Alert State Detection and Switching Order Generation at a 400/120 kV Substation using Knowledge Server

J. Nacsa, G.L. Kovács
{nacsa, gkovacs}@sztaki.hu
Computer and Automation Research Institute, (MTA SzTAKI)
Budapest, Hungary

Abstract - At the operator level a new, PC-based SCADA system was introduced at the electrical substation of the Paks Nuclear Power Plant. An AI-based, intelligent advisory system was developed and connected to the SCADA system as knowledge server. The paper describes some of the advisory functions and their realizations in rules and procedures. Besides increasing reliability and safety of energy supply the basic goal of the system is to assist the operator in faster and more effective reactions, and to assist the plant engineer to better understand and evaluate any possible events.

Keywords: power plant, intelligent systems, SCADA, high voltage substation, knowledge server

I. INTRODUCTION

The production and distribution of electrical energy are critical tasks for all communities in our era. These processes should have the maximal safety and reliability all the time. Independently of the type of electrical energy production (fuel, fossil, nuclear, water, etc.) the distribution uses different types of substations at different energy and voltage levels. We do not need too much abstraction to accept that the activity of a substation is similar to the activity of any other technical/industrial process. This way problems of fault detection, supervision and safety of substations are similar to problems of any other technical processes.

In the paper some ideas and measures will be discussed which were implemented at the 400/120 kV substation of the Paks Nuclear Power Plant. The goal of the work is to increase safety and availability of the substation by means of supervision and fault detection and by assisting the operators and engineers in faster and better reaction to events and in better evaluation and design. Some intelligent functions were designed, implemented and embedded into the SCADA system (Eurocom, 1998) of the substation. These are:

- Equipment diagnostics & maintenance design;
- Topology analysis using voltage and current maps; Determination of dangerous topologies;
- Alarm warnings based on measurement values;
- Intelligent interlocking system based on the measured voltages and currents;
- Diagnostics of disturbances, determination of places & types of disturbances, and advising in recovery procedures;
- Automatic generation of switching sequences.

Two of these functions and their effects will be detailed later on. Namely the determination of alerts means model based trend calculating and detailed topology analysis while the switching order generation is a fully rule based procedure.

II. THE GENERAL FEATURES OF THE INTELIGENT OPERATOR SUPPORT SYSTEM

The intelligent operator support system of the 400/120 kV substation performs intelligent data acquisition, diagnostic and advisory functions based on the real-time data of the substation. It is deeply integrated into the SCADA system of the substation providing on-line voltage and current measurements as well as events, warning and alarm messages derived therefrom. The operator support system serves two types of users:

- Substation operators on a technician level with intelligent evaluation and advice in alarm situation,
- Maintenance and plant engineers to provide information on operation and maintenance characteristics and overall plant operation information.

Fig. 1. shows the topology of the 400/120 kV substation with the three available voltage levels indicated by different colors. The 120 kV fields are shown on the top part of the figure while the 400 kV fields are on the bottom right part with all the switching equipment. On the bottom left of the figure the transformer field is seen that contains two transformers and an 18 kV feeder.

The voltage and current map generation is a basic function of the operator support system which is performed periodically using the measured voltage and current values provided by the SCADA system. It gives information to all the other on-line functions. The computation of the map is able to substitute missing or false measured data using the topology information and gives intelligent alarm messages in the case of detected contradictions.

The equipment diagnostics and maintenance design monitors the switching actions of all equipment and calculates the relevant operational characteristics: the number of switching actions, the slowest and quickest switching time, the average switching time and the standard deviation, the mean switched current values, etc. It compares the calculated data with the ones in the catalog and warns the operator on the need of maintenance if necessary. It also examines the conditions of the switching actions and classifies them. It provides maintenance data about the aging of the equipment.

