

DIGITAL SYSTEM PROTECTION DESIGN – A NEW TOOLCHAIN FOR PROTECTION SYSTEM AUTOMATION

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ABSTRACT

Future power grids are facing an increased diversity of operation and disturbance conditions. These are caused by fluctuating infeeds of renewable energy sources as well as the use of unconventional grid devices like voltage source converters or short-circuit current limiters. Maintaining a high degree of supply reliability, the protection systems and their design process have to be adapted to the changing conditions.

This paper is proposing an integrated digital toolchain for the design and parametrization of protection relays. The process flow is fully digitized and automated. It considers the grid and the protection behavior as a whole with the use of integrated grid and protection models. Thus it can be adapted highly flexible to frequent changing grid conditions. Moreover an optimization tool finds the best feasible solution of the protection system concerning the supply reliability under diverse grid conditions. A case study illustrates the functioning of that process and the results to be achieved.

BACKGROUND

The decarbonization of the electrical infrastructure causes fundamental changes of the power grids. Operation and disturbance conditions with respect to overloading or short-circuit scenarios become diverse and probabilistic as well as hardly to predict. Protection systems are still one of the decisive players in the grid in terms of system security. A fast and selective fault clearing is the basis to maintain a reliable power supply.

The conventional design and parametrization workflow of protection systems is based on so-called protection design and coordination studies. Until now these are rarely automated and have a low degree of digitization. At best, these studies are able to consider some presumed grid scenarios regarding a couple of different short-circuit infeed capacities or other grid figures. The temporary adaption of protection concepts, algorithms or settings isn't provided. Thus, these studies can't cope with frequent and probabilistic changes of the power grid conditions and have increasing difficulties to maintain supply reliability in future grids consequently.

CHALLENGE

The workflow of the conventional protection system design process must be refurbished to comply with the changing grid conditions in the future. It has to become highly flexible and adaptable regarding the application areas and the goals of employment of the workflow results. Only a high degree of automation can provide the possibility of a frequent use on demand or on a routinely base. The use of integrated grid and protection models are the prerequisite to a proper approach of system simulation as a whole. The expected big amounts of input as well as output data of each workflow step requires dedicated data models and database systems. Protection typicals are general protection relay configurations referring to special grid structures. For the universality of use, protection typicals should be the basis of the protection design process. On the other hand, an optimization method should find best applicable solutions at the end of the design process.

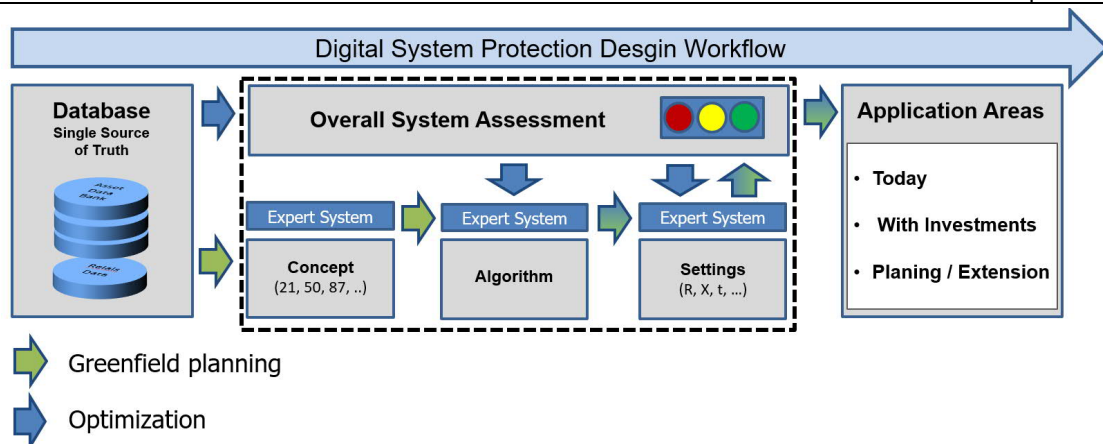


Figure 1: Overview about the Digital System Protection Design Workflow

APPROACH

In this paper a new workflow for a digital system protection design is proposed. Our design process is realized as a toolchain and divided into five process steps: Database System, Concept, Algorithm, Settings and Overall System Assessment. Figure 1 is illustrating the workflow of the proposed Digital System Protection Design (DSPD) as well as its internal interactions. The process flow is fully digitized and automated. In that way, a high flexibility adapting the protection to frequently changing grid conditions as well as routinely protection performance checks can be carried out. In the following, the five process steps will be explained more in detail.

