PROBLEMS AND TASKS FOR ASSESSING THE QUALITY OF RELAY PROTECTION DEVICES

Evtim Kartselin, *University of Mining and Geology "St. Ivan Rilski", Sofia, BG*
Angel Zabchev, *University of Mining and Geology "St. Ivan Rilski", Sofia, BG*
Nikolay Minekov, *Assarel-Medet JSC, Panagyurishte, BULGARIA*
Petar Kolev Petrov, *Technical University of Gabrovo, Gabrovo, BULGARIA*
Krasimir Marinov Ivanov, *Technical University of Gabrovo, Gabrovo, BULGARIA*
Georgi Tsonev Velev, *Technical University of Gabrovo, Gabrovo, BULGARIA*

ABSTRACT: *The paper inhere summarizes some results in regard with the operation, the reliability and quality of relay protection devices (RPDs), used in the electrical power systems. Some important studies and solutions have been formulated in order to enhance the quality of RPDs and the long-term stability of the electrical power system of a country.*

KEY WORDS: *failures, quality of relay protection devices.*

1.INTRODUCTION

Regardless of the significant achievements of theory and industrial technologies, the electricity systems at the beginning of the 21^{-st} century face serious problems to solve, such as:

- 20^{-st} century energetics is built on the so-called "non-renewable hydrocarbon sources" (coal, oil, gas), which stocks at today's consumption rates will be exhausted in foreseeable future;
- 20^{-st} century energetics is built on the basis of technologies and processes that have a strong negative impact on the environment. By virtue of international treaties, this negative impact must be severely reduced within a short period of time;
- The Chernobyl nuclear power plant (1986) and Japan's Fukushima - 1 nuclear power plant (2014) have had a strong impact on reducing and limiting the rates of development of nuclear power sources as a serious alternative for the 21^{-st} century;
- Energy sources included under the generic term "renewable energy sources" are not yet a serious alternative to non-renewable sources. This is because there are still a number of important issues and problems that limit their day-to-day and year-round use (providing technical capabilities and solutions for accumulating electrical energy in industrial scale, etc.);
- These and some other issues and problems pose the necessity of accelerating the development of renewable energy sources and the implementation of achievements in Nano- and information technologies;
- The actuality of these problems and tasks is determined by the following two essential and relevant factors:
  - ✓ The occurrence of failures and accidents in electrical power systems in different countries around the world, including in the industrially developed ones, is not an exception but a frequently occurring event.
- ✓ The operation of energy systems with today's design, equipment and principle, will not change in the next 25-50 years, around the world;

In many countries, different technical systems have been put into operation, where the interruption of power supply inevitably leads to major failures and disasters.

The paper inhere summarizes information on some results in regard with the operation of RPDs and the methods that are used to determine their quality.

2.METHODS AND EXAMPLES FOR EVALUATING THE QUALITY OF RPDS IN THE ELECTRICITY SYSTEMS.

In a number of EU countries, the reliability of RPDs has been assumed to be assessed by the following three indicators [2]:

- ✓ Tripping reliability (Dependability) *D:*

$$D = \frac{N_C}{N_C + N_F} \quad (1)$$

- ✓ Non-tripping reliability (Security) *S*:

$$S = \frac{N_C}{N_C + N_U} \quad (2)$$

- ✓ General reliability (Reliability) *R:*

$$R = \frac{N_C}{N_C + N_F + N_U} \quad (3)$$

,where N_C – number of correct RPD trip-outs; N_F. – number of RPD trip-out failures; N_U - number of RPD unneeded (faulty) trip-outs.

Expressions (1), (2) and (3) doesn't reflect correctly the RPD reliability, since they do not take account of internal faults and malfunctions inside the RPDs, which can result in relay protection disfunction.

