

DYNAMIC PERFORMANCE ON DIGITAL SIMULATOR

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Abstract - One of the more important and interesting activities performed during the design process of an HVDC project is the Dynamic Performance Study. The objectives of this study are to optimize control parameters, and to see if any special control functions or operational restrictions are needed so that fast and robust performance may be attained. This type of study has traditionally been made on an analog real-time simulator.

This paper will describe how the Dynamic Performance Study (DPS) for the SwePol HVDC Cable Link was performed utilizing a fully digital simulator instead of an analog real-time simulator. The fully digital simulator was based on the PSCAD/EMTDC program [1]. Before presenting details of how the study was performed in PSCAD/EMTDC, a brief general description of the Dynamic Performance Study is provided.

I. PROCEDURE FOR A DPS

Before the study can start, an equivalent(s) for the AC network(s) must be available. The equivalent(s) should represent the dynamic behavior of the complete network for the main oscillating modes. The equivalents can be designed by utilizing an electromechanical stability program (e.g., SIMPOW, PSS/E) to investigate the dynamic behavior of the complete network. The equivalents should also include representations of important AC lines, where faults can be introduced and the appropriate AC lines disconnected. On an analog simulator, there is a physical limitation on the size of the equivalent. While in PSCAD/EMTDC, there is no physical limitation on the size of the equivalent (except, perhaps, the size of the hard disk), there is a practical limitation—the execution time for cases may be

excessively long if the equivalent is too large. Therefore, it is essential to reduce the size of the equivalent to represent only what is relevant for the dynamic behavior of the converter bus.

Besides the equivalent (s), the setup for a DPS includes a full HVDC model, including the AC filter, converter transformer, valve, DC filter, smoothing reactors, HVDC cable, control and protection system, etc.

Next, all critical fault cases are identified in consultation with the client. Selection of the first set of parameters is based on experience from a previous project of similar design and with similar AC system conditions. With this first set of parameters, power/current order steps are performed and Nyquist diagrams are produced to verify small signal stability for the chosen parameters. The critical cases agreed upon with the client are then scanned. During this process, other critical cases are found that may necessitate changes to the chosen parameters. Additionally, all special functions used for large-scale signal disturbances are tested and optimized. If undesirable performance is observed, the process is repeated with a new set of parameters. Finally, the chosen set of parameters is again verified with a run-through of all cases using the final settings.

It should be pointed out that setup work and changing from one configuration to another is very time consuming when working with analog simulators. Furthermore, during the course of the study, there may be faulty components in the analog simulators that require considerable time to trace. The PSCAD/EMTDC simulator tool offers much more flexibility and efficiency in this respect.

II. THE CONTROL SYSTEM

The control and protections system plays an important role in the DPS study in achieving good overall performance levels for the transmission system. The control and protection system MACH™ (Modular Advanced Control for HVDC), adopted by ABB Power Systems, uses the latest technology from the fields of electronics and microprocessors. MACH™ is a fully computerized control and protection system. The main characteristics of the MACH™ are its high degree of functional integration and the open systems interface approach. The open systems strategy is reflected both in the use of industrial standard serial and parallel communication buses, as well as in the use of standard formats for all collected data (such as events, alarms and disturbance data). This makes it possible to take advantage of the

latest achievements in electronic engineering, thus ensuring timely development of more advanced functions and performance enhancements for a long time to come.

The converter control and protection principles are based on the well-proven ABB HVDC Control and Protection System, now in operation at over 80 converters around the world. The experiences from these installations have been utilized to ensure a safe and robust control and protection system, named the Base Design. The Base Design is the internal name for a complete well-proven platform for the implementation of the control and protection system of an HVDC project, including the methods for working with such a project.

The first installation of the MACH™ system using the Base Design concept—the Skagerrak III project, a cable transmission between Norway and Denmark—was put into commercial operation in late 1993. This first installation proved extremely successful from the start, without a single forced outage caused by the control equipment during the first year of operation. By early 1996, another two installations relying on the MACH™ system had been turned over to customers—the Baltic cable project between Sweden and Germany and the Kontek project between Denmark and Germany, both cable transmissions. Today, there are several MACH™ system in service around the world and, for the SwePol project, the next MACH™ system hardware generation is used—the MACH 2. This system uses the same Base Design platform.

The MACH 2 system is based on high-performance standard computers as building blocks. These are referred to as the Main Computer. Typically, the Main Computer is a PC-architecture motherboard with multiprocessor features. A standard high-end computer now has the computing capacity to meet almost any demand. Add-on boards are available for expansion and connection to the distributed I/O. The boards are equipped with floating-point digital processors (DSPs), which are typically used for signal processing, fast calculation and firing pulse decoding.

