequences or probability of the refusal admission – *D*. The quantitative assessment coefficient *D* made on a rate scale of the probability assessment of detection presented in table 4.

At the fourth stage, using analysis results of on-line maintenance subprocess of the power convertor TDTN-25000/150-70 U1 TP carry out the calculation of critical violations operations of TS and R, for on-line maintenance subprocess of the power convertor TDTN-25000/150-70 U1 TP. The calculation makes for the formula (1).

Tab. 2. Importance scale (consequences) (*S*) of risk

Consequences	The value of the failure consequences	Coefficient K_S
The very insignificant	Violation of TS and R don't influence on operational indicators	1-2
The insignificant	Defects are subject to repair and easily removable	3-4
The considerable	Refusals cause gradual loss of safety and decrease in operational characteristics	5-6
The critical	Defects are capable to cause accidents	7-8
The catastrophic	Refusal threatens safety (danger to life and human health, to failure of devices) and contradicts normative documents	9-10

Tab. 3. Rate scale of the predicted probability of defect emergence (*O*)

Risk probability	Criterion of defect emergence	Coefficient K_O
Very low	The risk of defect emergence is improbable. The probability is next to nothing.	1-2
Low	Very insignificant probability.	3-4
Average	Average probability.	5-6
High	Process of TS and R corresponds to projects at which application in the past has a large number of refusals.	7-8
The very high	Defect emergence is inevitably.	9-10

Tab. 4. **The detection probability scale of the risk (*D*)**

Detection probability	Detection probability of discrepancies on the basis of the providing control operations	Coefficient K_D
Very low	Emerging faults cannot be identified (no access or opportunity to control). "Latent defect"	10
Low	Identification of the arising refusals difficult / technological checks are inefficient	8-9
Average	It is difficult to identify refusals at control and tests	7-6
Moderate	Detection of discrepancies is improbable	5-4
High	Easy to identify refusals	3
The guaranteed	The arising refusals obviously are distinguished (Detection probability > 95 %)	1

Tab. 5. The calculation of critical violations operations of TS and R, for on-line maintenance subprocess of the power convertor TDTN-25000/150-70 U1 TP

Transactions number	Coefficient K_S	Coefficient K_O	Coefficient K_D	Critical violations operations K_R (*RPN*)
1	6	6	3	108
2	7	3	3	63
3	8	7	8	448
4	7	8	5	280
5	9	7	3	189

Tab. 6. The calculation of critical violations operations of TS and R, for on-line maintenance subprocess of the power convertor TDTN-25000/150-70 U1 (after elimination (reduction) of potential causes of infringement)

Transactions number	Coefficient K_S	Coefficient K_O	Coefficient K_D	Critical violations operations K_R (*RPN*)
1	4	4	3	48
2	5	2	3	30
3	8	5	7	280
4	7	6	5	210
5	7	5	3	105

Calculation results of critical violations operations TS and R at on-line maintenance subprocess of the power convertor (table 1) given in table 5.

At the following stage ranging of critical violations and refusals, for which criticality of operation was carried out K_R (*RPN*) exceeds limit (100...125) and for which the correcting actions after decrease in coefficients criteria of risk are developed. The organizational and technical solutions directed on prevention of possible failures, minimization of probability of emergence of the revealed potential failures by improvement of technical servicing and repair systems, operating rules, improvement of diagnostics methods and quality control and to introduction of special measures for the prevention, identification and elimination of defects, etc. developed for this purpose.

Calculation results of critical violations operations TS and R of on-line maintenance subprocess of the power convertor TDTN-25000/150-70 U1, after the taken measures for system improvement TS and R and the repeated analysis of possible causes of infringement and potential consequences of violations, provided in table 6.

According to the calculated data of critical violations operations *RPN* for on-line maintenance subprocess of the power convertor before elimination of potential causes infringement (table 5) and after elimination (table 6) construct the diagram of critical operations of on-line maintenance subprocess of the power convertor (fig. 2). Where: *RPN*1 critical violations operations (1, 2, 3, 4, 5) of on-line maintenance subprocess of the power

