PROTECTION PERFORMANCE ASSESSMENT OF A MUNICIPAL MEDIUM-VOLTAGE DISTRIBUTION SYSTEM

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ABSTRACT

Power system expansion and continuous change in municipal distribution systems make it necessary to regularly review and adapt protection settings and schemes. In particular, the increasing penetration of distributed generation has a significant impact on the protection system. This paper describes a new assessment methodology and summarizes the findings from a systematic network protection performance project carried out for a complete municipal 10kV distribution system of a 300,000 resident city.

INTRODUCTION

To ensure that the protection system meets the changing requirements caused by the evolution of the power system, the distribution system operator münsterNETZ GmbH in cooperation with Siemens division Energy Management conducted a systematic evaluation of the protection system of their municipal 10kV distribution system.

The goal was to analyze the performance of the currently used protection schemes and settings in the complete 10kV distribution system for all main operating states. The assessment criteria were to ensure selectivity and reliable starting of the protection devices for varying fault conditions.

To meet these targets, it was necessary to simulate the integrated power and protection system behavior for a large number of operating state and fault scenario combinations. The existing power flow and short-circuit model of the municipal 10kV distribution system was enhanced for this purpose by adding the protection devices and their main settings. On this basis a comprehensive and automated fault simulation and interpretation of the protection system performance was carried out.

The outcome was a clear overview of the protection system performance and the identification of potential improvements. In this paper the used assessment methodology is described and main findings from the systematic protection security assessment project are summarized.

BACKGROUND

MünsterNETZ GmbH, is a company of the Stadtwerke Münster group. Their municipal medium voltage system supplies electricity to 300,000 residents in the city of Münster. The annual peak load is approximately 220 MW and the circuit length is ca. 1,500 km. The medium voltage network is supplied by 10 primary substations feeding customer and distribution stations via open rings. Load centers are supplied via distribution stations. The distribution stations are connected via parallel cables to the particular primary substation.

Power System Model

MünsterNETZ GmbH can create a complete power system simulation model of their 10kV network from their geographic information system. The resulting model is available in Siemens‘ PSS SINCAL [1] power system simulation software and is updated regularly. The complete model comprises 12,000 buses, 10,000 cable segments and 2,500 distribution transformers, 15 110/10kV transformers and 70 distributed generation units.

In its original form, the network model has a geographic representation of all stations and cables. It is particularly suitable for structural system planning tasks because length and location information are directly available.

For operational planning and protection coordination tasks a schematic representation of the power system is more practical because main supply circuits and protected areas are more easily identifiable. Therefore, a schematic network diagram was added in the course of the project enabling users to switch between the geographic and schematic graphic.

Protection System Model

In the course of the project, the protection devices were added to the 10kV network model. In total approximately 600 distance and 100 overcurrent-time protection devices of different manufacturers were added to the network model. The protection settings are available electronically in spreadsheets from which they were imported by Siemens into the network model database.

The resulting integrated power and protection system model of the 10kV system was readily prepared for automated fault scenario simulation and checking of selectivity and pickup criteria.

Protection System Simulation

The objective of a comprehensive evaluation of the protection concept requires the checking of reliable pickup, tripping and selectivity of all protection devices for all possible fault locations and types. The application of these evaluation requirements on a large network model results in a very high number of fault location and fault type combinations that should be studied.
Particularly in meshed network structures – e.g. parallel feeder cables supplying a distribution station are considered as a simple meshed structure - additional complexities such as effects of parallel circuits and intermediate infeeds must be considered. Resulting consequences on the protection performance can only be fully assessed by means of simulation. As simulation solution, the SIEMENS software SIGUARD PSA [2] (Protection Security Assessment) was used in this project to simulate and assess the performance of the protection system.

Protection Performance Assessment

The protection performance assessment was done using the Protection Security Assessment (PSA) methodology [3–7] developed by Siemens which was already applied in distribution and transmission networks worldwide [8-10]. The protection security assessment includes data model creation and plausibility checking, power and protection system simulation, result interpretation, risk evaluation and optimization of the protection system.
The protection security assessment software is used to automate the combined power and protection system simulation, the performance assessment of the protection system, and result visualization and documentation. The application of a powerful software solution is necessary to be able to comprehensively and efficiently handle the complete protection system, consisting of both main protection and back-up protection.
Only a high degree of automation allows the systematic analysis of all possible network and fault scenarios. With classical protection coordination methods, this is generally not possible because they are mainly relying on the graphical depiction of setting characteristics in diagrams that are only valid for one or few operating states.
In contrast, the applied method evaluates the reliability of the protection system function based on integrated power and protection system simulation.

