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TRAINING FOR OPERATING STAFF IN CONTROL CENTRES AS ONE KEY FACTOR FOR OPERATING RESILIENCE

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Abstract: In large interconnected power systems the operating conditions become more and more complex. The challenges for the operating staff in the responsible control centres are thereby steadily increasing both in grid and system operations:

- The rising share of decentralised energy sources (DER) inverses the power flow between TSO and DSO and leads to extended coordination needs between control centres.
- Inaccurate forecasts for decentralised infeed and loading challenge system balancing.
- In highly loaded systems each unavailable device (e.g. for service) endangers the (n-1) security, and lead to the risk of cascading effects, system splits and blackouts.

Control centre staff is one key factor in operating the power system in a safe and secure way, especially in critical situations. The staff has to be steadily aware of the system state in the entire system. Technical knowledge and communication skills of the operators are key factors as well as, coordinated operational concepts and procedures. In interconnected operation, like in the European Network for Transmission System Operators ENTSO-E (ENTSO-E) [1], multiple Transmission System Operators (TSO) are together responsible for coordination and safe operation. The paper outlines the actual situation and challenges in interconnected systems, and the conditions for secure operation are described, with focus on required skills for operators in control centres. Based on that a training program for control centre operators is described, including setups for the training, objectives, organisation and scenarios, as it is actually performed for many operators in the ENTSO-E area [2]. It is elaborated, how the performance of a coordinated training program contributes to safe and secure operation and therefore increases the overall system resilience.

Keywords: Operator Training Programs, Control Centre, OTS, Operator skills, Inter TSO Training courses, Restoration

INTRODUCTION

Wide area power systems are one of the largest technical constructions in the world. They are operated interconnected and are spanned over multiple countries. This interconnection idea has many advantages for the secure supply of customers. Sharing reserves in case of unit outages was one of the main drivers for building these systems.

The interconnection between the countries has been strengthened significantly in the last decades. This enables trade of large amounts of energy in the entire system. The resulting power flows have to be handled by all grid- and system operating companies in the interconnected area.
In a liberalised environment, system and grid operation are usually split by voltage levels:

- Transmission system (e.g. 400kV & 220kV), operated by a Transmission System Operator (TSO)
- Regional distribution and transmission system (e.g. 110kV), operated by a Distribution System Operator (DSO), and
- Distribution system (e.g. 10kV), operated by a medium voltage DSO.

In that context grid operation comprises everything dedicated to switching actions and grid security. System operation is everything related to frequency control. Traditionally the TSOs are responsible for frequency control in their operational area, the so-called "control area".

Each system is operated by a dedicated control centre. Dependent on the company size all systems are operated from one single control centre, but the roles and tasks are always split across individual desks.

In addition to grid- and system operation there are more operators and control centres involved in the overall process:

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- Conventional unit control centres operating the unit locally (Production Location PL),
- Power Production Control Centres operating and / or coordinating a pool of units commercially (PCC).

Figure 1 shows the principle interaction of different control centres in an interconnected area.

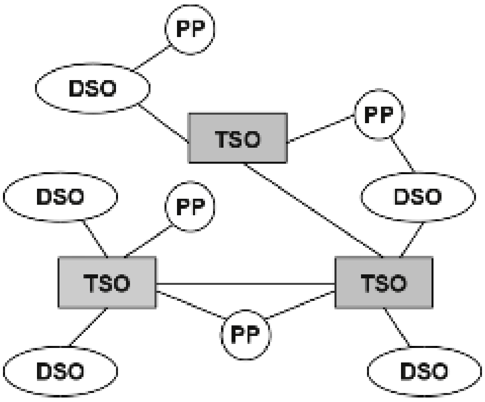

Figure 1: Control centre structure

In this example structure an important element is missing, the control entities for decentralised production units connected to the distribution level.

Conventional units are fully controlled by their PL and PCCs in charge. They

- follow a schedule for active power delivery,
- provide regulating power for frequency control,
- provide short circuit power for selective detection of faults,
- and contribute actively to the voltage profile by delivering reactive power.