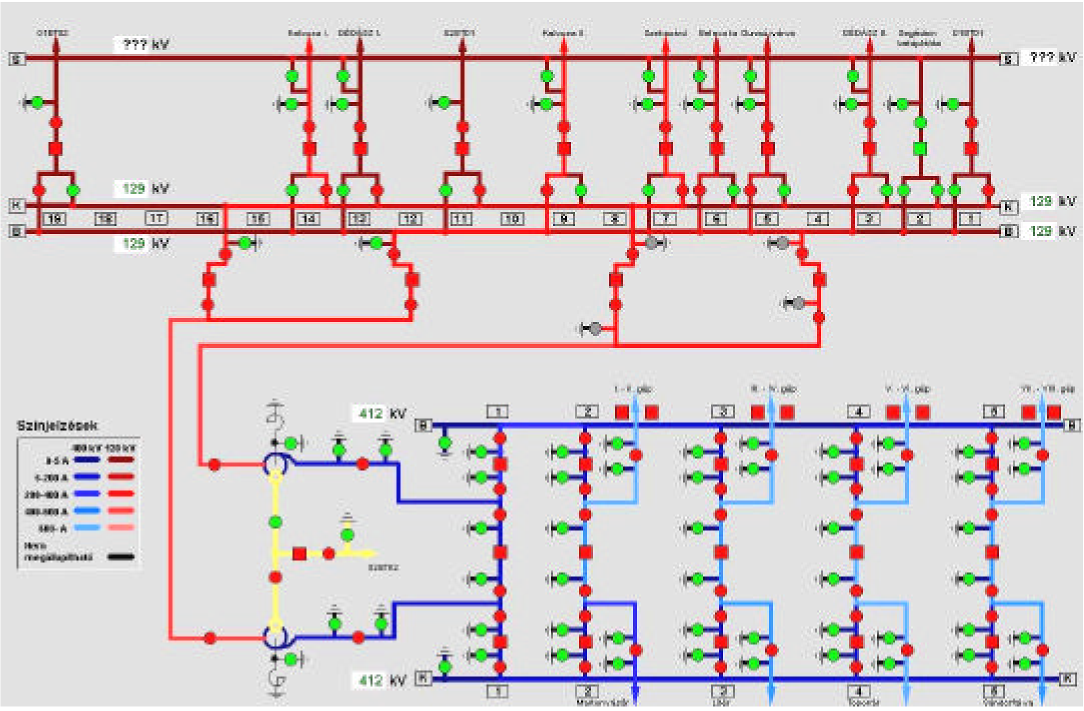

Figure 1. The current map of the 400/120 kV substation

The intelligent interlocking function determines whether or not the equipment in the topology can be switched based on the "Voltage and current map". It sends warning message to the operator if any conflict is detected between the intelligent interlocking status and the built-in interlocking mechanism.

The intelligent automatic protection sequence analysis function operates on the primary error and warning signals of the SCADA system in the case of alarm situations when automatic protection procedures are taking place. It detects the changes in proper order and matches them with predefined "protection samples" to find out what actually happened. The best-fitted sample is shown to the operator on-line and stored for the maintenance engineers for further analysis. In many samples the experts defined "key" signal (which means it must be there) and "forbidden" signal (it must not be there).

The automatic generation of switching sequences function gives advice to the substation operator in all cases when he needs to perform switching sequences to drive the plant from its current state to a predefined different one commanded from the control center of the Hungarian Electric Board. This function is described in details in Chapter IV.

The intelligent detection of dangerous states (Chapter V.) based on the present topology state and on some secondary signals together the system may indicate an alarm situation that is very difficult to detect for a human operator (for example: oil pressure instability when only one transformer is switched on). The trends of different secondary signal may show ALERT cases.

III. KNOWLEDGE SERVER CONCEPT

This advisory system was the first industrial application of the Knowledge Server for Controllers (KSC) introduced in our laboratory.

KSC is a server providing capability of intelligent data processing for other systems. It allows the basic system to reach external intelligent processing resources, because it has not any. The KSC contains a high performance reasoning tool, and different knowledge based modules. All the modules have their special rules and procedures. The client system calls these modules, pass them specific data if necessary, but the KSC module can collect data if the knowledge processing requires. All the data acquisition and user interaction is done by the client system (see Fig.2).

The KSC allows the different modules to run independently, to cooperate as agents or to control each other. The third case means that one module is started by another one because either the second one uses the results of the first one or the inference of the first one led to the need of the second module. In this application e.g. the protection sequence analysis function starts the equipment diagnostics.

Generally the resources of the KSC can use more clients (controllers or SCADA systems). It leads to a cost effective AI solution. The overhead of the KSC (network connection, one more computer, some delay etc.) is much less comparing to the advantages. One costly AI tool can solve all the intelligent problems in a distributed environment. Using the KSC together with the component based software technology (e.g. CORBA) gives a very adaptive software frame to solve complex problems.

The KSC (Fig. 2) was implemented at the power-plant substation within the G2 intelligent real-time environment (Gensym, 1999). G2 has been selected in other cases as the implementation tool of the intelligent operator support system (e.g. ABB, 1996). The following properties of G2 has been intensively used:

- real-time and object-oriented features,
- advanced graphical development tools,
- rapid prototyping capabilities,
- easy interfacing capabilities (to the SCADA system and its SQL data base)

The software environment of the whole system is as follows. MSWinNT, FIX Scada, MS SQL Server and G2.

