A Novel Series Capacitor Bank Protection Scheme
Validity Tests

A. Kumar, Member IEEE M. Wokusch
R. Krebs
SIEMENS AG, Germany

S. Hofmann
Technical University, Munich Germany

Abstract - Recent developments in hybrid optical current measuring techniques revolutionize the design of protection schemes of fixed and thyristor controlled series capacitor banks. The scheme, described in this paper, is completely independent of the line current, as an auxiliary power source for the current sensors, as well as for the gap trigger electronics on the platform.

Extensive tests using RTDS were performed to establish the performance of protection. An essential feature of the real-time simulation is the fairly accurate representation of the non linear characteristics of the MOV elements.

The functions tested included: a) Capacitance overload and unbalance b) Line current supervision supplemented by subharmonic current detection c) Gap and Platform Faults d) MOV overload protection.

The tests encompass simulation of different fault conditions including external and internal faults to confirm the design of MOV energy requirements.

Results and detailed discussions of these RTDS – tests are presented in this paper. One section of the paper highlights the different simulation techniques used, to enable the testing of all protection functions.

The reaction of protection on the control strategy of the TCSC scheme is also established during the RTDS tests.

I. INTRODUCTION

Series capacitors are very often used on long transmission lines [1] to

a) produce a substantially flat voltage profile at different loads
b) improve steady state stability limits by increasing the maximum transmitted power
c) act as a reactive power source for the line reactance.

Recent developments in the FACTS-technology permit the use of thyristor controlled series capacitor banks (TCSC) [2] which improve system performance through

i) inhibition of subsynchronous resonance
ii) improved load flow and
iii) Power oscillation damping

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Series capacitors are installed on isolated platforms per phase. They can be split into switchable segments where each segment forms an independent series capacitor installation, permitting different compensation levels. Each installation is protected by MOVs and / or GAPs, a bypass circuit breaker , a control and a protection system.

Control and protection functions plus protective and switching devices are used to protect the series capacitor installation from severe damages due to internal and external faults.

Control functions consist of:

- reinsertion of the series capacitor bank after protective device operation with or without delay (manually or automatically),
- bypass or insertion of the series capacitor bank from ground level controls,
- provisions for connecting external controls (remote control),
- lockout from predetermined protection functions, indication and alarm contacts, interlocking of bank disconnectors and earthing switches.

Protection functions include:

- limitation of maximum capacitor voltage to a predetermined level,
- limitation of duration of sustained capacitor overvoltage to specific level and time,
- monitoring the MOV stresses through energy measurement and subsequent reaction
- monitoring the duration of current through the protective gap
- detection of capacitor unbalance current,
- detection of platform faults,
- detection of gap malfunctioning
- detection of faulty bypass breaker, initiation of transfer trip,
- supervision and detection of faults in the platform to ground signal transmission system,
- loss of power supply (ground level power supply)

Protective and switching devices are:

- capacitor fuses,
- overvoltage limiting devices (MOV and gap as specified),
- bypass circuit breaker,
- bypass isolators (disconnecting switches).

With TCSC installations these control and protective devices are supplemented by ground level thyristor controls and platform mounted cubicles containing the power thyristors.

Developments in sensor technology have mainly contributed to new and effective protection schemes based on optical data transmission and numerical protection algorithms.

On the testing side, the classical transient network analyzer based on analog models is being replaced by RTDS schemes, which use powerful signal processors.

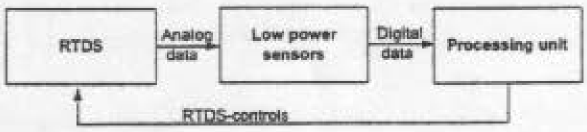
In this paper, the developed protection scheme is briefly outlined. Tests carried out on this protection using a fixed and controlled series capacitor RTDS model are described. An essential feature of the RTDS model is a flexible U-I characteristic of the MOVs, which can be matched to suit different varistor discs.

The entire test set up is an indication of the impact of emerging technology on the future testing practices. The future protection schemes process the digital data outputs of RTDS directly without any need for converting them to analog signals and amplifying them. Consequently, the costs of the future testing equipment will be considerably reduced.

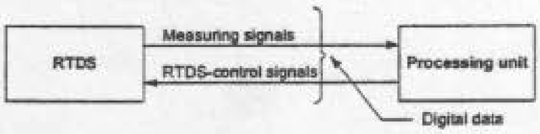
In the scheme described here, however, the input signals to the protection are low power analog signals. Hence, the analog outputs of RTDS can be directly connected to the protection sensors without any need for power amplification.

The present and the emerging testing procedures are illustrated in Fig.1 below.

(a) Present practice for dynamic testing of protection schemes



(b) Testing of series capacitor and HV-DC protection and control schemes using low power sensors



(a) Dynamic testing of protection schemes in emerging technologies

Fig.1 Trends in dynamic Testing Procedure with RTDS

II. CURRENT MEASURING TRANSDUCERS

For protecting the different equipment on the platform, currents in individual components of the series capacitor bank have to be measured.

Earlier practice was to use voltage/frequency converter on the platform, convert the frequency pulses to optical signals and transmit them to the ground based equipment. At the ground level they were converted back to analog measuring signals and processed. The auxiliary power for the platform based electronics was derived from the line current. Even the gap trigger electronics on the platform, needed to trigger the gap, was powered by line current [3].

This system has following characteristic:

a) A minimum line current is required [ca. 0.1 pu] to power the electronics. Below this line current, the bank has to be bypassed.
b) Cubicles are required on the platform containing the auxiliary power supply and converter equipment.
c) Specially designed current transformers and/or the input circuits are required to protect the electronic equipment at high currents.

