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TEXAS A&M UNIVERSITY

MARCH 28–31, 2022

75th Annual

Conference for Protective Relay Engineers

Transformer Loss of Life Monitoring

A review of in-service highlighting achieved benefits

TEXAS A&M UNIVERSITY, 75th Annual Conference for Protective Relay Engineers

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03/29/2022

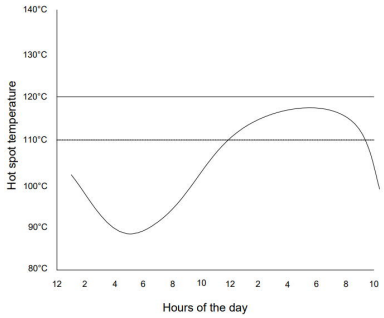
Hitachi Energy

Overview

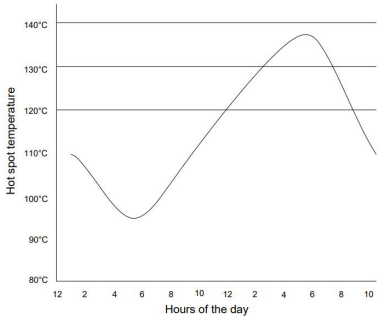
- Transformer load profiles
- Insulation aging
- Loss of life
- Hot spot
- Top-oil temperature rise
- Top-oil temperature
- Tap changer
- FAT/SAT lessons learned
- Benefits

Normal and sacrifice transformer life expectancy

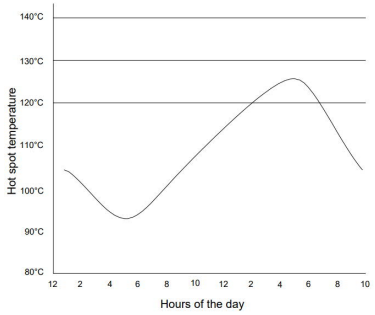
Normal life expectancy
Loading to rated output



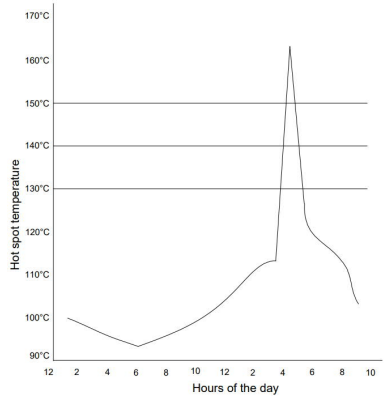
Long time emergency loading
Prolonged outage of some system element



Planned loading beyond nameplate rating
Planned repetitive load



Short time emergency loading
Unusual short time heavy Power system disturbance events



