On IED Interfacing
(Substation Environment Influence On Protection Reliability)

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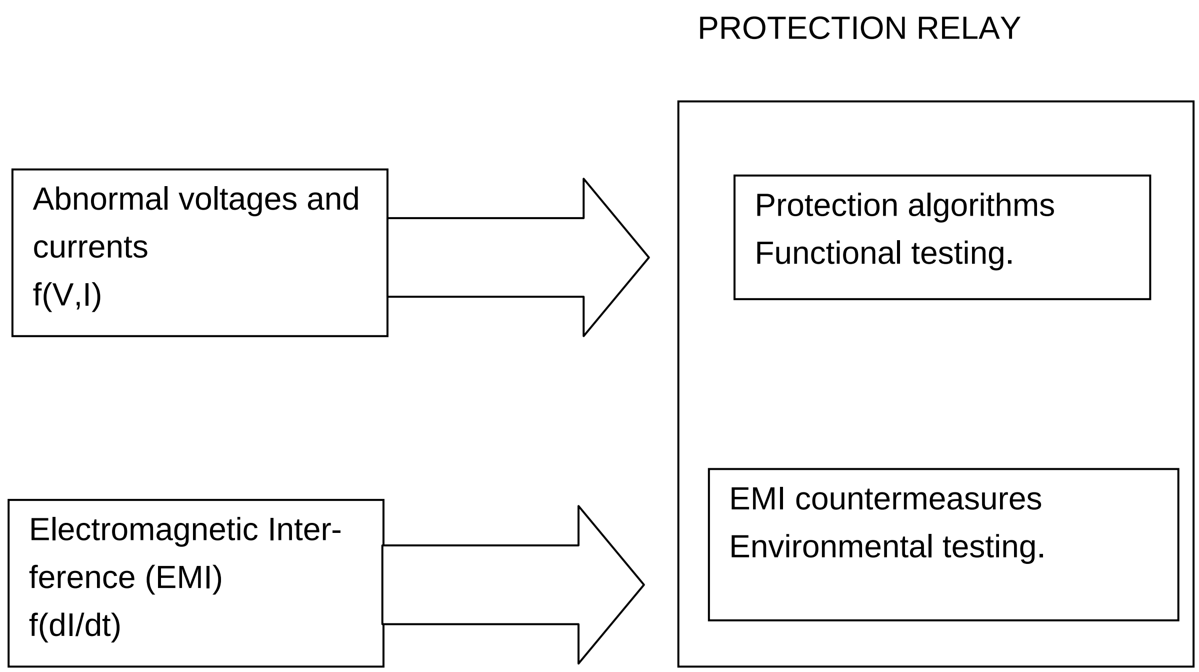
1 SUMMARY

This paper provides a review of present set of Standards that govern design, testing and operation of IEDs in the Substation Environment.
Protection reliability is addressed and new methods of relay testing and modifications of the Standards are suggested.