In Russia, the issue of estimating the reliability of RPDs is not addressed directly nor regulated in legal documents. Instead, it is stated in [3] that "a key indicator for the correct operation of RPDs is the percentage of their correct trip-outs, obtained by the formula:

$$K = \frac{N_{PS}}{N_{PS} + N_{IS} + N_{LS} + N_{QS}} 100\% \quad (4)$$

,where N_{PS} – number of correct RPD trip-outs; N_{IS}. – number of unnecessary RPD trip-outs; N_{LS} - number of faulty RPD trip-outs; N_{QS} - number of RPD trip-out failures

When comparing these two methodologies, it is clear that they are perfectly identical and cannot properly reflect the reliability of RPDs. The explanation is that such methods for evaluating the performance of RPDs operate with absolute rather than with normalized indicators [8].

In Fig. 1. are presented graphically analyzes about the reasons for RPDs'failures.

In each figure (Figure 1 a, b) there are two diagrams: one for Electromechanical Relay Protection Device (ERPD) and the other for Microprocessor Relay Protection Device (MRPD).

In regard with [8], the frequency for occurring of failures in MRPDs and ERPDs is comparable, but the ratios of reasons for these failures are different.

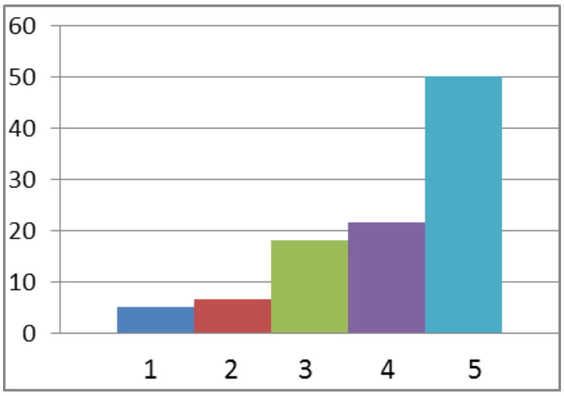
In other words, if we make conclusions about reliability in regard with the frequency for occurring of failures, it can be assumed that the reliability of MRPDs and ERPDs are comparable. The question is if it is acceptable to make such a conclusion on the basis of a comparison of the left and the right parts of the diagrams in Figure 1?

Such a comparison is unacceptable because the number of relay units in operation for which the numeric values of failures are used is not taken into consideration in the diagrams. This is a typical error for counting the absolute values rather than the normalized ones (i.e., relative to the number of objects under consideration).

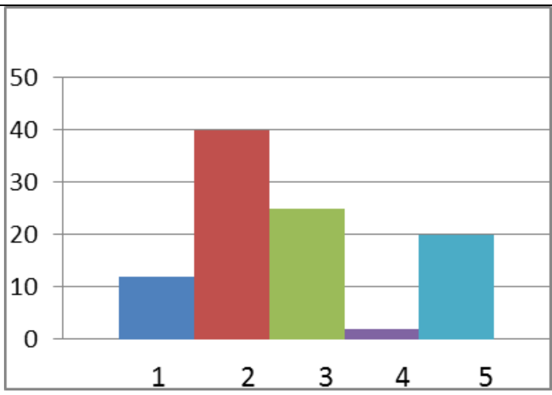
In [6] is presented data about the operation of MRPDs and ERPDs.

In the period between 2000 and 2009 are registered 2913 cases of MRPDs' trip-outs in electrical power lines and electrical equipment with rated voltage of 110 kV. In 89.5% of the cases, the tripping has been correct and in 10.6% has been faulty.

For the same period of time, ERPDs have tripped-out 17 529 times. In 93.52% of these cases tripping has been correct, and only in 6.48% faulty. In this example normalized RPD failures have been rendered, i.e. the number of failures for each type of relay is represented as a percentage of the total number of relays' triggering. Dividing 10,6 to 6,4, it is concluded that MRPDs are 60% less reliable than ERPDs.