IEEE Std C57.12.00-2010

Transformer insulation aging

Chemical degradation of insulation paper

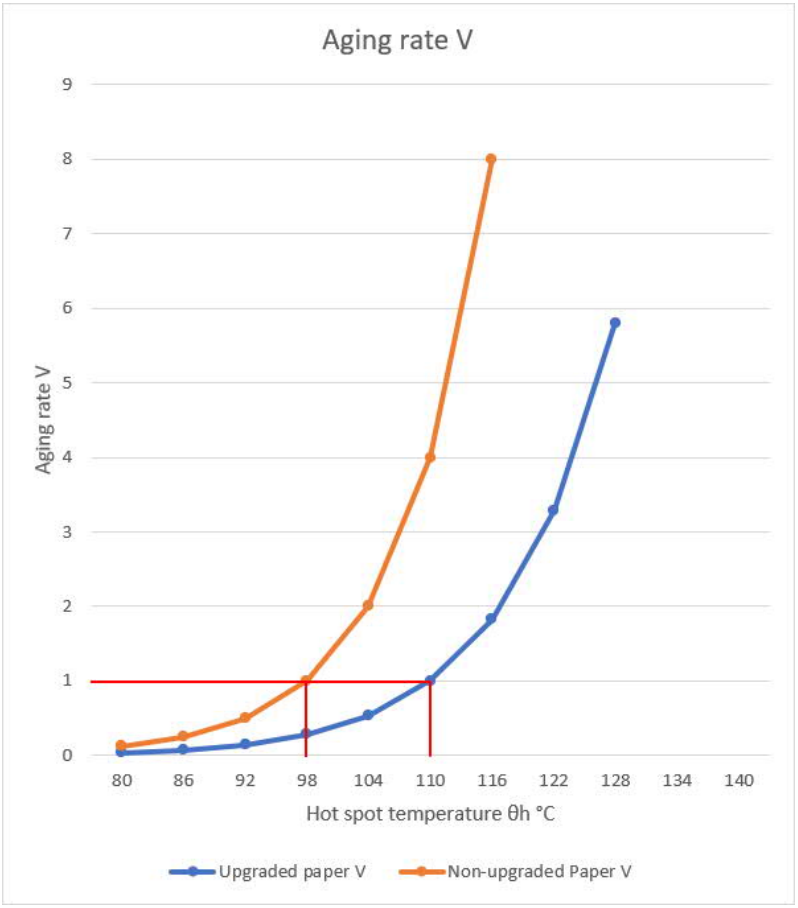
- Oxidation
- Hydrolysis
- Pyrolysis

$$V = 2^{(\theta_h - 98)/6} \qquad V = e^{\left(\frac{15\,000}{110+273} - \frac{15\,000}{\theta_h+273}\right)}$$

	Paper insulation	
	Non-upgraded	Upgraded
θ_h (°C)	V	V
80	0.125	0.036
86	0.25	0.073
92	0.5	0.145
98	1.0	0.282
104	2.0	0.536
110	4.0	1.0
116	8.0	1.83
122	16.0	3.29
128	32.0	5.8
134	64.0	10.1
140	128.0	17.2

IEC 60076-7:2017

Aging rate V = 1.0 corresponds to a temperature of 98 °C for non-thermally upgraded paper and 110 °C for thermally upgraded paper



Loss of life

- Loss of life

$$L = \int_{t_1}^{t_2} V \, dt \quad \text{or} \quad L \approx \sum_{n=1}^{N} V_n \times t_n$$

L = Loss of life

V = aging rate

Percentage of loss of life

$$\%Loss - of - life = \frac{V * t * 100}{Normal\ insulation\ life}$$

Hot spot temp °C	V	Percent loss of life. Normal life of 180,000h (20 years) for upgraded paper						
		0.0133	0.02	0.05	0.1	0.2	0.3	0.4
110	1	24	—	—	—	—	—	—
120	2.71	8.86	13.3	—	—	—	—	—
130	6.98	3.44	5.1	12.9	—	—	—	—
140	17.2	1.39	2.1	5.2	10.5	20.9	—	—
150	40.6	0.59	0.89	2.2	4.4	8.8	13.3	17.7
160	92.1	0.26	0.39	0.98	1.96	3.9	5.9	7.8
170	201.2	0.12	0.18	0.45	0.89	1.8	2.7	3.6
180	424.9	0.06	0.08	0.21	0.42	0.84	1.27	1.7
190	868.8	0.028	0.04	0.1	0.21	0.41	0.62	0.82
200	1723	0.014	0.02	0.05	0.1	0.21	0.31	0.42