A DEC Alpha workstation equipped with the PSCAD/EMTDC program has served as the simulator for the study. PSCAD is a powerful graphical user interface, used for running the EMTDC electromagnetic transient program on a workstation. It substantially increases productivity in simulation undertakings. EMTDC is a program designed to aid engineers in the study of complex power systems. The strength of EMTDC lies in its ability to model virtually any conceivable power system. The user is provided with an extensive library of power system component models. Users may also choose to develop their own unique models for use with EMTDC. ABB uses a custom model as the base for the Control and Protection System in the plant version. For more detailed information on PSCAD/EMTDC, see [1].

III. MODEL USED

The model used for the SwePol Link is shown in fig. 1. Included in the setup are the equivalents for the Swedish and Polish AC systems. The equivalent on the Polish side consisted of four machines with exciters and governors, five buses and six AC lines. The transmission line model, where the conductor placement and tower configuration is modeled, was used for the

AC lines close to the converter station. On the Swedish side, the model consisted of four machines with exciters and governors, six buses and six AC lines. The Bergeron model was used for the AC lines close to the converter station. The setup of the HVDC cable link consisted of the AC filters, converter transformer, valve representation, smoothing reactors, cable model, etc. The cable model is made up of p-links. Furthermore, the control and protection system—the most essential system for performance—was included in the setup.

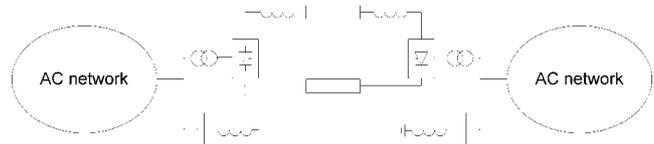


Fig. 1. Model used

To perform the study in a relevant and correct manner, one must ensure that all included models have been validated. The PSCAD/EMTDC program offers a complete package of validated models for the main circuit. For the control system used with PSCAD/EMTDC, the software is identical to the software used in the plant. All source files are programmed in the graphical language HIDRAW. The graphical files are transferred to PSCAD/EMTDC directly. This means that the source files are the same as for the plant. When a modification is made to the DPS set-up, the modification will be consequently applied to the Factory System Test (FST). Because of this, there is never any question of whether the control system software used in the study is identical to that used in the plant version. See fig. 2.

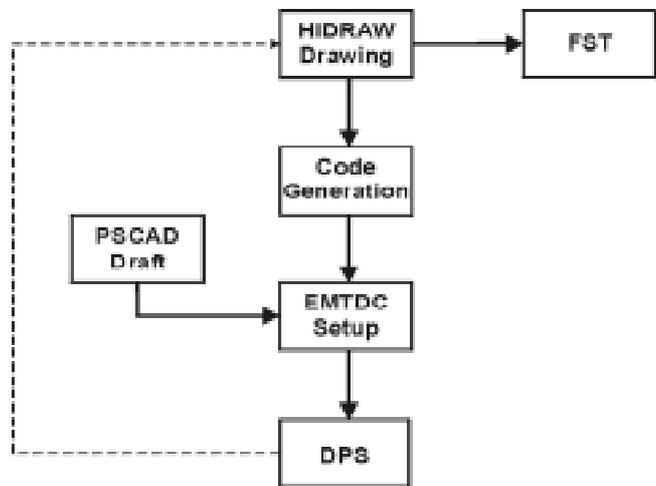


Fig. 2. Code Generation

IV. DPS STUDIES

The digital DPS is divided into two studies of converter performance. In the first study, the frequency domain response of the converter is measured; while in the second, the transient response in the time domain is measured. This is just like the conventional DPS on an analogue simulator.

Frequency domain response is demonstrated with polar plots, allowing gain and phase margin measurements to be made for determining Nyquist stability. The frequency response measurements are made at the rectifier, as this is the current controlling station and is therefore of most relevance. The rectifier's DC

current order is modulated and the current response is measured. By recording the modulating frequency and magnitude together with the current response, it is possible to plot one point on a polar plot. Once measurements are made at several frequencies, it is possible to draw a complete polar plot. See fig. 3.