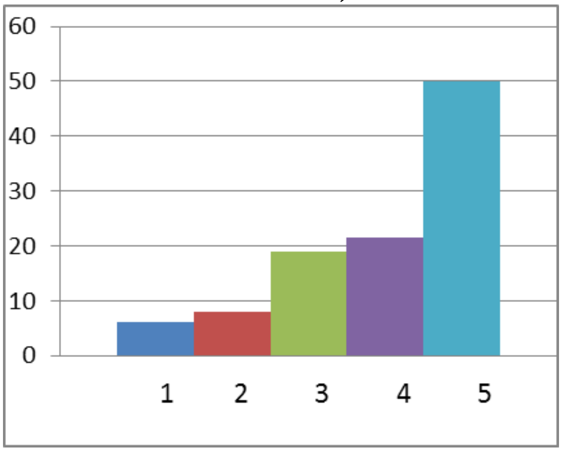


Electromechanical RPDs

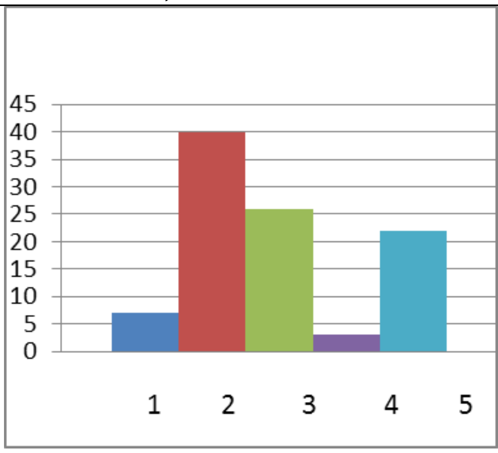


Microprocessor RPDs

a) RPD failures in the period 200 – 2009, %



Electromechanical RPDs



Microprocessor RPDs

a) Annual RPD failures, %

Figure 1. Diagrams of failures of distance relays, protecting electrical power lines: a) data taken from [4]; b) data taken from [5], where: 1 - failures as a result of testing errors and during the operation; 2 - failures as a result of errors in the definition and the adjustments of the tripping settings and their values; 3 – failures, as a result of structural disadvantages; 4 – failures as a result of technical problems; 5 – failures by undetermined reasons.

The important conclusion that can be made from the analysis of fig. 1 is the sharp increase in the percentage of RPD failures, associated with the so-called "human factor" in the transition from ERPDs to MRPDs:

- ✓ failure rate, associated with errors in defining and configuring of relays' settings increases almost 6 times;
- ✓ in the process of testing and in operation the RPDs there is an increase of failure rates with 4 times.

The "human factor" influence is also confirmed by other researchers and according to them the "human factor" is a reason for 52,8% of the cases with inadequate tripping of RPDs [7].

According to [4] in a number of European countries this percentage is even higher and reaches 78%, i.e. in fact, this factor is one of the main reasons for inadequate operation of RPDs.

One of the main questions is: Why is the transition from ERPDs to MRPDs, accompanied by a sharp increase in the impact of the "human factor"?

An answer of this question is given in [8] in regard with the Multifunctional protection relay Siprotec 7SJ642 (Siemens). The operating manual of this protection relay includes more than 100 pages and the operator must enter about 500 parameters (settings) via the terminal or via computer interface. Considering the need to compile assignments for setting-up of protocols for verification of the terminals, in which all setup parameters must be specified, the volume of documentation becomes too large.

The large amount of information that is introduced complicates the set-up of the protection relay. The reserve of information (surplus) increases the probability for human errors. The Technical Reserve requires highly qualified specialists to work with the terminal of the relay. The manufacturer's documentation for operation with the relay terminal consists of thousands of pages, and often inside there is a lack of information, mistakes are also not excluded.

On the basis of the above, the reasonable question arises: how is it possible to assess the level of technical reliability of modern RPDs without taking into account the influence of the "human factor"? It is not important what is the reason for failure (improper behavior) of the RPD for assessing the reliability. Incorrect settings, wrong logic, programmatic bypassing of separate functions during testing, and the usual "forgetting" to recover them to default after completing the tests - all these are put under the common name "human factor" and lead to the same malfunction of the relay protection, as in possible internal faults and malfunctions in its electronic circuitry. Moreover, since one type of relay differs from the other on the element base and the schematic technical solutions used, different brands of relays will have different reliabilities, having also different programming interfaces. Some MRPDs have simple and comprehensible interface and other are too "complicated" and "unpleasant" to work with, which shall result in significant increase in the influence of the "human factor".

