SOPHISTICATED REAL-TIME TESTS ON PROTECTION RELAYS AND TURBINE CONTROLLERS WITH DINEMO-II AND PSS™NETOMAC

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Abstract

The DINEMO-II (Digital Network Model) is an intelligent signal treating device that works as a real-time transceiver between protection relays or turbine controllers and simulation programs for electrical power systems like PSS™NETOMAC, running on a standard Windows-PC. DINEMO-II allows real-time simulation with up to 16 in PSS™NETOMAC continuously calculated analog output signals and the treatment of four analog or sixteen digital feed back signals of the equipment under test, thus allowing a closed-loop interaction between protection relays or controllers and the simulation program. This reaction in real-time with round-trip times of up to 0.15 ms, depending on the network traffic, is possible using PSS™NETOMAC with its high speed calculation algorithms together with Dual Core CPUs under Win XP. DINEMO-II is used for tests with analog controllers with input voltages of max. ±10 V and with frequencies of up to 5 kHz. With additional power amplifiers close-to-reality tests can be accomplished with standard protection relays. The test networks can be easily designed using the graphical editor Netdraw which comes with PSS™NETOMAC. This allows to make extensive tests on protection relay configurations using detailed models of all network elements.

Keywords: DINEMO-II, PSS™NETOMAC, Power System Simulation, Protection Relays, Real-time Tests

Presenting Author's biography

Georg Duschl-Graw was born in 1959 in Backnang, Germany. He studied Electrical Engineering in Stuttgart and Berlin, where he got his diploma and in 1992 his PhD. He works with SIEMENS since 2002 and is Professor for Electrical Machines and Renewable Energies at the University for applied Sciences TFH Berlin since 2007.

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1 Introduction

The DINEMO-II (Digital Network Model) [1],[2] is an intelligent signal treating device (see Fig. 1) that works as a real-time transceiver between protection relays or analog controllers and test or simulation programs like PSS^{TM}NETOMAC (Network Torsion Machine Control) [3], [4], running in real-time on standard Windows-PCs with Dual-Core CPUs. With the possibility to output dynamic process signals (e.g. instantaneous voltage values), the DINEMO-II sets new criteria on testing protection and control equipment in power systems. The real-time communication with the DINEMO-II is realized with a normal Ethernet connection with standard Ethernet cards using a special protocol.

The DINEMO-II allows with its incorporated micro-controller (Intel Xscale) the time-synchronized real-time output of up to 16 actually calculated or pre-stored current and voltage curves from a test or simulation program and the treatment of the feedback (4 analog or 16 digital signals) of protection or control equipment in real-time, thus allowing a closed-loop interaction between external hardware and the simulation program. This reaction in real-time with round-trip times of up to 0.15 ms (depending on the complexity of the simulated network) is made possible by means of standard Windows computers (PC from 1.6 GHz Dual Core) and powerful simulation programs like PSS^{TM}NETOMAC. For closed loop operation of the DINEMO-II this Power System Simulation Program of the SIEMENS company is the recommended simulation software. Its high speed calculation algorithms and its implemented software interface allow to directly control the DINEMO-II.

The DINEMO-II can be used without external power amplifiers for tests on analog controllers with DC-input voltages of max. ±10 V. For the testing of standard protection relays with standard input voltages of ±100 V rms and nominal current ranges of ±5 A rms or ±1 A rms the signals of the DINEMO-II must be amplified. This is done using external power amplifiers like the OMICRON CMS156 [5] which is the recommended hardware for this purpose.

DINEMO-II can be controlled with the software program DINEMO which runs on a windows PC with an Ethernet connection. The DINEMO software can be used as a multi-channel programmable curve form generator. But it can also output pre-calculated or measured data, like fault recordings of protection relays to the hardware under test. The special converter program Aladin transfers input data files, available as ASCII or Comtrade file to a specific file format, which is used for the communication with the DINEMO-II. This allows the user to produce his own curves to output them through the DINEMO-II or to use curves of fault currents and voltages, which have been previously recorded from e.g. protection relays.

