SUBSTATION TRAINING SIMULATOR

Product Overview

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1 Introduction

In the last three decades the technology of the power substation has developed fast so far. The schematic walls in the substations were sidelined, the computer based process control systems (SCADA) have taken their places and have become vital importance in the substation staff’s daily work. This technology gave the opportunity to monitor and control the substations from a central control centre. The number of primary and secondary devices, controlled by the dispatchers had significant increased. At the same time the responsibility weighing heavily on the dispatchers and the chance of making mistakes became larger.

Considering these facts we may declare, that the dispatchers and the substation staff must be trained to achieve of their daily work.

The Substation Training Simulator (STS) is an efficient equipment to training the substation and control centre staff.

The main aim of the Substation Training Simulator is to make possible for the substation and control centre staff planning and executing switching sequences, recognising and understanding phenomena taking place in consequence of short-circuits, and failing of protection relays or primary devices in a simulated environment.

Its application is beneficial when the mistake of the substation crew may cause large financial losses, and the cost of simulator-based training is negligible compared to the possible losses.

As STS is able to simulate several substations, it can be used for the training of Network Control Centre (NCC) staff as well. STS does not support the load-frequency and the voltage-reactive power control activities, as these are typically system operator tasks. Nevertheless, establishing a data connection between the STS and a whole-scale power system simulator makes a cooperative training possible for substation staff (or Network Control Centre staff) and system operator staff.

2 The substation telemechanical system and the training simulator

The substation SCADA system collects the different type of technological data from the substation via the RTU system. The substation RTU system usually communicates with the local SCADA system through only one data cable.

If we unplug this data cable from the substation telemechanical system and plug into a simulator, which models the entire substation, than we get a virtual substation on the SCADA system screen. (See the following picture)
The connection of the simulator and the substation telemechanical system

The Substation Training Simulator is the most accurate copy of the real-time SCADA system. The trainee uses the same operator terminal as in real operational environment, and experiences the behaviour of the simulated power system through STS.

3 The overview of the technological simulator

The Substation Technological Simulator system is build up from two main parts:

- Local SCADA system (Substation operator terminal)
- Substation Technology Simulator (STS)

In the simulated environment the SCADA system is a perfect replica of the real-time SCADA system, providing that the simulator and the real-time system operator functions will be identical. The STS system is simulating the substation technology. That characteristics of modelling makes the highly realistic operation in the simulated real-time environment possible.

In the simulator the SCADA interface module provides the connection between the SCADA data-points and the simulator (STS) technological signals. The association of the SCADA datapoint identifiers (e.g.
Technological Address) to the STS database coordinates must be defined during the parameterisation of the STS.

The STS and SCADA connection type is the same as the SCADA connection to the RTUs.

Up to now, the following STS-SCADA protocols were developed in the STS system:

- IEC 870-5-101 – serial line data-connection
- IEC 870-5-104 – LAN TCP/IP connection
- SAM85 – serial line data-connection

As STS can easily be extended with other data-connections (e.g. simple FIFO), thus making STS compatible to new type of SCADA systems, or NCCs.

### 3.1 The main modules of the STS

The following picture shows the main modules of the STS.

![Modular structure of the Substation Training Simulator](image)

#### 3.1.1 Substation technology subsystem:

**Topology model, simulated primary topology equipment:**

The STS topology model describes the connections between the primary high-voltage network elements. The switching devices are modelled with 3 independent phases, because in some power system single-phase operation can occur due to protective operations. The topology model supports the following type of equipments:
• Switching devices
  o circuit breakers
  o disconnectors
  o grounding disconnectors
  o load break switch
  o breaker truck
  o pole-mounted switch
  o transformer tap control

• Series network elements
  o transformers
  o transmission lines
  o bus bars
  o nodes

• Shunt network elements
  o generators
  o loads

• Measuring elements
  o current transformer
  o voltage transformer

• Fault locations

Interlocking model:

The interlocks prevent that one could disconnect current-flow by a disconnector or create an earth fault with a grounding disconnector, and other prohibited switching actions. The STS supports logical and topological interlocking systems.
The logical interlocks evaluate logical equations. The variables of these equations are status information of switching devices. Subject to the results of these evaluations, the switching action is enabled or disabled.

