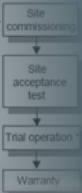


FAT \* of system equipment



\* optional

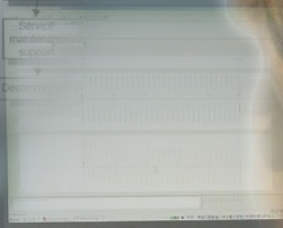
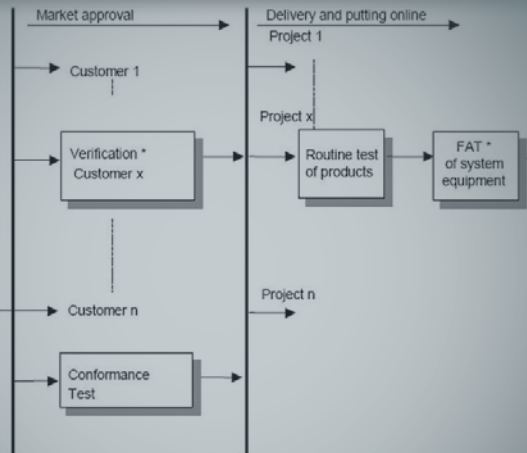


ABB WINTER 2009



\* optional

# Philosophy

A system of principles for conduct of life.



# Testing Philosophy

## The Numerical Relay Perspective

An old Chinese saying ... “You can't do today's job with yesterday's methods and be in business tomorrow.” Are you testing numerical relays using the same philosophy and practices used for electromechanical or static (EMS) relays?. If the answer's YES, it's time to update your philosophy for testing numerical relays so as to benefit from their important attributes and testing capabilities. This can significantly reduce the amount of testing and thus, realize savings in cost and time, and more efficiently use testing resources. Ultimately, these actions are key business drivers in today's competitive world.

LET'S REVIEW THE EVOLUTION OF the protection relay, examine the key attributes of numerical relays, then update the testing philosophy, and finally verify it against actual in-service failures.

A protection system clears HV faults within its operating zone/range of the electricity network, must not trip for through faults. The system comprises HV CBs, CTs, and VTs, protection relay, protection signalling (if required), circuitry and control equipment necessary to clear the fault and indicate operation or basic system failure, eg trip circuit monitoring, VT supervision. The protection relay undergoes rigorous testing because it directs protection signalling, CB tripping and other back up and control functions such as CB fail or auto-reclose.

### Definitions

We need some definitions so that we're all in phase.

**Philosophy** is defined as “system of principles for conduct of life”. A protection example is “dependability of protective scheme operation has precedence over security of supply”. This is based upon the fact it's easier to restore incorrectly tripped plant

than damaged plant or a ‘blacked out’ electricity network.

**Numerical protection relay** is a fully digital relay utilizing microprocessor technology with analogue to digital conversion of the measured values and subsequent numerical processing by computer programs.

**Measurand** is a measured analogue quantity at the relay's input terminals, eg AC voltage.

**Operand** is a relay's internal value derived from a measurand(s) and it's processed in an algorithm, eg a phase differential current.

### Electromechanical & static technologies

The protection relay has evolved from ‘dumb’ electromechanical (eg Brown Boveri L8 or LZ3) or static relays (eg transistor based Reyrolle THR, IC based BB LIZ6) to an “intelligent”, self monitoring, communicating, numerical protection relay (eg SEL 421, Areva P44x, GED60).

For EMS technologies, the testing philosophy was based upon proving the integrity of the relay's operating characteristic and operating time for each fault type against the

manufacturer's specification. This philosophy was verified or updated according to results from acceptance testing / commissioning or in-service failures. The failure mechanisms were diverse between technologies, types of relays, manufacturers and age of hardware. Here are some interesting examples which were all hidden failures:

- Degradation of zener diode VI characteristic in a static bias differential relay (shown in Figure 1 as ‘Relay failed characteristic’) on 1 phase;

- Drying out of electrolytic filter capacitors in a power supply (increased ripple voltage affected comparators in static relay) (all phases);

- Degradation of insulated cam of (electro-mechanical) induction cup comparators by sunlight over 10 years caused variable pick up performance on 2 phases;

- Verdigris of copper in second harmonic filter inductor allowed random tripping by electromechanical bias differential relay when the associated power transformer was energized (filter should have increased restraint operand – 1 phase).

