Remote Controlled Testing of Communication Schemes for Power System Protection Using Satellite (GPS) Synchronization and Modern Communication Technology: A New Approach

Author: Dipl. ing. Zeljko Schreiner OMICRON electronics GMBH, Austria

Co-Author: Reinhard Kuntner OMICRON electronics GMBH, Austria

1 Introduction

Protective Relay Schemes (Systems) are becoming more and more complex. Requirements to keep the supply of electrical energy safer, more reliable, and more economical bring additional importance to the Power System Protection Testing.
Development of modern communication technology and the need to selectively switch line faults in the shortest time have inspired Power System Protection Communication Schemes for:

- Current Differential
- Phase Comparison
- Distance Protection Communication based Protection

Communication based power protection schemes use some communication carrier to connect the protection devices. Such protection schemes serve to detect and to selectively switch off the faults in the shortest time. The entire functionality of such protection schemes are dependent on the protective relays (on both line ends) and on the communication carrier. Testing of such protective schemes is not simple. It requires two testing teams using sophisticated testing equipment that provide highly accurate synchronization and specially developed testing software.

2 Description of the Current Testing Method

Testing of the communication based power protection schemes has required the use of two test sets, one on each line end, which is named End-To-End Testing. These two test sets have to be synchronized to simulate real fault conditions on the line.

To synchronize testing start time of the two devices, the following technical solutions have been employed:

- Connecting the two test units via pilot wire; this is possible only for short distances.
- Synchronizing with the power system (accuracy 1ms and error 18° on 50 Hz)
- Synchronizing with special fiber synchronization link; this is a very good solution available in Japan but it is only possible with specially developed protection relays.
- Synchronizing using GPS satellite system; this is presently the most common method used.

The GPS-Global Positioning System consists of twenty-eight satellites, which were launched by the US Department of Defense primarily to provide a high accuracy navigation aid for both military and civilian purposes. Twenty-four satellites are in operation at all times. Four satellites are available for back up. Each satellite has a highly accurate atomic clock on board. This clock transmits a synchronized time code to earth, which contains the accurate time and the almanac of the satellite (such as information about the satellite’s orbit, or its position with respect to time). If a GPS receiver locks on four satellites, the propagation time is a direct measure of the distance between the GPS receiver and each of the satellites. The accurate time can be calculated by using the surveying principle with four equations and four unknowns and the accurate position in three dimensions. Accuracy of the time is 100 ns if 4 satellites are tracked; or if one satellite is tracked, the actual position of the GPS receiver is known within 25 m.

To be able to use the time signal for synchronization purposes, the GPS clock is needed and it provides a number of timing signals which include IRIG-B, 1 pulse per second, 1 pulse per minute (PPM) and programmable pulse signal. These signals are available in a TTL type output on most modern GPS clocks.

In particular, the latter two signals can be used to synchronize to the nearest 100 ns test equipment at any two locations around the world .

Synchronization accuracy is very important. Synchronization error of 1 ms at 50 Hz produces an 18° error between two current vectors at about 22° at 60 Hz. For successful end-to-end testing, synchronization has to be better then 10 μs, which produces a phase error of 0.18°. The best testing equipment in the world today can achieve a synchronization accuracy of 1 μs, which is more than adequate to test even travelling wave relays at an 0.018° phase error.

End-to-end testing of communication based protective relay schemes using GPS-satellite synchronization of the testing devices were evaluated by several companies in 1994 and 1995.

This testing methodology is suitable to verify the function of the communication link between protective schemes and simultaneously to verify protective relay functions.

