OPERATOR TRAINING SIMULATOR FOR A DISTRIBUTION SYSTEM

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ABSTRACT

For years Operator Training Simulator (OTS) systems based on the EPRI-OTS or similar products have been in use for transmission and generation systems in order to train new control center operators or to drill experienced operators for rare network conditions. However, due to lack of suitable products it was not possible to train Distribution Management System (DMS) operators the same way i.e. in a realistic environment, resembling on-line operations.

The paper describes a novel OTS for DMS that closes the gap and allows for the first time training of DMS operators on their own system, getting realistic system responses. A key module of the new OTS is a reliable and field-proven power flow for distribution networks which is identical to the real-time version.

Another novel module of the OTS is a trainee evaluation module that evaluates the trainee against criteria such as number of switching actions, reaction time to limit violations, reaction time to de-energized equipment and outaged clients, etc.

INTRODUCTION

In the last two decades, i.e. with the advent of energy market liberalization and utility unbundling, power systems have become increasingly complex and the requirements placed on operators in all phases of system operations have increased correspondingly. Particularly with view on distribution networks, this trend has got even more momentum with the increasing number and size of distributed generators all over the place – mostly based on non-dispatchable renewable energy resources. In past years, training of power system control center operators was done largely on the job. Experience in the operation of the power system under normal conditions was accumulated relatively quickly since most systems are operated under normal conditions most of the time. However, experience in alleviating emergencies is accumulated much more slowly since on most systems, these conditions occur much less often.

With Operator Training Simulators (OTS), it has become possible to improve the quality of training for power system operators. Since operators may be exposed to simulated emergency and restorative conditions on the OTS, frequently and at will, as opposed to rarely and by chance on the job, the time required to train a new operator may be significantly shortened. However, while OTS systems are meanwhile well introduced in the area of transmission network control centers they have not yet found their way to distribution. One of the reasons, of course, is the fact that in the past operator mal-operation on the transmission level could be the cause for system blackouts while this could rarely be the case on distribution. With the increasing complexity of distribution operation due to much more complex load-generation-pattern the risk for – local or regional – blackouts has occurred at the distribution level – and thus the need for appropriate training.

Why not just re-using the OTS approaches from the transmission level also in distribution? A major reason is the different approaches to load flow calculation in a meshed transmission network of some 1,000 buses as opposed to an – in most parts - radially operated distribution network with some 10,000 components. The paper first describes the basic architecture of an OTS in general, then outlines the special arrangements made for distribution network training, and finally presents the principles of the trainee evaluation module.

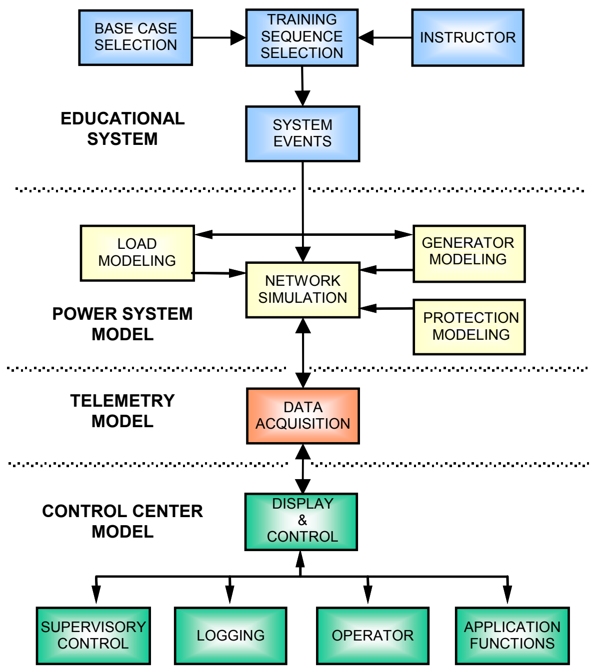

Figure 1: Overview of OTS function

BASIC OTS ARCHITECTURE

The overall simulator system can be logically divided into four principle subsystems

- the Educational System
- the Power System Model (PSM)
- the Telemetry Model, and
- the Control Center Model (CCM)