In Europe the Transmission System Operators are organised in ENTSO-E, the European Network of Transmission System Operators Electricity. There, the technical and organisational interaction of all interconnected TSOs are organised in a set of guidelines and policies [1]. In the big interconnected European power system 40 TSOs from 36 countries have to coordinate their operational actions. Figure 2 gives an overview of involved TSOs. Not the complete area is operated synchronously. Actually there are 4 different synchronous areas: the Continental area, the Nordic system, and Ireland. The Baltic area has been recently synchronised [4]. Nevertheless those areas are interconnected by HVDC links.

Each TSO operates at least one control centre for the control area, usually with desks for grid operation and system operation. Additional desks for unit coordination, redispatch and Intraday coordination are common. With higher complexity of tasks the number of desks increases. Figure 3 shows the setup in a control centre with several desks.

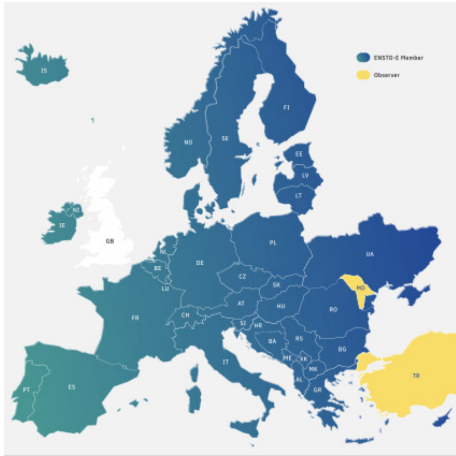

Figure 2: European interconnected system [3]

Figure 3: TSO control centre [5]

Using the recorded data, the signal processing and activity detection algorithms were systematically evaluated. During these tests, the system successfully detected 22 out of 23 activity events, yielding a high detection accuracy with only a single missed event (metal cutting using a jet saw). Importantly, no false alarms were recorded. A summary of the detection Furthermore each TSO control centre coordinates several connected DSOs. The interaction of such a big number of control centres and operators involved in system operation creates endless possibilities in system operation.

Actually the interaction becomes more and more intense in all time scopes. One example is the introduction and implementation of common platforms for sharing of regulating power across Europe, MARI and PICASSO. Those highly automated systems increase the complexity, which can become a challenge for operators in critical situations. TSO operators have to deal with many interdependant tasks simultaneously. The steadily increasing renewable energy makes the daily business harder and more stressful.

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1. PARADIGM SHIFT IN SYSTEM OPERATION

Renewable energy is being promoted throughout the world triggering a shift away from large conventional synchronous power plants to small power plants distributed over large geographical areas [6].

Decentralised production units, better known as Distributed Energy Resources (DER), have less technical beneficial operational properties than conventional units with synchronous generators.

- The available power is predictable, but is not always delivered reliably due to the stochastic behaviour. They are simply weather and time dependent. This circumstance was the decisive trigger for the implementation of the operation planning processes with different time scopes.
- The voltage support is usually limited. Technically it is possible to give voltage set points comparable to synchronous generators, but the coordination is the challenge.
- Inverter based DER actually do not contribute to the system inertia.
- Provision of regulating power is limited.
- Short circuit power is limited to the rated power value.

The largest share of DER is connected to DSO systems, DSO operators have to ensure that their system is always operated within allowed limits in case of both high and low DER production. Often the only countermeasure for handling overloads in high production phases is to reduce the active power via remote control technology. In some cases bigger PV or wind parks can support voltage in the system.

With steadily rising number of DER installations the DSO regularly exports power to the TSO, e.g. on sunny days or in high wind periods. Conventional and DER production on TSO level combined with heavily fluctuating time and weather dependent TSO-DSO exchange lead to big power transits on all levels of the interconnected system, which has proven to be critical [7].

This paradigm shift in the structure of the power system has had and still has a major impact on various aspects of system operation, especially on the work of operators in 24/7 control centres.

