SIMULATOR FOR INTER−COMPANY OPERATOR TRAINING

Udo Spanel, **Gerhard Krost, Dieter Rumpel**

DUtrain GmbH
D−47239 Duisburg, Germany
email: udo.spanel@dutrain.de

Duisburg University FB9−EAN
D−47057 Duisburg, Germany
email: krost@uni−duisburg.de

Abstract: Today power system operation underlies a variety of rapid changes due to external political, ecological and economical impacts, altogether requiring a more extensive co−ordination and parallel acting of all control centres involved under 'normal' as well as 'abnormal' operating conditions. The latter can be achieved through practical operator training which is evolving to an essential key−factor in today's power supply industry as well as additional auxiliary EMS functionality in the control centres based on innovative technologies such as expert systems. Operator training simulators are powerful tools to bridge the gap between required skills and practical experience of operators, if they represent the power system performance with operational realism under all system conditions, as well as the interacting control centre structure including all players involved.

Keywords: Power−system control, Training Simulators, Data handling systems, Expert systems.

1. INTRODUCTION

Diverse non−technical issues like extended energy trading, increasing competition, free network access and enhanced customer services become more and more relevant for today's power supply industry and influence the operation of a supply system in addition to prevailing technical conditions. From the technical point of view all these impacts lead to

- higher loading of power units,
- operating the power systems close to their limits,
- rapidly changing operational conditions,
- an increasing number of participating companies in electrical energy supply with own control centres.

However, irrespective of these changes all operators independent from their control centre level must continue to anticipate threatening situations to avoid disturbances and, where this can not be achieved, to restore power supply as quickly and effectively as possible. Due to the increasing number of participating companies disturbance handling and restoration tasks are becoming more and more crucial and require extensive co−ordination and parallel acting of several control centres. A mutual understanding of interrelated impacts on the separated control instances of individually acting control centres is required from all operators concerned. Regarding these conditions, training the operators' decision making and, in doing so, keeping their knowledge, skills and experience up to date in theory and − what is quite more important − as well in practice is a key factor of today's power system operation. To cope with this demand, the participation of operators of several control centres in well designed and structured training programs containing practical sessions performed on an operator training simulator (OTS) is an efficient and increasingly practised solution (Krost, on behalf of CIGRE WG 39.03., 1998).

2. REQUIREMENTS OF AN OTS IN TODAY'S ENVIRONMENT

The effectiveness of such preventive training programs is highly dependent on the capability of the OTS used. To train the operators' job under realistic circumstances in today's electricity supply structures it is necessary to **simulate several control centres and their responsibility areas in parallel**. These control centres have different functionality within the complete supply system, and therefore they require different man−machine interfaces displaying different information and allowing different operations:

The **system operator** needs an overall view on the system status; operators working in **regional control centres** need a view on the system under their regard in a different manner and detail. Operators controlling a **power pool** need diverse information than operators from network control centres, which results in a total different display of the information. There is also the problem of the **trainer**'s desk. To follow up the simulator training from the technical point of view, the trainer needs an overview of the complete physical supply system − independent from control centre structures and areas under regard since physics does not stop at control areas' borders. On the other hand, the trainer needs an arbitrary view on each particular control area with all operational detail to follow up the single operational actions performed there, and to survey the inter−company actions. This is essential for integral training in today's multi−control−centre environment.

Especially situations like disturbance handling or even system restoration which are different from normal day to day operation dictate **additional requirements** to the **modelling** of system performance within the simulator. The used models have to cover the occurring physical phenomena to give the operators a realistic representation of system performance under these 'abnormal' conditions. Whereas under 'normal' operation conditions large power systems are usually operated with interconnections, emergency situations may lead to a splitting of the whole power system into several islands. Under 'normal' conditions a high grade of system control is automated (e.g., AGC, automatic transformer tapping) but under 'disturbed' or 'restorative' operation conditions it is often required to take these automated functions out of service which then have to be taken over by the operating personnel. Even under 'restorative' conditions the power system and its equipment are often operated at their limits. Whilst the modelling of, e.g., a generation unit represented by a simple gradient model close to, or around, a pre−defined set−point is sufficient under 'normal' conditions, modelling of the same generation unit under 'restorative' conditions has to cover the full performance range from tripping to house−load to nominal power. The modelling of load performance under 'restorative' conditions requires − in addition to, e.g., voltage dependency − to provide different trajectories of recovery depending on type of load and outage time. Thus, the capabilities of the models used in a simulator are another essential key factor for the scope for, and success of, practical training. On the other hand, the more complex training tasks are, the more comprehensive information for the simulator models is required.

