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INCREASING POWER SYSTEM EFFICIENCY SOME PRINCIPLES FOR MANAGING, PLANNING, OPERATION AND TRAINING

КУСА СОДРЖИНА

Како резултат на либерализација на пазарот на електрична енергија и на приватизацијата електроенергетските компании станаа предмет го привлекоа вниманието на регулаторните комисии. Во различните режими националните комисии го надгледуваат спроведувањето на недискриминаторниот пристап да мрежата, независните инвеститори, размена на електрична енергија, ниските тарифи за пренос на електрична енергија и добро снабдување и сервиси кои се нудат на потрошувачите. Овој труд ја прикажува улогата на електроенергетските компании во пазарот на електричната енергија. Главните деловни движечки сили на електроенергетските компании се планирањето, оперативното работење и одржување на електроенергетскиот систем и неговите компоненти. Со оглед на регулативата и законодавството, но исто така и со оглед на високото ниво на квалитетот на електрична енергија, расположливоста на снабдувањето со електрична енергија треба да биде реализирано како очекувано резултат на инвестициите. Во овој труд се прикажани некои основни принципи на планирање на електроенергетскиот систем, менаџирање на средствата, работењето на електроенергетскиот систем и оперативна обука за постигнување на висока ефикасност. Целите се базираат на компјутерски базирани контролни центри, далечинска контрола на трансформаторските станици и разводни постројки, автоматизација и релејна опрема во електроенергетскиот систем. Покрај „SCADA“ новите менаџмент функции ќе обезбедат обемен информатички систем кој ќе ја прикажува техничката и комерцијалната состојба на електроенергетскиот систем. Постои потреба за препораки за оптимизација, замена и инвестициони циклуси. Персоналот ќе продолжи да има важна улога во елиминирање на ургентните состојби, да ги одржува средствата и да одлучува за работењето на електроенергетскиот систем. Поради тоа од голема важност се вештините на персоналот. Континуираната едукација и средства за обука ќе помогнат во зголемувањето на ефикасноста како на професионалното работење, така и на комерцијалниот успех.

Клучни зборови: Ефикасност на електроенергетскиот систем, оперативна ефикасност, менаџмент на средствата, лоцирање на грешките и обнова на напојувањето, обука на оперативното работење.

ABSTRACT

As a result of the market liberalization and privatisation the grid companies have come under the special attention of the regulation authorities. In various regimes the national authorities observe non discriminative access to the power grid, independent investors, power exchange, low energy transfer prices and good customer supply and services. The paper focuses on the grid companies’ role in the energy market. The main business drivers of the grid companies are planning, doing operation and maintenance of the power system and its components. With respect to the regulations and laws as well a high level of power quality, supply availability as a reasonable return of the investments are to be realized. The paper discusses some important principles of power system design, managing the assets, power system operation and operational training to achieve higher efficiency. The goals lead to computer based control centres, remote control to the

stations and substations, automatics and relays equipment in the grid. Besides SCADA new management functions will provide an extended information system presenting the power system's technical and commercial state. There is a need also for recommendations to optimize maintenance and replacing and investments cycles. The staff will keep the important role to clear emergencies, to maintain the assets and to decide about power system operations. Therefore the staffs' skills are important factors. Continuing education and training facilities will help to increase efficiency on both professional acting and commercial success.

Keywords: Power System Efficiency, Operational efficiency, Asset Management, Fault location and restorations, Operational training.

1 Introduction and Goals

Primary business drivers of the grid companies are to provide a high level of quality, availability and stability of the power supply. The main toolbox for a successful business contains the power grid and its components, the information system and the control instrumentation and the staff to operate [1-3]. As investors have a strong view on the returns, a balance between financial income and costs has to be settled matching also further conditions given by national legislation and regulation authorities [9]. Financial income results from the power transfer fee which builds the financial base of the grid company. Every missing (not transported) MWh reduces the companies' income. Some regulation authorities already settled financial compensation to customers in case of switch offs, which seriously can reduce the companies' income [5]. Costs result from investments, maintenance, staff and tools to operate. Obviously all power system components have to be in good condition by doing maintenance and replacement of components at the right time. Components like transformers, cables etc. are extremely expensive but they last for centuries. It is essentially important to be informed about the components (data and e.g. load history) and the technical state to optimise maintenance cycles and replacement. The optimization strategy to do this is called Asset Management. We will focus on those methods a little later. Also during operations the efficiency can be increased by using the right strategies in normal and exceptional power system states. To increase operational efficiency the following goals can be scheduled:

