Software solution for the protection calculation and documentation of the protection technology at Stadtwerke München (SWM)

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1. ABSTRACT

Stadtwerke München (SWM) introduced an integrated software solution to support the dimensioning of their protection systems in the SWM network and to improve the documentation of the protection technology. The solution consists of the standard software products *PowerFactory* and *StationWare* of DIgSILENT as well as individually developed interfaces and automation scripts. The network calculation software *PowerFactory* takes on the entire task of the network and protection calculations. The *StationWare* protection database manages all data and documents related protection technology, in particular the settings values of protection devices, and represents the process of protection documentation, e.g. for periodic inspections and commissioning tests.

Power system and protection calculations are executed in *PowerFactory*. For this purpose, SWM's high-voltage network is maintained in *PowerFactory* and extended by selected medium-voltage networks. These are imported from the SWM network information system (GIS) to *PowerFactory* via a data interface developed for SWM and connected to the high-voltage network there.

In order to carry out protection calculations, the protection devices are imported into *PowerFactory* via a data interface using the current *StationWare* data status. This device and data import includes the protection devices and transformers in use, their settings values and the linking of protection devices for the purpose of signal transmission. With this network model, the objectives defined by SWM can be implemented: (1) visualisation of the protection scheme on the network, (2) simulation of the starting and tripping behaviour of the protection devices, (3) optimisation of selectivity, coordination of the protection systems and the starting safety, and (4) verification and evaluation of protection concepts.

StationWare manages the information of the protection devices and transformers in a data hierarchy that is structured according to protection group and location. Linked protection devices and transformers are connected by *StationWare* links. Other documents of general interest, such as device manuals and test templates, are managed in the *StationWare* library. *StationWare* also supports working with automation scripts.

This paper describes the requirements, the implementation, the difficulties with the data basis and the way of working with the software solution.

2. INTRODUCTION

SWM is a distribution company in the south of Germany that supplies around 1.5 million inhabitants with 6GVA power. The motivation for the implementation of a software-based solution that covers the above described objectives was to increase the power reliability to the citizens.

Figure 1 illustrates the solution implemented at SWM that is mainly based on the software *PowerFactory* for the power system and protection calculation and *StationWare* for the protection documentation.