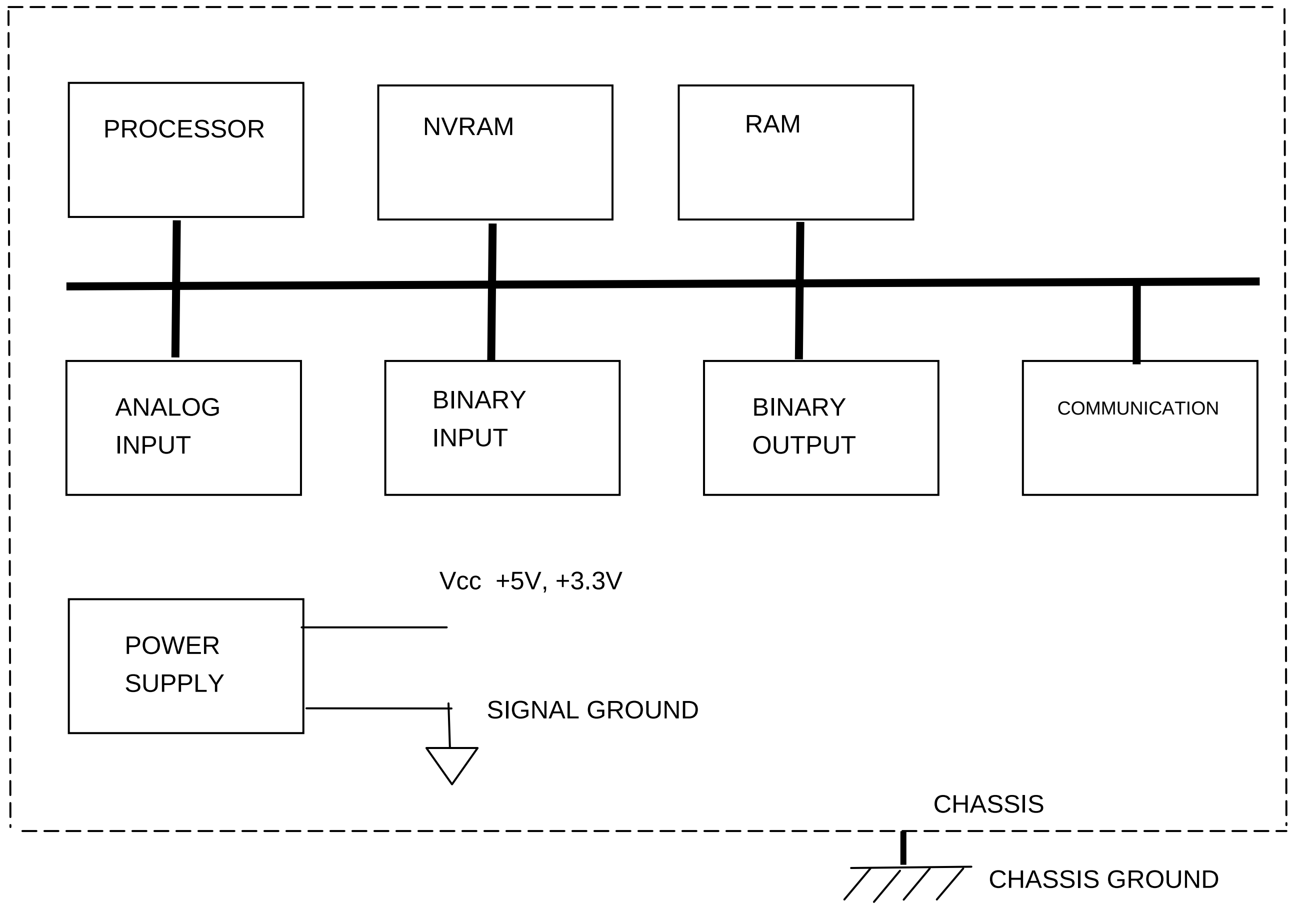
The handling of power system fault by the modern, microprocessor relay can be graphically presented as below



It is obvious that in real life abnormal power system parameters coincide in time with Electromagnetic Interference EMI, therefore Functional and Environmental testing should be performed simultaneously. Existing Standards do not reflect this requirement.

2 IED ARCHITECTURE

Modern Intelligent Electronic Devices (IED) such as Protective Relays, Remote Terminal Units, Teleprotection Devices, Disturbance Recorders, Programmable Logic Controllers, encountered at a Substation, conform to a common architecture:



A processor directs Analog and Binary Input subsystems to acquire data from the power system; a Binary Output provides system control and Communication Subsystem interfaces to Substation Automation, SCADA and Energy Management Systems.

The rigid, real time performance demands placed on Protective Relays, Remote Terminal Units, Communication links, SCADA and EMS systems, coupled with harsh operating environment, make these systems complex to design, install and operate.
Existing Standards, for design, test and operation of IEDs are summarized in the following paragraph

3 ENVIRONMENTAL TEST SUMMARY

Item	Description	Type	IEEE 1613 clause	IEC 60834-1 clause
1	General			
2	Temperature and humidity	Service	4	1.3.1
3	DC Supply Voltage		5	1.3.2
4	Impulse Voltage Withstand	Insulation	6.3	3.1.2
5	High Voltage Withstand and Insulation Resistance		6.2	3.1.2
6	**Damped Oscillatory Disturbance Withstand**	**Electro-magnetic Interfer-ence EMI**	**7.3.1**	**3.1.3**
7	**Fast Transient Disturbance Withstand**		**7.3.2**	**3.1.4**
8	**Radiated Electromagnetic Field Withstand**		**8**	**3.1.6**
9	Electrostatic Discharge Disturbance Withstand		9	3.1.5
10	RF Disturbance Emission			3.1.7
11	Dependability			4.3.2.2
12	Security			4.3.2.1

IEEE Standard 1613 above is based on these IEEE Standards:

C37.90.1

IEEE Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus

C37.90.2

IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers

C37.90.3

IEEE Standard Electrostatic Discharge Tests for Protective Relays

C37.90

IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus

4 FUNCTIONAL TESTING

The Environmental Testing requirements presented in Paragraph 3 do not include functional testing i.e. relay response to various types of faults.

