POLITEHNICA UNIVERSITY OF BUCHAREST

FACULTY OF POWER ENGINEERING

Doctoral thesis

ANALYSIS OF PROTECTION SYSTEMS INFLUENCES ON POWER QUALITY

ENGLISH RESUME

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1 Introduction

The problems of power quality, important for functionality of power systems, have gained in the recent years a topicality and a special importance, especially due to the emergence of increasing consumers sensitivity to disturbance.

This situation had led to a permanent concern at the current stage for power quality, planning, monitoring, standardization of disruptive emissions and the establishment of compatibility at all levels as international, European and national.

The topic proposed in this thesis addresses the current concerns regarding the power quality supplied and the identification of deviation areas from the parameters of reliability focused to the protection relays systems.

2 Objectives of the thesis

The objectives of the thesis appear from the real need of a better knowledge of the areas of impact on power quality indicators, given that the current power systems are becoming increasingly charged and sensitive due to the increase in energy supply for both industrial and residential consumers.

By conduction a simulative study, the main objective of this thesis is to obtain new sets of information for the power quality indicators related to the functionality in power systems of protection relays. Starting from the theoretical bases and current regulations in the energy field, the paper focuses on the study of the influences of protection relays on and from the power system in terms of the quality of energy supplied to end users.

Based on the simulation study, in addition to identifying the behavior of protection relays on power quality, this paper aims to identify areas that require legislative changes in the energy field.

3 Importance and actuality of the topic

The current development trend of smart grids, the wide implementation of distributed generation and renewable energy sources as well as the specific requirements of the energy market have led to increasing concerns about the power quality provided to the end users.
The variable nature of generated energy by renewable sources, the possibility of user participation in the energy market as an active user (producer and user), the possibility of insularized operation of smart grids, substantial increase of electronically controlled equipment, can cause large variation in power flows in the energy transmission and distribution networks as well as the propagation, in the energy networks, of some important electromagnetic disturbances with negative effects on the power quality indicators

Ensuring the level of power quality to end users depends on the actions of the energy supplier but also on the action of active users from network. The main measure to be taken in order to maintain the quality of energy in the network is to establish the level of disturbances allocated to each user so as the ensure the level of quality required by regulations in the network.

4 Thesis structure

Analyzing and studying more than 80 bibliographic, scientific papers from the energy field, this thesis is structured in 5 chapters containing consistent and actual information, presented in approximately 200 pages. The chapters of the thesis are structured as follows:

— **Chapter 1** represents an introduction to the study conducted by presenting the objective and structure of the thesis, pointing out the importance and timeliness of the subject studied;

- **Chapter 2** focuses on outlining the basic theoretical notions of protection relays and their role in the power systems. In addition, are presented the requirements for relay protections by specifying the types of protection depending on the role in the system or the controlled size. In this chapter are classified the existing types of relays, pointing out the technical differences from one generation to another;
- **Chapter 3** presents the general theoretical aspects regarding the quality of energy, the standards and regulation up to date, highlighting the primary and secondary components of power quality. This chapter presents also the theoretical notions regarding the indicators needed to assess the quality of the power supply service and the impact of system disruptions on protection relays. In this chapter is also presented information on the general existing regulations with the identification of regulations on compensation for non-compliance with performance indicators of the power supply. In the final part of the chapter are introduced and presented the basic notions regarding the damages associated with the deviation from the power quality indicators;
- **Chapter 4** presents the basic theoretical notions regarding the probabilities and applied statistics that were used in the applicative study of this thesis. Statistical methods of probability and correlations are also presented in this chapter;
- **Chapter 5** represents the application part of the thesis in which was performed a statistical and technical-economical analysis of the influence of protection relays in association with power quality. This study aims to identify the functionality of different types of protection relays in energy systems in terms of quality parameters of electricity. The final chapter is aimed at establishing conclusions and perspectives, as well as emphasizing all the original aspects of this thesis.

The theoretical part of the doctoral thesis, contained in the first 4 chapters, focuses on the presentation of basic notions of power quality in relation to the impact on the functionality of protection relays in power systems, with guidance in presenting the concepts used in conduction the application study presented in chapter 5. This part was written studying and analyzing a volume of over 80 articles and bibliographic papers, conducting a comparative study of existing information published in the energy field, in order to present the theory in a topical form and related to the subject of the thesis.

