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Protection Testing
Tony Porrelli – Applications Engineer
6 February 2015
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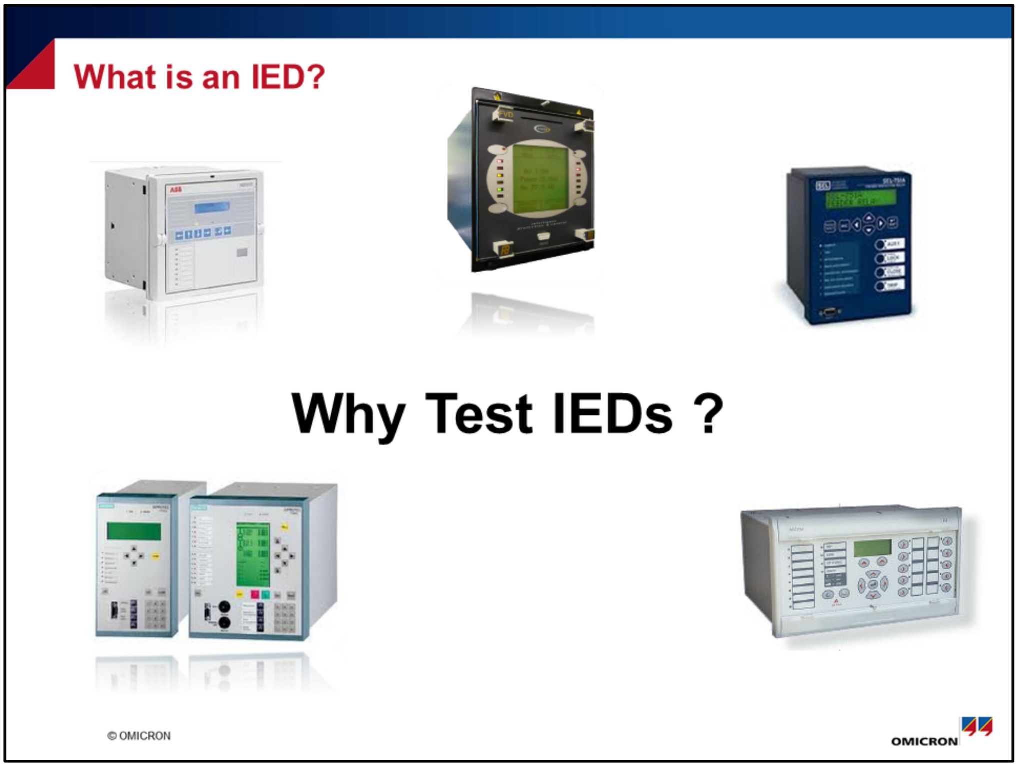
What is an IED?
Why Test IEDs ?
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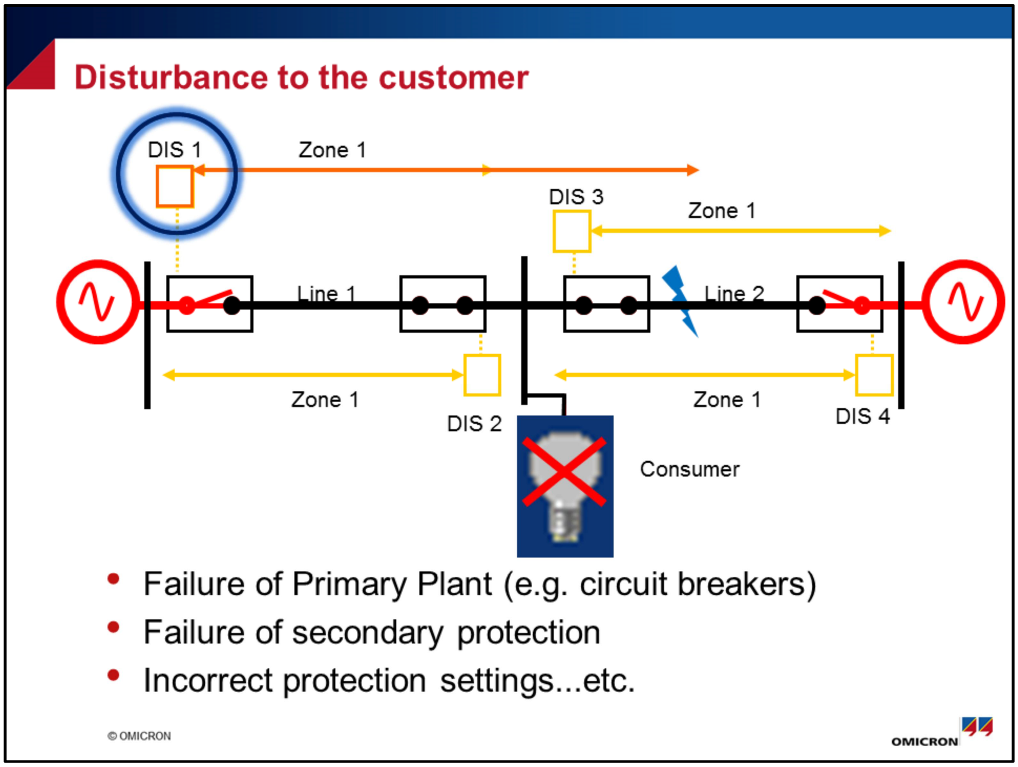
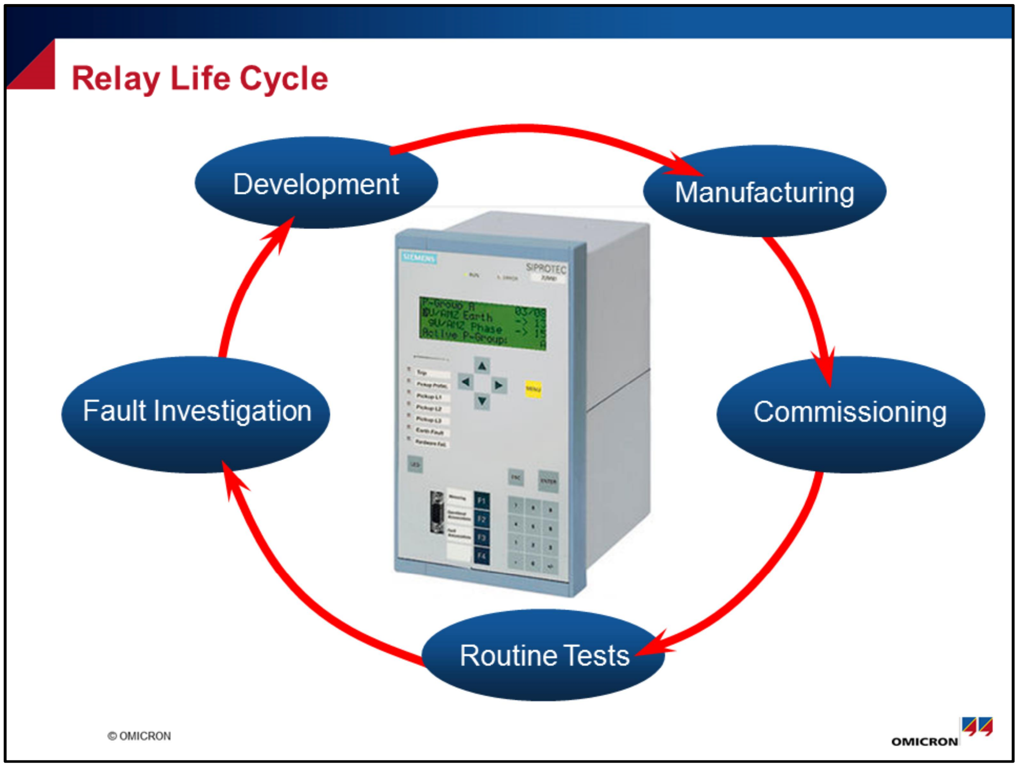


When a fault occurs on Line 2 the fault is seen in Zone 1 by the IED DIS 3 and DIS 4
They should clear the fault.

But if IED DIS 1 has a wrong grounding factor settings it might see the fault in Zone 1 too. It opens the circuit breaker and the customer looses power supply.

We see distance scheme, Z1 set to 80%. There is a race to trip 1st between DIS 1 and DIS 3.
If DIS 3 opens as planned then the customers would be OK.

KEY-is that parameters of distance Relay 1 not set correctly.



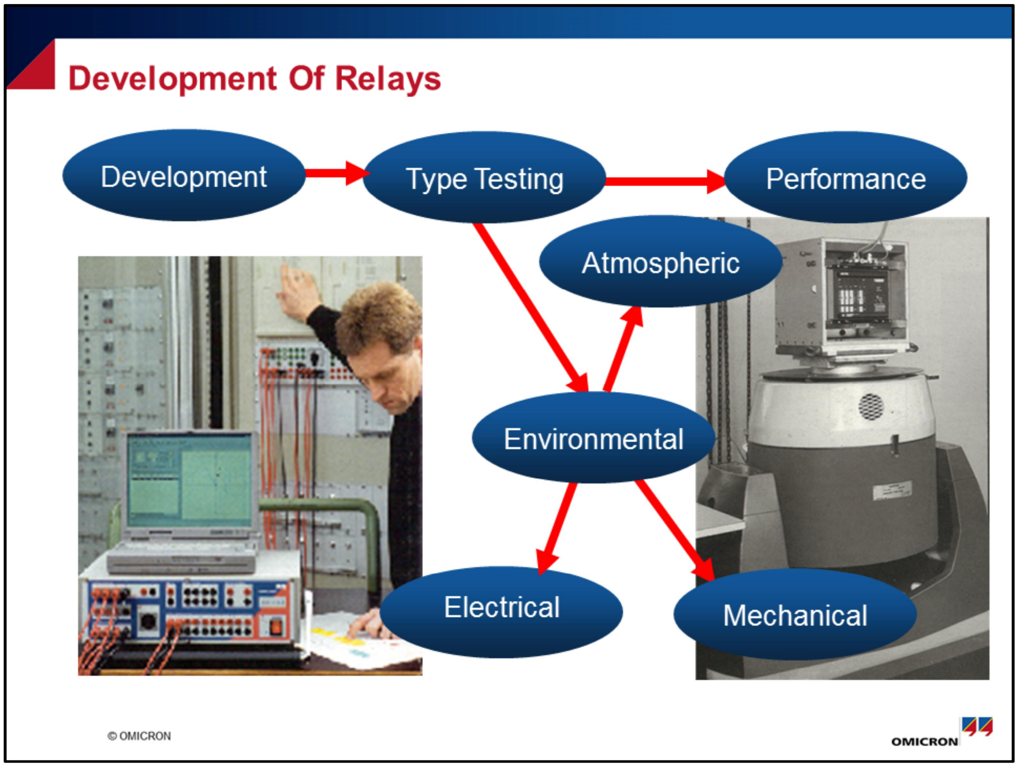
DEVELOPMENT – in the development process of IED design we need to ensure that the design is OK. Design engineers in the design process must check their IEDs.

MANUFACTURING – after manufacture, take 1 from the production line and check that the manufacturing process is correct

COMMISSIONING – when the IED is first installed on-site is must be checked that the settings and wiring of the relay are correct

ROUTINE TESTS – need to ensure that a periodic test carried out to ensure that the IED s are still in an operational condition

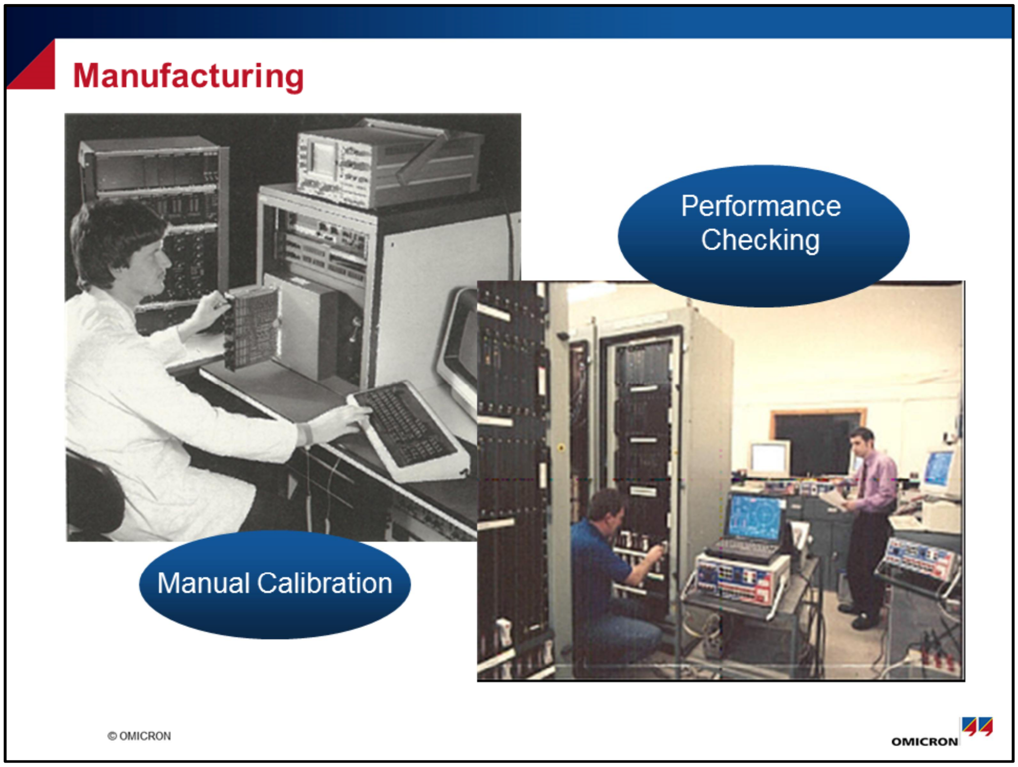
FAULT INVESTIGATION – following a system fault, assess the information in the IED to find out why it tripped. If it is a limitation of the IED then input back into the DEVELEPMENT process.



