

# IMPLEMENTATION AND VERIFICATION OF A GENERIC RESTORATION GUIDANCE SYSTEM

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**Abstract:** Restoration guidance systems for bulk power systems usually contain large portions of network, generation and utility specific information and knowledge, thus forming individual single solutions that cannot be applied to different power systems. In contrast with that, at Duisburg University a complex generic approach has been worked out. Implementation of this generic restoration guidance together with an independent operator training simulator gives it the characteristics of a system-control application function which can be employed to any given power system for which the simulator is parameterized as well as to any disturbance scenario adopted, thus behaving as a flexible restoration training adviser. Furthermore, this variability gives the opportunity to extensively test and verify the capabilities of the restoration guidance system. An example with an extended 110/25/10 kV municipal system, represented in full operational detail on the simulator, is reported.

**Keywords:** Restoration, Expert System, Scenarios, Test and Verification

## 1. INTRODUCTION

Power system restoration was one of the first and steady topics of interest for the application of expert systems in the area of power systems operation [1,2]. Despite this fact the number of restoration systems that are practically applied is quite small, which seems to be caused by three major reasons:

- Restoration is the most complicated and demanding task in power system operation, especially in case of bulk systems including generation. Therefore, many prototypes based on substantial simplifications never reached the level of practical realism.
- Integration of expert systems into the existing environment of power system operation, consisting of the technical SCADA/EMS system as well as the human operators, proved much more complicated than assumed.
- Due to the high grade of individuality of the power systems themselves as well as the utilities' operating philosophies, the portion of specific information within the restoration systems is usually very large. Thus they are individual solutions that cannot be employed for any given power system in the sense of an application function such as, e.g., an operational load flow program or other. Consequently, development cost considerations prohibit the common use of such systems.

These aspects and past experiences motivated at Duisburg University power system institute to take

the challenge of developing a generic restoration guidance system which is able to flexibly adapt to any given power system as well as any disturbance situation. The general concept of this system and the components which resulted from the realization are described in [3]. In the following the practical implementation of this system together with an independent operator training simulator is sketched, and its verification with the example of an extended 110/25/10 kV municipal system, represented in full operational detail on the simulator, is reported.

## 2. IMPLEMENTATION OF THE GENERIC RESTORATION GUIDANCE SYSTEM

Regarding its basic functionality, the generic restoration system can be implemented in principle

- a) with a real SCADA/EMS system, thus providing on line restoration guidance;
- b) with a training simulator, acting as trainer/supervisor in preventive restoration training.

Whilst the first way of implementation a) presupposes to trust to correct suggestions of the restoration system in any upcoming disturbance situation, the latter way b) enables testing and verifying the restoration guidance under various conditions and disturbance scenarios, and making use of the explanation capabilities implemented. Furthermore, coupling with an independent simulator allows to perform such verification with different power systems, the data of which the simulator is parameterized with. These

considerations together with the fact that such kind of independent simulator was available decided the matter that the simulator coupling b) was realized.

## 2.1 TRAINING SIMULATOR

At Duisburg University's power systems institute a simulator was developed that allows to implement any given power system independent from the system itself, the control center structure and hierarchy within system control and the therefore displayed information [4]. The internal models covering the behavior and phenomena of loads, networks, power units, external infeeds and all related equipment, as well as secondary devices, protection, SCADA and EMS functions, simulate a realistic performance of the complete power system under 'normal' as well as 'abnormal' operating conditions. Powerful tools for base-case and scenario definition and setting even during the training session limit the time needed for training preparation and allow 'lively' training sessions.

For simulator set-up all required static and dynamic information of the power system (networks, power units, loads, interconnections,...) is entered as system description in a readable form (GDL format [5]). A fully automated generation process creates directly from this readable source code:

- the complete process data model for the simulator including network, generation and loads;
- the interactive switchyard and substation diagrams [6] including their direct process coupling;
- a condensed surface for lumped operation of all power plants under regard;
- parameterization of the power system simulation core;
- all necessary system states for consistent setting of the simulator.