IEEE Std C57.91-2011

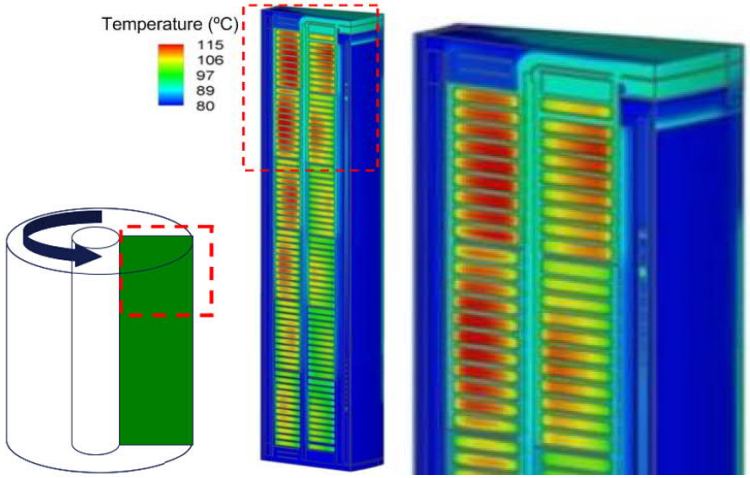
Hot spot

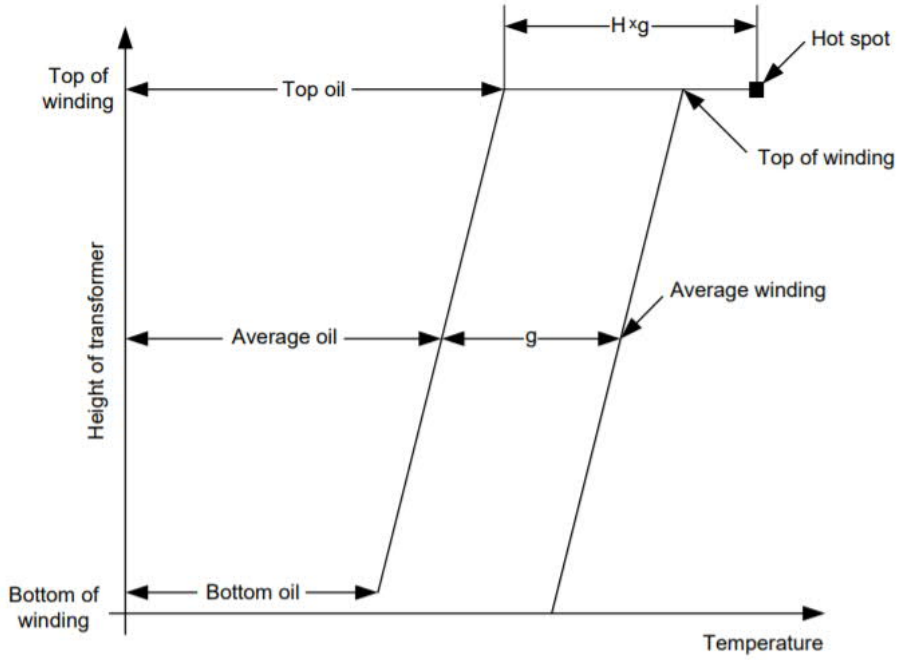
Hot-spot temperature is affected by:

- Top-oil temperature
- Top-oil temperature rise above top-oil temperature

$$\theta_h = \theta_o + \Delta\theta_h$$

θ_h = hot spot temperature
θ_o = top-oil temperature
$\Delta\theta_h$ = hot spot temperature rise above top-oil temperature



