

Verified Protection Relay Models - A concept for comprehensive settings management and analysis

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Abstract—This paper describes the process of interchanging relay settings between PowerFactory, StationWare and relay vendor software and some of the technical challenges in supporting bi-directional settings exchange between several fundamentally different settings formats. Furthermore, the paper describes DIgSILENT Pacific’s methodology for streamlining this process by developing ‘Verified’ relay models to ensure that the relay software model represents the physical device variant to a high level of accuracy. Some challenges with settings export from PowerFactory to StationWare are presented from recent verified model development experience for Transend and solutions for addressing these challenges are posed. Ultimately, the development of a fully integrated approach to relay settings management, settings analysis and deployment is shown to have significant benefits in terms of increased engineering productivity and reduced error rates.

I. INTRODUCTION

Development of numerical relay settings, management of settings files and analysis of protection performance has typically been approached from several often disparate areas. A typical environment for an engineer involved in relay procurement, settings deployment and assessment might involve the use of several tools:

- The relay vendor (OEM) software used for communicating with the physical relay, downloading, updating and sometimes managing the relay settings files. Most companies utilise more than one vendor so an engineer must be familiar with multiple software platforms and versions.
- A database, spreadsheet or server used as a repository for settings.
- A power system analysis tool used to determine system fault levels and provide input to other tools such as spreadsheets that determine the ultimate relay settings and operating times.

DIgSILENT PowerFactory has for some time supported the complex functionality available within most numerical and analog relay devices including amongst other functionalities, ANSI/IEC inverse time over-current curves, mho characteristics, quadrilateral characteristics, under/over voltage protection and under/over frequency protection.

By simulating protection devices from first principles, it enables settings to be checked and developed directly within the power system analysis tool. It also minimises the use of external applications that increase settings development time

and add overhead. Historically, the difficulty with such models is the high level of complexity for implementation and the manual entry of settings that can be time consuming and prone to error.

DIgSILENT StationWare was developed as a complete relay settings repository to provide a central web based storage and management facility for an organisation’s relay settings. StationWare, through the use of settings import filters supports the interchange of settings information with relay OEM settings files.

DIgSILENT Pacific recognises the barriers to entry for developing and maintaining PowerFactory relay models of multiple variants of relay types along with tools for importing settings to such models and has developed a concept of ‘Verified’ models (VM) to alleviate this burden from the customer. A complete VM consists of a matched pair of StationWare and PowerFactory models and DPL import/export scripts to enable exchange of settings information between StationWare and PowerFactory. When this is used in conjunction with an OEM settings import filter in StationWare, settings information can be taken directly from the relay and imported into the representative PowerFactory model for analysis with a high degree of confidence. DIgSILENT Pacific believes this process can cut down on protection settings management overhead and ultimately improve the accuracy and efficiency of relay settings management.

II. THE STATIONWARE SETTINGS DEFINITION FILE AND IMPORT FILTER

In StationWare, a relay is defined by an XML template. It defines the settings groups the relay settings files should contain. Furthermore, it influences how the settings are displayed in the StationWare web interface and how the settings are identified during the import/export process to PowerFactory. Optionally, this XML template can also define all settings parameters including valid ranges and enumerations. However, manually defining settings parameters within this file is not recommended for complex numerical relays due to the large number of settings. Such settings files are normally dealt with ‘on-the-fly’ by specialised settings import filters within StationWare.

The settings import filter is responsible for reading the manufacturer specific relay settings file and creating the StationWare relay settings template. In some cases, the OEM files also provide additional information about the settings such as

valid ranges and enumerations and this information can be imported into the StationWare definition during settings import. In cases where the settings file does not provide additional information about the relay settings, then this information can be read from additional settings definition files obtainable from the OEM software, or hardcoded directly into the settings import filter. The main idea of the settings import filter is to provide an equivalent copy of the OEM settings within the structured StationWare XML format and provide a consistent interface for all relay settings regardless of manufacturer.

Note that although a settings import filter is mandatory pre-requisite for a complex numerical relay verified model, for licensing purposes DIGSILENT does not consider the import filter part of the VM package and they are licensed separately.

III. THE COMPONENTS OF A VERIFIED MODEL

The verified model consists of four components:

- 1) The PowerFactory relay model;
- 2) The StationWare settings XML definition;
- 3) A DPL import script;
- 4) A DPL export script;

The process for settings exchange between StationWare and PowerFactory is illustrated in Figure 1. Each of the components of the settings interchange is explained in further detail in the following sections.