1. Keeping the optimised technical and economical state of the power system as long as possible.
2. Early warnings for dangers and disturbances and avoiding if possible.
3. Limiting disturbances damages and costs if 2. could not be reached.
4. Detailed documentation of emergency events to avoid future failures like this.
5. Producing indicators as decision support to the corporate management for both specifications for planning and for operation of the power system.

The interacting "components" are particularly the electrical components, the information system and the technological facilities to get out relevant information from the power system. System state and dynamic developments have to be known for proper staffs' reactions and operations. Adequate relays equipment, sufficient components and reserves, smooth interaction of men and machine and the consequent use of the tools are of a high importance. For example: Standard functions of modern control system as "interlocking against dangerous operation" and "switching simulation" should be used by the staff before real operation to avoid harmful consequences. The goals above can be supported by according strategies and tools which will be described now.

2 Efficiency by computer based central control

One important factor is the central and computer based supervision of the power system. If all relevant power system measurements, automatic states and relays information are available in the control centre, the most probate decisions and actions can be taken. A SCADA control system uses information links to the stations and substations so that the control engineers have fast and remote access to the grid's equipment. Two functions are important to increase efficiency and availability: "Switching simulation" allows calculating and checking the power system state before doing the real switch operation and "Contingency analysis" which calculates the system state taking possible outages into account. Both functions based on load flow programs and are somehow standards since the 80th of last century and appeared to be very helpful. Also topological checks after selection of switchgear may result in warnings of e.g. „short circuit danger“ or „Load cut off danger“ or „remaining bus connection by isolators“ etc. Modern SCADA systems also present economic indicators to qualify the power system’s economic state as well [4]. Online measurements are processed by taking contract parameters and cost curves etc. into account, see figure 1.

