EUR18_25 - Power Transformers for Industry Case Studies

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Case studies

Why look at case studies?

- When things go wrong is a rich learning experience
- Root cause analysis allows to:
  - Determine the (several) things that caused the problem
  - Take appropriate corrective action(s)
  - Change processes to prevent future occurrences
  - Decide who pays for what
- Case studies involve transformers from several major manufacturers

Other things that are learned:

- Know what you are responsible for
- Always know who pays for each expert involved
- Be truthful and be able to justify reasoning
- Be very careful in providing information not directly asked for
- "*Speech was given to man to disguise his thoughts*" (Talleyrand - French diplomat)

1) Arc furnace installation – China – January 1, 2007

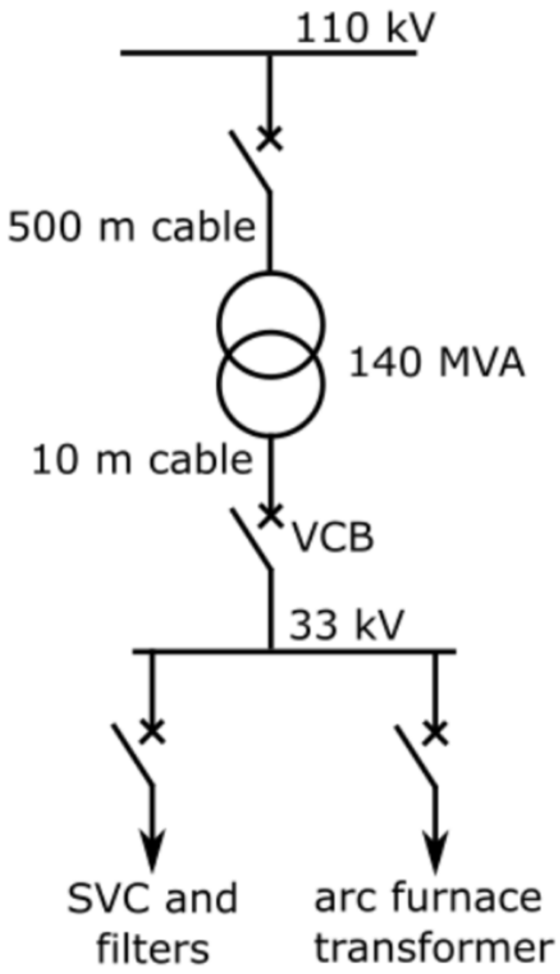
Mechanical forces blew tank apart and oil sprayed around the transformer. Did not flow into the pit.

Pressure relief mounting plate broken

Tank ripped open in several locations

Arc furnace installation - investigation

110 kV cable clamps broken



Extensive internal damage

VCB disintegrated

Root cause analysis results

- Earth fault inside transformer caused by VCB restriking*
- Earth fault degenerated into 110kV phase-to-phase fault after 138ms
- Tank earth fault protection set to 1 sec**
- Overcurrent protection set to above maximum short-circuit current***

* No surge arrestors or other over-voltage protection provided by switchgear supplier
    - Switchgear supplier had overall 33 kV power system responsibility, not just switchgear

** Zone protection so should be set with 0 time delay
    - Correct setting would have prevented total destruction, only winding replacement

*** Switchgear supplier had protection system responsibility
    - Subcontracted settings to relay manufacturer

Conclusions

Final actions taken

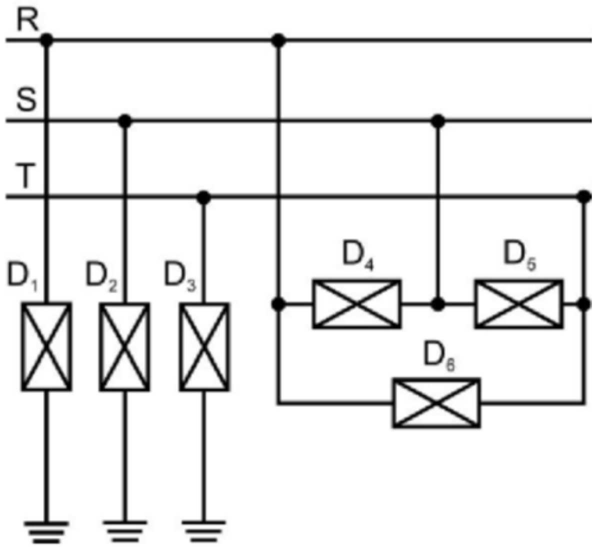
- New 140 MVA transformer manufactured and air-freighted from Europe
- Switchgear replaced by 72,5 kV indoor air-insulated switchgear
  - SF_6 breaking technology has lower over-voltages
  - 2nd harmonic filter generates high overvoltages at every switching operation

Difficulties encountered

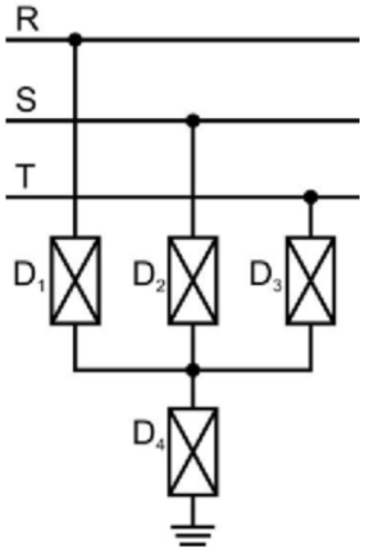
- Few people at site when failure occurred – no eye witnesses
- Contradictory information in the limited available recorded data points
- Many different participants at different times with limited knowledge
- Language barrier

Overvoltage protection for transformers

- Most overvoltage protection for lightning
- Switching surge overvoltage protection
  - For very high rated system voltages
  - Special cases when VCBs are used
- Arrestors must be close to transformer terminals
- Earthing connection to arrestor must be short and direct (no loops)
- MCOV to exceed maximum possible system voltage for which system is designed
- Arc furnace installations often require phase-to-phase and phase-to-earth protection



solution using
6 arrestors



Neptune connection
with 4 arrestors

Cost effective but
inferior protection

Installation of arrestors on transformers

Arrestors located very close to terminals

Connection of arrestors at site

Arrestors located close to terminals
on separate supports

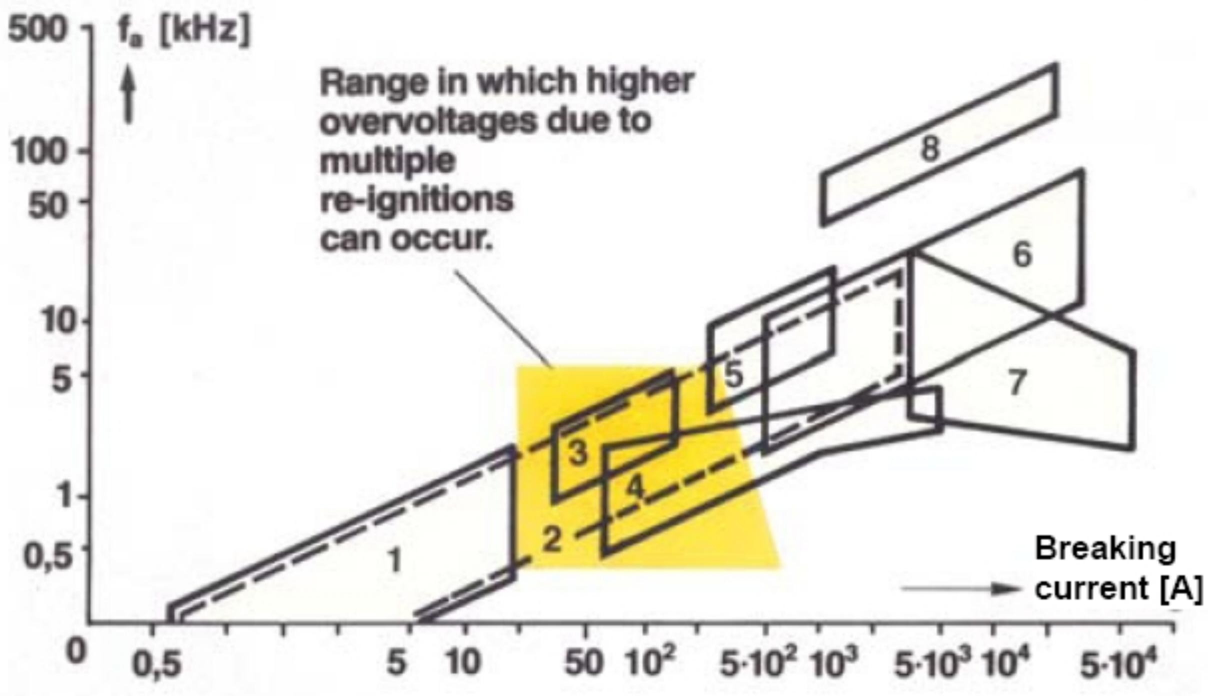
Best arrestor location – also
connect arrestors before bushings