The methodologies used to assess the quality of RPDs do not reflect the objective factors and need serious corrections. In [8] it is proposed to take into account the following three types of RPD failures when assessing the reliability:

- ✓ *relay failures* that are not related to improper behavior of the RPD, but require repair or replacement of out-of-order elements, blocks and modules - M_S;
- ✓ *Incorrect RPD trip-outs*, i.e. unnecessary tripping in the case of an absence of a fault or not tripping in typical faults, when these incorrect behavior is not associated with human mistakes - M_D;
- ✓ *Personnel errors* related to the operation, testing, and programming of RPDs that affect their proper functioning, and are detected before or after the RPD malfunction - M_P.

All these components are included in a generalized and normalized RPD failure indicator, defined by the expression:

$$M_{\Sigma} = \left(\frac{M_S + M_{Di} + M_{Pi}}{N_i} \right).100\% \quad (5)$$

, where M_{Si}, M_{Di}, M_{Pi}. – number of failures from the respective type for relays from the i^{-th} kind for a chosen time period; N_i - number of relays under operation from the i^{-th} kind for a chosen time period.

If the above method is used, it seems that the reliability of MRPDs is significantly lower than that of the ERPDs. This does not mean that the process of production and implementation of MRPDs should be limited.

However, it must be taken into account that the operation of MRPDs is accompanied by serious problems that require proper studies and solutions.

Some of the ways to solve these problems are proposed in [8]. These ways are summarized as follows:

- ✓ Prohibition of the use of functions in MRPDs which are not associated with their main protective function, such as functions for electrical equipment monitoring etc.;
- ✓ Significant limitation of the number of functions performed by a microprocessor terminal; optimizing the number of these functions not only on the RPD value criterion but also on the reliability criterion;
- ✓ Disabling the use of algorithms with undetermined logic, allowing for unpredictable relay protection actions;
- ✓ Simplifying the programming interface as much as possible on the basis of one and the same interface platform, applicable for all MRPDs’ manufacturers and models;
- ✓ Manufacturing of computerized testing equipment by leading manufacturers with a set of programs fully compatible with the universal RPD programming platform, allowing for fully automating the MRPDs’ testing and substantially reducing the impact of the "human factor";
- ✓ New principles for the design of MRPDs based on universal interchangeable functional modules.

3.A SOLUTION FOR ENHANCING THE QUALITY OF MICROPROCESSOR RPDS WITH DEPENDENT CHARACTERISTICS

One of the features of modern microprocessor relay protection devices is that they have one independent and up to 11-16 dependent characteristics. Functional dependence $t = f(i)$ of the dependent characteristics is described by mathematical models corresponding to the requirements of:

- ✓ Standard IEC 255-4
- ✓ Standard ANSI/IEEE (used only by European manufacturers);

For example, for relays with dependent characteristics, manufactured under the IEC standard, the dependence between the flowing current and the trip-out time is presented by:

$$t = \frac{k\beta}{(I/I>)^{\alpha} - 1} \qquad (6)$$

, where t - trip-out time, s; k - coefficient; I - current flowing through the relay, A; $I>$ - relay trip-out current, A; α and β – constants, which values are given in the documentation of the manufacturer.

One of the problems to solve during the design and the implementation of MRPDs is the choice of the most appropriate type of characteristic and the calculation of the relay trip-out current value $I>$.

In [16], about MRPD of the Sepam company (having 16 standard characteristics), it is recommended to start with the sample method with one particular characteristic. In [16] using the Micom MRPD (with 11 standard characteristics), examples are given for the use of specific characteristics in different conditions, which requires prior knowledge and experience. In both cases it is suggested to work on the "trying" method.