From the organisational point of view the large number of DER is an operational challenge. TSO and DSO operators usually do not have direct “contact persons” for DER. Due to the big amount of installed capacity, operation and control of DER is highly automated, and often not comparable to conventional units:

- PCCs operate the active power set-points of DER yield optimized. As a result many lines and transformers are often operated at their operational limits. It is the task of the DSO and TSO operators to operate within allowed limits.
- For that purpose, in some cases grid operators can limit the active power output for reducing bottlenecks in the grid (curtailment). But this is an imprecise tool, which often does not work due to insufficient remote control technology.
- Voltage control by set-point is usually not implemented.

TSO operators are in contrast to DSO operators in the comfortable situation, that most connected units are conventional and therefore fully controllable. However, their number is decreasing. At the TSO level only big DER parks are connected. Especially big offshore wind farms with AC or DC connectors play a more and more important role in TSO systems.

Due to the DER an operational task has risen, providing more information on fluctuating power production.

2. NEW ROLE OPERATIONAL PLANNING

All operators mentioned are responsible for the real time system state, Real Time Operation (RT). Since DER plays a significant role, information on the infeed situation has to be considered beforehand. For that purpose processes for so-called Operational Planning (OPL) have to be implemented.

The basic idea is not to wait until a bottleneck in the system occurs in real time, e.g. a (n-1)-violation or an overload on lines or transformers, but to detect it beforehand. With advance notice it is possible to organize countermeasures, e.g. starting of conventional units for redispatch. The planning processes start a year ahead, a month ahead and a week ahead. The exact grid state, the infeed situation (DER and conventional) and power consumption are then estimated as accurate as possible. In the day ahead process (D-1) available information becomes more precise. Figure 4 shows simplified the principle of the Day ahead security assessment, which is principally the task of the Operational Planning operators in a TSO (or DSO) control centre.

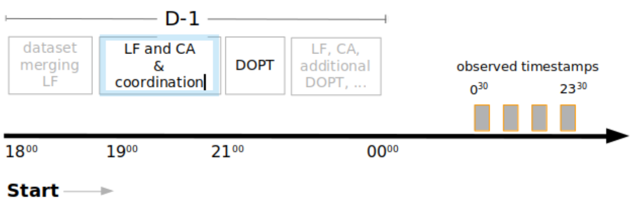

Figure 4: D-1 security assessment

All interconnected TSO provide for each hour of the next day:

- grid topology including detailed switching state
- production schedules for conventional units and DER
- power consumption

From those individual data sets on overall grid model can be derived in a merging process. The result is a so called timestamp. For each timestamp a security assessment is performed: (n-1) calculations and limit violation checks.
The Operational Planning operators work together to coordinate countermeasures for the system for the next day. This is a world running in parallel to the Real Time Operation world, with heavy interaction and exchange needs.

3. OPERATIONAL CRITERIA, SYSTEM STATES AND MEASURES

If everything works as scheduled, prepared and planned the system can be operated in a safe and secure state. All "operational criteria" are fulfilled in case of the following:

- All voltages (U) are within allowed upper and lower limits.
- All currents (I) are below the maximum limit.
- The system frequency (f) is within allowed limits.
- The level of short circuit power (SSC") is sufficient to detect faults in the system for selective disconnection.
- The (n-1) criterion is fulfilled, or in case of an overload after a failure appropriate measures can be implemented fast enough.

In that case the system state of the related country is defined as "Normal", marked in green, according the European Awareness System [8]. Further states are yellow, which indicates an "Alert" state, red, which stands for "Emergency", black, which is for "Blackout", and blue, which stands for "Restoration". The EAS system states are set individually for each control area manually by the operators to give other TSOs fast information on their own system state.

All operators in the control centres contribute to a resilient system by fulfilling operational criteria and keeping reserves available:

- Operational Planning Operators prepare measures to be applied the next day for safe system states.
- Real Time Operators are responsible for ad hoc measures and system balancing. All operators in the interconnected area together are in charge to react on disturbances and deviations from schedules and forecasts.

The potential for critical situations in the system increases steadily due to high loading by DER production at the DSO level and wide area transport. Technical issues are beside others high flows, (n-1) violations, extreme voltage profiles and fluctuating frequencies.

In the different time scopes and system states various countermeasures are available to prevent or react to overloads and limit violations.