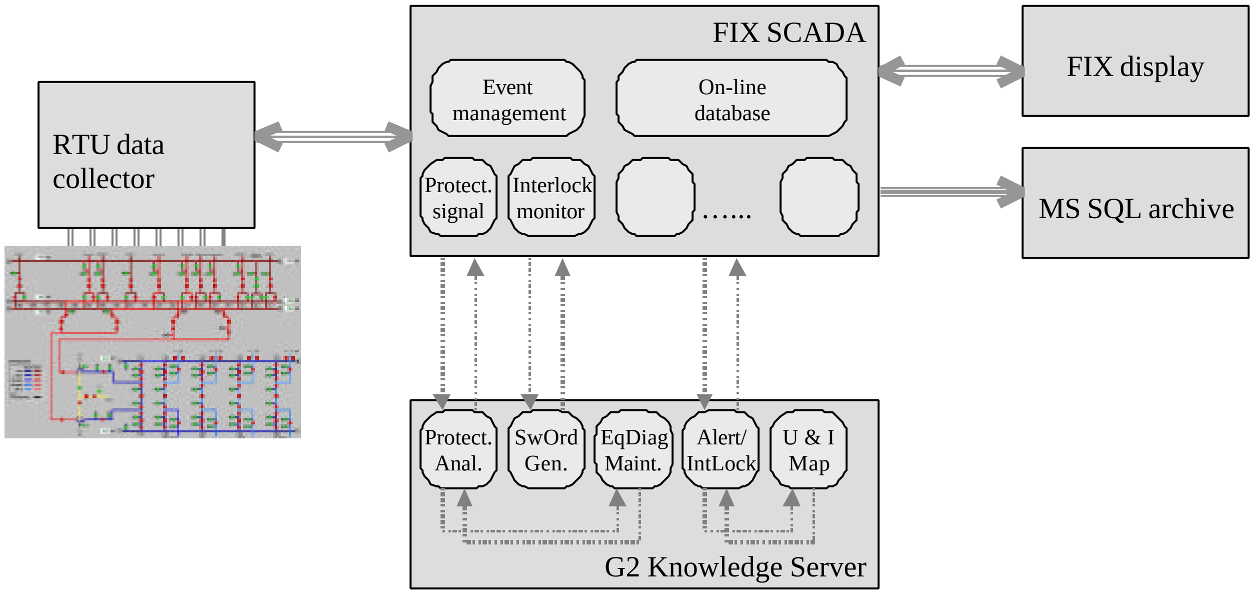

Figure 2. Knowledge Server connected to the SCADA

IV. AUTOMATIC GENERATION OF SWITCHING SEQUENCES

In normal conditions the switching tasks of the substation are given by the operators of the nuclear blocks or remotely by the control center of the Hungarian Electric Board. They define the following stable state of the substation in a short command like “Switch off the Martonvásár transmission line”. The actual state and the command together exactly determine the following state after a sequence of switching that fulfills state changes required in the command. It was possible to define a clearly structured menu tree for all the possible switching command. So a simple switching command selection program was designed and developed for the substation operators.

Each switching command belongs to a built in list of switching equipment with a dedicated state (e.g. off or on). The switching command is executed successfully if all the equipment in this list reached the state indicated in the list. This data (lists belonging to each command) is stored in an external file and it is possible to download into the advisory system during run-time. Some lists are “meta-list” when two or more commands are the same except that the fields of the equipment are different.

As additional information the type of the switching sequence is also added to each switching lists. Four different types were defined:

- switch off,
- switch on,
- light changeover and
- dark changeover.

The light or dark changeover means that during the switching transient the transmission line should or should not be supported with current.

When the operator gave the switching command to the system, it generates automatically a correct switching sentence, then prints it out. The operator must check and sign it, then must ask permission from the control center of the Hungarian Electric Board, and finally he/she may execute it manually.

There are many important constraints of the sequence generation which must be satisfied in every elementary switching steps, as follows:

- It must fulfill the basic electrical rules (e.g. “must not switch current with disconnector”).
- It must generate sequences according to the special custom rules followed at Paks (e.g. “first must switch the ‘BS’ disconnector then the ‘BÖS’ one”).
- It must be executable, that means it must not break the existing interlocking system in any situation.