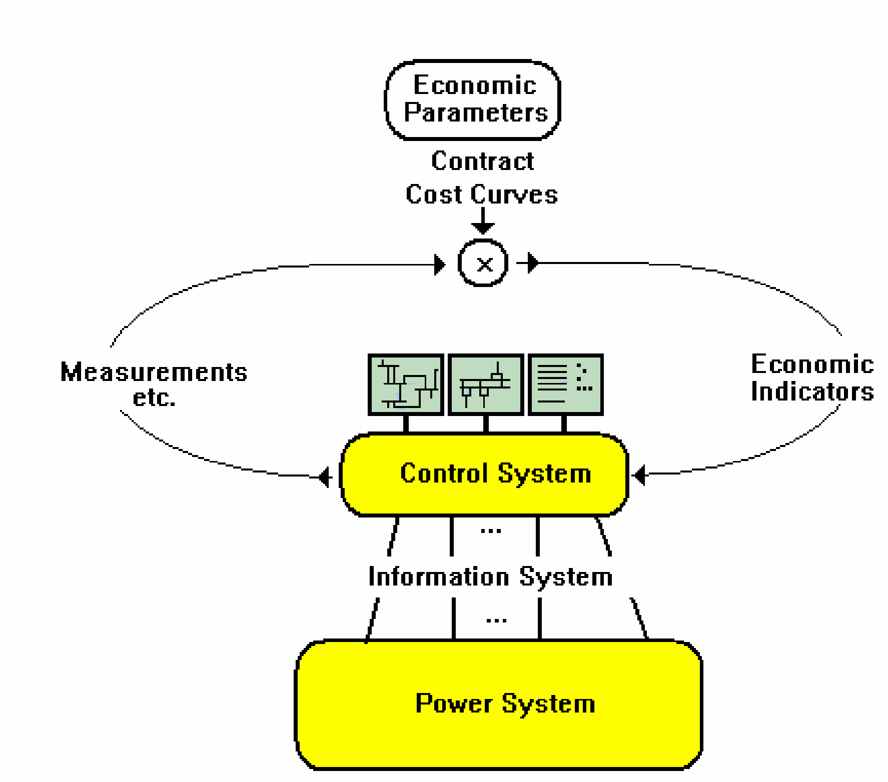

Fig. 1: Creating economic indicators in the control system

The economic indicators should be viewed, traced and optimised to raise efficiency. Just three examples: One indicator presents the active losses. The losses were calculated by online measurements, using load low and current measurements. Many power system operations have an effect on that indicator and the system parameters can be adjusted to reduce the losses. A second example: One indicator informs the engineers about the grid company’s income by summing up the transfer fees due to the actual flow. Third example: CENS-indicators have been created according to CENS (Compensation of Energy Not Supplied). Regulators push the utilities to pay a financial compensation to customers in case of cut offs. See the effect: Engineers can trace the economic effects of outages online in the SCADA system. They were guided to see the most expensive customer groups, e.g. by presenting the financial increment to be paid for a minute (€ / min). The decision is easy what group should be reconnected first in any case of doubt. By exercising different fault localization strategies etc. the most efficient way can be trained. Operational handling will be driven by achieving lowest CENS figures.

3 Efficiency by Asset Management

Asset Management in utility companies is a concept which appeared due the liberalisation and privatisation process of the electricity sector. To compete effectively in the market, utility companies are faced with a continuous balancing act of managing costs while maintaining a reasonable level of quality and service. No longer could utilities afford to pour huge investments into network infrastructure without regarding for the impact of those investments on the quality of service to customers. Investments in the wrong areas can cause profitability and network reliability to suffer. That is why the major concerns of the contemporary network operators, managers and owners are concentrated on asset management. It is an efficient way of organizing assets and their data to perform the best decisions for maintenance, cycles and replacement. Even risk calculations and risk management can be done. See fig. 1. A diagram shows the states of all MV/LV-transformers. The qualification “importance” is extracted by the e.g. the peak load, type of the customers etc. The qualification “probability of outage” is extracted by the age, the failure history, the general environmental impact etc.

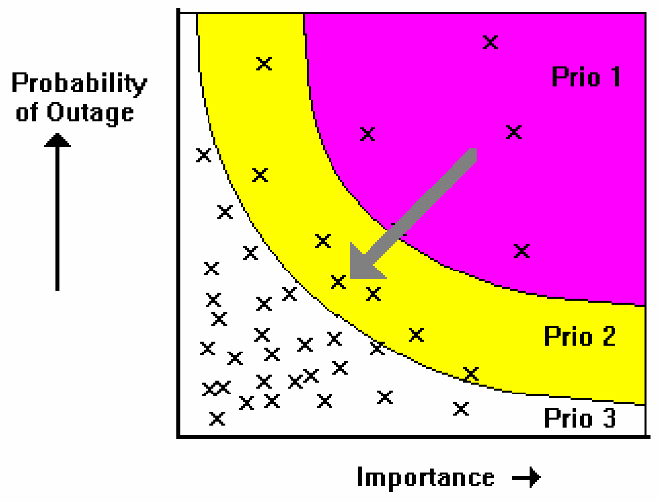

Fig. 2: Asset qualification for decision making

Importance and probability opens a layer to calculate the place of each transformer due to its parameters. Priorities to replace are calculated by the product of both parameters and the priority direction starts with the transformers in the upper right corner (prio 1).

Asset management’s workflow includes all levels in utilities organization. The components’ parameters first have to be collected, validated, entered and stored in a relational data base to be further processed and finally checked and reported. It is clearly providing a good information system helping to understand and to schedule all processes to be executed.

4 Efficiency increase by power system operation

A further increase of efficiency can be done simply by reducing the grids’ active losses. OPF-optimal power flow is a software program for parameter calculation to adjust e.g. the injections and transformers’ taps to minimize the losses in the power system, usually used in UHV- and HV- power systems. What about MV-power systems? In MV we do not have such flexibility and less online data. In MV also every change of the topology state, of injections, taps of transformers and compensations etc. do have influence on the system, on losses and thus also on the economic situation. Also in the MV an optimisation is possible, as it will be demonstrated.