New developments in sensor technology, however, overcome the above mentioned limitations of line current powered equipment.

The principle of the sensor is shown in Fig.2.

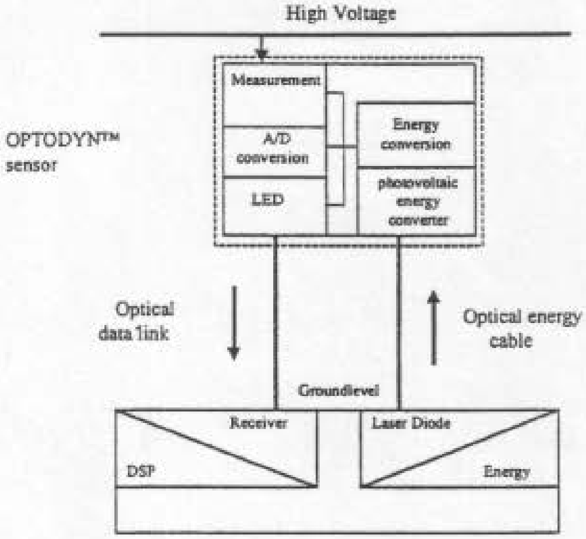


Fig.2 Block diagram of the current measuring sensor OPTODYN™

Current in the high voltage section is transformed by a medium voltage current transformer burdened by a resistance. This voltage is converted to light pulses by an A/D-converter and an LED. The auxiliary power required by the platform based electronics is supplied by a Laser diode at the ground level. The optical energy at a definite wave length received at the platform is converted to corresponding voltages by photovoltaic power converters.

Each OPTODYN™-sensor is equipped with two optical fibre connectors; one for the input light energy and the other for the data of the measuring signal. It is, of course, possible to use a single fibre for both data and energy. However, due to the very high sampling rate used (6 KHZ), it was decided to use two optical fibres.

The electronics on the platform has a very low power consumption (< 50 mW).

The characteristic features of such an hybrid optical sensor are as follows:

a) being very compact in form, it does not require any elaborate housing equipment on the platform. Can be very easily accomodated in CT-terminal box.
b) high sampling rate enables the digital fault recording functions
c) state of the art technology
d) through underrating of the laser diodes, a high life expectancy is ensured.
e) Temperature range of application –50 °C to + 85 °C
f) Negligible signal delay (≤ 150 µs)
g) Burden on main CT ca. 50 mW
h) Max. distance between sensor and ground ≤ 1000 m.

Up to 7 sensors are provided on a platform for current measurement. With TCSC, 2 additional sensors are required. A typical arrangement of these sensors on a platform are shown in Fig.3 below.

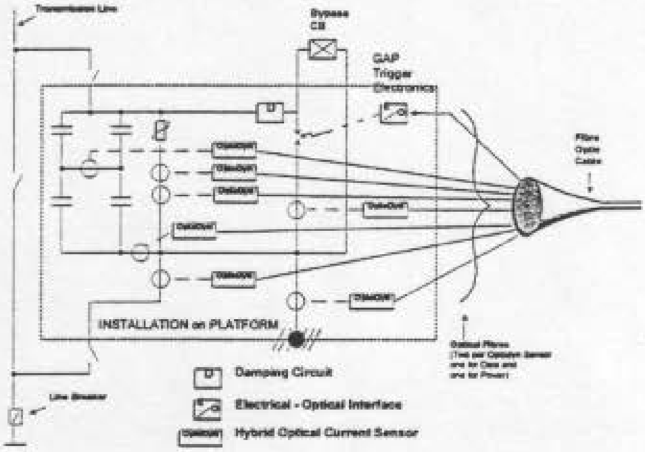


Fig .3 Typical arrangement of OPTODYN-sensors on a platform

II. PROTECTION SCHEMES WITH MEASURING ALGORITHMS

The general architecture of the series capacitor control and protection scheme is shown in Fig.4. Optical measuring signals from the platform are processed by the bank protection unit SIMPROT 98. Depending upon the type of fault, four reactions are possible:

a) Bypass command to the breaker followed by reinsertion
b) Trigger signal to the gap
c) Permanent lock out of the bypass breaker
d) Line trip due to bypass breaker fail

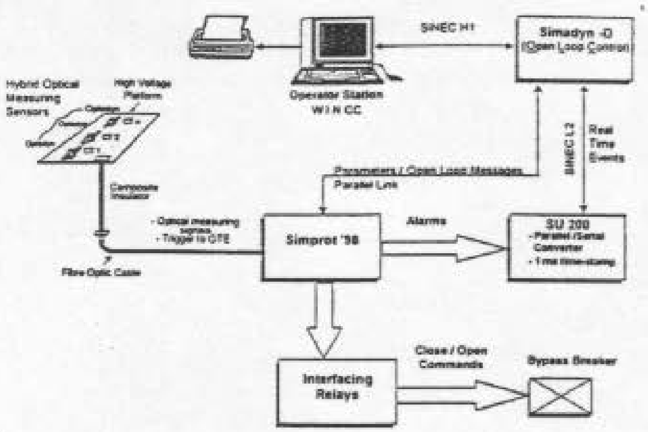


Fig .4 General Architecture of the series capacitor control and protection scheme.

Besides these commands, the protection unit also provides alarm outputs for real time event recording and sends messages to the WINCC(Windows Control Centre) based HMI(Human Machine Interface), for logging purposes.

An open loop control interacts with the substation switchgear to open and close disconnectors, earthing switches and bypass breaker with interlocking facilities.