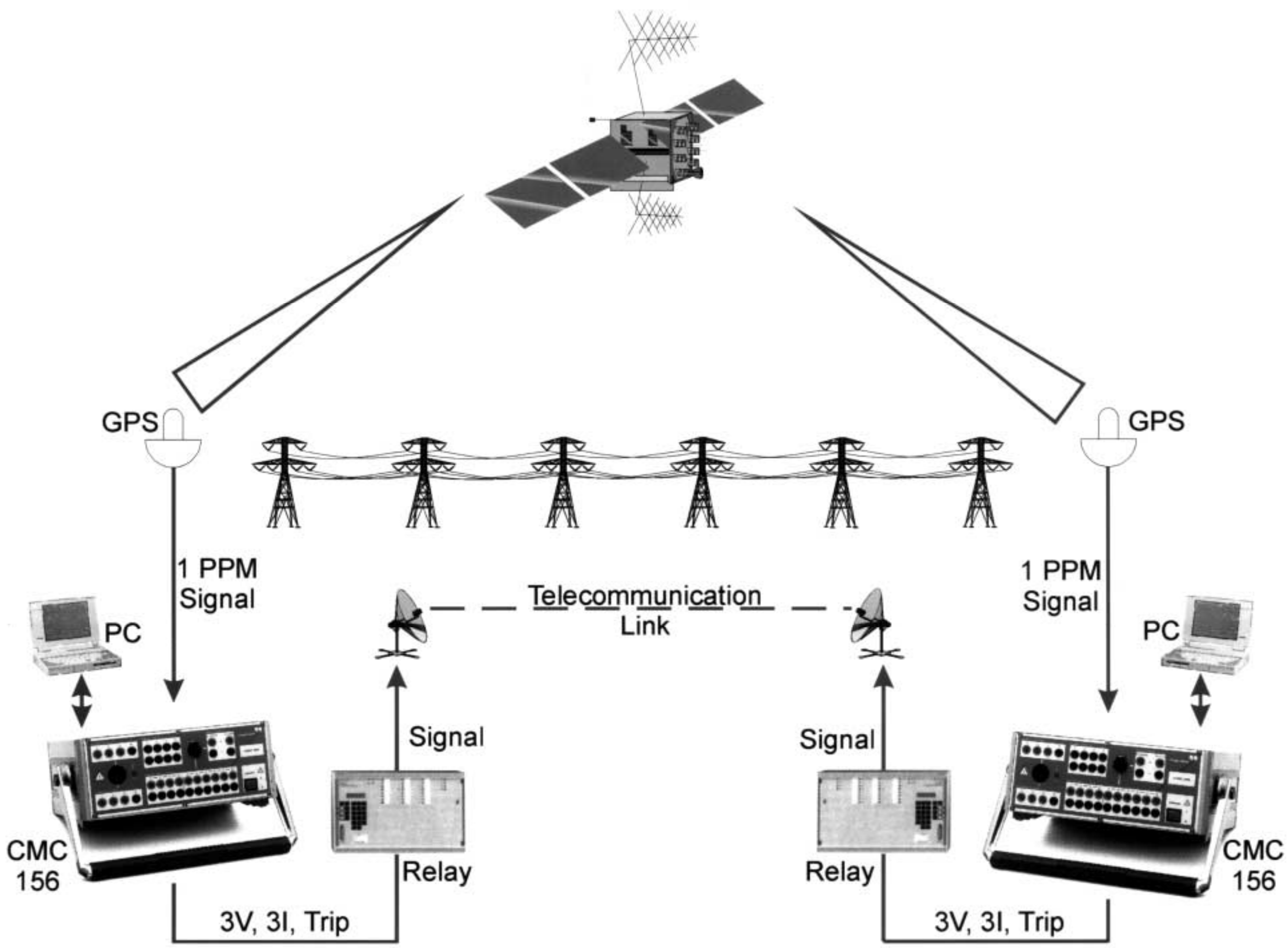


Figure 1 - Testing of the Communication-based Power System Protection Schemes using GPS satellite system for the test synchronization.

Standard end-to-end testing methods use the following equipment on each side of the transmission line:

- Protection relay test equipment (Signal generators 3xI , 3xU suitable to replay fault simulation)
- GPS-satellite receiver for the time synchronization of the two test devices
- Fault simulation can use one of the following sources:
  –EMTP Electromagnetic Transient Program
  –Real Transient Files recorded by Disturbance Recorders (IEEE standard COMTRADE files)
  –Steady-State voltage and current test sequences for evaluation of the setting thresholds
  –Special application testing software
- 2-3 test engineers on each side are needed for performing the test.

The end-to-end test flow can be specified as follows for each substation:

1. Preparation of the test sequences
2. Connecting the test equipment to the test objects (Protecting relays).
3. Connecting the GPS receiver and locking them to the appropriate number of satellites.
4. Preparing the test software for starting the test.
5. Coordinating with the testing team on the other side (i.e., telephone) regarding the starting time, and the locking of the GPS receiver.
6. Coordinating with the other side about starting the first test sequence.
7. Starting the first sequence and waiting for the satellite trigger.
8. Coordinating with the other side regarding a successful start.
9. After the first test sequence is finished, coordinate with the other side regarding the results of the test and eventually the arrangements about editing of the test sequence (for example, correction of the nominal time).
10. Communicate with the other team, before and after each test sequence, about the test flow. Sometimes the test teams use permanent communication.

3 Problems with the End-To-End Testing Methods

The end-to-end testing methodology described in the earlier sections was established several years ago and is suitable for verifying the whole communication scheme and the behavior of the power system protection at the same time. This methodology is an accurate simulation of the real fault condition and is a proven way to test the communication based protection schemes.

An actual application of this methodology brought several problems to light. The difficulties many protections engineers worldwide encountered were:

1. Time consuming (Testing of an overhead line or a cable protection system with teleprotection requires one day).
2. Expensive (high personnel and equipment costs)
3. Complicated testing control (coordinating two teams at two substations)
4. Complicated testing procedures
5. Lack of fully automatic test procedures
6. No direct communication between the GPS receiver and the protection test equipment (synchronization is not part of the test procedure)
7. It is complicated to edit test procedures onsite (Two PC's and two protection engineers in two substations)
8. The supervision and the full evaluation of the test results is possible only via direct communication (e.g., telephone) between the test teams (verbal communication after each test step and synchronizing the test results
9. Complicated canceling and repeating of the testing procedure
10. The major influence of the synchronization accuracy on the fault current error

Because of all the described problems and difficulties, end-to-end testing methodologies have not become the standard routine of today. Many electrical utilities avoid this type of testing and the eventual separate testing of the communications device; they try to satisfy testing standards with the classical one-side protection tests. The results of such testing are only partial and cannot be used for the verification of the whole power protection system. The trip time and the selectivity can be evaluated only with a real simulation.

4 Description of the Practical Problem

VEW Energie AG, which is a German utility located in the Ruhr area, wished to reconstruct protection on the 380 kV overhead line Uentrop-Nahden (approximately 120-km line length). The overhead lines were equipped with old, doubled, electromechanical distance protections and autoreclosure relays as **main 1** and **main 2** protection (R3Z27 with under-impedance starting) on both sides. For the time being, the reconstruction plan was to exchange the protection of only one side against two modern digital distance relays, PD571 and 7SA513, with the Permissive-Overreach scheme. The plan to exchange only the main1 and the main2 protection on one side, to keep the old electromechanical distance protection on the other side and to use the Permissive-Overreach scheme resulted in dilemmas for the VEW protection engineers:

- What are the effects on the total trip time if the old electromechanical protection relays are in connection with the two new digital protections?
- What is the maximum needed communication time?
- Which protection setting is suitable to meet the reliability and the selectivity requirements?
- What impact does the Permissive-Overreach scheme have on reducing the trip time?
- How is this new protection system efficiently tested?

The answers to these questions are:
END-TO-END test using GPS synchronization with the test plan shown below.