The functional testing requirements are presented in IEEE 37.233 Draft Guide for Power System Protection Testing

Here are the definitions of parameters historically associated with the performance of protective relays

- Dependability: the probability of not having a failure to trip operation.
- Security: the probability of not having an unwanted operation.

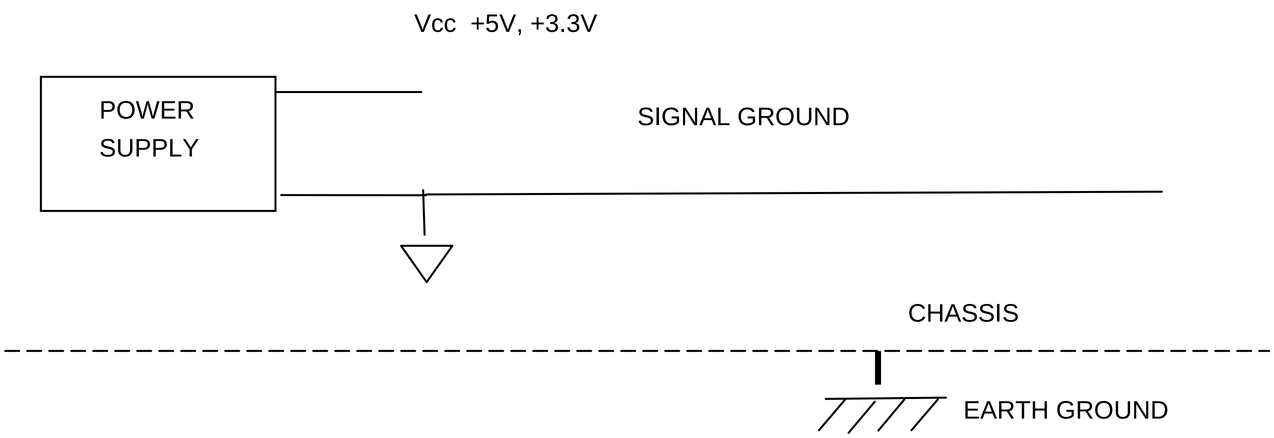
[3]

5 REFERENCING SIGNAL GROUND TO EARTH GROUND

There are two basic configurations of IEDs that exist side by side, sometimes within several inches from each other.