Logical Interlocking based on logical equations

Example: LDC disconnector can only be switched off, if CB circuit breaker and LGDC ground disconnector are open simultaneously.

The topological interlocks are scanning the topology and enable or disable the switching actions according to electrical rules, supporting full-scope interlocking.

The logical and topological interlocking can be independently enabled or disabled in the simulator. When both of them are inactive, the trainee is able to cause miss-switchings leading to short-circuits. In this case protections clear the faults.

Protections and automatics, simulated protection equipment:

- Transmission line protections:
  - Distance protection
  - Overcurrent protection
  - Line differential protection
- Transformers
  - Differential protection
  - Gas protection
  - Overcurrent protection
- Busbars
  - Busbar differential protection
- Other protections
  - Breaker failure protection
  - Abnormal/asymmetric breaker state protection
  - Thermal overload protection
  - Voltage protection
  - Transformer oil and winding temperature monitoring
- Automatics
  - Transmission line auto-reclosure
  - Transformer switching over automatics
  - Automatic synchronous switching automatics
Flexible protection system

- numerous protections and automatics of the most common types – not dependent on any manufacturer
- custom protections fulfilling special customer requirements
- Its modularity enables custom configurations to be built.

Protection model:

- The protection model serves educational purposes for electric personnel, not for protection experts
- The modelling is rather functional than relay deep – the behaviour seen from outside is of great importance
- The principals of any protection is binding, thus none of the modelled protections or automatics has any special characteristics of any manufacturer
- The simulator handles fast and frequent protection operations with a time resolution of milliseconds
- The starting of protections is based on events

The protection system is built up by defining the connections between protection devices, providing a large-scale flexibility in modelling.

Example: the example configuration shows a source being connected to the power system through a circuit breaker, and has a current transformer for measurements. Two primary protections and a backup protection are triggered by the measurements of the current transformer, and as certain circumstances are met, they give a switching off command to the circuit breaker. The switching off also triggers the autoreclosure automatics, which tries to switch the circuit breaker back on – after several attempts, it gives a final switch off command, if the power system is still in a faulty state.

Modelling measurements: power flow and voltage simulation

- Active power
- Reactive power
- Apparent power
- Current measurements per phase
- Voltage measurements per phase (phase and line-to-line voltage)

The integrated analogue model provides believable analogue
measurements on the SCADA displays, and it will always harmonize with the following physical rules:

- The power-flow and voltage values are zero in a de-energized network areas
- The voltage values in an energized network area are not zero
- The power-flow values are not zero on the switched on branches (equal flow through parallel branches)
- Kirchoff's Current Law is always fulfilled.

The model can also handle non-symmetrical states (e.g. a transmission line, of which circuit breaker is opened in one phase, and closed in the others).

### 3.1.2 Telemechanical subsystem

The main task of the telemechanical subsystem is to simulate the base functionality of an RTU:

- Compose combined signals (e.g. breakers combined status signals)
- RTU’s automatics simulation (e.g. synchro-check automatics)
- RTU’s interlocking functions
- Protocol handling (IEC 870-5-101, IEC 870-5-104, SAM85)

### 3.1.3 Training subsystem

The training subsystem is controlling the simulator operations and supports the trainer to create prompt commands in the network model, build and execute scenarios and record and play-back simulation activities.

- Prompt commands

The trainer is able to create the following prompt events in the simulated substation or power network from the trainer interface:

- Changing state of switching devices
- Automatic controls (e.g. enable/disable)
- Clearing faults and device failures
- Transformer tap change
- Setting temperature
- Enable / disable the interlocking system
- Restart from the initial network state
Network events
- Short circuit / Fault events (one-, or multi-phase)
- Breaker failure event (stuck in or stuck out, broken drive, in any phase)
- Protection fault (starting failure, operating failure, fallback failure)
- State modification of switching devices (to set a base network state)

3.1.4 Trainer user interface

The trainer user interface of the simulator consists of three main parts.
(See the following picture.)

