Health Index: the last frontier of asset management

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Fabio Scatiggio was born in Venezia, Italy, in 1957. He is with Terna Rete Italia where he is in charge as Chemical Laboratory Manager.

He is the Italian representative in many IEC TC 10 and CIGRE A2&D1 working groups. Mr. Scatiggio has published many papers on transformers diagnosis by DGA and on problems related with presence of corrosive sulphur in oil.

Mr. Scatiggio received the “IEC Award 1906” in 2008 and was awarded as “CIGRE Distinguished Member” in 2012.

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Health Index: the last frontier of TSO's asset management

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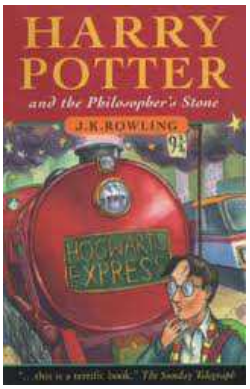
HEALTH INDEX = PHILOSOPHER'S STONE ?



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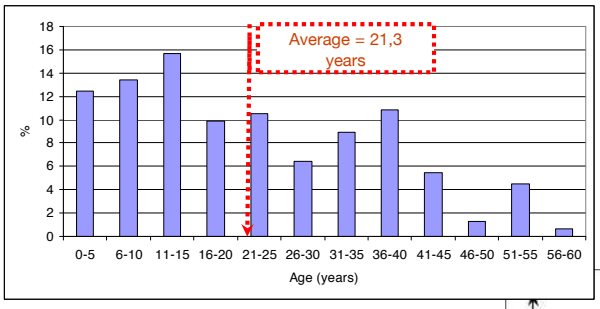
Introduction

Power transformers have indisputably the highest value of the equipment installed in transmission substations, comprising up the 60% of the total investment.

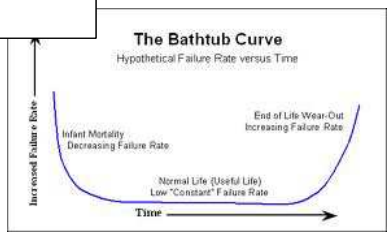
The asset management needs a tool for supporting engineering decisions and capital replacement plans → HEALTH INDEX

Introduction

Up today the maintenance and the replacement strategies are basically age oriented



TERNA's transformers age



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Benchmarking

In 2012 a CIGRE WG has published an interim report:

- CIGRE A2.37 “Transformer Reliability Survey: Interim Report” – Electra N° 261 - April 2012

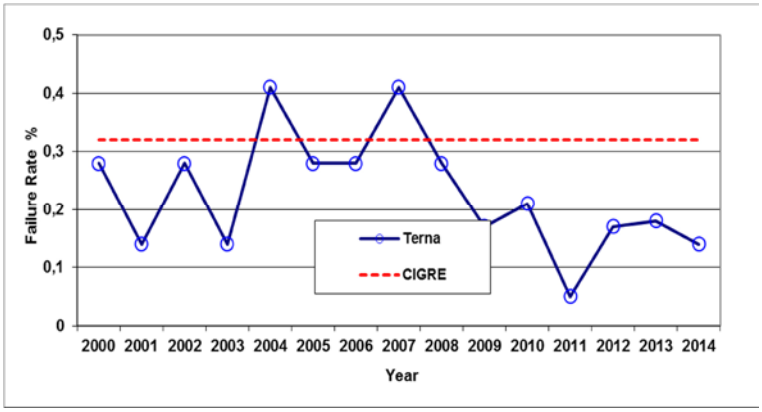
as update of the previous CIGRE report published in 1983:

- A. Bossi et al. “An international Survey on Failures in Large Power Transformers in Service – Final Report” – Electra N° 88, pp. 22-48, 1983

Failure rate (λ) is expressed as: $\lambda = 100 \cdot \frac{\sum_i n_i}{\sum_i N_i} \%$

Major Failure: any situation which required the TF to be removed from service for a period >7 days, for …

Benchmarking



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Risk

The risk can be expressed as $R = N \cdot L \cdot P$

- **N** number of dangerous events (like: lightning strokes, energizations, etc.). N is function of several parameter as the location of the substation, the number and the characteristics of the incoming overhead lines, etc;
- **P** probability of one dangerous event may cause a damage. P is function of the capability of the transformers to withstand at the negative event without serious consequence: this capability may be considered as an "health index" of the transformer;
- **L** is the average damage and is function of the economical asset of the transformer and its location (visibility, proximity to houses, etc.). Magnitude evaluation.