Database System

The automated approach of the DSPD implies an integrated data management. Therefore, the initial dataset is prepared combining primary and secondary equipment data. An adapter to access data from different sources, such as PSS@Sincal or CIM, brings flexibility for the installation in heterogeneous environments.

The structure of the dataset is dynamically extendable. Modules can add additional data such as different views, measurement data from PMUs and result data. The module data is referenced to the original input data. This enables the availability of all relevant data in a single source for every step of the workflow keeping the flexibility of storage areas for module specific data. At every step the data is validated and checked for plausibility to ensure a reliable dataset for the next step.

This database concept enhances the automation of the DSPD-workflow and integrates easily into existing environments.

Concept

In a protection system design study the first step is to define a protection concept. The concept comprises all protection functions for each equipment, which are needed to secure safe operation and fast selective fault clearing.

In present the concept is designed by a protection engineer, who collects all the relevant data of the power system e.g. topology, position of current and voltage transformers and so on. Based on these data the protection engineer decides which protection functions are mandatory.

The selection of the protection functions within the Concept Block is made based on pre-defined typicals, which describe standard topologies (e.g. single feeder, double line,..). Each protection typical consists of a topology and the protection functions, which are necessary to ensure fast and selective fault clearing. These typicals are normally written down in guidelines and based on the expertise of protection engineers [1].

In relation to the description of the power system the typicals are represented as graphs in RDF semantic. This step further enables a variety of algorithms of computer science like search and matching algorithms [2, 3]. Figure 2 shows the graph representation of an exemplary protection typical describing a ring feeder protected by differential and distance relays. The graph representation has different connections, red means “is connected to”, blue “has” and green “communication link”; and nodes. The nodes represent primary, secondary equipment and protection functions. The graph representation of the power system and the protection typicals is used to implement a graph pattern matching to find protection typicals in the grid topology. This means a protection concept can be generated in an automated way.

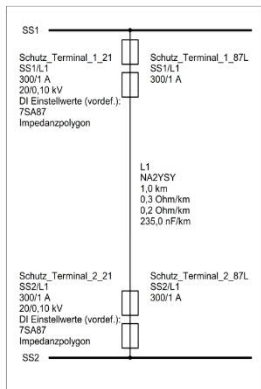


Figure 2: Exemplary protection typical and graph representation

The protection engineer can choose the best solution out of all computed ones. The idea is to find the one with the lowest number of used typicals (best coverage) and coverage without any white spots (full coverage). In future this can be done by heuristic optimization.

The next step is to add the protection functions for each location of protection devices to the grid database and to prepare the data for the algorithm decision in the following block.

Algorithm

The Algorithm Block selects a proper algorithm for every protection relay. As shown in Figure 3 the algorithm block's choice derives from information provided by the dataset, the concept function block and the assessment function block.

It can gather knowledge from the database system regarding customer preferences on algorithms and the protection relay capability in terms of parameterization, data storage etc.

Furthermore, the algorithm block uses information on protection function of the protection relay, grid topology, communication channels, interlocking and other linkups between protection relays as well as the type of the protected asset (transformer, cable, etc.) provided by the concept block. In case of unsatisfying simulation results, the overall system assessment may trigger a change of algorithm as well.

The selection process uses a rule-based expert system. This expert system handles and evaluates all the incoming information and consequently chooses the appropriate algorithm from an adjustable algorithm library. The algorithm library can contain both conventional and innovative algorithms. [3, 4]

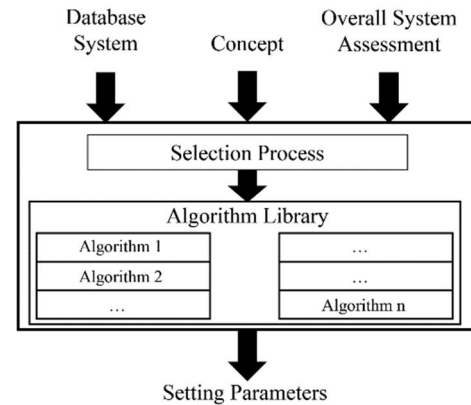


Figure 3: Data in- and output of algorithm block

Settings

In present the protection settings are manually calculated by a protection engineer. Based on relevant data the engineer calculates the settings according to guidelines and expertise.