Surge counters

- Arrestors installed on tank
- Surge counters provided per phase
- Counter showed 24 surges had occurred
- Location in tropics, high isokeraunic level

Switching surges

- Present a real danger to transformers
- Worst case is switching during energization
- Cause of failure of failure of main transformers at an LNG plant



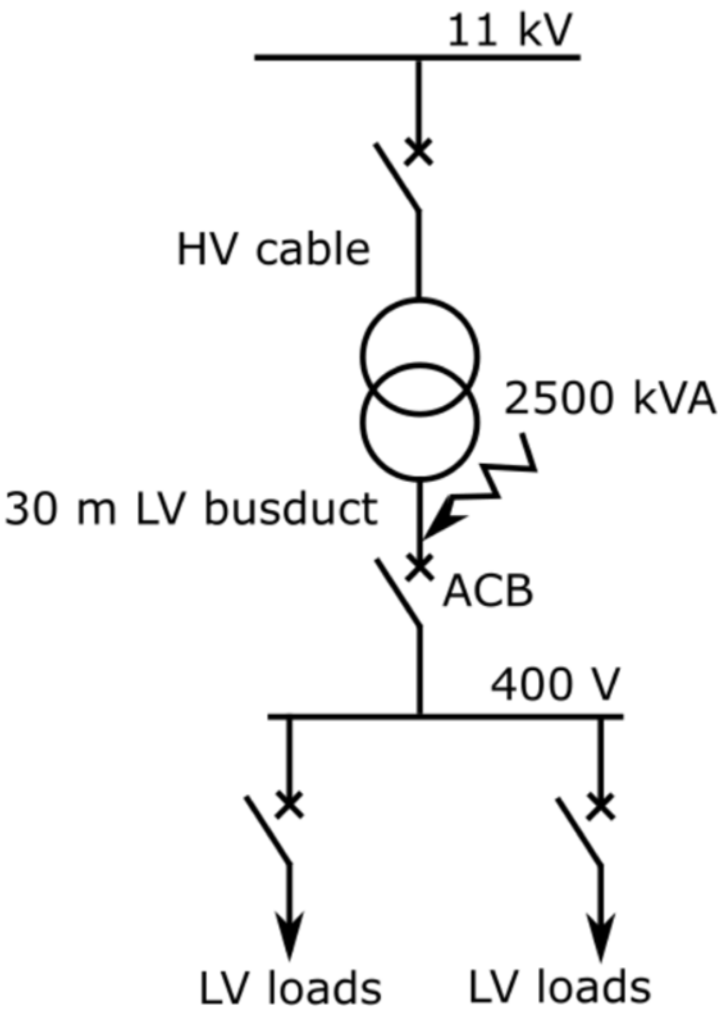
Five prerequisites must be simultaneously fulfilled for multiple reignitions plus virtual current chopping:

1. Switching off a purely inductive load (e.g. motor during run-up, locked rotor or jogging).
2. Opening of the first pole-to-clear < 0.5 ms prior to current zero. This corresponds in three-phase systems to a probability of occurrence of 15 % at 50 Hz (or 18% at 60 Hz)[1].

[1] At 50 Hz: current zero occurs every 3.3 ms in one of the three phases. Thus the probability is 0.5 ms / 3.3 ms = 0,15

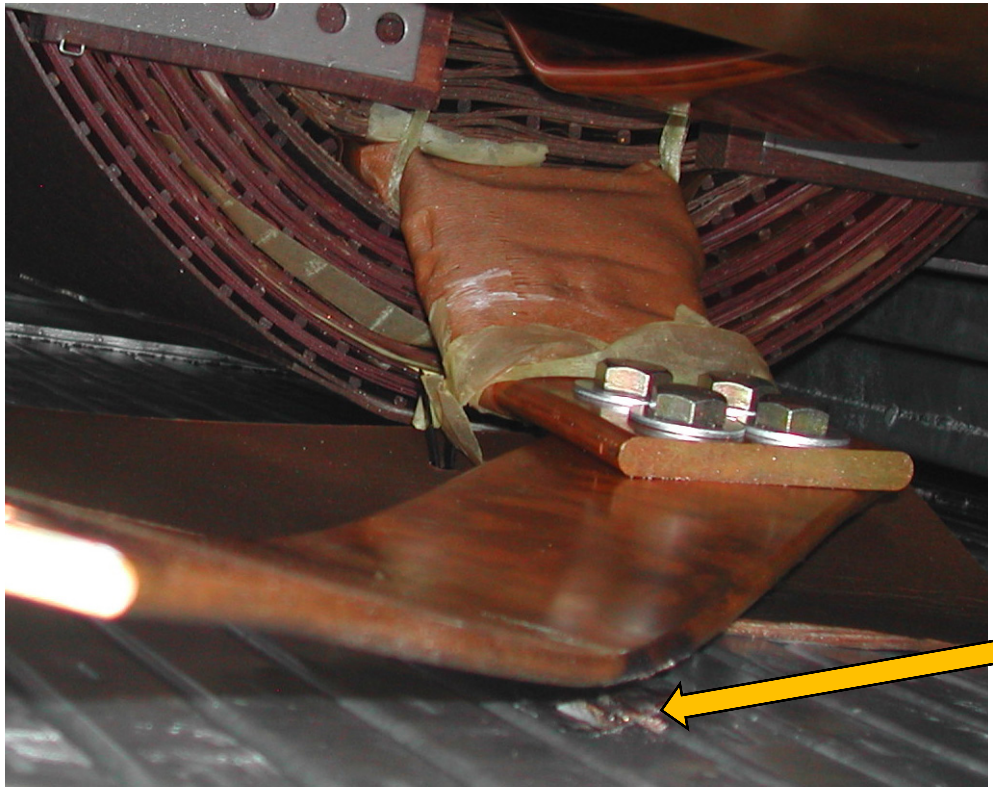
- Probability 15-18% not negligible
- Arrestors alone are not sufficient
- RC circuits required to flatten waveforms
- PCIC Europe papers on this subject – Fig. and text from 2011

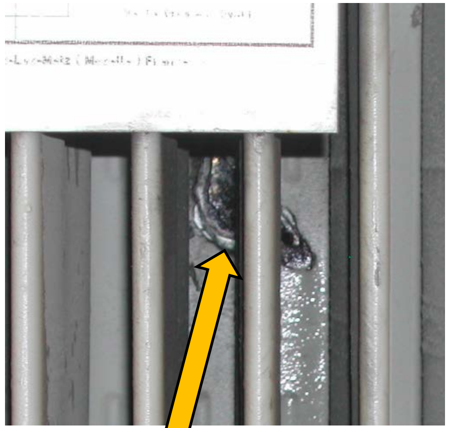
2) Transformer failure on downstream fault



- 3-phase fault occurred in LV bus duct
- Fault location inside switchgear room near A/C duct
- Fault cleared by protection relay of 11 kV feeder
- Standard over-current protection implemented in 11 kV
  - Very inverse time for overload and through-faults
  - Definite time for 11 kV short-circuit protection
- Transformer specification: withstand bolted secondary fault current for 2 seconds

Transformer damage





Transformer tank pierced

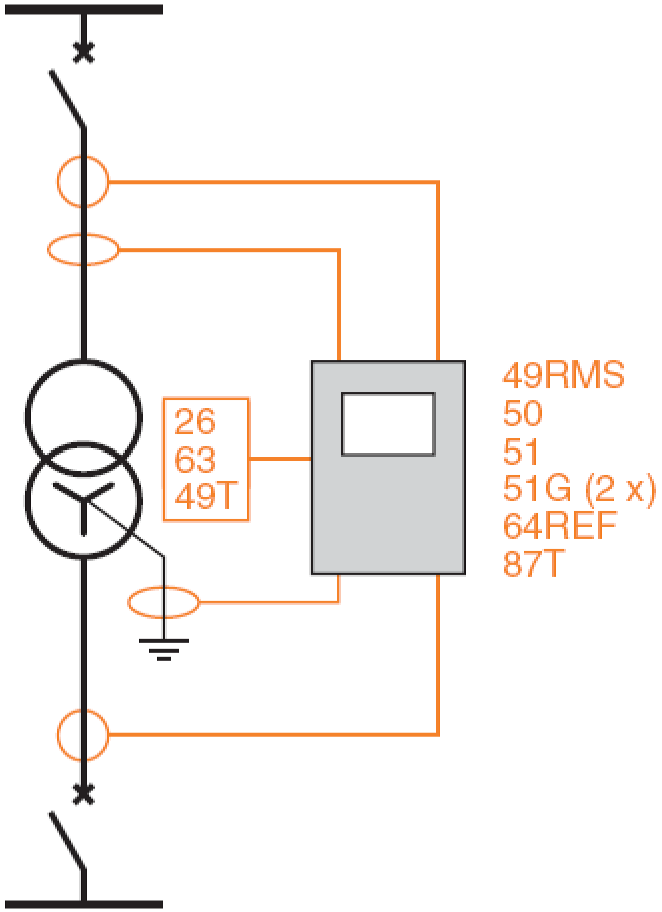
Transformer did not withstand the short-circuit through current (non-conformity).
Fault cleared after 1,3 seconds by 11 kV protection.

