Journal of Power and Energy Engineering, 2014, 2, 525-531
Published Online April 2014 in SciRes. http://www.scirp.org/journal/jpee
http://dx.doi.org/10.4236/jpee.2014.24071

Automated Protection Performance Assessment and Enhancement

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Received October 2013

Abstract

New strategies and methods for assessing the security of protection systems to reduce the risk of unnecessary disturbances and blackouts are the main topic of the present paper. The system behavior of a protection system and network is analyzed and assessed as a whole. Hence, the established algorithms are capable to handle complex network structures with regard to an intelligent data management as well as data validation. Protection security assessment comprised two different aspects: on the one hand the behavior regarding dependability and security in terms of speed and sensitivity, on the other hand the behavior regarding the response on dynamic network phenomena as voltage stability and transient stability. A new automated method for assessing the dependability and security of protection systems is shown. The short-circuit simulation tool is used to provide a simulation system including network and protection devices as a whole. The handling of the large amount of resulting data is done by an intelligent visualization method like a "fingerprint" analysis. Further on the paper is focused on the protection response on dynamic network phenomena and presents innovative strategies for this investigation aspect. The structure of simulation environment will be described. Results of a case study show the application of this method on a real network. The system tool which is concluding these two aspects of protection assessment is called SIGUARD® PSA.

Keywords

Protection Security Assessment; Dependability; Security; Protection Coordination; Generic Protection Models; Dynamic Protection Simulation

1. Introduction

Protection security assessment of power grids is getting an important task in the course of a decarbonized power generation and a competitive energy business. The analysis of past blackouts shows that protection relays are involved in a high percentage rate of all major disturbances. Thus the prevention of blackouts has to deal with network and protection aspects as a common issue [1-3].

On the one hand an important issue for protection security is a regular review of the protection tripping be-

How to cite this paper: Jaeger, J., Liang, X.-P., Krebs, R. and Bopp, T. (2014) Automated Protection Performance Assessment and Enhancement. *Journal of Power and Energy Engineering*, **2**, 525-531. http://dx.doi.org/10.4236/jpee.2014.24071

haviour regarding selectivity, speed and sensitivity. On the other hand, the response of the protection system on dynamic network phenomena is influencing the network security particularly. Thus both aspects should be considered performing a full protection security assessment system. The **P**rotection **S**ecurity **A**ssessment System SIGUARD®-PSA is covering both items as shown in **Figure 1**. The part of short-circuit (SC) fault simulation is handling networks as a whole. By simulation of routinely sequences of faults and contingencies bottlenecks of the protection systems can be revealed practically. Based on the identification of bottlenecks, adapted settings can be derived, improving the protection behaviour and network security. This automated method is based on the simulation engine as PSS®SINCAL [4] and also applicable under ongoing changing network conditions.

The second part is represented by the investigation of the dynamic protection behaviour, which is also one focus of this paper. The network and the protection system will be handled as a whole as well. It is requiring an applicable modelling of the protection relays to manage the big amount of input data and relay type versions. The protection models are preferably restricted to the dynamic functionality to be investigated. A further prerequisite is a powerful simulation engine as PSS®NETOMAC [5] which complies with the simulation requirements to a great extent.

Both parts of SIGUARD®-PSA are complementing each other and can lead to an important enhancement of the protection and network security of today's and future power grids.

2. Investigation of Sc-Fault Simulation

The presented method is analyzing networks as a whole [6-8]. By simulation of routinely sequences of fault and contingency scenarios bottlenecks due to dependability and security of the protection system can be revealed. Based on the identification of bottlenecks, adapted settings can be derived, improving the protection behavior in particular under ongoing changing network conditions. The principle structure of the automatic system is shown in **Figure 2**. The system includes a data storage system to provide all necessary information. It contents the grid model data, a system for the management of simulation and an evaluation tool with a qualification and an assessment center. Moreover the evaluation tool controls the methods for analyzing the tripping behavior and the interactions of trippings on the grid.

2.1. Data Storage

The holistic approach of the presented method demands an extraordinary effort of calculation and storage of all result data getting from these calculations. Therefore, a well-designed data handling structure and storage system is essential. The data storage system is implemented on a MySQL-database running on a database server. At the beginning of the procedure the power grid model will be copied to the database. All other systems get their required information from the database and feed their results back to that after calculation. By the use of an entity-relationship-model, the data storage system enables associations and filtering by key terms between all scenarios, simulated faults, results and the selection of data under consideration of various scenarios. This is an important basis for an intelligent analysis of a big amount of data and indispensable for this method.