5 Simulative study

Chapter 5 presents the results obtained and methods used in a simulated way to evaluate the behavior of classical and numerical protection relays in relation to power quality indicators. The main purpose of the simulative study is to identify the influences of protection relays on and from the power distribution networks, influences related the power quality indicators.

The simulative study was performed starting from a real electrical distribution scheme that was transposed and implemented software with a calculation algorithm to evaluate a set of reliability parameters (time and number of interruptions, power and energy not supplied) related to two scenarios (numerical and classical relays) The study includes the following phases:

- **Phase 1**: Establishing the studied parameters and identifying the technical characteristics → material presented in chapter 5.2. In this phase are identified the parameters studied starting from the reliability indicators to the characteristics of the studied relays (numerical relays and classical relays) and the structure of the distribution network used;
- **Phase 2**: Statistical analysis of secondary power quality indicators → material presented in chapter 5.3. In this phase are presented the results of the simulation performed on the test network implemented with operating algorithm and probabilistic calculation

method (Monte Carlo method) on the two scenarios studied (numerical and classical relays)

- **Phase 3**: Evaluation of the probability distributions of the power quality indicators, interruption time and number of interruptions for the distribution test network → material presented in the chapter 5.4. In this paragraph are presented the results obtained on the test network for probabilistic distribution curves and correlation between the studied scenarios;
- **Phase 4**: Method of confirming the results obtained (simulated vs real data) → material presented in chapter 5.5. At this phase, MSE, RMSE and MAPE errors were determined for the simulated results compared to a real situation;
- **Phase 5**: Analysis of the technical and economical forecast for interruption duration of the studied test network → phase presented in chapter 5.6.
- **Phase 6**: Propose a calculation formula for rewarding users → phase presented in chapter 5.7.

6 Conclusions

C1 – General conclusions

- A mathematical algorithm developed in the Matlab program was successfully implemented to simulate the real operation regime of medium voltage system having in active component both the switching and protection equipment through relays;
- The algorithm developed for the simulation of electrical network was implemented having as probabilistic method of occurrence of defects in the system the Monte Carlo method;
- In the simulation algorithm was implemented as a test network the single line diagram of the UPB electrical diagram with the identification of quality characteristics (probability of connection and probability of selection) for protection relays using comparative data obtained from simulations performed in ETAP program and from technical characteristics in the user manuals of protection relays from several manufacturers. Was considered 2 scenarios consisting of numerical relays (Scenario 1) and classical relays (Scenario 2);
- The results obtained on the test network implemented in the simulation algorithm were compared with the analytical values of the reliability indicators, an approach that highlighted the fact that Monte Carlo method applied to the data falls withing the 95% confidence interval compared to the data obtained from real system;
- From the diagram of the probability curves correlated between the scenarios it can be seen that the numerical relays have a better selectivity and shorter response time compared to the classic relays;
- Comparison of the simulated results with the data obtained from the real systems (actual situation recorded in 2 different MV stations) confirms the correctness of the study and identifies a 15% increase in interruption time for older generation of relays (Scenario 2, Classic relays) compared to modern relays, numerical relays. It can be concluded that the systems consisting of older generation of relays bring additional costs annually through the longer interruption period by 15% more than the newer relays generation.

C2 – Original contributions

- The algorithm developed for the simulation of distribution networks can be used for any single line diagrams by stratifying the lines and nodes and by extracting the incidence matrices and implementing in the algorithm created;

— A complex study was conducted on the influence of power quality on and from the protection relays part, comparing 2 different generation of protection relays;
— Taking into account the results obtained in the study, a formula was proposed to reward users who have in the internal systems new generation of relays.

C3 – Prospects for further development

— Algorithm that can be improved by using artificial intelligence algorithms in order to reduce analysis times as well as errors that may occur as result of numerical analysis;
— Publishing articles in specialized literature in Romania to popularize the need to integrate the latest generations of protection and SCADA systems;
— The basis for the implementation of the penalty calculation formula with the support of the re-engineering of the stations on the protection side;
— Continuation of refining the statistical analysis algorithm based on real data from the system;
— The proposal for the implementation at the level of power regulator for the bonus/ penalty schemes for not meeting within the standards limits the quality of electricity voltage for the power distributors in Romania;
— Identifying a mechanism for judiciously allocating the cost of implementing new technologies in the field of protection and active control in order to optimize the high costs of possible penalties associated with the distributor as well as the consisted reduction of power outages for users.

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