To understand the range of the net losses in MV-power systems first an example is discussed: Taking a grid example and an average load of 1000 MW and 5% losses a year approximately 450 GWh/a losses arise. At costs of 60 €/MWh, about 25 Million € for a year will arise. If only 5 to 10% of these losses can be saved by net operations and adjustments, it is worth to justify efforts and investments. Growing load also means growing losses and the question arises in which way the losses can be lowered as far as possible. The MV distribution networks are usually designed in a mashed type and are operated in normal conditions as star networks, see fig. 5, case A. Main idea is to increase the customers’ supply availability because in case of a short circuit a switch off of just one track line, a half ring happens, see fig. 5, case C. This is usually only half of the amount of customers compared to a fault of a closed ring. The splitting point is permanent, realized by an open isolator somehow in the middle of the ring. It has been calculated during grid planning phase and usually stays for years. The losses in the ring are not minimized. In a closed ring the minimal loss condition always appears automatically due to the Kirchhoff’s laws, see fig. 3, case B.

What has been done? To achieve the positive consequence of increasing availability at (the seldom) case of short circuits the losses are not minimized for all the time. As loads have changed during the years and even vary during daytime the minimum losses criterion is neglected permanently to get a higher availability in rare cases.

Both advantages can be combined. Therefore the splitting point is closed by a breaker and a protection relay, see fig.3 D. The minimal loss condition adapts automatically. In case of a short circuit somewhere in the grid, the protection relay operates automatically and opens the ring. One half ring is selectively switched off, see fig. 3 E. Modern digital protection unites give additional help for localization of the fault by sending the impedance measurement to the regional control centre. Positive experiences are already known. The information connection to the centre can be done by GPRS (General Package Radio Service). GPRS can be used for far distance stations. It is a reasonable solution and not very expensive for seldom transmitted information.

Examples in MV grids show that about 10% of the losses can be saved for unbalanced loads (2:1) by closing the separation point. For every 10 MW approximately 25-30 kW can be saved depending from the cable parameters.