Figure 1 shows the relationship of these subsystems and their components. The **Power System Model** simulates response of load, generation and network conditions (flows and voltages) to control actions, which were initiated either from the Educational System or CCM. The PSM includes a load model function, network modeling which is implemented as a network topology processor, a load flow algorithm, and a set of prime mover models and frequency response programs.
The **Telemetry Model** connects the simulation with the CCM. Each telemetered data point is connected to an RTU or to an ICCP/ELCOM partner. If an RTU disturbance (or ICCP/ELCOM link disturbance) is simulated the connected data points are set to 'not renewed' and changes in the simulation are not anymore updated to the CCM. For individual digital data points a disturbance can also be simulated either for the proper operation of the device as such, meaning a status change does not occur neither in the simulation nor in the CCM, or for the telemetry only, meaning a status change occurring in the simulation is not updated to the CCM. For individual analogue data points a transducer error (expressed as a factor) can be set, or the data points can be set to 'invalid'.

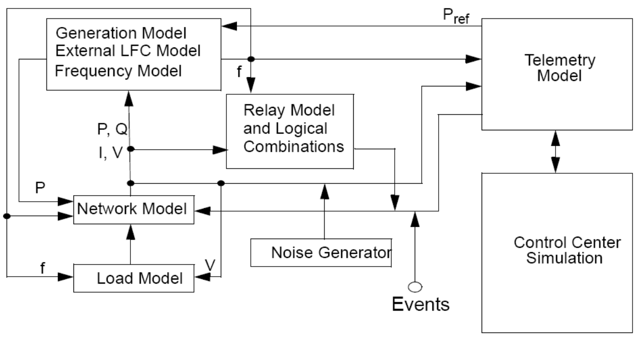

Figure 2: Overview of OTS Cycle Calculation

The **Control Center Model** includes a replica of the control functions in the SCADA/DMS. Replication means that the features and UI of these functions in the SCADA/DMS and OTS are identical, as seen by the trainee at his console. The following functions are included in the OTS:

- Data Acquisition
- Data Processing
- Data Dissemination
- Supervisory Control
- Power System Network Analysis functions
- Distribution Management Functions

The SCADA/DMS functions that have interaction with RTUs are altered so that they interact with the PSM, but are identical from the viewpoint of the trainee.
The **Educational Subsystem** provides a means for sequences of events to be defined, stored and retrieved by the instructor. Separate displays are used to define each sequence and to catalog by title those presently stored. The base of the **Event Scheduling Module** is the individual event. The following event types are available:

- Alarm / Status
- Alarm / Status disturbance
- Analogue value
- Transducer error
- RTU failure
- Relay operation
- Relay disturbance
- Short circuit
- Logical combination disturbance
- Load modification (single or global)

An event can be executed in the following contexts:

- Spontaneous event executed by trainer
- Scheduled event as part of an event scenario
- Conditional events triggered by network situations
- Events with daily schedules (e.g. reactive compensation)
- Operator commands, which trigger event sequences

Special substation automatisms or protection devices can be modeled via **Logical Combinations**, also known as conditional events. A graphical editor allows the definition of the condition by comparing status information/analogue values with constants or other status information/analogue values; sub-conditions are combined by means of Boolean operations (AND, OR, NOT). The sub-conditions finally yield a result, which - when it changes state e.g. from 'False' to 'True' - activates an associated event sequence.
The major component that distinguishes an OTS for distribution from a transmission system OTS is the **Power System Model**. The simulation of the power system is carried out through solutions of the loops, as shown in Figure 2. While Figure 2 shows the PSM modules of a general OTS, in the case of a distribution network the Frequency Model and the External LFC model can be omitted.
A single execution of the modules shown in Figure 2 is called an OTS cycle. Once every cycle the load and protection models are updated. If the Educational Subsystem or relay actions introduce changes such as breaker openings into the electrical network, the new network topology is determined by the network topology processing function and a power flow solution determines the flows and voltages throughout the network (network model).