The simulation core combines partial models representing the long-term and mid-term dynamic performance of network, power units and loads [7]. These models are designed to cover also the special phenomena encountered in the restorative phase which especially means:

- The load-models 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 well as voltage and frequency dependency.
- The power unit models for thermal units (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 lumped performance of each network island.

Furthermore, all usual types of protection relays and other automatism such as synchronizing equipment, paralleling lockout, automatic tap-changing on transformers and AGC are represented.

The results of the simulation are either stored back to the process data model as 'measurement' values with a refresh rate of 10 seconds, or handled as actual events, thus giving the trainees a realistic control-room sight of system performance.

## 2.2 COUPLING

The general concept of coupling the generic restoration guidance system with a SCADA/EMS system is pointed out in [3]. In the case regarded here the real power system including its control is just replaced by the simulator. This means that the restoration guidance system's knowledge based nucleus as well as its algorithmic satellite programs [3] fully rely on the process data of the training simulator, thus making use of all power system specific information available from there and without containing any of such specifics within itself.

## 3. VERIFICATION OF THE GENERIC RESTORATION GUIDANCE SYSTEM

To check and prove the guidance system's genericity, application to several power systems and various disturbance situations is necessary which is currently being performed. For the time being, primarily the 110/25/10 kV municipal system of the Duisburg region (Fig.1) was used for two weighty reasons:

1. For exactly this power system the former specific restoration expert system of Duisburg University had been designed, which was reported about on several previous ESAP/ISAP conferences [8 and other]. This allows to immediately compare the performances and capabilities of both versions.
2. The power system including its generation was represented already on the simulator in full operational detail. This means that all operational functionality of the real control system (including, e.g., remote control of switchgear where installed, all alarm messages and indications, transformer tap setting and so on) is represented and the original operational names and abbreviations are truly used.

### 3.1 SAMPLE POWER SYSTEM

Fig.1 shows the one line overview diagram of the system. The external network boundaries were chosen to be on the neighboring busbars of the interconnected systems (RWE, not shown in Fig.1), and on the load side to be on the 10 kV busbars, from where the particular feeders are assumed to supply lumped loads (see example in Fig.4). The represented primary equipment of the system comprises:

- 5 power units (4 thermal and one gas turbine, altogether having 487 MW nominal power);
- 18 substations including:
- 41 switchyards on 110 kV, 25 kV and 10 kV levels equipped with single, double and triple busbars (partly sectionalized) and coupling bays;
- full set of switchgear installed (breakers, isolators, grounders, sectionalizers, ..)