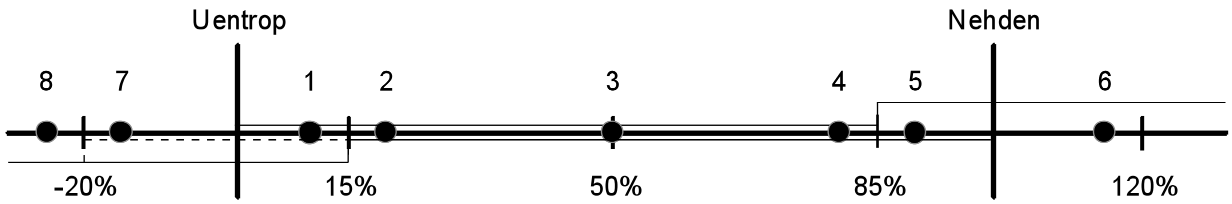


Figure 2 - Test Plan

Other solutions created the problems and difficulties described earlier. This caused the VEW protection engineers to look for the optimization and simplification of the testing method.
Co-operation between VEW Energie AG and OMICRON electronics GmbH resulted in a new approach and the simplification of the described testing method.

5 The New Testing Method

Optimizing the End-To-End testing method was a big challenge for all parties involved. At the beginning, it was important to define what was the fundamental problem of the current testing method. After detailed analysis and much research work, it became clear that there were several smaller goals that needed to be obtained. These included a reduction in the time-consuming tasks, a reduction in the total-cost, a simplification of the test procedures, a simplification of the test control, and an improvement in the synchronization accuracy.

Specifically, this resulted in:

1 Establishing the One Side Remote Controlled Testing.
–Whole test has to be controlled by one master PC that controls the slave PC on the another side.

2 Increasing the synchronization accuracy and simplifying the whole testing procedure.
–A highly accurate GPS satellite receiver specifically developed for the protection testing applications integrated within the test procedure and coupled with the testing software.

3 Increasing the efficiency by testing the whole system at the same time.
–A need for testing hardware suitable for simulating two three-phase systems (for the Main1 and Main2 protection at the same time)

4 Establishing a general, automatic testing procedure with the possibility of using it as a standard routine testing procedure.
–Developing only one multifunctional test procedure for either end of the lines.

5.1 Realisation

5.1.1 Establishing of the One Side Remote Control of the Test :

For this methodology, very stringent requirements were necessary:

- Commercial remote terminal emulation software based on a 32 bit Windows system
- Testing software suitable to run under this remote terminal emulation software
- Communication media accessible in the electrical substation and suitable for the high speed data transmission
- Very fast communication between the test software and the test hardware (parallel port)

Microsoft NetMeeting was found to be the best candidate for the remote communication (Remote terminal emulation).

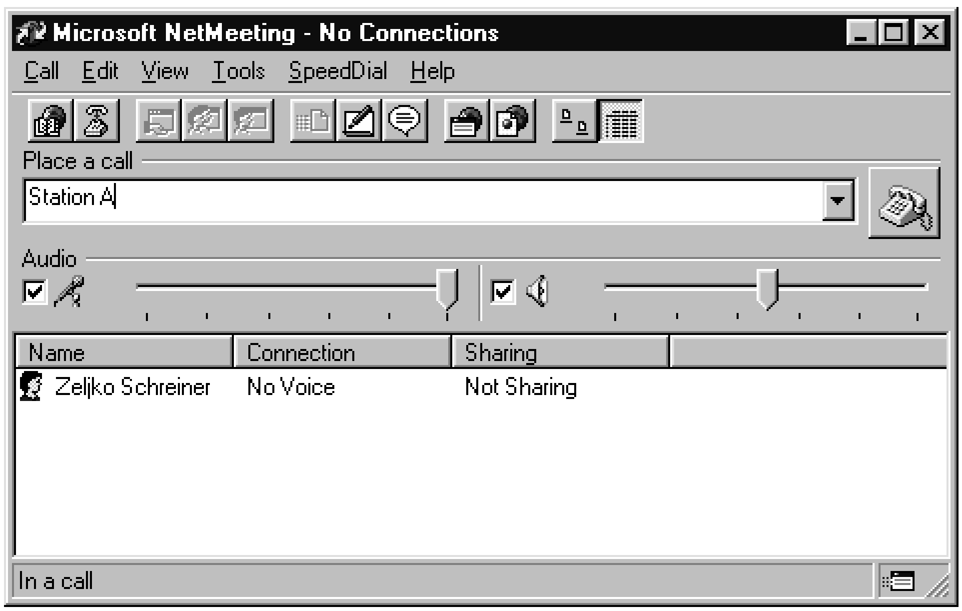


Figure 3 - Microsoft NetMeeting

This software has three advantages:

1. The software is free of charge
2. The software can use any communication between two computers with a minimum of 14400 bps (Modem, Internet, Intranet, Wire, etc.)
3. The software is simple and user-friendly

The communication had been a standard analog telephone line available in the substations. The communication was established using a PCMCIA standard modem card with up to 33 600 bps even though the telephone line allowed only 28 800 bps. It was researched also with Internet and Intranet and the results were excellent. Communication was very fast, stabile and allowed parallel voice and video communications. This will certainly be one of the future communication media available in electrical substations.
After the communication was successfully established between two computers, it was possible to run a special test module (State Sequencer) and to control testing on both sides only from the master computer (via the PCMCIA modem card).