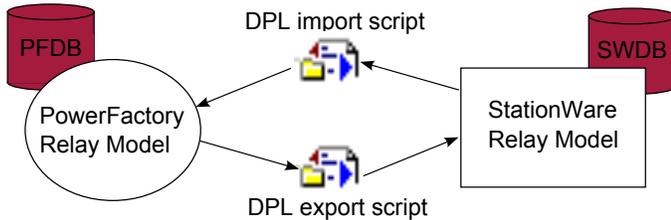


Fig. 1. StationWare - PowerFactory settings exchange diagram

IV. THE POWERFACTORY MODEL

The PowerFactory model of the relay is a mathematical model that represents in detail the complex behaviour of the relay. This includes models for such typical protection functions as:

- Measurement and signal acquisition
- Over-current characteristics (directional and non-directional)
- Differential characteristics (phase and magnitude comparison)
- Quadrilateral (polygonal) characteristics
- Mho characteristics
- Directional measurement
- Voltage polarising
- Impedance and over-current starting
- Reclosing functionality

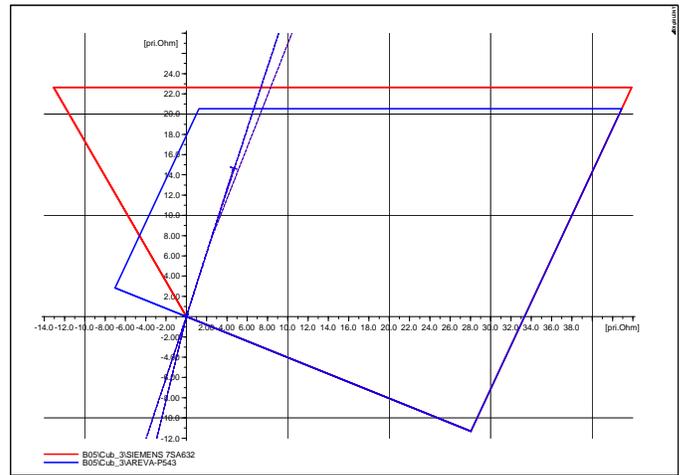


Fig. 2. Siemens 7SA632 and Areva P543 Quadrilateral characteristics

- Out of step and power swing blocking
- Load encroachment
- Under/over voltage
- Under/over frequency; and
- Custom logic

Most of these blocks contain configuration parameters that enable the block to exactly mimic manufacturer specific functionality. For example, each relay manufacturer implements the quadrilateral distance characteristic slightly differently with different input parameters defining the structure of the characteristic. Consider the Siemens 7SA632 and Areva P543 quadrilateral characteristics with similar settings overlaid on the same diagram (Figure 2). For the 7SA632, the position of the top line of the characteristic is defined by specifying the X-Reach directly $X(Z1)$ [1], whereas for the P543 the parameter entered is defined as $Zx Ph. Reach$ [2] and the position of the top line of the characteristic is then $Zsin(\Theta)$. Furthermore, there are differences in the directional characteristics that significantly affect the shape of the characteristic.

For the user of the model, it is preferable if the parameters entered correspond as directly as possible to the OEM software. This makes the resultant model easier to use and simplifies the transfer of settings. To achieve this, in the generic 'Polygonal' block within PowerFactory it is possible to select from several different quadrilateral characteristics with many of them based directly on the manufacturer specific characteristics [3].

As a second example of the complex functionality supported by the PowerFactory relay models, consider voltage polarising which is used by all distance relays. It is well known that relays from different vendors use different types of voltage polarising. For example, the SEL311L mho element uses the positive sequence voltage as a polarising quantity. By contrast, the Areva P543 distance elements use a combination of self and memory polarisation. In PowerFactory, it is possible to accurately represent this functionality in the dedicated polarisation block because it has the ability to employ several

different types of voltage polarisation including self, cross, memory and positive sequence.

The PowerFactory polarisation block also models zero sequence and mutual compensation. The relay model can accept the k0 and k0m factor in several formats depending on the format accepted by the vendor relay.

The PowerFactory model generally contains only a subset of the total relay settings because many settings within the relay are not required for correct simulation of the relay functionality. Furthermore, there are various other reasons why the PowerFactory model settings would not match exactly the OEM settings. These include:

- The fact that not all relay functions are supported by PowerFactory relay models. For example, functions such as demand metering, fault locator and breaker failure. However, it is noted that it is normally not required to model such functionality.
- PowerFactory relay models do not require many OEM settings file configuration parameters. For example, many relays store network topology information such as line length and rated frequency. This is stored within the network model already defined within PowerFactory.
- Custom user logic is often not implemented by the PowerFactory relay model, although can be supported if desired.
- Multiple settings group are generally not included in the PowerFactory relay model, although can be if desired.
- Some settings do not have a one-to-one relationship between the OEM representation and the PowerFactory representation.