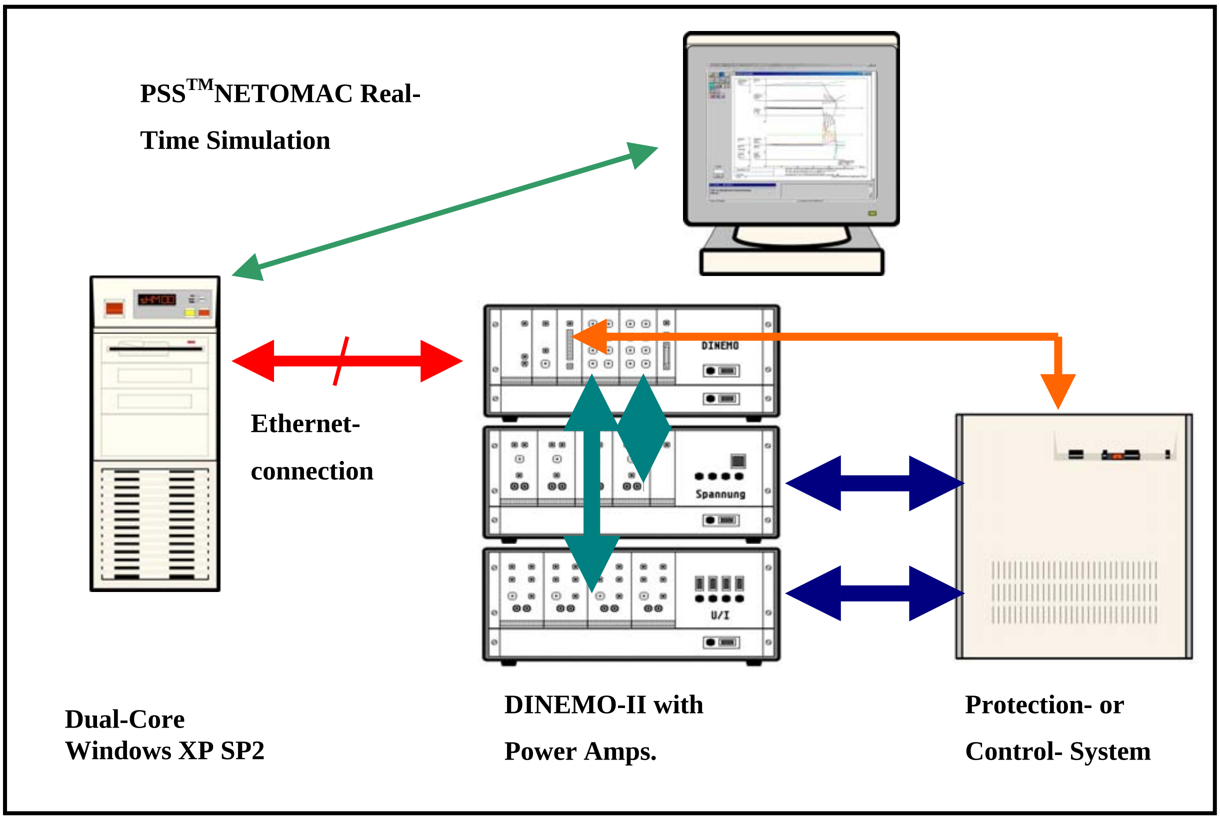

Fig. 1: The DINEMO-II with hardware under test.

2 Brief Description of the Hardware

The complete DINEMO-II test system with high-voltage and high current outputs (e.g. necessary for tests on protection relays) consists of the following devices:

- The DINEMO-II basic device with optional Input and Output modules
- External voltage and current amplifiers (e.g. OMICRON)
- Dual-Core PC with Windows XP
- PSS™NETOMAC or PSS™NETOMAC light

The DINEMO-II basic device with its optically isolated digital input interface is shown in Fig. 2.