All above mentioned requirements are directly related to the data which have to be incorporated into the simulator. The **data needed** for replicating the physical power system are in principle available in the control centres, but represented in quite different manner such as:

- technical process data of the control system (e.g., substation configuration and connectivity),
- data in listed paper form (e.g., protection configuration parameters, governor parameters of power units),
- experienced data in the heads of the operators (e.g., load recovery performance).

All these data have a special meaning only within the particular control centre environment, and they only represent this particular part of the entire system. In general, within a network control centre − independent whether it is built for system operation or for regional distribution − data of the power units and their generators are not available and vice versa. Explicit load data are in general only available on the distribution level, whereas on the system operator level usually only the transformer loads are known. But for the implementation of the whole physical system that should be simulated including its control structures, all these diverse kind of data are needed. They can be subdivided into

- **physical** power system data, covering all information to describe the power system performance in the required detail, comprising static information as well as dynamic performance parameters of all
  - network equipment and devices, their states and topological interconnection,
  - generation including external ties,
  - loads or sub−posed networks,
  - measurement,
  - alarms and messages and their indications,
  - SCADA/EMS functions.
- **organisational** power system data comprising the relationship of physical equipment to a particular control centre (e.g., a power plant or unit, a substation or even a single busbar or transformer), the control centre structure and hierarchy within in the complete physical system.

Regarding the actual **data sources** it must be stated that

- the information needed as set−up data for such kind of integral simulator is not available at a single location,
- it is only partially available in form of technical process information which might be directly copied from the control centre's process database,
- all other data have to be collected and entered with a considerable effort.

To keep the overall effort within tolerable limits, a data system is needed which enables to facilitate the simulator set−up by use of a uniform and open data structure for all kind of required information. If the original operational notions are used, further reduction of effort is achieved.

In conclusion of all this, a simulation system for an effective treatment of comprehensive power systems with a multi−control−centre structure must have the following features:

a) efficient data input and set−up
b) data accessibility for (simulative) process environment
c) operational surfaces
d) correct physical modelling of all system components in full operational range.

3. A FLEXIBLE APPROACH

The above requirements a)−d) are met with the GDL process data system (www.uni−duisburg.de) on which the flexible simulator described in the following is based. This simulator which was developed at Duisburg University's power systems institute allows to represent any given power system independent from the system itself, the control centre structure and hierarchy within system control and the therefore displayed information. Its flexible set up allows to provide training for single individuals and cross training simultaneously for teams of operating shifts and groups of teams from different companies, all acting on replica of 'their' networks. The trainer's desk − including all necessary supervisory functions − and the number of trainee desks − each representing one particular control centre − are set up as required for the operational tasks and training needs. The trainer can make use of role playing facilities and has full insight into all performed actions as well as an overall view on the entire system. Powerful tools for base−case and scenario definition and setting even during the training session on the one hand limit the time for training preparation and on the other hand allow 'lively' training sessions.

The simulator (**Fig.1**) consists of four main modules:

- system description module with an implemented scenario builder,
- central process data model within a SCADA system,
- independent user interfaces for network and generation process control,
- simulation system for the power system's physical performance.

The configuration of the simulator regarding the diverse network control centres and generation control centres is derived from the process data model contents. Specific functions including an online scenario handler residing in the trainer's domain complete the simulator to be an adequate powerful training tool.