The representation of a software relay model that mimics the exact functionality of the physical device is extremely powerful when combined with a detailed network model in PowerFactory. It enables the protection engineer to simulate faults on the power system and observe the exact relay response. This can be a useful tool for determination of correct relay settings, or for investigation of relay coordination problems.

The tools for protection analysis within PowerFactory such as R-X diagrams, time over-current plots and time-distance diagrams allow for rapid development of relay settings and rapid checks for consistency of existing settings. Automated checks or searches for specific conditions such as load encroachment or remote infeed under-reaching are also supported. Such tools avoid the need for complex external relay settings calculation spreadsheets that take considerable effort to produce and maintain.

When multiple relays are modelled and settings imported from StationWare, complex protection coordination issues between devices can be identified. Such issues otherwise might not be discovered when analysing each relay in isolation.

In terms of engineering safety, Arc-flash hazard assessment has also become a focus for many large industrials and utilities

[4]. The determination of the arc flash incident energy is critically dependent on the fault clearing time which can only be accurately established through detailed protection modelling and simulation. By setting up a network model consisting of the complete protection system, fault clearance times can be accurately determined at any point in the system and thus the arc-flash hazard quantified.

V. DPL IMPORT AND EXPORT SCRIPTS

The DIgSILENT Programming Language (DPL) scripts shown in Figure 1 implement the exchange of settings information between PowerFactory and StationWare. Because the PowerFactory model does not contain all relay settings like the StationWare model and due to other reasons mentioned in the previous section, these scripts have to describe the relationship between the settings within the two locations. Effectively, the DPL scripts become a translation map for the settings variables in each of the two databases.

In some cases settings translation requires the application of logic to address cases where settings dependencies exist. For example, in the SEL311L line differential relay, the setting E21P (Phase Mho Enable) is an enumeration that can have values "N", "1-4", "1C-4C". This setting does not specifically exist within the PowerFactory relay model, instead there are four Mho blocks that can be individually enabled or disabled. Consequently, the DPL script must check the setting E21P and then decide to enable or disable the correct number of Mho blocks within the relay. This decision tree for the DPL script is illustrated in Figure 3.

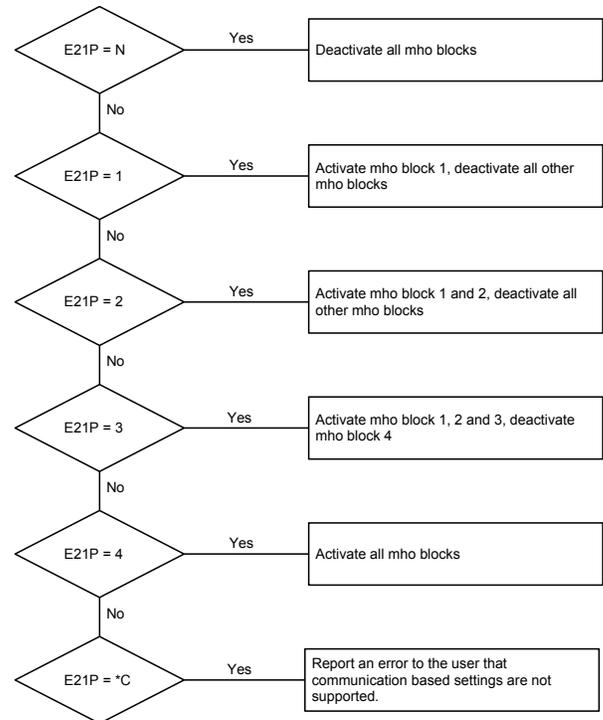


Fig. 3. Decision tree for E21P setting

This example is a simple illustration of the type of checks that the script must perform when translating settings from one database to another. There are many settings within a typical

relay such as the 311L that require such decisions, and some cases additional logic calculations are required depending on the complexity of the setting.

VI. CHALLENGES WITH THE SETTINGS EXPORT PROCESS

Because the PowerFactory model does not maintain an exact copy of the OEM settings like the StationWare model, the export of settings back to StationWare can present challenges. To deal with this, StationWare takes the existing 'Applied' settings and uses these to reconstruct the 'missing' settings from the PowerFactory export. This means that settings exported from PowerFactory to StationWare are a combination of the existing Applied settings and the exported PowerFactory settings. The process is illustrated in Figure 4.