Short-circuit withstand IEC 60076-5

- Ability to withstand dynamic stress either by test or calculation
- § 4.1.3 specifies duration of 2 seconds
- Testing seldom specified:
  - For utility transformers if several ordered
  - Testing is done on one of the transformers delivered: some minor damage might occur
- Acceptance by test § 4.2.7.4
  - Routine tests repeated and ok
  - Lightning impulse test done and ok
  - No combustible gas in the Buchholz relay
  - No traces of arc or displacement inside transformer
  - Variation of impedance values < 2% to < 7,5% depending on construction

Protection for power transformers

- Protection functions used depend on importance of transformer
- Correct settings are essential
- Intertripping often required
- Be careful of zones between transformer and circuit-breakers



26 - oil temperature

63 - Buchholz

49T - winding temperature

87T - differential

64REF - restricted earth fault

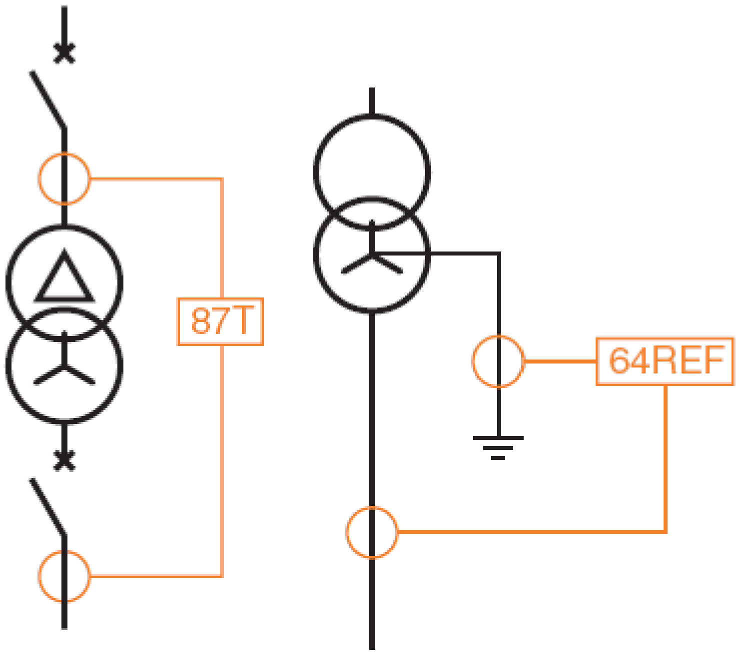
51G1 - earth fault

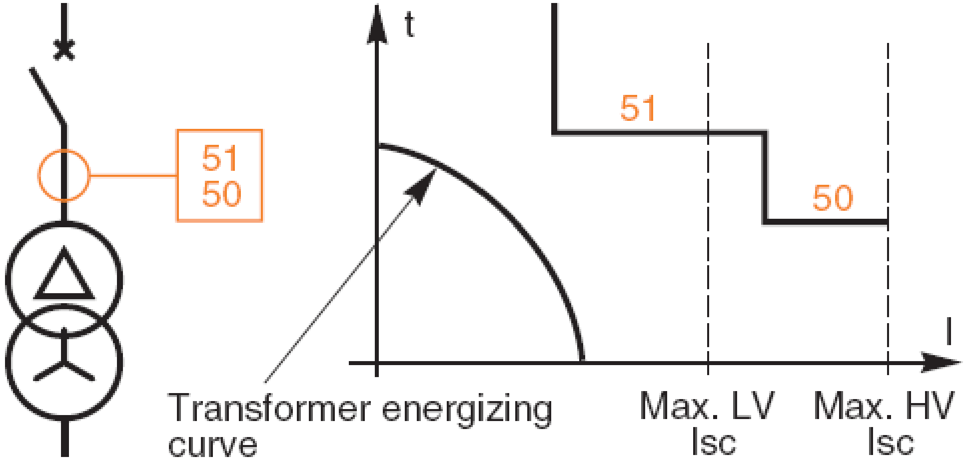
51G2 - tank frame fault

49RMS - thermal image

50/51 - overcurrent

Zone and time-current protection

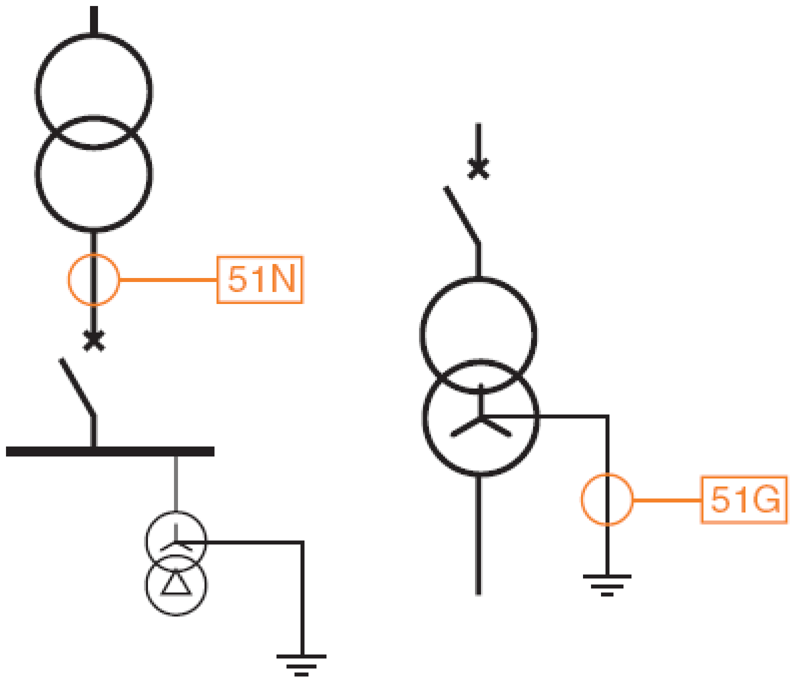




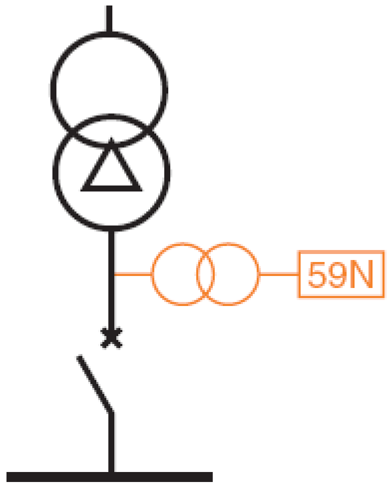
- Differential protection is primary protection
- Often with restricted earth-fault
- Zone protection so very fast acting
- Protection zone defined by CT location

- Overcurrent protection is backup for overload
- Can provide some protection downstream
- Must be set above inrush current

Transformer time-current earth-fault protection



- Earth-fault protection depending on winding vector group
- Requires coordination with other earth-fault protection

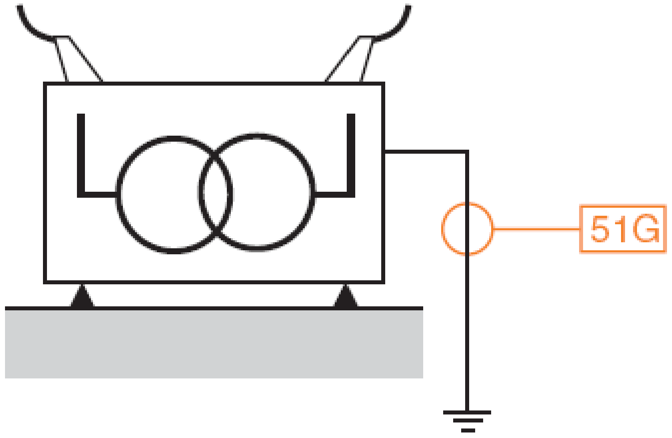


- Neutral voltage displacement with high resistance earthing
- Allows operation with earth fault

