# Improve Protective Relaying Systems Reliability by Dynamic Testing

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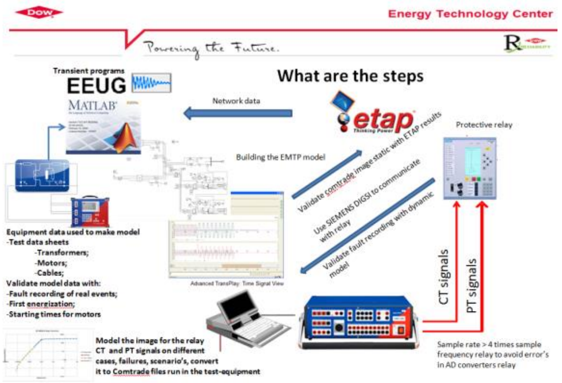
## Abstract

Reliable electrical power distribution to the petrochemical plants becomes more and more important. False trips could lead to equipment damage, environmental issues, production loss, etc. Power dips in the public grid are not rare anymore due to the distributed generation, changes of the grounding system in public grid, etc. A chain in the reliable power supply to the chemical plants is the stable operation of protective relaying. No false tripping, fault ride through (power dip immunity) and fast tripping when an electrical fault occurs in the equipment are essential to reliability. Protective relaying manufacturer are putting more and more functions into the relaying box. The flexibility of the relaying (multifunctional relays) leads to long setting lists that needs to be tested, this making total scheme testing more and more important.

This paper describes the modeling for critical protective relaying testing (line, generator, bus, transformer and transfer protective relaying) and the use of Advanced Transplay. Dynamic testing has become a standard within DOW on critical protective relaying system and is a part of the total scheme testing. EMTP (ATP) models are used to generate PL4, COMTRADE files. The currents, voltages and input changes are injected to check if the relaying is stable or not stable. The CT Analyzer, CPC 100 data is used to model current transformers. Generator protection relays, transfer systems, line, bus and transformer differentials are tested dynamically by the use of Advanced Transplay module. The developed method of testing is used on all critical protective relaying applications with DOW Europe.

## 1 The Procedure Used for Dynamic Testing

The model is based on the available network and machine data from the machine manufacturer. The network data is validated with fault recording data from the relays. DOW uses ETAP to do loadflow and static short circuit calculations. Based on all of this available data, an EMTP model is made. A developed EMTP model is validated with the network calculation program ETAP. Short circuit calculations are made in both programs to check the results and to validate the EMTP model.



What are the steps

Network data

Building the EMTP model

Validate comtrade image static with ETAP results

Use SIEMENS DIGSI to communicate with relay

Validate fault recording with dynamic model

Equipment data used to make model
-Test data sheets
-Transformers;
-Motors;
-Cables;
Validate model data with:
-Fault recording of real events;
-First energization;
-Starting times for motors

Model the image for the relay CT and PT signals on different cases, failures, scenario's, convert it to Comtrade files run in the test-equipment

Sample rate > 4 times sample frequency relay to avoid error's in AD converters relay

*Figure 1: The Procedure for Total Scheme Testing*

Making the model is the most difficult and time consuming part. Garbage in is garbage out, so modeling should be validated. The next step is defining the critical simulation cases (network faults, power dips, etc). Sometimes different sensitivity runs are made to find the most critical system events and identify where more precise modeling is important to the results. The simulated data from the EMTP model is converted to COMTRADE files with the right sample frequency. The next step is to import the COMTRADE of PL4 file in Test Universe software of the OMICRON test set. The simulated cases can be played back. The OMICRON Test Universe software generates directly a report of the test. Some relays are using adaptation of the sampling frequency to produce correct results over a with frequency range 11-69 Hz. A healthy pre-fault state is always simulated to make sure that the adaptive frequency sampling is working correctly. The modeled data is exported with a sample frequency of 10 kHz. The minimum sample frequency of the data should be a minimum of four times the sample frequency of the relay to avoid error due to the A/D conversion and filtering of the relay. During the testing the fault recording of the relays are captured and analyzed. In the fault recording the injected image of the test case can be shown and checked with the injected one.

## 2 EMTP Models

### 2.1 Current Transformers

To inject realistic currents into the relay system the current transformers should be modeled. For new installations the data is coming from the manufacturer and testing during FAT and SAT. With new installations or during substation shutdowns the current transformer characteristics are obtained with the OMICRON CT Analyzer or CPC 100. These devices give the data needed for the modeling. In figure 2 the EMTP model of the CT is shown:

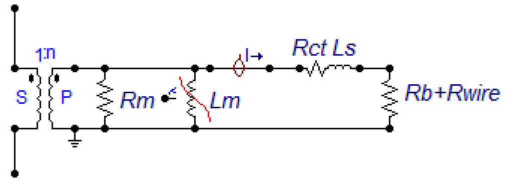


*Figure 2: Current Transformer Model in EMTP*

The primary data $R_p$, $L_p$ can be neglected for protective relaying studies. When the excitation curve is not known, a KEMA typical curve is taken. The $R_{ct}$, $R_b$ and $R_{wire}$ values are calculated in this case. The EMTP model needs the flux linked values in [V-sec] peak. The IEC 60044-6 measurement is taken to convert to volt-sec values. In figure 3 you will see the difference between the IEC 60044-6 and IEC 60044-1 converted to peak values.

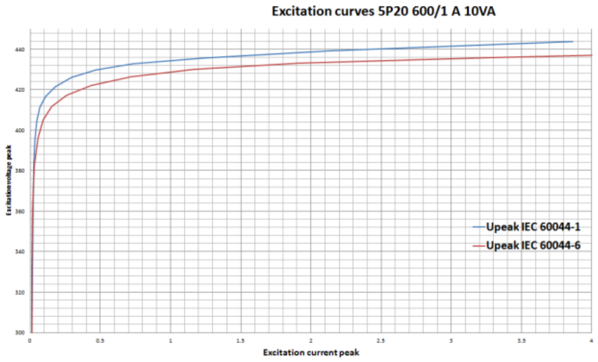


*Figure 3: Excitation Curve IEC 60044-1/IEC 60044-6*

When the data is filled into the model the model is validated to let the EMTP program run the excitation test.