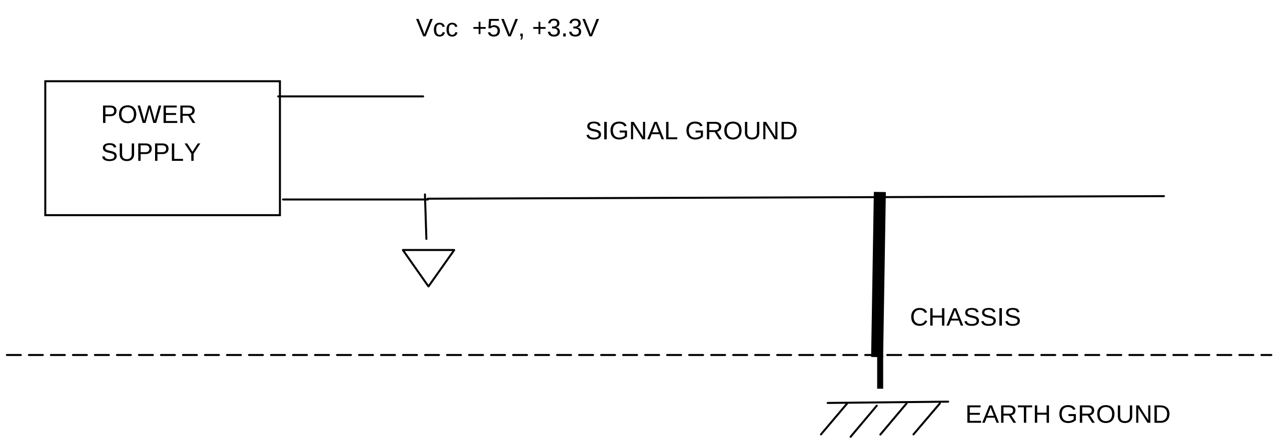
5.1 Isolated Signal Ground

This is the most common configuration of Protective Relays



5.2 Signal Ground connected to Chassis Ground

This arrangement is prevailing in IEDs such as Teleprotection, Remote Terminal Units, and Programmable Logic Controllers



"Experience has shown that the best (noise) immunity of an electronic system is achieved when the internal electronics is grounded by the use of directly grounded system." [1]
In such systems reference or Signal Ground is connected to the Earth Ground via Chassis Ground.

This is prevailing practice in the field in the Industrial Factory Automation, where IEDs listed above originally evolved.
It is the Author's opinion derived from experience that this is a preferred way to design an IED.

6 COMMUN ICATION SUBSYSTEM

6.1 RS 232 Interface highlights

The original DTEs were electromechanical teletypewriters and the original DCEs were (usually) modems. When electronic terminals (smart and dumb) began to be used, they were often designed to be interchangeable with teletypes, and so supported RS-232. The C revision of the standard was issued in 1969 in part to accommodate the electrical characteristics of these devices.

Single-ended signaling referred to a common signal ground limits the noise immunity and transmission distance.
Cable length is one of the most discussed items in **RS232** world. The standard has a clear answer; the maximum cable length is **50** feet, or the cable length equal to a capacitance of **2500 pF**.
Keep in mind, that the **RS232** standard was originally developed for **20 kbps**.

RS 232 or EIA 232 Standard is the **least suitable method of communication at the Substation** at the time of fault when demand for error-free communication is the greatest**.**

The only worse method of communication is the improperly applied RS 422/485 as explained in the following paragraph.

6.2 RS 422/485 Interface Application Primer

There is a common misconception that RS-422/485 requires only two (half duplex) or four (full duplex) wires.
This is due to improper interpretation of the differential character of the interface signals,

RS-422/485 always requires at least three or five conductors: 2 or 4 signal wires and 1 signal return (Signal Ground) path.

Vast literature such as silicon manufacturer's data sheets and system providers often fails to clearly point out this simple fact.

The EIA/RS-485 standard states:
"Proper operation of the generator and receiver circuits requires the presence of a signal return path between the circuit grounds of the equipment at each end of the interconnection. The circuit reference may be established by a third conductor connecting the common leads of devices, or it may be established by connections in each using equipment to an earth reference."

The reasons for the above requirement are:

- RS422 Interface has limited maximum Common Mode Voltage (voltage with respect to ground.) immunity of approximately 7V.
  Common Mode Voltage (Noise) is similar in nature to the well-known phenomenon at the High Voltage Substation called Ground Potential Rise.

This problem is especially acute during the time of fault.
By providing connection between Signal Grounds of both communicating devices the influence of Common Mode noise is eliminated.

- External Interface signals while differential in nature are internally (on silicon) referenced to common Signal Ground. Each side of the differential signal
[A (+) and B (-)] is driven in unison but separately.

Most of the existing installations of RS 422/485 are in the Industrial Factory Automation.
It is a very little known fact that the prevailing practice in that field calls for internal connection of Signal Ground to Chassis Ground.
Thus the above "earth reference" exists and 2 and 4 wire cabling is sufficient.

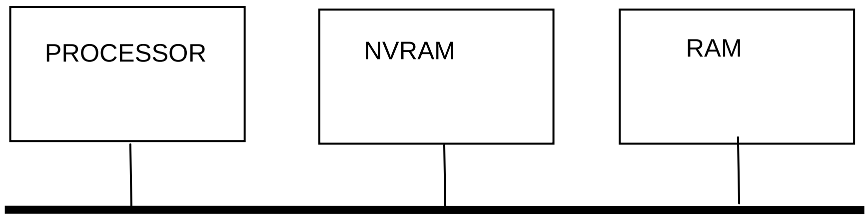
The 422/485 Standard is the basis of several commonly used Field Buses such as PROFIBUS, BITBUS, INTERBUS.
In all of these buses Common Ground wire is provided.

