Reliability improvement of PILC cable circuits by CBM programs

ICC educational program
on PILC-Cables

April 30 2003, Cincinnati, OH

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Introduction

- PILC is cable with good design and good reputation
- usually old cable in complicated circuits
- old cable is not necessarily bad cable
- purpose of CBM is to prioritize maintenance efforts
- purpose of testing is to separate good from bad parts
- several test methods are available
- interpretation of test results
- case studies are more convincing than presentation

Situation of present PILC cables

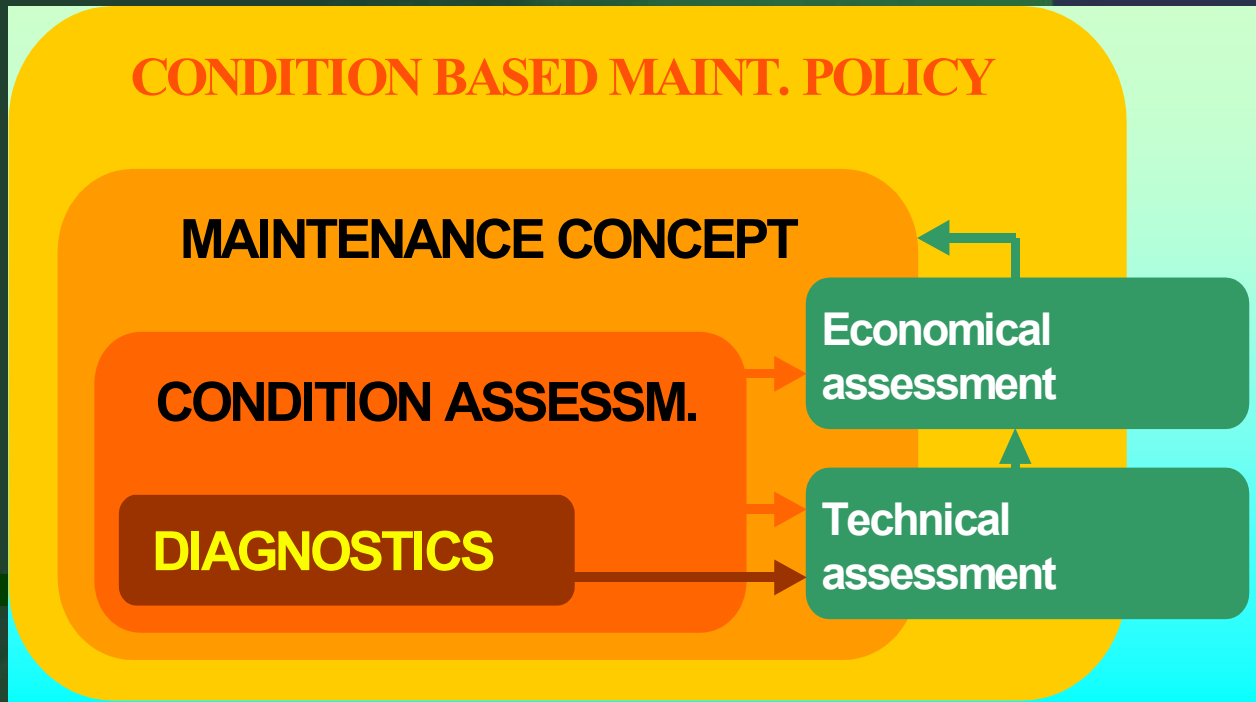
- aging of cable and accessories
- environmental problems (lead)
- complicated accessories (skilled personal)
- cyclic loadings implies more aging than contant load
- extruded cable systems are supposed to be cheaper than PILC
- PILC gradually exchanged by extruded (XLPE, EPR)

Maintenance options

- corrective maintenance
- time-based maintenance
- condition-based maintenance

CBM approach

- desk study technical risks
- desk study financial risks
- evaluation
- testing
- interpretation
- CBM actions