2.2. Simulation Tool

The simulation tool starts with the initialization of the power grid model to be assessed. In the first step, all installed protection devices are analyzed, categorized and linked to their associated electric equipment. From these

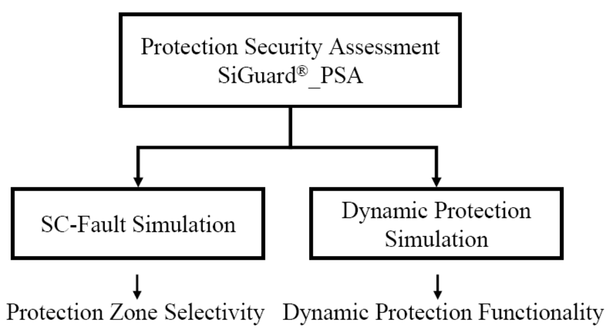


Figure 1. Principle structure of SIGUARD®PSA.

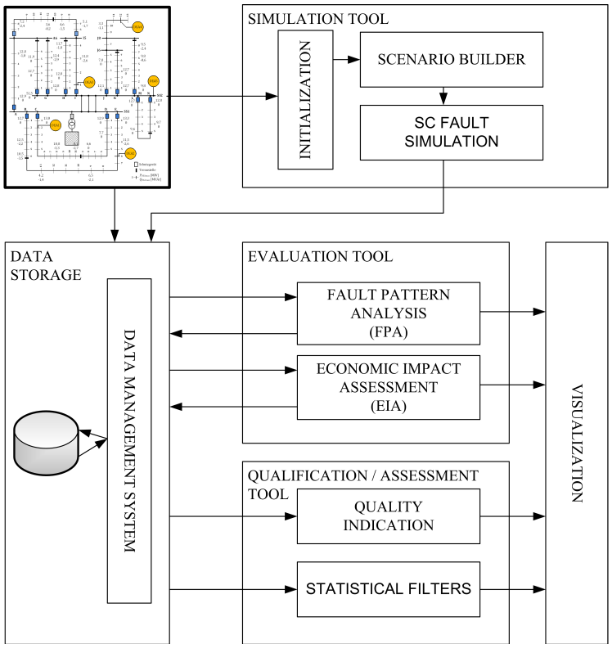


Figure 2. Principle structure of SC-fault simulation and assessment.

results protection zones and requirements due to dependability and security may be defined. After initialization and storage of the results, the scenario builder generates a broad diversification of grid states with different load flow situations. For each defined scenario and for each protection zone the SC fault simulation program calculates different kind of short circuits and different amounts of fault resistances. The location of the SC-faults is moving from calculation to calculation through the whole network in steps of *i.e.* 1% - 5% of the line length. The settings for step size, resistances, scenarios, etc. either may be on standard values or may be limited or specialized by user's selection over graphical user interfaces. The use of an automatic control of the applied simulation tool allows various simulations of different networks and fault scenarios without making any time-consuming manual changes in the simulation model. The simulation tool calculates the reaction of all considered protection devices during all simulated SC-faults. After simulation, those reactions are stored into the database and are linked according to their fault type, to the resistance and to the related scenario of the power grid.

2.3. Evaluation Tool

A general evaluation method of protection system behavior is given by following terms:

Reliability—The probability that a protection system will operate with the required performance. This parameter includes the aspects dependability and security.

Dependability—The probability that a protection system will trip circuit breakers when it is required.

Security—The probability that a protection system will not trip circuit breaker when it is not required to do so.

The use of the database with entity-relationship-model as storage system enables automatic evaluation of all calculated results in many different ways. This paper shows two main approaches to evaluate the protection system: Fault Pattern Analysis and Economic Impact Assessment.

The fault pattern analysis is generating finger-print charts that display the behavior of the protection system in the case of faults occurring in one scenario with defined power flow, fault type and fault resistance as described in [5]. The technical reason for maloperations can be worked out. This information is dedicated for protection engineers.