- Schematic window
- Event log window
- Scenario window
Mapleton 220kV

- **Schematic window**
- **Fault location**
- **Protection**
- **Breaker**
- **Disconnector**

**Scenario window**

**Event log window**
3.1.4.1 Schematic window

The schematic window displays the following objects:

- Substation schematic view
  - Breakers
  - Disconnectors
  - Grounding disconnectors
  - Series devices (transmission lines, transformers)
  - Busbars
  - Transformer tap positions
  - Short circuit locations
- Protection devices and automatics, their control boxes
- Interlocking states
- Measurement outputs

The main aspect of the schematic window realization:

- Integrated into the STS a WinCC SCADA software (Siemens) performs the schematic window-management.
- The graphic objects of the switching devices represent the actual states of the devices (open/transient/closed, stuck in/stuck out/broken drive, etc.).
- The colour of the protection control box represents the actual failure of a protection device.
- The visualisation of the schematic pictures is always fitted to the needs and requirements of the customer. The simulator and the SCADA system usually use the same graphic symbols.
- Network colouring of schemas by voltage levels or islands can be applied.

The trainer can open several menus and dialogue windows from the active objects of the schematic window, in order to modify the state of the network elements. The trainer can perform two types of modification:

Direct changes, which make a prompt effect

- Changing state of switching devices (open/close)
- Automatic controls (e.g. enable/disable)
- Transformer tap change (up/down)
- Clearing faults
- Clearing switching device failures
- Clearing protection device failures
- Setting control variables (e.g. setting voltage and temperature)
Preparing scenario events (timed events)

- Changing state of switching devices (to set a base network state)
- Place faults by type (1PHG, 2PHG, etc.), phase (A, B, C) and duration (permanent, temporary), or clear faults
- Switching device failures can be programmed or cleared
- Starting failure, operational malfunction and fallback failure can be programmed or cleared

3.1.4.2 Scenario window

The scenario window holds the composed scenario events.

Scenario composing procedure:

- Edit the sequence of the elementary events (append, insert, overwrite and delete).
- The trainer can save the complete scenario as a file.
- The trainer can load a saved scenario files.
- From the scenario window the trainer can run the scenario.
- The trainer can stop the running scenario from the scenario window.
- The trainer can start the scenario archiving and store the archived results into a file.
- The trainer can load and playback an archived training (in real-time, or step-by-step mode).

Each event is in millisecond resolution in the scenario window. The displayed time-stamp is relative to the starting time of the simulation. During the execution of the scenario the actual event is highlighted in the event list.

Example for a short-circuit and a circuit-breaker failure in the scenario editor:

1. 00.00.05 Permanent 1LG fault in A phase appears at MAPL-2-3KCSVK_ZH
2. 00.01.12 MAPL-2-2KT refuses to open in B phase

(MAPL-2-2KT breaker is stuck in, in B phase.)
3.1.4.3 Event Log

- The event log contains all of the simulator technological changes, except measurements
- The events are logged with actual time-stamp, in resolution of milliseconds.

Event log activities

- Delete event log
- Change the font size of the event log (small/medium/large)

4 Training activity with the simulator

The simulator supports single or multi user training, depending on the SCADA workplace configuration connected to the simulator. The trainer always uses the trainer interface of the simulator.

The trainee tasks are:

- To execute normal, routine switching actions, and tasks
- To communicate with the system-operator, and regional dispatching centre
- To communicate with other regional and local staff
- To recognize and eliminate disturbances

The trainer tasks are:

- To prepare the training (define the subject, create the scenario, set the base network state, adjust the model)
- To publish the tasks to the trainees
- To play the role of the regional or local staff (e.g. change the states of non-telecontroled devices from the trainers schema)
- To play the role of the system-operator and regional dispatching centre
- To generate disturbance events
- Monitor and evaluate the performance of the trainees

Scope of applications:
- Training new control staff
- To keep the active staff in practice, and keep their knowledge up-to-date
- Demonstration of real disturbances, real operational malfunctions

5 List of references

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