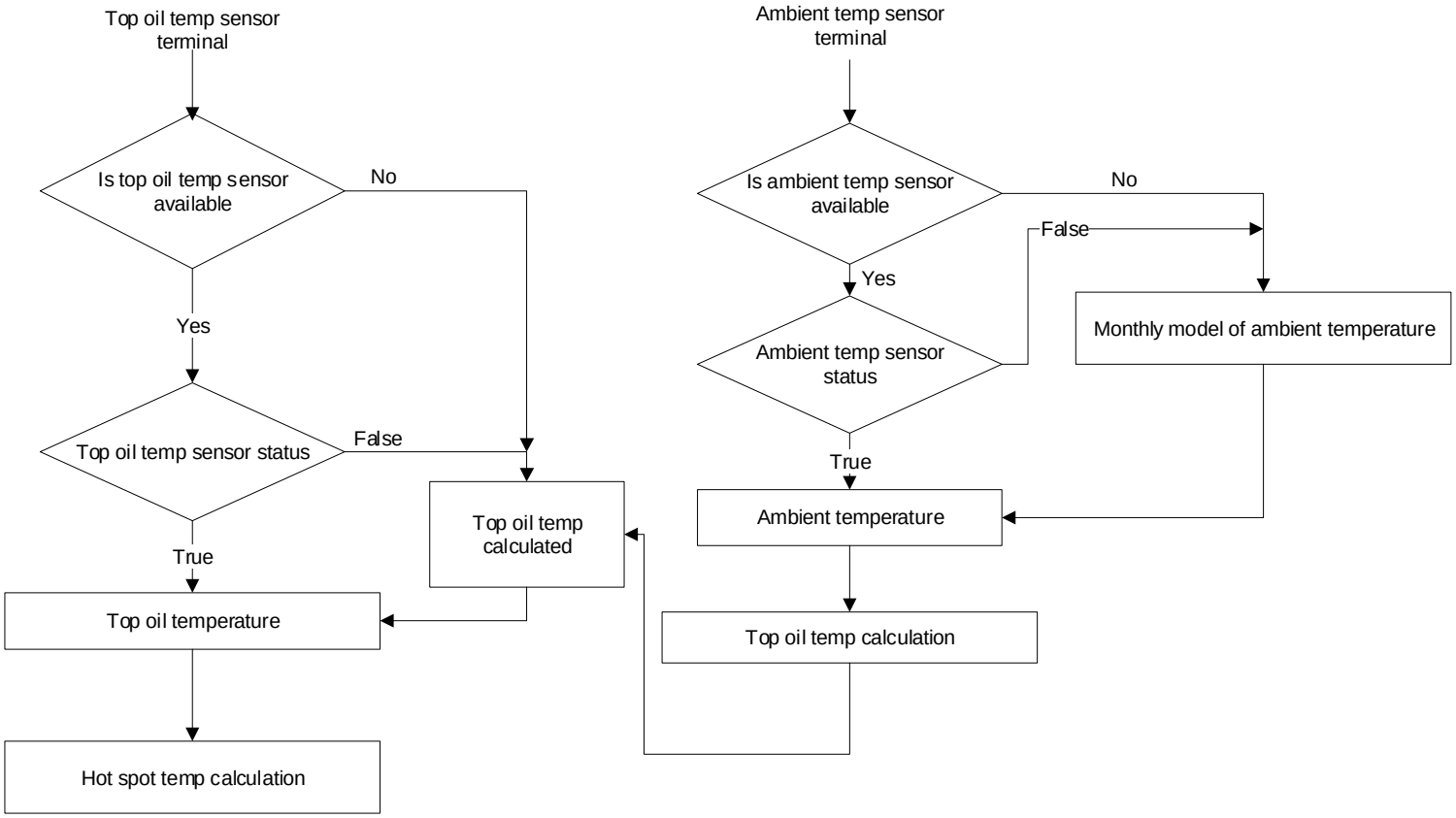


Top-oil temperature rise above top-oil temperature

Top-oil temperature rise above top oil temperature is affected by:

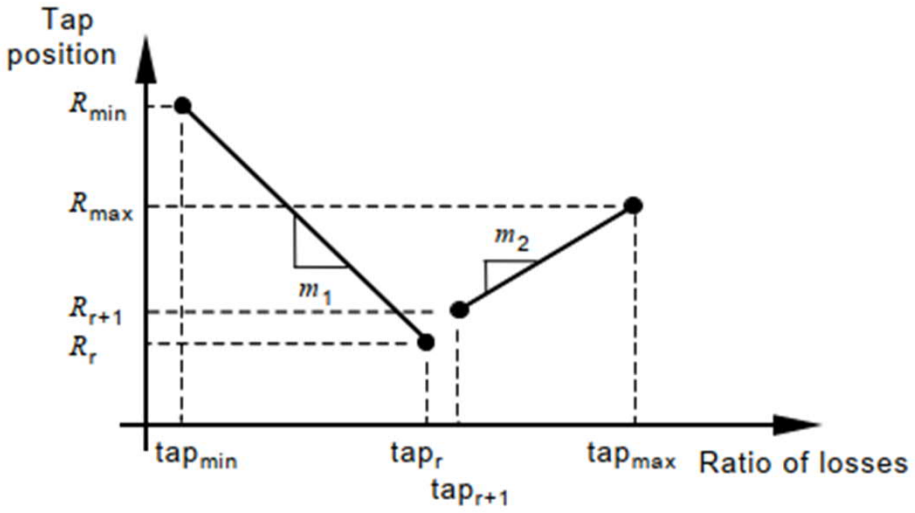
- Load
- Winding and oil time constant
- Winding and oil masses
- Ambient temperature
- Cooling
- Losses
- Tap position

Top-oil temperature



Tap changer

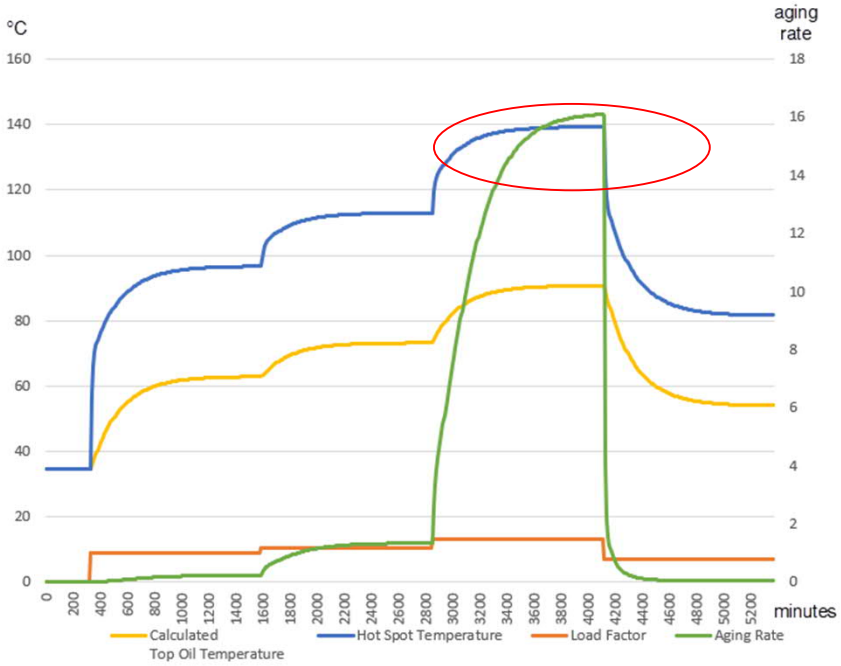
- Losses change caused by tap changer positions