TYPE TEST – after development of products it is usually standard to have it approved by a regulating Testing Authority to ensure that IED is safe and operates as desired and suitable for the network, ie Fast Transient testing

Test ENVIRONMENTAL – temp, humidity leading to ATMOSPHERIC testing, cold & cold, pressure

We follow with MECHANICAL – vibration tests and ELECTRICAL testing



Old mechanical relays were calibrated using trim pots for adjustment, this is a pic from the early 1980's showing how it was done.

Then we seen the manufacturing of a panel where the IED will be installed and the wiring and IED settings will be checked. This is an example in industry of an old Power Plant.

Commissioning

Summary of tests:

- **Wiring/Schematics**
- **General Inspection**
- **CT/VT Testing**
- **Secondary Inject IED's**
- **Operation/Timing**
- **Primary Inject circuit**
- **Checking tripping and alarm circuits**

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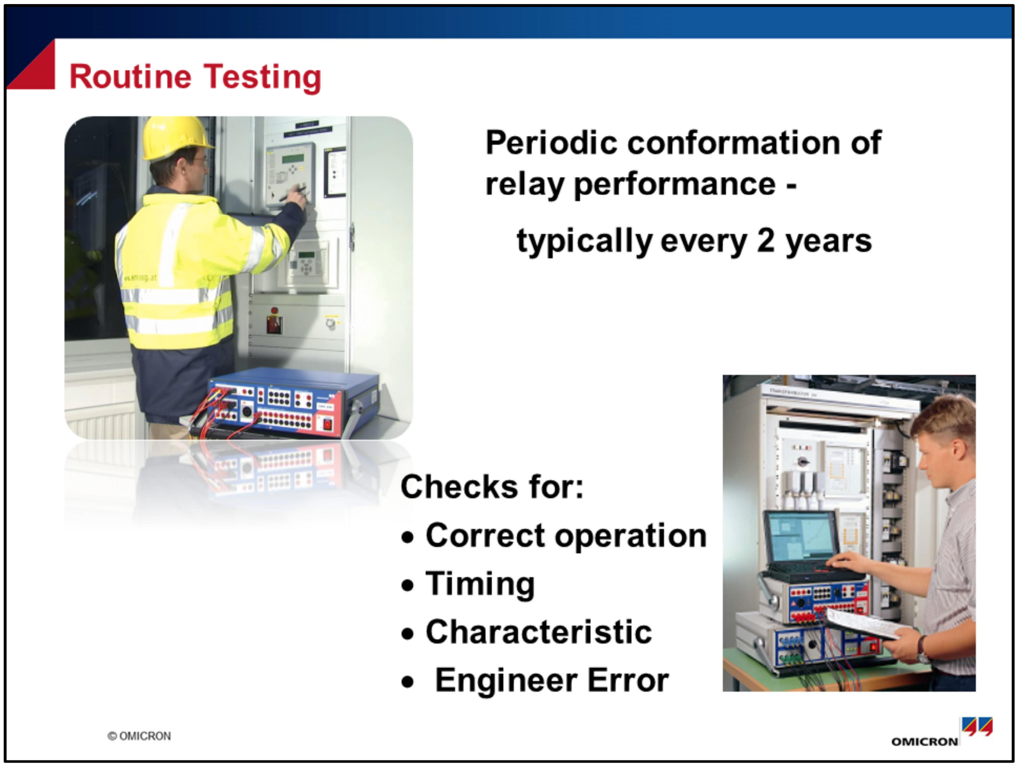
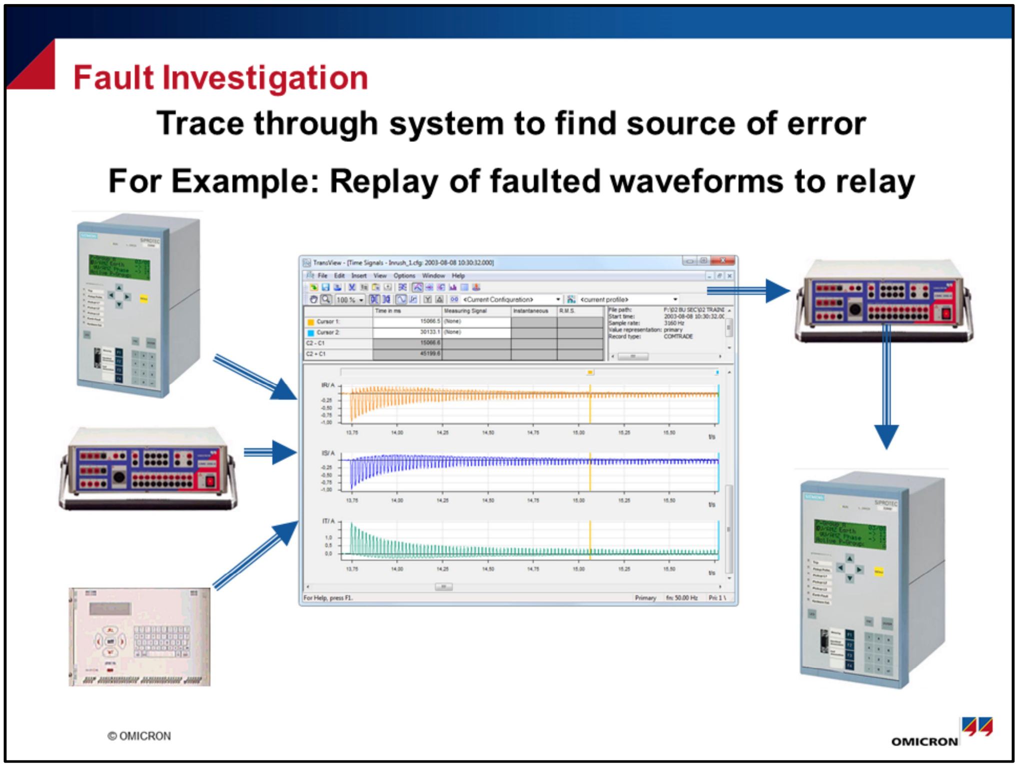
Commissioning – after installation it is important to fully commission the IED



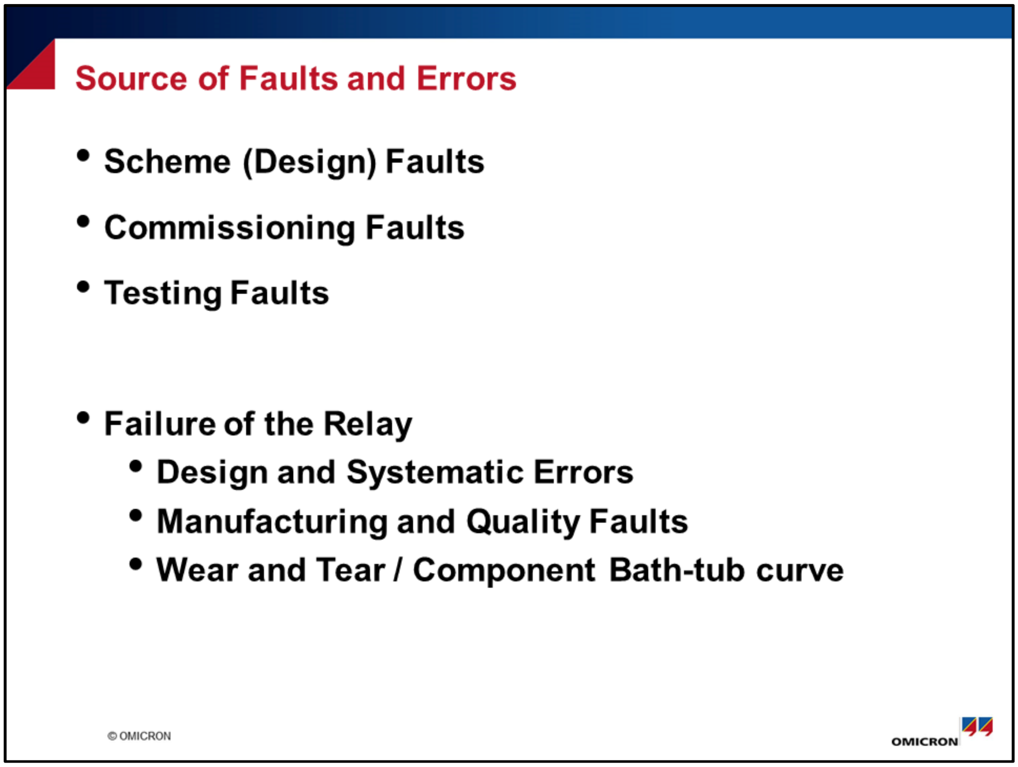
Routine testing is down the companies own policies. After the commissioning has been completed we need to ensure the IED will continue to operate correctly and that it or its system has not developed any faults.



Very often BAD things happens and faults are developed.
Here we see 3 different types of kit that can be used for fault investigation.

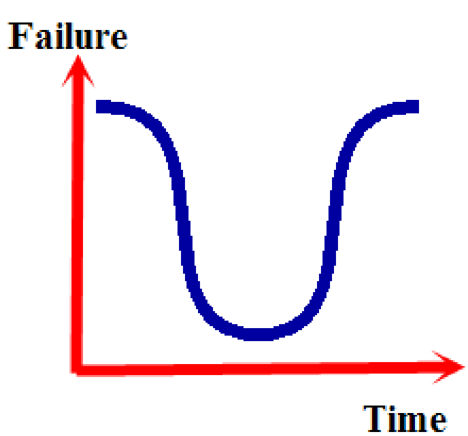
The IED may include a fault recorder function, the OMICRON CMC unit can be used to record system faults, or 3rdly we can use a Disturbance Recorder. These disturbances are generally recorded in a COMTRADE file.

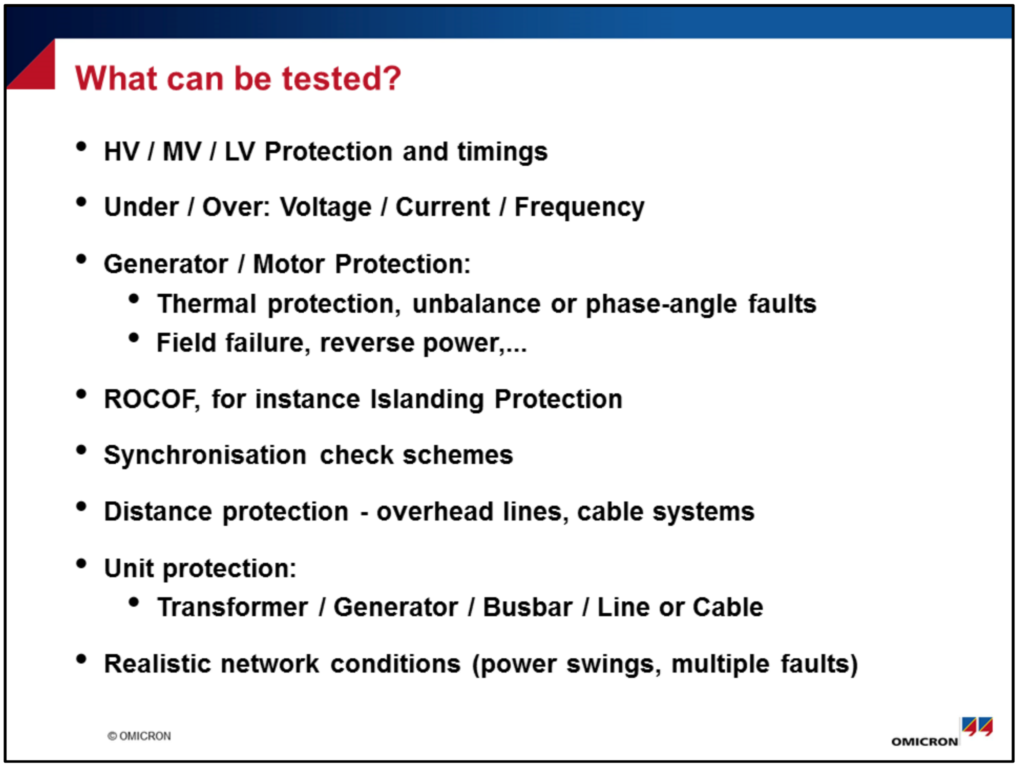
We can use the CMC to play back these files and replay the fault into a IED to investigate what was happening during the fault condition.