In the practice the interlocking system warrants that any switching equipment can not switch if the states of its neighborhood equipment do not permit of. The interlocking system means logically a set of logical equations (in both switching directions) belonging to each switching equipment. These equations are in the SQL database of the SCADA system. If the version of this database has changed, the advisory system loads them into its knowledge base, generates its own logical functions in run-time and runs when the operator starts the generation of the switching sequence.

The generation algorithm first calculates the new final state from the actual state and the switching command. It defines a list of equipment to switch. The advisory system determines the correct order in a software loop. In an elementary step of this software loop, the advisory system tries to find the next equipment to switch. First it calculates which equipment the interlocking equations allow to switch in this step. It defines a temporary list and then the switching rules are invoked both the electrical and the custom ones. The rules delete the equipment from the list if another equipment found in the list that must switch sooner according to the given rule. If only one equipment remains on the temporary list, the advisory system switches it virtually and starts a new step of the software loop.

In the following lines these rules are illustrated as examples to one electrical and two custom rules in switching-off commands:

for any disconnector D in SWG-LIST if there exists a circuit-breaker in SWG-LIST then remove D from SWG-LIST

for any 400-line-disconnector LD1 in SWG-LIST if there exists a 400-line-disconnector LD2 in SWG-LIST such that (the branch of LD2 = the symbol br-ö) and LD1 is not the same object as LD2 then remove LD1 from SWG-LIST

if there exists a sf6-line-disconnector LD1 in SWG-LIST such that (is-contained-in-text ("_BS" , the text of the names of LD1) = true) and there exists a sf6-line-disconnector LD2 in SWG-LIST such that (is-contained-in-text ("_BÖS" , the text of the names of LD2) = true) then remove LD2 from SWG-LIST and conclude that SWG-NXT = the names of LD2

The rules are separated in three categories, namely switch-off (A), switch-on (B) and both-direction (C). If the switching command defines switch off, then A + C rules are invoked. In changeover cases the equipment are separated into switch-off and switch-on phases. In light changeover first the switch on tasks are done then the switch off ones. If an error occurs during the generation, the operator gets an error message that explains the problem the advisory system found.

V. DETERMINATION OF ALERT SITUATIONS RELATED TO THE TOPOLOGY

In the substation there are different topologies, which are critical in the sense of safety (e.g. two of the four 400kV transmission lines are off), and the operator has to be aware of them very easily. Other topologies are not dangerous per se, but together with other events they may be critical and also it is difficult to see and detect them. Two groups of these cases can be separated:

- Some lines are switched off, and on the remaining ones any of the circuit breakers have some secondary signals, which show that the given equipment is not perfectly reliable. E.g. only one transformer is running and the circuit breaker close to it (9101_ÖT) has too low gas pressure value indicating that the given circuit breaker may not switch in a protection event causing big troubles at the whole substation.
- If the total consumption is too low in Hungary, all the four blocks are running and some transmission lines are off, then the operator must start to execute a special set of actions because of the “Transient stability problems”. Even though it is not easy to determine these cases

In the advisory system all the cases of the two groups are handled. The system runs a topology analysis twice a minute and generates a full voltage and current map based on the measured values and the states of the equipment. Using these maps any type of topology can be detected very easily. Also all the relevant secondary signals (gas and oil pressure values, power output of the blocks and reactive power) are collected permanently. In each topology analysis cycle all the alert cases are searched for and if any of them is valid, an alarm message is sent to the operator.

VI. CONCLUSIONS

An intelligent, multi-function advisory system was implemented and introduced which supports the operators and plant engineers in the 400/120 kV substation of the Paks Nuclear Power Plant. The KSC concept, as the main environment of the implementation was introduced. Two of the functions which are the most relevant to process safety were discussed in details, namely the switching order generation and the determination of dangerous (alert) situations. This latter one is a typical rule based system from the processing point of view, while the previous one is a combined rule-based and traditionally computed.

Based on the first year of experiences the intelligent switching order generation function is the most often used part of the advisory system.

VII. ACKNOWLEDGEMENT

The project was sponsored and assisted by the Paks Nuclear Power Plant Ltd. The contributions of Eurocom Ltd., as system integrator of the SCADA system, Eroterv Ltd. as domain expert are accepted and highly appreciated.

VIII. REFERENCES

Eurocom Ltd.: Local information control system, (Helyi Irányító Rendszer), System Books, 1998, in Hungarian

Gensym: G2 Reference Manuals, Gensym Corp. 1999,

ABB: Power Plant Control based on G2, 1996, www.gensym.com/expert_operations/stories/abbpower.html