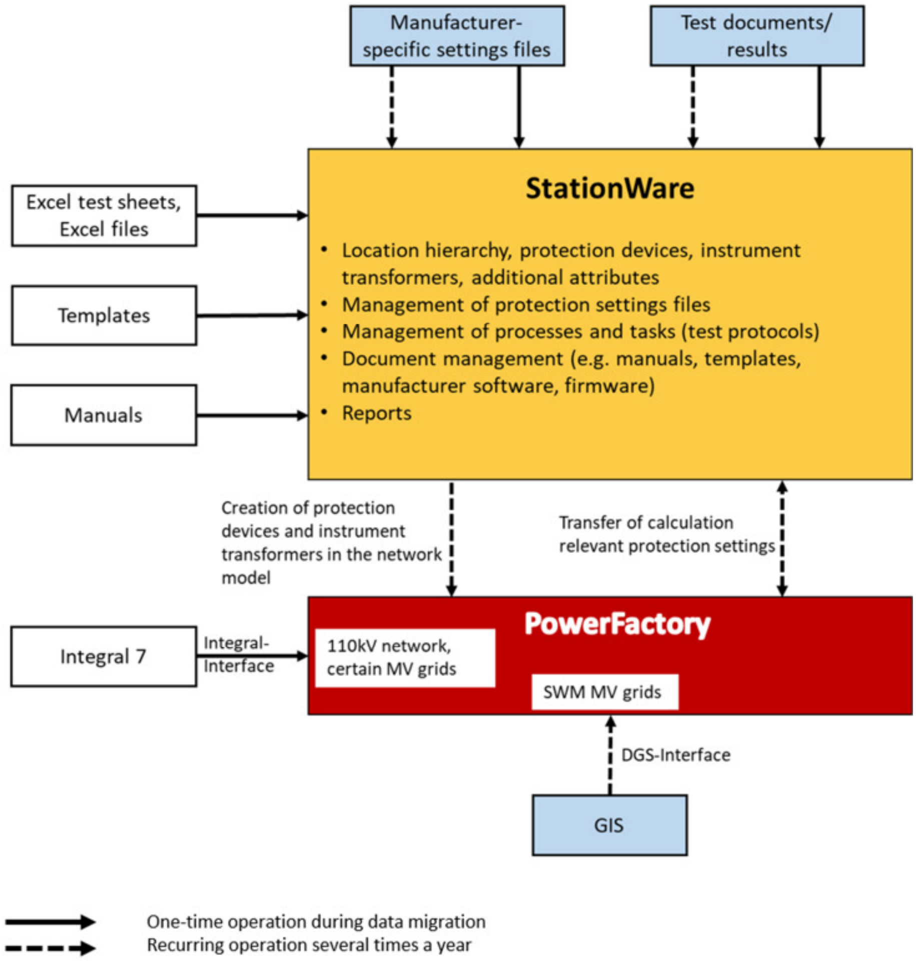

Figure 1: System overview of the SWM software solution

Both systems work independently of each other. *PowerFactory* manages the primary equipment data and the topology of the SWM networks and *StationWare* stores the secondary equipment data (protection devices, transformers, ...) with locations and settings. The usual work requires an interface between the two systems that regularly generates the protection devices in the network model and exchanges the settings.

3. IMPLEMENTATION OF THE POWER SYSTEM AND PROTECTION CALCUALTION SOFTWARE

Before the software implementation project, SWM used INTEGRAL for their power-system calculations. This means, the maintenance of the primary data of the high-voltage network and selected medium-voltage networks was done in INTEGRAL. The majority of medium-voltage networks is maintained in the GIS (geo information system). For economic and network model quality reasons the tool to calculate power systems and to verify and validate protection concepts should be the same. Therefore, the first step involved the migration of the high-voltage and the selected medium-voltage network data to *PowerFactory*. The objective of the migration was to obtain comprehensible calculation results from the network calculation software with a deviation of at most 1% from the results obtained by the previously used INTEGRAL. GIS remains as management tool for the medium-voltage networks. If necessary, the data for the medium-voltage networks that will be investigated are imported from the GIS to the power system calculation software and will be joined to the high-voltage network to form an overall network model. This overall model forms the basis for network investigations with *PowerFactory*.

3.1 WORKING WITH THE NEW POWER SYSTEM CALCULATION SOFTWARE

SWM works in the power system calculation software in a multi-user environment, i.e. several users perform network calculations and use the same network model as a basis. To ensure that this network model is still maintained centrally, it is managed as a so-called base project in the public area of the multi-user database. A Data Administrator is in charge of maintaining the base project in the public area. This person has the access rights to update the base project and to create new versions (a *version* is a snapshot of a project taken at a certain point of time). All other users work in their individual database areas with so-called derived projects from the last version of the base project released by the Data Administrator. Derived projects are virtual copies of a project version that behave like normal copies for the user and have been introduced to avoid a large amount of data duplication. Modifications in a derived project are only merged in the public base projects, if they are of general interest. The exchange of processing statuses of network studies with other users takes place by assigning read- and write-access rights on the derived projects.