Protection settings are done via WINCC.

III. PROTECTION SCHEMES WITH MEASURING ALGORITHMS

The bank protection system SIMPROT includes following functions:

a) Capacitance unbalance and overload
b) Gap and Platform faults
c) Line current supervision and pole discordance
d) MOV overload protection
e) Bypass breaker fail

IV. CAPACITANCE UNBALANCE

The capacitance unbalance consists of two stages i) alarm and ii) bypass.

Both stages are stabilized by the capacitance current.

Fundamental frequency components are calculated for both the unbalance current and the capacitance current using a one cycle window.

The capacitance cans are grouped to a H-connection (see Fig.3) and the unbalance current is measured by a CT in the H-link.

The pick up characteristic of the capacitance unbalance protection is shown in Fig.5.

Both the slope as well as the unbalance current threshold can be individually set for the alarm and the bypass stage.

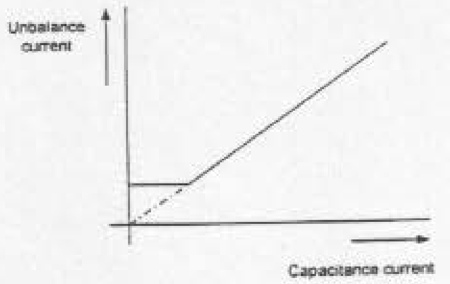


Fig .5 Pick up characteristic of capacitance unbalance protection

V. CAPACITANCE OVERLOAD

The overload cycle can be set as desired. Following three possibilities are provided:

i) IEC 143
ii) IEEE std 824 – 1994 and
iii) Customer specific

With TCSC installations, an additional output is provided to reduce the impedance through firing angle control, if overload picks up, before giving a close command to the bypass breaker.

VI. GAP PROTECTION

Gap is triggered only by the MOV-overload function. If triggered, the gap has to be supervised to ensure its proper functioning.

Following supervisions are included:

i) Gap self trigger
ii) Gap refused to trigger
iii) Gap delayed trigger
iv) Prolonged conduction

If there is a self trigger of the Gap, the protection unit closes the bypass breaker temporarily and initiates reinsertion. Such situations are generally possible on external faults, where the voltage across the gap is sufficient to flashover, if triggered. However, in a well designed protection the MOV-protection does not issue any gap trigger signal, since the MOVs are designed not to be overloaded on external faults.

In cases ii) and iii) permanent closing of the bypass breaker results, since these situations indicate a defect in the gap circuitry warranting maintenance.

Normally, it is the practice to give a trigger signal to the gap and the closing command to the bypass breaker. If the bypass breaker operates properly the current commutates from the gap to the bypass breaker. If, however, the bypass breaker fails to close, the current through the gap flows longer than it should, indicating prolonged conduction. Under these conditions, it is generally the practice to trip the line.

VII. LINE CURRENT SUPERVISION

Line currents are monitored for the following functions:

a) Some utilities bypass the capacitor if the line current is below a set limit
b) Reinsertion of the capacitor bank after successful clearance of internal faults may be desirable only if line currents are within certain limits.
c) Bypass,if subharmonic currents above a set value are detected in the line currents.

Subharmonic currents generally are a result of switching on an unloaded transformer, with series capacitors in the circuit.

VIII. MOV-OVERLOAD PROTECTION

One of the very important and fast protection function is the MOV-overload detection.

The MOVs are generally designed to absorb a certain amount of energy on external faults. The protection does not normally pickup under these conditions. On internal faults, however, the permissible energy may be reached very fast due to higher fault currents. In this case, the protection gives a trigger signal to the Gap and/or simultaneously issues a close command to the bypass breaker.

Depending upon the utility practice, the bypass may be single or three phase.

The MOV-temperature is continuously monitored and if it exceeds a set value, the gap is triggered and the bypass breaker closed.

Reinsertion is permitted only if the MOV-temperature is below a set value. Summarizing, the MOV-protection includes following functions:

a) current monitoring and Gap trigger/Bypass
b) continuous temperature calculation, comparison with a set value and Gap trigger/Bypass
c) Monitoring of energy gradient (instantenous power) and reactions like a)
d) Temperature controlled Reinsertion

IX. BYPASS BREAKER FAILURE AND POLE DISCORDANCE DETECTION

Since the above mentioned functions give a closing command to the bypass breaker, this must be supervised for failure. The classical method of failure detection through current monitoring is used. If bypass breaker fails, one could trip the line or issue a close command to the bypass disconnect switch. The advantage of the second method is that the line remains in service without compensation. The drawback of this method, however, is that the contacts of the disconnect may get welded due to closing with heavy current, hence demanding its replacement during the next maintenance cycle.

Another protection function associated with the bypass breaker is the pole discordance function. The poles are supervised for unsymmetrical operation. If pole discordance is detected, the reaction is similar to the breaker fail situation. If single phase bypass is practiced, the time delay for pole discordance detection is set higher than the maximum reinsertion delay.

either the breaker or fault 1 is closed. When the breaker or fault 1 is closed, , the breaker or fault 1 will conduct all of the current and the gap will conduct none. If the breaker is closed, then neither the fault 1 nor the GAP will conduct any current.In the RTDS model used, current starts flowing through the gap 70 µs subsequent to receiving the trigger signal.

8. RTDS provides normally open and normally closed binary outputs to signal the position of the bypass breaker. These contacts can be delayed as required to match the bypass breaker.
9. It is possible to set the closing and opening delay for the line and bypass breaker. The breakers themselves are simulated as three single pole units with pole selective opening and closing coils.
10. The arrester model operates according to the following V- I characteristic equation (in quadrant 1) where Id and Vd are the crest discharge current and voltage respectively.
    Fig.7 shows the shape of the characteristic.