Such an approach, related to the requirement to co-ordinate this MRPD with the neighboring RPDs (before and after) is extremely difficult. This is a reason often in practice RPDs with dependent characteristics not to be used, although their use is better in terms of relays coordination and selectivity.

In the process of producing of computer software to calculate the settings of RPDs for protection of power lines 6 - 10 -20 kV using MRPDs with dependent characteristic, a typical problem is the automation of the process of selecting the correct characteristic type. The graphical methods adopted in [16] and [17] to determine the RPD selectivity are based on a visual evaluation that is not suitable for automated computations.

In order to overcome and solve these problems and difficulties, the authors of [18] develop and implement algorithm for automatic selection of the RPD characteristic, following the condition for simultaneous co-ordination with the characteristics of the neighboring RPDs

A new concept of "Characteristics Rating" is introduced to perform quantitative analysis. The calculation of the rating of all types of characteristics for a particular MRPD allows, in an analytical way, to assess the relevance and efficiency of using each of them under the condition for co-ordination with adjacent RPDs.

"Characteristics ratings" is a computed abstract value that allows comparing the efficiency of use of MRPD's characteristics for the conditions of a particular line.

Fig. 2 shows an example, about the calculation of MRPD's settings for power line 2, the characteristic of which is selected and coordinated with the settings of the adjacent relays (1 and 3) using the characteristics rating.

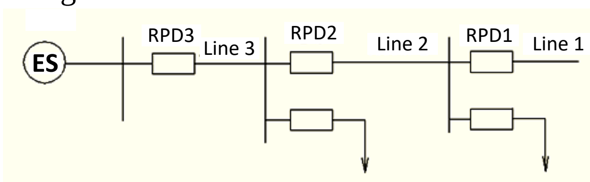


Figure 2. Equivalent circuit for determining the relay protection settings.

4.SOME RESEARCH TASKS TO IMPROVE THE QUALITY OF RELAY PROTECTION DEVICES

- ✓ Development of principles for building adaptive RPDs, i.e. which automatically change their setting depending on the mode of operation of the Electricity system(ES);

✓ Developing and verifying of ES modeling and research technologies for the purposes of relay protection;

✓ Development and implementation of new principles for building RPDs based on modern communication and nano-technologies;

✓ Solving practical aspects of functional integration, including questions about the distribution of functions between devices, including additional features such as monitoring, increasing measurement accuracy, determining the location of grid failures, etc.;

✓ Opportunities to increase the computing resource of intelligent electronic devices in order to provide cyber-security by encryption/decryption of output/input signals;

✓ Principles for implementation of multiple levels of access to intelligent electronic devices (restricted access, access control, full access);

✓ Evaluation of results about the advantages of use of standard solutions in the RPDs;

✓ Exploring and solving of issues, related to RPDs' settings and adjustments control;

✓ Development and validation of technical documentation, which regulates the requirements for design, operation and maintenance of systems for automation in "digital" substations;

✓ Coordination of RPDs with the requirements to the Energy systems of the 21^{-st} Century;

✓ Development of modern methods for onsite adjustment, testing and verification of RPDs' settings at the installation site.

✓ Development and implementation of modern cyber-security solutions for relay protection and ES control systems;

✓ Development and creation of a methodology for checking the relay protection functions under real operating conditions on the basis of the IEC 61850 standard;

✓ Development of principles and methods for ensuring normal operation of RPDs in the conditions of increased levels of electromagnetic disturbances in the ES;

✓ Development of RPDs for application in the intelligent electrical power networks with active and adaptive functions;

✓ Summary of the issues and development of curricula for quality training, qualification and improvement of relay protection professionals.

CONCLUSIONS

✓ The state of the 21^{-st} ES in each individual country will be one of the main indicators of life quality, national security and environmental safety;

✓ Experience taken from major accidents in the Energy Sector with catastrophic consequences in industrially developed and developing countries is an indisputable proof for the existence of unsolved issues and problems in this area, one of which is related to the quality of RPDs, used in the electricity systems.