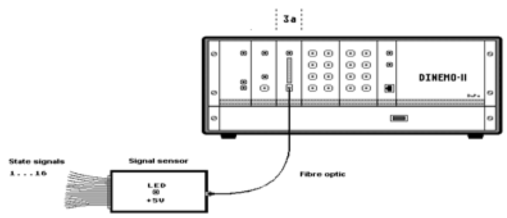

Fig. 2: DINEMO-II basic device

The basic device consists of a 19” rack with different electronic modules, which can partly be used optionally. Up to 16 BNC or four LEMO sockets are used to connect external power amplifier or directly controllers under test to the DINEMO-II and either the 16 digital inputs or 4 analog inputs are available for the feedback signals. The DINEMO-II can be connected to a single PC or to an Ethernet cluster using a standard 100 Mbit Ethernet card and it can receive its IP-address from a DHCP server.

3 Theory of Operation

DINEMO-II is an intelligent measurement system with an Ethernet transceiver which acts as a server in a local network. DINEMO-II listens on the Ethernet and communicates with a PC client who asked for the DINEMO service. During an initialisation procedure the PC client informs the DINEMO-II about the desired step rate and the input and output channel configuration for the simulation run. The DINEMO-II is then waiting for a start signal together with the first data set to be output to the equipment under test. The simulation software on the PC sends then the first set of data to the DINEMO and waits for the digital or analog feedback. From this time on the real-time master clock for the simulation run comes from the DINEMO-II, which controls with a precise internal clock generator the simulation step rate. DINEMO-II transfers the data from the PC as analog voltages to the external hardware and reads the feedback. The feedback signals are then transferred to the simulation PC within the same time step. The simulation program on the PC can then with or without using the received data (closed or open loop mode) calculate the next set of data and send it to the DINEMO-II.

The real-time control of the simulation run and the time-step monitoring is done by the DINEMO-II. If there is for any reason a communication error or a time-step loss, the DINEMO-II informs the simulation program and resets the hardware if necessary.

Figure 3 shows a sine signal which has been built using data which has been continuously calculated on the PC and than sent to the DINEMO-II. The step rate for the data output was exactly 1 ms and one time period of the 50 Hz sinus signal is constructed using 20 input data samples. Guidelines for protection relays of the German VDN [6] prescribe a sampling rate of 1000 cycles per seconds for the fault recording of protection relays and this step rate is accurate enough for many applications. But today sample rate for protection relays has increased and some manufacturer (like ABB) deliver line protection relays with sample rates of up to 4000/s. DINEMO-II allows to perform step rates of up to 0.15 ms in real-time (see Fig. 4) and can therefore be used for a wide range of tests on line protection relays and turbine controllers.

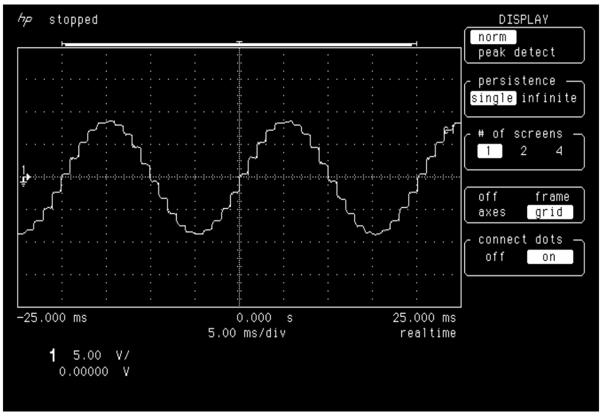

Fig. 3: Synthetically produced sine signal with a step rate of 1 ms.