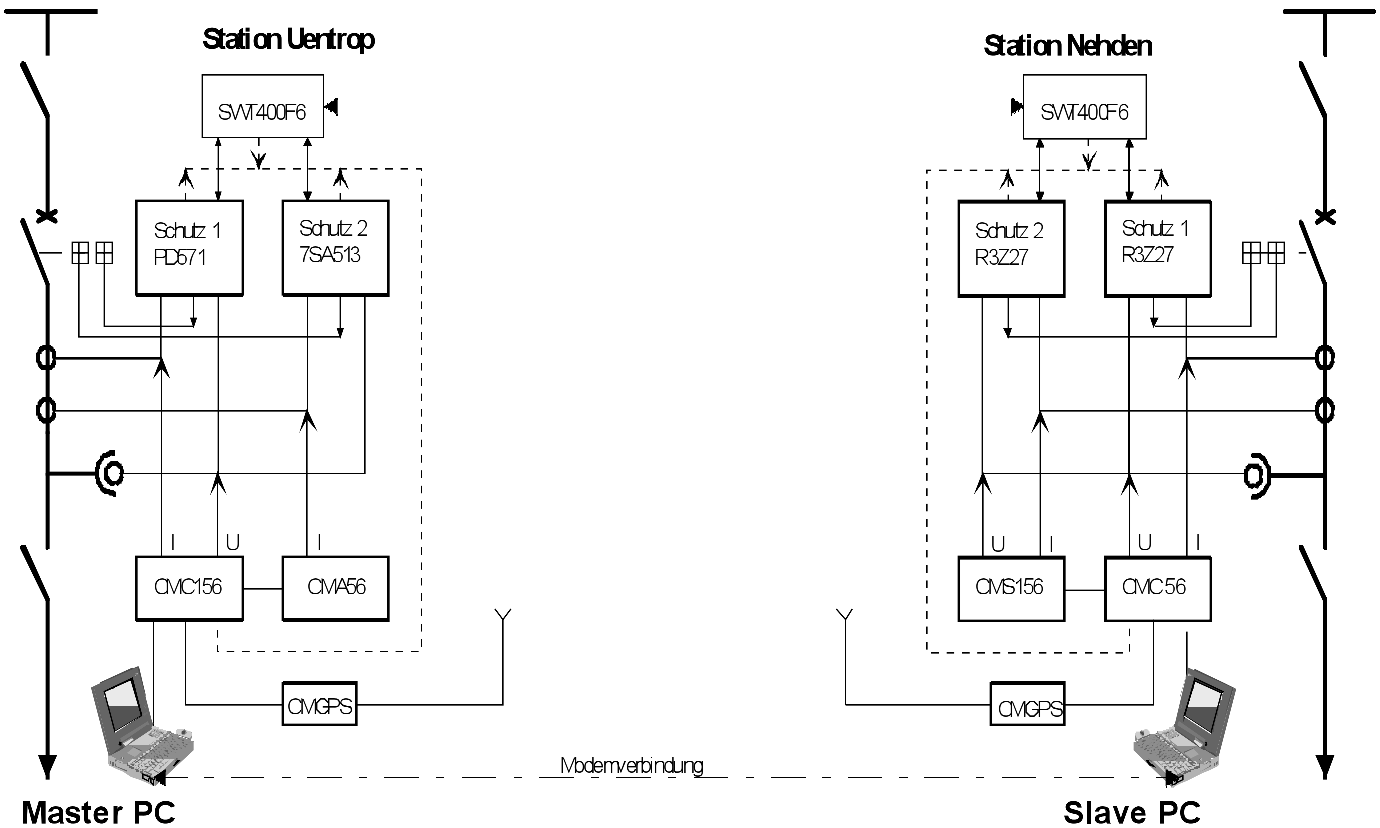


Figure 4 - New Approach to Testing

5.1.2 GPS Synchronisation

Standard methods for GPS synchronization triggering use the trigger pulse of the GPS receiver via a binary input. In this way synchronization error is about 120 µs (because of the influence of the binary inputs). Synchronization control and monitoring is only possible via control panel on the GPS receiver and there is no connection with the testing software.
To improve the synchronization process, use of the GPS receivers were necessary. This avoided synchronization through the binary input and made the synchronization parameter visible to the testing software (adapting the GPS technology to the protection testing). CMGPS was newly developed with a GPS receiver specially designed for the synchronization used in protection testing.

The accuracy problem was solved by directly connecting the GPS pulse to the DSP (digital signal processor) of the test set. This way the synchronization accuracy was improved to **< ±1µs**. The additional control and monitoring of the CMGPS, which was performed by a software that is also part of the entire testing software.