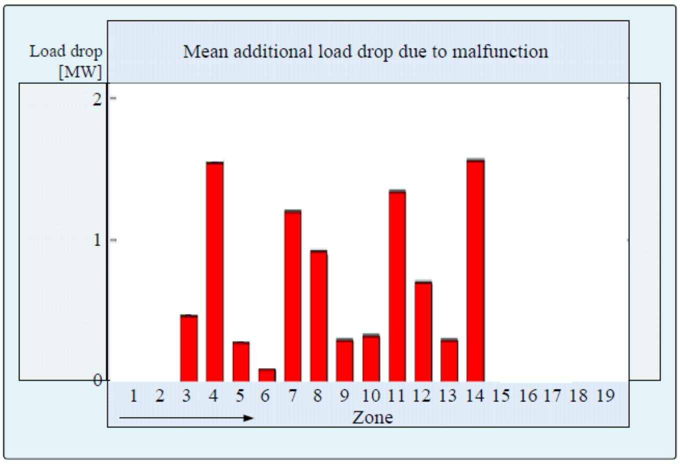
To display the economic effect of those malfunctions and to assess the need for improvement, there is a second automated evaluation mode-the economic impact assessment. This method uses the centralized database recordings of faults and the related protection system response. Every fault that has to be tripped causes a loss of load especially in distribution networks. Violating dependability or security of protection devices will lead to additional losses. The differences between unavoidable losses and those additional losses can be calculated. **Figure 3(a)**) shows additional losses for an exemplary distribution network displaying 19 protection zones on the x-Axis.

Especially the protection devices that protect zone no. 4 and no. 14 cause the biggest amount of additional load losses through all of the simulated faults and scenarios.

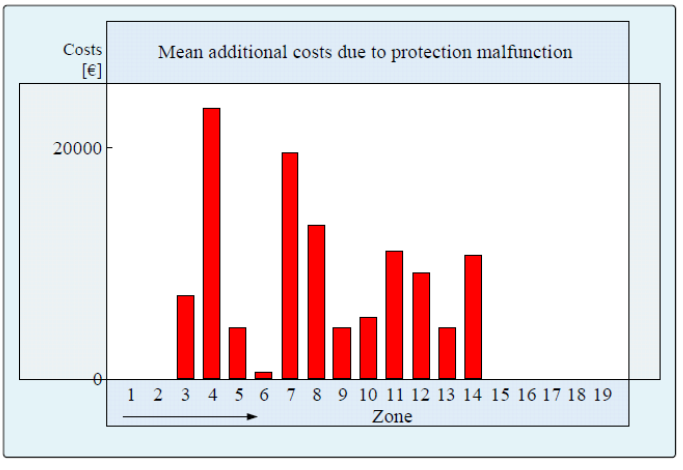
Assuming the importance of every load in the network is known, the economic impact can also be evaluated monetary as shown in **Figure 3(b)**). This diagram shows additional peak costs at different zones, which are caused by different importance of individual loads in the protection zones. For example, critical consumers like hospitals or industrial plants represent a higher importance level as housing areas. This evaluation method supports the decision for a system enhancement and suggests strategies due to a protection equipment exchange under monetary aspects.

3. The Dynamic Protection Simulation

Dynamic protection simulation of a power grid is a time domain simulation considering effects like power swings and voltage instabilities. These dynamic occurrences are likely responsible for the cascading tripping and following major disturbances. A steady-state simulation cannot describe such dynamic effects and is only reflecting the situations pre- and post-fault but not the behaviors during transient fault scenarios. Therefore the identification of critical dynamic situations must be done with a dynamic protection simulation. The dynamic protection simulation comprises the dynamic network and protection behavior.



(a)



(b)

Figure 3. Example: Unnecessary loss of load due to malfunctions.

Protection devices can change the network topology during the simulation in case of a trip signal. Then the protected device (e.g. line, generator etc.) will be removed from the network after a trip. The parameters of the protection devices must be calculated at every time step to realize such functionality. Thus there is a need of protection device models which include the possibility to be simulated in time domain and interact with the network.

The models shall be integrated into large up to nationwide power grids for the simulation to identify the grid parts which reveal poor dynamic protection behavior and are prone to major disturbances. For this reason the use of generic protection models is an essential part for the assessment of dynamic protection behaviors of power grids. These generic models include the important functions of the different protection devices to describe dynamic protection behaviors. Particularly the right functionality of the timer element is of high importance to realize time domain protection simulation. In this way large networks with many different protection types can be handled properly.