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## The existing testing philosophy and practices for EMS technologies are still relevant.

In summary, testing was aimed at detecting incorrect ratings and setting(s), inaccurate performance or failure in one or more protection elements in the relay. This was a reflection of the relay's use of analogue signals, its variability or failure on a single phase basis and its rudimentary self supervision function which usually consisted of a 'loss of DC supply' alarm.

### Numerical relay

**Attributes and Capabilities:** The numerical relay is based upon microprocessor technology and its basic architecture is shown in Figure 5. This technology measures the measurands in an A/D converter and passes these numerical values to computer programs called firmware. The program contains the protection algorithm which determines if an 'in zone' fault exists.

Let's look at the attributes of numerical relays which affect testing philosophy and practices:

- Self supervision function is more

comprehensive with monitoring covering 80–90% of the protection relay 5. The major areas being supervised are the power supply, microprocessor, A/DC and associated components. An in-service example of its effectiveness is shown in Figure 4 where the relay has detected a fault, failed to a safe state and activated its "relay fail" contact;

- The relay measures AC inputs and calculates operands (eg 'A' phasor current, 'A' phase differential current, I<sub>2</sub>, I<sub>0</sub>) and displays their values. This function is extremely important in determining the relay's correct operation because of the 'garbage IN, garbage OUT' principle, ie incorrect phasor VI measurements guarantees incorrect relay operation. However, the following experiences have forced changes to the 'measurement display test'. (This shows testing is also reviewed against and shaped by in-service faults.)

- Some relays 'seamlessly' switch between input ranges, eg 0–2A, >2A. Hence the manufacturer must provide details and then the measurement display test is performed on each range;

- A relay had a bug which appeared as a 'split personality' between 1A and 5A ratings. Figure 6 shows a 1A relay measuring input current correctly (301A for single input injection) but the operands

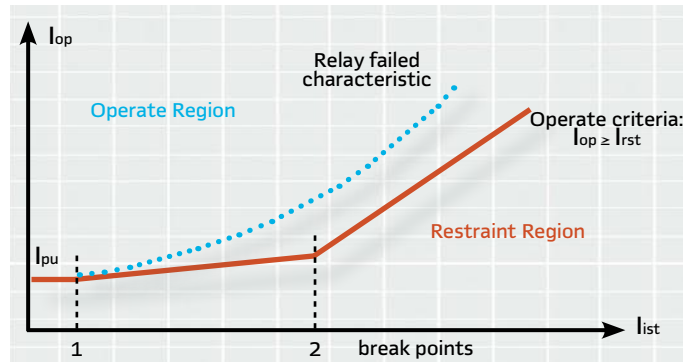
for differential protection were referenced to a 5A rating (0.1A calculated instead of 0.5A). Hence this shows the operands must be carefully checked for accuracy.

- Relay application programs (firmware) provide protection functions which are executed in supervised algorithms which consist of equations and logic statements. In addition, numerical phasor quantities are passed to a common protection program module for processing all the similar fault combinations, eg A-n, B-n;

**This is an extremely important point** - once the firmware function has been proven to operate correctly (note this means no bugs), it will always operate within limits provided the relay measures correctly, self supervision function doesn't find a fault, I/O is not damaged, and the firmware remains unchanged. This is also true for all relays of the same type, hardware, firmware and settings. From experience, a bug in a numerical relay becomes evident when a unique sequence of events are executed. The hard part is finding the sequence and type of events to 'turn it on'.

- Manufacturers' application software is used to set the relay's protection functions and to generate a setting file which requires specifying the exact model

## 1 Biased differential relay characteristic



## 2 Examples of distance relays

Electromechanical



Microprocessor



## The significant differences between numerical and EMS technologies clearly demonstrate the need to create a new testing philosophy.

code (including options and ratings);

■ The setting file is downloaded into the relay from a computer and its integrity is confirmed (by software) by comparing the relay's settings and model code against the original file. Therefore, there's negligible chance of incorrect settings being applied by the test technician or the wrong model relay being used.