The third step within DSPD is to automatically calculate the settings of each protection function by using smart protection settings.

The smart protection setting is designed with two parts as shown in Figure 4: Dictionary and Setting Units. The dictionary is a setting unit finder, which can find out the expected setting unit based on the information of protection function, protection algorithm and protected element layout. The setting units work like LEGO bricks that include all considered protection functions for all considered typical layouts. Each setting unit has got an ID number and is designed to take necessary network data to calculate the setting based on expert rules. The protection settings should be coordinated with operation condition, design limit of protected

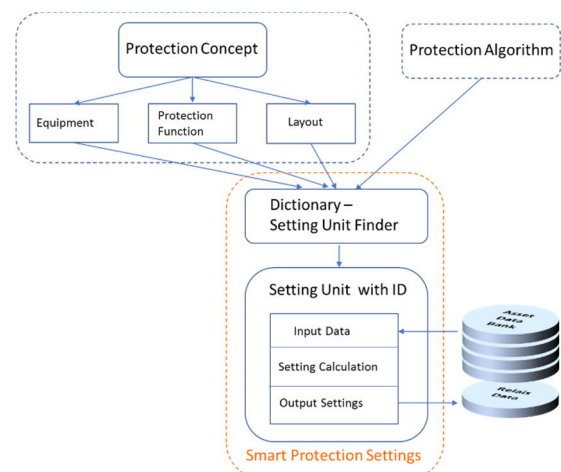


Figure 4: Exemplary smart protection settings

equipment, grid code and to secure safe operation and fast selective fault clearing.

The calculated settings will be added to the dataset to complete the data for simulation.

Simulation and Overall Assessment

In the last step, the automatically designed protection system concept including all protection relays with set up algorithm and settings must be simulated and validated.

Therefore, the overall system assessment block receives all necessary information like primary and secondary grid data, generator models and customer specification from the dataset and the previous blocks. It will dynamically simulate the network and protection system behavior within the software PSS®NETOMAC as a whole. All protection relays are generic models realized as controller able to change the network topology during ongoing simulations.

Based on routinely sequences of fault and contingency simulations the protection system behavior of all relays is simulated. Criteria like Selectivity, Speed, Dependability, Fault Clearing Time, Fault Location, etc. are analyzed. After that, various indices are used to evaluate the overall system security. Depending on the results the system security is declared safe, so the protection system concept is approved or the results are provided back to the previous blocks for recalculation and optimization. The optimization process can be done either through expert systems or heuristic optimization algorithm.

CASE STUDY

Figure 5 shows a part of an urban 20kV distribution grid with an infeed from the 110kV level and has two main branches connected to a substation. The transformer has a nominal apparent power of 31.5MW. The branches can be interconnected via a switch to a ring structure. Various smaller loads with a power consumption of 7.9MW are connected via cable with different R/X ratio to the main branches. At the end of one branch a biomass plant with a feed-in capacity of 8MW is connected. The protection system on the 20kV side consists of three distance protection relays (21) and one overcurrent protection relay (50/51). Fault location mainly takes place via short-circuit current indicator.

Load and infeed developments in the distribution grid are causing voltage limit injury and unacceptable line

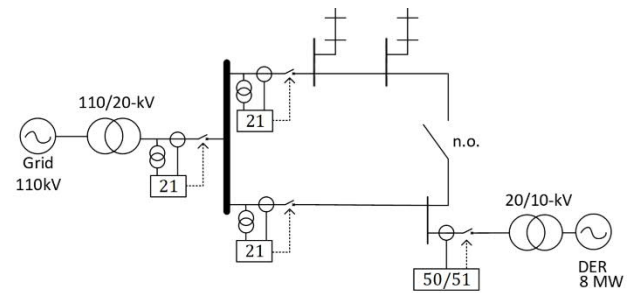


Figure 5: Urban 20kV distribution grid with 110kV infeed and open ring structure

load. Two solutions are conceivable to solve those problems. On the one hand, the grid can be expanded, which is associated with high costs. On the other hand, the ring structure can be closed, but for this, the protection system needs to be checked and adapted if necessary.

The Digital System Protection Design method is used to investigate the structure with closed ring.

At first, the grid data and all other necessary information are loaded into the dataset to provide information for the next blocks.