NETWORK SIMULATION MODULE FOR DISTRIBUTION NETWORKS

The Network Simulation Model is the core of the DMS OTS. It consists of the following components:

- Topology processor
- OTS-Distribution Power Flow (OTS-DPF)

The OTS-DPF is a slightly modified version of the DPF, which is used in the real-time SCADA/DMS of the Spectrum Power 4™ control center system ([1], [2]). It is important to note that the OTS thus hosts two distinct power flow functions: one is identical to the DPF in the real time system and can be used by the trainee in the usual way, the other one is used for the simulation (OTS-DPF).
Further specialties of the network simulation module for distribution networks concern:

- Load model
- DPF activation
- Creation of relay models
- Internal history system for the trainee evaluation module

Load Model
OTS-DPF runs in a dedicated simulation context (PSM) separate from CCM. Upon session start all status information and measured values from a saved case are updated in the simulation context; non-measured loads at distribution transformers are determined from load curves taking into account the simulated date and time. An initial run of the OTS-DPF is started with scaling of the loads to the measured values (e.g. at feeder head). This initial run determines scaling factors for each load by comparing the OTS-DPF solution to the load value derived from the load curves.
DPF activation
In the **cyclic activation** (15 min cycle), the loads follow their respective load curves. The DPF is run without scaling but using the scaling factors determined initially. The load flow results are used for the telemetry model, the relay model and the logical combination model. The distribution grid is typically structured in subsystems where a subsystem comprises all feeders connected to a single HV infeed. In the course of a cyclic OTS-DPF activation all subsystems are calculated one-by-one. During the Factory Acceptance Test of a real project the data of about one third of the subsystems were entered including 33,000 line segments, 150 transformers (excl. distribution transformers), 26,000 bus bar segments, and 20,000 loads. It took OTS-DPF about 30 sec for handling those subsystems (Sun M3000 server).
A topologically relevant status change and a load modification event trigger a **spontaneous activation** of OTS-DPF. Further processing is identical to cyclic activations except for recalculating only affected sub-systems. In this way, the time between a CB status change and the updating of the changed values in the single line diagrams is kept down to about 5 sec, a very realistic value.
Relay Modeling
The relay model consists of the following types of relays:

- Relays triggered by OTS-DPF results (over current, over voltage)
- Relays triggered by scheduled short circuit events located at an equipment (transformer, bus bar, or line) with subsequent topological search of affected CBs
- Relays triggered by combined events in the scheduled event list i.e. ‘relay event’ plus ‘CB open’ event

If a relay disturbance is simulated via a relay disturbance event, other relays can isolate the fault.
Relays need not be entered manually via the database management system. Rather they can be created automatically based on the locations of their associated alarms. An automatically created relay is assigned a setting (current limit, voltage limit) based on the limits defined in SCADA; the setting can be modified later on. Furthermore, a flag for an automatic recloser can be set in a relay editor. In the course of the above mentioned data entry for 30% of a real network a total of more than 16.000 relays was automatically created. Hence, an automatic creation of relays can be deemed indispensable.

TRAINEE EVALUATION MODULE

The Trainee Evaluation Module aims to allow an objective assessment of the training progress. It will be available in the future also in the EMS version of the OTS. It consists of the following components:

- History system for all events and analogue values necessary for the evaluation
- Dialogues for defining limits for the criteria
- Evaluation and Report system

History System

The following criteria can be considered:

- Number of switching actions
- Reaction time to isolate a fault
- Limit violations
- De-energized equipment
- System loss
- Duration of trainee session
- Interrupted loads and customers affected
- Communication with other departments / sub stations

Each run of a training session as trainee is kept in an archive.

Criteria Setting

Before starting a training session, it can be defined whether the session shall be

- without evaluation
- run as a trainer
- run as a trainee

If it is run as trainer, all results will be used as expected (best) values for subsequent trainee sessions. The worst case will be determined as twice the value of the best case. For example: if the trainer needs 5 switching actions to fulfill the goal, this is the expected value, and 10 is the upper limit (worst value).