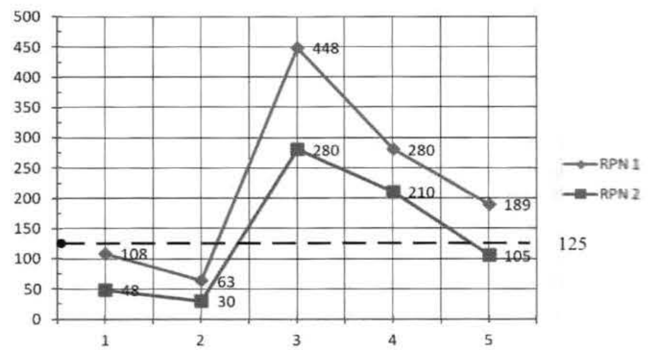

Fig. 2. *Critical operations RPN of on-line maintenance subprocess of the power convertor TDTN-25000/150-70*

convertor by results of primary analysis; *RPN*2 critical violations operations (1, 2, 3, 4, 5) of on-line maintenance subprocess of the power convertor after elimination of potential causes of infringement of operations (improvement of maintenance system). As we see, the most critical operations in on-line maintenance subprocess of the power convertor are operations 3 (*RPN* = 448 > 125), 4 (*RPN* = 280 > 125) and 5 (*RPN* = 189 > 125) before improvement of system and operation 3 (*RPN* = 280 > 125), 4 (*RPN* = 210 > 125) after improvement of technical servicing.

Using results of the possible dangers analysis [McDermott, Mikulak, Beauregard 1996; PTC Windchill FMEA], causes of infringement and potential consequences of violations at the organization of power equipment technical servicing TP ECh-2, and also equations (1), (2), (3), make the calculation of criticality subprocesses: No. 1 – maintenance planning, No. 2 – preventive check (survey), No. 3 – on-line maintenance, No. 4 – inter-repair tests, No. 5 – capital repairs of the equipment, No. 6 – works financing on technical servicing.

According to computation data of subprocesses criticality No. 1, No. 2, No. 3, No. 4, No. 5, No. 6 of system TS and R of power equipment RS construct the comparative criticality diagram, the critical value that is rather established by experts *RPN* = 125 (fig. 3).

As can be seen from the diagram (fig. 3), the most critical subprocesses is No. 6 – works financing on technical servicing (*RPN*6 = 175, 3 > 125); No. 3 – on-line maintenance (*RPN*3 = 170, 8 > 125); No. 5 – capital repairs of the equipment (*RPN*5 = 156, 1 > 125). To solve this problem, necessary to continue the work on the development of measures to improve the quality and continuous improvement of TS and R of power equipment RS. The information about conducted activities have to record in terms of

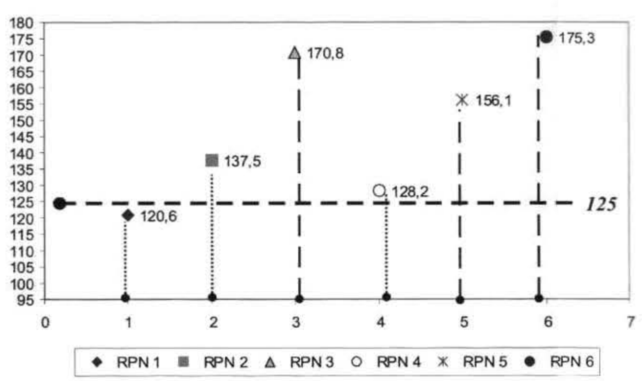

Fig. 3. *Subprocesses criticality of TS and R system of power equipment RS*

implementation with time-aware, taking into account the duration of their implementation and the expected cost.

Subprocess: No. 1 - maintenance planning (*RPN1* = 120, 6), No. 2 - preventive check (survey) (*RPN2* = 137, 5) and No. 4 - interrepair tests (*RPN2* = 128, 2) are on the verge of criticality. These subprocesses require timely intervention wearing corrective nature of the organization and maintenance of the equipment.

Conclusions

Today, FMEA/FMESA used worldwide in various industries, and has become an integral part of quality assurance systems. It is especially necessary to carry out FMEA/FMESA when creating new production process to test them to ensure the desired product quality. The main objectives of improving the system of TS and R of railway substations for quality assurance are detection and prevention of functionally weak and critical to the reliability and dependability of equipment locations and documentation for quality assurance. Improvement of quality considered reached if the new priority number of risk of RPN after improvement of system has smaller value than earlier. The offered technique of continuous improvement of system TS and R of railway substations allows to carry out the analysis of critical operations and subprocesses of system, and to define surgery area in process of technical servicing and repair of the equipment at operation, throughout life cycle.

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Authors:

Dr. Eng. **Matusiewicz Oleksandr** - Dep. „Power Supply of Railway Transport", Dnipropetrovsk National University of Railway Transport, Ukraine

Prof. Dr. Habil. Eng. **Syczenko Wiktor** - Dep. „Power Supply of Railway Transport", Dnipropetrovsk National University of Railway Transport, Ukraine

Dr. Eng. **Białoń Andrzej** - Instytut Kolejnictwa, Poland