On the other hand Electric Utility conventions keep Signal Ground separate from Chassis Ground for most of Intelligent Electronic Devices.
In this case the above Circuit Reference must be provided by the "third conductor" in the interconnecting cable.

The greatest dangers of using of RS422/485 without common circuit reference in the interconnecting cables are:

- Intermittent data communication errors during the time of power system faults.
- False alteration of processor RAM memory by currents seeking ground return.
- The other, less severe problems are interface driver/receiver overheating and explosive chip failures.

7 PROCESSOR SUBSYSTEM



Processor performance have increased from 6MHz, 16 bit in early 1990s to 200 to 400MHz, 32 bit today
NVRAM, nonvolatile memory where relay program is stored have evolved from
128 kbytes EPROPM (electrically erasable read only memory) to 255-512 megabytes of flash memory.
Similarly random access memory RAM for data storage is reaching the size of 64 Mbytes.
It shall be noted that RAM which is volatile is also used to store intermediate results (flags) of processor execution of protection programs.
Increased density of Processor components makes them especially susceptible to EMI.

It has been observed in the field that the program execution was affected by “destroyed” flags in RAM. Segregated phase current differential skipped phase B, C and Ground subsystems and recognized faults on phase A only until relay was powered down and on power-up the destroyed flags were reinitialized, thus restoring proper operation of the relay.

8 RELAY RELIABILITY

For the purpose of this presentation Relay reliability can be expressed as:

$$R = 1 - \frac{M}{T}$$

Where:
R – Reliability
M – Number of misoperations (false trips +failures to trip)
T – Total number of faults
Please note that the relay misoperations have been historically associated with false trips, failures to trip are equally devastating and shall not be overlooked.

Total number of faults in the lifetime of an element of the power system is measured by tens, not by hundreds.
Even a single misoperation viewed in light of the above definition produces reliability figure of concern.

9 SUGGESTED CHANGES

Here are the proposed changes to existing Standards and procedures that should result in improvement of protection relay reliability :

9.1 Comments to IEEE 1613

The sections of this paragraph in *italics* are direct quotations of IEEE1613; the underlined portions are suggested revisions.

7.8 Application of test wave

All external connections to the system shall be considered in one of the following four groups

a) Power supply

b) Outputs, such as alarms

c) Digital data

d) Signal circuits

Items that can be excluded from testing include the following:

— Temporary connections to maintenance computers or test equipment.

There are hundreds of installations today that connect RS 232 ports (meant for the above connections) to Substation Automation networks, thus providing permanent antennae to unprotected interfaces.

— Connections that, as stated by the manufacturer, shall be less than 2 m in length.

It shall be assumed that these connections WILL be more than 2m long and tested for disturbances.

Even for intracabinet wiring (that this paragraph seems to suggest) the communication wires (RS232 and RS422) were found to be tightly bundled to CT and VT secondary wiring

The test voltage shall be applied to the respective external connection groups in common or transverse mode according to 7.11.

The test shall be applied to each terminal separately.

The most common method of surge protection of I/O circuit installs filter consisting of 0.001 uF 5 KV capacitor to Chassis Ground.

The resulting impedance acts as a voltage divider to test Generator whose internal impedance is 50 Ohm.

Thus the Test Voltage of say 4kV is reduced by the divider ratio.

Connecting the Generator to a Group of N I/O points reduces the output voltage further by a factor of N

7.13.3 Additional condition to be met by Class 2 devices

Established communications in accordance with 7.11.3 shall NOT be disrupted or experience errors during the period the SWC tests are applied.

Very ambiguous!

The Standard does not specify the communication error rate (BER).

The communication errors are guaranteed to occur, even if Fiber Optic Medium is used.