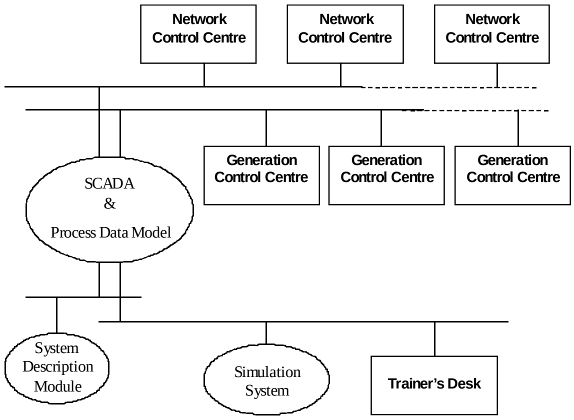


Fig.1 Components of the simulator

For simulator set−up all required static and dynamic information of the power system (networks, power units, loads, interconnections, protection, ...) is entered as system description in a readable form (GDL format). The generation of the central *'Process Data Model'* as well of control centre user interfaces (Rumpel, *et al.*, 1996) and the parameterisation of the *'Simulation System'* are done automatically from scratch which means they are directly set up from the readable 'system description' generated by use of the *'System*

Description Module'. In that sense the simulator is 'self−adaptable' to the described power system. The implemented models of the *'Simulation System'* cover the physical performance of the given power system during 'normal', 'emergency' and 'restorative' conditions (Dickers, *et al.*, 1987) with respect to the operators' view.

It is worth to be mentioned that the *'System Description Module'* and the *'Simulation System'* are the key elements for the flexible use of the simulator. The process of entering data into the simulator (3.1) as well as the implemented models within the simulation system (3.2) will be described in more detail. Of further importance for the flexibility but not described here in detail is the set−up of each particular control centre surface which is automatically derived from the 'system description' and the '*Process Data Model*' (Rumpel, *et al.*, 1996).

3.1 Training simulator set−up

Thanks to the GDL data system (www.uni−duisburg.de) it is possible to update the simulator within only a couple of man−weeks for any given power system). Contrary to today's updating of control systems, GDL makes use of a **language oriented data system**. The definition of system objects (e.g., system devices, measurands, messages and alarms, ...), their sets of potential states (e.g., 'On', 'Off', 'Disturbed', ...) − in original operational notions −, and further the correspondence between the operational notions and process data declarations of the particular objects are entered in one step. All system objects, their operational identifiers − which are combined from original operational notions − and their topological connections, representing the complete power system, are entered in a second step only in one format−free ASCII file. Operational identifiers and topological connections are implicitly expressed by the GDL syntax.

Already in the phase of 'system description' a base case representing a current system status can be entered and further be used as a default process set−up for the simulator training session. The performance description of loads, of the power units − both even under restorative conditions −, the parameterisation of all models (3.2) embedded in the simulator as well as the base case and scenario definitions make use of this 'GDL syntax', too.

In general, what is entered here on this level is the description of the entire physical system which should be simulated. In addition to the physical description the system control hierarchy and structure is described, thus expressing the relationship between each particular control centre and the system devices under regard.

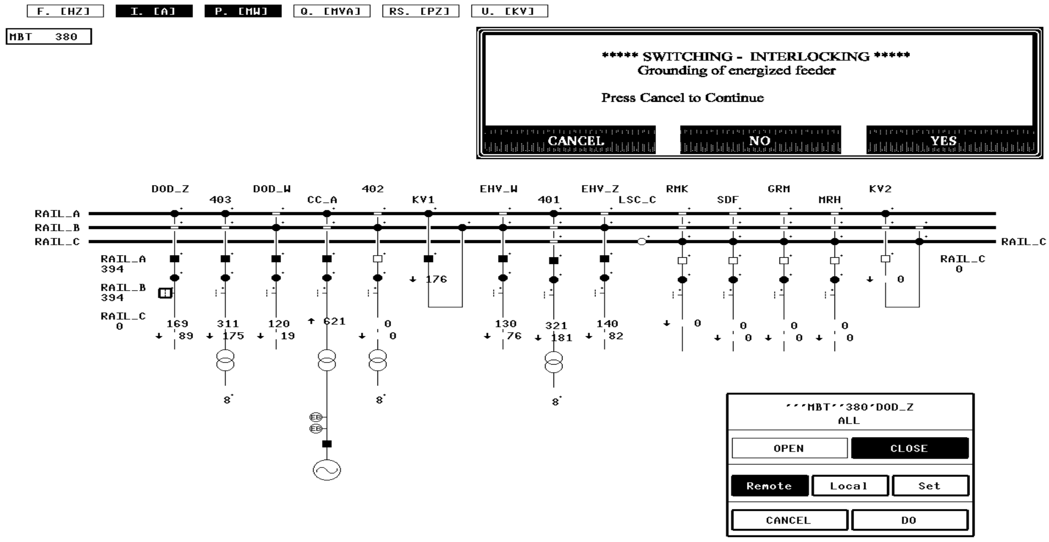
A **fully automated generation process** creates directly from this readable source code