The measures are actually based on the availability of controllable conventional units. On sunny days with low conventional and high DER share the options for redispatch are limited. Adjusting the voltage profiles requires tight TSO-DSO coordination, because the reactive power resources are then connected to the DSO level.

The responsible shift teams in the control centres have the task to prevent the system from critical states, which pose the risk of system separation, large area islanding or blackouts. To accomplish this task the operators should have special knowledge and skills. Hereby knowledge refers to familiarity with factual information, but skills refer to the ability to apply knowledge to specific situations.

4. OPERATOR TRAINING REQUIREMENTS

In this complex environment, the coordination of all control centres involved for all time scopes is essential and contribute to the resilience of the power system.

As systems are operated closer to the limits, nowadays operators can gain experience in handling critical situations in their daily work. So, is then training still needed? The answer is yes, coordinated training programs offer various advantages.

In the ENTSO-E area TSOs are obliged to organize common training sessions for their operators. There, training is coordinated by TSO training coordinators and according to ENTSO-E Synchronous Area Operational Agreement (SAOA) and Commission Regulation (EU) 2017/1485 (SOGL 58-4) Guideline on electricity transmission system operation and (EU) 2017/2196 (NC ER) Network Code Emergency and Restoration [9]. The ENTSO-E regulation recommend simulator based training, so here a multi control centre capable simulation has to be applied.

According to the guideline the training session should be performed as a simulator training, which reflects the multi control centre environment as in the real interconnected system.

Simulator based training is a specific kind of training for power system operators improving practical skills and knowledge as well as online decision making related to real time power system operation.

Those courses for the interconnected European system are regularly performed and have proven to improve the overall operational performance of operators [2].

The training courses can be organised as

- Inter company training courses: TSO operators train together with operators from directly connected DSOs and PCCs, or as

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- Inter TSO training: TSO operators train together with other surrounding TSO operators in the region. TSO group configurations and other training forms will be elaborated later in this paper.

The overall training goals, improving practical skills and knowledge as well as online decision making, reflect the operational tasks and conditions, which operators face in their daily business.

Operators in control centres are highly specialized people. Working on shift in TSO / DSO control centres is a challenging and demanding task:

- In shift work, a sudden change from phases without events to absolutely critical moments is possible in which the right thing has to be done very quickly. Otherwise there is a risk of failures and blackouts.
- The required technical knowledge level is high due to the complexity of the electric power system. This fact is often underestimated. The technical skills are dependent on the task in the control centre. Grid security and switching actions require other skills e.g. operating the load frequency controller and even differ between TSO and DSO. The level of specialization of control center personnel is increasing with the number of tasks which appear in the control centre. The rising number of tasks lead to a higher demand of operator specialisation.
- Due to the growing specialization at each control centre desk, not every operator can serve every desk. Especially the system operation operators face fast changing boundary condition, e.g. for activation of control power and activities at the power exchange.
- Meanwhile more and more tasks are tool supported and with further development of artificial intelligence based systems this trend will continue.
- Even today many control center tools work as a “black box”, operators may have no insight into detailed functionalities. Nevertheless operators have to be able to detect malfunction, and must be able to initiate manual countermeasures.

So in modern control centres, with multiple tasks, the operators form a control centre team. The work in the team must be carried out in a coordinated way. Relevant information must be exchanged efficiently between the desks. This could be a challenge in operational situation, which are critical and not standard anymore.

The control centre, or more specifically the individual operators in their roles, interact with other corresponding control centre roles. Usually, communication takes place over the telephone, bilaterally or in telephone conferences. In addition, regular video conferences on recurring topics are becoming more common. This is how a control centre group is formed, as shown in Figure 1.

Figure 6 shows the basic requirements for coordinated grid- and system operation. Both knowledge and skills are required. Technical operator skills are coloured in orange, social skills in blue.