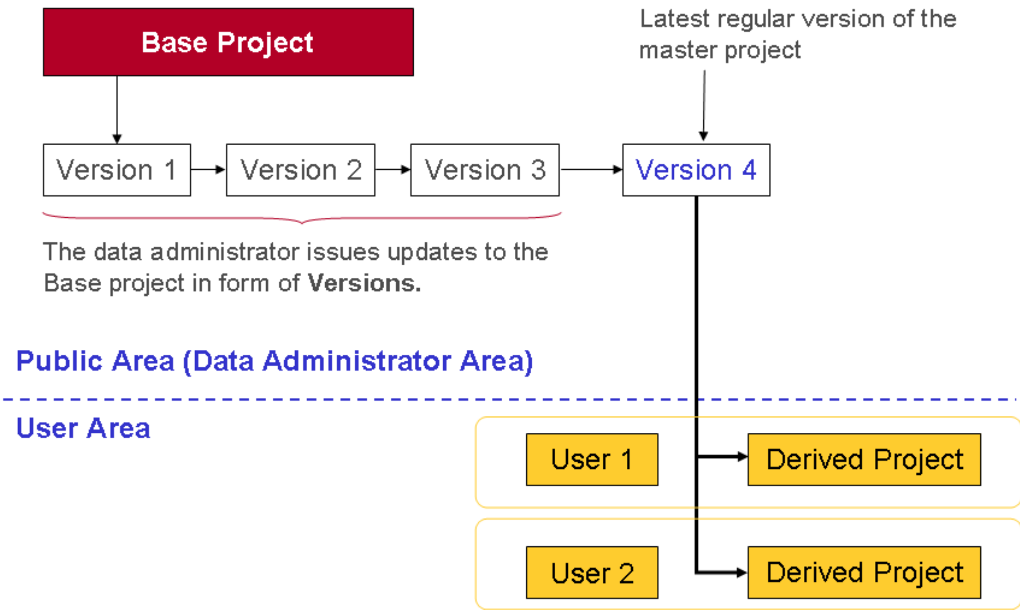

Figure 2: Derived projects in a multi-user database

3.2 INITIAL MIGRATION OF THE NETWORK MODELS INTO THE NEW WORKING ENVIRONMENT

At SWM there were two network models in INTEGRAL7-specific xml format available for the high-voltage network. One described the actual state of the network, the other the normal state. Both were imported into the power system calculation software via the *PowerFactory* standard import interface for INTEGRAL data. At first two separate *PowerFactory* projects were created. The INTEGRAL type library was imported into a separate project. After checking the correctness of the data in the projects, the final project structure was created in the multi-user environment. The type library was moved either to the global library in the *PowerFactory* database or to the project library in a template for the future base project. A project template is a project with default settings (and type library) that can be used as a template for all other projects in the public domain. The template settings were automatically transferred to the projects of the high-voltage network models with a command available in *PowerFactory*.

The two high-voltage network models were then manually merged into one project and one network. Planned expansion stages were created in variations / expansion stages. After the high-voltage network model had been checked for correctness (visual check of the network diagrams and comparative calculations for load flow and 1- and 3-pole short circuit) and a version had been created, it was transferred to the area of the publishing user SWM as a basis project and released for all users.

Most medium-voltage networks are maintained in the GIS and are imported into *PowerFactory* for calculations via a GIS-DGS interface and linked to the base project (high-voltage network). Therefore, the connection points (transformer LV-side / busbar / medium-voltage outgoing feeder) between the high-voltage network and the medium-voltage networks had to be defined accordingly. A connection between the high-voltage grid and the medium-voltage grid imported from the GIS can now be established automatically using foreign keys. The GIS-DGS interface is not discussed in detail. It was not part of this project, but was developed in parallel. All 34 medium-voltage networks were available in *PowerFactory*-DGS format. In these DGS files, foreign key references to types and connection points in the high-voltage network in the base project were used. The DGS files also contained loads and branch objects with foreign keys that correspond to NLS (network control system) or SAP. These DGS files were migrated by importing all medium-voltage networks via the DGS interface from the GIS into a derived project of a previously created version of the base project. Based on the foreign key references, the medium-voltage networks were automatically connected to the high-voltage substations. Afterwards, the networks were supplemented by a DGS import with further data, e.g. rated power of the transformers as default assignment of the loads at local network stations, measured values at feeders, etc. Once the derived base project has been checked and versioned, the import of the primary equipment data was complete and the protection devices and transformers could be automatically created in the derived base project and filled with setting values. After the testing and versioning of the derived base project, the import of the secondary equipment data was also completed and the tested changes were compared with the base project in the public area. After this completion of the full migration of the high-voltage network and the selected medium-voltage networks, they are only maintained in *PowerFactory*. The other 34 medium-voltage networks are regularly imported from GIS.