An additional advantage is that for the first time it enables the complete evaluation of all relevant combinations of expected operating and fault conditions. It reduces the risk that critical conditions are overseen. All fault scenarios are automatically created as illustrated in figure 2.

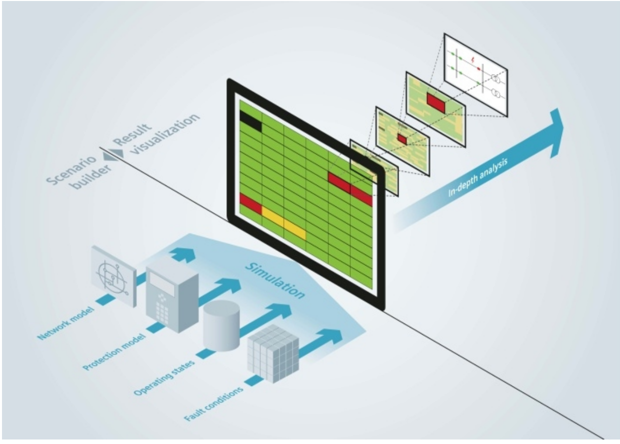

Figure 2: Scenario creation and graphical result visualization

From figure 2, it can be seen that the necessary input data – i.e. network parameters and protection data - can be imported and merged from different data sources, such as power system simulators, geographic information systems, EMS/DMS systems, equipment and protection databases. Alternatively, the data can also be entered or changed manually via a user interface.

Computation and result visualization

Depending on the network size the number of relevant operating conditions and fault scenarios can be become considerably high. All defined scenarios will be simulated and assessed in the background using parallel computing. Fault location, type and resistance are varied automatically within a specified network area based on user specifications. A fast simulation engine outputs the results even for large network sizes only after a relatively short computation time.
Another practical challenge is that the protection engineer has to select the scenarios that are relevant and critical for the optimization of the protection settings or schemes. To support this task a concise aggregated graphical result overview will be prepared summarizing all simulated cases.
The overall results are visualized in form of a matrix. The individual scenario results are indicated by means of color-coded cells. Critical cases are colored in yellow, red, black and non-critical cases in green. If required, critical scenarios can be analyzed in further detail (see figure 2). If necessary, each step of the fault clearing sequence can be viewed and analyzed in detail. All currents, voltages and impedances measured by protection devices are reported so that the protection system behavior is explained.

This solves two practical challenges. Firstly, the applied methodology gives a system- or area-wide overview of strengths and potential weaknesses of the protection systems which can otherwise not be created because it would simply be too time-consuming. The benefit is that the comprehensive results of the systematic protection performance assessment are the basis for the optimization of the protection system under both technical and economical aspects, i.e. it helps making well informed decisions.

Secondly, the repetition of the assessment for different operating scenarios, future network development phases should be fast and easy. The high degree of automation makes regular reviews of the protection system in a complete network area possible, and it allows fast checks of special cases. The benefit is that the provided deep insight into the behavior of the protection system allows not only identifying potential risks and improvement measures but also their validation and prioritization.

Consequently, the application the protection security assessment methodology assists and complements the conventional workflow of protection coordination tasks.

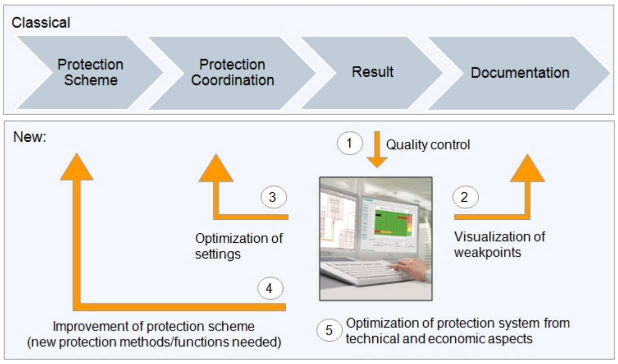

Figure 3: Classical vs. new protection coordination workflow

Optimization

The automatic evaluation is complemented with a meaningful result visualization enabling the identification of the few critical cases out of the large number of all studied operating and fault scenarios. This provides the basis for the next assessment step, i.e. the optimization and treatment of potential weak points. In general, the solution can be optimized protection settings, the enhancement of the protection scheme or changes in the primary system design.