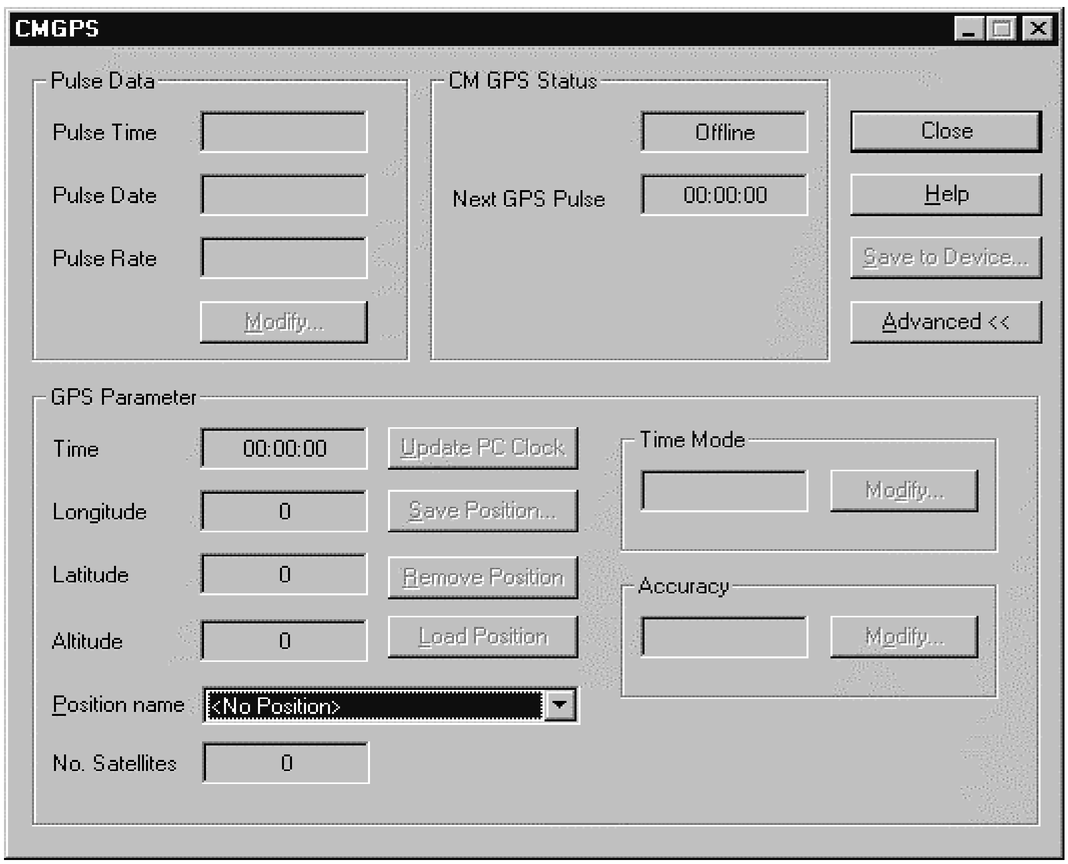


Figure 5 - CMGPS Software

5.1.3 Test Hardware

To simulate the whole power system at once, it was necessary to have six-phase voltage and six-phase currents to supply independently the Main 1 and the Main 2 protection.

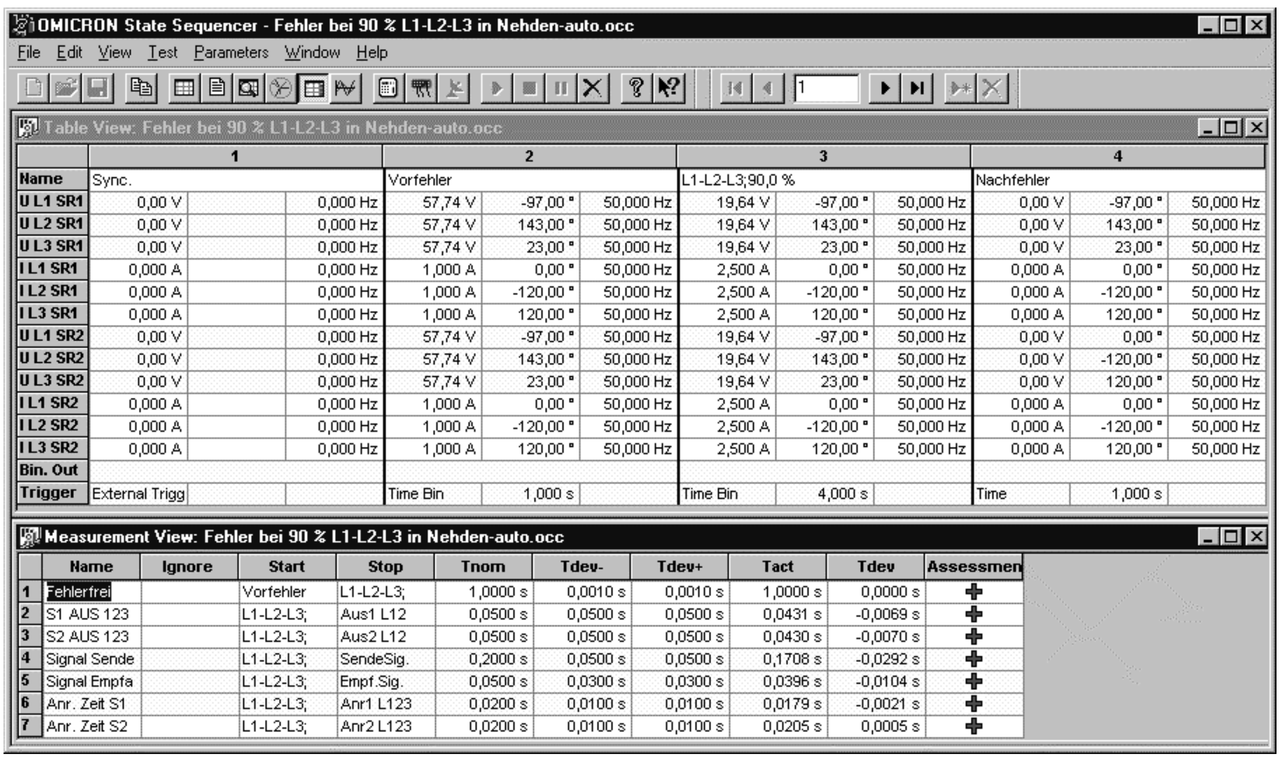
Each side used:

- CMC 156 3xI ; 3xV test set with fast parallel port PC control
- CMS 156 3xI ; 3xV amplifier
- CMGPS satellite receiver

The testing software was suitable to control the twelve generators at the same time (six from the test set and six from the amplifier). In order to generate a second circuit simulation for the Main2, an amplifier was used.

5.1.4 Testing Procedure

Each line side (substation) created automated testing procedures. According to the test plan showed in Figure 2 - Test Plan, the testing procedure had twenty-four tests (three fault types in eight points). Each test had four states (Synchronizing State (GPS), Pre-fault State, Fault State and Post-fault State). See Figure 6 - Test sequences: Synchronizing, prefault, fault, postfault.