9.2 Functional testing

The paragraph from quotation marks below is from IEEE 37.233, Draft Guide for Power System Protection Testing:

"The document addresses the following testing situations in detail:

1.6.1 Functional or application certification type tests in the factory or laboratory

The objective is to verify the engineering design and performance of the system and its components through simulation of the full range of expected operating conditions. These cases can be in the form of playback of simulation results or real-time interactive testing. Typically, the developers run such type tests only on a first production sample if more than one is to be built.
In the case of playback of simulated cases, the tests rely on power system or apparatus modeling, simulation, and tools to demonstrate the security and dependability of the scheme before shipping to the site. Features include comprehensive modeling of the application, standardized test cases, large variety of test cases to exercise design, and simulation of communications and environmental challenges of a field installation. The test personnel document the test cases and results in some detail. For a specialized protection system or critical application, representatives of the end user may witness some or all of the type testing process to learn the system and gain confidence.
In general, component devices of a system under test have been or should be type-tested according to relevant standards for physical and electrical environment. For example, protective relays are tested according to specified revisions of ANSI/IEEE C37.90 and C37.90.1, .2, and .3; such test results are documented separately. These well-defined product type tests are not discussed further in this document"

The environmental tests in the above context are treated as a separate entity from functional testing.
As suggested earlier in this document:

It is obvious that in real life abnormal power system parameters coincide in time with Electromagnetic Interference EMI, therefore Functional and Environmental testing should be performed simultaneously.
Modern, computer based real time simulation tools such as RTDS used for functional testing provide ability of running hundreds of test cases in a single day.
Typical transmission line relay testing might require up to 1500 test cases.
On the other hand it takes about two weeks to perform complete repertoire of environmental type testing.
Obviously one can not repeat this testing for every functional test case.
Here the suggestion based upon experience.
The most demanding environmental test is Fast Transient IEEE 1613, 7.3.2
Meeting this test guarantees compliance with other EMC tests.
So synchronizing the Fast Transient generator with RTDS will perform the desired testing requirement.
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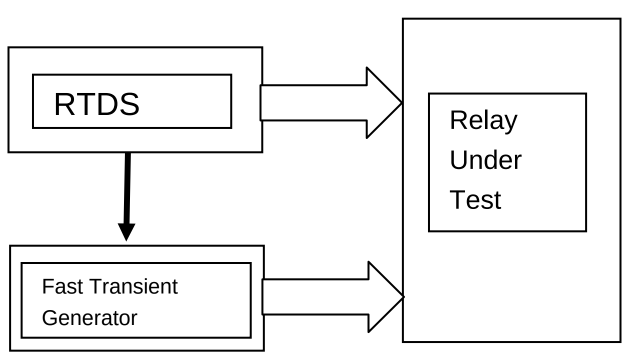
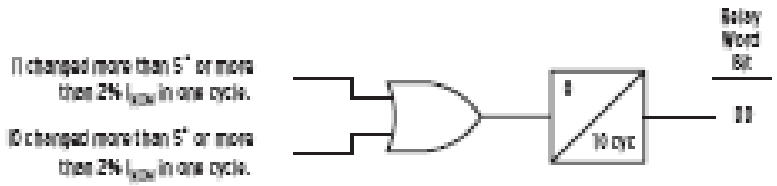


It is suggested <u>that IEEE</u> <u>37.233</u> *is modified to reflect the above*

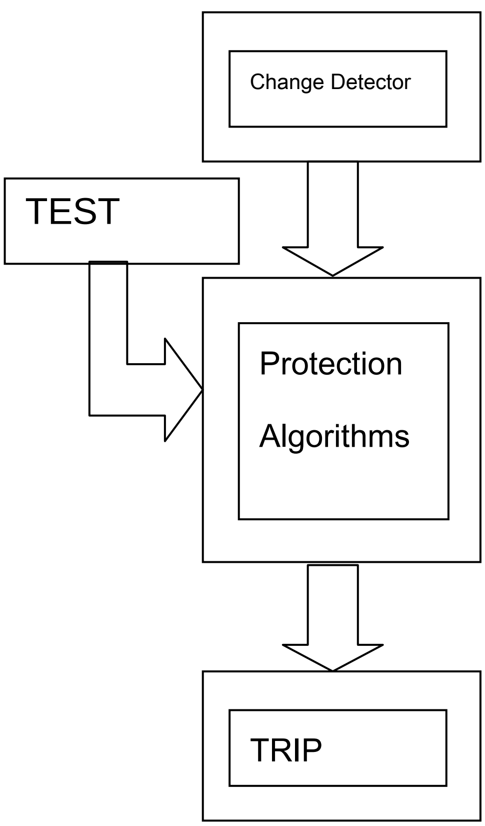
9.3 Environmental testing

Protection and Trip functions of a microprocessor relay are supervised by a Change Detector CD.[2]



Change Detector is activated by the abrupt change of Current or Voltage associated with a Power System Fault.