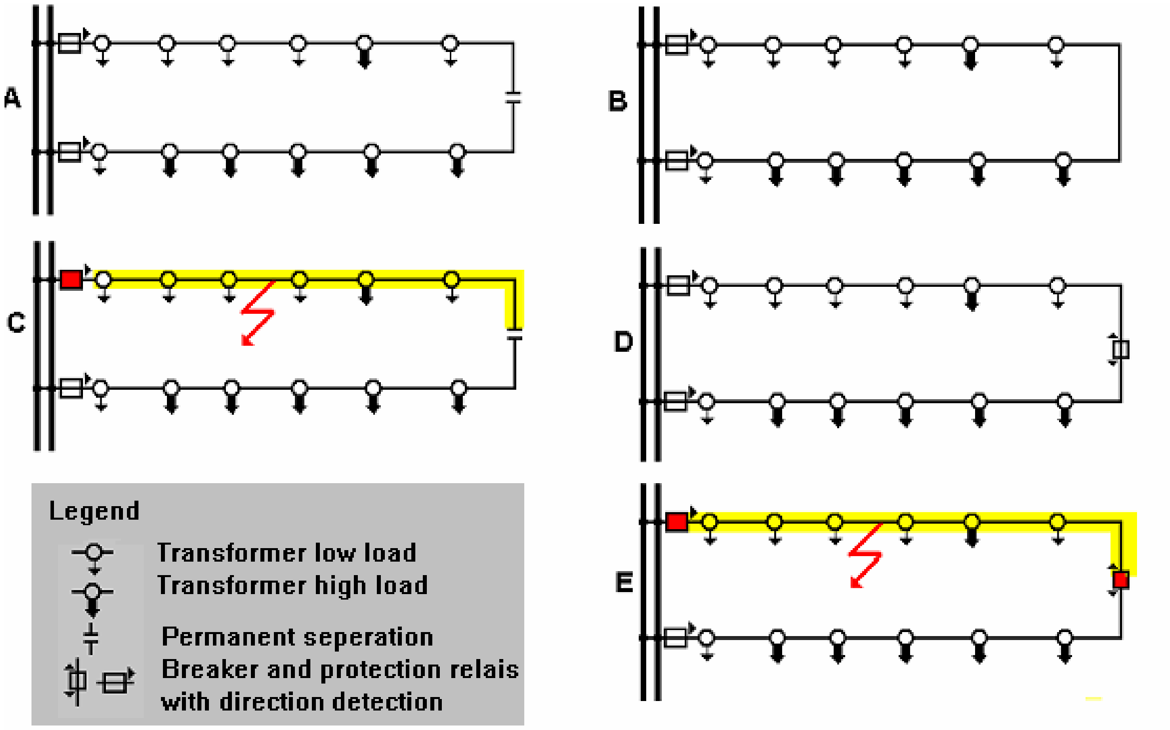

Fig.3: Network configurations to achieve as well selectivity as minimum losses

For a city of 1000 MW average load on MV and an "annual duration" of unbalanced load 5000 h/a and an electricity price of € 60/MWh the value of about € 500,000/a can be saved. The higher and the greater the unbalanced load in the ring, the higher savings at losses will be achieved by this strategy. We have focused on MV grids. Now let's see the HV/MV transformers and their potential.

5 Optimization of by transformers connected in parallel

Generally we can use the same strategy in this case: Two HV/MV transformers see fig. 4, feed two MV-bus bars separately in the station West 20. The transformers are loaded asymmetrically. Trafo 69, see fig. 4 , feeds two 20-kV load groups, through busbar 2 together with 60 A. Trafo 69 is low loaded, just 7% of rated load. Transformer 70 feeds busbar 1 with total 604 A and is approximately 70% loaded. The total transformer losses are 185 kW.

After parallel connection by the busbar coupling, transformer 69 is now loaded by 328 A and transformer 70 by 338 A, see fig. 5. The total losses are 111 kW now, a difference of 74 kW appears. 50 stations like this and a significant unbalance of 5000 h/a one can save up to 1 Million Euro a year of losses depending from the type of transformers by parallel switching. The bus bars are connected by a breaker and a protection relay. In case of a short circuit the coupling and the effected track line is switched off. The availability is equal to the separated transformers.