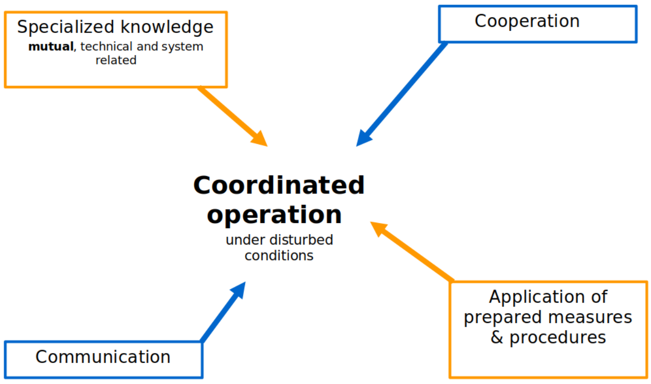

Figure 6: Balanced skills

- The operators need specialized technical knowledge and skills in their own area of activity. This implies system knowledge and the ability to operate the technical systems and tools in their own control centre.
- Many operational processes are described in company individual procedures and rules. Additional national or European cooperation agreements and rules have to be followed. The operator should be aware of that and must be able to apply those procedures. In the end the main tasks for all operators is to prevent the system from disturbances and blackouts, even in those situations, which are not described in valid procedures. For that purpose they should be able to act beyond the rules.
- To apply technical skills additional skills are required in the area of communication. This implies e.g. communication techniques like using correct switching language. Particularly in non-standard critical situation a precise communication is crucial. To ensure that the communication partners understand the same, 3-way communication should be applied.
- Last but not least all partners must be able and willing to cooperate. Here, individual human factors play an important role. Human perception and abilities vary and depend on the context and work environment. It still has to be emphasized, that human beings are interacting with each other. This can lead to misunderstandings that may have negative impacts on system security.

While this works well in standard situations, it becomes increasingly difficult in critical situations. A coordinated operator training program is an appropriate way to build and keep skills in operator teams and operator groups.

5. TRAINING ENVIRONMENT AND OBJECTIVES

In real critical control centre situations the operator is under high pressure. In group training sessions participants are under pressure as well, because own "faults" could negatively influence the systems of other control centres. But this "stress" is less negative in the safe training environment. Especially skilled trainers accompany the sessions. They observe the session and support participants and can answer technical questions. In case of misunderstandings in the group or a technically critical development of the session they can interrupt the simulator session for common analysis in the group. At the end of the training session group feedback can be given by the trainers.

It's beneficial for participants to know that they have a neutral contact person in the trainers for all their questions. The goal of the trainers is to create a positive learning environment.

In a simulator session all participants form a training group. They get to know each other and exchange. A personal acquaintance promotes cooperation in real critical situations.

The safe training environment allows faults (which should not occur both in training and reality). But here, faults, errors and misunderstandings can directly be analysed, and countermeasure can be developed with the group or in cooperation with the trainers.

In that learning and training environment required knowledge and skills can be built and improved according to the real tasks in 24/7 power system shift work. Training objectives in an Inter TSO or Inter Company group are as follows.

- All involved and affected operators in the entire control centre group and in the control centre teams can commonly build situational awareness of the overall situation, including exchange of relevant information, e.g. the own system state by using the EAS.
- The technical behaviour of the entire system including automatic defence measures can be observed and analysed. Hereby technical skills can be checked and expanded.
- Available related procedures can be applied and checked. The compatibility of company individual procedures can be checked during sessions.
- Operators practically apply or develop strategies to improve or solve the current situation. This gives the opportunity to build, strengthen or expand operational skills by practical training, both technically and socially.
- According to the human factors mentioned each situation in the common sessions will be solved individually. So in each session cooperation skills can be trained as well as online decision making in the control center group.
- Group interaction can be trained as well as team interaction within the control centre.

Figure 7 shows an example training environment of an independent training centre in Europe [2], where both Inter TSO and Inter Company training courses are regularly performed. In each row is the operator team of one control centre. Communication within the team takes place directly. Interaction with other teams in the group is done with the training centre internal telephone installation.

Figure 7: Operator training simulator with multiple control centres configuration

The Operator Training Simulator (OTS) plays a key role in the sessions. The simulator should deliver and represent the real system behaviour and response in normal up to disturbed and blackout situations. Dependent of the technical capabilities of the simulation tool the simulation range is from cyclic RMS load flow calculations up to fast transient effects.