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Risk: Classification in iso-attention classes

Two different contributions (static or dynamic) by three parameters (N, P, L)

1. Site specificity (static)
   - Keraunic level
   - Substation layout
   - Closeness to towns or human premises
   - Recrudescence of catastrophic events, etc.
2. Transformer condition (dynamic)
   - Dielectric
   - Thermal
   - Mechanical
   - Oil aging
   - Economical transformer residual value

The mathematical combination of the 3 parameters generates the **iso-attention class of risk**, which is of capital importance for addressing the managing of large transformers fleets

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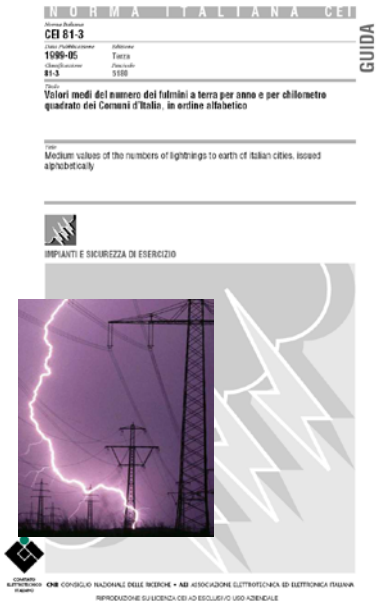
N: Dangerous Events

Keraunic level

- Norma CEI 81- 3: Medium values of the numbers of lightnings to earth of Italian cities (lightning/year· Km^2)

GE	TIGLIETO	4	CB	TORELLA DEL SANNIO	2,5
AT	TIGLIOLE	4	PG	TORGIANO	4
BS	TIGNALE	4	AO	TORGNON	1,5
NU	TINNURA	2,5	TO	TORINO	2,5
AQ	TIONE DEGLI ABRUZZI	2,5	CH	TORINO DI SANGRO	2,5
TN	TIONE DI TRENTO	2,5	BA	TORITTO	2,5
SO	TIRANO	2,5	CR	TORLINO VIMERCATI	4
BZ	TIRES	4	NO	TORNACO	2,5
CZ	TIRIOLO	2,5	CH	TORNARECCIO	2,5
BZ	TIROLO	1,5	CR	TORNATA	4
SS	TISSI	2,5	AQ	TORNIMPARTE	2,5
PZ	TITO	2,5	CO	TORNO	2,5
RM	TIVOLI	4	PR	TORNOLO	1,5
PR	TIZZANO VAL PARMA	1,5	CB	TORO	2,5
RE	TOANO	1,5	NU	TORPÉ	4



P: Health Index (HI)

Transformer condition

- From in-lab and on-site periodical checks

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P: Health Index (HI)

Transformer condition

- From on-line detectors (DGA, PD, tan delta, etc.) continuous checks

P: Health Index (HI)

Transformer condition

- Dielectric & Thermal (DGA = hydrogen, methane, ethane, ethylene and acetylene)
- Purely Thermal (2-FAL + CO_2 + CO + CO_2/CO)
- Mechanical (Inductance + SFRA + FDS/PDC)
- Oil (water + acidity + breakdown voltage + DDF)

PCB and Corrosive Sulfur weren't considered because removed or mitigated

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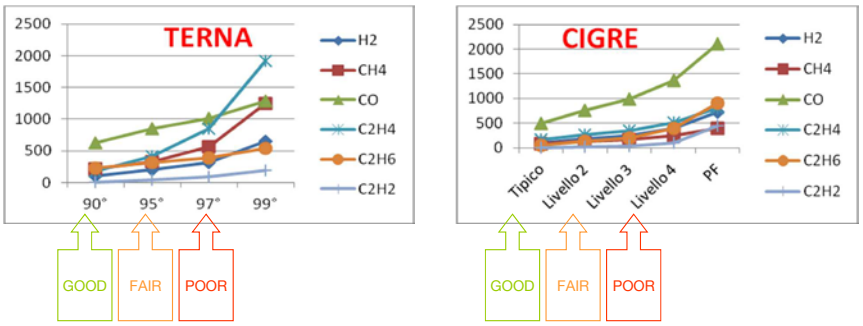
Thresholds and limits

For comparison

- From IEC, IEEE, CIGRE
- From owner's practices

1) DGA from CIGRE (concentrations, rate of increase and type of fault)



