SIMULATOR BASED OPERATOR TRAINING − ENSURING QUALITY OF POWER SYSTEM OPERATION

U Spanel, M Kreutz, C Roggatz

DUtrain GmbH, Germany

ABSTRACT

Liberalisation of the electricity supply industry causes new operation requirements and training needs for staff members in power system control [1]. Market principles lead to a more customer and quality oriented business with increasing interest in reliable system operation.
A key issue to ensure the quality of operation is the control centre personnel’s job performance and competence [2]. The rapidly changing technical and commercial prevailing conditions forces an ongoing improvement of operator’s knowledge, experience and skills under normal as well as abnormal system conditions.

Well structured simulator based training courses and programs have proved to be highly effective to mediate practical experience, especially in cases where performance requirements could hardly or not at all be trained on the job [3]. Especially crucial time constrained tasks like system defence and restoration could be trained effectively using a training simulator with adequate capability [4]. Key factors of such training are of various kinds and particularly differ, depending on the training goal and the thereof derived training requirements [5].

In the following some experience of simulator based operator training is summarised, which is gained in an independent training centre for power system control over the past years from the execution of more than 70 training courses (more than 500 participants in total throughout Europe). The designed training courses are grouped to a defence and restoration training program, developed and performed for transmission system operators, regional transmission and distribution operators as well as power production operators [6]. The paper describes the training requirements, organisational issues to be respected during the design phase as well as the training program and performance aspects.

ENSURING QUALITY OF POWER SYSTEM OPERATION

A key issue in quality of power system operation is the ability of the human operators working in the control centres to analyse the ongoing process, to draw the right conclusions and to act properly according to the current status of the power system under regard to maintain reliable supply of energy to the customers.

The liberalisation of the electricity sector puts high pressure on the utilities to act more *customer focused* in a most *cost efficient* way. That forces the companies to run the systems closer to their limits, to act faster to the demanded services, to increase cost awareness and economic thinking instead of technical dominated system operation with the aim to *provide a full reliable business platform* for all participating actors. The actors *(customers)* are becoming more and more aware of the necessity for a reliable supply and ask for service guarantees. Especially disturbance clearing services gain a high priority. A growing interest in quality of operation under ’normal’ as well as ’abnormal’ system conditions is seen on both sides − the customers and the companies.

Experience shows that various conditions caused by the liberalisation process dominantly influence the operator’s job in the control centres and accordingly determine additional prevailing conditions to ensure the quality of system operation.

The liberalisation is a stepwise process accompanied by an extensive legal and procedural framework. The operation of the system underlies an increasing formalism (e.g. contracts, rules), which has to be followed. On the one hand it makes the whole process more traceable but on the other hand it decreases the flexibility of actions which could be taken by the operators.

Especially the preventive defence of the system to avoid disturbances becomes more difficult, due to the fact that the system itself is

- used by many various actors (with own business interests) causing rapid changes (e.g. flows),
- more stressed and has to be kept within dedicated limits (e.g. voltage limits, power factors).

To follow the *market requirements* new operational limits − often beyond the nominal values (e.g. 110% on lines and cables, 120% on transformers) which lead to a more risky system operation − are introduced. The barrier between ’normal’ and ’abnormal’ operating conditions is sensitively decreased. Preventive defence of the system is intensively requested to cope with the supply requirements and to avoid any loss of supply. To enhance *customer services* disturbance clearing − in case an outage could not be avoided − is often guaranteed by fixed timeframes (e.g. 30 minutes for disturbance on 110kV level).

The handling of abnormal system statuses puts enormous pressure on the operating personnel. Predicted time periods for disturbance clearing requires fast decision making and immediate acting. But the liberalisation causes a split of responsibilities and authorisation in acting on the system due to the separation into the various business areas (e.g. system operator, power producer, market operator). In many cases more than one company and respectively control centre is involved in restoring the services. This requires parallel acting in diverse control centres and therefore extended communication. It is absolutely necessary that all operating personnel involved has a clear common understanding of the process to be performed.

Companies have to be *cost effective*. Early retirement programs are set up to reduce staff which results in a *valuable loss* of knowledge and experience especially in the control centre. Operational areas are extended by mergers of companies with the same business focus and at the same time the grade of *automation is increased* to decrease the number of field personnel and substation operators.