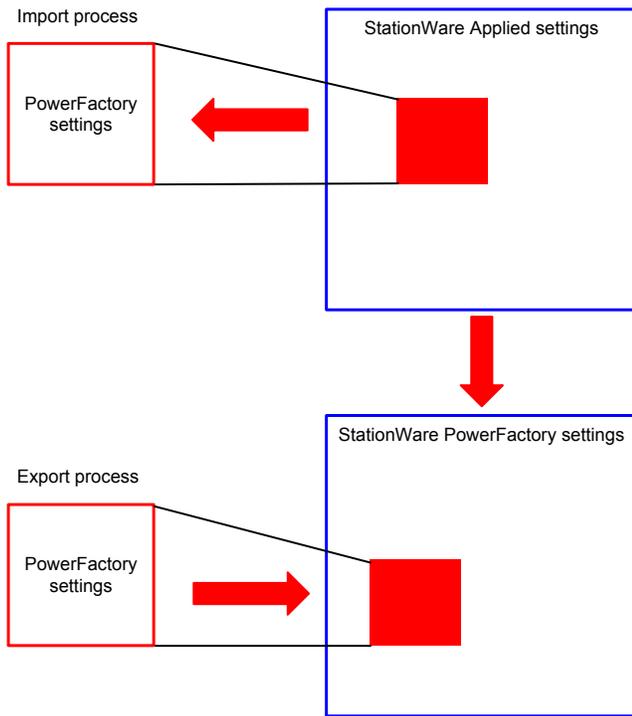


Fig. 4. Reconstruction of exported settings

This can lead to problems when settings dependencies exist. For example, in the Siemens 7SA632 distance protection relay, there is a load encroachment element (Load Area) element that is only enabled (and present in the OEM settings file) when another setting 'Distance protection pickup program' is set to 'Z< (quadrilateral)'.

PowerFactory has a representation for the distance protection pickup setting within the specialised starting block and does automatically consider the dependencies of this setting within the block. Consequently, various other settings in the block become visible or invisible depending on the option shown in Figure 5 that is selected. However, the load encroachment block is modelled separately to the starting block and dependencies in PowerFactory, aside from a few exceptions, cannot generally be considered across different blocks. Consequently, the DPL export for the load encroachment block must check the starting block distance protection pickup setting and

only export the load encroachment parameters if the setting is 'Impedance Z'.

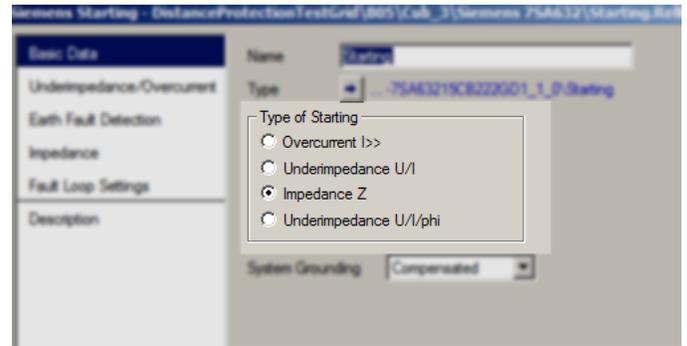


Fig. 5. Siemens starting element in PowerFactory showing the selection of starting type

Consider the case where a user has imported settings with the starting block set to 'Impedance Z'. Subsequently they decide to alter this setting in PowerFactory to over-current, then export the settings back to StationWare. The export script correctly sees that the starting element is set to over-current and therefore does not export the load encroachment parameters. However, StationWare sees the load encroachment settings as 'missing' from the PowerFactory export, so it uses the applied settings to reconstitute the disabled load encroachment settings. The exported settings in StationWare now contain incorrectly enabled load encroachment elements.

DIGSILENT is aware of such limitations of the settings export process and has identified future enhancements to PowerFactory and StationWare that will enable a more robust settings export process from PowerFactory.

VII. CONCLUSION

DIGSILENT Pacific has developed a process to develop so-called Verified protection relay models in PowerFactory and StationWare. A Verified Model consists of a matched StationWare model, PowerFactory model and DPL scripts to transfer the relay settings between the two software products. Such a system reduces the time to develop relay settings and avoids the use of complex external calculation settings spreadsheets. Furthermore, when combining an accurate verified relay model with a detailed network model of the power system, complex protection coordination issues can be studied to a level of detail that isn't practically possible without the benefit of automated settings import from a comprehensive protection settings database such as StationWare.

Some limitations with settings export from PowerFactory to StationWare have been identified. However, these are now well understood and future enhancements to PowerFactory and StationWare will allow for an improved settings export process with the eventual goal of being able to accurately reconstruct an OEM settings file from settings exported from a PowerFactory relay model.

ACKNOWLEDGMENT

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ing the opportunity to refine the verified model process for complicated distance and line protection relays.

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