The switching of network circuit-breaker via the protection models makes it possible to simulate cascading tripping and report the timeline of the whole cascade of events. Every tripping causes a new physical situation for the network. Hence new critical network situations can arise and other protection devices could mal-trip consequently.

3.1. Methods of Simulation-Structure and Environment

The above mentioned dynamic protection models were developed on the basis of a dynamic simulation program PSS®NETOMAC. The generic models are realized as controllers in the environment of this simulation system. The controllers can react on the behavior of the system variables by changing the topology.

The user is creating the settings for the protection devices via a graphical user interface (GUI). The settings are created based on the network data and the adjusted settings of the user. After performing of settings, the protection devices will be included in the environment of the simulation system. Also dynamic devices like switched shunts and HVDC connections can be included. The critical system parameters and actions of controllers, especially of the protection models, will be reported and visualized appropriately. It is intended to make relation between the results of the SC-fault simulation and the dynamic protection simulation assessment getting a comprehensive protection assessment under interacting steady state and dynamic aspect.

3.2. Case Study

The dynamic protection simulation was tested using a transmission grid of 527 lines, 416 busses and 119 generators. The grid supplies a load power of approximately 19 GW and transmission lines with voltage levels between 69 kV and 500 kV are installed. The generators are equipped with AVRs and governors. This network is schematically shown in **Figure 4**.

The network is characterized by remote generation areas and load areas in the north and south respectively which are connected through weak inter-ties. Especially the southern grid is very prone for stability problems.

The northern and southern grids are tied by two 230 kV and 115 kV transmission lines. The contingency is also shown in **Figure 4**. It is a 3-phase fault at 10% of the 230 kV transmission line L_00256 which will be tripped correctly by the distance protection on this line. The response of the system on this contingency is a stable power swing of the generators between the south and north/center part.

Distance protection devices for all transmission lines are modeled for this network. Hence 1054 distance protection devices are simulated. All 119 generators are equipped with the simplified and generic protection functions over-current, under- and overvoltage, under- and over-excitation and under -and over-frequency. These functions perform the backup protection of the network. In summation 1273 controllers are calculated for modeling the protection devices.

The simulation result shows that the lines L_00255, L_00188 and L_00187 tripped in addition to line L-000256 and but unnecessarily. With regard to **Figure 4** the southern grid part is isolated from the north/center part.

As a consequence of this cascade tripping all generators in the southern grid part were shut down because of under frequency. In the south, an unbalance of generation and consumption occurs. The load power is greater than the generated power of the existing generators in this area. Therefore the generators decelerate and their frequency will slow down. The first unselective mal-trip happens at the transmission line L_00255 after the selective trips of the two distance protection devices of line L_00256. **Figure 5(a)**) shows the trajectory in the