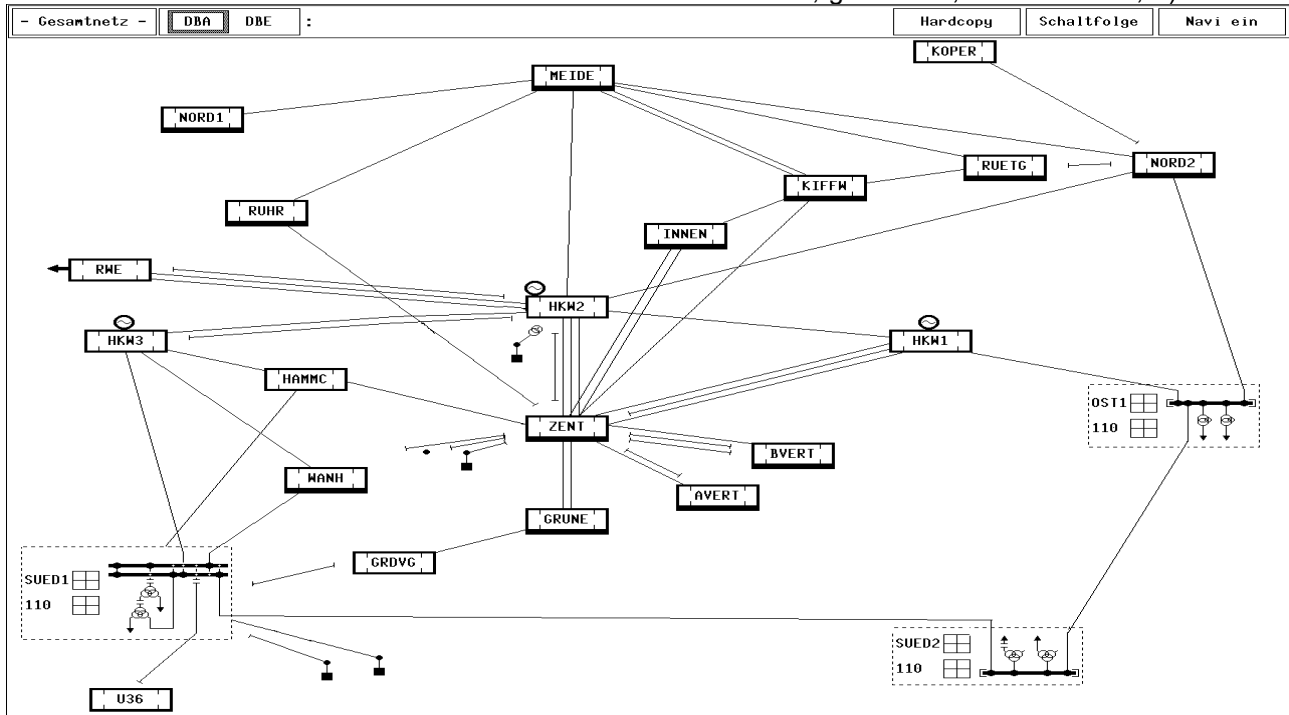


Fig.1 Overview diagram of simulator showing sample power system with 3 substations in node point display

- 34 transformers between meshed 110 kV and radially operated 25 kV and 10 kV levels;
- 44 lines (pure cable network);
- 4 compensation reactors;
- 208 lumped loads fed from 25 kV and 10 kV levels having 350 MW peak load in total;
- measurement points of frequency, voltages, currents, active and reactive powers as present in the real system;
- differential protection of all transformers, cables and busbars;
- distance relays as backup protection for transformers and cables;
- Buchholz relays for all transformers;
- overload protection.

All indications and messages of statuses, measurements and events occurring in the real control center are replicated on the simulator. Full remote operation from the main control room is provided for transformer tap setting and for all switchgear on 110 kV level as well as for all

breakers on 25 kV and 10 kV levels except for one switchyard situated immediately adjacent to the main control room, all corresponding to the real system under regard. Thus the restoration guidance system has to deal with a realistic set of SCADA information, on the base of which various disturbance test cases and restoration scenarios have been executed for this system so far.

### 3.2 EXAMPLE SCENARIOS

To mediate an impression of the restoration guidance system's capabilities, in the following different restoration cases carried out on the simulator are roughly sketched.

Scenario 1: Full blackout with no internal primary source available. Under these conditions the restoration must purely rely on the tie transformers connecting to the strong external system of RWE (see Fig.1), and there is no power-frequency balance necessary in this case. The stepwise load recovery under application of the new generic system during the first 50 minutes is shown in Fig.2 (original display in German). Comparatively the moment of first load

reconnection under the former specific system [8] is marked.

system frequency in detail

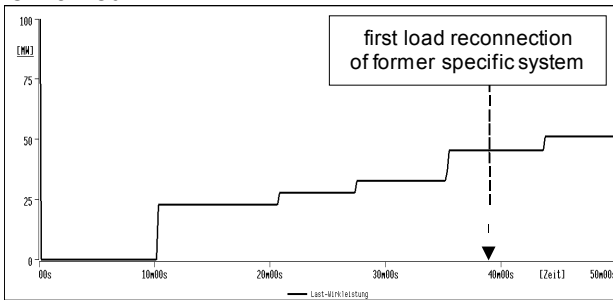
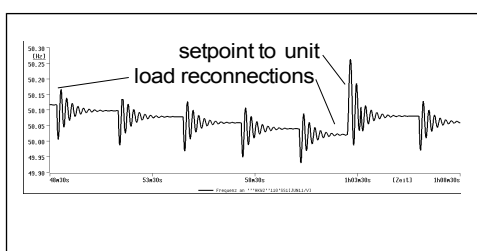


Fig.2 Load recovery of generic system (scenario 1)