For real time operator training for large groups with multiple control centres, the so called SCADA time frame has proven to be feasible to reach the training goals, which comprises cyclic full Newton-Raphson load flow calculation and fast frequency modelling, including all SCADA elements and basic protection. Dynamic security assessment has to be included, as this is part of the according control centre scope.

The requirements for an OTS have increased significantly with invention of many new devices and functionality in the real power system, which has to be modelled individually.

- Example for new devices are: DER and conventional units, HVDC connectors, battery storage devices, Offshore windfarm connectors, phase shifting transformers and automatic system defence functionalities.
- Example for relevant functionalities are: Load frequency controllers, platforms for regulating power.
- Examples for control centre functionalities are: (n-1) calculations, short circuit power calculation, awareness tools like the EAS [8].

The technical OTS capabilities determine which scenarios can be trained. More details on the OTS used for Inter TSO training in the ENTSO-E area, which meets those requirements, is described in [10], including the training environment for Operational Planning training.

6. TRAINING PROGRAM, COURSES & SCENARIOS

It is not possible to reach described objectives in only one simulator based training course. The combination of requirements and objectives lead to a training program for operators, which has to be implemented at each individual TSO and DSO.

The main objectives of an operator training programs are:

- Building and expanding knowledge, expertise and experience.
- Gaining and strengthening technical and social skills including communuication and coordination in practical exercises.
- Enabling operators to recognize critical situations.
- Preparing operators to safely handle critical situations according to the company's rules and procedures.

The training program consists of different training courses. Each course has own goals. As operators regularly participate in the courses in the program the overall objectives can be permanently achieved.

The SCADA and tool environment in the control centres is very complex. Operators have to train using their own tools. This individual tool training has to be organised internally.

Analogue to this, operators should be trained using the OTS training environment. An OTS for the training of multiple control centres simultaneously cannot provide a work environment which is identical with each individual control centre environment. Nevertheless the OTS should have identical functionalities. So in a first step operators have to be trained to train. This should obviously done in small training groups for the control centre team.

One or two control centre teams can perform a Company Training. In case of two teams two Independent simulators can be used with identical scenarios. Each operator overtakes the same role as in real life (switching, balancing, coordination). The trainers overtake role-play for those operators, who are required for the scenarios, but are not part of the training group.

System restoration scenarios after blackouts are ideal for company courses, because in this case each company starts according to their own procedures. In the case of a black start, it is advisable to involve operators from the blackstart unit into the course. In that way the compatibility of concepts and procedures can be checked and comunication skills can be improved.

For new colleagues the company training can be organised as a Basic Training, where the focus is on basics in operation and simulator handling.

After passing the company training for single operator teams the program continues with courses for control centre groups: Inter Company Training or Inter TSO training. In those course the group interaction can additionally be trained. Figure 8 gives an overview on the training group configurations.