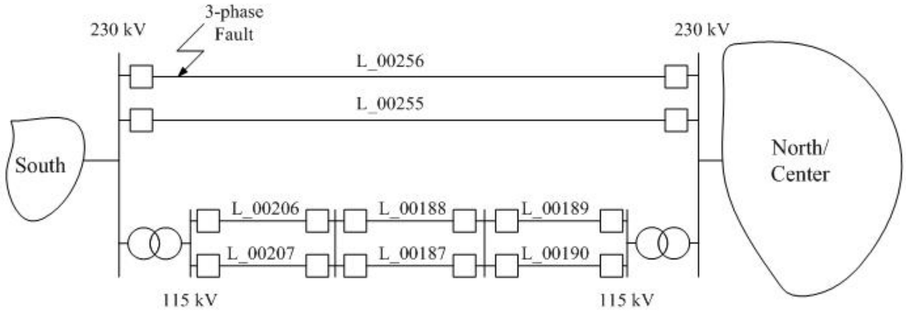
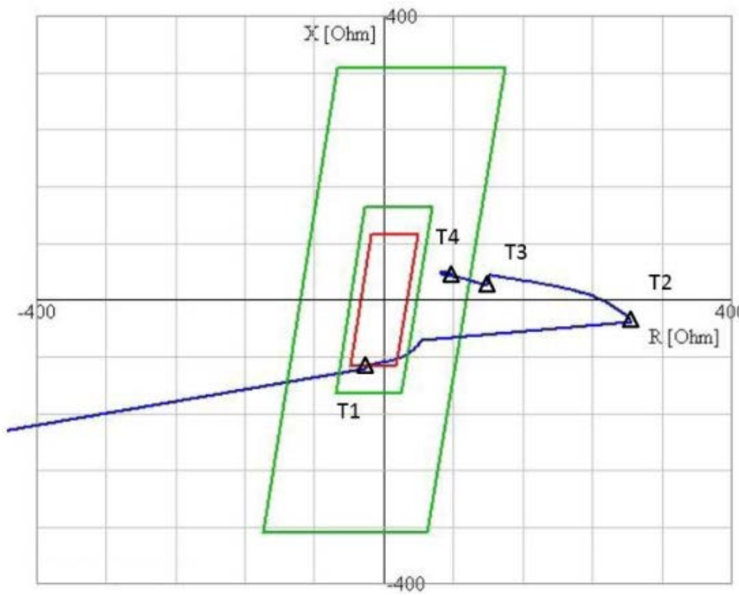
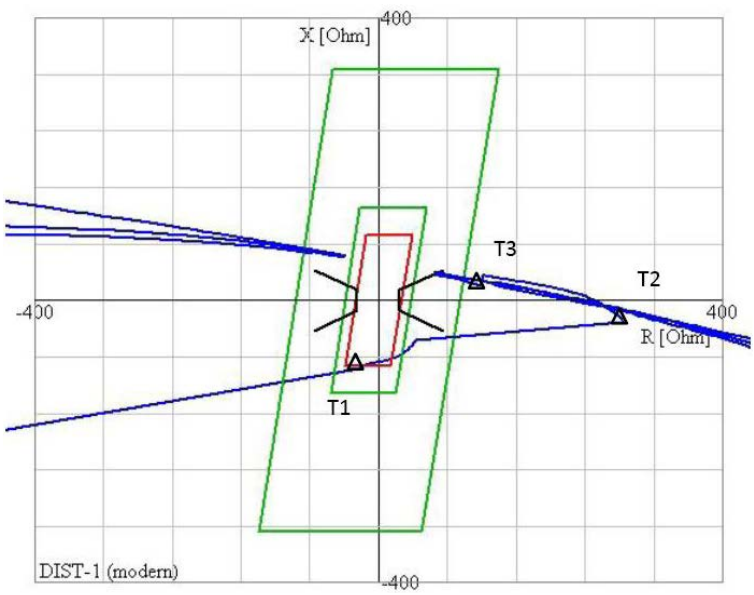


Figure 4. Test network for case studies-weak inter-tie of southern grid part.



(a)



(b)

Figure 5. Trajectory in the R-X-plane of Distance Protection of L_00255.

R-X-impedance plane of the distance protection devices at line L_0255.

The trajectory of the impedance vector is crossing the zone 3 and the timer of zone 3 elapses before the trajectory could leave the zone. Four time events T1, T2, T3 and T4 are marked in **Figure 5** to describe the timeline. At T1 the fault appears at line L_00256, T2 is the time after the selective trip in zone 1 of the protection device located at the southern station. T3 is the moment after the trip in zone 2 of the other distance protection of line L_00256. The last time T4 describes the mal-trip in zone 3 of the distance protection of line L_00255. This trip provokes that the swing center moves into the 115 kV voltage level. Now the trajectory is crossing the tripping zones of the distance protection devices of the lines L_00188 and L_00187 and both lines trip. Hence the north/center grid is separated from the south grid. One possible countermeasure against this cascading fault and the consequent major disturbance is shown in **Figure 5(b)**. The introduction of blinders may avoid the unnecessary tripping of L_00255 and the cascading fault is not taking its course.

4. Conclusions

New innovative strategies of protection security assessment are proposed. It could be shown that the protection security can be improved using the SIGUARD®-PSA system. This can be applied to nationwide transmission systems as well as space limited distribution systems. Different aspects can be checked using only one simulation setup.

The proposed simulation method is able to identify critical contingencies with regard to short-circuit current simulation as well as the dynamic protection behaviour. Many different influences on the dynamic protection behaviour are given by the network and the protection system itself. The evaluation gives rather reliable results based on real network data. The case study shows that it is important for the assessment of the dynamic behaviour to consider protection devices simultaneously because stable situations can be changed into unstable problems by protection responses. Major disturbances or blackouts are often activated by such problems and could be identified and prevented by such a simulation. The analysis of these problems can also help to derive new practical protection functions in order to avoid unnecessary power supply interruptions anticipatorily. This is properly supporting the protection security assessment in today's and future power grids.

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