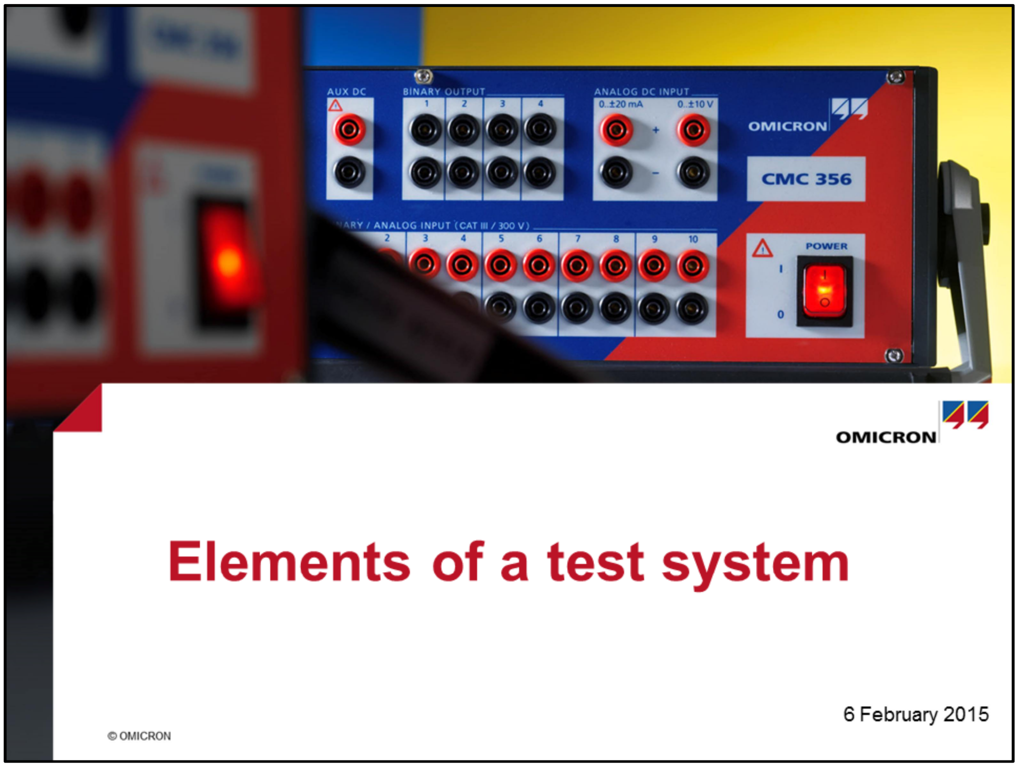
SCHEME FAULT – something in the design that causes the IED to operate when it should not, ie blocking scheme
COMMISSIONING FAULTS – failure to commission correctly
TESTING FAULTS – maybe the IED was not tested correctly

Bath Tub Curve:
Lots of component failure early in design life but then it drops off as reliability improves, but then as product get older components start to fail.





ROCOF – rate of change of freq – measures how quickly the freq reduces – monitoring a generator freq at overload and see how quickly the freq reduces rather than wait until the freq reaches a defined low level resulting in the removal of the generator from the grid before any damage can occur.


AUX DC
BINARY OUTPUT
ANALOG DC INPUT
OMICRON
CMC 356
POWER
OMICRON
Elements of a test system
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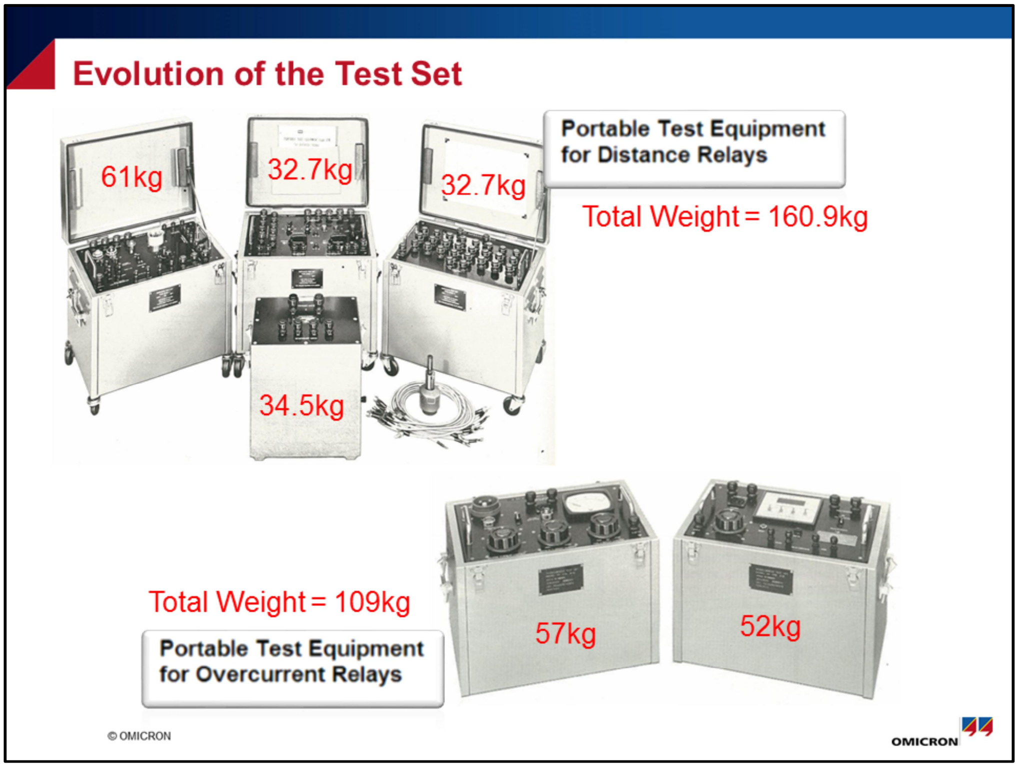
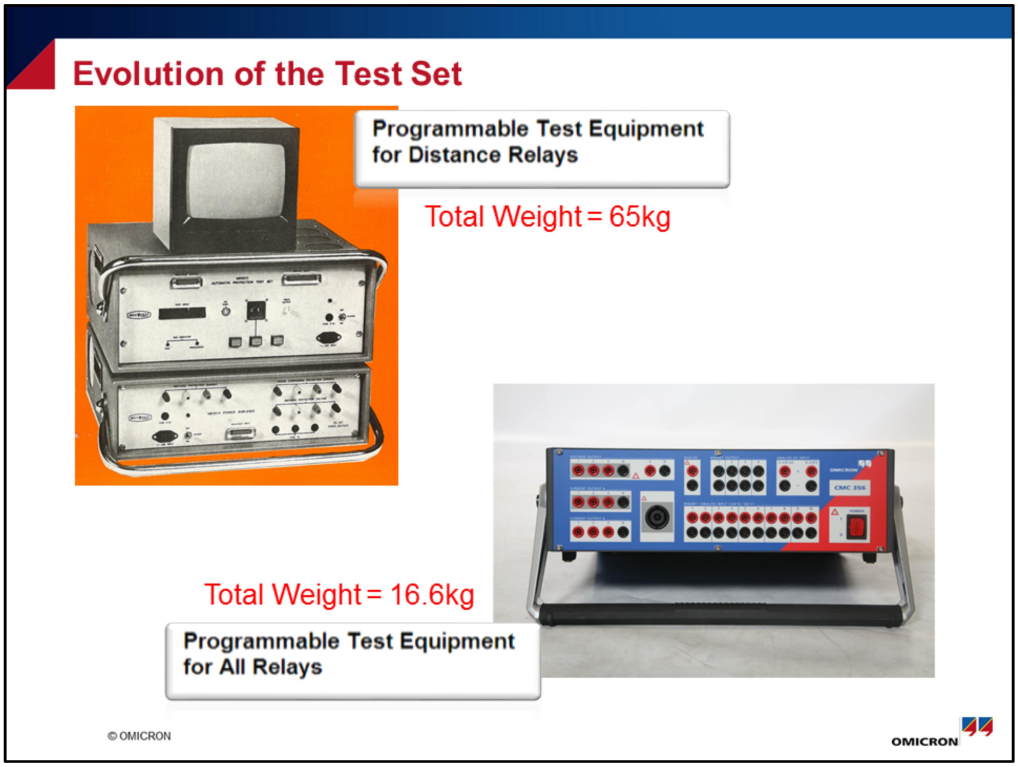


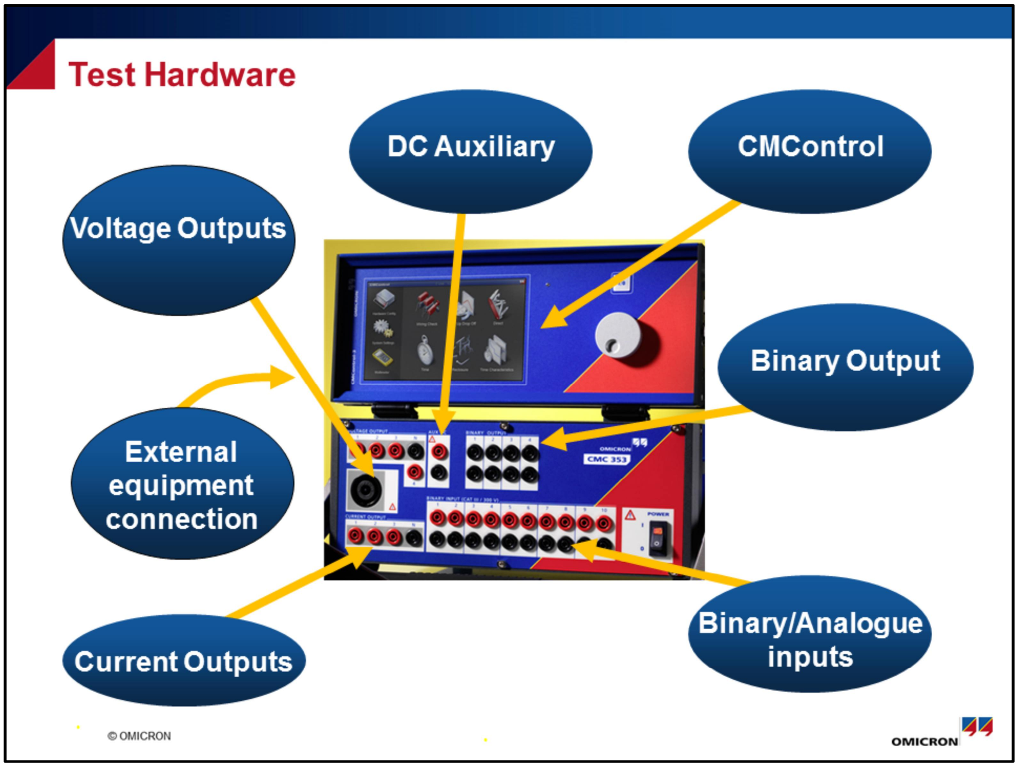
1st pic – GEC ZFB – full of copper and Iron, was state of the art until the late 70's, it's a distance protection test set (impedance test set)

2nd pic – Old overcurrent protection test set.



