H

USE CASE 13 – ADAPTIVE TRANSMISSION LINE PROTECTION

Use Case Title

Adaptive Transmission Line Protection

Use Case Summary

The requirements for improvement in the performance of protection relays under different system conditions lead to the implementation of adaptive protection that adjusts to changes in the configuration of the electric power system. This is especially important in the cases of double circuit transmission lines or lines that have one or more segments in parallel with one or more transmission lines on the same or on different voltage levels.

Changes in the state of any of the parallel lines or the system around them may affect differently the operation of the line protection relays for faults on the protected line or even on some of the parallel lines.

The protection system needs to be able to adapt to changes in the system configuration. This requires first of all the availability of a CIM model of the system including detailed information of the mutual coupling between the protected line and any other parallel line in its neighborhood. Information on each substation configuration, as well as the windings and grounding of the transformers is also required. Information on the grounding status of a parallel line out of service is also required.

Then, based on the state of the switching devices received through IEC 61850 locally and switching and grounding of transmission lines or other changes in the system configuration received from the system level, the adaptive protection system will change settings or setting groups in one or more relays to adapt to the system or substation changes.

This use case follows from the zone of protection definition through the analysis of the different possible modes of operation. The objective is to stress the 61850/CIM interface to discover aspects of the "seams" which exist between these two standards.

The CIM and 61850 must both be used at least at both ends of the process for this use case to be of practical use.

Use Case Detailed Narrative

The utility needs to configure the protection of a transmission line that is mutually coupled with one or more other transmission lines on the same or different voltage levels, on the same or different towers as the protected line. It is important to also keep in mind that usually these lines are not transposed and may have unsymmetrical configuration.

Parallel transmission lines have been extensively utilized in modern power systems to enhance the reliability and security for the transmission of electrical energy. The different possible configurations of parallel lines combined with the effect of mutual coupling make their protection a challenging problem. Different types of protection and algorithms have been proposed in the past to overcome some of the performance related issues. In addition to the effect of mutual coupling, fault resistance and pre-fault loading consideration, cross-country faults have to be considered as well in order to determine the protection response. In the case of use of distance relays, the determination of the final fault impedance is therefore not that straight forward as a number of system conditions affect it:

1. The dynamic changes of the characteristics of the power system, such as in generation capacity, load and in the network topology

2. Inaccuracies in the measuring instruments, relay measuring inputs, line parameters and protection algorithms

3. The state of the parallel circuit and its grounding.

The effect of the dynamic characteristics of the system on protection is normally dealt with by traditionally determining the relay settings according to worst-case scenario studies. Inaccuracies in the electric power system need to be considered in the process. For example, a sequence components based model for a protection coordination study of a transmission line that is not completely transposed, will result in a difference between the results from the simulation and real fault conditions. These are even more complicated in the case of parallel lines because (as described earlier) they may involve mutually coupled circuits with unsymmetrical configurations.

Inaccuracies in the image of the primary system conditions seen by the protective relays due to the errors in the measuring circuit can be limited by using properly selected current and voltage transformers and more advanced relay input modules.

To compensate for the above described effects, the relay settings require large safety margins. A typical Zone 1 distance setting is 80% of the line impedance, but the effects of unbalance, load current magnitude and direction and system source impedances at the ends of the protected line need also to be considered. These settings have to be appropriate for extremely weak system conditions, as well as in the cases where over or under tripping could further weaken the system and lead to stability problems.

Since distance relay settings may therefore not be appropriate for all system conditions in terms of security and dependability, adaptive protection based on different setting group selection are often considered in practice to improve the protection of double circuit lines.

Figure H-1 shows the effect of mutual coupling on a typical double circuit transmission line – the simplest case of parallel transmission. Current reversal after initial high-speed trip at an end closer to the fault, followed by current reversal is shown.