Thresholds and limits

- From IEC, IEEE, CIGRE
- From owner's practices

2) 2-FAL from statistical computation of analytical data-base

GOOD
FAIR
POOR

percentile	2-FAL (mg/Kg)
90°	0.95
95°	2.35
97°	3.25
99°	6.57

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Thresholds and limits

- From IEC, IEEE, CIGRE
- From owner's practices

3) Oil aging from IEC 60422

Parameter	M. U.	TR voltage > 170 KV		
		GOOD	FAIR	POOR
Water	mg/Kg	< 15	15-20	>20
Acidity (NN)	mg KOH/g oil	<0.10	0.10-0.15	>0.15
BDV	KV	>60	60-50	<50
DDF		<0.1	0.1-0.2	>0.2
Parameter	**U.M.**	**TR voltage < 170 KV**		
		GOOD	FAIR	POOR
Water	mg/Kg	< 20	20-30	>30
Acidity (NN)	mg KOH/g oil	<0.10	0.10-0.20	>0.20
BDV	KV	>50	50-40	<40
DDF		<0.1	0.1-0.5	>0.5

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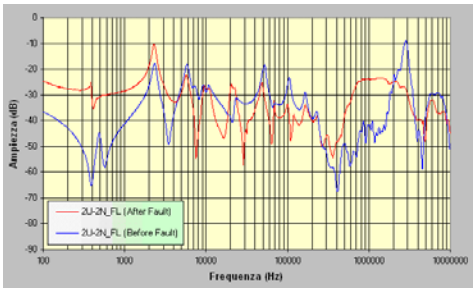
Thresholds and limits

- From IEC, IEEE, CIGRE
- From owner's practices

4) SFRA



SFRA	
Overlap	Good
Not overlap	Poor

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Thresholds and limits

- From IEC, IEEE, CIGRE
- From owner's practices

5) Leakage inductance and FDS/PDC

INDUCTANCE		
ΔL %	Condition	Action
< 1.5	Normal	None
1.5 – 2.5	Attention	Yearly check
2.5 - 5	Fair	Replacement scheduled
> 5	Poor	Replace

FDS/PDC		
RH %	Condition	Solid insulation status
< 2.2	Normal	Dry
2.2 – 3.7	Attention	Partially wet
3.7 – 4.8	Fair	Wet
> 4.8	Poor	Extremely wet

Example of calculation (water)

Since the test parameters are expressed in different units (kV, ppm, %, etc.) they must be converted in a non-dimensional number (rank).

Test	IEC 60422, for >170 kV	Relative Weight	True or False	Rank
Water = 18 mg/Kg	Good < 15	0	No	0
	Fair 15 -20	0.15	Yes	0.15
	Poor > 20	0.3	No	0
Weighted rank for water content =				0.15

Since the risk relevance of the different parameters is largely different, the scoring system is designed so that every individual measure is multiply by a relative weight.

The relative weight applied is inevitably questionable.

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Health Index (HI)

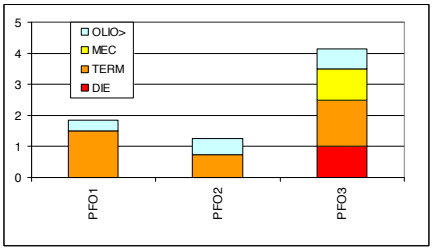
The same approach was applied at all the considered parameters for oil evaluation

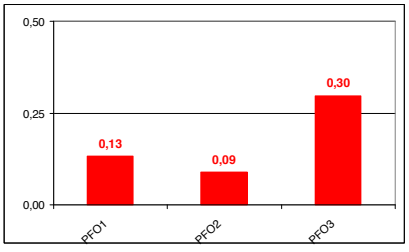
$$HI_{oil} = Weighted\ rank\ test1 + Weighted\ rank\ test2 + + \ldots test_n$$

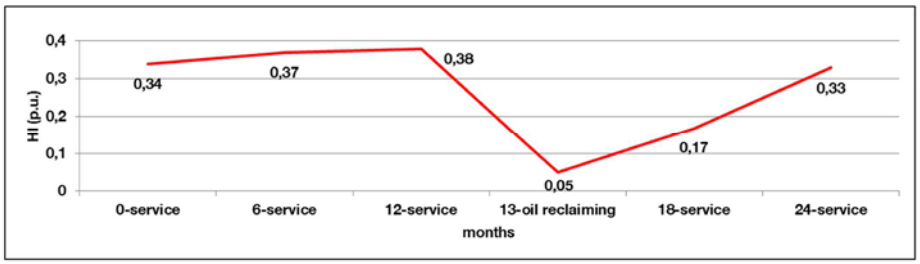
And then also to all the other categories

$$HI_{(p.u.)} = \frac{HI_{dielectric} + HI_{thermal} + HI_{mechanical} + HI_{oil}}{\max}$$