The identification of the best option and the verification of the validity of the proposed measure can be done through additional simulation runs. Potential options and their pros and cons can be explored. This interactive optimization process can be repeated iteratively until all identified issues are resolved. The simulation based approach relieves the protection engineer from time-consuming calculations. Instead he/she can focus on the important issues and has more time to identify the most suitable solution.

Saving time and resources while having more accurate information readily available improves the protection coordination process. These are the drivers to apply the described approach on the complete 10kV distribution system of the münsterNETZ GmbH.

PROJECT EXECUTION AND RESULTS

Workflow

For the practical execution of the project, the complete 10kV power system model as shown in figure 1 was structured by defining supply areas fed from one primary substation. This allows the separate and parallel evaluation for one or multiple selected network areas. Due to the large network model size, it made the practical handling easier and improved the efficiency of the simulation. Following this approach the complete network can be studied by sequential evaluation of individual network areas that are part of one large model.

In order to validate the provided and imported power and protection system, data plausibility checks were performed prior to the main studies. A pre-analysis with an increased simulation step size was performed to identify potential data inconsistencies which could occur while merging data from different sources. At this workflow step, network and protection system data were consolidated so that the results are meaningful and trustworthy.

For the pre-analysis, it was deemed practical to evaluate only three to five fault locations per cable circuit. This reduces the number of fault scenarios to be analyzed and the computation time by a factor 2 to 6. When performing the detailed protection performance assessment the step size of the automatic fault location placement is decreased to five to ten percent of the circuit length. This increases the computation time requirement and, therefore, parallel computing of the earlier defined supply areas was used to keep the total computation time low.

Results

The evaluation of the assessment results showed that the large majority of the currently applied protection settings meet the defined quality requirements regarding pickup, fault clearance and selectivity. This is as expected because of the well structured network, and use of well established protection schemes and grading strategies.

In the first phase of the assessment process, for a small number of 37 protection devices unexpected performance with respect to selectivity were observed in the simulation results. These cases were then be analyzed in more detail.

For some of these protection devices the non-selective behavior was caused by obsolete or incorrectly entered input data in the protection data and setting spreadsheets. These cases were easily found and corrected.

Additionally, scenarios were found where non-selectivity would not occur in practice. The reason was for instance that in reality existing main protection schemes such as line differential or current comparison protection scheme were initially missing in the system model.

However, there were also cases identified for which the selectivity requirement was not met. Such an example will be discussed in more detail in the following. The protection security assessment results of an exemplarily selected network area are shown in figure 4.

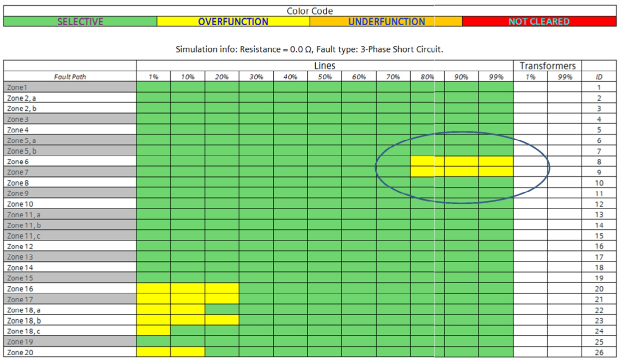

Figure 4: Results for original settings

The lines in the result matrix correspond to the protection zones (i.e. the part of the network protected by one or more protection devices) and each cell represents a fault location on a specific cable segment. The step size of the fault locations in the shown example is 10% of the circuit length.

From the results, it can be seen that faults are cleared selectively for the majority of the fault locations. Only for a small number of fault locations protection overfunctions – highlighted by the yellow cells - are observed. In the shown example, these fault locations are close to busbars which indicates that the zone reaches of one or multiple distance protection devices could reach potentially too far.

In the selected example, the identified protection overfunction for simulated fault locations occurs between 80% to 100% of the length of protection zones 6 and 7. The relevant cells in the result matrix are marked with the blue ellipse at the top right in figure 4. The analysis of these cases was done by evaluating the detailed results of each fault clearance sequence step in the protection simulation. The cause of the non-selectivity is illustrated in figure 5.