Early electronic test set

Computer controlled test set


Test Hardware
DC Auxiliary
CMControl
Voltage Outputs
Binary Output
External equipment connection
Current Outputs
Binary/Analogue inputs
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Test Hardware
Amplifiers
Accessories
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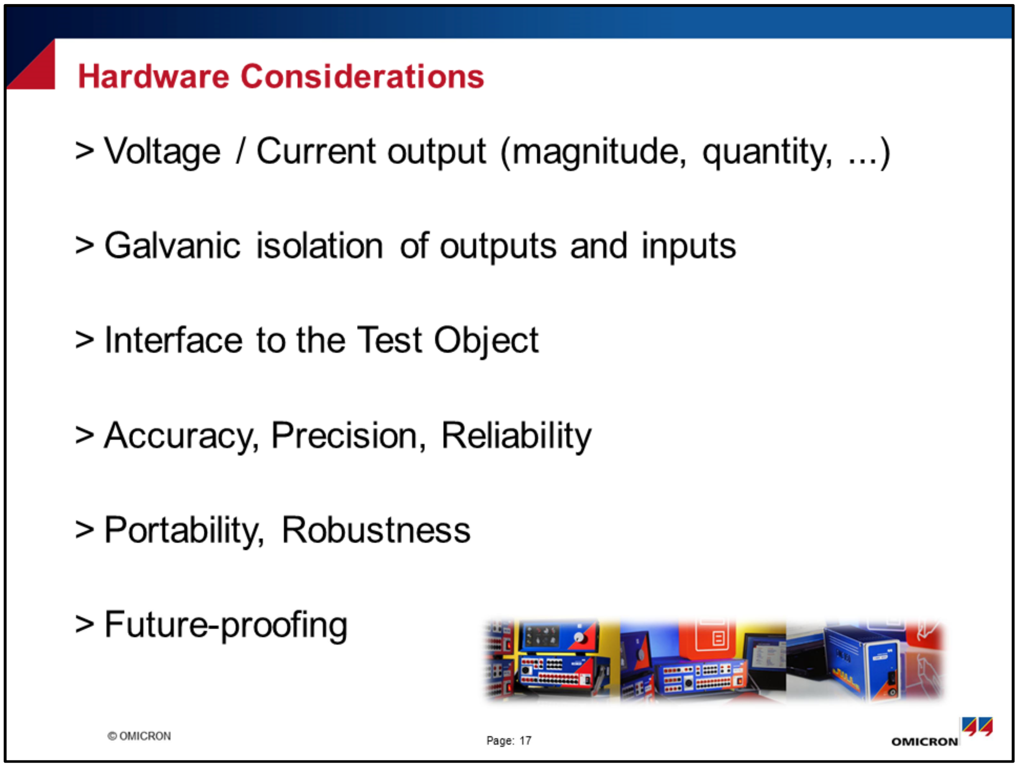
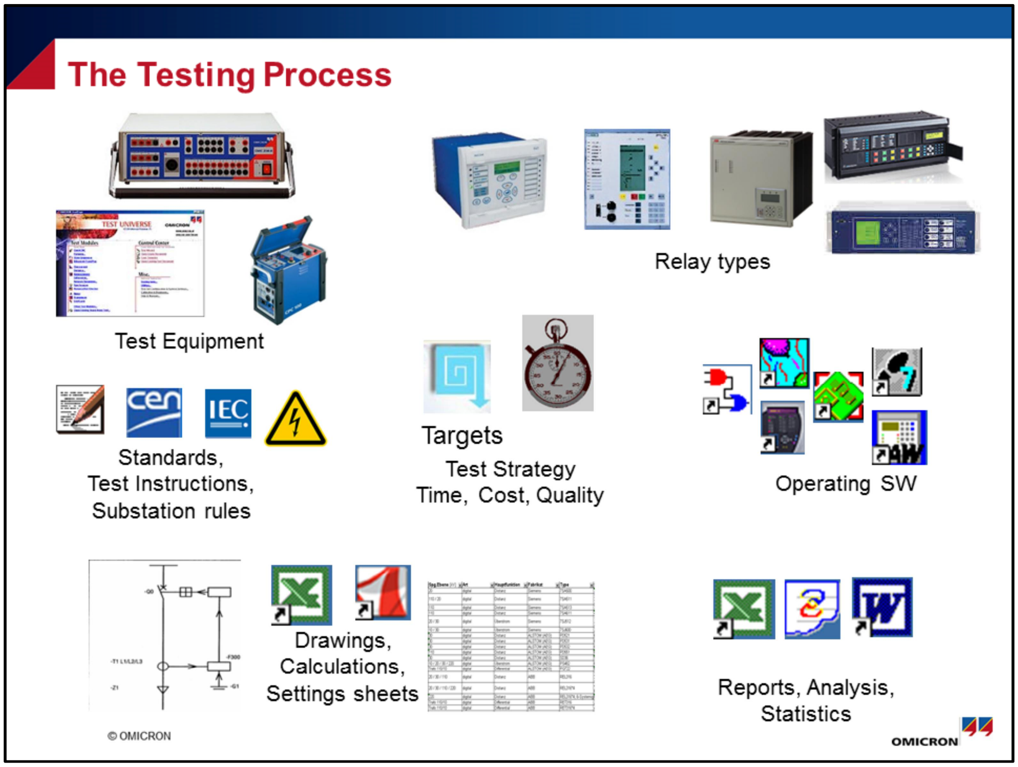


Future proofing the test set can be considered to include IEC 61850 activities that need to be tested on IED's. For hardware, this means that the test set should have an Ethernet connection installed.

Software Considerations

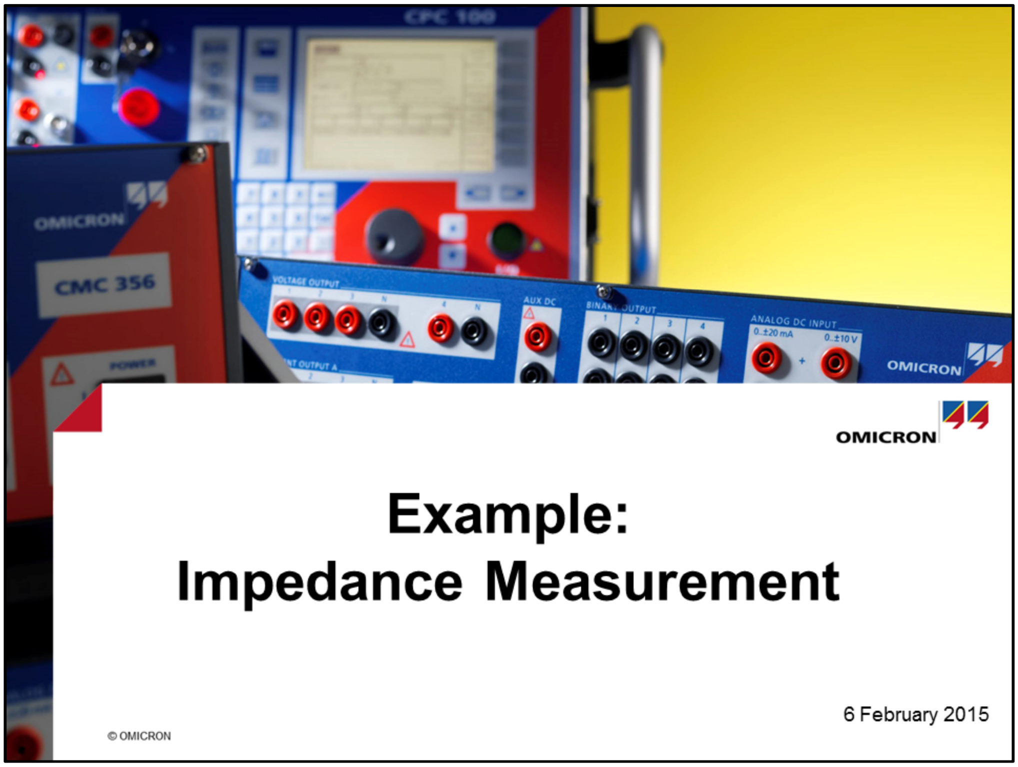
> Automated / Manual control of the hardware
> One software for any type of hardware
> On-line or off-line preparation
> Standard PC / Laptop control
> Ease of Use and Time-saving
  > No Programming
> Reliability and Reproducibility
> Versatility
> "No Limits" license
> Production of Reports



What is required when commissioning:

What are the strategys of the company, do they focus testing based on time/cost?
Documenation required – data sheets, setting sheets
Are there any standards that need to be followed and safety standards
Multiple IED types in a sub station leads to multiple ED opertaing software

Test Equipment must be flexible to cater for different testing methods and final reporting essential.


CPC 100
OMICRON
CMC 356
VOLTAGE OUTPUT
AUX DC
BINARY OUTPUT
ANALOG DC INPUT
OMICRON
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Example:
Impedance Measurement
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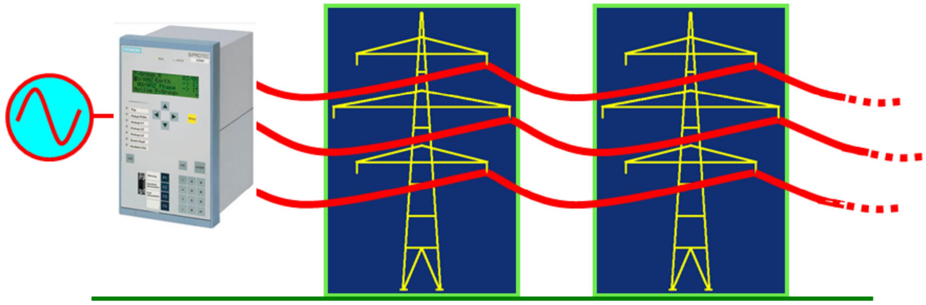
Impedance Measurement



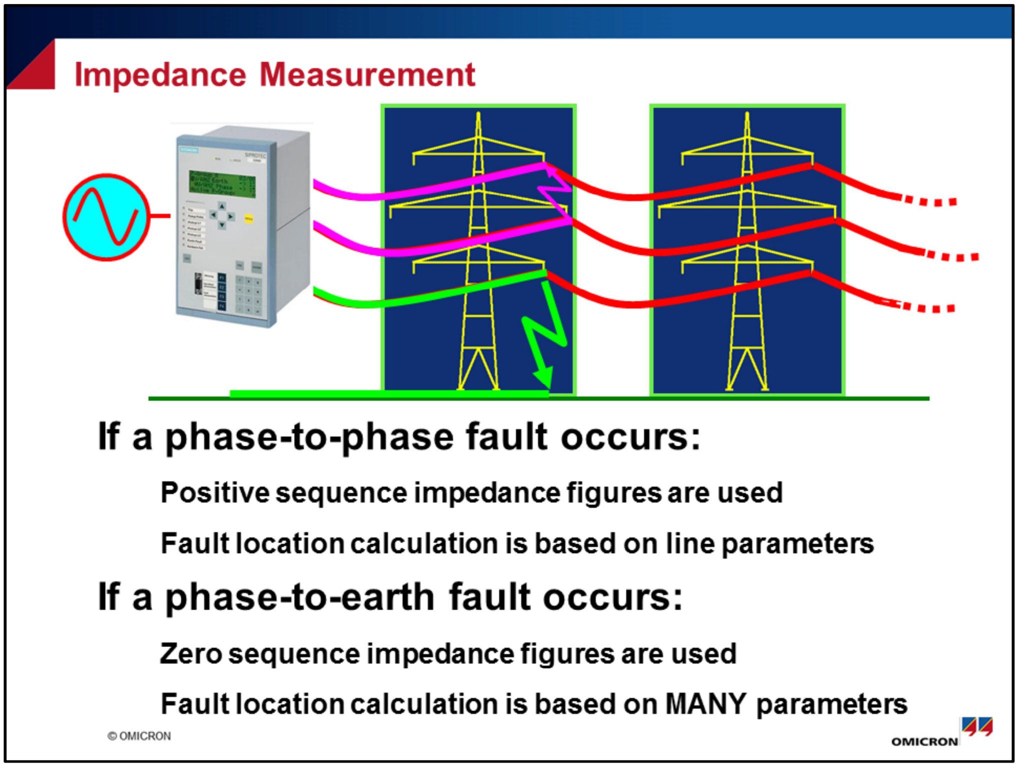
Distance Protection:

Identify and Selectively-Clear faults on the line

Provides 'instant' protection of the system

Fault Location:

Find where the fault is so that it can removed


Impedance Measurement
If a phase-to-phase fault occurs:
Positive sequence impedance figures are used
Fault location calculation is based on line parameters
If a phase-to-earth fault occurs:
Zero sequence impedance figures are used
Fault location calculation is based on MANY parameters
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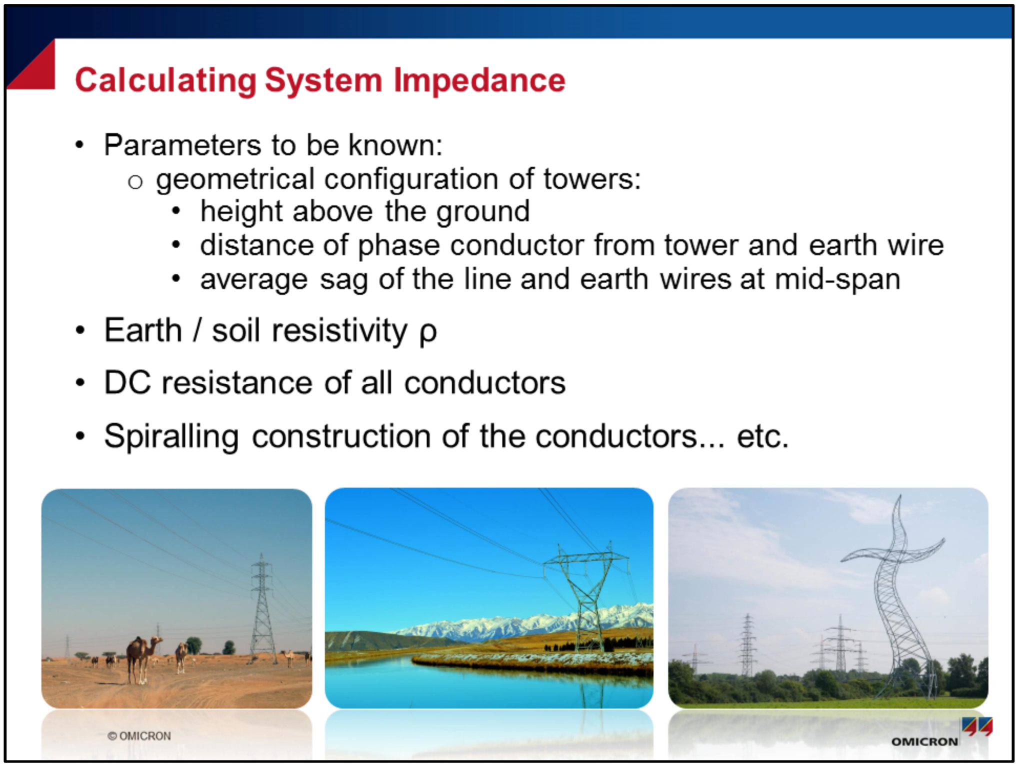
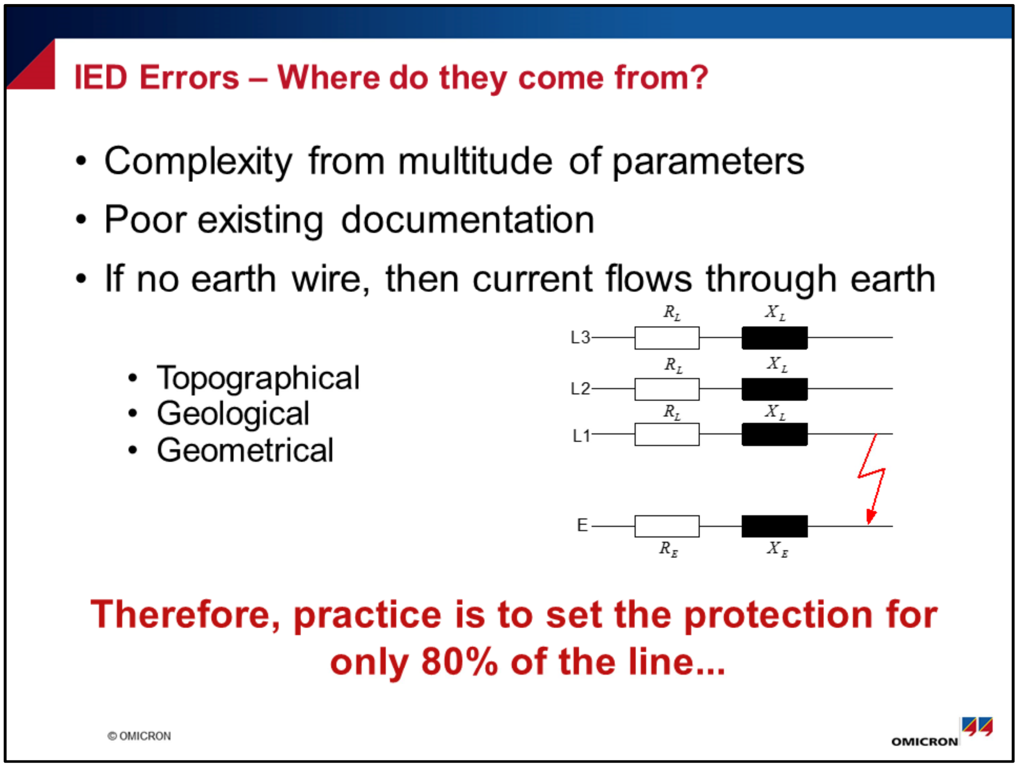