There are two methods available for gathering data at several frequencies. The first method uses a constant modulating frequency, and after steady state has been reached, a measurement is made. This entails making a large number of computer runs, each with a different modulating frequency. This task is made easier with a PSCAD feature called Multiple Runs. With Multiple Runs, a number of runs can be made with different values for one or more variables. Unfortunately, this feature cannot be utilized on the DEC Alpha workstation presently used. The reason for this is that Multiple Runs always causes a core dump after three runs—a problem that is known but not yet solved. The second method involves one long run over several hundred seconds. In this case, the modulating frequency is slowly and continuously increased over the frequency band of interest. It is important that the sweep is slow enough to ensure steady state operation at all frequencies. It is this method that has been adopted by ABB. As a check, it is possible to compare the results of frequency sweeps of increasing frequency with those of decreasing frequency. Results that differ are caused by a sweep being made too quickly.

Time domain response demonstrates transient behavior and is used for check of step response and various AC faults. Typical fault cases include single and three-phase AC faults with either low (<5%) or high (80%) remaining voltage. Fault duration can be added as a variable, along with auto reclosure or permanent disconnection of a plant component. This, together with varied AC configurations, leads to a large number of possible cases to be studied. With experience, we can decrease the number of cases to create a workable number of time domain simulations. A typical number of cases would be 90. Each case needs to be run with fault inception at different points on a half-cycle of AC voltage. This makes for a large number of time domain simulations.

Because the time domain simulations are relatively short, the action of the governor can be ignored and the machines run on constant torque. This decreases the time required to reach steady state and allows the fault cases to be run much more quickly.

Three hours is required to set-up the machines for the desired steady state. After this, a “snapshot” is taken that is used in starting the simulation. With the snapshot saved, the case can be run at any time in the future with a minimum of set-up time.

The study was performed on a DEC Alpha 433 MHz workstation. With this machine, a one second simulation is accomplished within 2.5 minutes.

V. RESULTS

Some results from cases run for the Sweden-Poland HVDC cable project are presented here. There are two time domain plots and one polar plot. The polar plot is shown in Fig. 3, and the time plots are shown in Fig. 4 and 5. The two time domain plots show a single-phase and three-phase fault at the rectifier. Adjustment of converter firing controls permits fast and stable operation to be achieved. Power transfer is restored rapidly, re-

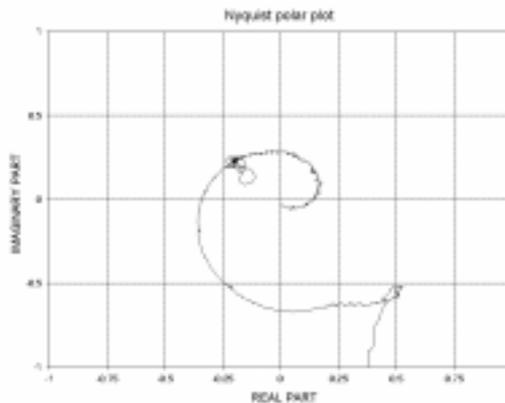


Fig. 3. Nyquist Diagram

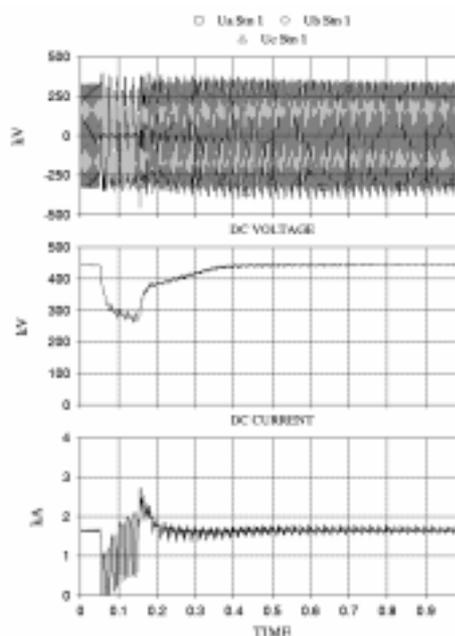


Fig. 4. Single-phase to ground fault in the rectifier

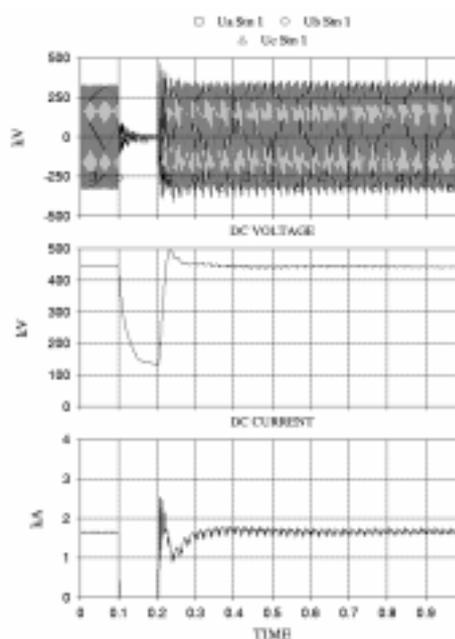


Fig. 5. Three-phase to ground fault in the rectifier

sulting in a minimum of energy unbalance in both countries.