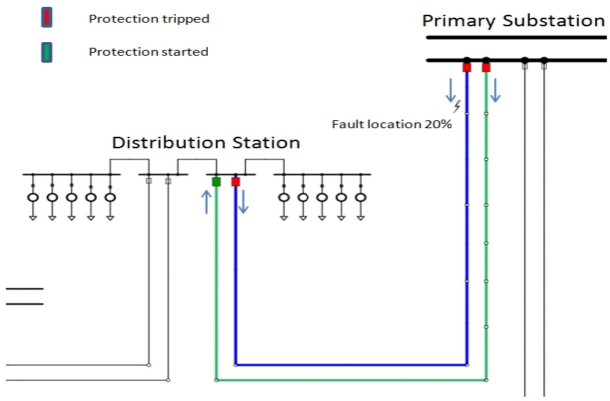

Figure 5: Example area

From figure 5, it can be seen that the analyzed fault location is placed at 20% of the cable length towards the busbar of the primary substation on the right side.

The results of final sequence of the stepped event fault clearing sequence analysis show that the distribution station would be unnecessarily disconnected in case of the considered fault scenario. This is because both protection devices protecting the two parallel cables from the primary substation would trip (marked in red). It was found that the overfunction would be caused because of the overlap of the zone 2 reaches of the distance protection relay in the distribution station and the one at the parallel cable in the primary substation.

In the described case, the power flow direction is unidirectional from the primary substation to the distribution station. Therefore, the non-selectivity can be resolved by extending the zone 1 reach setting of the distance protection device in the distribution station to 120% of the impedance of the cable from the distribution station to the primary substation.

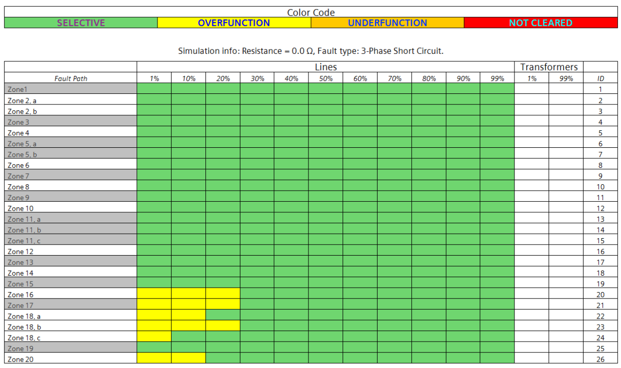

Figure 6: Results for new settings

To validate the effectiveness of the mitigation measure, the newly proposed settings were entered into the simulation model and the protection security assessment was repeated. The effect of the improved settings can be seen from comparison of the assessment result matrixes of the original and new setting in figures 4 and 6 respectively. It can be observed that the yellow cells in protection zones 6 and 7 have now changed their color into green (meaning selective fault clearance), i.e. the overfunction could be resolved by adapting the setting strategy of the distance relays in the distribution station.

Following the same approach, all identified potential weak points in the protection settings were successively analyzed and where necessary improved by münsterNETZ GmbH and Siemens protection experts. The effectiveness of each proposed improvement measures was verified by simulation.

SUMMARY

The application of a protection security assessment solution such as SIGUARD PSA enables münsterNETZ GmbH to review the performance of the protection schemes and settings for their complete municipal distribution system.
The protection performance assessment project confirmed the general correctness of the applied protection strategies. The systematic assessment also identified special cases which otherwise could not have been found. The system-wide assessment provided valuable information for the refinement and optimization of the applied protection concepts and setting calculation strategies helping to improve selectivity in the entire system.
Another significant benefit of the used assessment approach is that it can be applied easily for different operating conditions of the network and it is even possible to study the performance of the backup protection behavior.
Hence, it enables to assess and optimize the protection systems performance for all expected operating conditions. This is particularly relevant when there are changes in the power system, e.g. caused by construction projects which lead to new or abnormal switching states over a longer period of time for which selectivity and fault clearance must be guaranteed.
For such applications, automated protection security assessment solutions offer an efficient way to evaluate all operating states, and to determine and validate the suitability of protection settings or different parameters sets.

CONCLUSION

The project showed that the applied protection security assessment methodology and software enables systematic protection performance assessment for large municipal distribution systems. It provides deep insight into the protection system behavior and helps to optimize the protection system performance.

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