Transformer tank earth fault zone protection

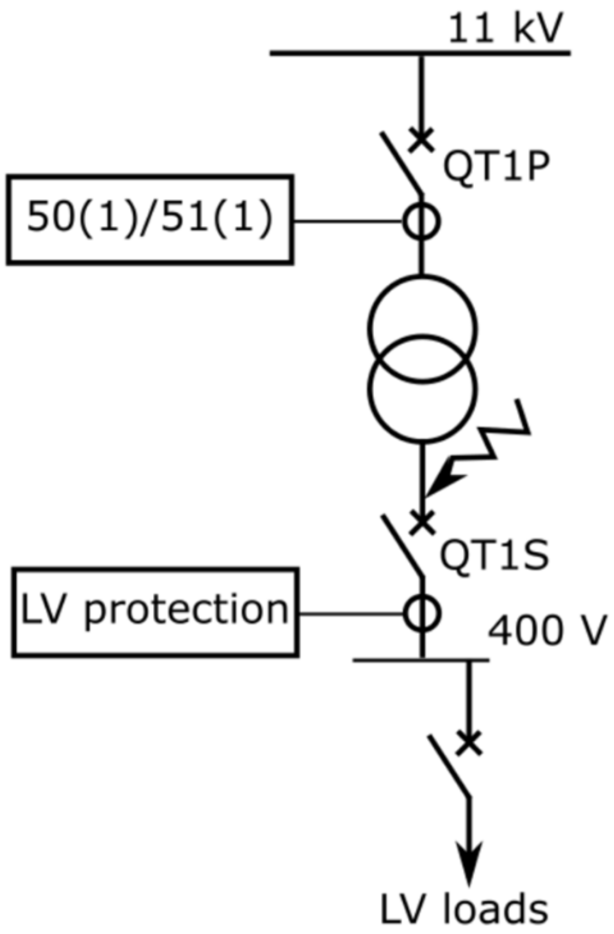
Connection to earth via CT

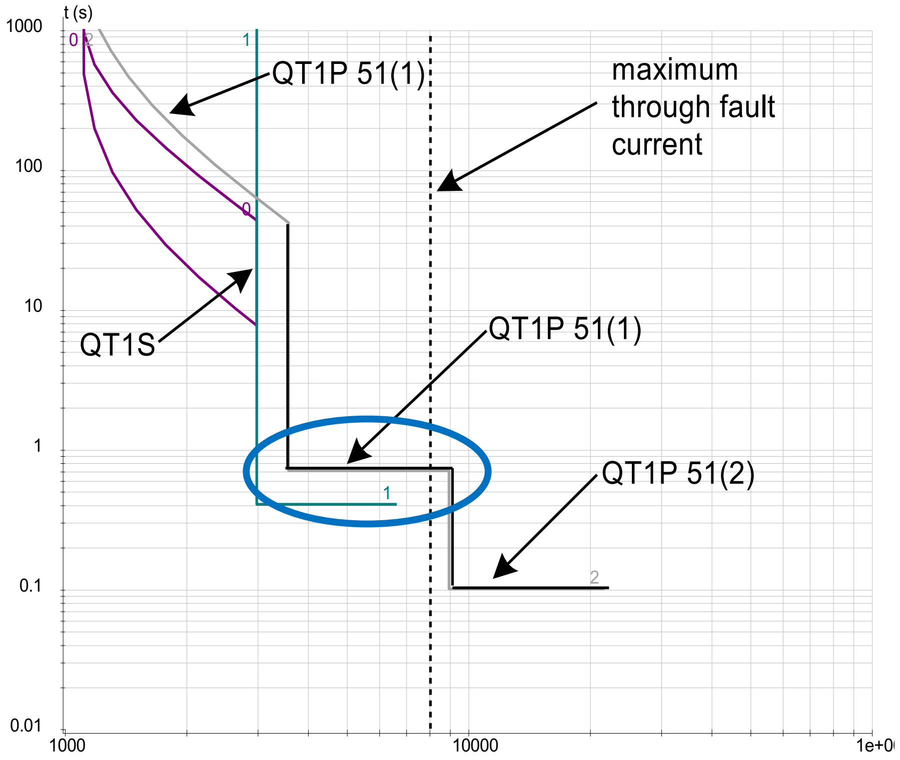
Tank insulation



- Tank earth-fault protection is primary protection
- Zone protection so very fast acting (no time delay)
- Internal faults often start as earth faults

Transformer secondary side protection





- 11 kV protection had only one time dependent curve QT1P 51(2)
- Very inverse curve QT1P 51(1) intersected QT1P 51(2) at maximum through fault current
- Faults on LV side of transformer but upstream of QT1S cleared by very inverse curve at times > 1 second
- Recommended adding additional time dependent curve (in blue) to clear downstream faults quicker
- This could have limited damage but not prevent failure of this transformer

Conclusions

Final actions

- Transformer was replaced. Supplier questioned about failure to meet specification.
- LV busduct replaced and space heated added – condensation thought to be root cause
- Changes in 11 kV protection functions and settings proposed to reduce damage

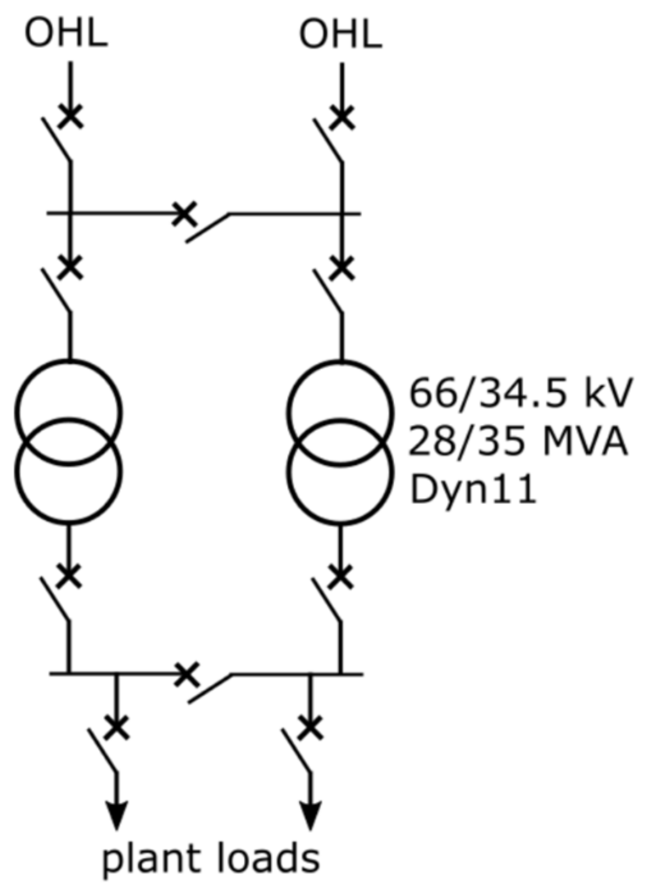
Difficulties encountered

- The disturbance recorder showed erratic action near the time of fault. This was not explained.
- Limited access to on-site documentation.

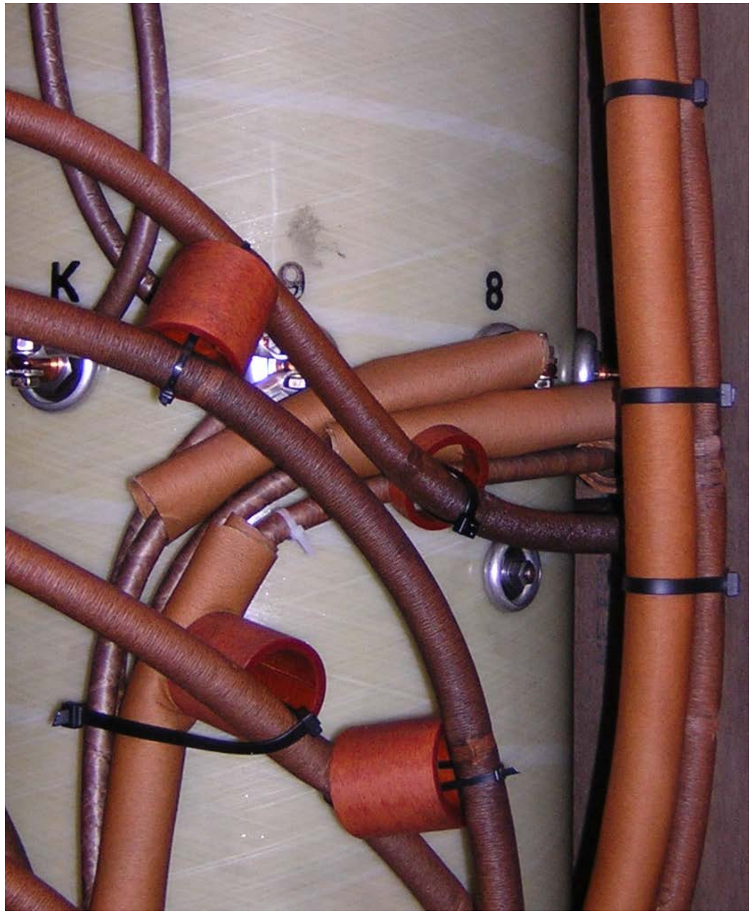
3) 35 MVA Substation transformer – Africa – oil extraction

Several incidents with substation step-down transformer

- First problem:
  - partial discharge on regulation winding
  - was fixed at site (active part extracted for repair work)
- Second problem
  - Internal fault (DGA at site had indicated problems after repair)
  - Root cause analysis at manufacturer in spite of shipping cost
  - Production maintained using other transformer
- Root cause analysis done in plant
- Transformer repaired and retested
  - Transformer failed partial discharge tests
  - Contamination of insulation materials thought to be the cause
- New transformer manufactured (using only existing tank)
- Transformer failed long duration partial discharge tests
  - Client bought equivalent transformer from another manufacturer