✓ Development of science, justification and development of new principles and methods for the design and operation of sites in the energy sector, ensuring a certain level of safety, is a current task for implementation;

✓ The quality of the design, manufacturing, installing, setting-up and operating of objects in the ESs is primarily dependent on the quality of all specialists and professionals, involved throughout the entire life cycle of an electrical system. That's why one of the most important strategic tasks in the 21^{st} century electricity systems should be the development, training and qualification of qualified professional technical staff;

✓ Creation of research centers on specific topics, issues and problems, related to the energy systems of the 21^{st} century in narrow collaboration with the technical universities will result in the better management of Electricity Systems.

REFERENCES

1. Grechin, V. P., M. V. Sharigin. Questions related to diagnostics of electrical power equipment via the "Chaos" theory, IGEU, vol. 9, 2009
2. Moxley R. Analyzing Relay Fault Data to Improve Service Reliability: http//www.selinc.com.

3. RD 34.35.516-89. Instruction for calculation and assessment of the operation of relay protection and automation of the electrical part of the power system. Energy Union, 1990.
4. Kjolle G. H., Heggset J., Hjartsjo B. T.q Engen H., Protection Systems Faults 1999-2003 and the Influence on the Reliability of Supply. 2005 IEEE ST. Persburg Power Tech., St. Petersburg (Rusia), 27-30 June 2005
5. Voropay, N. I., N. E. Sartova, Analyses of failure statistics of relay protection and automation devices on the microprocessor base by modeling of cascading accidents. - Reports of the 3rd International scientific and technical Conference "Power systems: management, competition, education", Ekaterinburg, 13-16 November 2008.
6. Konovalova, E.V., Main results of the operation of Relay Protection Devices and Automatic Equipment of power systems in the Russian Federation. – Collection of papers of XV scientific and technical Conference "Relay protection and automation of power systems", Moscow, 2002.
7. Beliaev, A. B.. V. V. Shirokov, et.al, Digital terminals of Relay Protective Devices. Experience in their adaptation to the Russian conditions, News in Electrical Engineering, 2009,Vol. 5.
8. Gurevich, V. I., Problems, assessments of the reliability of relay protection devices. Electricity, 2011, Vol. 2.
9. Gospodinov, D. K., Investigation of relay protective devices intended for asynchronous motors in special design. Abstract of a dissertation for awarding educational and scientific degree "PhD", TU - Gabrovo, 2015.
10. Ordinance No. 3 for the design of Electrical Installations and Electricity Lines. (Published in Official Gazette No. 90 and 91 of 2004).
11. IEC 61850-5: 2003, Communication Networks and Systems in Substations; Communication requirements for functions and device models.
12. IEC 61850-7-3: 2003, Communication Networks and Systems in Substations. Basic communication structure for substation and feeder equipment – Common data classes
13. Maksimov, B. K., A. O. Anoshin, Testing and development of relay protection devices and automation equipment under the condition for compatibility by the requirements of IEC 61850. Moscow niversity of Electrical Power Engineering, 2007
14. Gurevich, V. I., Problems of testing microprocessor protection relays for resistance to intentional electromagnetic disturbances. Components and technology, 2014, Vol. 12.
15. Gurevich, V. I., Problems of testing microprocessor protection relays for stability to intentional electromagnetic disturbances, Component and Technology, 2015, Vol. 3.
16. Solovev, A.P. Choice of characteristics and settings of protection relays for electrical equipment using microprocessor terminals – Library “Electrical Engineering”, 2008, Vol.4.
17. Recommendations on the selection of settings for relay protective devices of electrical equipment using ALSTOM microprocessors. Kiev, Energomashvin, 2000, Vol.
18. Fleginsky, N. M., Calculation of relay protection settings of microprocessor protection relay with dependent characteristics, intended for power line 6 - 10 kV, Electrical Stations, 2009, Vol. 4.