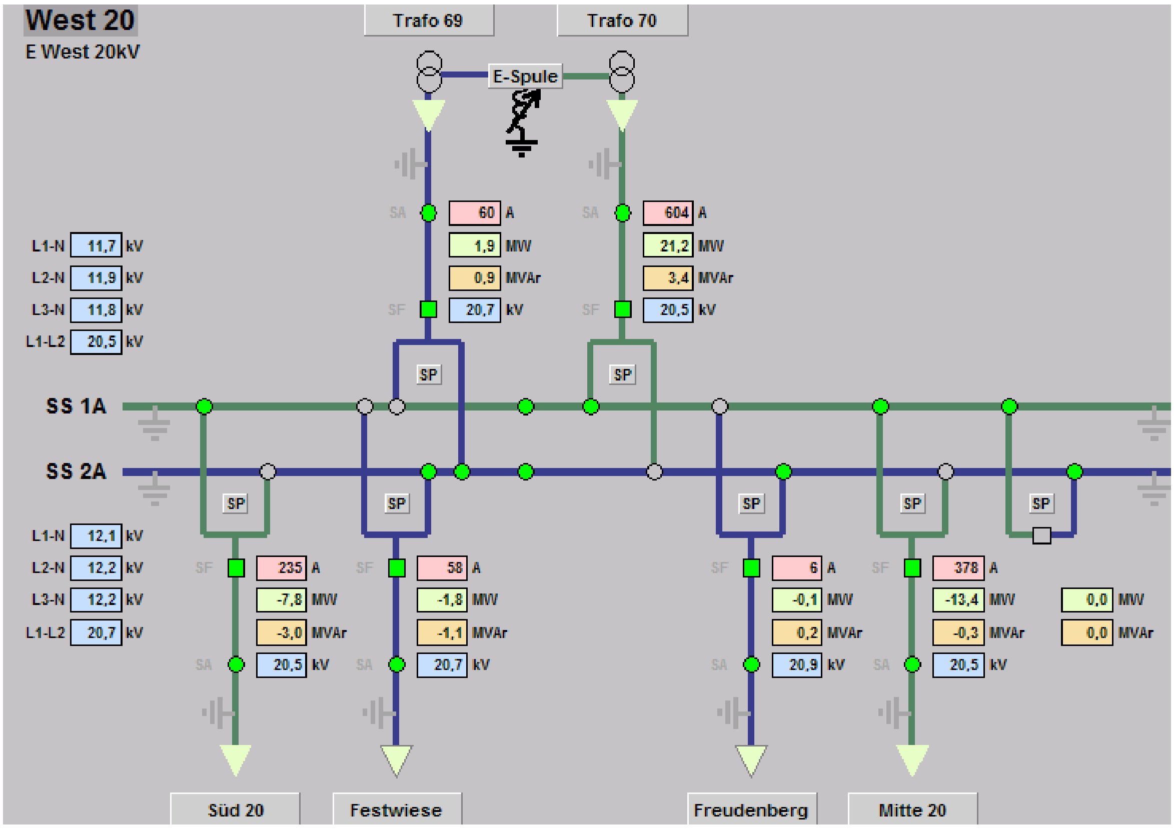

Fig. 4: Asymmetrically loaded 110/20-kV transformers

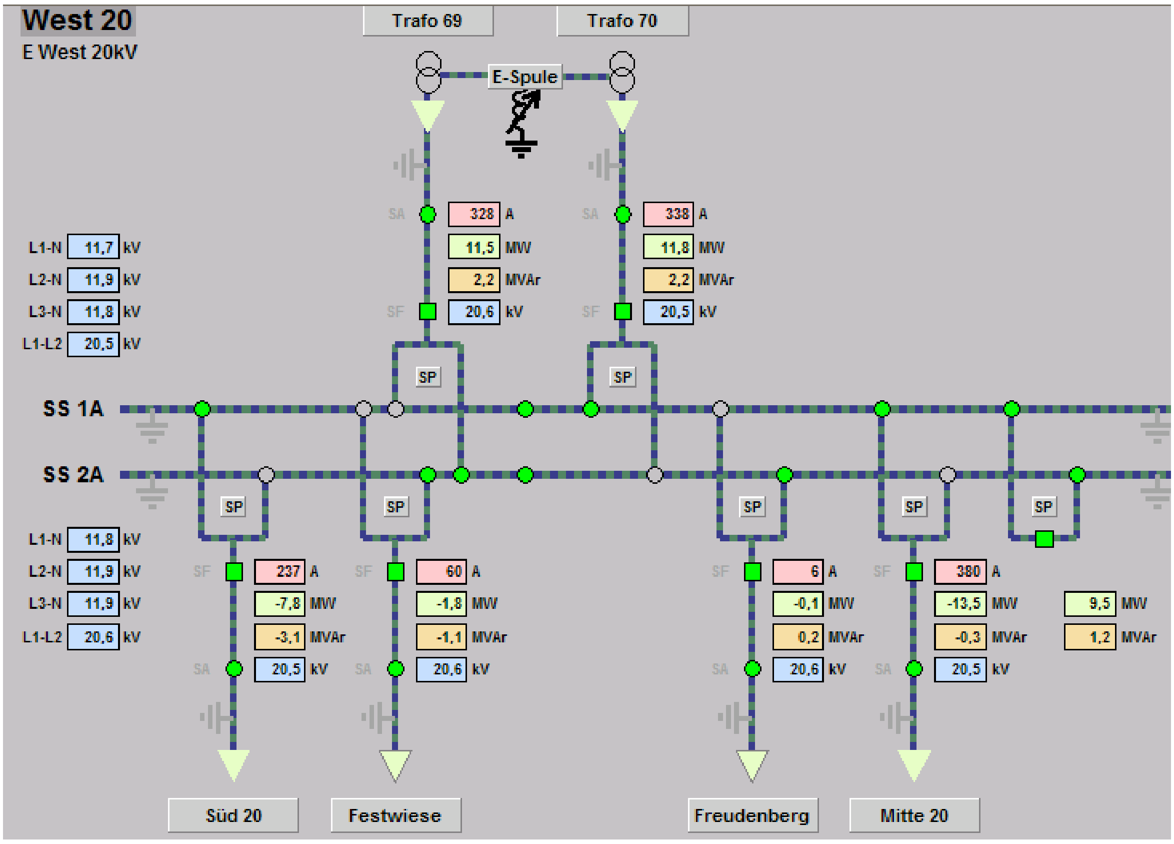

Fig. 5: Transformers switched to parallel by busbar coupling

6 Increasing efficiency by fast fault location and restorations

Fault location and restorations is an important task. The main steps of it: Fault analysis and detection, fault locating, re-supply and repair. We look at a short circuit case in a MV net. The nets are designed in mashed type and operated as star nets. Just the transformer stations and main net node stations are connected by telecontrol installations to operate from the control centre. There is typically no telecontrol inside the distribution grid. A short circuit leads to switching off a half ring. Corresponding alarms, reports of protection relays and protection triggering come in the control room. The analysis of the causal fault can be made easier by filter functions at a great report flood with time- and priority-sorting. The fault detection hereby can be completed rather fast and even faster by using distance relays.