During the phase of transition to a liberalised environment especially operational staff is hired by new upcoming entities like market operator, traders, trading departments and the power exchange as well as by companies of the IT−business. Reasons why staff is leaving the control centre are:

- Operators can earn more money at related companies with less stress and without working in shifts;
- During the phase of transition and therewith rapid changes in the environment there is less job guarantee;
- This uncertainty lead to a new job orientation.

With respect to the same reasons it becomes more and more crucial for the companies to attract people for the operator’s job. As a heritage from the personnel reduction programs candidates for the operator’s position could only hardly be recruited from company’s staff − especially from the remaining field and substation personnel like it was done before in many cases. Operating personnel is then hired from outside and mostly has to learn the control centre job from scratch. This leads to the contradictory situation that the initial training for these candidates needs more time whilst the fluctuation of staff forces to shorten the training period.

Despite of these influences operational performance has to meet the requirements. Ensuring the quality of operation requires an ongoing training of operating personnel to also ensure operator’s competence. The current state of practised competence evaluation is reported about in [2].

A high level solution to improve operator’s competence is *simulator based operator training*, especially in cases where tasks could only hardly or not be trained on the job. The use of an operator training simulator with adequate capability within well designed courses allow operators to gain practical experience in such tasks.

SIMULATOR BASED OPERATOR TRAINING

The conventional and mostly practised form to mediate practical experience is on the job training of operators [6]. With respect to system operation the training takes place in the control centre during shift hours. Operating procedures under ’normal’ system conditions are mostly performed as practical exercises done by the trainees at the control desk using SCADA/EMS functionality. The actions are supervised by an experienced (senior) operator.

Procedures dealing with ’abnormal’ system conditions have mainly to be studied by the operators themselves and are trained as paper exercises which might be supported by some calculation. Whilst the theoretical background is trained, improvement of practical skills and experience is not dealt with. It must be noted that during restorative processes decision making and acting to fast changing system situations often under time pressure have to be done without any support from EMS functionality and automatic devices (e.g. switched off AGC).

Simulator based training bridges the gap between the theoretical background and the required practically performed actions. Embedded in training courses, the use of operator (dispatch) training simulators (OTS/DTS) can provide an efficient and realistic environment to mediate power system’s performance. Of course, a successful use depends on the training tasks as well as simulator capabilities.

Training requirements

Based on the experiences made during the past years in performing simulator based operator training at an independent training centre for power system control, the requirements for operator training with respect to 'abnormal' system conditions could be summarised as items a)−g).

a) Simulation of transmission system, generation and load performance under SCADA real−time conditions
b) System replica and user−interfaces under operational realism
c) Combined training of personal from several control centres (e.g. interaction of transmission, subtransmission, distribution and generation)
d) Communication between control centres
e) Decision making in stress situations
f) Evaluation of training efficiency
g) Adjustment of training to technical and organisational changes

The transfer of these requirements into practicable training leads to a lot of various prevailing conditions of different kind which have to be taken into account.

Practised simulator based training

Meanwhile training modules have been developed which can be flexibly grouped to courses. The courses are combined to a training program which is adjusted to the specific client company's(ies') needs. Special modules have been developed with focus on preventive defence and restoration of power systems. The resulting program consists of dedicated courses which are performed as practical exercises on an especially developed training simulator representing several control centres for network as well as production and load operation. Participants act in parallel on the entire power system, whilst each control centre is set up to the particular system under regard [6].

Items a)−c) require the use of an **operator training simulator** which represents a realistic view on the power system performance under normal as well as restorative conditions. Special emphasis has to be put on the simulation models to deliver realistic results within SCADA real−time. In case the entire transmission system is embedded in an interconnected power system (e.g. UCTE) the performance of the neighbouring system has to be modelled, too. Different operational surfaces must allow system control actions under operational realism on the network as well and on generation which also requires to set up several diverse and independent SCADA environments, all acting on a common power system representation.

In the training centre a simulator (Fig.1) is used which could flexibly be set up to

- the physical power system and its operational equipment,
- the control hierarchy and structure,
- represent in parallel several control centres with their particular part of the system under regard [4].

The training simulator is especially designed to provide operational realism within SCADA timeframe representing mid− and long−term performance of the entire physical system comprising the grid, the power production and the load situation under 'normal' as well as 'total blackout' conditions.
The set up is determined by the participating control centre personnel as well as the tasks to be trained. This requires an initial data model for the training simulator representing the necessary detail for the practical training. Data comprises the physical information of the entire power system to parameterise the simulation models (e.g. powerflow, generators, load trajectories) as well as organisational data to respect particular control equipment in a control centre (e.g. transmission, distribution, generation) and the overall operational control hierarchy (e.g. System Operator, Regional Operator, Distributor). For initial update and maintenance of the data model the required data are collected from the diverse clients' control centres. The data model itself is filled with these information at the training centre. As result all participants act on a replica of 'their' network.