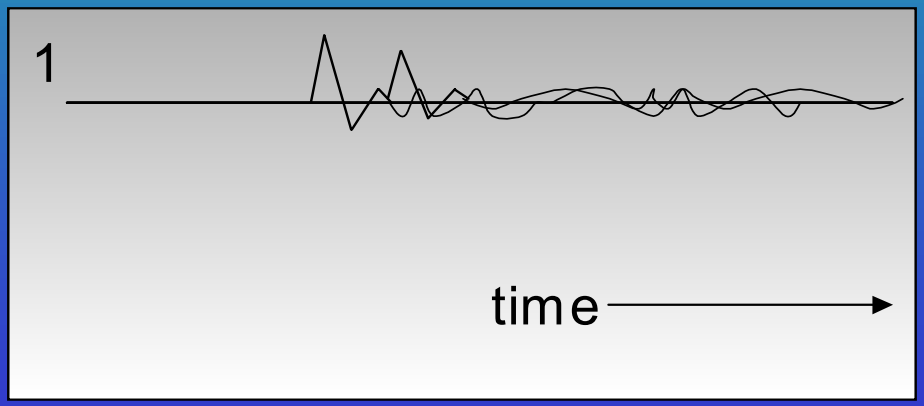
Diagnostic Testing

- PD testing
- DC testing
- Tan δ testing

PD Testing

- on-line: to measure short lengths at operating voltage
- off-line: 0.1Hz- 60 Hz - 0,1/1kHz at different voltage levels
- two methods:
  - single terminal / reflectometry

single terminal / reflectrometry pd test



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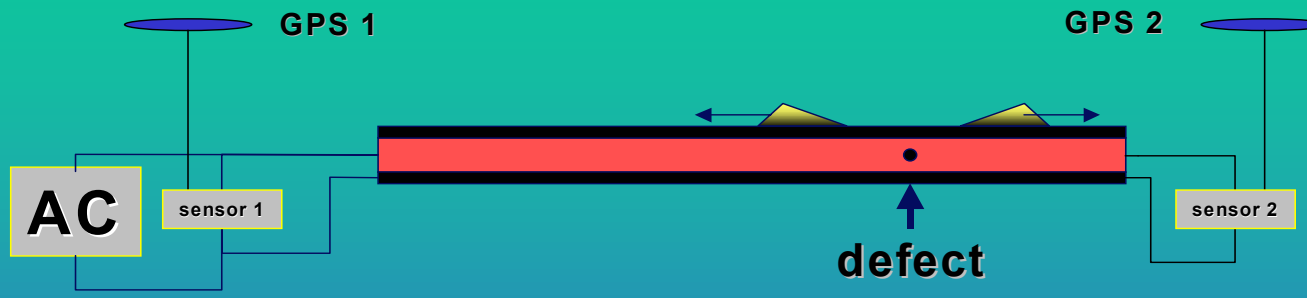
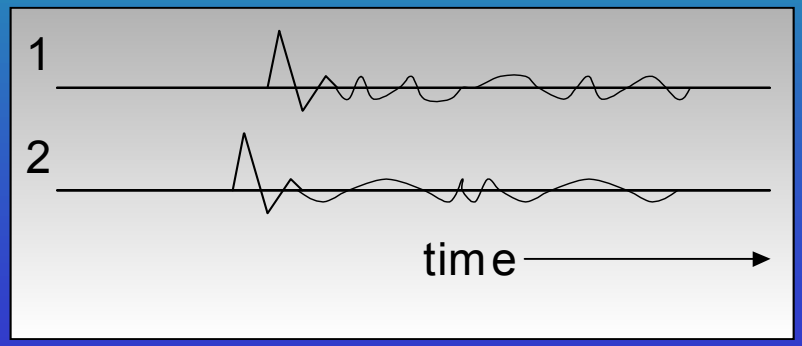
multi terminal / GPS pd test