Since customers are switched off usually one immediately starts with the fault locating (search of the faulty line section). The net service group is activated and sent to the grid. Switches are executed to separate the lines into sectors. Testing switches are done to finally locate the effected sector. Using modern digital distance protection relays the testing switches can be reduced. Those relays analyse the short circuit conditions locally and report direction and distance (as impedance). Additionally short circuit indicator relays can be implemented in all MV/LV transformer station just to report about short circuit currents passing this station. This equipment seriously reduces the cut off time of not directly effected customers.

7 Increase efficiency by frequent power system operational training

A control centre gets completed by a dynamic power system simulator which takes on the role of the power system for trainings. The training idea is similar to a flight simulator for pilots. Engineers can switch the operation station to a training mode for exercising all operations as during real control. All power system reactions are authentically simulated by software “power system simulator”. See figure 6. The SCADA software can be linked to the simulator calculating the power grid’s and components’ behaviour. In the training mode engineers can practically exercise all operations in real time using their origin workstation. Practice shows that the basic essential of effective power system operation is the consideration of the power system as a system of interacting components. The dynamic operational training is a new practical solution consequently following new technical facilities. Experiences can be gathered risk free.

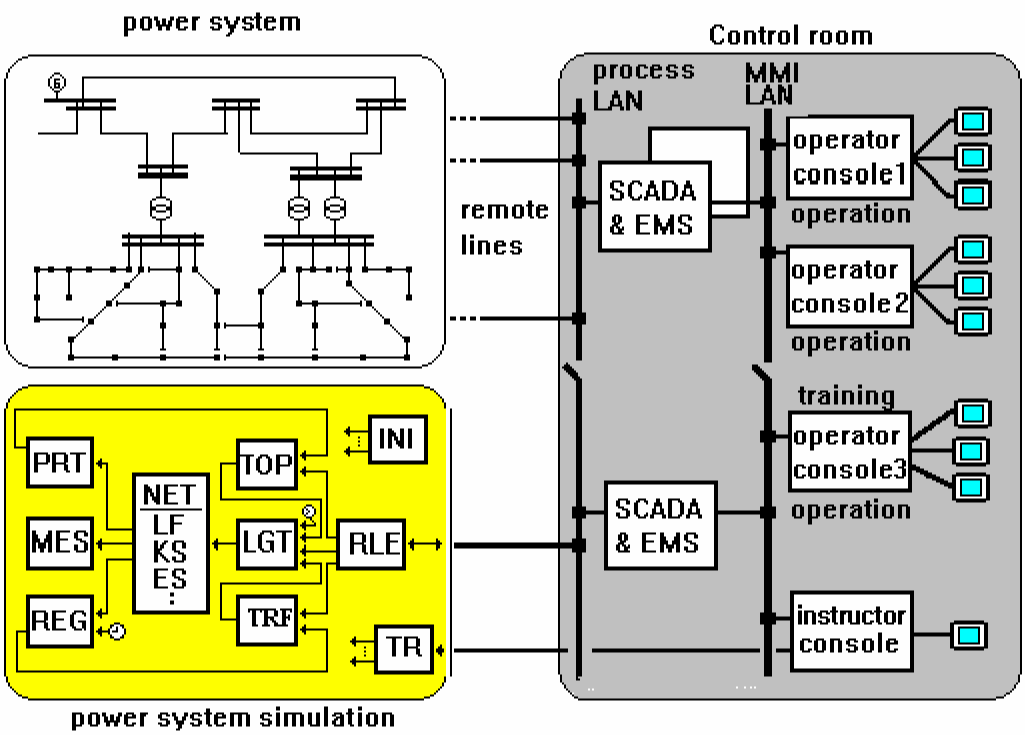

Fig. 6: Control system for on line operation and parallel operational training

The dynamic power system training simulator allows a risk free training [11-12]. The operators do not feel a significant difference between online operation and operational training because the simulation parameter sets are power system snapshots and the calculations are performed in real time. Beginners and experienced operators can improve their skills by operating and solving power system emergency situations. Only experienced and well trained engineers can achieve an optimum under consideration of all economic demands and technical constraints. Staff qualification can be increased well by a frequent training. All technical and commercial effects of operational handling, of strategies, of different contract situations etc. can be trained efficiently to find the most proper solution. This will result in countable profit increase.