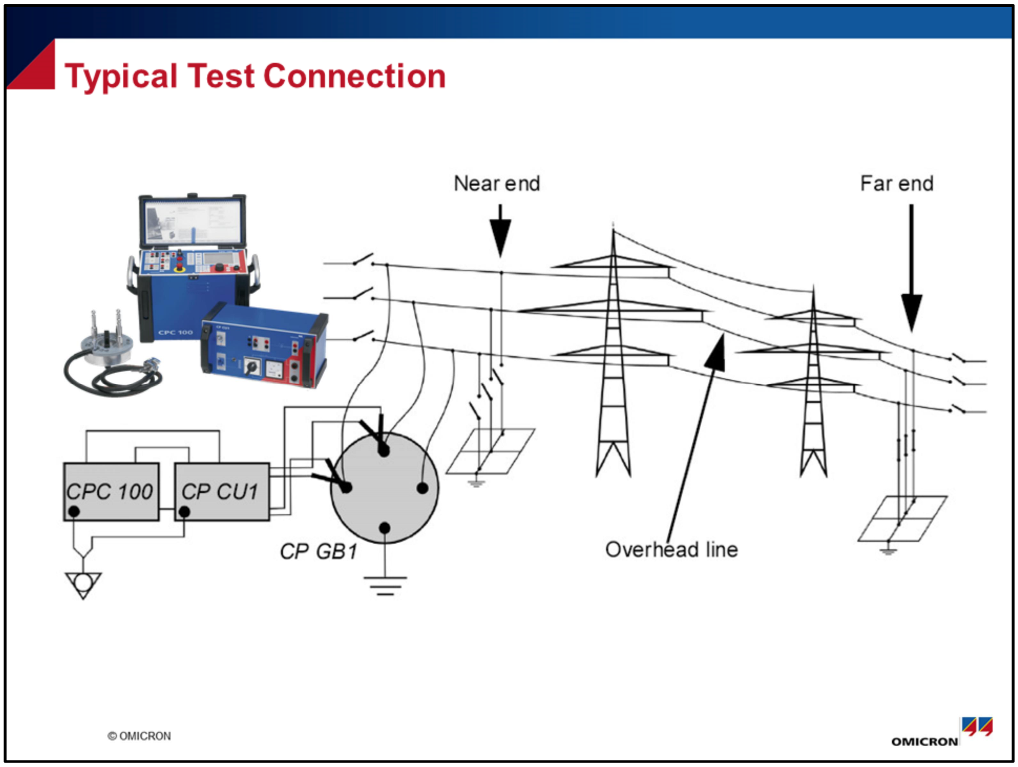
Pics show diff environment for pylons
Desert, arctic conditions, vegetation, everyday conditions



Complex – at system design, errors in calculations
Docs – old sub stations may lose documentation
CT/VT accuracies
Geometrical – geometery of the power system

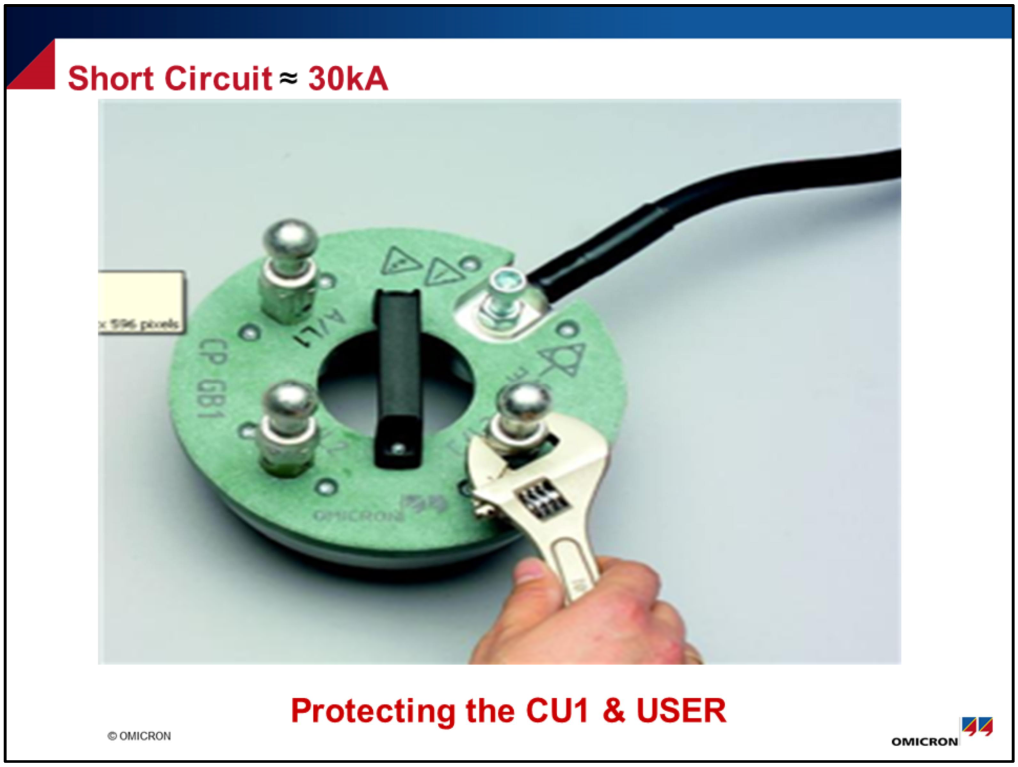
Setting distance zone to 80% of the Line allows for these kind of errors

In the past, when unsure about Line Impedances there was a requirement of a large generator to make the measurement at line frequencies.
This size was to overcome effects of surrounding noise, effects of cables etc



•We are not connected directly to the lines and the GB1 has safety surge arrestors if any line coupling occurs.

•CPC 100 is connected via the coupling unit CP CU1 and the grounding box CP GB1 to the overhead line
•The CPC is the variable frequency signal generator and frequency selective measurement unit, the CP CU1 has a power transformer and measurement transformers for galvanic insulation, the CP GB1 is used to couple the signals onto the overhead line and to give maximum safety in case of undesired high voltage
•The grounding switch on the far end stays closed during the whole measurement!
•The grounding switch on the near end is opened for a short period of time during the measurement and closed afterwards again for safety reasons.


Short Circuit ≈ 30kA
x 596 pixels
CP GB1
OMICRON
Protecting the CU1 & USER
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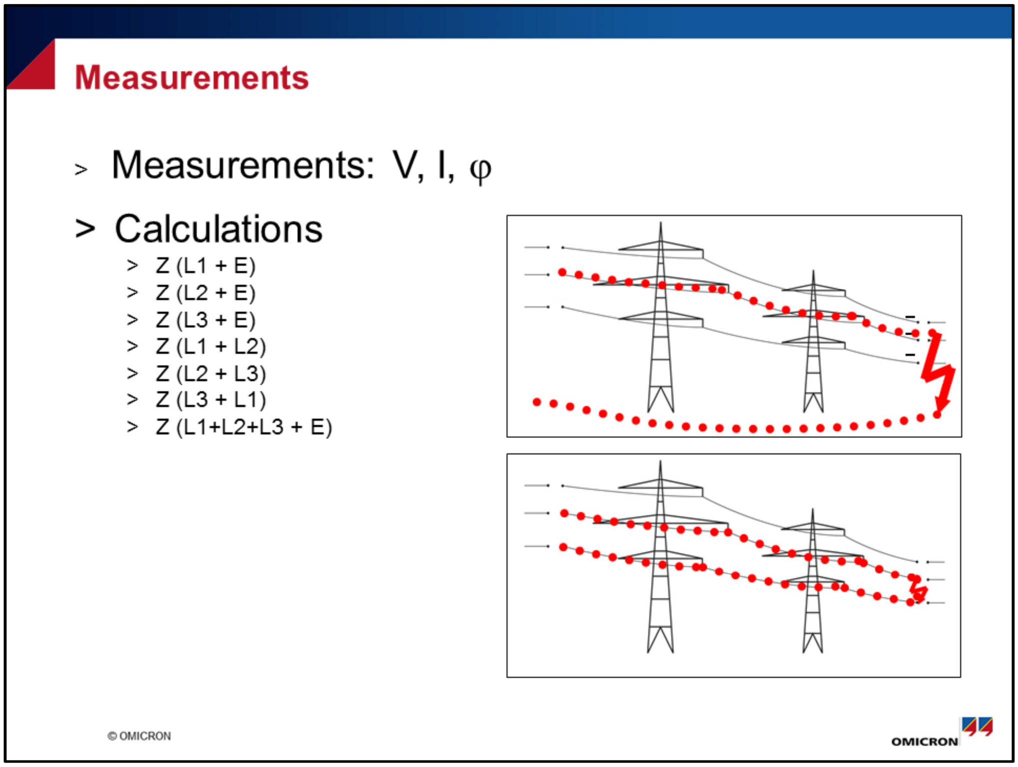

Calculates the different fault loops

Example Results

Results

	R [Ω]	X [Ω]	Z [Ω]	Phi (°)
Z L1-L2	20.100	73.036	75.751	74.61
Z L2-L3	20.008	72.375	75.089	74.55
Z L3-L1	19.912	73.031	75.696	74.75
Z L1-Earth	15.770	53.370	55.651	73.54
Z L2-Earth	15.920	53.311	55.637	73.37
Z L3-Earth	15.724	53.200	55.475	73.53
Z (L1-L2-L3)-Earth	9.011	29.023	30.389	72.75
Z1	10.003	36.407	37.756	74.64
Z0	5.677	16.887	17.816	71.42
k0= Z0 / Z1			0.471862	-3.22

$$\underline{Z}_1 = (\underline{Z}_{L1-L2} + \underline{Z}_{L2-L3} + \underline{Z}_{L3-L1})/6$$

$$\underline{Z}_0 = \underline{Z}_{(L1-L2-L3)-Earth} - \underline{Z}_1/3$$

$$k_0 = \underline{Z}_0/\underline{Z}_1$$

Impedance results along with the Z1 +ve and Z0 zero sequence results
k-factor (residual compensation factor)
entered into the relay to allow calculations to compensate for the return path of the fault