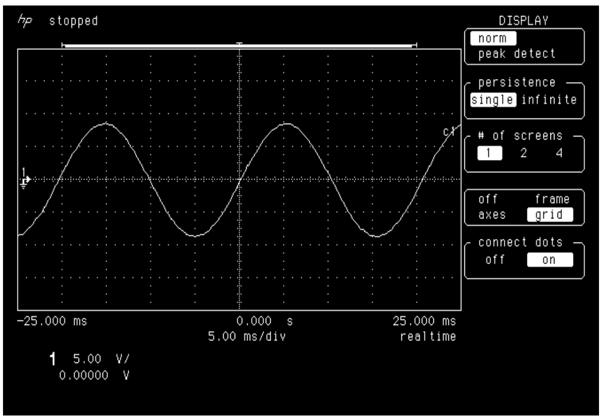

Fig. 4: Synthetically produced sine signal with a step rate of 0.2 ms.

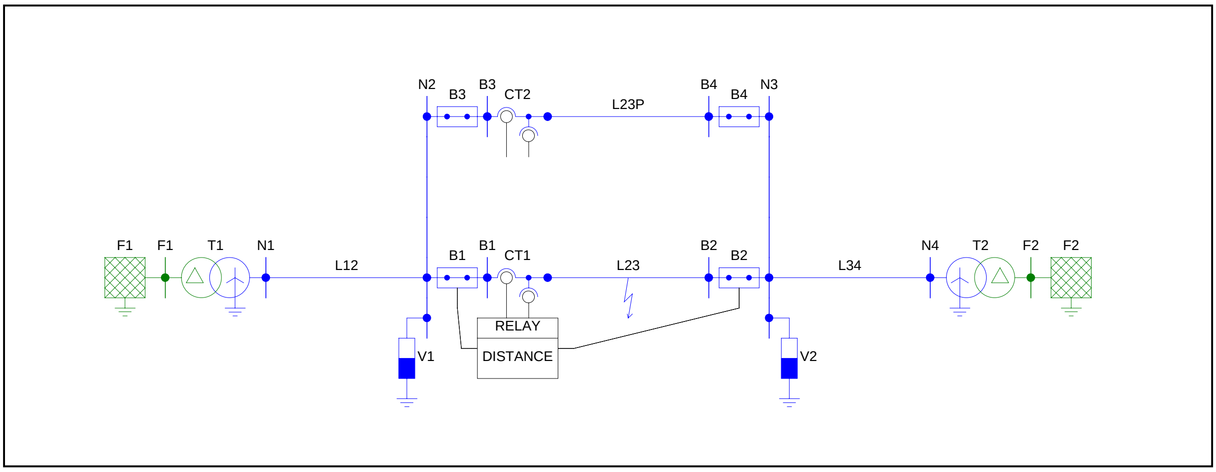

Fig. 5: Basic test of a distance protection relay

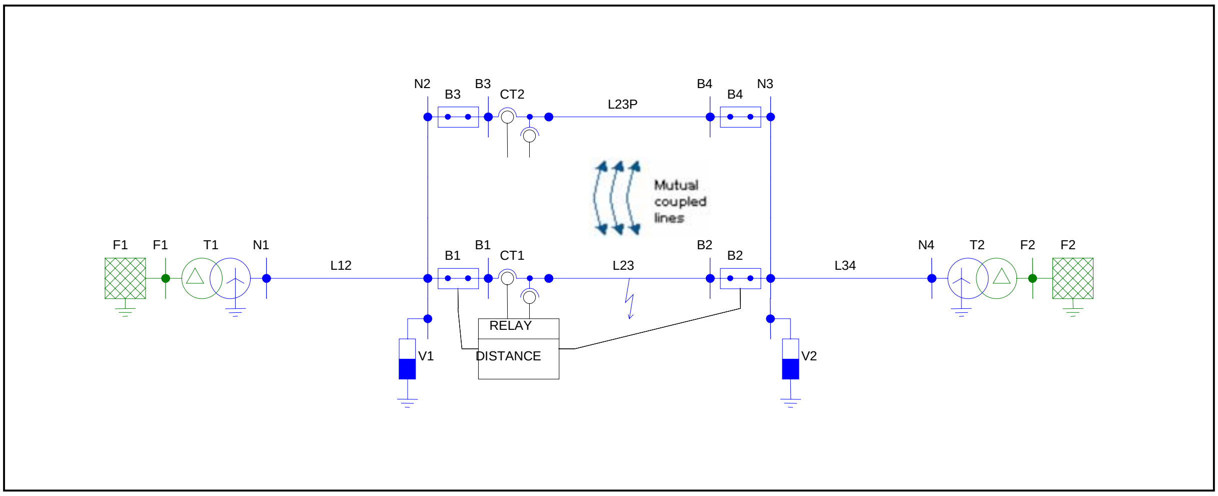

Fig. 6: Network for tests of distance protection relays with parallel mutual coupled systems

4 Test of a Distance Protection Relay

A standard test for distance protection relays is a single fault on a line. As a test example a small network with a 400 kV double circuit line L23, L23P for simulation with PSS™NETOMAC is drawn with Netdraw (see Fig. 5). A single phase fault is simulated at the end of line L23 near node B2 (from km 43 to km 50), expecting a trip of the protection relay in its 2nd zone with a pre-set time delay (here:0.3 s). Two different cases have been simulated for this example.

Case 1: Simulation of the network with neglect of the coupling of the lines L23 and L23P (Fig. 5). The distance to fault is varied from km 43 to km 50 (end of line) in steps of 1 km. The measured distance to the fault is recorded.