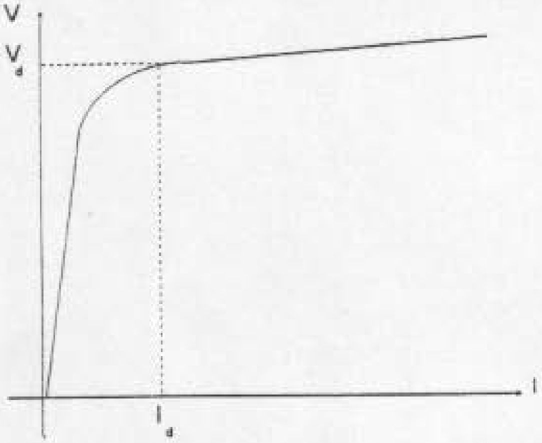


Fig.7 Voltage - Current characteristic of the arrestor model

The characteristic equation is

$$I = I_d \left[V / V_d \right]^N$$

The model will allow the user to select values of N between 2 and 32. However, a very high value of N means that the curvature of the arrester characteristic at the knee point is very high. Since the cooling of the arrester takes hours, the simulation of the arrester cooling is not included in the model. The correct choice of I_d , V_d and N is made by matching the characteristic of the actual varistor with the characteristic simulated in RTDS.

11. As can be seen from Fig.6, measuring points are platform current, Gap current, total Capacitor current, capacitor unbalance current, line current and, 2 x arrester current.
    These measuring points are indicated as >.

XII. TEST PARAMETERS AND LINE MODEL

The test setup is shown in Fig.8. The actual CT ratios are matched with proportional RTDS factors.

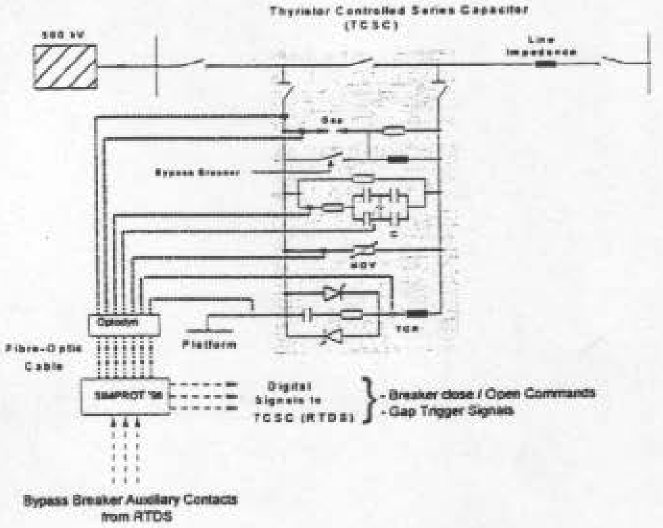


Fig.8 Test Set up with OPTODYN and SIMPROT

Voltages proportional to the matched current values from RTDS are input to the corresponding OPTODYN - sensors, which convert these voltages to corresponding light pulse telegramms. These light pulses are transmitted by optical fibres and input to the protection unit SIMPROT '98.
The network is modelled as shown in Fig.9.
The short circuit level of both the sources are 15 GVA. The compensated line is 200 kms and the other line is 100 kms long.

The parameters of the arrester characteristic (Fig.7) have been determined from the data of the actual arrestor and are Vd = 240 kV, Id = 4600 A .

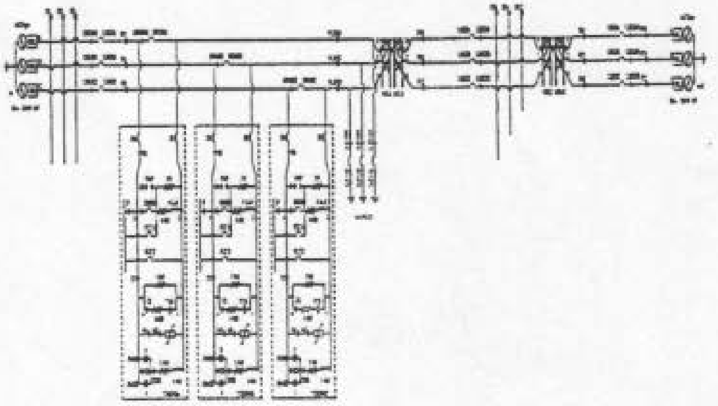


Fig.9 Simulated Network

X. SOFTWARE DESIGN

Software for each Protection Unit consists of three main parts:

- Fast Task (Measuring signal sampling rate) for measuring (interfacing of hybrid optical sensors OPTODYN™) and evaluation of measuring values. Depending on the protection unit, this includes reactions to instantaneous values (e.g. gap trigger commands via fiber optic output), calculation of RMS values and a thermal model observing the MOV disc temperature.
- State control task providing the appropriate reaction to values preprocessed in the fast task. There is one unified basic state chart for all protection units, supplemented by functions required for the special purpose. This basic state chart contains common protection reactions such as bypass/lockout, reinsertion and line trip commands as well as a sophisticated self monitoring strategy (e.g. concerning sensoring troubles).

  By using state control architecture, easy testing and commissioning is guaranteed. The software design is easily comprehensible and diagnosis of sequence of events is supported by an internal trace buffer for recent states.