8 Efficiency by evaluation of staff, equipment and work flow

All network components, the level of supervisory tools like SCADA and new management functions, the information transfer and remote access system, the maintenance and re- investments do seriously affect the companies' efficiency. The staff will keep the important factor to do the decisions to operate and to clear emergencies. Obviously the staff, the equipment and the interaction between have to be evaluated to come to higher efficiency. The following table defines goals to follow and also gives principles, actions and evaluation topics to increase efficiency. Just two facts:

1. The goal to keep the technical and economical optimum needs a central computer based control system and tools to clearly qualify, quantify and present the state of the power system. Optimization can be done only if these figures can be seen. A continuous education for effectively using the control centre tools have to be installed and evaluated frequently

2. The goal for avoidance of disturbance needs a central computer based control system and simulation tools like switching simulation and the n-1 contingency function. As November 2006 UCTE failure indicates that it is not sufficient to have the tools available – the functions should be consequently used before operation. Evaluation of existing work flow is important.

Table 1: Goals, principles, actions and evaluations to realize efficiency

Goals	**Power System**	**Power System Control**	**Staff education**
Keeping the technical and economical optimum	Planning values Forecasting Risk management Optimizing losses Optimizing network structures	SCADA Remote lines Power system analyzing tools n-1 contingency analysis Online technical analysis Online economical Indicators	Access to economical Indicators Frequent training of standard operations Continuous education and using control centre tools
Avoidance of disturbances	Construction, material, Route for lines and cables Peterson coil grounding Inspections&maintenance Asset-Management Risk-Management,	Load forecasting Interlocking system Switching simulation History of loading History of switchgears	Training of operations close to components' limits Exploring limits and further effects during training Safety in acting close to power system limitations
Damage limitation and fast restoration	Relays implementation as - single ground fault ind. - short circuit indicators - protection - Short ciruit impedance Remote control in distribution grids	Disturbance Management: Failure localisation Identification of not effected sections Indication of CENS costs	Training of potential and of seldom types of failures Preparation for optimized actions and workflow
Documentation	Exact deposit of the marked-out cable routes (GPS) structural and geographical connections	Documentation of the activities, documentation of the mains failures, missing supply and accompanying data, disturbance processes	Training: Net losses, Training of failure cost effects due to the restoration strategy
Analyzing for future managing staff and assets	Component statistics: Life cycle, Load-failure history, Risks Substitution costs and time Supplier qualification	Providing in house and regulator statistics as SAIFI, CAIDI, SAIDI,…	Evaluation of failures, actions and experiences Future training concept Develeopement of new indicators

9 Conclusions

Grid companies' business is to transport electricity to the customers. An optimized power system with regard to the costs, life time and availability is in the strong interest of all market participants. In the paper particularly the operative business has been analyzed with regard to improve power system efficiency. The discussion shows that developing efficiency leads to a computer based control system, an information system presenting technical and economic data, remote control for fast operations and a training mode to improve staffs' skills and security in operation. Notes have been given for guiding the staff in decision making, supported by SCADA including new functions to present economic indicators which economically qualify the power system state.

Important prerequisites for efficiency are the components' planning, maintenance and replace strategies which can be supported by an asset management system. Adapted to the special components' history and actual state the corresponding maintenance and investments can be clearly decided. In the long run this pays back by a rare number of disturbances over many decades. Furthermore efficiency can be improved by the way of grid operation. Therefore operational training is useful which results in safer decisions and faster operations even in the conditions close to power system limitations. Finally an evaluation process of the components, the system, the workflow and the interaction including staff will result in higher efficiency. Investments in equipment and staff educating will present a long-term amortization which in today's times seems to be hardly any heard argument.

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