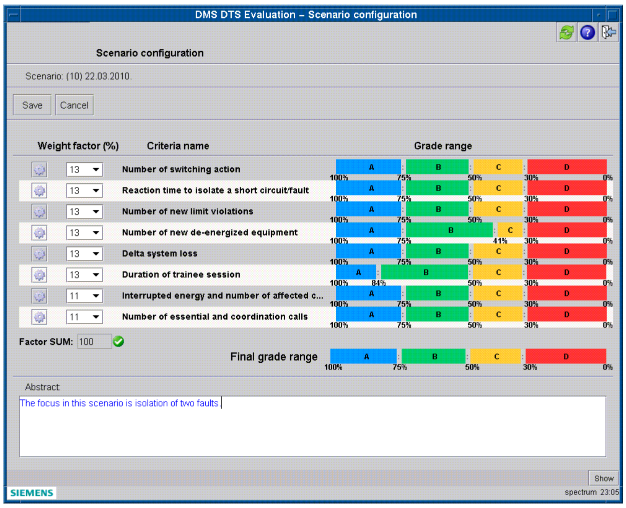

Figure 3: Assignment of required fulfillment percentage

Evaluation and Report

The evaluation assigns to each criterion a fulfillment percentage (between 0% and 100%) based on an upper and a lower limit for this criterion. If the actual value is outside the limit a special mark ('Excellence' or 'Poor') is assigned for that criterion. For each criterion the percentage is transformed into a grade (A – D), with the possibility to set the percentage to grade ranges. Finally, a final percentage and grade are calculated, with the possibility to set individual weight factors for the criteria. Criteria can be disregarded by setting their weight to zero.

The evaluation is done for each trainee participating in the training individually. If several trainees are working in the same area their evaluation is aggregated into a group. Groups can also be aggregated manually. A pdf-formatted report is available for each trainee (or group of trainees), which contains the following information:

- User name, session abstract, trainer comments
- Criteria weights and used grade ranges
- Grades and percentage per criterion and final
- A radar like graphical representation of the fulfillment (Figure 4)
- Switching actions
- Details for all criteria

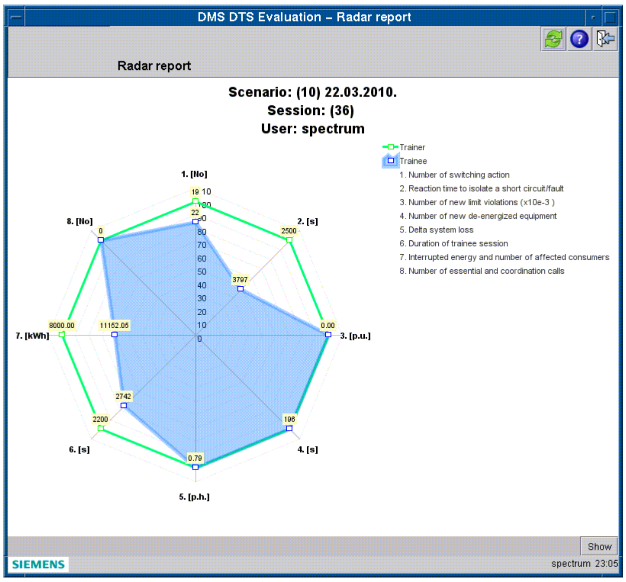

Figure 4: Sample of trainee evaluation diagram

FUTURE OUTLOOK

The OTS as described above is currently being implemented in a first project. The Factory Acceptance Test has been successfully passed and the complete SCADA/DMS including OTS is planned to be handed over to the customer in August 2011. After hand-over the OTS will be used to train the operators of a distribution network serving 500,000 customers through 21,000 km of distribution lines facing an annual growth rate of 12%.

In a next step of OTS development it is planned to add modules to the Generation Model of the PSM that allow more detailed modeling of Small Distributed Generators that are scattered throughout the distribution network. These are, for instance, photovoltaic panels on building roofs, small wind turbine plants, small hydro generators, etc.

In order to fully close the gap between training simulators in the transmission area and the distribution area the ability to model distance protection relays in combination with short-circuit calculation will be added to the latter.

REFERENCES

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[2] I. Roytelman, 2006, "Real-time Distribution Power Flow - lessons from practical implementations", *Proceedings IEEE Power Systems Conference & Exposition (PSCE)*