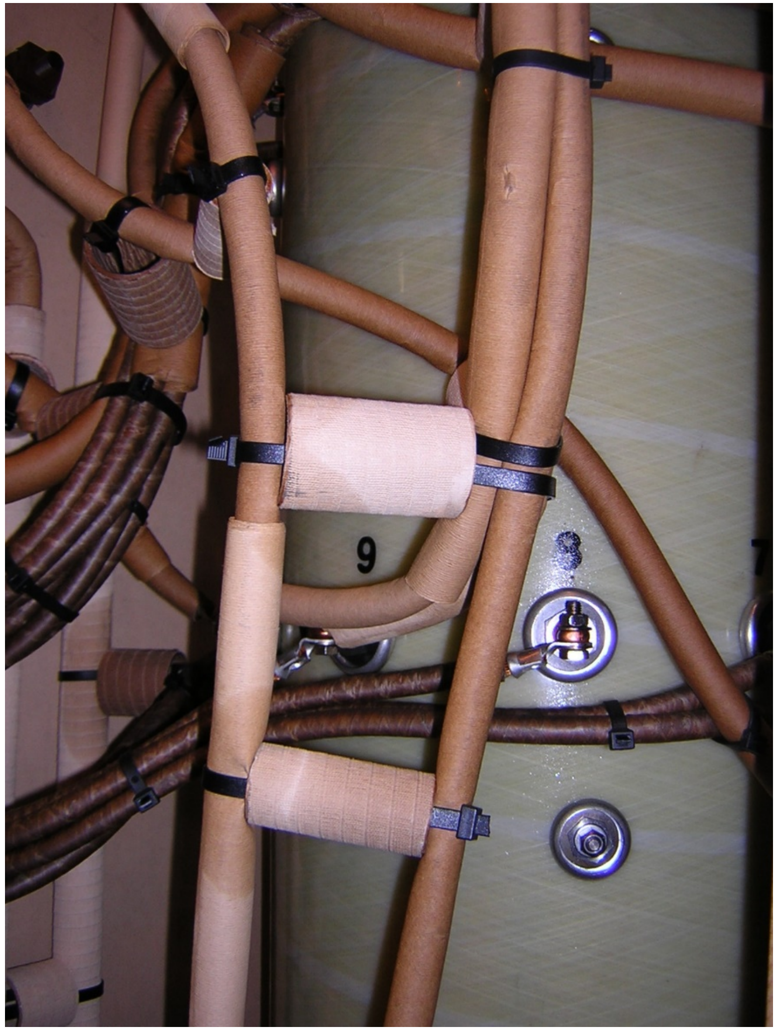


Analysis of first fault during factory inspection



Partial discharge in regulation winding

Reason for first fault



Increased separation distance after second repair

Analysis of second fault

Insulation punctured

Multiple evidence on insulation materials of water penetration into transformer

- Site repair report mentioned thundershower, covering transformer, possible water ingress.
- Conclusion: water caused second fault, dielectric failure

Importance of transformer tank construction

- Water ingress during repair work at site
- Transformer tank not designed to withstand vacuum
- Not possible to remove water from inside transformer at site

Procedure for drying windings at site

- Short circuit the terminals and circulate current in windings
- Apply a vacuum and extract water vapor from inside tank
- Procedure used in some plants to dry the windings during manufacturing

Recommendation:

- Specify that transformer tank must be designed to withstand a vacuum

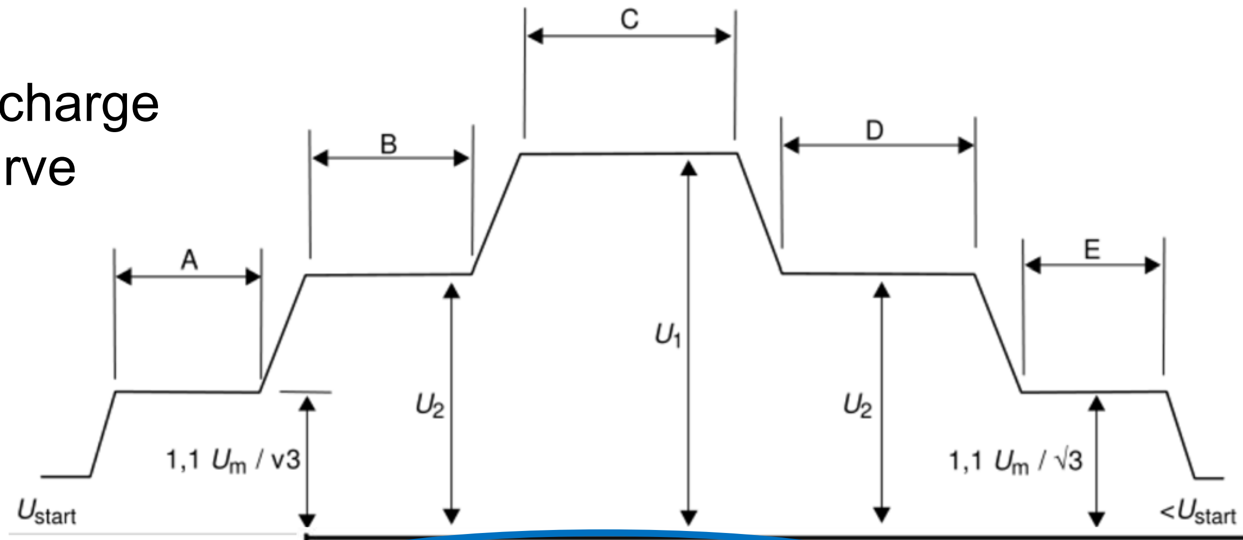
Partial discharge testing conducted as per IEC 60076-3

Checking repaired and new transformer

- Agreed to do partial discharge tests
  - Not a requirement in IEC for Um $\leq$ 72,5 kV
  - Standard partial discharge tests conducted on repaired transformer
  - Tests failed
- Decision to construct new transformer
  - Some parts such as tank could be reused
  - Long-duration partial discharge testing agreed
  - Test duration: 60 minutes
  - New transformer failed after 57 minutes

Partial discharge test procedure IEC 60076-3

Partial discharge test curve



A = 5 min
B = 5 min
C = 120 seconds x 60Hz/150Hz
D = 5 min
E = 5 min

Test duration

Test results on 138/34,5 kV unit substation transformer

Um = 145 kV				Background noise level = 10 pC					Guaranteed Values
Tap changer position: 3		= 138,0 kV							
Test Voltage (phase to phase)			time	max partial discharge measured after: 1 min	2 min	3 min	4 min	5 min	
x Um	HV [kV]	MV [kV]		[pC]	[pC]	[pC]	[pC]	[pC]	[pC]
1,1	159,5	38,14	A	17	18	17	17	17	
1,3	188,5	45,08	B	25	24	24	24	24	
test voltage	275,0	65,76	C	---	---	---	---	---	
1,3	188,5	45,08	D	33	31	30	30	30	300
1,1	159,5	38,14	E	20	18	18	18	18	100

Specific texts for partial discharge testing

- For U_m > 72.5 kV, a routine test
- By agreement, partial discharge measurements may also be performed for $U_m \leq 72.5$ kV.
- Failure to meet the partial discharge criteria:
  - agreement between purchaser and supplier about further investigations (annex A IEC 60076-3)
  - a long-duration induced AC voltage test (see § 12.4) may be performed
  - if transformer meets requirements of § 12.4, the test shall be considered successful.

Dissolved Gas Analysis (DGA)

- Oil sample is taken and analyzed for dissolved gases
- Like a blood test, and provides valuable information about transformer condition
- Some major oil companies do DGAs every year on important transformers
- Results of DGA:
  - Concentrations of different types of gasses determined
  - Analysis of ratio of certain gases indicates internal arcing etc.
  - Trend of concentration of certain gases indicates worsening conditions
- Taking the oil sample
  - Use the valve provided for this
  - Be careful not to contaminate the oil sample
  - Send to the lab immediately for analysis
- Incorrect sampling can cause unnecessary concern at site