Critical consideration proves that

- much time (ca. 40 minutes) and auxiliary energy are wasted by the former system due to the specific directive to open all breakers before restoration beginning. However, this rule cannot simply be skipped since all the further strategy relies on open breakers. On the other hand, the generic system immediately begins with restorative actions (i.e. load selection and path preparation) and the first load recovery doesn't take more than 10 minutes.
- the selection of loads to be re-supplied next is restricted in the specific system whilst it can be individually influenced by intrinsic or operator determined criteria in the generic system; this gives additional freedom in adaptation of load portions to the actual available power.
- in the former system the availability of components/devices is checked only in some cases, thus tending to fail due to missing alternatives. The generic system categorically checks the availability and if necessary flexibly cares for alternatives.
- due to prognostic pre-calculation in advance to any restorative action performed, overload is prohibited on principle in the generic system and the strategy is correspondingly influenced, whilst the specific rules of the former system are based on less certain heuristic assessment without leaving any flexibility in strategy change.
- arbitrary counteraction of operators against the former specific system's conception might perturb the strategy, whilst the generic system flexibly responds to any action, be it in accordance with its initial conception or not.



Scenario 2: Full blackout with only one thermal unit (HKW3, see Fig.1) remaining under household operation but no external tie available. Thus, at the very beginning the proceeding must purely rely on this single unit and care for prudent start and re-synchronization of further units. Careful power-frequency balance is crucial in this case. From Fig.3 it can be seen that also in this situation the restorative actions of the generic system directly begin with connecting first loads to the unit that is running in household operation: Since the generic system has estimated the total power demand for the unsupplied loads (which is the full system load in this case), the household of further units is reconnected with priority to provide their earliest possible availability for re-synchronization (marked in Fig.3). According to the actual available power and the frequency underswing

expected after reconnection - which both are heuristically assessed [9] - further loads are resupplied after their topological interconnection has been established and overload of devices has been excluded by prognostic (power flow) calculation. An excerpt of the weak system's frequency course during such actions is also shown with higher time resolution in Fig.3. It can be seen that besides avoiding critical frequency swings - possibly causing trip of loads or units again - the generic system's heuristic power unit setpoint assignment function [9] succeeds in re-adjusting the frequency close to the nominal value, thus taking over the task of AGC which is normally set out of operation in case of such heavy disturbances.

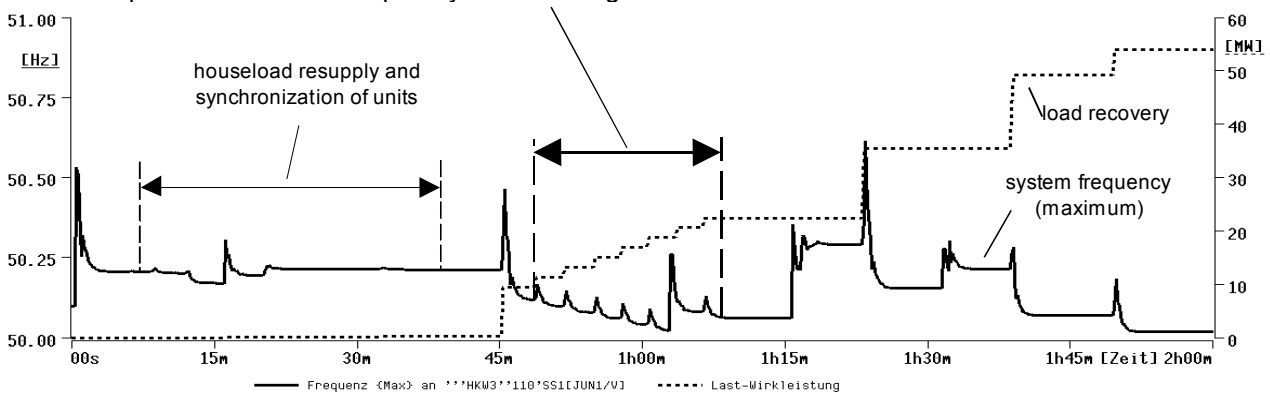


Fig.3 System recovery 2<sup>nd</sup> scenario (commented original displays)

Scenario 3: Loss of one 10 kV busbar section by trip of protection (left section of busbar SS1 in Fig.4). In contrast to the heavy disturbances on the 110 kV transmission level discussed before, the generic system is able to deal with such minor local faults on the distribution level as well, applying the same generic strategy as outlined in [3]. The essential steps of proceeding are:

- check of topology and power availability for resupply from alternative busbar
- change busbar ( SS2) and recovery feeder by feeder

- check if alternative busbar (section) is available
- open sectionalizer(s) of affected busbar

Despite the high grade of detail, no specific rule is necessary to be applied also in this case. The switching actions required in particular are determined and checked by employing the generic sequencing and interlocking function which was presented in more detail in [10].