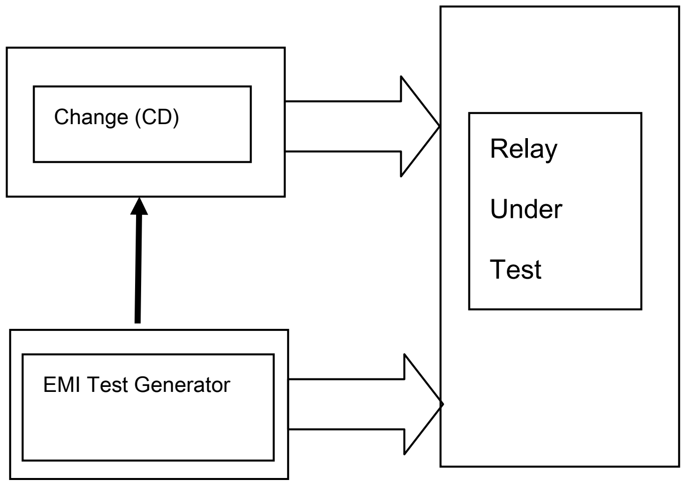
It follows that the Trip functions are also supervised by CD.



Keep in mind that Electromagnetic Interference EMI phenomenon occurs simultaneously with abnormal currents and voltages during fault.

Again it follows that to enable trip elements during EMI tests the CD should be asserted.
This can be achieved by:

- applying simulated change of Voltage or Current, or
- Putting a relay in TEST mode that asserts CD, (if provided by relay software)



It is suggested that IEEE 1613 is modified to reflect the above requirement.

10 CONCLUSIONS

1. Proposed changes to existing Standards, that govern functional and environmental tests will result in:
- Increase of Test Confidence
- Improvement of protection relay reliability.
2. Substation Data Communication shall be performed by Fiber Optics.
3. Avoid copper whenever practical.
4. Relay self-testing should include thorough and frequent RAM testing during relay operation.

11 LITERATURE

1. Interference-free electronics, Stan Benda, Chartwell-Brat Ltd

2. SEL-387L Line Current Differential Relay   Instruction Manual

3. Improving Reliability for Power System Protection   S. Ward T. Dahlin W. Higinbotham RFL

Janusz W. Dzieduszko is a native of Poland, and M.S.E.E. graduate of the Academy of Mining and Metallurgy in Cracow.
He has experience in engineering management, design engineering and marketing, SCADA/EMS, protective relaying, load management, and data communications.
He is currently **Consultant with Power Systems Management Consulting Inc.** in Raleigh, NC.
From 1997 to 2003 he was **Executive Advisory Engineer in Electric systems Technology Institute of ABB Power T&D Company** in Raleigh NC.

Prior to joining ABB ETI, Janusz was Manager of Consulting Engineering at ABB Power Automation and Protection Division in Coral Springs, Florida. He was responsible for the development of the current differential and phase comparison line protective relays**.**
In 1996 he was given the ABB Power T&D **Award of Excellence** in product design for the phase comparison relay.
In addition he directed and completed work of major part (Input and Output Subsystem) of International ABB development project involving ABB locations in Sweden, Switzerland and Finland.
Prior to joining ABB, he was with **Westinghouse Electric Corp. as Senior Design Engineer**, responsible for Hardware and Data Communications Subsystems of Integrated Substation Protection and Control System WESPAC.

His earlier work experience includes:
General Electric Company, Manager, Power Line Communications
Responsible for Load Management system.
BBC Brown Boveri Control Systems Inc, Manager, Hardware Development
Responsible for design of Remote Terminal Units and SCADA hardware.

Mr. Dzieduszko holds five patents in data communication, data acquisition and system protection.
His biography is included in Marquis' "Who is Who in the World" and "Who is Who in America"
He is a member of the IEEE Power Engineering Society. He speaks fluent Polish and Russian.
Janusz is the author of several papers in the protective relaying field and co-author of "Communication Interface Specification", published by EPRI.