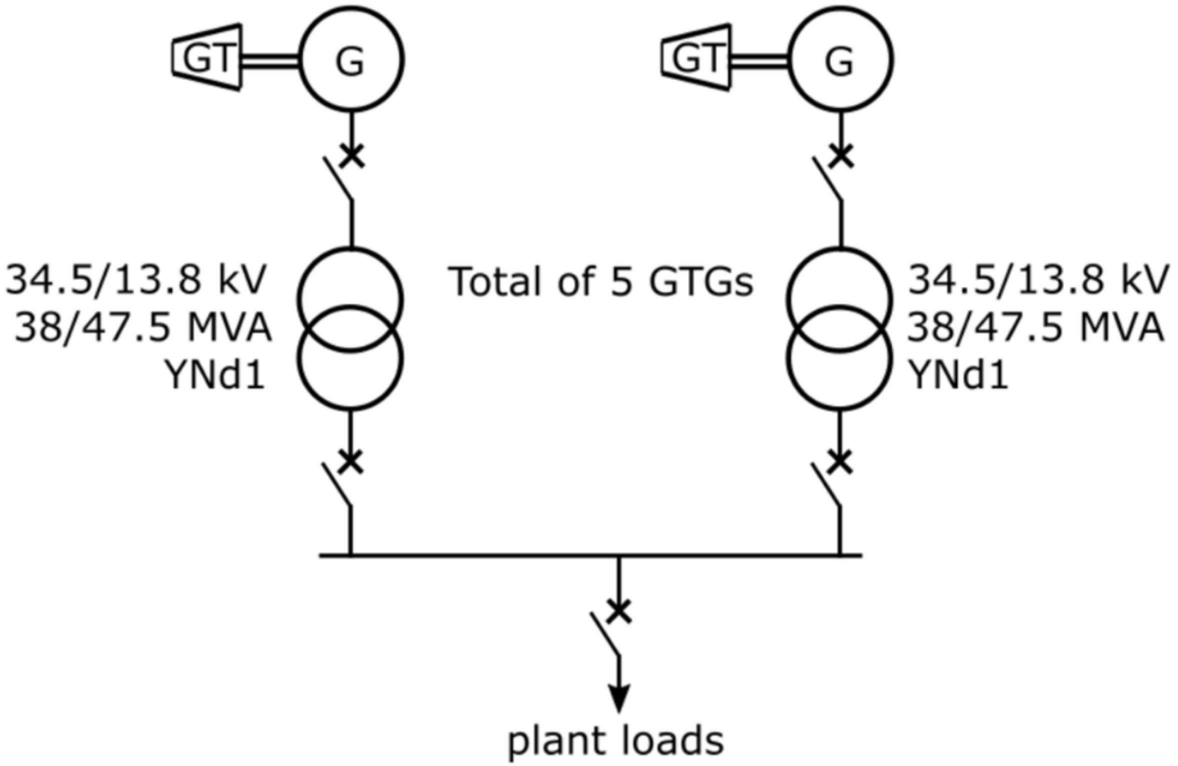
Example DGA

Analysis Nr Report Nr Sampling date and temperature (°C)		4 / 4 60037620 5 / 08 / 2005 47	3 / 4 60037484 3 / 08 / 2005 ----	2 / 4 60037039 14 / 07 / 2005 ----	Concentrations not overran by 90% of apparatus (µmoles/l) according to CEI 60599 (1999-03)
Sampling point		oil	oil	Bas de cuve	
Hydrogen	H2	15	14	16	2-6
Oxygen	O2	68	38	43	ND
Nitrogen	N2	1300	1300	1700	ND
Carbon monox	CO	11	13	16	22-37
Carbon dioxi	CO2	52	56	59	210-540
Methane	CH4	4,9	4,3	4,9	2-5
Ethane	C2H6	4,7	4,9	5,5	2-4
Ethylen	C2H4	0,46	0,56	0,65	2-12
Acetylen	C2H2	< 0,02	< 0,02	< 0,02	0.1-2
Propane	C3H8	2,9	3	3,5	ND
Propylen	C3H6	1,6	1,7	1,8	ND
Propadien	C3H4=	< 0,02	< 0,02	< 0,02	ND
Propyne	C3H4	< 0,02	< 0,02	< 0,02	ND
IEC 60599 (03-1999) Codes		C2H2/C2H4 = < 0,1 CH4/H2 = 0,3 C2H4/C2H6 = < 0,2	undeterminated case		*ND : "undeterminated"

Measured concentrations are not enough. Evaluation of the results is provided by the laboratory.

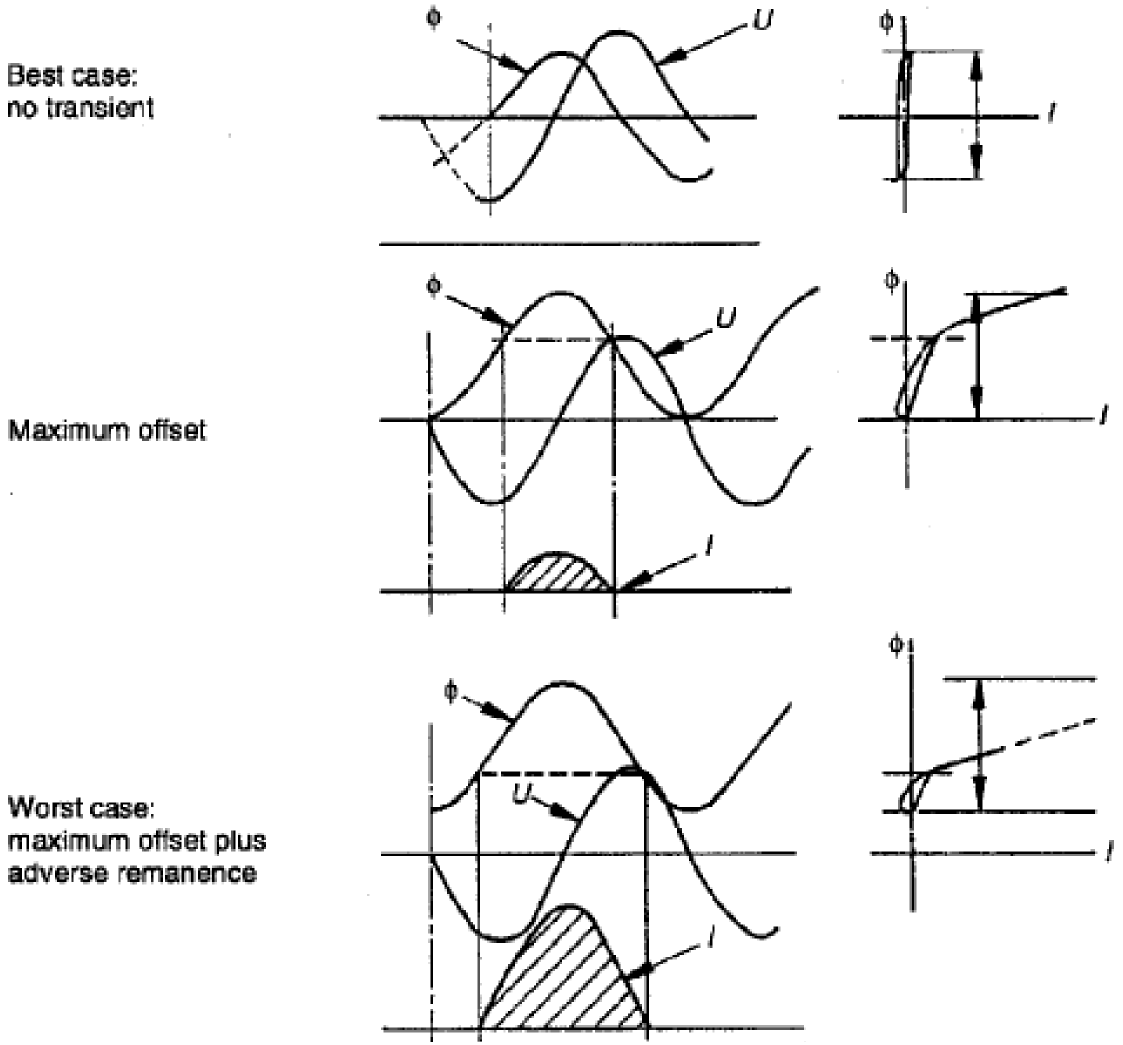
Transformer inrush current issues at same site

- All power at site from 5 GTGs
- Nuisance tripping when energizing generator transformer
- Client requested:
  - protection information from switchgear vendor
  - inrush current measurements from transformer vendor
- Measurements made at site



Variations in magnetizing current

- Depends on moment when voltage is applied (least inrush when maximum voltage is applied)
- Remanent flux in opposing direction will also increase inrush current
- Depends on design of magnetic circuit



General information

- Energize preferably high-voltage winding (not always possible)
  - HV winding is normally farther from core
  - Surface area of HV winding is larger than LV winding so more inductance and less inrush current
- Higher flux densities result in higher inrush currents
  - Lower flux density $\Rightarrow$ larger core, more steel and copper
  - Specify limits on inrush current as required
  - Include flux density limitations in bid specifications as backup specification to inrush limitation
- IEC standards say nothing about acceptable values of inrush current
- Generally not a problem on strong networks
- Can be a problem if local generation is source of power
- Protection relays sensitive to CT saturation may cause nuisance trips

Inrush current measurements

- Used Rogowski coils to avoid saturation
- Measured peak current 3,5 kA
- Time constant 564 ms