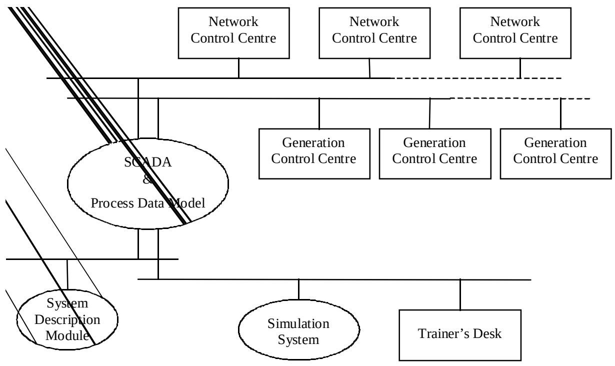

Fig.1 Principle structure of the used simulator

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 by 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.

During the simulator based sessions training personnel is required for taking the job of simulation control and depending on the tasks also acting as **role−players**. Simulation control is done by members of the training centre. Further these members take over role player function for technically dominated actions (’technical role playing’, e.g. setpoint for generators, field personal for non−remote actions, neighbouring system operator). It is proved to be good practise to distinguish ’technical role playing’ and ’organisational role playing’ (e.g. public press, company internal reporting, governmental issues). In case the latter one is part of the training it could be performed in a general manner by training centre members, too. More realistically due to specific knowledge in the organisation area − and therefore the preferable solution − this role playing is performed by a client company’s member.

Item c) additionally puts requirements on the **training organisation** (e.g. early announcement and information exchange). Operators from different companies working in different shift schemes must be trained at the same time in the same place.
Within the companies it has to be taken into account that operators participating in training are not available for shift duties at that time. Reduction of operators caused by the liberalisation leads to time restriction for training (i.e. training days per operator per year).
The availability of operators also determine the duration of the course which also influences its contents. This has to be respected in the **training design** phase.
At the training centre it has been proved that under regard of the main training objectives a combination of upgrading courses grouped in a training program is the best practicable solution. During the past years training modules have been developed each focusing on specific tasks (e.g. restoration strategies, physical phenomena, generation control, active power flow control, communication). These modules are flexibly combined to a course paying respect to operator availability and possible training course duration.

Apart from the simulator, the use of **telecommunication equipment** is required (item d). Within the diverse control centres different equipment and infrastructure is existing and used. Within training a similar infrastructure has to be set up. If more than one control centre is set up for the training a compromise has to be chosen.
At the training centre the communication requirements are regularly analysed. When starting to do training in the early days a simple telecommunication set was installed thus providing call−by−call connections without conference possibility. Of course this equipment could not be compared with control centre facilities but some interesting results turned out:

- Due to reduced communication capability, operators build up a communication culture. Conversation becomes more objective oriented. Instructions are reduced to the necessary minimum and communicated more precisely with less discussion about ’why and wherefore’.
- The importance of using switching language for acting on the network was clearly understood which leads to a similar communication style between network and generation operators.
- This is also observed in the companies even during ’normal’ operation of the system. The number of ’misunderstandings’ are reduced and as a result operators act faster and better to the system demand.

Operator’s decision making in stress situations (item e) could easily be misunderstood as ’causing some **stress**’ on the operators.
Compared to ’normal’ operating conditions in ’disturbed’ and ’restorative’ statuses of the power system the tasks to be performed become ’time−constraint actions’. In most situations automatic devices will not work correctly (e.g. AGC, Zero−Voltage−Breakers) and have to be put out of service. Additionally EMS functionality during the restoration process after a major blackout could not efficiently be used (e.g. State Estimator). Operators have to rely on their own knowledge and experience to make the correct decision at the right time. Fast changing system status, never seen before system topologies, incomplete information on system situation and extreme workload causes the **stress**.

At the training centre stress is caused as in reality by system conditions (e.g. blackout scenarios), time constrained actions (e.g. manual load shedding within minutes), not correctly working equipment (e.g. partly outage of telecommunication), reduced control options (e.g. no AGC) and real time system performance in the SCADA time frame. Additional stress is caused by the operators themselves.
It has to be accepted that operators are human beings and like all other people have different mental constitution which depends on various factors and may change in unwonted situations.
Emphasis has been put especially on operator caused stress to better understand what are the influences and what are ’motivating’ and ’de−motivating’ factors.