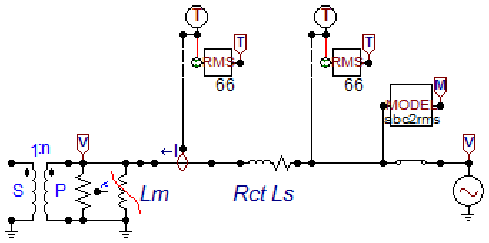


*Figure 4: Excitation Test in EMTP for Validation*

Normally points are added to the excitation curve to get the right response in the deep saturation region. For auto-reclosure schemes the hysteresis should be modeled. The effect of remanence in the simulation should be taken into account by specifying the steady state flux level at the beginning of the simulation. DOW uses a level of 40 % remanence when doing a sensitive study on relay performance with current transformer saturation.

## 2.2 Voltage Transformers

For modeling the voltage transformers in EMTP DOW uses a saturable single phase transformer. The excitation curve can also be used if needed.

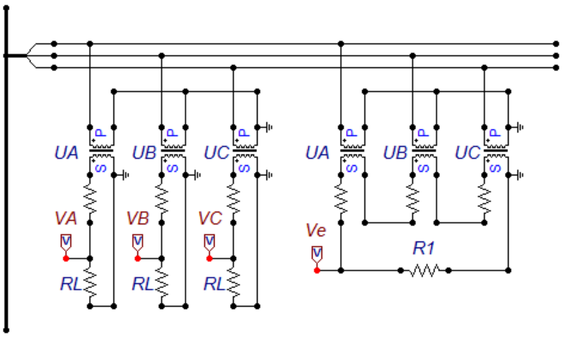


*Figure 5: Voltage Transformer Model in EMTP*

Coupling capacitor voltage transformers can also be modeled, but these are not typically used within the company`s networks.

## 2.3 Fault modeling

The fault modeling is done with single pole time controlled switches with a resistor in series. The arc resistance is taken very low, 1 mΩ and can be changed easily. Arc model is not used in the simulations while in the industry networks most of the connections are made with cables and the systems are low resistance grounded. In the industrial networks the company sees that faults start as a ground fault and evolve to a double ground fault in a few cycles. Most relays have problems with ground faults out of zone evolving to a phase to ground fault into the zone. This phase to phase ground fault causes CT saturation and some relays have delayed tripping for these scenarios.

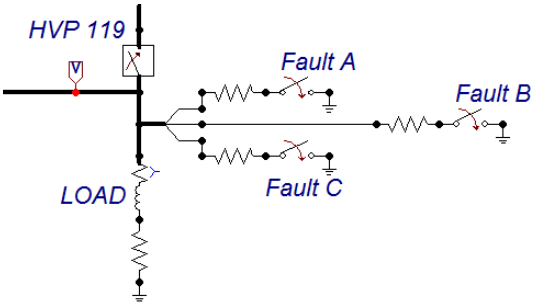


*Figure 6: EMTP Fault Model*

The fault inception angle defines the angle of the voltage at instant of the fault. The fault inception angle controls the amount of asymmetrical transient current generated in the fault. The DC component will affect the saturation of the current transformers and by that the operating speed and security of the relaying. For differential protection testing DOW varies the fault inception angle, and test as a minimum at 0, 30, 60 and 90 degrees. With the results DOW can see the saturation, worst case, and if more, sensitivity study is needed. Pre-fault load is used to get stable operation of the relaying before the fault is simulated in the network. Some of the relaying like Siemens 7UM needs stable voltage signals before it can work right, they are using adaptation of the sampling frequency. Load current injection during line differential or directional testing will show the direction of the currents that are injected.

## 2.4 Cable Modeling

A three phase simple cable with the exact PI-equivalent model can be used to model the short cables in an industrial network. For the relaying DOW does not need the high frequency dependency model for the cabling. The anti-aliasing filters are cutting off the high frequencies anyhow. The modeling is not made for electromagnetic transient study.

## 3 New Line Differential Test Siemens 7SD80

The old line differentials with pilot wiring will be replaced in the coming years. The DOW protective relaying team in Terneuzen did dynamic testing on the Siemens 7SD80 relay to see if the relay met the specification and could be used on the old installations. An EMTP model was made of a cable feeder from the main substation to the plant substation. CPC 100 current transformer measured data is used as input.

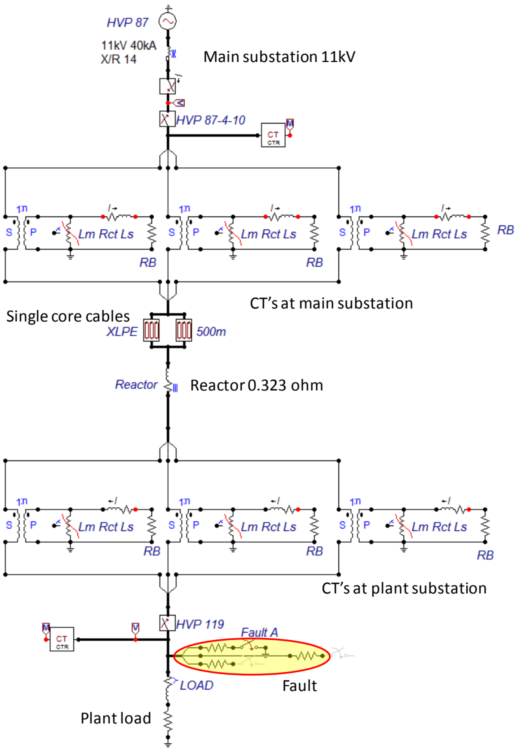
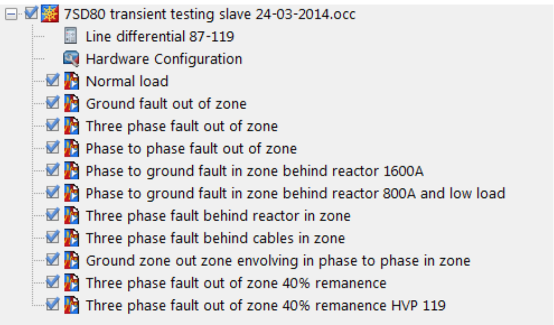


*Figure 7: EMTP Model for Differential Relaying Test*

The following cases were simulated:



- ☑ 7SD80 transient testing slave 24-03-2014.occ
  - Line differential 87-119
  - Hardware Configuration
  - ☑ Normal load
  - ☑ Ground fault out of zone
  - ☑ Three phase fault out of zone
  - ☑ Phase to phase fault out of zone
  - ☑ Phase to ground fault in zone behind reactor 1600A
  - ☑ Phase to ground fault in zone behind reactor 800A and low load
  - ☑ Three phase fault behind reactor in zone
  - ☑ Three phase fault behind cables in zone
  - ☑ Ground zone out zone envolving in phase to phase in zone
  - ☑ Three phase fault out of zone 40% remanence
  - ☑ Three phase fault out of zone 40% remanence HVP 119

*Figure 8: Test Cases*

The simulated currents and voltages are imported in Advanced Transplay, a master and a slave OCC files are made. Two CMC 356 sets were used to inject the currents at two places at the same time.