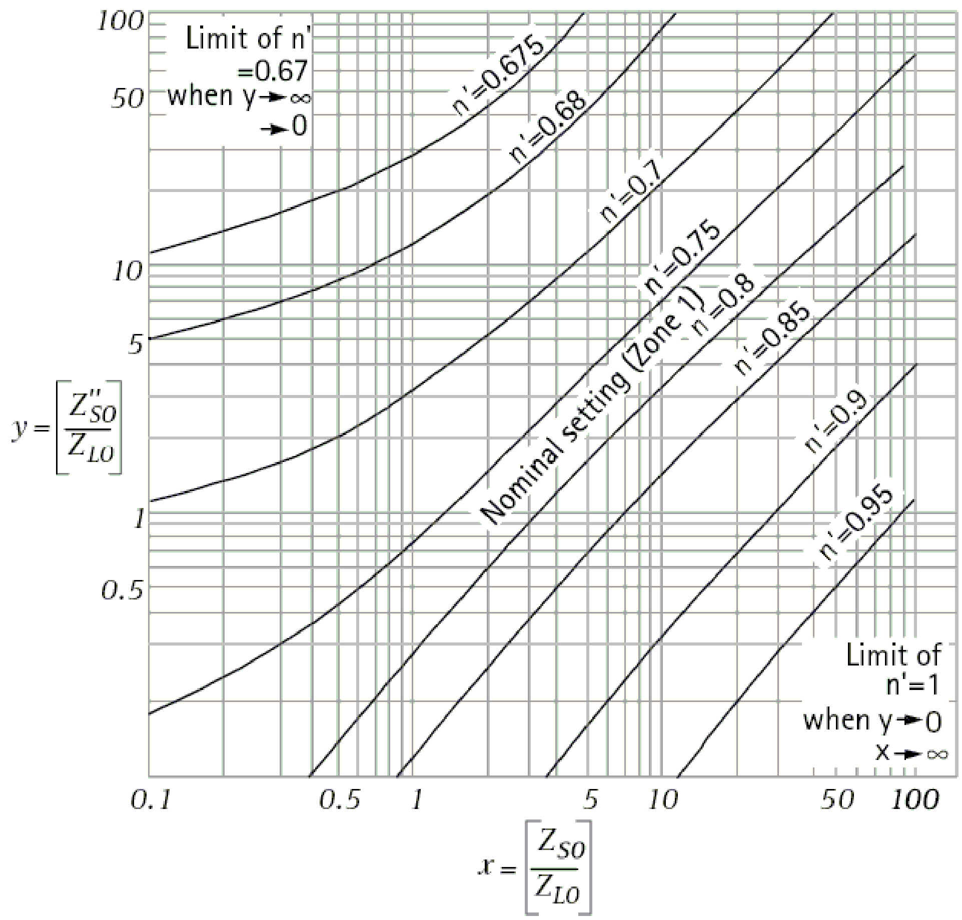

Figure H-1
Mutual Coupling Effect

From the above it is clear that the configuration of the transmission line protection and the knowledge of the current state of all switching devices on any of the parallel circuits are essential for the faster operation of the protection.

The topology of the system surrounding both ends of the protected line needs to be known in detail, especially considering the mutual coupling. Since the mutual coupling can be only over a section of the line and the end substations can be far from each other, it is clear that direct communications between the relays protecting the different lines might not be possible. A system level Adaptive Protection Central Unit (APCU) may be required.

Topology algorithm in APCU determines dynamically the electric scheme of the power system area covering multiple parallel lines. The results from detection of changes in local substation configuration need to be sent to the APCU in order to trigger the adaptive protection change.

The local detection is typically based on monitoring the status of auxiliary contact of circuit breaker and isolators or the availability of current flow through the monitored switching devices.

Once this data is received in the APCU it is used to determine the global topology of the system. At the end of process, the central unit determines if there is a need for executing adaptive protection functions and sending signals to specific protection IEDs to switch from one to another setting group.

It is essential that at each step of the process APCU knows the current state of each protection IED included in the adaptive protection system.

The topological model needs to allow the identification of each segment of transmission line running in parallel with a segment from another transmission line, as well as its association with circuit breakers and isolators at each end of these lines.

The global system topology is updated every time when a change of state of a switching device is indicated from the available at the system level reports.

Once a protection IED receives the command to change its setting group, it needs to send back confirmation indicating that a change has occurred and the active setting group.