- ’Motivating’ factors increase the willingness of the operators to perform as good as possible and could be interpreted as factors causing ’positive’ stress.
- ’De−motivating’ factors in this sense are causing ’negative’ stress.

In general operators, who are motivated to perform the job are motivated to take part in training courses. Job motivation is the task of the company, but it could be increased even in training. Especially the handling of ’abnormal’ situations and the related extreme conditions forces all participants in a course to act as a group. This builds up a team spirit, which is consolidated during a social event in the evening. Further this training delivers an ideal platform for discussion and information exchange among the control centres’ staff.
Additionally motivation is seen by the operators due to

- Participating control centre managers as visitors. During training they have no authority but show their interest.

- Receiving a certificate which is not only signed by the training centre manager but also by company responsible. This also demonstrate the interest in operator’s job and performance.

De−motivating factors are any kind of uncertainty and unrealistic reactions of the simulator and the role players. It is the trainer’s job to reduce these factors to a possible minimum.

- A major step to reduce uncertainty during training was realised when giving also the participants the right to stop the session. At that moment when the session should be stopped the current status is frozen and after clarifying the situation the session is restarted again. This gives the opportunity to follow the session at any time. In addition to session evaluation operators always receive which enable them to critically review their job performance.
- With regard to the simulator operators are given some extra time to check the reaction in any kind of situation and to compare the results with scenarios from real life.
- Apart from the training itself the training centre members regularly visit the client companies’ control centres to better understand the tasks to be performed and how they are performed.

Experiences made, show that the evaluation of **training efficiency** (item f) is strongly related to performance improvements and requests the definition of training goals and therefrom derived performance factors which allow to measure training results objectively. The definition of these factors is a crucial task and already starts in the design phase. They must allow to evaluate each single training session as well as the whole course.

Diverse **performance factors** have been defined for the training modules. Pure measurements of mainly technical nature (e.g. switching actions, number of voltage/current violations, tripping caused by protection) which are then related to time indicating measurements (e.g. use of available active /reactive power, total restoration time, gradient of load pick up) deliver a set of performance indicators which allow to evaluate the technical process as a whole as well as in detail. Specifically recorded measurements on the interfaces between the control centres (e.g. power exchange) further allow to evaluate the particular control centre performance (i.e. shift team). These measurement based indicators are also visible during the session at the trainer’s desk.

Additionally operators list their telephone calls to the other control centres (e.g. identifying the recipient, reason for calling). Especially the interface between network control and generation control becomes visible. After a simulator session these lists are compared with the simulator’s event log delivering suitable results about the actions that were performed.

The efficiency of training is measured as improvement of performance by comparing training results from training sessions with similar prevailing conditions.

Item g) also focuses on simulation requirements and with respect to simulator maintenance the training personnel. Besides the update of the simulator’s database also the base cases as well as the scenarios used for the training sessions have to be adjusted. Organisational changes like merger of control centres and/or operational tasks due to changed operation philosophy have to be taken into account by adjusting the training course according to new prevailing conditions. Especially the organisational changes in the phase of transition from the traditional monopolistic supply industry towards a liberalised environment lead to extreme workload in the training centre.

Additionally items f)−g) require **feedback** of the training personnel and the participants even during the training course and with the client companies’ personnel who is responsible for operation.

The feedback loop which is successfully used in the training centre is shown in Fig.2. In order to cope with changes of technical or organisational matter, regular information exchange is practised between the client company(ies) and the training centre. This guarantees an always up−to−date replica of the entire power system and its control organisation.

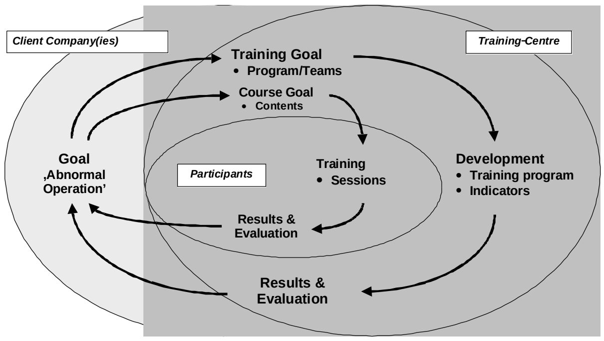

Fig.2 Feedback Loop

Participants directly evaluate the training course and its contents, its relationship to reality and usefulness for their practical work. This helps to

- verify the training needs,
- identify new topics for training,
- align existing courses to the requirements,
- design and perform ’useful’ training tailor made to the needs.