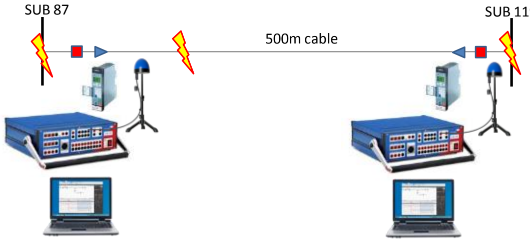


*Figure 9: Test Set-Up for Line Differential Testing*

An example of the currents with CT saturation is shown the next figure:

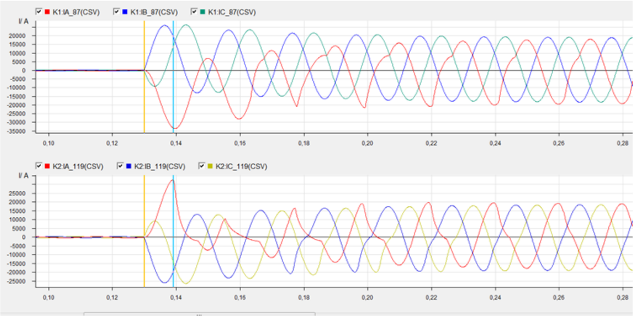


*Figure 10: Simulated Currents in EMTP that Are Used in Advanced Transplay*

Tripping times and stability checks are done to certify the relay within DOW Terneuzen.

## 4 Automatic Transfer System Testing

The purpose of an automatic transfer system is to switch to an alternate source of power when a primary source of power is lost. The automatic switching allows plant personnel to operate the plant without the need to determine if it is safe to switch to an alternate source of power. Correct working of transfer schemes and motor re-start can reduce business impact and save millions of dollars, and more importantly nowadays avoid environmental impact. Different transfer schemes are used in the industry. At DOW Terneuzen the residual voltage transfer scheme "Main tie Main" is used. The majority of loads in a chemical plant are induction motors. See typical plant substation layout.

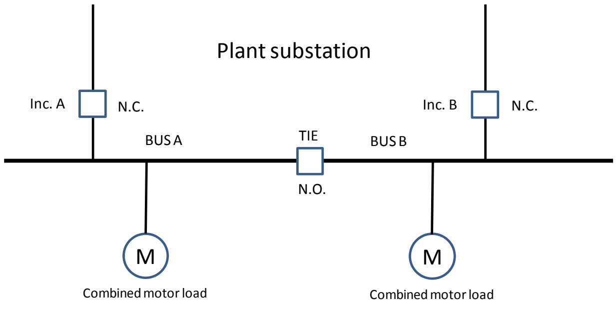


*Figure 11: Typical Main Tie Main Layout*

When a motor bus is disconnected from the power supply the trapped energy in the inertia and in the magnetic field of the spinning motors results in a decaying voltage at the bus. The magnitude and frequency of the residual voltage decreases as the slip of the motors increases. The residual voltage transfer scheme is slower than a fast or inphase transfer scheme. The residual transfer is permitted to close the coupler breaker when the bus voltage of the disconnected source is below 25 % of nominal. This setpoint can be decreased to limit the transient mechanical forces (torques) on the motors that are transferring. In the IEEE C50.41-2012 a recommendation is made that the V/Hz ratio should be less as 1.33 pu. In this code the recommended transfer time is 1.5 times T'do (open circuit time constant of the motor). The transfer times are 1-2 sec settings depending on the coordination in the network. The time settings should be validated and checked with dynamic testing. Also the air gap torque behavior during the transfer is checked in the simulation of the transfer and verified with the data from the manufacturer.

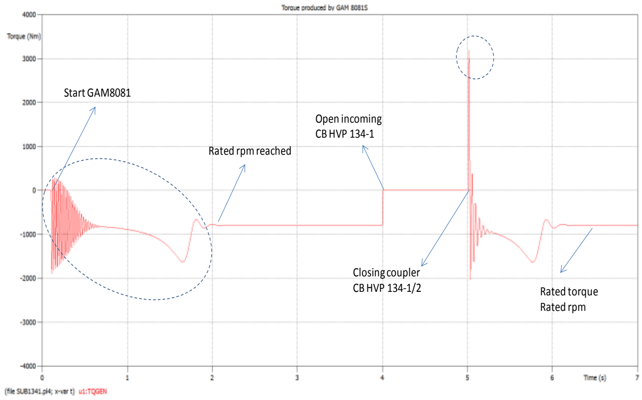


*Figure 12: Transient Air Gap Torques of the Induction Motor*

With dynamic testing the complete philosophy of the automatic transfer scheme will be checked: Will we ride through power dips? To make a good dynamic model DOW needs the manufacturer data of the motors, inertia, load characteristics and load inertia, and this data is used to make the motor model. In EMTP the UM3 induction model is used. See the model in figure 13.

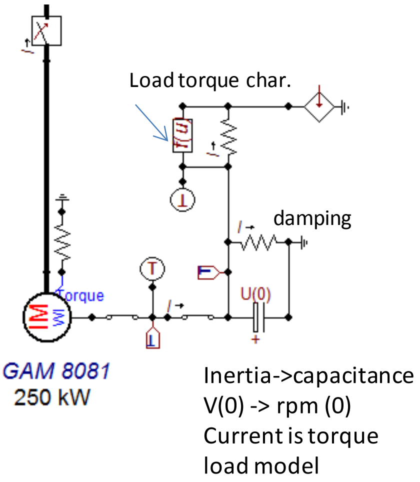


*Figure 13: UM3 EMTP Motor Model*

The load curve of the motor is also simulated, figure 14.