However, there's still the possibility the protection designer made a gross error such as not turning on a required protection function, misunderstanding a function's description in the relay manual, or a misplaced decimal point. Testing should check for these errors;

■ The high functionality of numerical relays can provide beneficial testing aids such as event records, a test mode, multiple setting groups, programmable LEDs, numerous binary inputs and outputs. All these can provide

excellent indications or test functionality for the test technician and automated test equipment. However, these functions must be suitably and correctly set by the protection designer and not left to test technicians to add in and then remove – this jeopardizes the integrity of the test process and it's unacceptable to a quality system such as ISO 9001.

In addition, it's very beneficial for the protection setting file and custom logic to be given unique serial numbers which are imbedded into the files. This simplifies traceability and change control requirements.

A word of warning on testing new protection algorithms which can use very complex operands – make sure the selected test method does not compromise the relay's performance. That is, the differences between test quantities and true fault quantities must have no or minimal effect upon the relay's operation. An example

is a microprocessor based test set can start a test anywhere on the sinusoidal waveform(s) without a complementary transient. This is unacceptable for fast tripping, distance relays such as SEL 421 and Areva P442.

**Summary:** The following important attributes will shape your testing philosophy for numerical relays:

■ The relay's measurement display function will prove the relay measures the AC inputs and calculates operands correctly for each phase. Where necessary, this test will be repeated for each input range as defined by the manufacturer. In addition, this function is very useful for the final load check of the protection scheme; especially line differential schemes where the remote currents can be displayed locally;

■ The protection functions are performed in firmware execution with VI numerical values (not VI analogue quantities). Hence, one or two strategic tests in each range of the function's characteristic will ensure correct setting and relay operation. This will also check for gross design error(s) if checked against the specified required value;

■ The relay's performance for each phase will be identical for the same value of phasor input quantity.

The new testing philosophy gives the possibility to greatly simplify and reduce the amount of relay testing without reducing the confidence level for correct operation.

### 3 Suggested test points on a biased differential characteristic



### 4 SEL 321 self supervision report:

Showing the detection of a faulty power supply and the disablement of the relay

T319 GLADSTONE NORTH-FDR 710 Date: 11/25/07 Time: 15:44:34.646  
 SELF TESTS  
 W=Warn F=Fail

	IA	IB	IC	VA	VB	VC	MOF
OS	0	0	0	1	0	0	0
	+5V_PS	+5V_REG	-5V_REG	+12V_REG	-12V_REG	+15V_PS	-15V_PS
PS	4.96	5.00	-5.06	10.05F	-12.09	14.92	-14.8
	TEMP	RAM	ROM	A/D	CR_RAM	EEPROM	SETTINGS
	39.0	OK	OK	OK	OK	OK	OK

**RELAY DISABLED**

The reasons are:

- where stated by the manufacturer, all protection settings are common to each phase;
- the firmware passes phasor quantities to a common routine in the program to perform the protection function in immutable equations or logic statements.

These facts enable a test on each phase to be strategically applied to each range of a characteristic as shown in Figure 3 for a transformer biased differential relay. This simplifies testing but still confirms settings;

- Standard template for settings and custom logic will be preferably used and given version numbers for control purposes. This template will undergo comprehensive testing to give functional and operating time assurance;
- The verification of downloaded setting file will ensure the settings

were correctly applied to the correct relay model;

- The protection design should provide test functionality to aid the test technician, indicate which protection functions are operating for this test, and provide test event records for test report.

**Revised testing philosophy**

The preceding sections have demonstrated the important differences between old technology relays and numerical relays, and the advantages of a prudent business strategy. Let's use these considerations to review and where necessary, replace the existing testing principles (see table 1).

**Test confidence**

All testing must give acceptable confidence that the protection system or relay will operate correctly. Obviously, any change to testing philosophy preferably should not reduce the confidence level. Let's examine its confidence