Analysis of Measurements

Calculation of line earth impedances from different measurements:	R [Ω]	X [Ω]	Z [Ω]	Phi (°)
Z_E from Measurement L1-E	1.318	2.384	2.724	61.07°
Z_E from Measurement L2-E	1.302	2.435	2.761	61.87°
Z_E from Measurement L3-E	1.420	4.180	4.414	71.23°
Impedance results:	**R [Ω]**	**X [Ω]**	**Z [Ω]**	**Phi (°)**
Line impedance Z_L	0.587	7.128	7.152	85.29°
Ground impedance Z_E	1.345	2.980	3.269	65.70°
Positive sequence impedance Z_1	0.587	7.128	7.152	85.29°
Zero sequence impedance Z_0	4.623	16.067	16.718	73.95°
Grounding Factor:			[1]	
$k_L = Z_E / Z_L$			0.457	-19.59°
R_E / R_L and X_E / X_L			2.291	0.418
Z_0 / Z_1			2.338	-11.34°
Caculation from L-E tests			[2]	
Z_0	4.627	16.127	16.777	73.99°
$k_L = Z_E / Z_L$			0.461	-20.57°
Calculated Data (Cusomer)				
Line impedance Z_L	0.5424	7.0192	7.040	85.58°
Difference [%]	-7.62681	-1.52246		
Zero sequence impedance Z_0	6.692	23.8224	24.744	74.31°
Difference [%]	44.7451	48.27374		

- 400kV Line, 22km
- Utility experienced Z1 time for faults located in Z2
- Impedance values calculated using simulation software
- Major differences in Zero Sequence values (> 48%)
  - Incorrect earth wire parameters

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this shows calculated values against measured values
Genuine reults taken from Germany
Shows big difference between calculated & measrued results and this can cause unwanted tripping
From data of real parameters from the cable therefore Ph-Ph faults will be fairly accuratly modelled but the Ph-E faults will be problematic

0 seq difference = (23.8-16.1)/16.1=0.478 = 48%

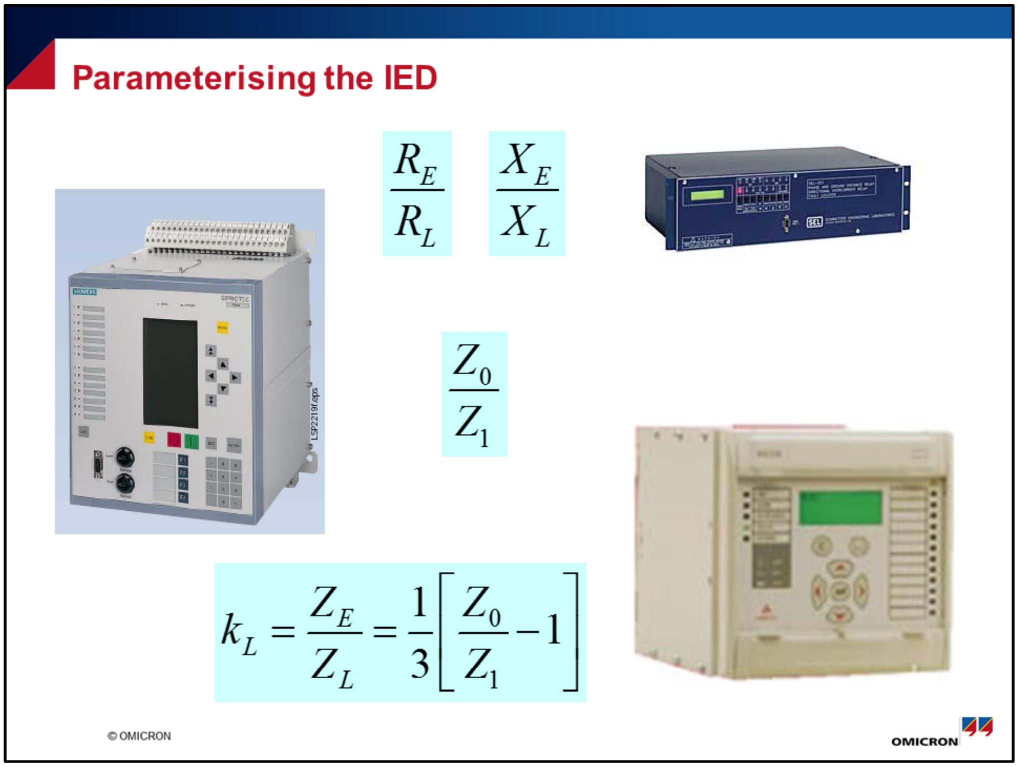
Measured Results

> Calculation of

- Positive Sequence Impedance (Line Impedance)
- Zero Sequence Impedance (Earth Impedance)
- Grounding/Earthing factor (k0)

$$\frac{R_E}{R_L} \qquad \frac{X_E}{X_L} \qquad \frac{Z_0}{Z_1} \qquad k_L = \frac{Z_E}{Z_L} = \frac{1}{3}\left[\frac{Z_0}{Z_1} - 1\right]$$

results will show whether the relay is set correctly



Re and Xe are the Resistive and Reactive reaches of the ground
RL and XL are the Resistive and Reactive reaches of the phase
Z0 is the zero-sequence impedance
Z1 is the positive-sequence impedance
Ze is the ground fault reach (without compensation)
ZL is the phase fault reach of the relay

This shows different ways of entering the residual compensation factor into different types of relays. Now we have enough information to enter data in any format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Distance
Characteristic Testing
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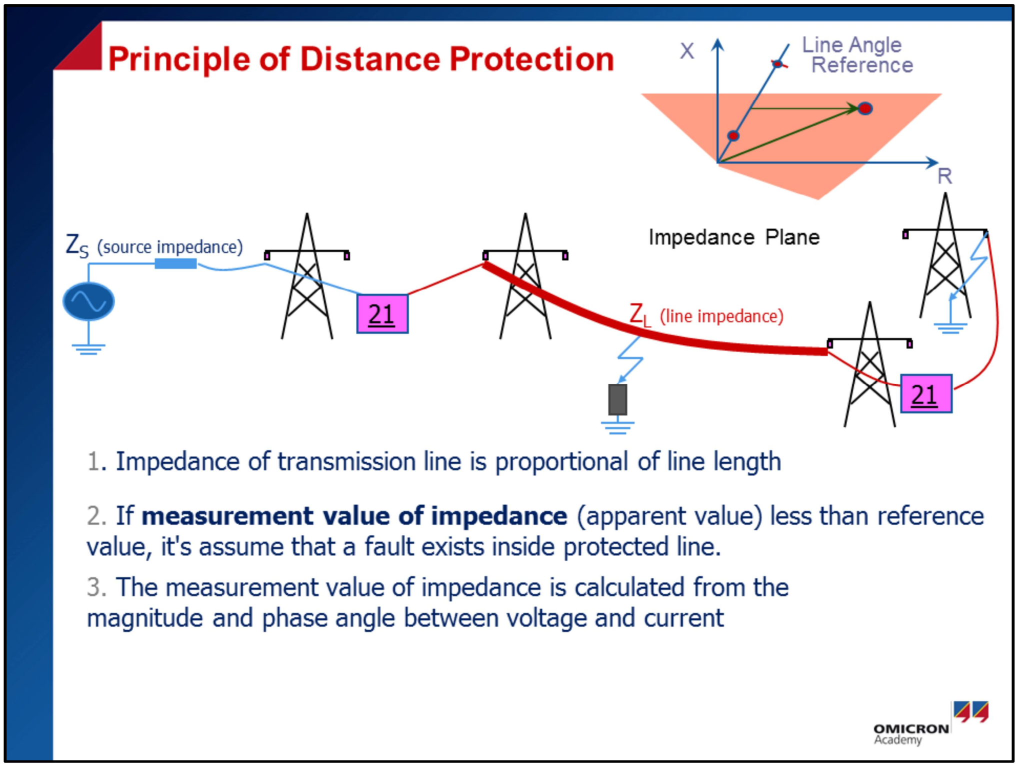
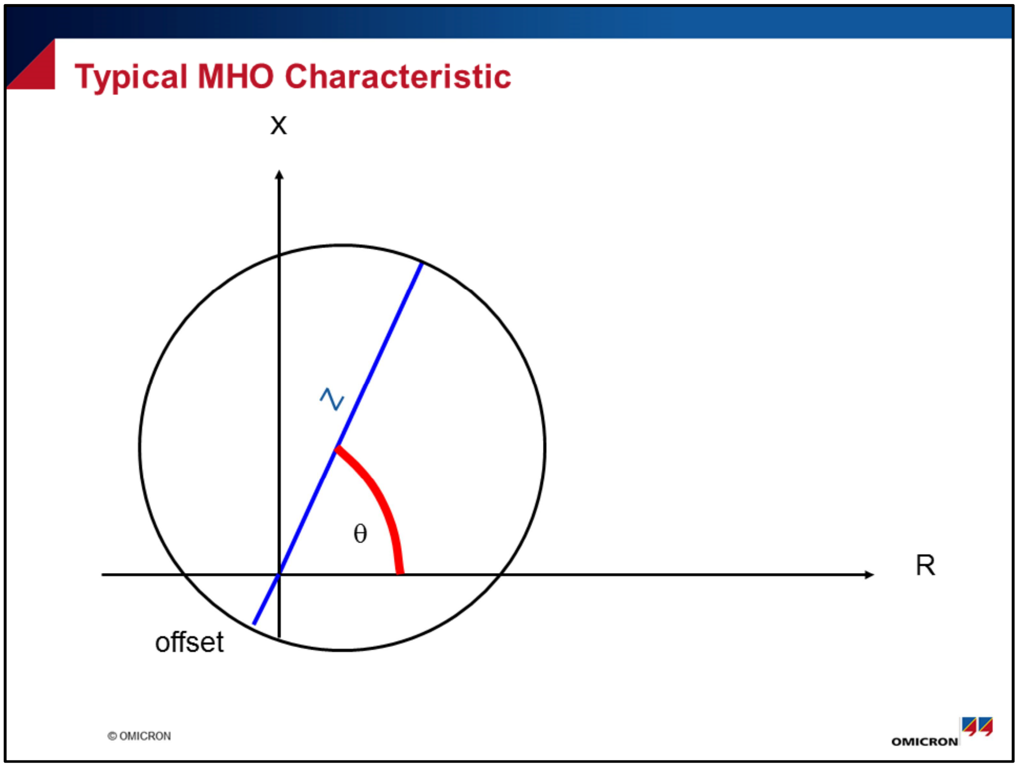
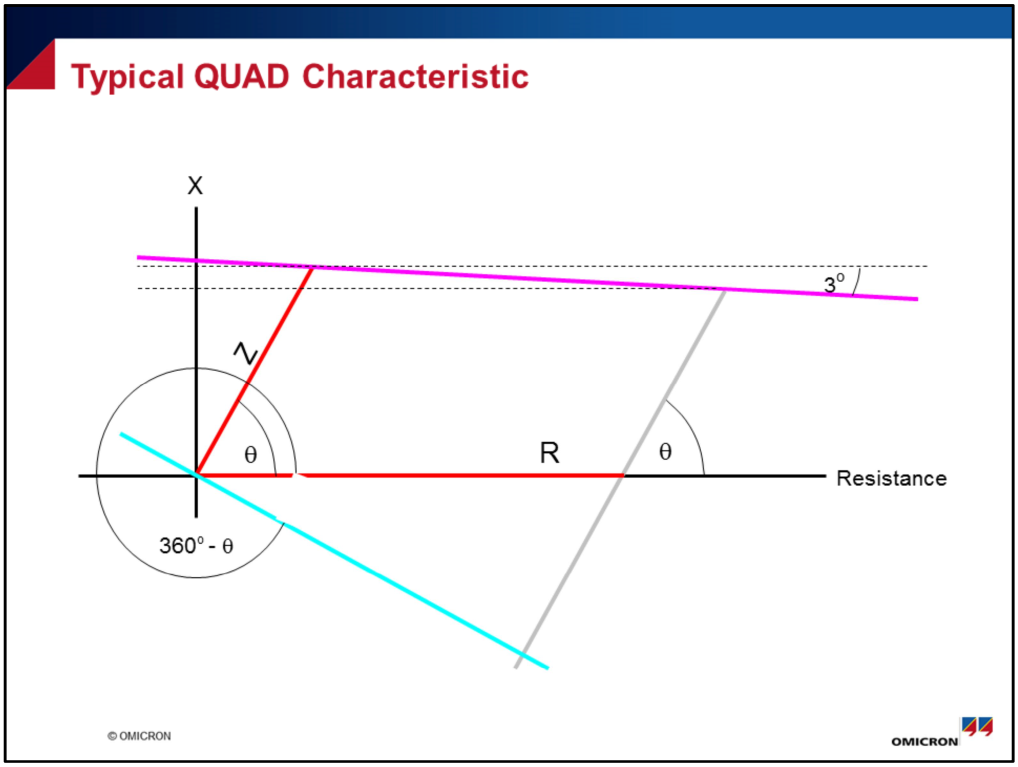
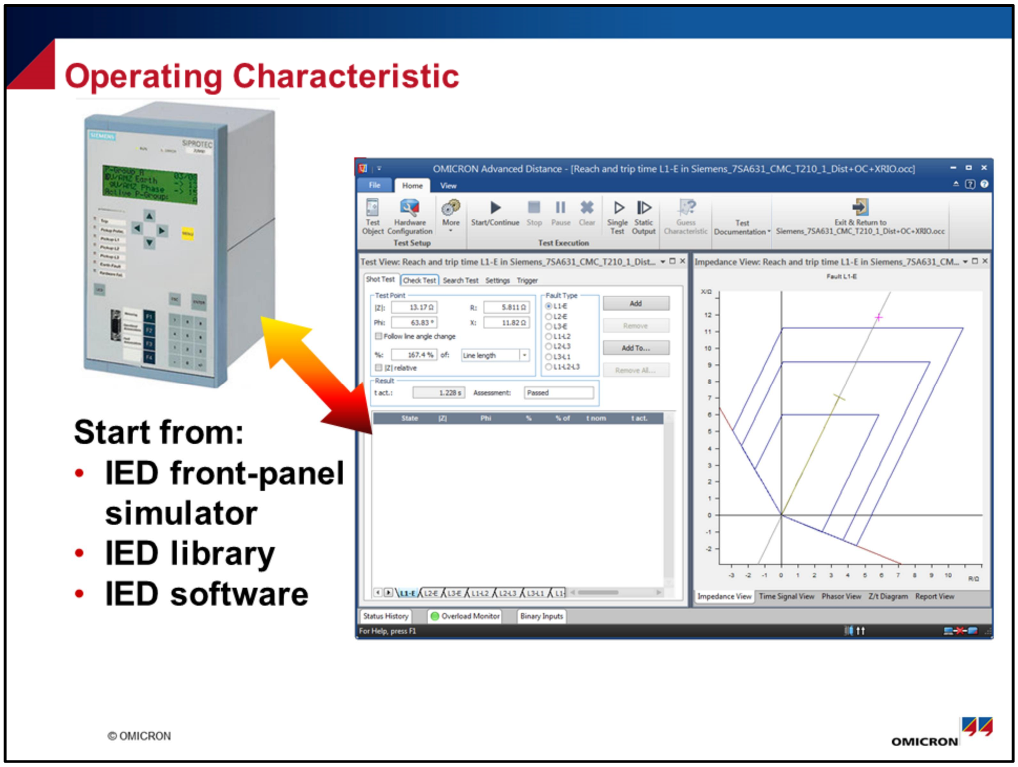