Real application to transformers







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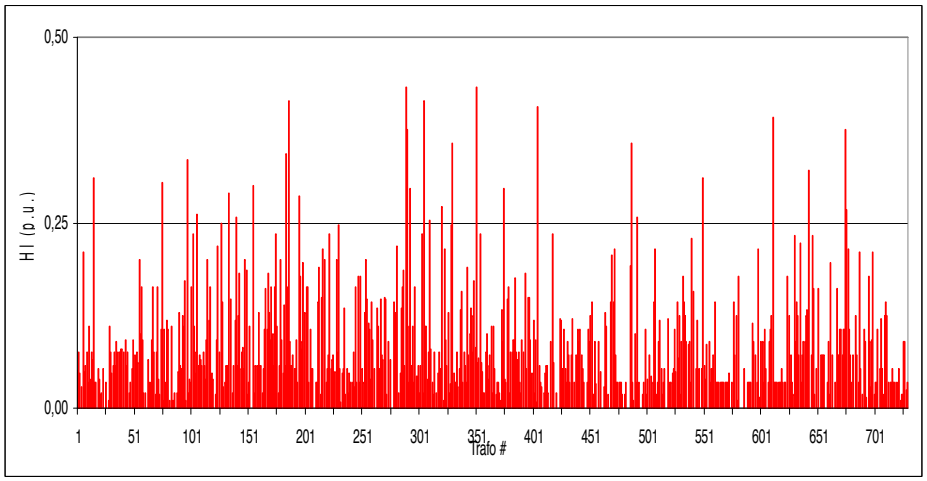
Real application to entire transformers fleet



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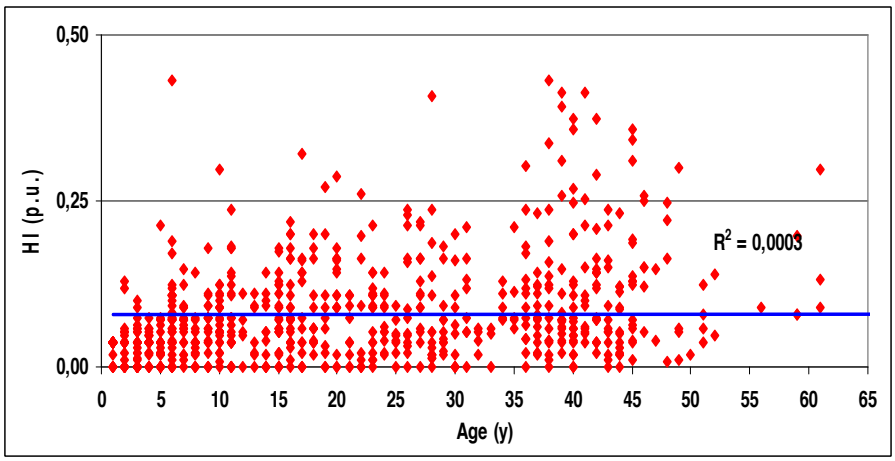
Health Index (HI) vs. Age



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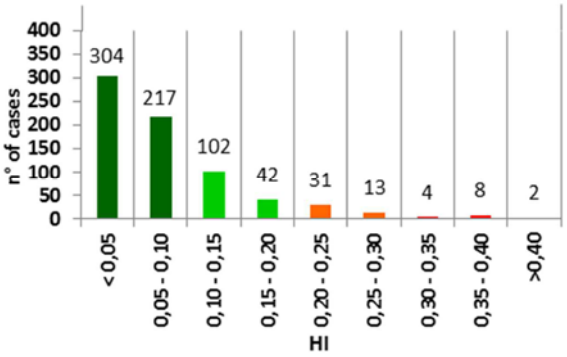
Health Index (HI) vs. Risk Condition

Health Index (HI)	Condition
0 - 0.10	Very Good
0.10 - 0.20	Good
0.20 - 0.30	Fair
> 0.30	Doubtful



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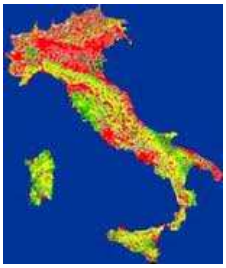
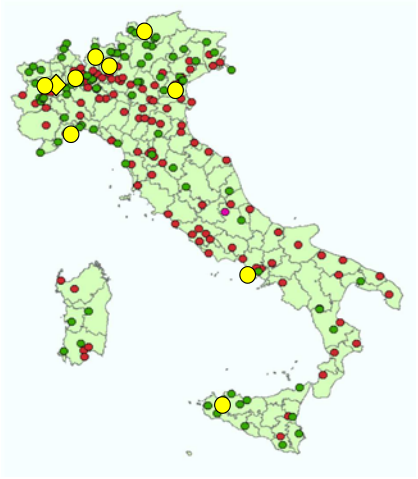
L: Magnitude Evaluation