- the complete ***'Process Data Model'*** for the simulator,
- all switchyard and substation diagrams − including the direct coupling to the ***'Process Data Model'***,
- all user interfaces − representing the particular parts of the complete power system under regard,
- all parameterisation of the models embedded in the simulator,
- all necessary system states for a consistent setting of the simulator.

The automatic generation of the ***'Process Data Model'*** (**Fig.1**) makes use of a **bi−directional compiler** which arbitrarily allows to translate the contents of the process data model back into the readable source code of the 'system description'. This mechanism is also used for creating and preparing scenarios before, during and after a training session.

The automatic generation of **switchyard and substation diagrams, system overview and node−point displays** as comprehensively described in (Rumpel, *et al.*, 2000) makes use of today's used symbols − which are pre−defined as default − and thus provide for a realistic system control representation (**Fig.2**). Additional manual work might only be required for different or additional object symbols, or intentional changes of the graphic presentation of the switchyards and substations. Comprehensive surfaces for power unit operation as well as a trainer's desk are generated automatically, too (Rumpel, *et al.*, 1996).

After the 'system description' was entered, the generation process for the complete simulator set−up takes only a couple of minutes. By this advantage changes to the power system (e.g., set of objects, circumference of control areas, control hierarchy, future systems) are easily implemented in a short time with a considerable time benefit.



***** SWITCHING - INTERLOCKING *****
Grounding of energized feeder

Press Cancel to Continue

Fig.2 Interactive switchyard diagram of training simulator with switching window opened and message due to interlocking violation

3.2 The simulation system

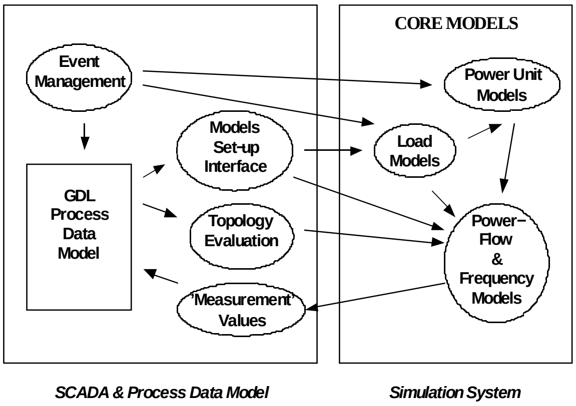
As shown in **Fig.1**, the simulation system is coupled to the *'SCADA & Process Data Model'*. It is controlled from the trainer's desk. This desk provides amongst other functionality full insight into the simulated physical process performance and allows to manipulate loads, power units, external infeeds. Also parts of the complete interconnected power system which are not under regard of the particular control centres are involved.

The models used in the *'Simulation System'* can be subdivided into

- **core models** which are elementary to run the simulation,
- **functionality and equipment models** which can flexibly be added to refine simulation details.