  Fast communication for real time messages is also included in the control task.
- Background task for parameter handling. This part of the software contains communication with the operator/HMI for changing and storing protection settings. Settings can easily be changed by dedicated HMI screens (including an archive function) and are transmitted to the protection units via a fiber optic link. Every protection unit stores its parameters in an EEPROM. There are checkback communication channels to make changes of settings fail safe. Storage into the EEPROM is being supervised for correct performance.

XI. DETAILS OF THE TCSC MODEL

The protection functions detailed described above were tested elaborately with the following RTDS model, which is shown as a single phase representation in Fig.6.

1. The Thyristor Controlled Reactor (TCR) has been implemented in the TCSC model so as to provide improved firing accuracy. The model also supports BOD-firing.
2. The TCSC model includes two platform disconnectors
3. Two switches Fault 1 and Fault 2 are also included to simulate platform faults. These two fault switches are connected from either side of the damping reactor to the platform. A measurement of current to the platform through a measuring device simulates the current transformer.

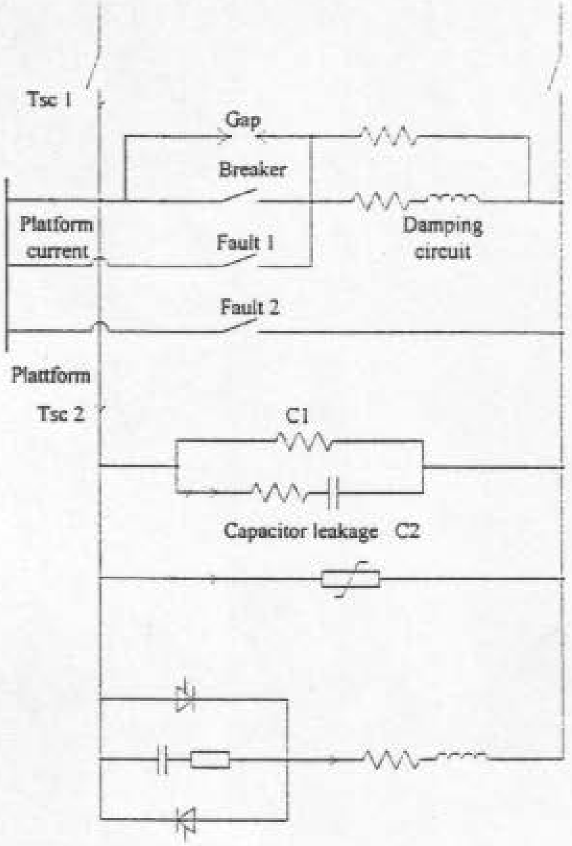


Fig.6 TCSC Modelled in RTDS with current measuring points and fault locations for platform faults (one phase representation)

4. Two measurements of arrestor current are created.Each can be multiplied internally by a user specified factor before output. The signals can be provided to D/A output channels, or monitored in run time. In the actual series compensating equipment these signals correspond to the low and high range CTs in the arrestor circuits.
5. Two measurements of capacitor current are created shown as C1 and C2 in the figure. The current C2 is the capacitor leakage current and corresponds to the capacitor unbalance. This current can be set to a desired percentage value of the main capacitance current.
6. The arrestor model has the ability to calculate the energy accumulation. It is also possible to switch the arrestor model ON and OFF. When the arrestor model is switched OFF, the accumulated energy is set to zero.
7. The main gap includes a damping circuit which damp the current oscillations when the gap is fired. The GAP will not fire unless the voltage across the gap is above a user specified magnitude. It will not recover until the current is lower than a user specified level for more than a user specified time period.The GAP, bypass breaker and Fault 1 are all in parallel. If more than one of these units is conducting at a given time, then the current through the damping circuit is assigned completely to one unit with a priority order of breaker, fault 1 and GAP. For instance if the GAP is fired, it will conduct all of the current until

Protection function	Test condition 1	Test condition 2	Test condition 3	Test condition 4
capacitance unbalance	Unbalance current Below alarm level	unbalance current above alarm level but below bypass level	unbalance current above bypass level without breaker failure	unbalance current above bypass level with breaker failure
Result	No alarm	alarm after set delay, no bypass	Bypass and no line trip	Bypass with line trip
Capacitance overload	overload cycle as specified with Reinsertion	Overload cycle as specified with Reinsertion blocked	-	-
Result	Bypass and Reinsection after set delay	Bypass and no Reinsection	-	-
Platform Faults	Fault with low Fault current and no breaker failure	Fault with low Fault current and breaker failure	Fault with high fault current and no breaker failure	Fault with high fault current and breaker failure
Result	Bypass after set definite time delay and no line trip	Bypass after set definite time delay and line trip	Fast bypass without line trip	Fast bypass with line trip
GAP-unit	self trigger with Reinsertion	self trigger with reinsertion blocked	Prolonged conduction	Delayed trigger
Result	Bypass with Reinsertion after set delay	Bypass with no Reinsertion	Bypass with line trip	Permanent lock out of bypass breaker
Line current unit	Pole discordance one pole	Pole discordance 2 poles	current without permit/present Reinsection limits	current within permit/present Reinsection limits
Result	Permanent lockout	Permanent lockout	No Reinsertion possible	Reinsertion possible

TABLE I: Protection Tests and Test Conditions

Testcase	**Result**
a) External 1-phase, 2-phase and 3-phase faults with successful reclosure (fault duration = 100 ms, dead time = 0,5 s)	MOV-protection did not pick up, since the current and energy level were below the pick up level
b) like a) with unsuccessful reclosure	Same as a)
c) like a) with line breaker fail (fault duration = 300 ms)	Same as a)
d) Internal faults with fault types like in a) with successful reclosure (fault duration = 100 ms, deadtime = 0.5 ms)	Gap trigger in faulty phase and command to bypass breaker. On low line current, no gap trigger but only command to bypass breaker
e) Internal faults with unsuccessful reclosure	Same as d)
f) Internal faults with line breaker failure	Same as d) Reinsertion was not possible since temperature > set value of 65 °C.