Similar cases have been simulated for various faults, such as with and without successful reclosure of AC lines, and with different configurations. Overall system performance demonstrate quick and stable recoveries.

VI. SOFTWARE AUTHENTICITY

It is necessary to use the same code in the DPS as in the HVDC controls for the FST. Not using the same code could result in errors. Mistakes could be made when transferring settings (settings used to generate code for the HVDC controls) from the DPS to the HIDRAW drawings. Mistakes could also be made when determining the representation of the controls. The programming language used in ABB HVDC controls is C. To ensure that the DPS is performed with the same code as the delivered plant, the DPS uses the same C code. It has been possible to integrate C code with the Fortran code normally used with EMTDC. This is one of the more important authenticity requirements that ABB has followed.

VII. DEBUGGER

In conjunction with the use of C code in the DPS, ABB has developed a graphical online debugger that allows any variable in C code to be monitored. Selection of variables can be made on the fly. There is no requirement for specifying selected variables before a run is begun, or for modifying a variable list in a file. This allows detailed analysis during a fault. It is advantageous that EMTDC does not run in real-time and that a run can be paused at any point. Because of these characteristics, there is time for detailed fault/debug analysis. With a digital system, it is very easy to rerun any fault case and examine software variables that might have been missed.

VIII. FUTURE DEVELOPMENT

The DPS was successfully performed on the fully digital simulator, PSCAD/EMTDC. However, a few things could be improved. One of these is the speed of the workstation/computers. The size of the network and the cycle time are the two most critical parameters in determining the execution time for a case. Looking at present computer development, we see that this enhancement is already on the way. Furthermore, the availability of PSCAD/EMTDC on the PC platform, i.e. Version 3, will make it easier to distribute the program and models to other users.

Much time is spent in achieving the desired steady state load flow. Because of this, it would be a considerable advantage if a load flow part was added, so that all regulators can be set to the correct value. Furthermore, Nyquist diagram testing is very time consuming. We believe there are ways of performing this more efficiently than those we employed in our study.

With the development of PSCAD/EMTDC for NT, it is now

feasible to run cases with PSCAD/EMTDC anywhere in the world—even during the commissioning of an HVDC plant. There are also very good graphical compilers/debuggers available on the personal computer platform. It is possible to set watches and follow variables, or to create log files without having to be present at all times. Once again, this enhances the possibilities for following software execution in detail.

IX. CONCLUSION

The Dynamic Performance Study for the SwePol link has been successfully performed using a fully digital simulator. The PSCAD/EMTDC program has shown to be a reliable and useful tool in the design of an HVDC system. This technology will benefit from the rapid development in the computer industry. There is no need for a large analog simulator in performing Dynamic Performance Studies. Using this fully digital simulator tool, i.e. the PSCAD/EMTDC program, the study can be setup anywhere in the world. Models used could be distributed to clients for further investigation of specific projects.

X. REFERENCES

- [1] Nayak O., Irwin G., Neufeld A. "GUI Enhances Electromagnetic Transient Simulation Tools." *IEEE Computer Applications in Power*, January 1995, pp. 17-22.
- [2] Lagerkvist M., Tulkiewics T. "Validation of EMTDC for HVDC Dynamic Performance Studies." *ICDS 97*.

XI. BIOGRAPHIES

Björn Ekehov was born in Gävle, Sweden on September 28, 1958. He received his master's degree in electrical engineering from the Institute of Technology in Lund, Sweden in 1983. He joined ASEA as a trainee the same year and started at the HVDC Division in 1984. Mr. Ekehov is the System Simulation Department Manager at ABB Power Systems.

David Shearer was born in Auckland, New Zealand on March 23, 1963. He received his bachelor's degree in electrical engineering (with honors) from the University of Auckland in 1986. After working for the Ministry of Energy in New Zealand, he joined ABB in 1993. He is presently working at the System Simulation Department at ABB Power Systems.

Lars-Ove Ellus was born in Sweden in 1952. He received his bachelor's degree in electrical engineering in 1972. In 1975, he studied physics at the Technical Institute of Linköping. From 1985 to 1988, Mr. Ellus studied electrical engineering at the Technical Institute of Västerås and the Royal Institute of Technology, Stockholm. He has been employed at Vattenfall and at its subsidiary companies since 1975. He presently works at SwedPower, dealing with network analyses and planning, with an emphasis on investigations of dynamic and transient performance.