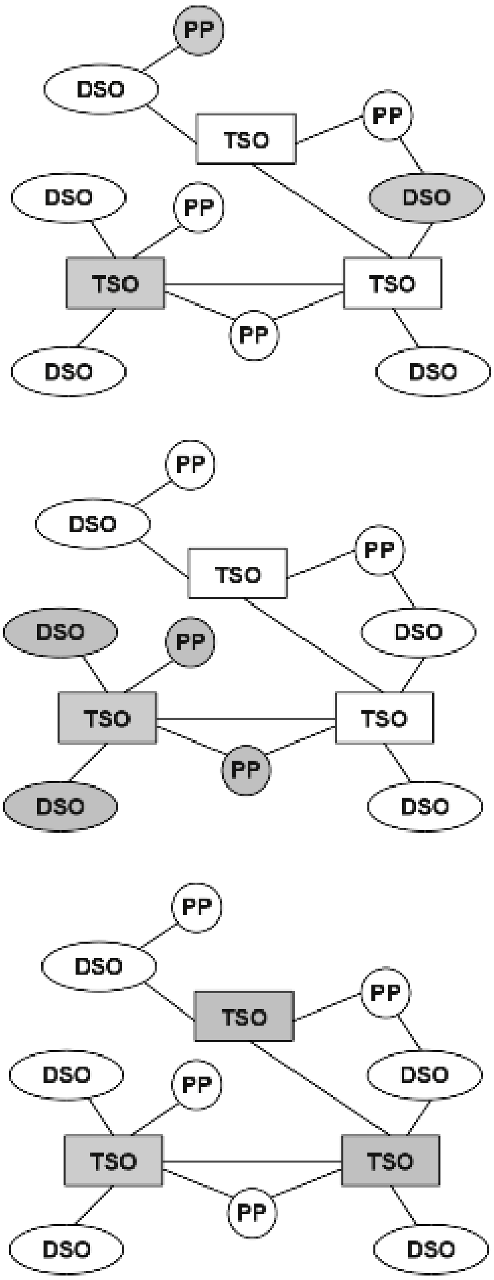

Figure 8: Company, Inter Company and Inter TSO training groups (Real Time)

Inter Company courses are organised as common training for TSO operators together with the directly connected DSO, unit operators and PCCs, usually for one control area. The courses combine technical skill training with group and team skill training. Each Inter-Company Training course offers all participants the opportunity to jointly apply and verify operational concepts. A particular focus is on the interface between power plant operation and grid operation during grid restoration.

The training course usually consists of two parts:

- System restoration: In the grid restoration scenario, the supply system is jointly rebuilt after a complete or partial blackout. Prepared concepts and strategies can be applied and verified. The restoration scenario can be performed as a blackstart scenario (bottom up), or with external help from partners (top down). Here, focus is on integration of DER in the different phases of the restoration process [11] [12].
- Coordinated handling of critical system states (alert and emergency states): Initially, the system is in a critical state. This state is analyzed jointly and countermeasures are developed. The main goal of the training group is to fulfill operational criteria and prevent further escalation. The focus of the scenario is the interaction between the TSO, grid and power plant operators, as well as the implementation of manual load shedding.

Inter TSO training courses are organised as 3 day courses in the training centre. During that time three scenarios are performed at the simulator, accompanied by scenario related theoretical modules, feedback and evaluatios as well as discussions. As an example a training course for the ”Central Eastern Europe” region (CEE) consists of three main parts.

- In a presentation workshop short presentations by participating operators inform everybody about actual developments in system control in the CEE area and create a common base for the simulator scenarios.
- The simulator scenario “Alert” deals with critical system states. The group has to tightly cooperate to stabilise the situation and to avoid further escalation. The goal is to bring the system back to a safe state with no violations of operational criteria.
- The simulator scenario “Emergency” deals with a system which is split into several asynchronous islands. Scenario goals are bringing the system back to a safe state in a coordinated way.

The group size of these Inter TSO courses is dependent of the number of participating TSOs. In the CEE Region with 8 TSOs control centres involved, up to 35 operators have to train together coping with “Alert” and “Emergency” situations.

Inter TSO training is organised in different regions. Each region has specific characteristics and challenges that can be individually addressed in training. Figure 9 shows two regions, for which Inter TSO training is actually performed, the Central Eastern (CEE) and the Central Western group (CWE) [2].