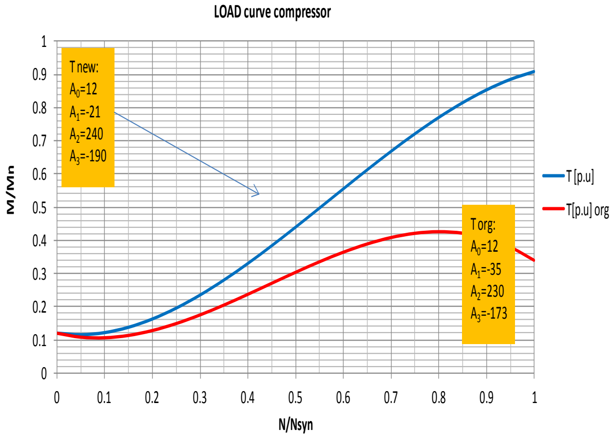


*Figure 14: Load Model*

The electrical data of the motor can be filled in the UM model. The load model should be made with a current source and capacitor. The resistor is added for friction and damping. The model can be validated with the factory data. Use a voltage source without impedance at 100 % voltage to simulate motor starting and check acceleration results with FAT data. When the motor model is validated, the model can be used in the complete power system model. The model below has two independent 11 kV power sources, two power transformers 11/6 kV, 6 kV pump motors and low voltage motors. The transfer system is measuring the bus voltages at both busses and the current at both incomers. The currents and voltages are simulated for different cases and converted to COMTRADE files at 10 kHz. These COMTRADE files are used to playback in two synchronized OMICRON sets. A master and a slave OCC file were made in Advanced Transplay. The transfer system is made out of three Siprotec relays. The software for the relays is made in CFC code. With dynamic testing DOW tests the ATS behavior with motor behavior. In the past the state sequencer module was used for this kind of testing. No dynamic behavior of motor load could be tested.

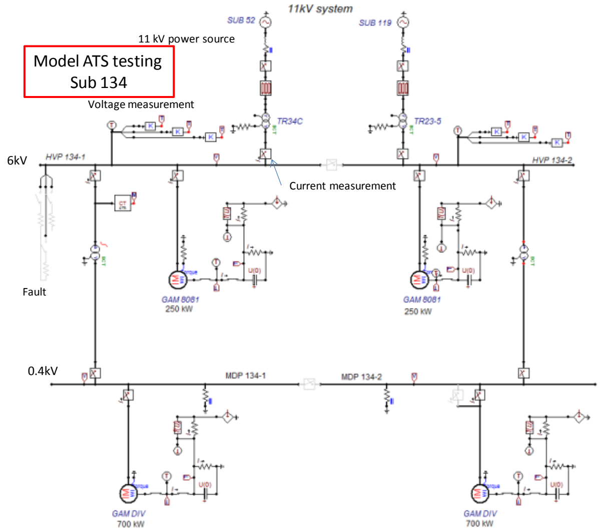


*Figure 15: EMTP Model for Substation with Motorload*

The transfer is initiated when all phase to ground voltages on one side are below 70 % and the healthy bus has a voltage on all three phases above 90 % and no blocking signal is active. The figure below shows the test configuration of substation 134.

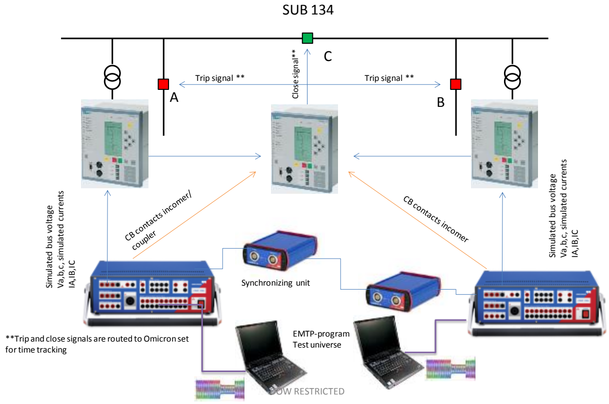
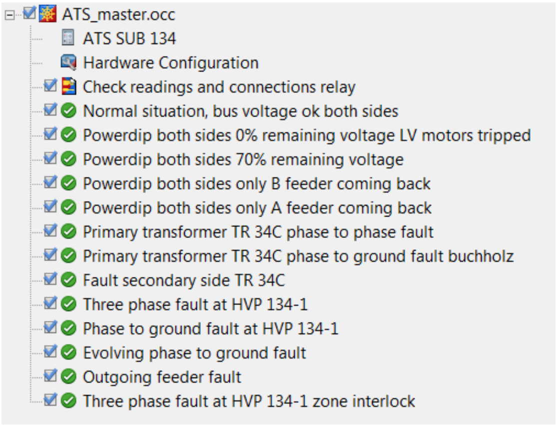


*Figure 16: Test Set-Up for Testing Main Tie Main Transfer System*

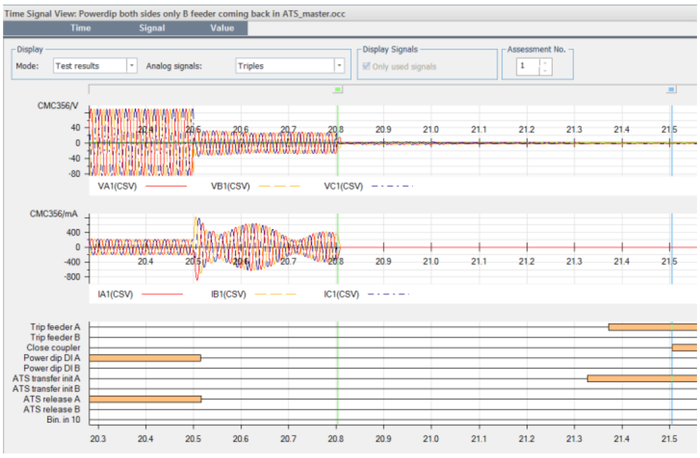
The two CMC sets are synchronized with two IRIG-B units. The following cases are simulated in EMTP and played back:



- ☑ ATS_master.occ
  - ATS SUB 134
  - Hardware Configuration
  - ☑ Check readings and connections relay
  - ☑ Normal situation, bus voltage ok both sides
  - ☑ Powerdip both sides 0% remaining voltage LV motors tripped
  - ☑ Powerdip both sides 70% remaining voltage
  - ☑ Powerdip both sides only B feeder coming back
  - ☑ Powerdip both sides only A feeder coming back
  - ☑ Primary transformer TR 34C phase to phase fault
  - ☑ Primary transformer TR 34C phase to ground fault buchholz
  - ☑ Fault secondary side TR 34C
  - ☑ Three phase fault at HVP 134-1
  - ☑ Phase to ground fault at HVP 134-1
  - ☑ Evolving phase to ground fault
  - ☑ Outgoing feeder fault
  - ☑ Three phase fault at HVP 134-1 zone interlock

*Figure 17: Simulated Cases*

The master file for a power dip on both sides with only feeder B coming back.