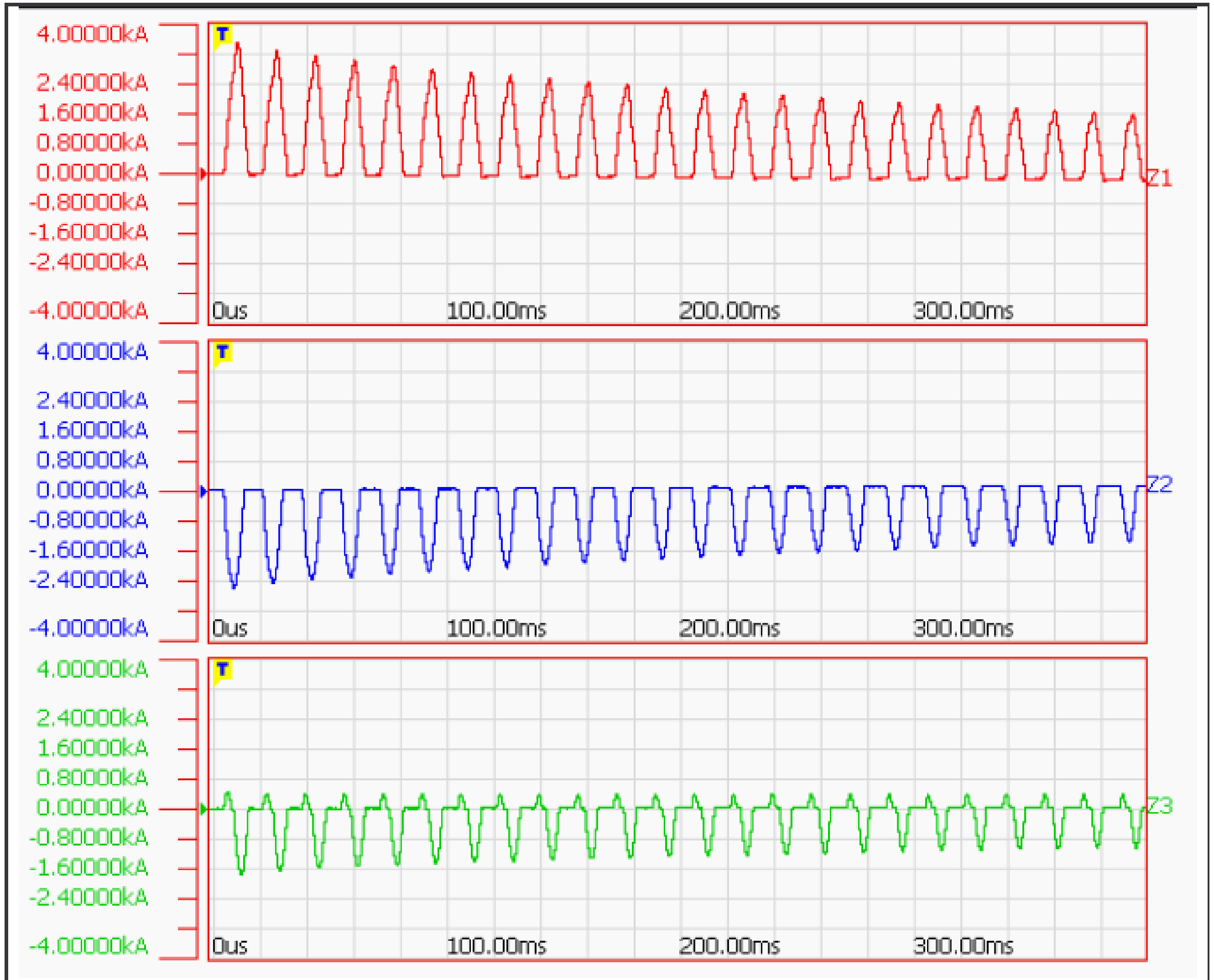


Figure 10 primary inrush current - Global view

Inrush current measured with CTs

- Peak values truncated
- Time constant much shorter
- Waveform distortion apparent

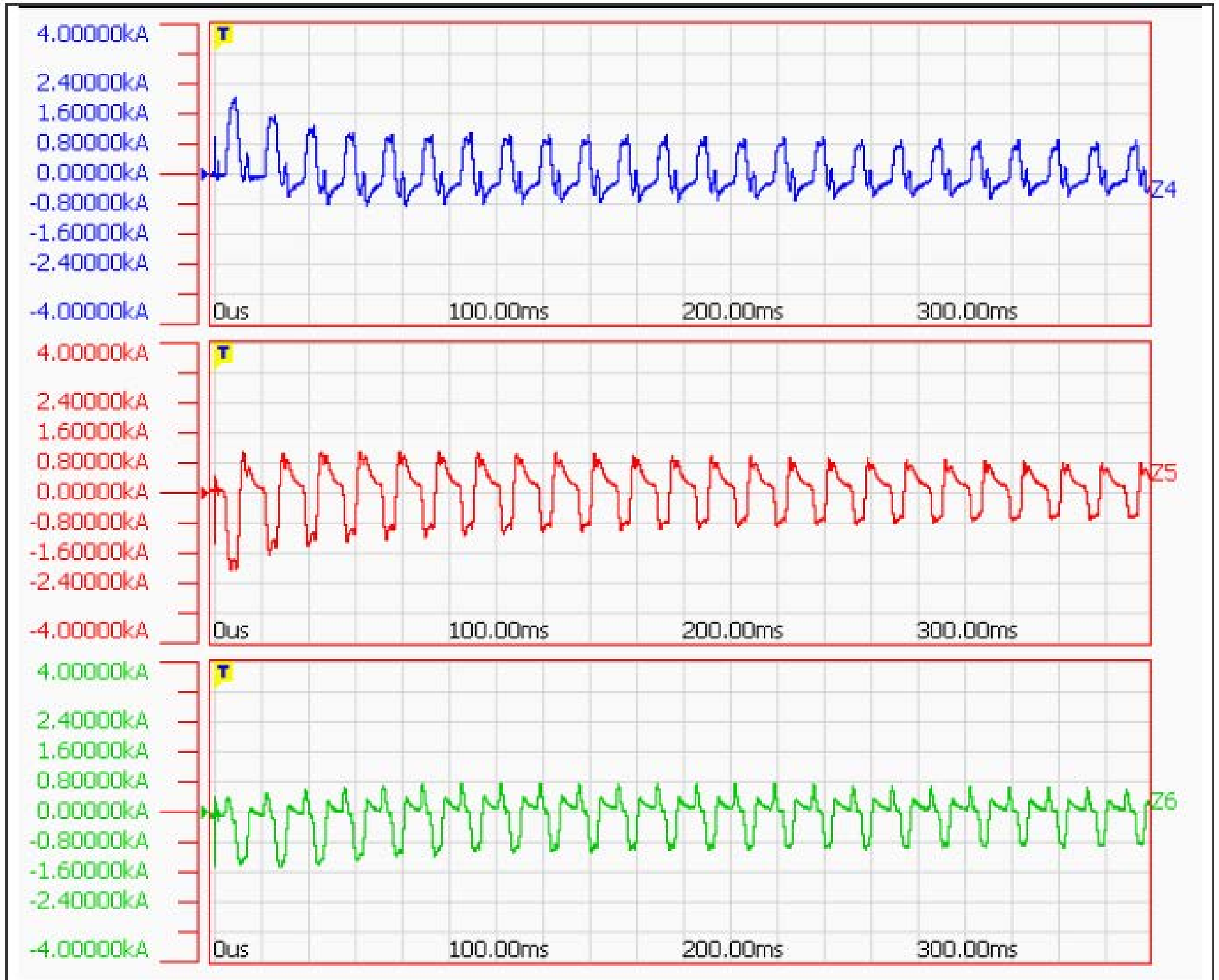


Figure 12 Primary inrush current at the secondary of CTs (re-scaled) - Global view

Comparison of CT output with current

- Distortion may cause nuisance tripping if protection relays do not have correct signal treatment
- Some trips occurred during inrush current measurements