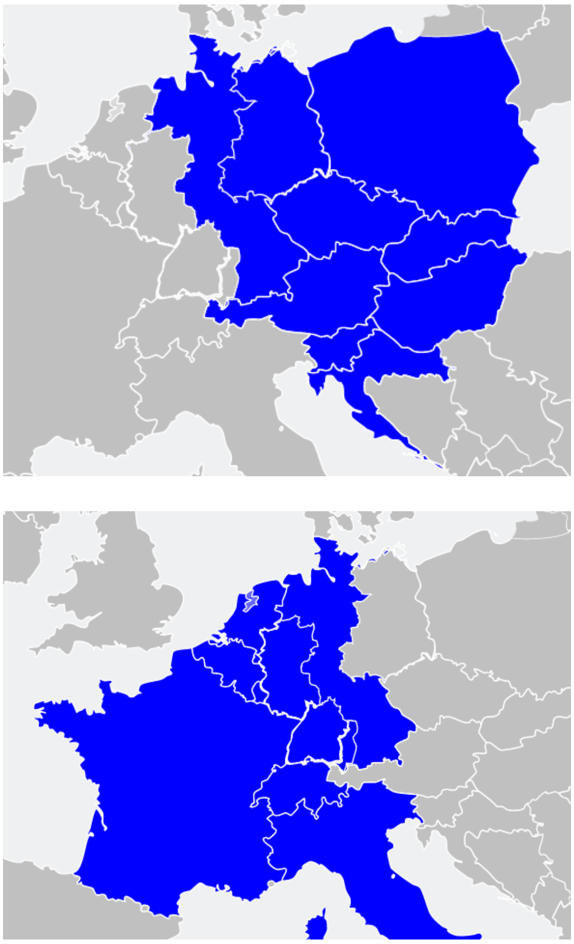

Figure 9: Examples for actual Inter TSO training groups (Real Time): CEE & CWE

So in the individual courses with the specific groups of operators different scenarios can be trained.

Table I: Potential scenario overview for Real Time courses.

Curse type	Related System states	Potential scenarios
Company	Restoration	Blackstart Top down restoration
Inter Company	Restoration	Blackstart Top down restoration
	Alert	Power shortage Voltage collapse
Inter TSO	Alert	Power shortage Voltage collapse System separation
	Emergency	Island operation Island resynchronisation Manual LFC operation

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The main goal of Operational Planning Training is to improve coordination between OPL operators, both day-head and intraday, with special focus on the interaction between the two different Regional Security Centres (RSC) in Europe (Coreso und TSCNET]. This includes communication, the use of vocabulary, different operational philosophies, getting familiar with technical effects and possibilities to create a deeper mutual understanding between all parties involved. Figure 10 shows an actual OPL group configuration.

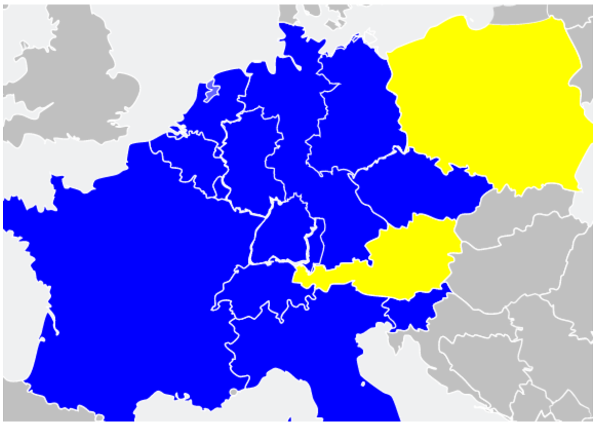

Figure 10: OPL CE training groups

The scenario distinguishes between the different operational time horizons.

- In the introduction workshop participants get familiar with the situation. TSO- and RSC-presentations clarify common processes in the two RSC-areas and summarize countermeasures.
- The D-1 section deals with day ahead planning process and includes the standard communication steps in that phase. An initial situation has to be processed in the day-ahead-planning process. This comprises amongst others PST-coordination and Redispatch. All measures are applied on the simulator on each prepared timestamp. The operational result will be the starting point for the Intraday-process.
- The Intraday section resumes the D-1 section. Some foreseen major incidents, like outages or significant forecast deviations, create a new operational situation in the Intraday time horizon. Here, the interface between Intraday-action and Real-time-actions will be the main topic, which will become more and more relevant in system operation.

7. CONCLUSIONS

The secure and safe operation of interconnected systems lies in the hands of many operators acting in several distributed control centres in 24/7 shifts. Due to broad tasks and the increasing complexity of the work caused by the still rapidly growing share of DER, all control centre teams in the connected area have to act in a coordinated way. This collaboration is not limited to transmission system operator teams, but has to be extended to DSO operation as well, because of the high share of connected production units.

In dedicated simulator based training courses for defined groups of control centre teams, the awareness and handling of critical situations can be trained in a safe training environment. Operators have to proceed several courses in a well defined training program, to improve knowledge and gain technical and communication / coordination skills in practical simulator sessions, to be well prepared for the challenges in real operation.

The main objective is, that regularly and jointly trained control centre teams are enabled to sovereignly master critical situations in the entire control centre group.

In the ENTSO-E region it has been proven, that a well organized training program combined with an appropriate training environment is a contribution to system resilience [2].

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