The **core models** (**Fig.3**) combine partial models representing the long−term and mid−term dynamic performance of network, power units and loads (Dickers, *et al.*, 1987). These models are designed to cover also the special phenomena encountered in the restorative phase which especially means:

- The **load−models** (Dickers, *et al.*, 1987) can mimic different recovery−load trajectories which represent the performance of real and reactive node−loads depending on their outage−time and time after reconnection as well as voltage and frequency dependency.
- The **power unit models** for thermal units (Dickers, *et al.*, 1987) (conventional and nuclear), gas−turbines and hydro, were designed for the **full range of operation** from start−up to nominal load, also respecting operation under house−load conditions.
- The **power−flow−calculations** can be computed for several independent network−islands existing in parallel.
- The **frequency model** represents the performance within each of the network−islands.



Computational effectiveness is achieved through **decoupling of the mid and long term dynamics** as comprehensively described in (Dickers, *et al.*, 1987): The results of the long term models of loads and power units − calculated in 10 sec. intervals − are handed over to the lumped frequency model which derives the frequency shape with a resolution of 100 milliseconds. In this way even very large systems can be treated in real time whereby all information relevant to the power system control view is procured quite realistically.

The principal coupling between the components of the *'SCADA & Process Data Model'* and the core models of the *'Simulation System'* is shown in **Fig.3**. All incoming spontaneous events from any of the independent user interfaces are centrally handled by the *'Event Management'* and distributed to the diverse models. The computed results of the *'Simulation System'* are stored back to the GDL *'Process Data Model'* as 'measurement' values and indicated within the substation diagram (**Fig.2**). The refresh rate of these values is 10 seconds, thus giving the operators a realistic sight of system performance.

Fig.3 Core Models for dynamic system simulation

The **functionality and equipment models** combine power system protection as well as equipment which is operated by automatism. These models are parameterised via the '*Models Set−up Interface'* and connected with the components shown in **Fig.3** in appropriate manner, corresponding to their functionality. **Protection** devices are of importance especially for training disturbance handling and restoration tasks but also for basic protection scheme understanding. The corresponding equipment can be represented such as differential−, distance− and diverse transformer−relays, overload and under/over voltage protection, relays for over/under−frequency unit/load tripping and reverse−power protection of units.

Automatism and equipment used in power system control is modelled for the following functionality:

- paralleling lockout,
- synchronising equipment,
- automatic tap−changing on transformers,
- automatic generation control,
- static VAR Compensation,
- HVDC−links.

All these functionality and equipment models can be **optionally and flexibly** added by just entering their required parameters into the 'system description' (3.1) in accordance to their existence within the power system under regard and to the training tasks to be performed on the simulator.

Roughly **summarised**, the simulation system requirements a)−d) for an effective treatment of comprehensive power systems with a multi−control−centre structure as formulated at the end of section 2 have been successfully fulfilled with the approach adopted here by the following **specifics**:

a) data input and set−up via GDL syntax using original operational notions and not via tables
b) GDL based syntactical process data model generated from source code
c) automatic generation of operational surfaces from process database contents
d) decoupling of mid and long term ranges in power plant dynamics.

4. PRACTICAL USE OF THE SIMULATOR

Due to the given flexibility the simulator is being used in several configurations for different aspects of training at a professional training centre as well as at Duisburg University's power systems institute.

At the professional **training centre** operators are practically and regularly trained on a replica of their power system (www.dutrain.de). The domain of applications covers at present:

- disturbance handling in a one control centre environment,
- initial operator training in interconnected systems in a multi−control−centre environment,
- inter−company restoration training in a multi−control−centre environment,
- validation of restoration plans,
- studies on, and validation of, future system control responsibilities.
- additionally the simulator is used to demonstrate mutual impacts of diverse control centres in a multi−control−centre environment.

For the particular training courses the simulator is set up as described above for the actual power system where the training is being performed for. For instance, for a municipal power system the simulator is implemented on two workstations, one representing the grid operator control desk and the other one the load dispatcher's place; for the large Dutch system (as described in Hoogveld, *et al.*, 1998) there are up to 9 workstations involved, representing national and several regional grid control centres as well as generation control centres and a trainer's desk. Before the actual training session, a scenario is entered into the simulator's process database by either manual switching or by mapping a prepared file. For practical reasons, a set of such files has been elaborated for each power system under regard as 'basic scenarios' that can arbitrarily be modified.