Substation vulnerability

- Based on "Jenks Natural Breaks" methodology
- Area type (farm, industrial, residential)
- Population density (inhabitants/km^2)
- Closeness to human habitations





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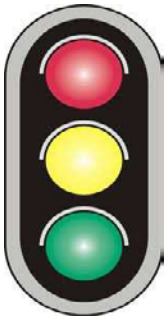
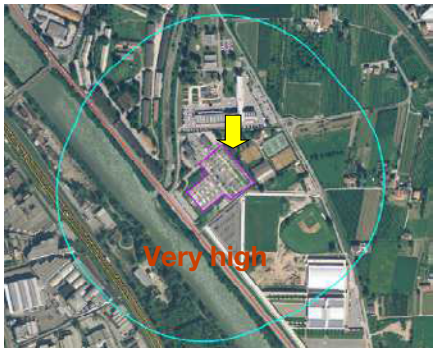
L: Magnitude Evaluation

Substation vulnerability

- Generate a "traffic light" tool, in 5 risk classes:
  - Very low
  - Low
  - Medium
  - High
  - Very high





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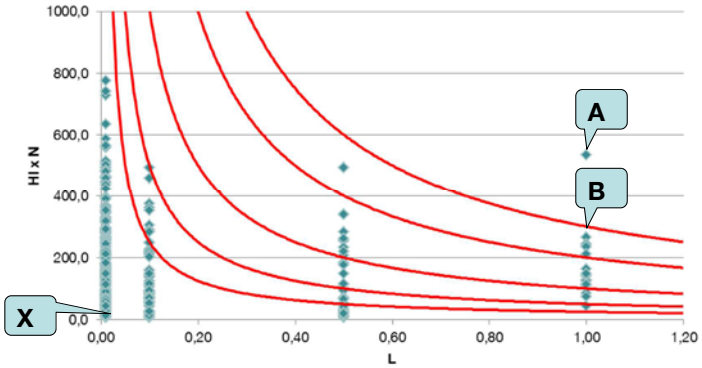
Classification in iso-attention classes



Case Study	MV A	kV	AGE (years)	P (HI)	L	N	Risk	Situation	Actions
A	33	220	40	0.43	1.00	1.235	533.7	High L, High N&P (HI)	Replacement in short time
B	33	220	40	0.21	1.00	1.235	264.6	High L, High N, Low P (HI)	Additional lightning countermeasure or change location
X	400	380	12	0.01	0.10	1.235	1.2	Regular Typical, Low L , Low N&P (HI)	None

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Case study A
This unit has a risk value 60 times higher than the average of all the others and, therefore, its operation must be strictly controlled. Part of the risk is due to the exposition to the lighting stroke and, therefore, this hazard can be mitigated adopting proper countermeasure. Any action of mitigation is possible for the P (also called Health Index) because its high value is mainly due to the irreversible degradation of the paper insulation (2-FAL=3.8 ppm). Furthermore, the unit is suffering of presence of hot spot with high ethylene production. Also the transformer location is quite critical (high L value). In conclusion, it should be recommended the replacement in a short range of time of the unit in conjunction with additional fire and explosion protection systems.

Case study B
The risk is mainly due the critical location (L) of the unit and the exposition to the lighting strokes (N). In this case the replacement will not have not beneficial effects (acceptable value of P), but it should be considered some additional countermeasure both of prevention and of protection.

Cases study X
It represents typical unit of the fleet under investigation not presenting critical situation in terms of number of dangerous events (N), “health index” (P) and average damage (L) in case of the event.

Reduction of Risk (R=N·L·P)

N number of dangerous events
- Improve Lightning Protection System.

P probability of one dangerous event may cause a damage
- Install barrier, fire extinction system, etc.(protective action)
- Change the transformers, before the failure (preventive action)
- Treatment/Change of the insulating oil (preventive action)
- Install on-line monitoring systems and adopt an intensive diagnostic program (preventive action)
- Improve quality management system with external expertise (preventive action).

L average damage
- Change location of the Substation
- Change rules for workers.

Conclusion

- Useful tool for representing the real condition of every single transformer
- Pragmatic tool for the maintenance and replacement strategies based on condition
- Limitations and flexibility due to overlapping of same parameters significance and their thresholds
- Future improvements:
  - Trend, variations over the time
  - Number of energyzations, load, oil and winding temperature, defects and relevant breakdown, trouble familiarity, leakages, etc.

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