Figure 7 shows the fault recording of the distance protection relay with a distance to fault of 45 km. The trip signal is coming in 2nd zone as expected. The switching-off of the fault current takes place at the zero-crossing of the current with respect to the time delay of the circuit-breakers of 0.05 s.

Case 2: Simulation of the network including the ohmic-inductive and capacitive coupling of the double circuit line L23, L23P (see Fig. 6). Again the distance to fault is varied from km 43 to km 50 (end of line) in steps of 1 km and the measured distance to fault is recorded.

Figure 8 shows the measured distances to fault for both test cases. It is evident that the mutual coupling of both lines enlarges the measured distance in comparison to the real distance to fault. This may lead to problems in the fault detection. Modern state-of-the-art protection relays therefore offer a parallel line compensation using the neutral current of the parallel system as an additional input signal.

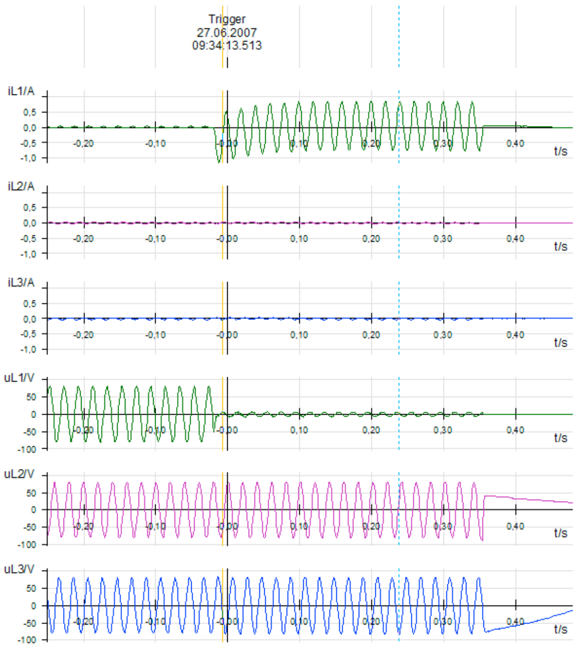

Fig. 7: Fault recording of the distance protection relay of a single-phase short circuit with a distance to fault of 45 km with delayed trip in the 2nd zone