In the next step, the concept block translates the given grid into RDF semantics and works them up graphically. Figure 6 shows a representation of the 110kV infeed and Figure 7 depicts a cutout of the whole graph and the connections of the typical from Figure 6. After that, the matching algorithm finds three Typical (110kV infeed, ring structure and decentralized infeed) building up the system, which are marked in color in Figure 8. The output of the concept block is to keep the already existing distance protection and overcurrent protection relays.

After that, the algorithm block receives the concept from the previous block and all necessary data from the dataset to start the selection process. The output results to use a new distance protection algorithm

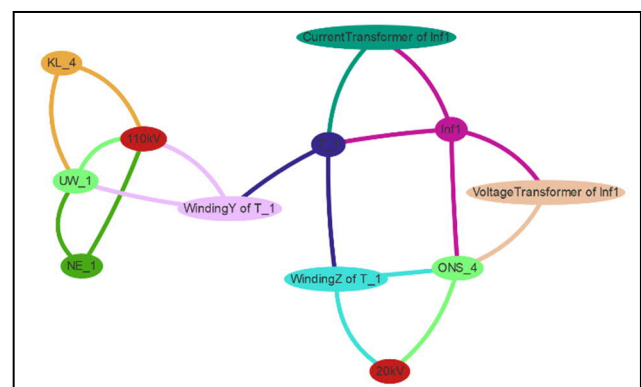


Figure 6: Graph representation protection typical "110kV-infeed" of the distribution grid

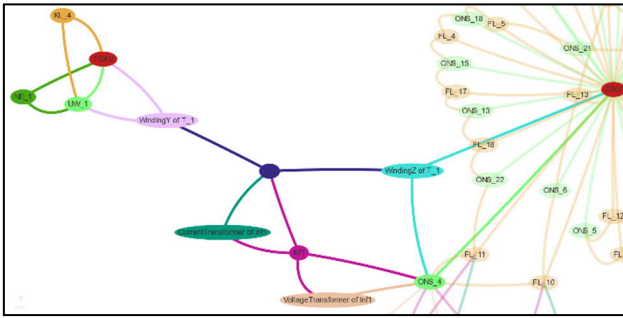


Figure 7: Graph representation of the distribution grid (cutout)

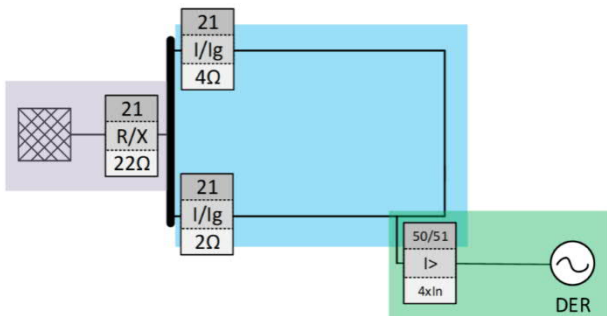


Figure 8: Resulting grid with chosen protection concept, algorithm and setting values

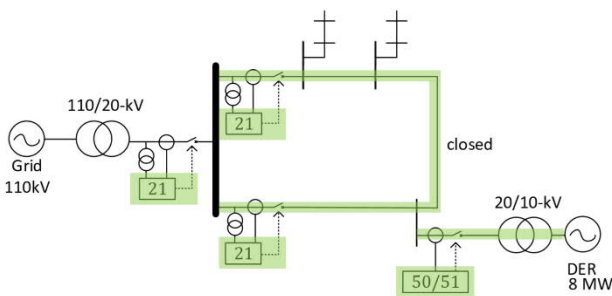


Figure 9: Evaluation result of the new protection design concept

(I/Ig) for the ring structure, which is based on a current divider principle and is described in [4, 5]. For the 110kV the classical impedance protection algorithm and for the decentralized infeed the classic overcurrent protection algorithms are kept.

The result is handled over to the setting block, which calculates the best setting values for the chosen algorithms.

In the last step, the whole distribution grid including the protection system is simulated within PSS@NETOMAC and the simulation results subsequently evaluated. The evaluation result is shown in Figure 9. The new protection design concept is safe, so the ring can easily be closed by adapting the protection concept.

Conclusion

A new workflow for the Digital System Protection Design (DSPD) is presented. It is a fully automated and digitized toolchain for a flexible protection design and parametrization process. Its features comply with the challenges of future grids regarding the diversity of operation and disturbance conditions and the use of unconventional grid devices. Thus, the proposed toolchain is able to contribute for an ongoing high level of supply reliability in the future power grids.

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