Principle of Distance Protection
X
Line Angle Reference
R
Impedance Plane
Zs (source impedance)
21
ZL (line impedance)
21
1. Impedance of transmission line is proportional of line length
2. If measurement value of impedance (apparent value) less than reference value, it's assume that a fault exists inside protected line.
3. The measurement value of impedance is calculated from the magnitude and phase angle between voltage and current
OMICRON Academy



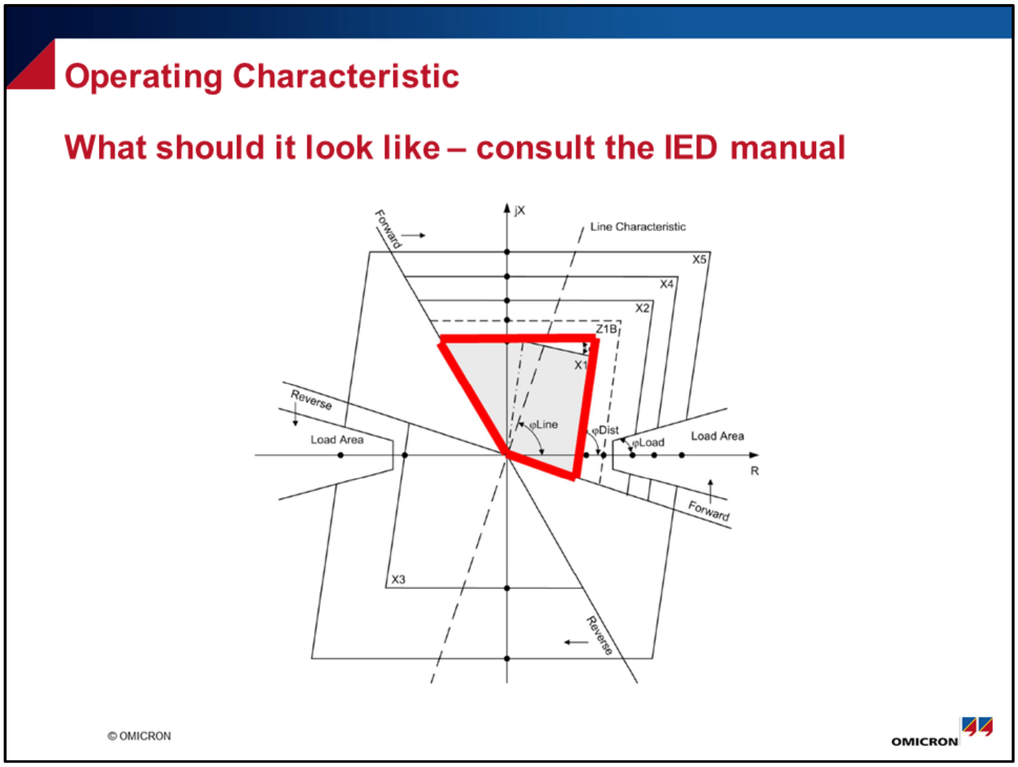
this is defined by the impedance of the line and the line angle
it has an off set indicating that the IED is directional looking forward along the line and also looking in the reverse direction by a certain distance.



This is used mainly for earth faults where there is a high resistive component giving the IED a larger resistive reach. Related to arcing or tower footing or if the return path is highly resistive.



Proving the characteristics:
create the characteristic from new
setting the characteristic from front panel of IED install a characteristic from a library
dump down from IED using software but remember to check against the settings sheet as IED settings may have been entered into IED incorrectly…….



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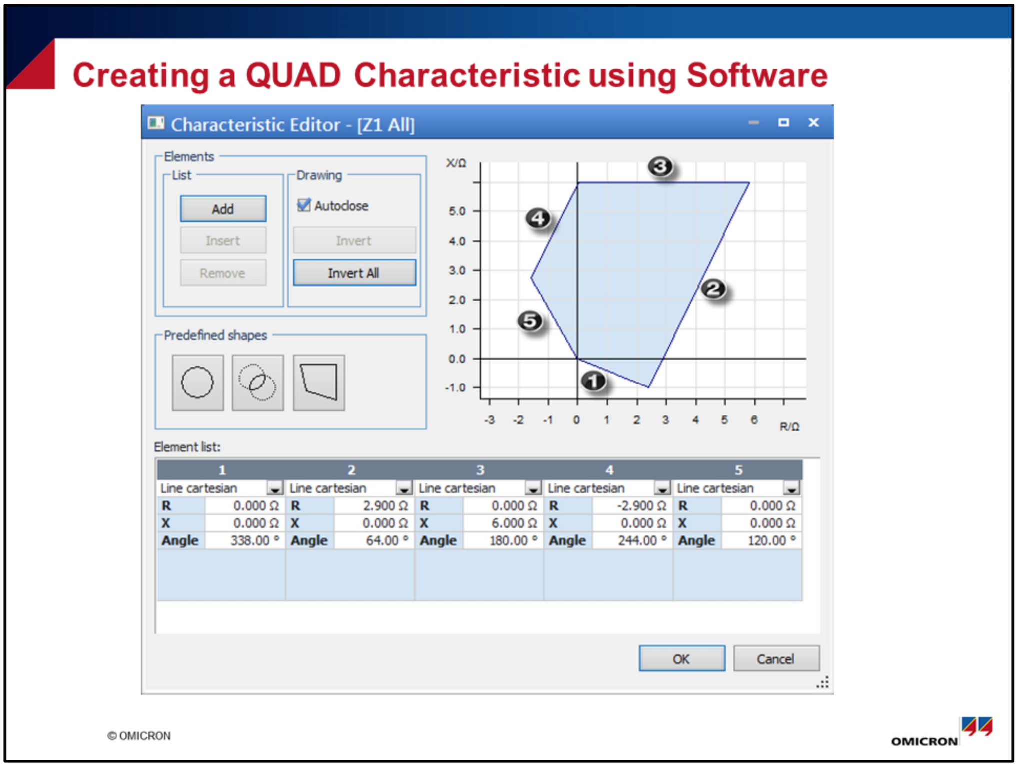
Creating a QUAD Characteristic using Software
Characteristic Editor - [Z1 All]
Elements
List
Drawing
Add
Autoclose
Insert
Invert
Remove
Invert All
Predefined shapes
Element list:
X/Ω
R/Ω
1 2 3 4 5
Line cartesian
R 0.000 Ω | R 2.900 Ω | R 0.000 Ω | R -2.900 Ω | R 0.000 Ω
X 0.000 Ω | X 0.000 Ω | X 6.000 Ω | X 0.000 Ω | X 0.000 Ω
Angle 338.00 ° | Angle 64.00 ° | Angle 180.00 ° | Angle 244.00 ° | Angle 120.00 °
OK
Cancel
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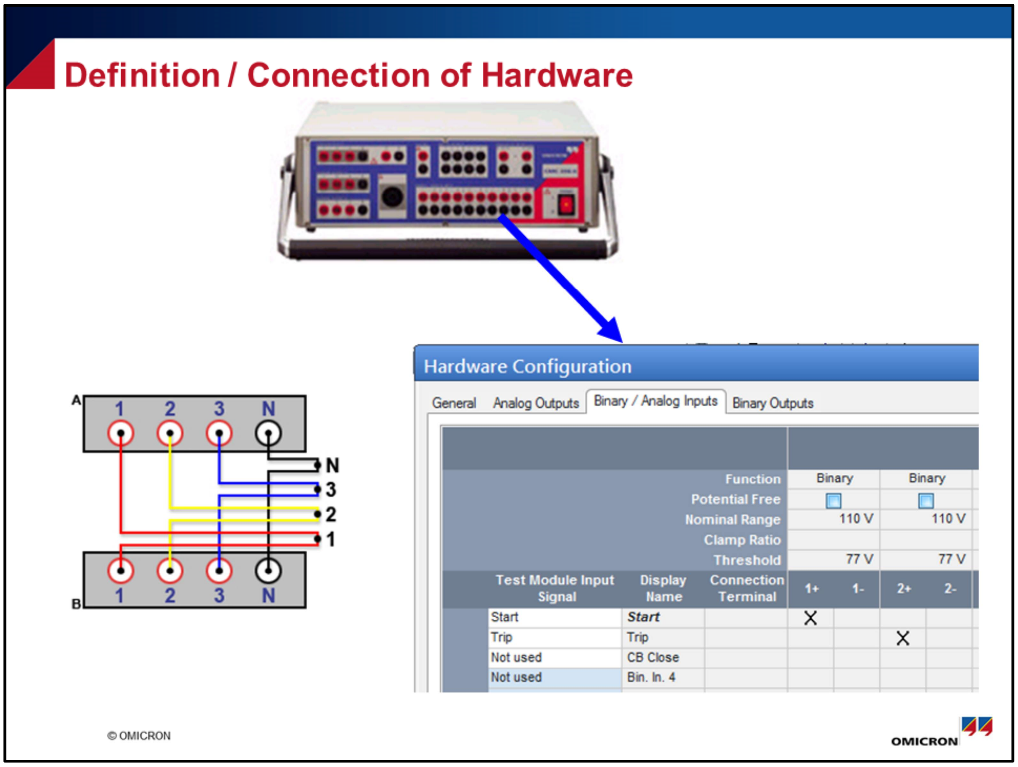
Definition / Connection of Hardware
Hardware Configuration
General
Analog Outputs
Binary / Analog Inputs
Binary Outputs
Function
Potential Free
Nominal Range
Clamp Ratio
Threshold
Binary
110 V
77 V
Test Module Input Signal
Display Name
Connection Terminal
1+
1-
2+
2-
Start
Trip
Not used
CB Close
Bin. In. 4
A
B
1
2
3
N
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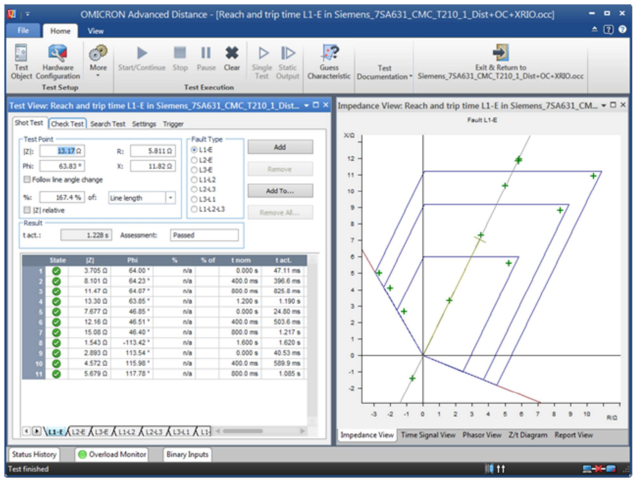
Dedicated Test Module