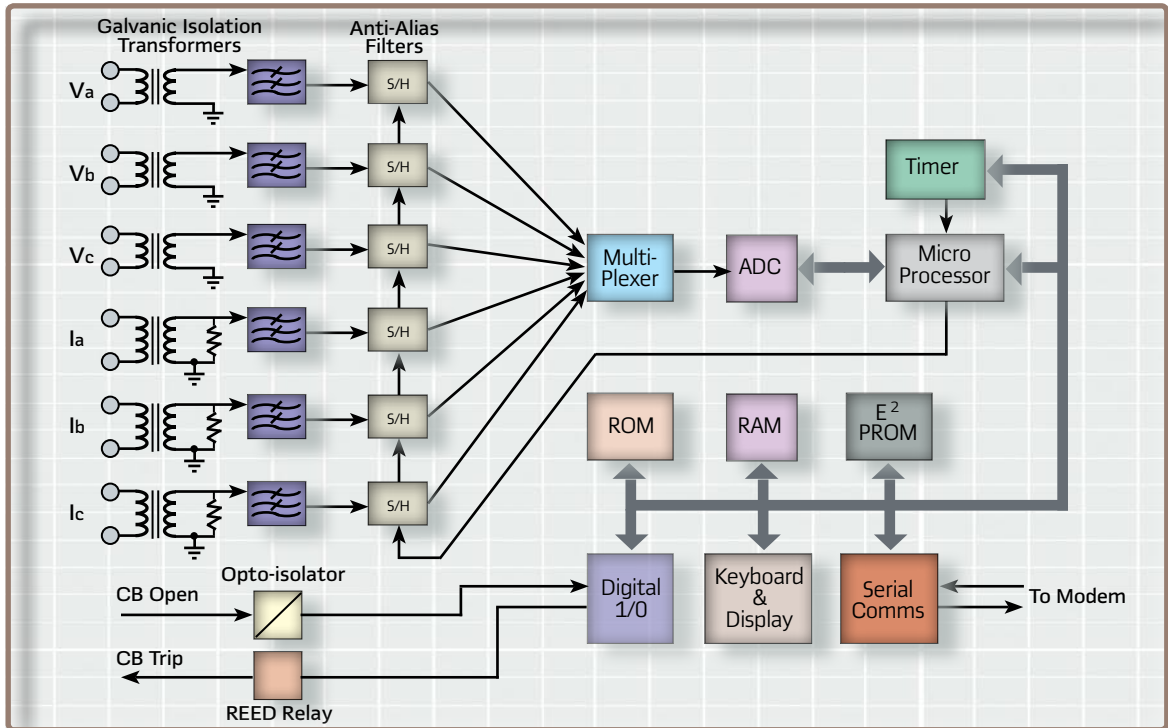
**6 Display report:**

The measurement display report is showing a firmware bug

Current Transformer Ratio					
CT R1=	600	CT R2=	600	CT R3=	600
CT R4=	600	CT R5=	600		
Current Normalisation Factor					
TAP01=	1.0	TAP02=	1.0	TAP03=	1.0
TAP04=	1.0	TAP05=	1.00		
Primary Currents					
Terminal	MAG(A)	ANG(DEG)	Terminal	MAG(A)	ANG(DEG)
FDR_1	301.811	0.00	FDR_2	0.429	178.57
FDR_3	0.528	155.11	TRFR_1	0.224	159.47
CB_1	0.197	52.08			
Differential Values (Sec. Per Unit)					
Operate Currents		Restraint Currents			
ZONE	IOP	IRT			
A	0.10	0.10			
Current Reference (A) I PU = 600					

level against experienced faults from either as received or in-service events. The failures which are shown in Table 2, occurred over a 15 year period with numerical relays. The fault cases from table 2 show the updated testing philosophy will yield the same results. The No response applies to both philosophies in all cases. See Figure 7, 8 and 9. ■

**5 Basic architecture of microprocessor technology**



The protection functions are performed in robust firmware routines using numerical values in immutable equations or logic statements.