TABLE II:Protection Tests and Test Results

XIII. ADAPTATION OF RTDS AND DISCUSSION OF FAULTS

In order to test the performance of all protection functions different adaptations of RTDS were necessary. The challenge on simulation side was to create a highly flexible simulation tool that allowed to investigate the variety of protection functions under different fault conditions. The following analog and digital signals were needed for validity tests with RTDS:

Analog output signals:

- Line current
- Gap current
- Platform current
- Capacitor and capacitor unbalance current
- Arrester current of low ratio and high ratio current transformer

Digital input signals:

- Gap triggering signals (single-phase)
- Signals for bypass breaker closing (single-phase)
- Signals for bypass breaker opening (single-phase)
- Signals for line breaker opening (three-phase)
- Signals for line breaker closing (three-phase)

Digital output signals:

- Bypass breaker status signals (single-phase)

Line and bypass breakers were opened and closed with a delay time of 50 ms. The gap was modelled as a circuit breaker with a variable delay time for closing. This delay time normally was set to 70 µs (time step size). If a bypass breaker was closed current flow through the corresponding gap was no longer possible. To reach a high level of flexibility each breaker as well as each gap could be actuated either by the protection device or by the sequencer of RTDS. The compensated transmission line was modelled as a travelling wave line model with RLC input. The time constant of the simulated transmission line was 50 ms.

The tests carried out on the protection system and the test conditions are sumarized in Tables I and II.

To illustrate the effectiveness of RTDS and establish the performance of the protection system, certain typical fault cases are documented here with the corresponding printouts from RTDS.

General comments

From the curves for the MOV-current and the capacitance current, following conclusions can be drawn:

a) If the MOV conducts, the capacitance current reduces to zero and the entire fault current commutates into the MOV.

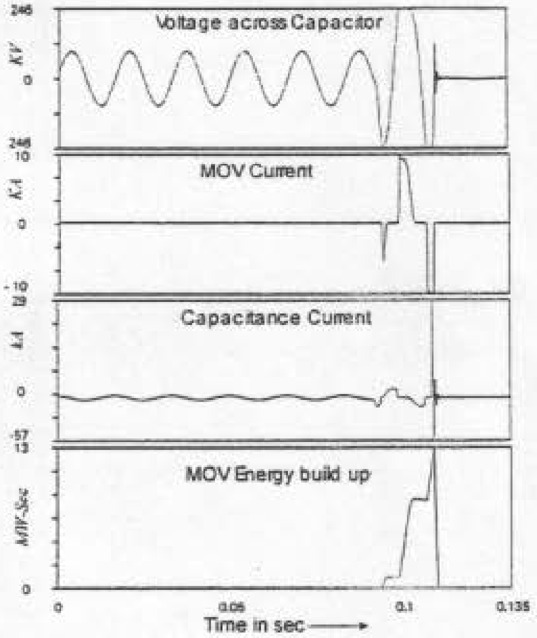
b) As long as the MOV conducts, the voltage across the capacitance remains constant.

c) The MOV-energy increases only during the conducting durations of the MOVs. If the current through the MOV reduces to zero, the energy gets clamped due to the very large cooling time constant of the MOV-arrangement.

6 cases are discussed here:

Case 1: Internal Line fault with successful autoreclosure (Fig.10)

The MOV energy reaches a value of 13 MJ within a time < 20 ms, due to high fault current. The gap trigger signal and a bypass breaker close command are issued as soon as the MOV-current exceeds the set value.A reinsertion command is issued by the series capacitor protection system after a set delay of 0.5 sec. The bank gets successfully reinserted, since the line fault gets successfully cleared.The oscillatory nature of the capacitance voltage and current is due to its discharge into the gap through the damping circuit.



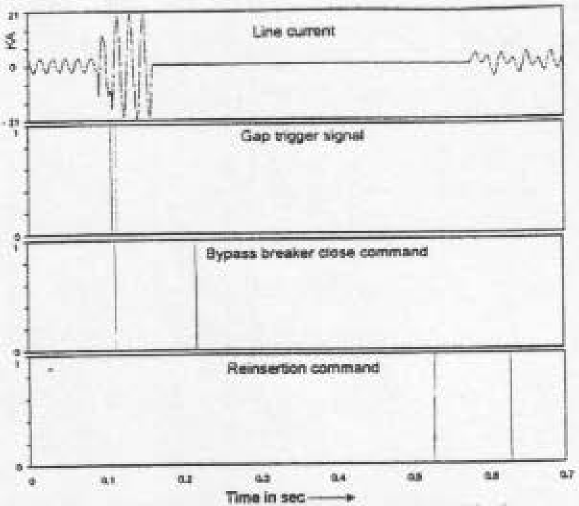


Fig.10 Currents and commands on internal faults

Case 2 : External Phase to Phase fault with successful autoreclosure (Fig.11)

The series capacitor protection does not issue any commands or gap trigger signals, since the fault is on the adjacent line. The energy reaches a value of 13 MJ during the fault duration of 100 ms.