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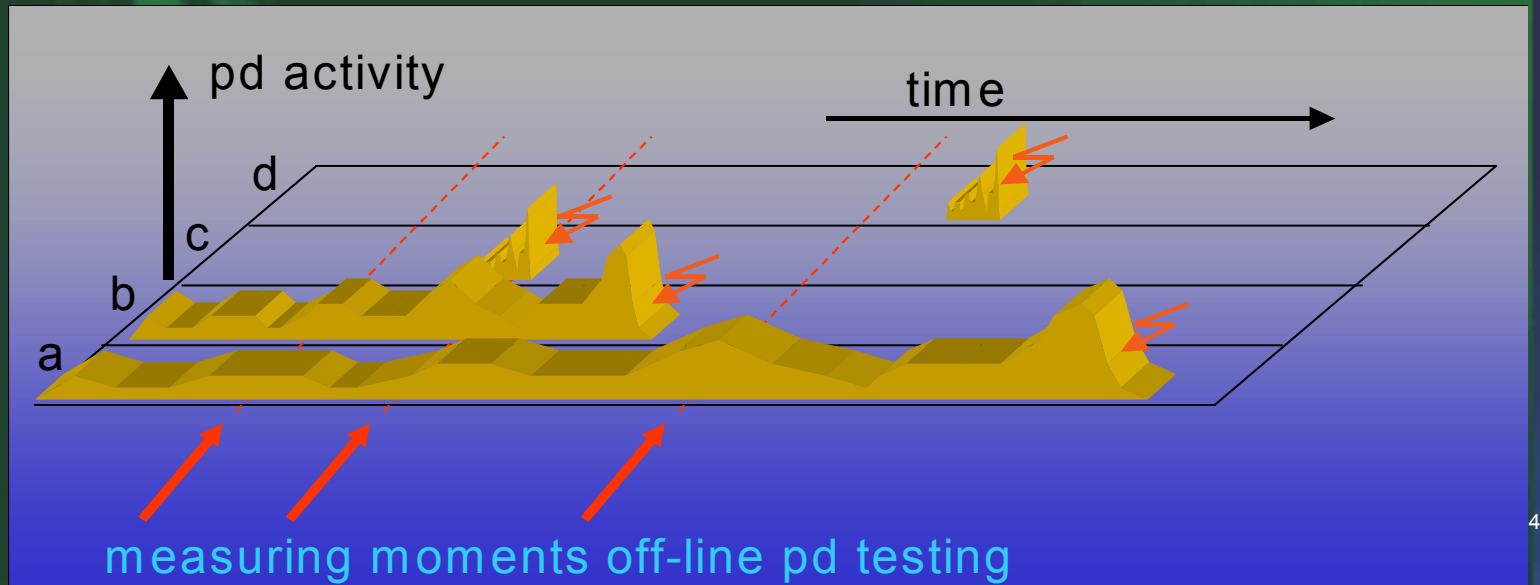
- interpretation of measured information needs knowledge rules

Relevant features of PD diagnostics

- wave form (KR per wave form)
- knowledge rules
- effectivity of PD measurement over time
- cooperation with utilities



Cases based on CBM PD testing

- REMU, NL
- ENEL. Italy

The REMU 10 kV Cable Network

- 3000 circuit miles of mainly PILC cable
- 27000 joints
- 30000 terminations

REMU case

failed components	percentage
cable circuits: · cables + joints = 57 % (mainly joints)	59 %
digging	17 %
mv switchgear	4 %
mv transformers	2 %
secondary installations	4 %
others and unknown	14 %

Cost / benefit analysis

Cost		Benefits
diagnostic testing		repair after failure [1)]
utility guidance		follow up failures [1)]
replacement cost before failure		loss of kWh sold [1)]
		penalties [1)]
		loss of goodwill [2)]
		(potential) customer claims [2)]
based on 1000 tests:	costs	216 k€
	benefits [1)]	192 k€
	benefits [2)]	330 k€

Selection rules

- expected outage time
- type of customer
- type of loading
- number of joints
- type of soil
- number of failures

Selection rules

value	expected outage time (# of switching operations)	type or region	loading current (power)	load pattern	nr of joints	kind of soil	total nr of failures in
1	0 (or automatic restore)	resid. areas	0 – 20 A	≤ 70% and constant	≤ 1	sand	0
2	1	shop. areas	20 – 70 A	≥ 70 % and constant	2 – 7	clay	1 – 2
3	2 or 3	offices and hospital	70 – 120 A	≤ 70% and very dynamic	8 – 13	-	3 – 4
4	≥ 4	industr. areas	≥ 120 A	≥ 70 % and very dynamic	≥ 14	peat	≥ 5
Multipl. factor	2	1.5	1	1.5	2	1	1

Conclusion about selection numbers (SN):

- SN > 26 — first selection
- 23 <SN < 26 — second selection
- SN <21 — not selected

Diagnostic Testing performed in 2002

- first selection , 380 circuits (average lenght 4500 ft), including 4300 accessories