As described in detail above, the system will require initial configuration process, followed by on-line monitoring of system changes and decisions to activate adaptive protection functions, based on system protection coordination analysis.

The configuration process will include the following steps:

1. Building of a system configuration model using a system configuration editor for relay coordination and short circuit analysis and based on data from a CIM system data base
2. Running coordination studies and determining conditions that require switching to adaptive protection mode and its corresponding settings
3. Creating the setting files, including multiple setting groups, for each of the relays included in the system
4. Creating a table with different system topologies and the corresponding setting groups of the IEDs included in the system
5. Downloading the settings in the relays
6. Determining the system topology
7. Activating the required setting groups
8. Reporting the active setting groups to the APCU

Once the system is configured, tested and put in service, it requires changes in configuration based on the continuous monitoring of the state of switching devices through the different IEDs reports.

The sequence of actions in this case will be:

1. Detecting the change of state of a switching device
2. Sending the report to the APCU
3. Determining at the APCU the system topology
4. Activating the required new setting groups

Each of the above steps imposes specific requirements for the harmonization between IEC 61850 and CIM.

1. Building of a system configuration model using a system configuration editor for relay coordination and short circuit analysis and based on data from a CIM system data base

A three phase impedance model (3x3 matrix) for single transmission line is needed.

A three phase impedance model for a double circuit line or a section of lines in parallel (6x6 matrix) is needed.

Connectivity model for transmission lines is needed to describe a line with multiple segments and multiple mutual couplings.

The connectivity model needs to be extended to cover mutual coupling on double circuit or parallel lines.

2. Running coordination studies and determining conditions that require switching to adaptive protection mode and its corresponding settings

No changes required.

3. Creating the setting files, including multiple setting groups, for each of the relays included in the system

No changes required.

4. Creating a table with different system topologies and the corresponding setting groups of the IEDs included in the system

The CIM and IEC 61850 models need to be extended and harmonized to support this function

5. Downloading the settings in the relays

No changes required.

6. Determining the system topology

No changes required.

7. Activating the required setting groups

The CIM model needs to be harmonized to be able to issue a change of setting group command

8. Reporting the active setting groups to the APCU

The CIM model needs to be harmonized to be able to perform as a logical node report client

The behavior of the adaptive protection system will then be based on the receipt of change of state reports from the IEDs and followed by steps similar to steps 6, 7 and 8 above.

Harmonization Tasks

- Based on the analysis of the above use case, the following harmonization tasks have been identified:
- A three phase impedance model (3x3 matrix) for single transmission line is needed.
- A three phase impedance model for a double circuit line or a section of lines in parallel (6x6 matrix) is needed.
- Connectivity model for transmission lines is needed to describe a line with multiple segments and multiple mutual couplings.
- The connectivity model needs to be extended to cover mutual coupling on double circuit or parallel lines.
- The CIM and IEC 61850 models need to be extended and harmonized to support the creation of a table with different system topologies and the corresponding setting groups of the IEDs included in the system
- The CIM model needs to be harmonized to be able to issue a change of setting group command

Business Rules and Assumptions

ACTORS

Actor Name	Actor Type (person, device, system etc.)	Actor Description
Protection Engineer	Person	Designs, tests, verifies, and analyses protection schemes (could be a team)
Protection IED	Device	Monitors system parameters in order to detect fault conditions within its zone of protection and take action to clear the fault.
Adaptive Protection Central Unit (APCU)	Device	Determines the change of system topology and the need for adaptive protection action based on active setting group change
Network Protection Application	System	System uses CIM and IEC 61850 data to read, create and verify protection settings files.
Protection Coordination Tool	System	Tool for the calculation of short circuit currents and voltages and checking of the coordination of protection relays settings
CIM Database	System	Contains CIM-level system topology and parameters
Relay Database	System	Contains the settings for each setting group for each relay in the adaptive protection system
Field Device Communication Interface	System	Generic architectural component that communicates with substation and field devices using IEC 61850. This system can translate IEC 61850 services to GID services.
CIM Model Server	System	