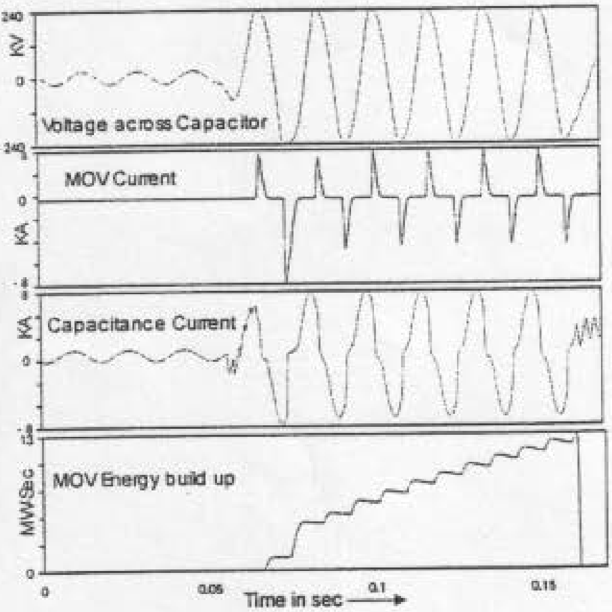


Fig .11 Capacitance voltage current and MOV energy on external Phase to Phase faults with successful reclosure

Case 3 : External Phase to Phase fault with unsuccessful autoreclosure (Fig.12)

Fig.12 shows the measuring signals on an external fault with unsuccessful reclosure.The behaviour of protection is the same as in Fig.8. During the dead time, the capacitance current and line current are identical and equal to the line charging current.

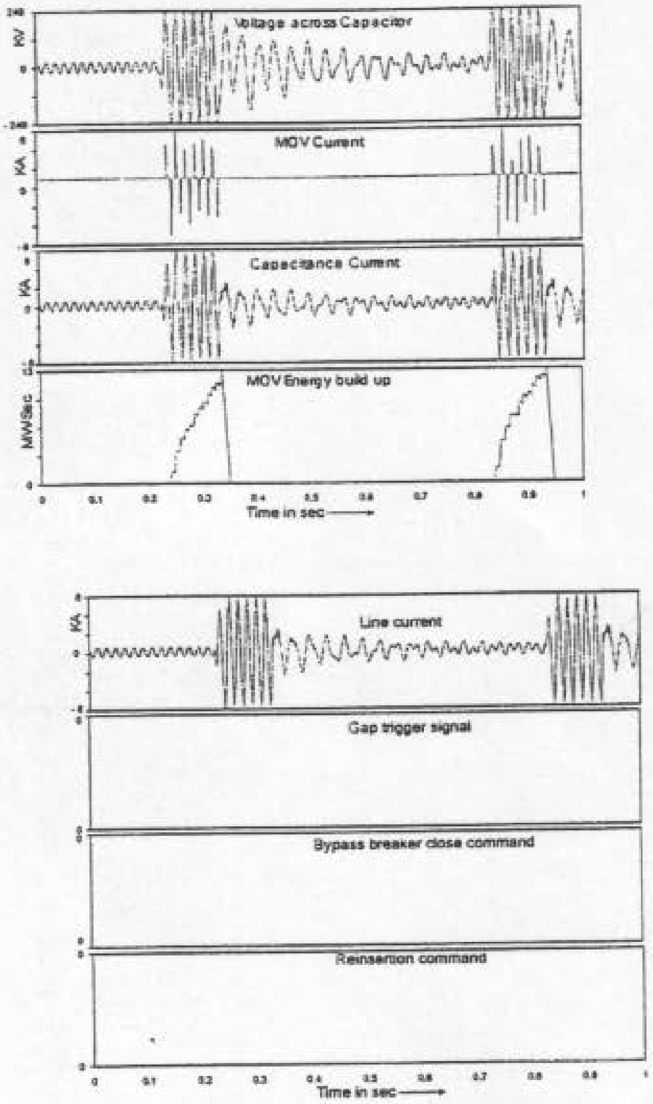


Fig.12 External phase to phase fault with unsuccessful auto-reclosure

Case 4: Capacitance unbalance fault without breaker fail (Fig.13)

Fig.13 is a case of capacitance unbalance current pickup.The unbalance current is simulated by manipulating the capacitor leakage resistance in Fig.6. The protection gives a bypass breaker close command after the set delay of 100 ms. At the instant of breaker closing the capacitor discharges into the bypass breaker, as can be seen by oscillations in the capacitance current.

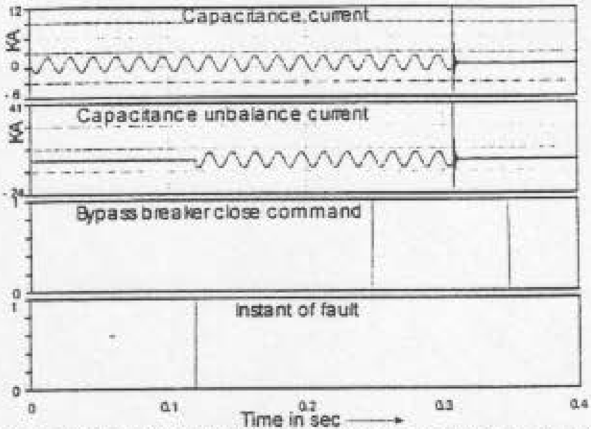


Fig.13 Performance of capacitance unbalance protection – bypass stage

Case 5 : Capacitance unbalance fault with breaker fail (Fig.14)

In Fig.14, the unbalance protection gives a close command to the bypass breaker, which, however, fails to close depicting a breaker fail condition. The logic in the series capacitor, protection scheme recognizes this situation and issues a line trip after a set time delay of 200 ms.