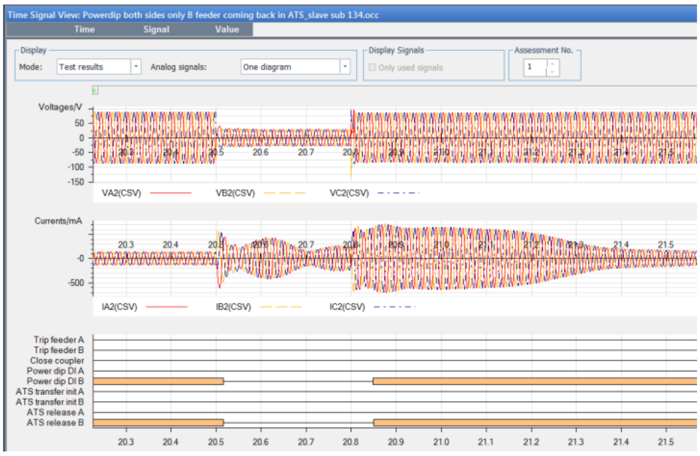


Time Signal View: Powerdip both sides only B feeder coming back in ATS_master.occ

Mode: Test results
Analog signals: Triples
☑ Only used signals
Assessment No. 1

*Figure 18: Advanced Transplay Output, Master File*

The slave file for a power dip on both sides, with feeder B coming back.



Time Signal View: Powerdip both sides only B feeder coming back in ATS_slave sub 134.occ

Mode: Test results
Analog signals: One diagram
☐ Only used signals
Assessment No. 1

*Figure 19: Advanced Transplay Output, Slave File*

In the traces it can be seen that the motor contribution during the fault and the inrush after the coupler is closed. The transfer scheme is built with simple 7 SJ relays. DOW discovered that the standard frequency tracking in the relays has problems with the decaying frequency of the residual voltage when motors are disconnected from the power source. This leads to faster, false, under voltage detection, zero volts. When the voltage reaches a frequency falls below 25 Hz the relay cannot define the voltage level anymore and transfer is initiated and faster closing of coupler breaker occurs. This behavior is taken into account when defining the transfer time.

## 5 Transformer Differential Testing

The matrix model BCTRAN is used to model the behavior of the transformer. The matrix elements for transformers with any number of windings can be derived from the short-circuit impedances between pairs of windings. The calculations are rather involved, and support routine BCTRAN available in EMTP should be used. BCTRAN produces the branch matrices from the positive and zero sequence short-circuit and excitation test data. The model is validated simulating the excitation test and the short circuit test. The results should be the same as on the FAT test documents. A model produced by BCTRAN is good from dc up to 2 kHz. It can take into account excitation losses, but nonlinear behavior is not represented and must be added externally, like for simulating the inrush behavior. DOW was very interested in the modeling of internal winding faults. How deep is the relaying protecting the winding especially with current transformer saturation? To model these winding ground faults in EMTP a new impedance matrix of the transformer should be made. The BCTRAN routine is calculating the healthy impedance matrix RωL. This healthy matrix should be changed to the winding ground fault matrix by splitting the $n_2$ winding in two windings a, b when the ground fault is at the secondary side, [5], [6]. For the resistance a simple proportionality principle is physically obvious, thus:

$$R_a = \frac{n_a}{n_2} R_2 \tag{1}$$

$$R_b = \frac{n_b}{n_2} R_2 \tag{2}$$

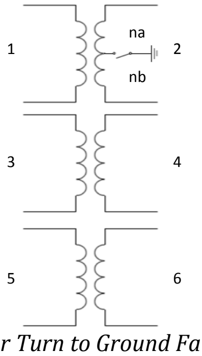


*Figure 20: Transformer Turn to Ground Fault in Secondary Winding*

The new matrixes are shown below:

$$L = \begin{bmatrix} L_{11} L_{a1} L_{1b} L_{13} L_{14} L_{15} L_{16} \\ L_{a1}\ L_a\ L_{ab} L_{a3} L_{a4} L_{a5} L_{a6} \\ L_{b1} L_{ba}\ L_b\ L_{b3} L_{b4} L_{b5} L_{b6} \\ L_{31} L_{3a} L_{3b} L_{33} L_{34} L_{35} L_{36} \\ L_{41} L_{4a} L_{4b} L_{43} L_{44} L_{45} L_{46} \\ L_{51} L_{5a} L_{5b} L_{53} L_{54} L_{55} L_{56} \\ L_{61} L_{6a} L_{6b} L_{63} L_{64} L_{65} L_{66} \end{bmatrix} \tag{3}$$

$$R = \begin{bmatrix} R_1 & & & & & & 0 \\ & R_a & & & & & \\ & & R_b & & & & \\ & & & R_3 & & & \\ & & & & R_4 & & \\ & & & & & R_5 & \\ 0 & & & & & & R_6 \end{bmatrix} \tag{4}$$