Participants’ and training session evaluation is compared with the training goals and is reviewed in the client companies. Regular meetings at client companies, their control centres and in the training centre are held, not only to review training, also to discuss upcoming new training tasks.

CONCLUSION

Simulator based training is proved during the past years to be beneficial for improving operator performance. Embedded in tailor made courses to company's(ies') needs this kind of training supports the knowledge, the practical skills and experience in the control centres to ensure the quality of power system operation. The experiences made in the training centre show that the design and development of dedicated training modules which could be flexibly grouped is essential to adjust operator training to fast changing technical and organisational changes, to preventively develop operational strategies according to the framework, to increase the mutual understanding of the jobs to be performed in diverse control centres as well on the technical and commercial interfaces and linking of the participating entities in today's power supply.

Appendix. As an example a training program for defence and restoration is shown in Fig. 3. Operators are coming from TSO, several Regional control centres and Power Production control centres.

The program consists of three upgrading courses and a specific course for power plant operators. All courses combine short lectures and extended practical sessions performed on a training simulator which is capable to comprise several control centres in parallel with operational realism under normal as well as restorative system conditions up to full blackout. The practical sessions are based on a replica of the client company's(ies') power system and all power plants feeding the voltage levels under regard as well as all interconnections to neighbouring transmission systems.

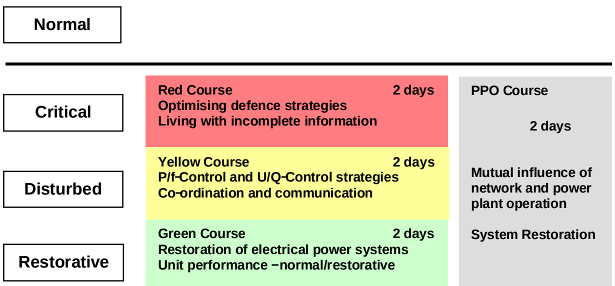

Fig. 3 Defence and Restoration Training Program

The ***green course*** starts with a co−operative trainer using pre−defined scenarios which are introduced to the participants focusing on e.g. basics of physical phenomena, performance of network equipment, units, load recovery and restoration strategies and control centre coordination. The cooperative trainer is the role player who also gives advise and always acts correctly and immediately to the trainees' requests. Compared to the non−cooperative trainer he will not introduce any handicaps to the power system.
In the ***yellow course*** communication via telephone of all parallel acting control centres and control strategies for active and reactive power flow are extensively focused on. Especially during restoration of large blackouts rescheduling of active as well as reactive power is extensively necessary to avoid overloads and to keep the voltage within the dedicated limits. The tasks are accompanied by not introduced more realistic scenarios, which are created by system breakdown based on a base case representing the normal system status. The trainer is acting non−cooperative introducing handicaps to the supply system even during the restoration phase.
The ***red course*** is based on normal day to day scenarios. The trainer is acting non−cooperative and uses technical (e.g. line fault) or organisational (e.g. additional transaction requests) on−line scenarios to run the supply system close to the limits or beyond. Main focus is put on optimisation of system defence and restoration strategy, on−line decision making for restorative actions as well in a single as in all participating control centres.

In addition the program also contains as an option a ***ppo course*** which is especially designed for power plant operators covering the basic interactions of network control and power plant control centre during restoration procedures. The course combine practically performed sessions on the training simulator and lectures, too. The operators perform actions on power units as well on the network and are introduced practically to the mutual influences caused by these actions on the whole system.

REFERENCES

[1] Spanel U, on behalf of Cigre WG 39.03, 2000, 'Operator Performance Requirements and Training Needs in the Commercial Environment', CIGRE SC 39 Session, Paris

[2] Lutterodt S, on behalf of Cigre WG 39.03, 2000, 'Certification and Competency Evaluation of System Operators', CIGRE SC 39 Session, Paris

[3] Hoogveld J, Siffels G, Rumpel D, Krost,G and Spanel U, 1998, 'Power System Restoration − Strategies and Operator Training in the Netherlands', CIGRE SC 39 Session, Paris

[4] Spanel U, Krost G, Rumpel D, 2000, 'Simulator for Inter−Company Operator Training', IFAC Symposium on Power Plants & Power Systems Control, Bruxelles

[5] 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

[6] http://www.dutrain.de