At the university's **power systems institute** the simulator is used for **initial operation training** in student labs. The realistic system performance, the live control room atmosphere and the opportunity to discover the complex phenomena in power system operation by themselves are greatly appreciated by the students. Due to its easy parameterisation and providing the flexibility to change the power system structure just by switching, the simulator is also successful in use as tool for **power system planning and analysis** studies.

Furthermore, the simulator has proven as an ideal **test bed for new applications** in the field of SCADA/EMS functions developed at the Power Systems Institute (Krost, Spanel, 1998): here the simulator replaces the 'real world', and operators' feedback as well as new ideas result from the training courses as described above.

A very interesting example for such innovative functionality is the expert system based **bulk system restoration guidance** (as comprehensively described in Spanel, *et al.*, 1999 and Krost, *et al.*, 1999). The genericity − i.e. the applicability of this tool to any given power system − could successfully be proven with the variety of power systems replicated on the training simulator. The proceeding is as follows: After pre−setting a disturbance scenario on the simulator as described above, the expert system guides the trainee through an appropriate restoration proceeding, decomposed from a global restoration strategy over its tactical adaptation to the present system status down to the particular control operations which are presented as suggestions to the operator (trainee) on the screen in natural/switching language form. They can either be executed on the simulator's operational surface and reconfirmed to the expert system, or be refused. In the latter case or if a system device is not available for operation (e.g., breaker in 'disturbed' position) the expert system searches for alternatives, thus flexibly adapting the strategy to the given situation. The execution of commands and the reaction of the power system are checked in the process database. The proceeding is explained by the expert system on request (Krost, *et al.*, 1999).

So far all functionality in and around the training simulator is related to the technical aspects of power system control. Caused by the restructuring process of the power industry additional instances and players are involved such as marketers, electricity stock exchanges, independent system operators and so on. Current development is related to complement the simulator by such kind of functionality thus enabling to extend the training capabilities also in this direction.

5. CONCLUSION

Due to its flexible and efficient set−up and the modular structure, the stand alone operator training simulator developed at Duisburg University is especially suited for multi−player inter company training. Regularly used at an operators training centre as well as at the university institute, it allows to perform individually arranged and adapted training sessions under operational realism. As shown with the example of the restoration expert system, the simulator also represents an excellent test bed for new EMS application functions.

1. REFERENCES

Dickers, K.; Rumpel,D. (1987): Modelling for Grid Restoration Studies; Electr. Power & Energy Systems, **Vol.9**, No.1, p. 45−55

Hoogveld,J.; Siffels,G.; Rumpel,D.; Krost,G.; Spanel,U. (1998): Power System Restoration − Strategies and Operator Training in the Netherlands; CIGRE SC 39 Session, Paris

Krost,G. on behalf of CIGRE WG 39.03 (1998): Impacts of Operators' Selection and Training on Power System Performance; CIGRE SC 39 Session, Paris

Krost,G.; Salek,K,; Spanel,U. (1999): Implementation and Verification of a Generic Restoration Guidance System; ISAP'99, Rio de Janeiro

Krost,G.; Spanel,U. (1998): Expert Systems Applied to Power System Control; 12th CEPSI, Pattaya

Rumpel,D.; Kempinski,W.; Litzinger,A. (1996): Transparent Data and Automatic User−Interface Design for Power−System Control and Simulation, 31st UPEC 1996, Iraklio, **Vol.2**, pp. 372−375

Rumpel,D.; Kempinski,W.; Krost,G. (2000): Interactive Visualisation System for Power System Control − Principles and Implementation of its Automatic Design; IFAC Symposium, Bruxelles

Spanel,U.; Krost,G. (1999): System Restoration Guidance as Intelligent Application Function in Power System Control; ISAP'99, Rio de Janeiro

http://www.dutrain.de/

http://www.uni−duisburg.de/FB9/EAUN/