A new 7x7 matrix is calculated in Excel. For the computation of the self and mutual inductance between the sub-coils a and b the following rules should be applied:

$$L_a = \frac{L_{22}}{\frac{1}{k^2} + \frac{2\sqrt{1-\sigma_{ab}}}{k} + 1} \tag{5}$$

$$L_b = \frac{L_{22}}{k^2 + 2k\sqrt{1-\sigma_{ab}} + 1} \tag{6}$$

$$L_{ab} = \frac{L_{22}\sqrt{1-\sigma_{ab}}}{(k + \frac{1}{k}) + 2\sqrt{1-\sigma_{ab}}} \tag{7}$$

k=$n_a$/$n_b$

If i coil is considered in the same leg as a and b, the faulty coil, then

$$L_{ai} = L_{2i}\sqrt{\varepsilon}\sqrt{\frac{L_a}{L_{22}}}\sqrt{1 + \frac{1-\varepsilon}{\varepsilon}\frac{L_{22}L_{ii}}{L_{2i}^2}} \tag{8}$$

$$L_{bi} = L_{2i} - L_{ai} \tag{9}$$

If the i coil is wound on the different leg than a and b then:

$$L_{ai} = \frac{k}{1+k} L_{2i} \tag{10}$$

$$L_{bi} = \frac{1}{1+k} L_{2i} \tag{11}$$

$L_{22}$, $L_{2i}$ and $L_{ii}$ are elements of the L matrix of the healthy transformer. ε is assumed to be 1. The leakage factor $\sigma_{ab}$ is equal to: $\sigma_{ab} = \frac{n_a}{n_2}\sigma_{12}$ and $\sigma_{12}$ is the leakage factor between primary and secondary winding of the healthy transformer and can be calculated by:

$$\sigma_{12} = 1 - \frac{L_{12}^2}{L_{11}L_{22}} \tag{12}$$

For example: the new impedance matrix can be calculated for the 50 % winding fault. The model in

EMTP is expanded with faulty transformer using the library module in EMTP. The faulty winding node is made 50 % into the secondary winding and is called ZZZZZZ.

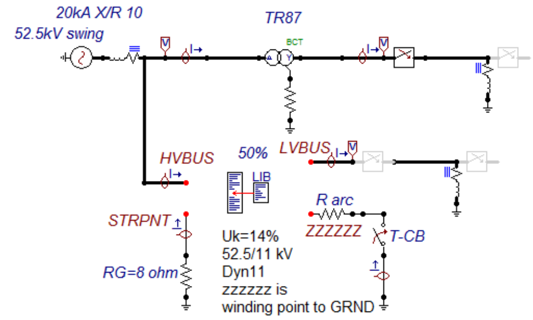


*Figure 21: EMTP Model for Secondary Winding Fault*

The results of simulation are shown below and used for testing the transformer differential Siemens 7UT613. Winding fault is initiated by closing the T-CB at 0.2 sec in phase C.

The 11 kV secondary voltage:

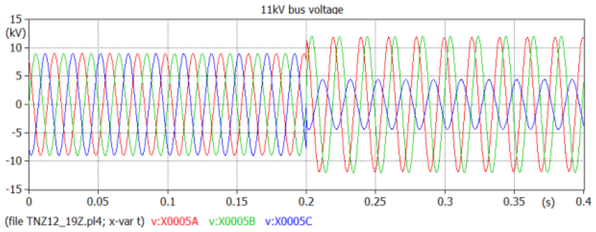


*Figure 22: Voltage at Low Side, Phase C is Faulted*

The phase jump is due to the ground fault. The C phase voltage is dropping 50 %. The driving voltage for the fault is 50 %.

The star point current is:

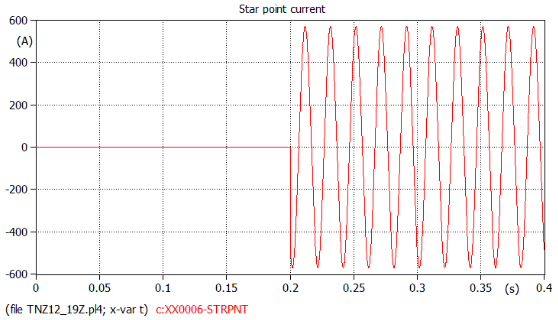


*Figure 23: Star-Point Current 50 % Fault into Winding*

The current is 570 A peak and 403 A rms and almost in phase with the driving fault voltage. The current transformer modeling was added to the model. Current transformers were measured with CPC 100 to get the right model data. Different cases were simulated and injected into the Siemens 7UT relay.

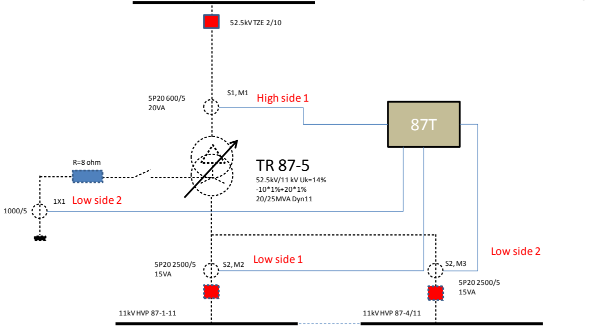


*Figure 24: Transformer Differential Set-Up*

Two synchronized CMC 356 units were used to test the relay.

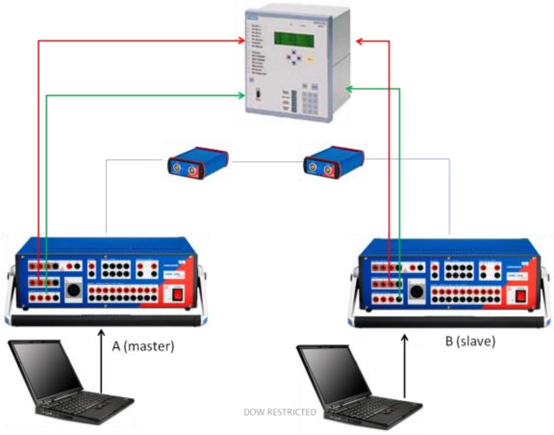
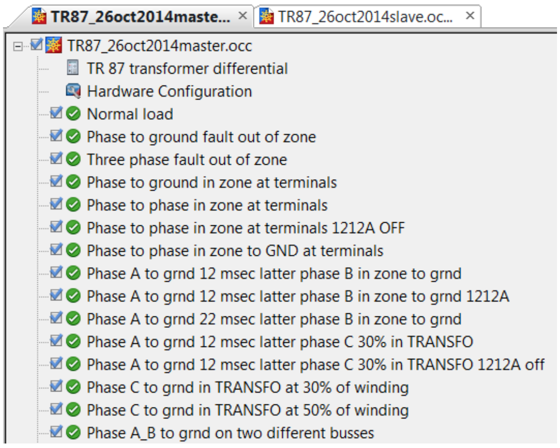


*Figure 25: Test Set-Up for Differential Testing*

The following cases are simulated and played back into the Siemens 7UT relay.