4. IMPLEMENTATION OF THE PROTECTION DOCUMENTATION DATABASE

In the past, SWM stored information about protection or field control devices and the parameters that were set in these devices in various files and folder paths on a server, sometimes with different responsibilities and permissions. During a working process, documents were often transferred to paper form. In addition, the handling of information via Excel lists was error-prone, unsustainable and difficult to trace.

For this reason, SWM decided to implement the *StationWare* protection database to maintain and manage the secondary equipment data (protection devices, transformers, ...) centrally. In the first step, *StationWare* is used for the central management of the protection devices with locations and parameters. If necessary, the settings values of the protection devices are updated from the manufacturer-specific settings files of the device software. In addition, the protection database plays a central role in the regular creation and parameterization of protection devices in the *PowerFactory* network models, which is necessary, for example, after each GIS import.

The following processes should be able to be realized with the protection database:

- Creating new protection devices incl. corresponding stations and bays
- Updating settings from manufacturer-specific settings files of the protection devices
- Creating new settings for protection devices based on protection calculations
- Maintenance of data from analogue protection devices
- Import of protection devices and their settings from *StationWare* to *PowerFactory*
- Administration of work processes, documents etc.
- Transmission of the protection setting values to devices, if necessary

4.1 WORKING WITH THE PROTECTION DATABASE

StationWare is a multi-user database. Access to database areas and objects is user-role-based. The different access rights to data-hierarchy objects, administration, lifecycles, library, and reports are configurable for each user. The protection devices and transformers and their data are managed in a location hierarchy. Linked protection devices and transformers are linked. Manufacturer-specific settings files of applied and historic settings are imported to the corresponding device via device-specific import converters. Protection settings values that are not available in a manufacturer-specific settings file (e.g. for analogue protection devices), and were previously maintained at SWM in Excel test files, are imported via a project-specific converter.

Calculation-relevant protection and transformer settings are exchanged bi-directionally via the standardized *PowerFactory* - *StationWare* interface. The data exchange of the settings values is controlled by protection-device-type-specific mapping tables.

The protection device settings are managed in the protection database according to a lifecycle that corresponds to the SWM workflow (see ***Figure 3***). Protection settings are planned, calculated in *PowerFactory*, passed on for review, released for adjusting, transferred to the device and are then in operation and documented.

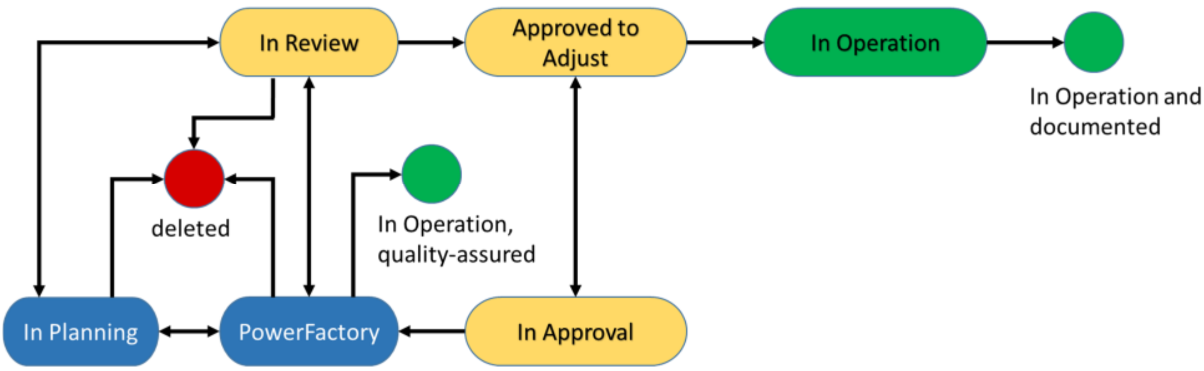

Figure 3: SWM settings lifecycle

StationWare provides data-change tracking, so that modifications in parameters and settings values can be traced as well as who made which changes and when.

In addition to protection settings, SWM also manages protection tests and commissioning in the protection database. These processes consist of tasks defined by SWM that must be performed according to a predefined workflow. The administration of process-specific documents is supported by the comprehensive document management function. It is possible to store test documents directly at the specific object, e.g. save the Omicron test file incl. meta information and manage documents such as test templates, manuals, manufacturer software etc. centrally in the library.