STEP BY STEP ANALYSIS OF EACH SCENARIO

Scenario Description

Primary Scenario: System configuration

Triggering Event	Primary Actor	Pre-Condition	Post-Condition
(Identify the name of the event that start the scenario)	*(Identify the actor whose point-of-view is primarily used to describe the steps)*	*(Identify any pre-conditions or actor states necessary for the scenario to start)*	*(Identify the post-conditions or significant results required to consider the scenario complete)*
Adaptive protection system is configured and put in service	Protection Engineer	CIM and IEC 61850 system models are available	Adaptive protection system is in service

Steps for this scenario

Step #	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step including the information to be exchanged. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column..*
1	Protection Engineer	Protection Engineer uses Protection Coordination Tool to build system configuration model	
1.1	Protection Coordination Tool	Protection Coordination Tool loads existing system model from CIM Model Server	CIM
1.2	Protection Coordination Tool	Protection Engineer uses Protection Coordination Tool to calculate settings for Protection IEDs	
1.3	Protection Coordination Tool	Protection Coordination Tool sends protection model changes to CIM Model Server	CIM XML
2	Protection Engineer	Protection Engineer runs coordination studies to determine conditions which require adaptive protection mode and the appropriate relay settings.	
2.1	Protection Coordination Tool	Protection Coordination Tool creates relay setting files.	
2.2	Protection Coordination Tool	Protection Coordination Tool creates database of possible system topologies and appropriate settings for groups of relays.	
2.3	Protection Coordination Tool	Protection Coordination Tool sends database of system topologies to Adaptive Protection Central Unit	
3	Protection Coordination Tool	Protection Coordination Tool downloads settings into the Protection IEDs.	IEC 61850
4	Adaptive Protection Central Unit (APCU)	Adaptive Protection Central Unit determines current system topology	
4.1	Adaptive Protection Central Unit	Adaptive Protection Central Unit retrieves current relay settings from Enterprise Communication Gateway	IEC 61850
4.2	Adaptive Protection Central Unit	Adaptive Protection Central Unit updates internal system topology model	

Step #	Actor	Description of the Step	Additional Notes
5	Adaptive Protection Central Unit	Adaptive Protection Central Unit transmits relay setting commands based on current topology	IEC 61850

Scenario Description

Primary Scenario: System operation

Triggering Event	Primary Actor	Pre-Condition	Post-Condition
(Identify the name of the event that start the scenario)	*(Identify the actor whose point-of-view is primarily used to describe the steps)*	*(Identify any pre-conditions or actor states necessary for the scenario to start)*	*(Identify the post-conditions or significant results required to consider the scenario complete)*
State change of a switching device	Adaptive Protection Central Unit	Adaptive protection system is in service	Protection settings are updated as system topology changes

Steps for this scenario

Step #	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step including the information to be exchanged. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column..*
1	Protection IED	Protection IED changes state	
2	Protection IED	Protection IED reports state change to Adaptive Protection Central Unit	
3	Adaptive Protection Central Unit	Adaptive Protection Central Unit updates internal system topology model	
4	Adaptive Protection Central Unit	Adaptive Protection Central Unit transmits relay setting commands based on current topology to Protection IEDs	
5	Protection IED	Protection IED updates internal protection settings based on received data or commands	

REQUIREMENTS

Functional Requirements

Functional Requirements	*Associated Scenario # (if applicable)*	*Associated Step # (if applicable)*
A three phase impedance model (3x3 matrix) for single transmission line is needed		
A three phase impedance model for a double circuit line or a section of lines in parallel (6x6 matrix) is needed		
Connectivity model for transmission lines is needed to describe a line with multiple segments and multiple mutual couplings		
The connectivity model needs to be extended to cover mutual coupling on double circuit or parallel lines		
The CIM and IEC 61850 models need to be extended and harmonized to support the creation of a table with different system topologies and the corresponding setting groups of the IEDs included in the system		
The CIM model needs to be harmonized to be able to issue a change of setting group command		

Non-functional Requirements

Non-Functional Requirements	*Associated Scenario # (if applicable)*	*Associated Step # (if applicable)*