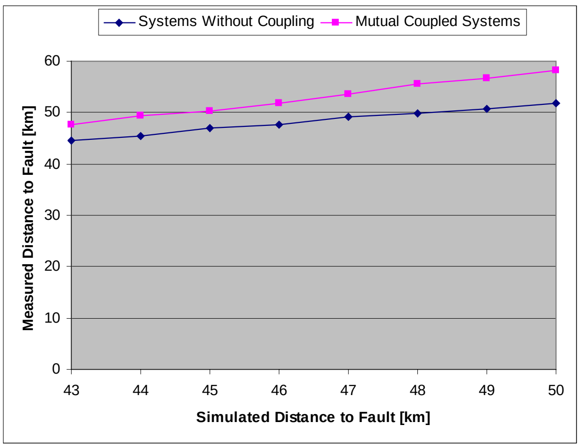

Fig. 8: Comparison of measured distances to fault for both test cases

5 Tests with 3 Differential Relays

In combination with three OMICRON amplifiers the DINEMO-II can be used to carry out tests on lines with three ends using three differential relays as shown in Fig. 9.

The connection of the power amplifiers to the DINEMO-II can be seen in Fig. 10.

For the test of the three differential protection relays a single-phase short circuit on line L1 is simulated. The simulation results of the primary currents of the three current transformers are shown in Fig 11. It is clearly visible in Fig. 11 that the switch-off of all three ends of the line with three ends (L1, L2, L3) was correctly carried out by the differential relays.

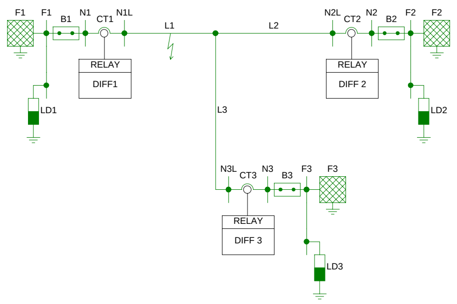

Fig. 9: Test on a line with three ends using three differential relays

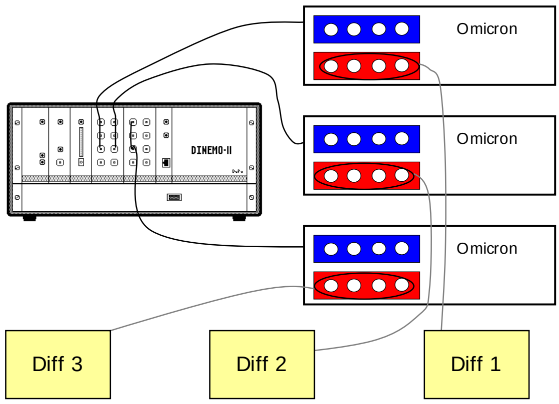

Fig. 10: Connection of three differential relays to the DINEMO-II

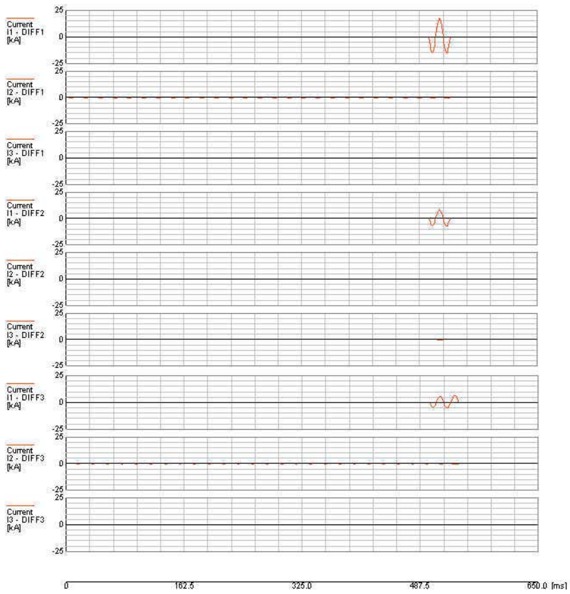

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Fig. 11: Simulation result of a single-phase short circuit on line L1 of the line with three ends showing the primary currents of the three current transformers

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6 Test of an External Machine Controller

For tests on an external machine controller which consists of an exciter (AVR) and a governor (GOV) an example network as shown in Fig. 12 has been prepared. Generator G1 is disconnected from the network and will be synchronised during the running simulation by setting the drive power and the terminal voltage using a real controller in hardware which is connected to the DINEMO-II and which incorporates also the control of the generator breaker B1.