4.2 INITIAL MIGRATION INTO THE PROTECTION DATABASE

Before the integration project, SWM stored secondary equipment data and related documents on a network drive. Locating and storing a document was by descending in the folder structure, and versioning of documents was in parts by folders, in parts by file names. The objective of the initial migration was to build up a location hierarchy in *StationWare* containing secondary-device objects and to transfer the relevant documents from SWM's "secondary technology" network drive to the hierarchy. The specification of the location hierarchy was based on automatically extracted and processed document data and manual corrections and adjustments. The specification of relevant documents required a thorough review of the files.

SWM's "secondary technology" network drive contained a variety of documents: test instructions, checklists, OCC test files, test protocols, settings values such as project files, parameter files, Excel test files for electro-mechanical protection devices, manuals. All data files were reviewed for the target location in *StationWare*'s protection database. Settings values files had to be imported as settings record at devices in the data hierarchy, device manuals and other documents of general interest had to be stored in *StationWare*'s data library, and test documents were attached to *StationWare* process containers.

The first step of the data migration into the protection database included the creation of the data hierarchy with locations and devices, the filling of the additional attributes of the *StationWare* objects and the linking of protection devices and the associated transformers, as well as feeder bays connected by lines. The location-hierarchy structure corresponds to the real SWM-specific location structure (e.g. group -> substation -> voltage level -> bay -> protection function). Different data sources (usually Excel files) were used to create the data hierarchy. The rules for evaluating the data sources and creating and filling the locations and devices in the protection database were defined in a mapping rule file.

The location structure was generated from data in Excel test files and from network information obtained by automatically evaluating *PowerFactory* network models. In the past, the Excel test files were used by SWM to manage protective device data and parameters. Among other things, they contained information on the primary installation location of the protection device, which consists of station, voltage level and feeder bay/counter feeder bay, as well as information on the device type and usage. Missing information in files was added and data had to be reworked and harmonized. The structure was supplemented by the network information for the installation locations, which contained the connection bays of the *PowerFactory* network elements of the type line, two-winding transformers or three-winding transformers, so that e.g. low-voltage-side of transformers or still unknown installation locations, such as the opposite side of a line, were newly created.

A further Excel file was defined for creating the protective devices to identify *StationWare* and *PowerFactory* device models from SWM device type names. Information, such as the installation of a device in *PowerFactory* or not, is maintained in the protection database in so-called "Additional Attributes" for the protection device. Additional attributes are data that can be defined for locations, devices, processes and tasks and are not setting values. The assignment of transformers to protective devices was based on location information and was defined in a transformer specification file. This file contained the descriptions and positions on the circuit-breaker for current transformers in the high- and medium-voltage range, additionally the connected protective device in the high-voltage range and the busbar name and the feeders on the busbar section for measuring field voltage transformers in the medium-voltage range. A further Excel file contains data on the outgoing feeder bays for lines that have been obtained by automatic evaluation of *PowerFactory* network models or manually maintained. Links in the database identify interconnected protection devices and transformers. Information for links was generated from location information from the *PowerFactory* network model via scripts. For example, links between fields describe the existence of a line what was required to assign a second current transformer to a differential protection device.

The settings values of the protection devices were imported either from the Excel test files or from the manufacturer-specific settings files. In *StationWare* the device creation is based on a device type that represents the real device and its parameters. Generic device types are used for manufacturer-specific settings files. They are part of the corresponding manufacturer-specific converter. Static device types are used, if no manufacturer-specific settings files are available, e.g. for electro-mechanical devices. During the project the static device type models were developed by SWM. The data source Excel test file or manufacturer-specific settings file was defined in a table for the particular device types. The manufacturer-specific settings files were imported via the *StationWare* standard converters. The Excel test file import was developed within the project. After importing the setting, it was immediately moved to the lifecycle phase “Applied”, because it corresponds to the setting currently active on the protection device.