TR87_26oct2014maste... × TR87_26oct2014slave.oc... ×

- ☑ TR87_26oct2014master.occ
  - TR 87 transformer differential
  - Hardware Configuration
  - ☑ ✓ Normal load
  - ☑ ✓ Phase to ground fault out of zone
  - ☑ ✓ Three phase fault out of zone
  - ☑ ✓ Phase to ground in zone at terminals
  - ☑ ✓ Phase to phase in zone at terminals
  - ☑ ✓ Phase to phase in zone at terminals 1212A OFF
  - ☑ ✓ Phase to phase in zone to GND at terminals
  - ☑ ✓ Phase A to grnd 12 msec latter phase B in zone to grnd
  - ☑ ✓ Phase A to grnd 12 msec latter phase B in zone to grnd 1212A
  - ☑ ✓ Phase A to grnd 22 msec latter phase B in zone to grnd
  - ☑ ✓ Phase A to grnd 12 msec latter phase C 30% in TRANSFO
  - ☑ ✓ Phase A to grnd 12 msec latter phase C 30% in TRANSFO 1212A off
  - ☑ ✓ Phase C to grnd in TRANSFO at 30% of winding
  - ☑ ✓ Phase C to grnd in TRANSFO at 50% of winding
  - ☑ ✓ Phase A_B to grnd on two different busses

*Figure 26: Test Cases*

During testing the relay, it had long tripping times for evolving ground faults at the secondary side. Sometimes the relay was not tripping when a ground fault out of zone evolved into the zone. By changing the settings after consulting Siemens we reduced tripping times. The current transformers were meeting the requirements of the relaying. Due to the current transformer saturation, which started at the moment of the double ground fault, the relay was blocking the tripping by second harmonics. When the current transformer saturation is gone the second harmonics are gone and the relay trips.

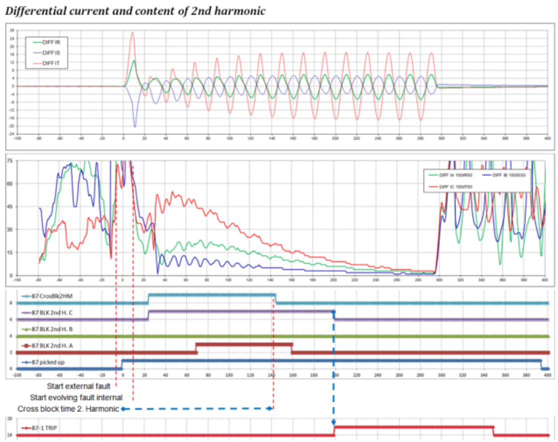


*Figure 27: Detailed Analyses of Delay in Tripping 7UT*

This was a good learning experience and a good test to validate settings. The experiences are that 90 % of the faults start with phase to ground somewhere at the weakest spot in the system and escalate to a phase to phase to ground fault. Fast clearing in this case is also needed and the protective relaying settings should be checked for this. In these cases modeling for protective relaying testing has proven added value.

# 6 Busbar Relaying Testing

In 2013/2014 a new Cogen facility was built in DOW Stade. A new 15 kV switchgear was installed to connect two gas-turbine generators. The manufacture of the new switchgear didn't pay a lot attention to the current transformer dimensioning, especially with the generators. After delivery of switchgear on site, the current transformers were measured with the OMICRON CT Analyzer and the data was used for modeling. After first simulation runs we discovered that the CT's were not dimensioned right due to generator contribution and due to remanence in CT's the saturation, free time was not long enough to guarantee stable relay operation. The simulation results were discussed with the switchgear manufacturer and they came to the same conclusion. Current transformers were exchanged for better ones and dynamic testing was done to prove the bus differential relaying was then stable for different scenarios. Four bay units were synchronized and injected at the same time.

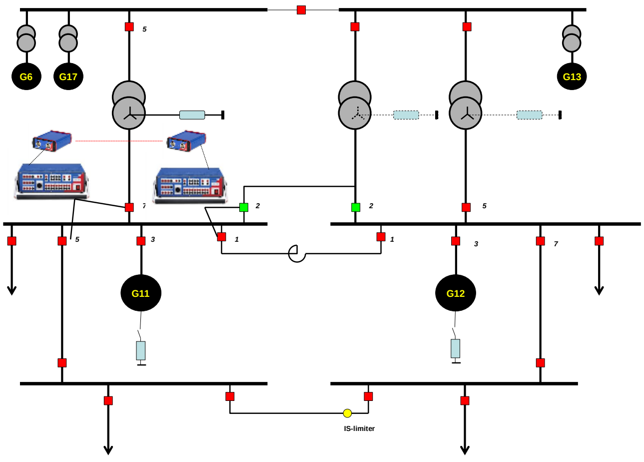


*Figure 28: Simplified Single Line of COGEN*

Breaker failure was also programmed in the bus differential relaying. So the output contacts of the initiating relays are also simulated in Advanced Transplay to prove correct tripping of feeders and upstream feeders. See figure 29 below, digital output signal breaker failure initiation, BFI.

*Figure 29: Advanced Transplay Results*

The use of EMTP simulation for testing can already detect early design mistakes early in the project.

# 7 Overcurrent Protection and Dynamics

The DOW chemical site in Terneuzen has a Cogen facility with two gas turbines connected to the 50 kV system. The gas turbines are each 125 MW. The complete 50 kV protective relaying scheme is based on operation of two GT's. Sometimes the normal operation mode is only one of the machines in service. The zone protection by differentials is the level 1 protection system and the overcurrent protection is level 2. The 50 kV overcurrent back-up protection is based on fast splitting of the two 50 kV busses TZE-1/2. This is done to keep two of the three 150/50 kV transformers on the healthy side. Both splitter over current relays, installed at both coupler breakers TZE 1-2,/TZE 2-2, are set the same. The settings are the same due to the fact that the contribution on one relay is always more than on the other relay depending on the fault place (with two generators running). An extremely inverse curve is used to get the current coordination. The total 50 kV protective relaying was reviewed again for the scenario of only one machine running. After developing the new relay settings for the splitter scheme, a test-schedule was also made to check behavior of the overcurrent functions. An EMTP model was made to check the different contributions and to make COMTRADE files for testing the relays and verify coordination in different fault scenarios.