	1			2			3			4		
Name	Sync.			Vorfehler			L1-L2-L3;90,0 %			Nachfehler		
U L1 SR1	0,00 V		0,000 Hz	57,74 V	-97,00 °	50,000 Hz	19,64 V	-97,00 °	50,000 Hz	0,00 V	-97,00 °	50,000 Hz
U L2 SR1	0,00 V		0,000 Hz	57,74 V	143,00 °	50,000 Hz	19,64 V	143,00 °	50,000 Hz	0,00 V	143,00 °	50,000 Hz
U L3 SR1	0,00 V		0,000 Hz	57,74 V	23,00 °	50,000 Hz	19,64 V	23,00 °	50,000 Hz	0,00 V	23,00 °	50,000 Hz
I L1 SR1	0,000 A		0,000 Hz	1,000 A	0,00 °	50,000 Hz	2,500 A	0,00 °	50,000 Hz	0,000 A	0,00 °	50,000 Hz
I L2 SR1	0,000 A		0,000 Hz	1,000 A	-120,00 °	50,000 Hz	2,500 A	-120,00 °	50,000 Hz	0,000 A	-120,00 °	50,000 Hz
I L3 SR1	0,000 A		0,000 Hz	1,000 A	120,00 °	50,000 Hz	2,500 A	120,00 °	50,000 Hz	0,000 A	120,00 °	50,000 Hz
U L1 SR2	0,00 V		0,000 Hz	57,74 V	-97,00 °	50,000 Hz	19,64 V	-97,00 °	50,000 Hz	0,00 V	0,00 °	50,000 Hz
U L2 SR2	0,00 V		0,000 Hz	57,74 V	143,00 °	50,000 Hz	19,64 V	143,00 °	50,000 Hz	0,00 V	-120,00 °	50,000 Hz
U L3 SR2	0,00 V		0,000 Hz	57,74 V	23,00 °	50,000 Hz	19,64 V	23,00 °	50,000 Hz	0,00 V	120,00 °	50,000 Hz
I L1 SR2	0,000 A		0,000 Hz	1,000 A	0,00 °	50,000 Hz	2,500 A	0,00 °	50,000 Hz	0,000 A	0,00 °	50,000 Hz
I L2 SR2	0,000 A		0,000 Hz	1,000 A	-120,00 °	50,000 Hz	2,500 A	-120,00 °	50,000 Hz	0,000 A	-120,00 °	50,000 Hz
I L3 SR2	0,000 A		0,000 Hz	1,000 A	120,00 °	50,000 Hz	2,500 A	120,00 °	50,000 Hz	0,000 A	120,00 °	50,000 Hz
Bin. Out												
Trigger	External Trigg			Time Bin	1,000 s		Time Bin	4,000 s		Time	1,000 s	

	Name	Ignore	Start	Stop	Tnom	Tdev-	Tdev+	Tact	Tdev	Assessmen
1	Fehlerfrei		Vorfehler	L1-L2-L3;	1,0000 s	0,0010 s	0,0010 s	1,0000 s	0,0000 s	+
2	S1 AUS 123		L1-L2-L3;	Aus1 L12	0,0500 s	0,0500 s	0,0500 s	0,0431 s	-0,0069 s	+
3	S2 AUS 123		L1-L2-L3;	Aus2 L12	0,0500 s	0,0500 s	0,0500 s	0,0430 s	-0,0070 s	+
4	Signal Sende		L1-L2-L3;	SendeSig.	0,2000 s	0,0500 s	0,0500 s	0,1708 s	-0,0292 s	+
5	Signal Empfa		L1-L2-L3;	Empf.Sig.	0,0500 s	0,0300 s	0,0300 s	0,0396 s	-0,0104 s	+
6	Anr. Zeit S1		L1-L2-L3;	Anr1 L123	0,0200 s	0,0100 s	0,0100 s	0,0179 s	-0,0021 s	+
7	Anr. Zeit S2		L1-L2-L3;	Anr2 L123	0,0200 s	0,0100 s	0,0100 s	0,0205 s	0,0005 s	+

Figure 6 - Test sequences: Synchronizing, prefault, fault, postfault

The whole test procedure was prepared in an office using the off-line mode. It simulated two systems with six voltages and six currents on each line side. See Figure 7 - Signal view with 6xV and 6xI and with recorded trigger on the binary inputs.