> Test signal generation
> Measurement
> Assessment and reporting

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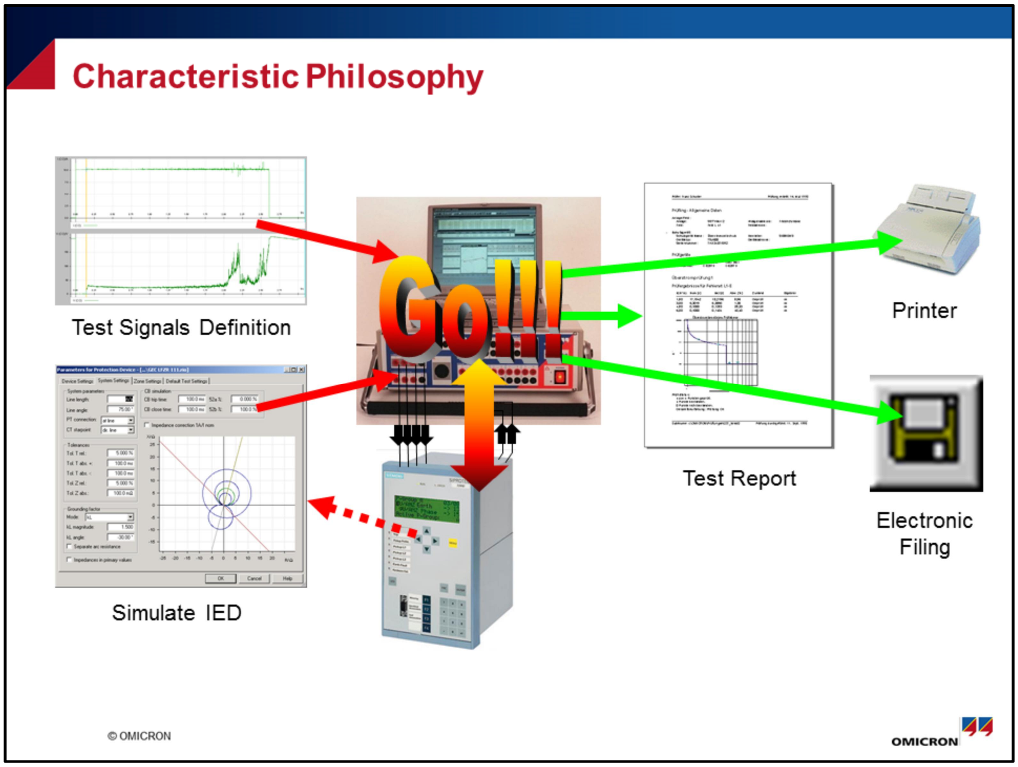
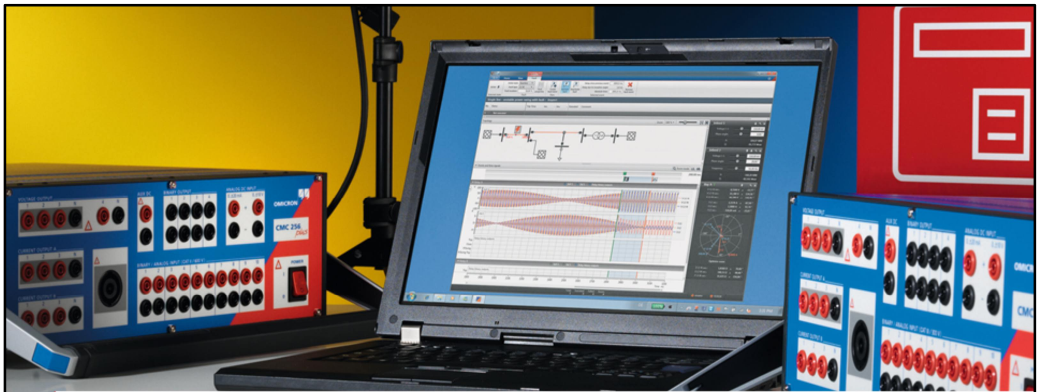


2 parts:
in software we have a complete simulation of the IED & we can assess how it performs under particular conditions

We can define test signals

We can store information for future use.



Relay SimTest

Easy to use software for simulation based, distributed protection testing with CMC test sets

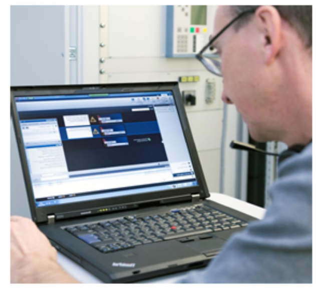
6 February 2015

Transient Network Simulation

- application oriented testing
- simulating the primary power system.

It features:

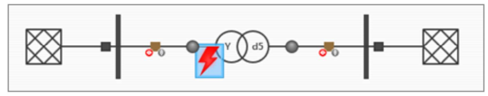
- Easy transient simulations
- Testing of advanced relay functions
- Model lines, busbars, infeeds (sources),
  - loads, two-winding transformers, ...
- Simulation of line capacitances,
  - stray capacitances and series capacitances
- Mutual coupling of lines



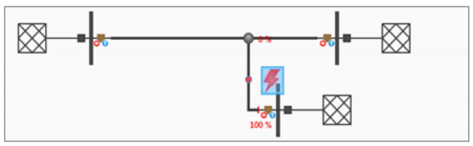
Test the whole system

Some Application Areas

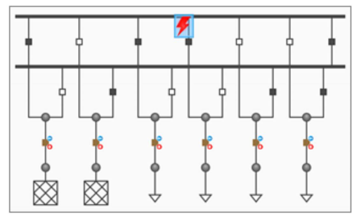
- Teleprotection schemes
- Line differential protection



- Transformer Differential Protection



- Three Terminal Lines



- Bus Bar Protection

Additionally

- Power Swing
- Breaker & a Half

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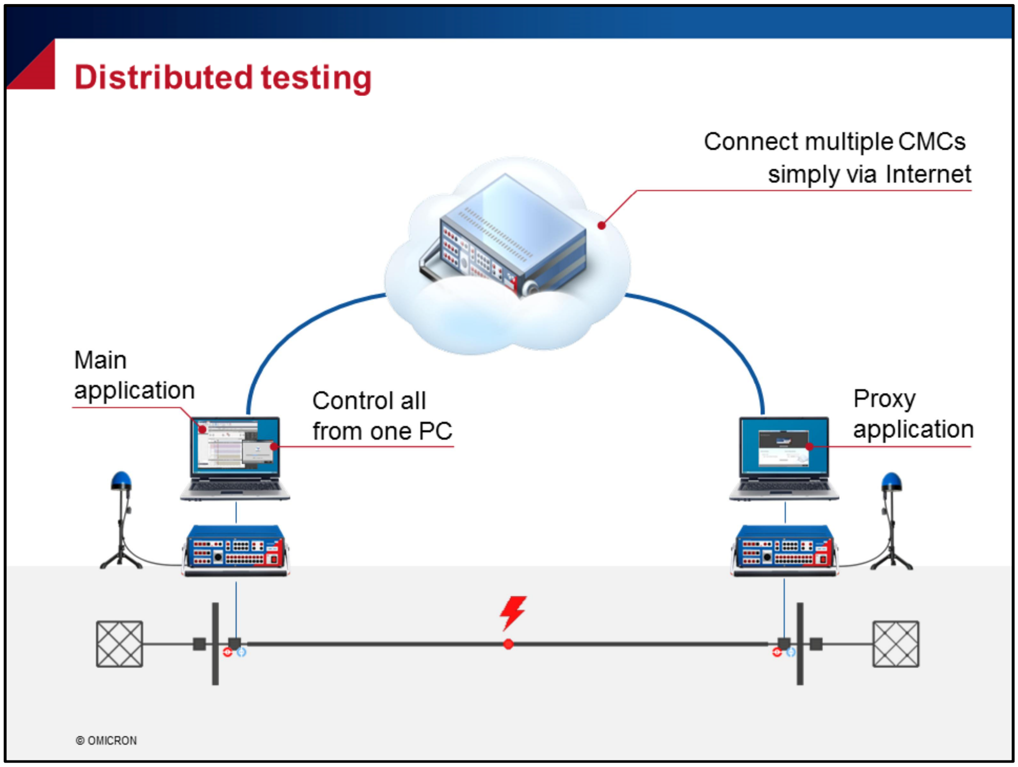

Distributed testing
Connect multiple CMCs simply via Internet
Main application
Control all from one PC
Proxy application
© OMICRON

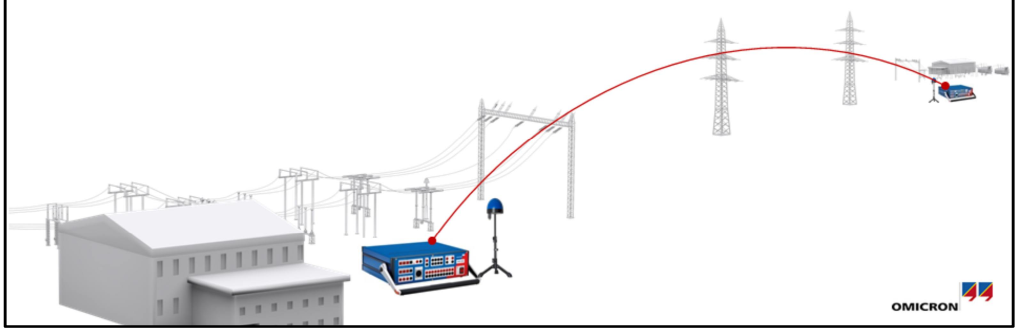
Distributed testing over the Internet

> Leverage available Internet access of mobile computers in the field (e.g. UMTS stick, mobile hotspot feature of Smartphone, ...)

> No complex setup of network connection necessary, just start proxy application at remote end

> Works through firewalls, routers, ... (only outgoing HTTP traffic = works if the user is able to browse the Internet)

> OMICRON provides the connection as a service in the cloud worldwide (free of charge for our customers)



Distributed testing

- Testing of distributed protection (teleprotection, line differential, ...)
- Control multiple CMCs from one application via Internet access
- Plug-and-play synchronization of multiple CMCs via CMGPS 588
- Execute a distributed shot as easy as a single-end shot
- All results are available for evaluation and assessment immediately
  (e.g. possible to measure delay times of teleprotection signals)
- Multiple test steps can be executed automatically in a row without manual interaction
- Troubleshooting of test steps can be done more effectively

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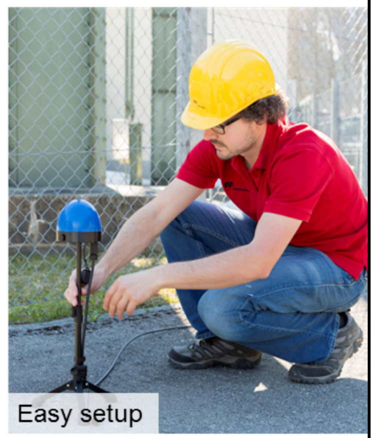
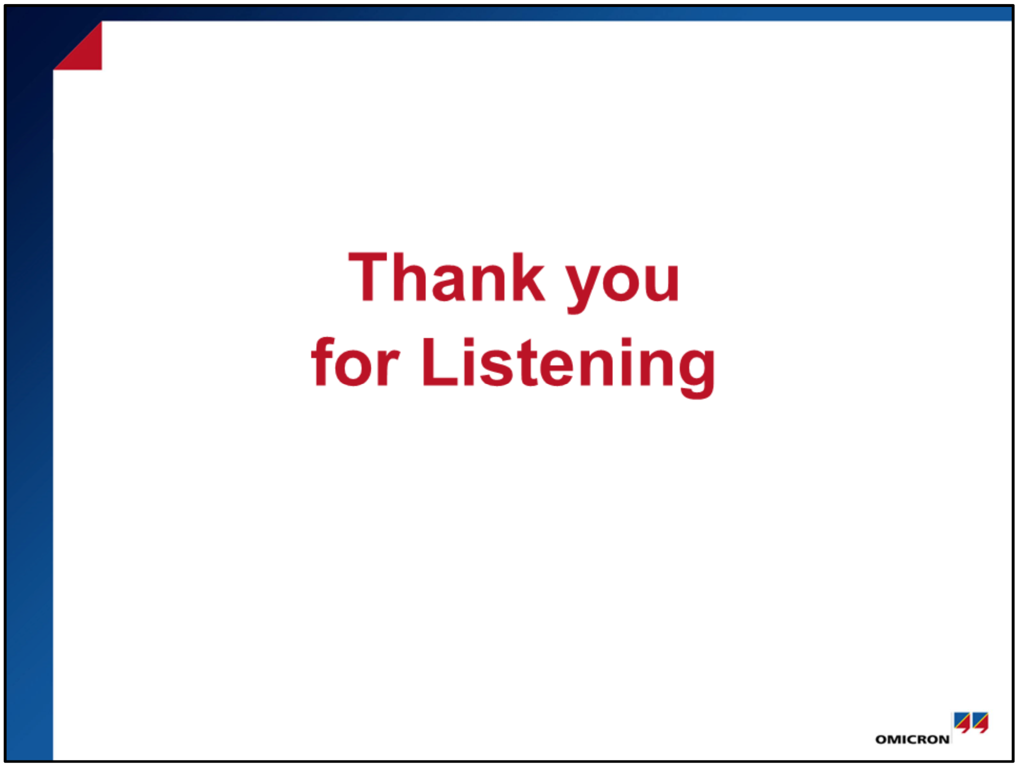
The benefits

- > Control multiple remote CMCs from one PC
- > New testing procedures for modern protective relays with complex algorithms
- > Testing the whole protection system, including communication between the relays
- > Easy to operate
- > Independent from relay type and manufacturer
- > Even for complex failure scenarios



Easy setup


Thank you
for Listening
OMICRON