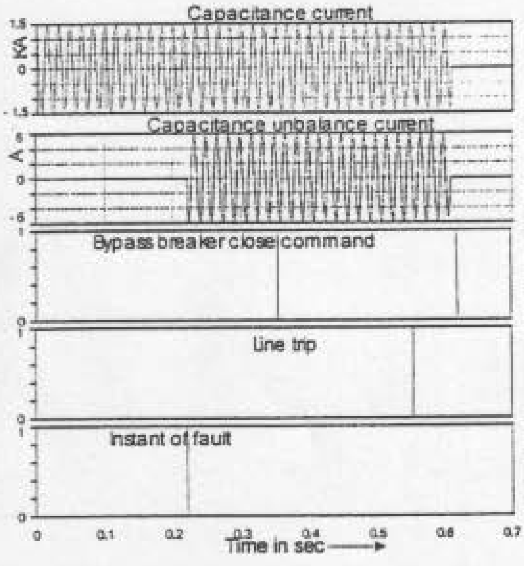


Fig.14 Performance of capacitance unbalance protection – bypass stage

Case 6 : Platform fault (Fig.15)

A platform fault is simulated on the RTDS. As can be seen from Fig.15, a very high instantaneous current flows through the platform CT, due to capacitor discharge into the platform. The protection issues a bypass command to the breaker. The platform current stops flowing as soon as the main breaker contacts close.

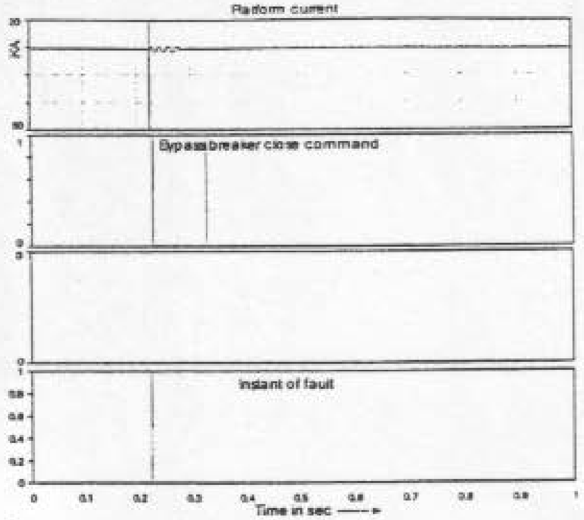


Fig.15 Currents and commands on platform faults

XIV. CONCLUSION

This paper establishes the performance of a new hybrid optical sensor based series capacitor protection scheme with tests on a powerful RTDS system. The modelled RTDS enables the representation of TCSC in all its details. A companion paper [4] presents the details of the TCSC model and the test results. New sensor technology combined with RTDS is a pointer towards new trends in dynamic testing of protection systems. Such emerging technologies simplify the test set up and procedures considerably. Even though, this report covers the testing of series capacitor protection systems, it is possible to extend this procedure to normal line relays as soon as these relays are available for the new optical and hybrid optical sensors.

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XVI. BIOGRAPHY

Stefan Hofmann was born in Nuremberg, Germany, on January 24, 1972. He received his Dipl.-Ing. degree in Electrical Engineering from the University of Erlangen in 1998. After finishing his studies he joined the Power Transmission and Distribution Department of Siemens AG in Erlangen. Since 1999 he is working in the Power Electronics and Electrical Drives Department of the Technical University Munich. His current interests include identification and control of nonlinear dynamical systems

Rainer Krebs was born in Pfledelbach, Germany on January 19, 1958. He received his Dipl.-Ing. degree in Electrical Engineering and Power Systems in 1982 and the Dr.-Ing. degree in 1990 from the Friedrich-Alexander University,in Erlangen.

He joined the 'Institut für Elektrische Energieversorgung' at the same University in 1983, working on calculation and measurement of power-system disturbances and unbalances, using space-phasor theory. In 1990 he joined the Siemens AG in Erlangen as a member of the System Planning Department. He started his work in the fields of power-system planning, power-system relaying, system and protection real-time simulation and fault analysis. Since 1998 he is head of the department 'Protection Design and Coordination'.

He is member of VDE, its associated section ETG and CIGRE.

Anil Kumar (M'64) received his B. Tech, ME and Ph. D from the Indian Institute of Science Bangalore in 1962, 1964 and 1969 respectively. From 1970 to 1972, he was a post doctoral fellow of the Alexander von Humboldt Foundaton at the technical university of Braunschweig, Germany. From 1973 to 1995 he was with the Protection Department of Siemens, Germany. Since 1995 he has been with the high voltage department as a senior project manager for HV AC and DC innovations. He has been involved in the design and development of digital protection systems from the beginning. In his 26 years service with Siemens, he has also carried out design and sales work for EHV line protection and customer oriented design tests of protection schemes on the AC/DC Simulator.

From 1980 to 1990, Dr. Kumar was a member of the CIGRE Working Groups 34.01 and 34.02 dealing with digital protection and control of power systems. He is a member of the IEEE and PES.

Michael Wokusch was born in Erlangen, Germany, on March 25, 1967. He received his Dipl.-Ing. degree in Electrical Engineering from the University of Erlangen in 1991. After finishing his studies he joined the utility Fränkisches Überlandwerk AG in Nuremberg, working in the field of regenerative energy sources. In November 1992 he joined the Drives and Standard Products Group of Siemens AG in Erlangen. From 1997 to 1999 he was with the Power Transmission and Distribution Group of the same company. In February 1999 he joined the Automation and Drives Group of Siemens. His current scope of interest includes innovative concepts for frequency converters and digital control systems.