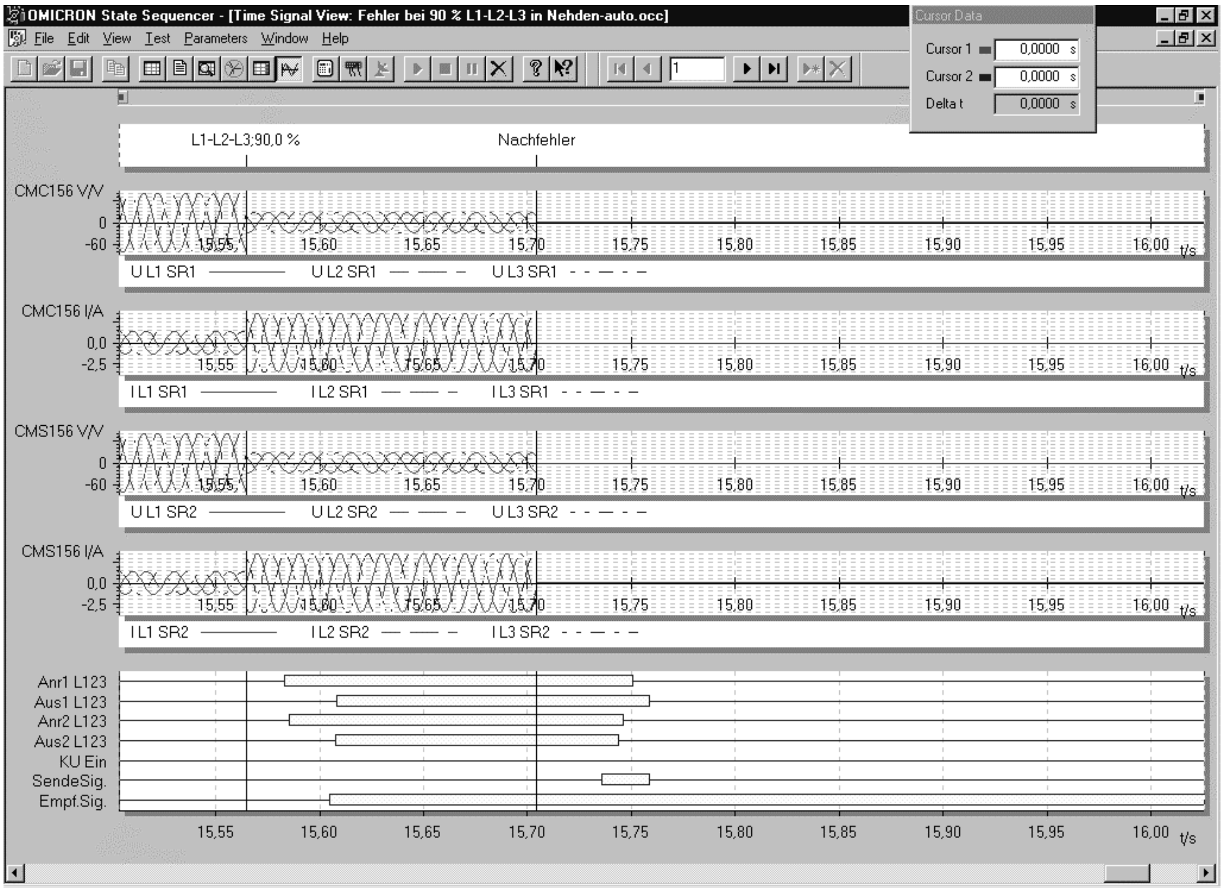
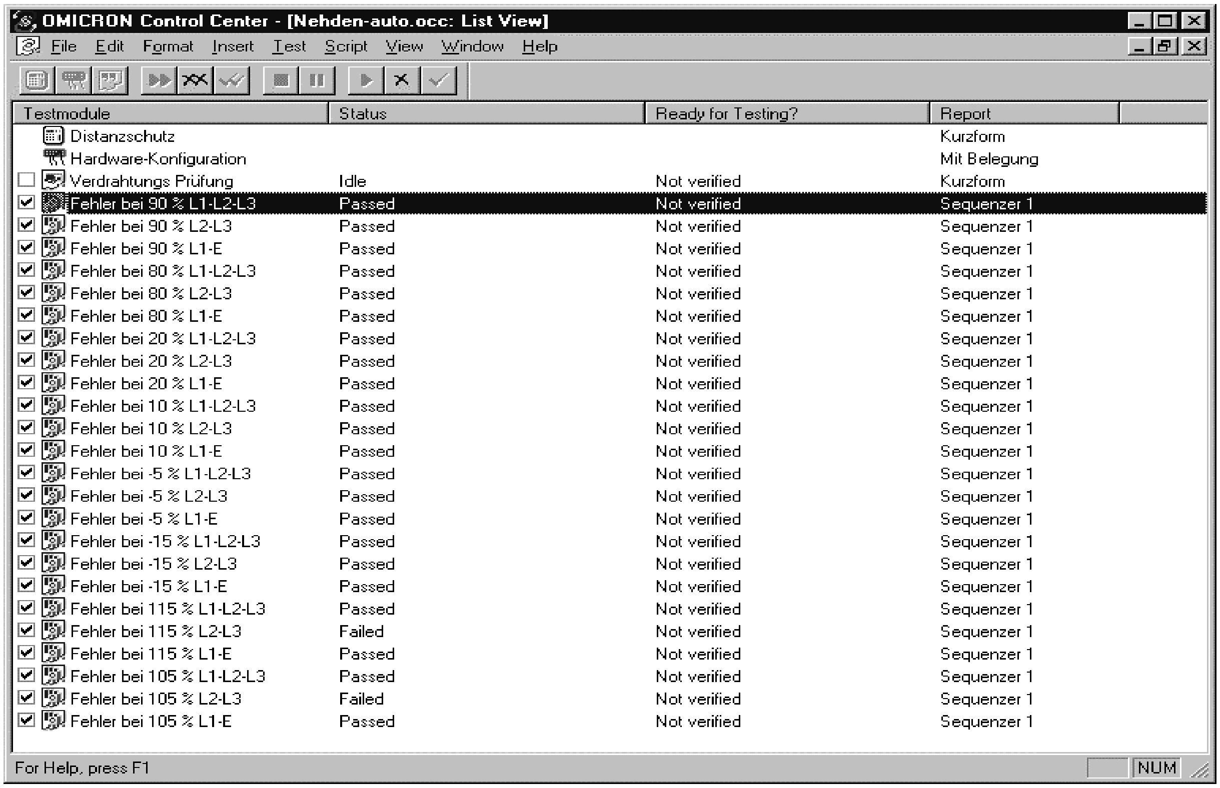