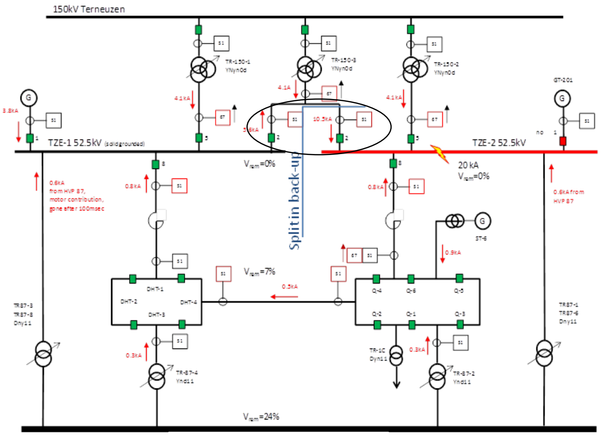


*Figure 30: 50 kV System DOW Terneuzen*

The COMTRADE data is generated out of the model. Governor and excitation models are taken into account. Only one generator is modeled to reflect the current situation. The contributions are shown below:

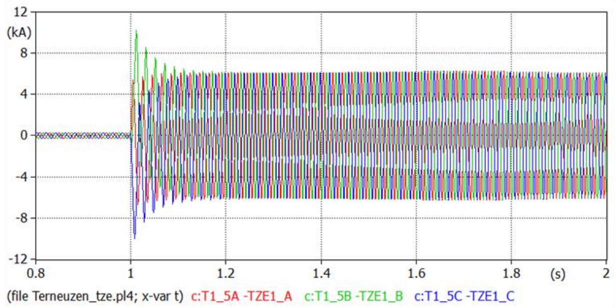


*Figure 31: Transformer Contribution*

The transformer contribution is approx. 4 kA, figure 31. The generator is also contributing approx. 3 kA, figure 32.

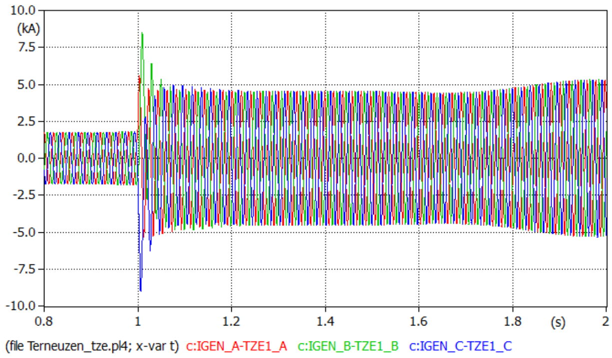


*Figure 32: Generator Contribution*

DOW expected to get a fault current of approx. 7 kA on one splitter and 7+4=11 kA on the other splitter relay. The simulation showed the following total contribution on one splitter, see figure 33.

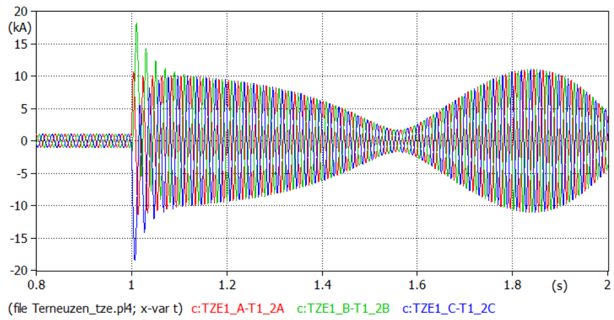


*Figure 33: Current in Splitter Breaker [TR+GT Contribution]*

The splitter breaker relays are set with an IEC extremely inverse curve to get the right current coordination. The gas turbine is accelerating due to the fact that no megawatts can be put into the system. So the frequency of the generator contribution is changing. The contribution over the splitter is not constant, see graph figure 33. The extremely inverse algorithm of the relay is an integrating function, so tripping times are not as stated in the manual with the normal injection, equation 13.

$$\textbf{EXTREMELY INV.}\ \text{(Type C)}\ t = \frac{80}{(I/I_p)^2 - 1} \cdot T_p \quad [\text{s}] \qquad (23)$$

$$\int_0^{t0} \frac{1}{t(I)} dt = 1 \qquad (34)$$

t(I) is calculated with the equation (13) and dt is time interval of calculation, for Siemens relaying 10 msec. In Excel or ATP you can easily calculate the tripping time of the IEC curve on the transient current. With the simulations and testing we tuned the settings of the splitter relaying.

# 8 Conclusions

Dynamic testing of relaying has added value for critical relaying systems in the chemical industry. The dynamic testing is done after the normal functional testing. More and more functions are put into a single relaying box by the manufacturer, which what leads to more complex relaying schemes and testing. Technicians need more knowledge of the relaying logic and communication. DOW has already two years' experience with dynamic testing on critical systems. The following can be addressed:

- Developing and validating the modeling in EMTP takes 80 % of the time. Garbage in is garbage out. So modeling and validation takes time, but is essential to success of the effort.
- The use of EMTP simulation for testing can already detect early design mistakes early in the project.
- Discovered delays in transformer differential trips due to current transformer saturation and second harmonic blocking. DOW needed to change standard settings for the 7UT relaying.
- The complete settings-list can be tested and no settings groups need to be blocked during this testing. This is an advantage with motor

protection and generator protection relaying testing.
- Settings can be tuned, after testing, to different power system faults.
- The residual motor voltage decay of motor busses can be simulated and tested for transfer systems. Sensitivity analyses on different parameters like inertia and motor load can be done. Motor restarting behavior after transfer is also tested.
- Background on transient modeling is needed to be able to use EMTP for relaying. ATPDRAW user interface makes modeling work faster and the user interface friendlier.
- The flexibility of EMTP is also a disadvantage for an engineer who does not have sufficient experience to understand all of its complexities.

## Literature

[1] ATP rule book

[2] J.L. Blackburn; Protective relaying

[3] ETAP 11

[4] Siemens Sigra

[5] D. Dakhlan; Modeling internal faults in three winding transformers for differential protection.

[6] M. Kezunovic; A new ATP add-on for modeling internal faults in power transformers.

## About the Author

**Steven de Clippelaar** is a power system engineer working for DOW Chemical Energy Technology Center.

OMICRON is an international company serving the electrical power industry with innovative testing and diagnostic solutions. The application of OMICRON products allows users to assess the condition of the primary and secondary equipment on their systems with complete confidence. Services offered in the area of consulting, commissioning, testing, diagnosis and training make the product range complete.

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