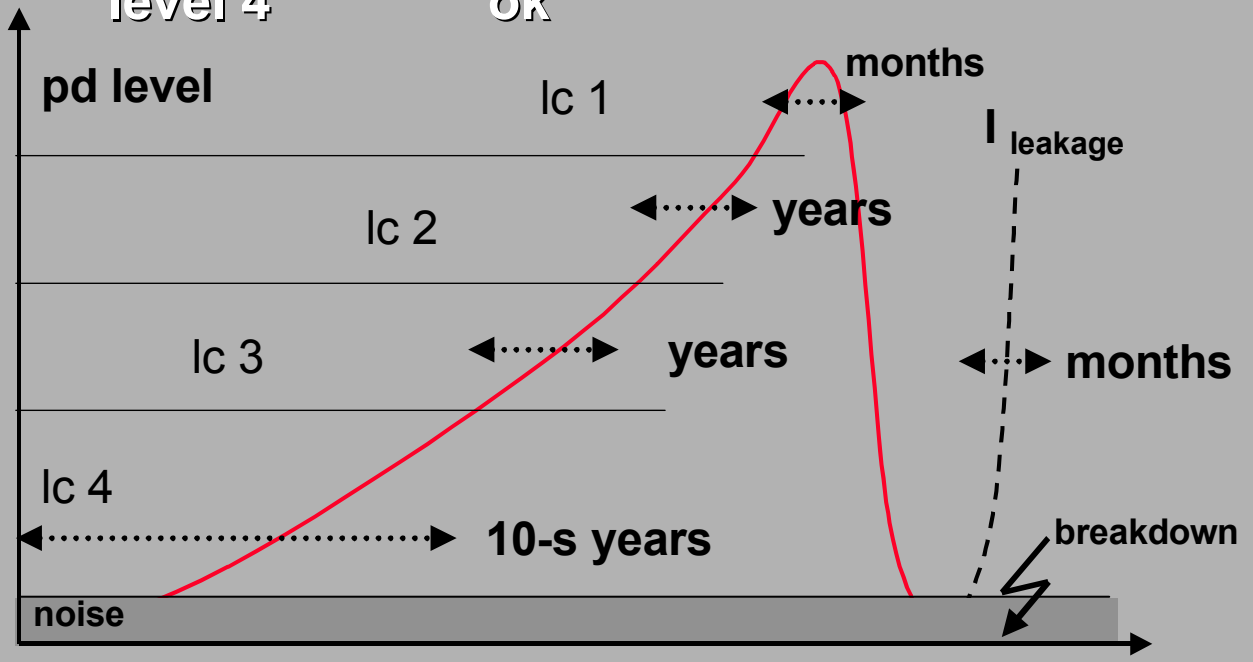
- second selection, 700 circuits (average length 2500 ft), including 5000 accessories

Knowledge rules

- how serious are pd's for a specific component / materials
- to transfer PD results into practical recommendations
- feedback from dissecting to confirm

Results (fig 1)

• 21 %	level 1	= urgent
• 8 %	level 2	< 1 year
• 11 %	level 3	test again after 1 y
• 60 %	level 4	ok



Check of results by inspec. /dissection

- 80% of 1st selection results have been inspected/ dissected
- 95% of inpsected/dissected cases confirm severity of defect (discharges, lead sheath, lack of oil)

ENEL case

- 125.000 circuit km
- penalty for outages > 30 min
- majority of failures related to incorrect assembling of accessories
- cost / benefit analysis (penalty / testing)
- 5% of network (9 - 20 kV), most urgent sections selected:
  - high failure rate
  - high penalty
- 2002-2003 testing period (project will be extended to mid 2004)
- activities:
  - check length
  - localize joint position
  - localize weak spots
  - indicate level: 1 = severe, 2 = less severe, 3 = retest, 4 = OK

Results

- 80% accessories, epoxy, lapped, heatshrink

- 20% level 1 and 2 (300 sections)
- 40% level 3 (600 sections)
- 40% level 4 (600 sections)

Check of results by insp./dissection

- 40 cases of level 1 have been dissected of which 39 confirmed severity of level 1 (2.5%)
- ENEL requirement for acceptable percentage of missing confirmation =15%
- ENEL confirmed lower failure rate for lines subjected to CBM

New development

- to integrate in diagnostic testing
  - use of selection rules
  - improved knowledge rules
- to develop on-line monitoring

Conclusions

- PILC to be exchanged using CBM approach
  - to improve reliability
  - to reduce cost
- to optimize CBM effect, improved selection & knowledge rules necessary