Case 1: Drive power and terminal voltage have been set to proper values using the external controller. That means that there are only small differences in voltage magnitude, angle and frequency on both sides of the generator breaker B1. After B1 is closed only small transient reactions can be observed in the real-time simulation (Fig. 13).

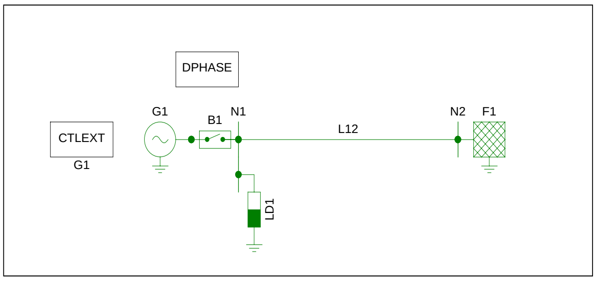

Fig. 12: Test of a machine controller

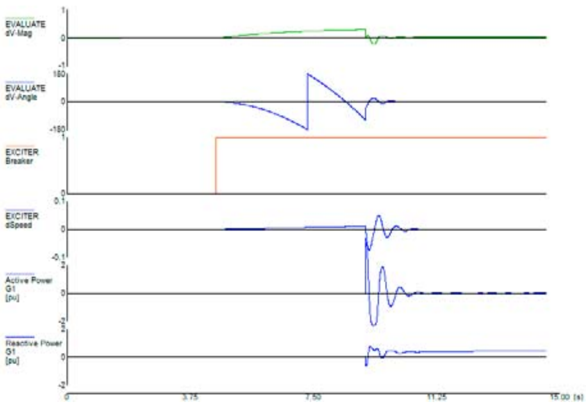

Fig. 13: Closing of the generator breaker after having synchronised the generator with the hardware controller

Case 2: Drive power and terminal voltage magnitude have been set to proper values, but between the voltages on the two sides of the generator breaker B1 there is a phase angle of about 180 degrees. After closing of B1 large transient reactions can be observed (Fig. 14).

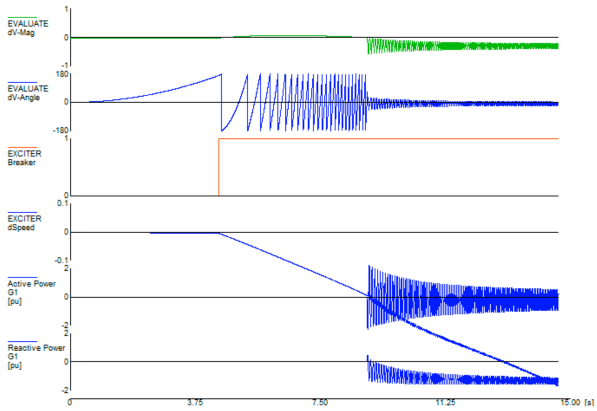

Fig. 14: Connecting the unsynchronised machine

7 Conclusions

The results show, that the DINEMO-II in combination with PSS™NETOMAC and Netdraw is very useful to carry out realistic dynamic simulations of networks. The system enables the user to validate the proper function of protection relays in relatively complex networks also for situations with complicate disturbances in a very short time.

Machine controllers can be tested under real working conditions and the controller behaviour can be monitored on the screen in real-time. This allows to adapt the parameters of a machine controller fast and easy to a given system.

8 References

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