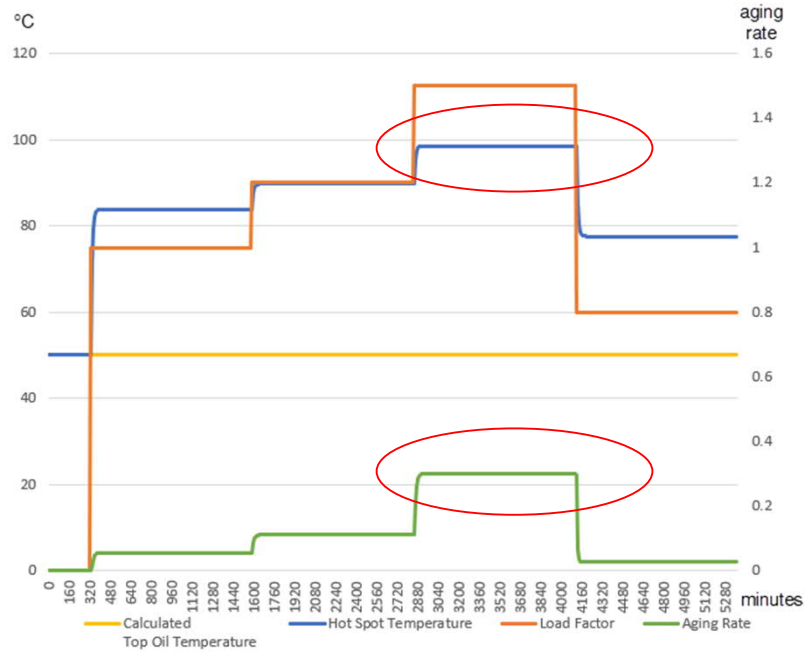
$$m_1 = \frac{R_r - R_{min}}{tap_r - tap_{min}} \qquad m_2 = \frac{R_{max} - R_{r+1}}{tap_{max} - tap_{r+1}}$$