# The analysis shows that yesterday's tools are not efficient for testing numerical relays.

**table 1 Revised testing philosophy**

Original principles	Revised principles for numeric relays	Reason
All protection functions will be tested	All USED protection functions will be tested with in-service test quantities.	Usually only a small number of functions will be used; too many functions to test.
All input and output circuits will be tested	All USED input and output circuits will be tested.	Larger number of I/O; reduction on cost basis.
All fault types will be tested as per next point	Provided evaluation testing confirms, strategically test fault types – see Figure 3.	A common software routine is used for a fault type.
The tripping characteristic will be tested x times in each zone/ range	The tripping characteristic will be strategically tested in each zone/ range – see Figure 3.	The tripping characteristic is determined by software algorithm and settings. This test checks the settings produce the correct values (pick up, operating time)
Relays have a MTF of x years and hence, periodic maintenance will be performed at x/y years, or alternatively, Reliability Centred Maintenance will be used (a business decision);	The relay's self supervision function will be relied upon to declare a failure except for: ■ relay calibration checked by analog display against AC injection; ■ used I/O will be checked by manual injection/ operation.	Improved self supervision and stability of analogue measurements allow increased interval between checks without reducing reliability.
No equivalent principle	Only one firmware version will be used for a relay model unless required by bug fix, beneficial feature or hardware obsolescence.	The consequences of this principle requires management approval; all orders will specify the firmware version no.
	Use one relay model and standard template.	Rationalize and standardize. This principle is critical to: ■ the success of testing and commissioning, the design process and the in-service performance of the protection system; ■ the cost justification and resource requirements which must placate management
	Each model of relay will undergo sufficient testing to confirm the assumptions stated in the testing policy.	Best method to check relay measures correctly and AC VI polarity, phase rotation etc are correct. If relay can't measure correctly, it can't trip correctly!
	Where possible, the relay's measurement display function will prove the relay correctly measures the input VI and calculates the operands for each phase. Where necessary, this test will be repeated for each input range as defined by the manufacturer. The correct values for operands will be stated in the test procedure.	

Providing testing aids in standard templates will give greater confidence in test results and 'as left' settings in protection relays.

**table 2 Test confidence**

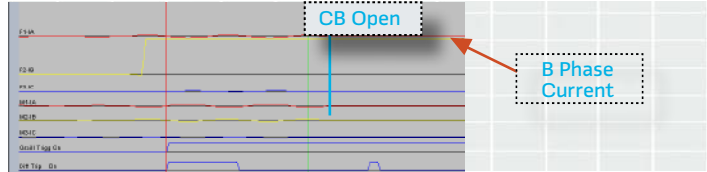
Fault	Detection method	Revised testing philosophy detection
Power supply failure.	In-service detection by self supervision (Figure 4).	Yes
Relay manufactured as 5A but nameplate shows 1A.	Commission testing.	Yes
Relay rebooted when fault occurred.	Not detected - NO trip occurred (mismatch of 36/40 bit hardware caused increasing DC offset in 40 bit register over time).	No- testing will not find fault because the underlying condition needed months to become critical.
Relay's RS232 communication port is held by defective external equipment.	Relay will not trip because it's waiting for communication data.	Yes
Line Differential relays have different firmware versions which generates a small spill current on load current.	Individual relay testing no; load check: a good tester = yes, other = no.	Possible with measurement display or use dual end injected test (2 test sets using GPS).
Distance relay with random, intermittent VI signals over fibre cable (external fault).	In-service detection by self supervision – relay disabled as shown in Figures 11 a-c.	Relay testing – NO. (Fault was poorly made fibre connectors and contamination)
DT overcurrent relay with bug in setting firmware: relay trips instantaneously.	In-service false trip.	Yes - Once failure sequence was found.
Return lead left opened in the CT circuit after testing; Neutral directional element did not operate on a reverse ground fault; A blocking scheme false tripped due to the lack of blocking action.	In-service false trip. Visual inspection only; not detected during on-load test with <b>balanced</b> currents.	No - external to relay test. Review of relay fault records or improve commissioning procedure to detect this case.
The element is called "neutral" but responds to I <sub>0</sub> , not 3*I <sub>0</sub> ; an engineer calculates a setting based on his/her assumptions.	Secondary injection and comparison to written design requirement.	Yes
Differential relay tripped on through fault – see Figure 8.	In-service false trip. DDR showed current 'flowing' after CB had opened.	No – analysis showed relay had a 'software latch' which was triggered by HF noise.

## 7 Event report

Alarm	Date	Time
Protection SYS X fail	22-Mar-02	18:48:19.443
X Protection diff. comms fail	22-Mar-02	18:48:36.793
X Protection internal warning	22-Mar-02	18:48:36.922
Protection SYS X OK	22-Mar-02	18:48:46.982
X Prot disturb. rec. operated	22-Mar-02	18:48:46.982

## 8 Disturbance report:

Captured trip on through fault because of design flaw in operating system which created a 'software latch' in current measurement.



## 9 Disturbance report:

Captured 10s break in AC VI quantities caused by contamination in fiber optic cable's poorly made connector