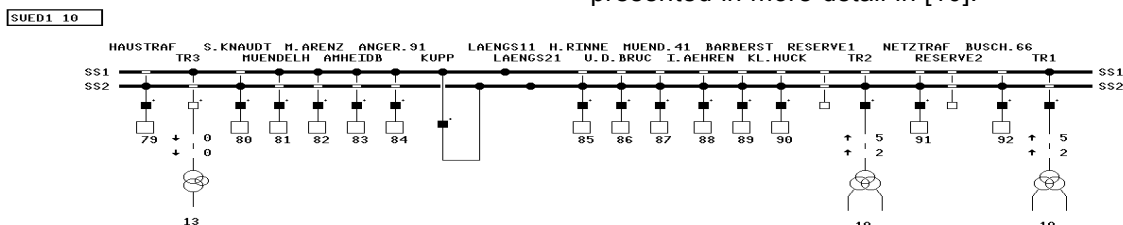


Fig.4 10 kV substation with lumped feeders in pre-disturbance status (3<sup>rd</sup> scenario)

Scenario 4: Multiple local fault on 110 kV: Short circuit on cable OST-SUED2 (see Fig.1) with protection maloperation in SUED2 and non-operating busselector in SUED2, bay OST. The resulting fault situation is that the breakers in substations OST and SUED1 (backup protection)

have tripped, thus disconnecting substation SUED2 with loss of loads on 10 kV (similar configuration on 10 kV level as in previous example). The generic guidance system's restorative proceeding (the particular actions of

which are suggested to the operator step by step) is:

- isolating and grounding of defective 110 kV cable OST-SUED2; due to the non-functioning busselector in bay OST the busbar sectionalizer in SUED2 must be opened;
- re-energization of left part of busbar in SUED2 from SUED1, partial recovery of 10 kV loads;
- recognition that the second transformer in SUED2 cannot be fed from 110 kV, therefore similar proceeding on 10 kV level as described in scenario 3.

The given examples prove that the generic restoration system is able to interactively provide meaningful restoration suggestions for various disturbance scenarios (each relying on the actual system status), and if needed extending its operations to all levels of the system which are controlled from the actual control center or represented on the simulator respectively. Current work is to also verify the restoration system with other power systems (e.g., the complete Dutch 400/230/150/110 kV transmission system).

#### 4. CLOSED LOOP OPERATION

In case of operating remotely controlled switchgear as well as setpoint assignment to units, the restoration system can arbitrarily be set into the autonomous operational mode as described in [11] and [9]. The result is that the number of necessary operator's interventions is drastically reduced, thus considerably speeding up the process of restoration. Currently also an intelligent automated selection of loads to be reconnected, of units to be involved and of topological connections to be preferred is under development, leading to another significant step towards closed loop system operation. Even if the practical involvement of such grade of automatism is still under critical discussion [12], the simulator integration enables operators to smoothly become acquainted with their functionality and developers to test them in multifarious manner.

#### 5. CONCLUSION

Restoration is one of the most demanding tasks in power system operation. Due to rare occurrence, lack of operators' experience, time pressure and stress, the involvement of technical systems for either on line support or preventive training is desired; but few approaches being practically employed so far are mainly individual power system specific solutions. The generic restoration guidance system reported here overcomes this drawback, taking over the characteristics of an EMS application function. Combination with an operators' training simulator ensures that the restoration performance can be verified in much detail under various conditions - for which several examples were reported -, and furthermore proves

as a powerful instrument for guided operators training in disturbance clearing. Finally, the potential of closed loop operation of such systems can critically be estimated.

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