Lessons learned during FAT / SAT

Good practice:
Top-oil calculated by function

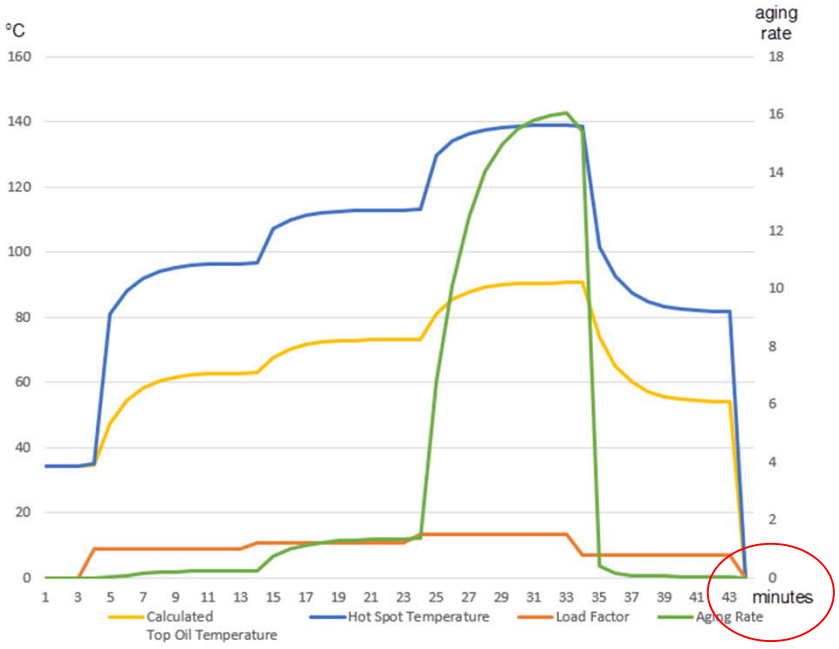


Bad practice:
Failure to simulate top-oil temperature



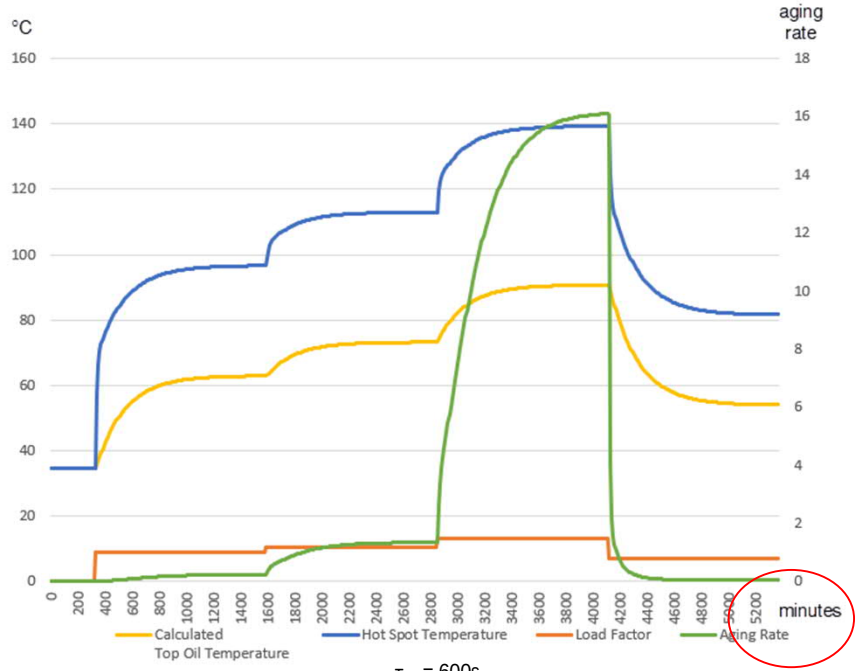
Lessons learned during FAT / SAT

Good practice:
Reduced oil and winding time constant
Test duration ~40 minutes
Injection time >6 times longer than time constants



τ_W = 10s
τ_o = 100s

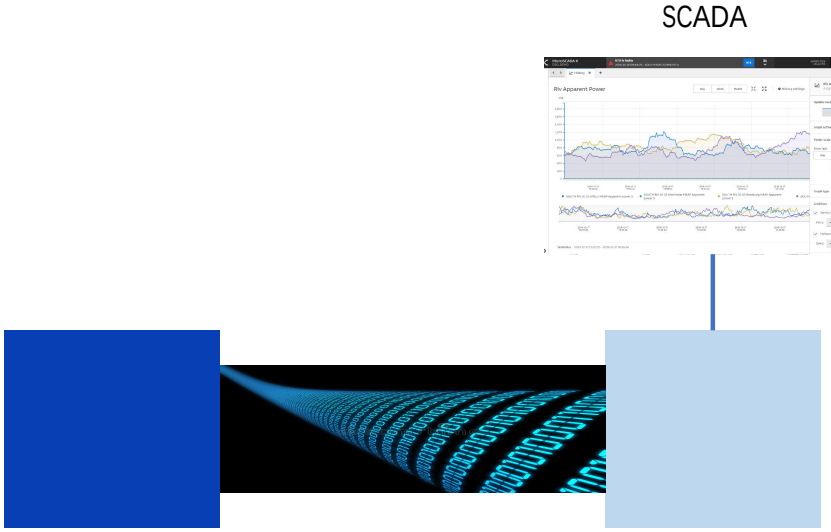
Bad practice:
Nominal oil and winding constant
Test duration ~3.5 days!



τ_W = 600s
τ_o = 12600s

Lessons learned during FAT / SAT

- Long duration tests in laboratory



Benefits

Reliability

- Real-time data centralized to the relay
- Calculated top-oil temperature in case of sensor failure
- 3 instances of loss of life monitoring each winding
- Load optimization during cold and hot days

Operation and maintenance

- Reduced footprint and spare parts management
- Hot spot temperature alarm improving protection scheme
- Improved cooling fans' control based on hot spot temperature optimized the wear and tear

Financial and technical - better visibility of assets = better technical and financial decisions

- Aging trends as tool to calculate overload in dollar amount
  - Plan load contingency
  - Load balancing
  - Transformer retrofit
  - Additional investments

Q&A

Thank you!