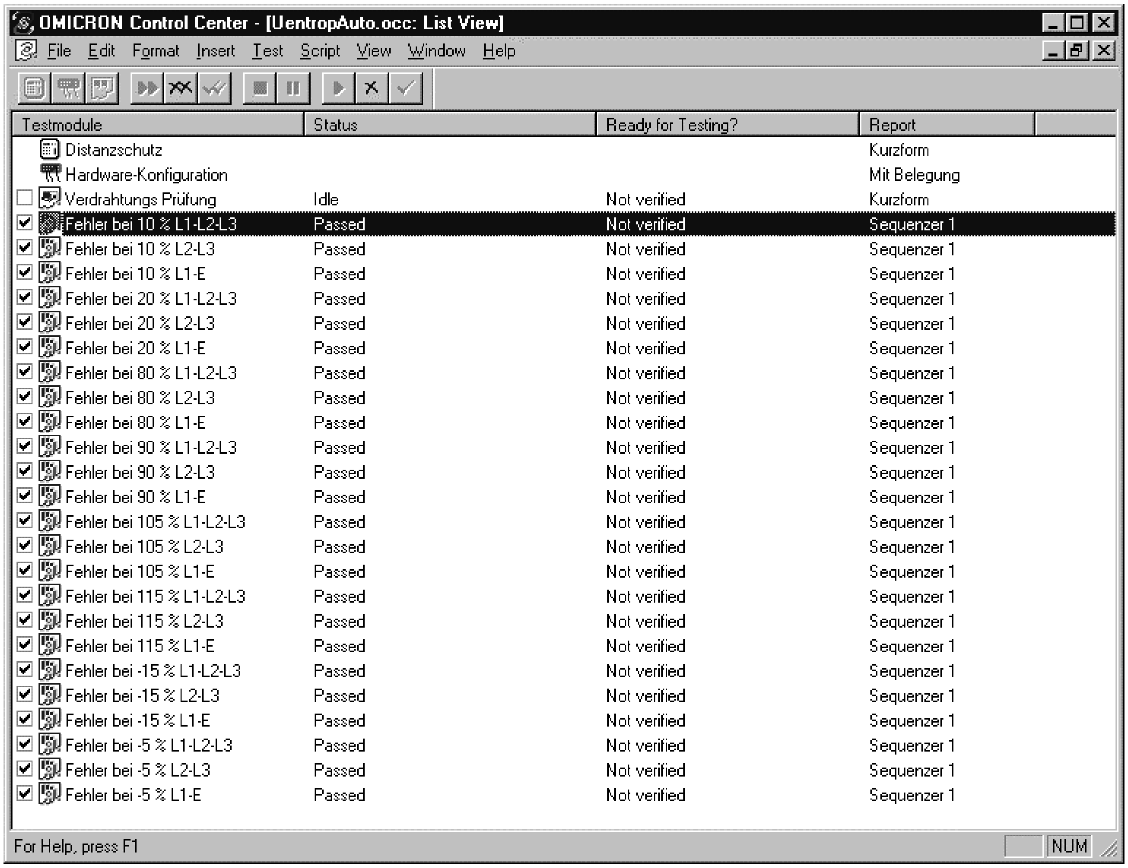
Figure 7 - Signal view with 6xV and 6xI and with recorded trigger on the binary inputs

The twenty-four test sequences embedded in the Omicron Control Center frame application automatically creates the entire testing procedure. (For each line side separately: 380 kV Substations Nehden and Uentro). See Figure 8 - OCC document with automatic test procedure: 380 kV Substation Nehden and Figure 9 - OCC document with automatic test procedure: 380 kV Substation Uentrop



Testmodule	Status	Ready for Testing?	Report
Distanzschutz			Kurzform
Hardware-Konfiguration			Mit Belegung
Verdrahtungs Prüfung	Idle	Not verified	Kurzform
Fehler bei 90 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 90 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 90 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei 80 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 80 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 80 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei 20 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 20 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 20 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei 10 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 10 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 10 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei -5 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei -5 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei -5 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei -15 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei -15 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei -15 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei 115 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 115 % L2-L3	Failed	Not verified	Sequenzer 1
Fehler bei 115 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei 105 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 105 % L2-L3	Failed	Not verified	Sequenzer 1
Fehler bei 105 % L1-E	Passed	Not verified	Sequenzer 1

Figure 8 - OCC document with automatic test procedure: 380 kV Substation Nehden



Testmodule	Status	Ready for Testing?	Report
Distanzschutz			Kurzform
Hardware-Konfiguration			Mit Belegung
Verdrahtungs Prüfung	Idle	Not verified	Kurzform
Fehler bei 10 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 10 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 10 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei 20 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 20 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 20 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei 80 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 80 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 80 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei 90 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 90 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 90 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei 105 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 105 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 105 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei 115 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 115 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei 115 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei -15 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei -15 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei -15 % L1-E	Passed	Not verified	Sequenzer 1
Fehler bei -5 % L1-L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei -5 % L2-L3	Passed	Not verified	Sequenzer 1
Fehler bei -5 % L1-E	Passed	Not verified	Sequenzer 1

Figure 9 - OCC document with automatic test procedure: 380 kV Substation Uentrop

These two displayed test procedures were synchronized using CMGPS. It was possible to control and see the whole test running from one computer as shown above by using the remote terminal emulation software NetMeeting.

The whole test ran in about seven minutes including creating the automatic test report.

6 Conclusions

The one-side remote controlled testing of the Communication Based Power protection schemes has been opening many new possibilities for testing facilities.
The ideas described in this paper have much bigger importance in remote trouble shooting, remote customer support, or remote expertizing.
Technical experts in the electrical utility cannot be everywhere so by using remote trouble shooting, they can efficiently help testing teams in the substations.
Contact with manufacturers will become another aspect as well. Onsite-support on demand, not having to write error reports and procedural descriptions, etc. will save time and subsequently will save on costs.
For future research, we are going to improve the described testing methodology with regards to testing the phase comparison protection on a three-legged line. We will use conference connection between three computers to control all three test sets by a master computer. This will open possibilities for test management when the expert is not present in the substation but is in his office or some other remote-testing center. The main idea is to use support from the experts wherever it is needed.

7 References:

- GPS Synchronized End-To-End Tests of Transmission Line Teleprotection Schemes in the ESCOM (South Africa) Network by Alexander Dierks, Ian Worthington, Peter Olivier
- Synchronized End-To-End testing of distance protection scheme between Durgapur-Farakka 400 kV Transmission line of Power Grid Corporation, India by Reinhard Kuntner; A.K. Yadaw; Ravi Kapor
- OMICRON Test Universe Getting Started
- Advanced Power System Protection Testing by Zeljko Schreiner