The transformer ratios are available as parameters in the manufacturer-specific settings files, so that they were obtained from the settings and transferred to the transformers via script in a post-processing step. For devices without manufacturer–specific settings files, the transformer ratio was obtained from the Excel test file.

Since the protection documentation, which was previously stored in a file directory, is also managed in the location hierarchy of the protection database, a file directory list was used to evaluate which document should be transferred and to check whether the location already existed or had to be created. Each document was stored for an operation (process/task) within the specified hierarchy level. The task name was also defined in the file directory list. If there were several tasks on the same level, the most recent document was set to the status "completed" and all others to "historical".

The evaluation of the different files, that were used to built-up the location hierarchy, to create and link devices and to extract information required for the modelling in *PowerFactory*, was realized with corresponding scripts. The development of these scripts was one of the main component of the migration project.

5. MODELLING OF THE SECONDARY EQUIPMENT IN POWERFACTORY AND SETTINGS TRANSFER

Current and voltage transformers were modeled as 3-phase devices. Each transformer corresponds to a real transformer core, since *PowerFactory* knows only single-core transformer models. The transformer ratio was not specified when a transformer was applied, but imported later as a settings value. The used *PowerFactory* transformer device types are manufacturer-independent and available in the *PowerFactory* standard library. These device types were extended by the necessary entries for primary voltage/current; these were taken from the transformer ratios in the Excel test file or the manufacturer-specific settings files. The information regarding transformer location in the network model, device type, device name and foreign key were generated from the protection database.

The *PowerFactory* standard type library provides a large number of protection device types for modelling protection devices. Further protection device types that were not yet available in the type library were developed type-specifically within the scope of the project und were delivered in a separate device type library. A device model template with all relevant settings was prepared for each device type to be created in the *PowerFactory* network models. When creating a concrete protection device, it was sufficient to create a copy of the corresponding template device element. A protection device was created on the outgoing side of the circuit-breaker at the installation location and the display name and foreign key was set. Assigned transformers were connected to the protection device; this step required that the transformers were created before. Controlled breakers were assigned. For line protection the breakers on both connected sides were controlled, for transformer protection the breakers on all connected sides were controlled. The information regarding *PowerFactory* device type, installation location and connected transformers were generated from *StationWare*.

The settings of the protection devices and transformers are transferred via the standard *PowerFactory* - *StationWare* interface. This is based on DPL scripts in *PowerFactory* that evaluate device-type-specific mapping tables. These mapping tables define which device-type-specific settings parameters in the protection database correspond to which protection device-type-specific parameters in the calculation software and evaluate certain logical parameter dependencies. For each *PowerFactory* protection device type for which data is to be transferred, a DPL import/export script and a corresponding mapping table are managed in the device type library. The mapping tables should normally be part of the *PowerFactory* device type and cover the main functions of the protection device. Specific mapping tables, e.g. for electro-mechanical devices, were part of the migration project. The import/export function is started from the calculation tool.

6. CONCLUSIONS

After a project duration of about two years, SWM implemented a software solution that provides an optimal basis for its protection calculations and protection data management and helps to reach the objectives defined by SWM (see abstract).

The challenges of the project lay in the data migration, which was the main part of the project. For the integration of protective devices into the network model, high network model quality in detail is very important. File storage and Excel data sheets allow many levels of flexibility. This results in many special rules and iterative test runs for data migration. A stable committed project team with sufficient time budget for the data migration, process definition phase and test phase on the customer side is indispensable for a good project flow. Furthermore, all user groups should be involved in the project in time to ensure a high level of acceptance.

7. REFERENCES

[1] SWM „Migrationskonzept: Softwareeinführung für Schutzsimulation, Netzberechnung“, München, 2017

[2] F. Pattis „Leistungsbeschreibung: Schutzsimulationssoftware“, München, 2014

[3] M. Schlemmer „Leistungsbeschreibung: Systemische Dokumentation Schutztechnik“, München, 2016

[4] D. Bangert „Poster: Softwarelösung zur Schutzberechnung und Schutzdokumentation bei SWM“, ETG-CIRED-Workshop 2018, Berlin, 2018