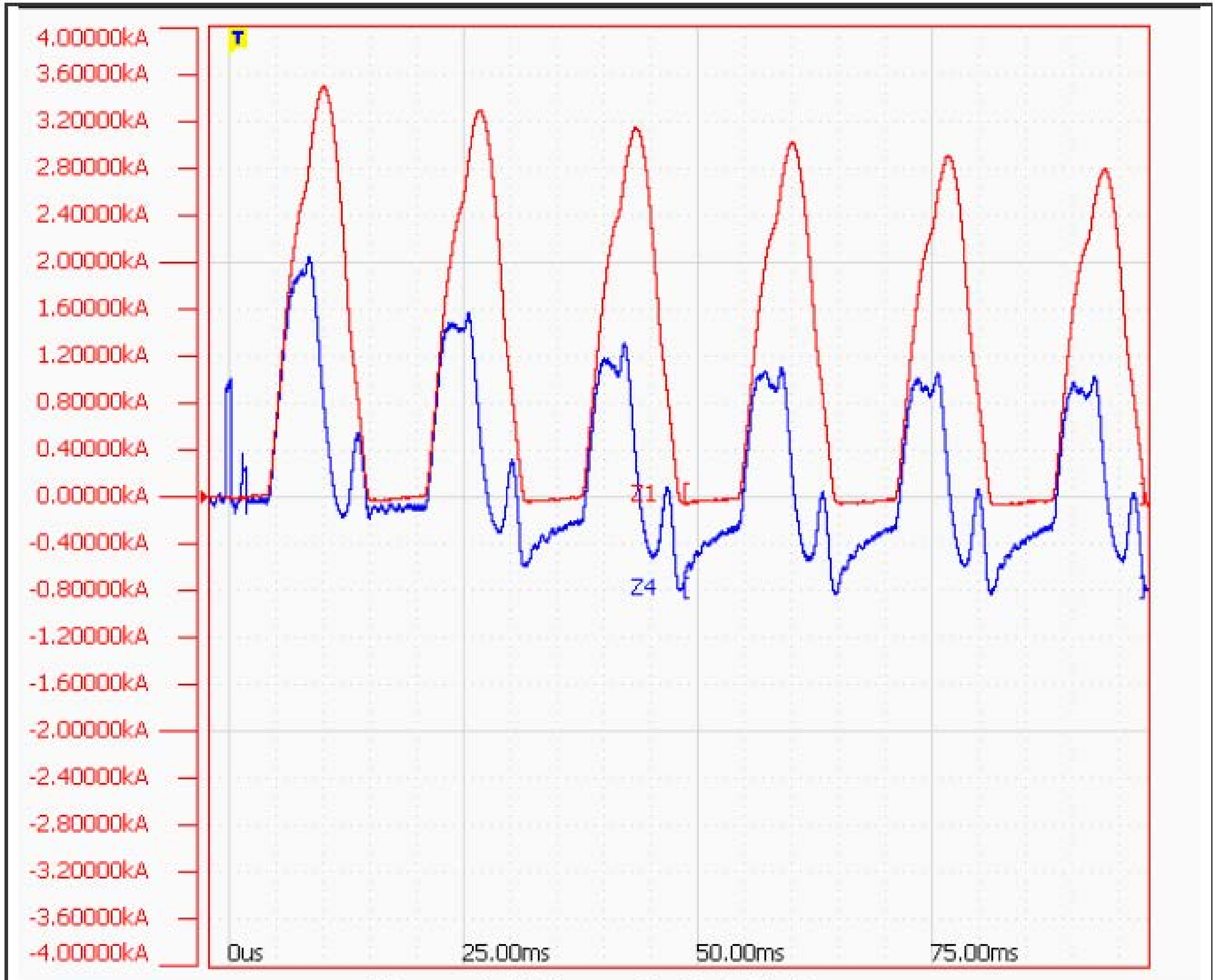
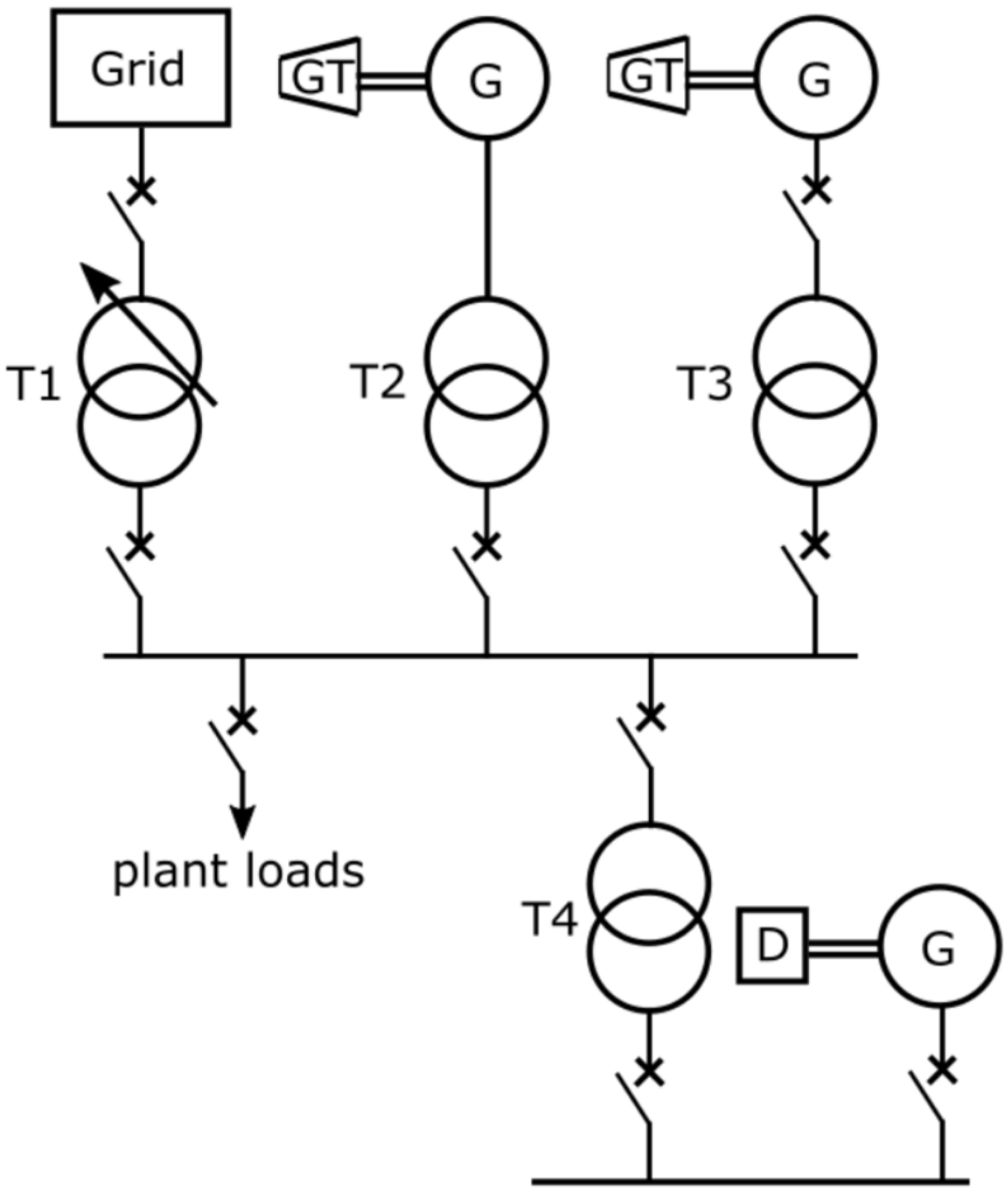


Figure 14 Phase A -Detail view

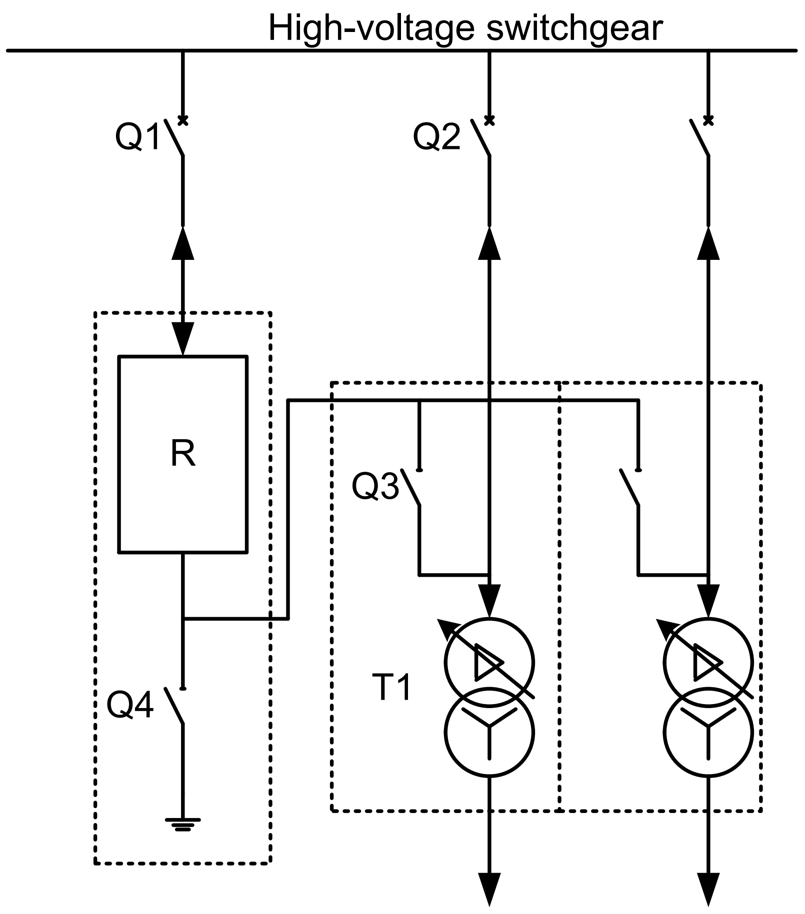
Considerations for transformer energization

- Energize T1 from grid
  - HV winding energized (lower inrush current)
  - Grid normally a stronger network (not always true)
- T2 can only be energized as GTG starts (no inrush current, no choice)
- Energize T3 from grid via T1
  - Requires a generator breaker
  - Steam turbine normally has no generator breaker
- Avoid energizing T4 from EDG
  - If necessary then energize during EDG start



Limiting transformer inrush current 1/2

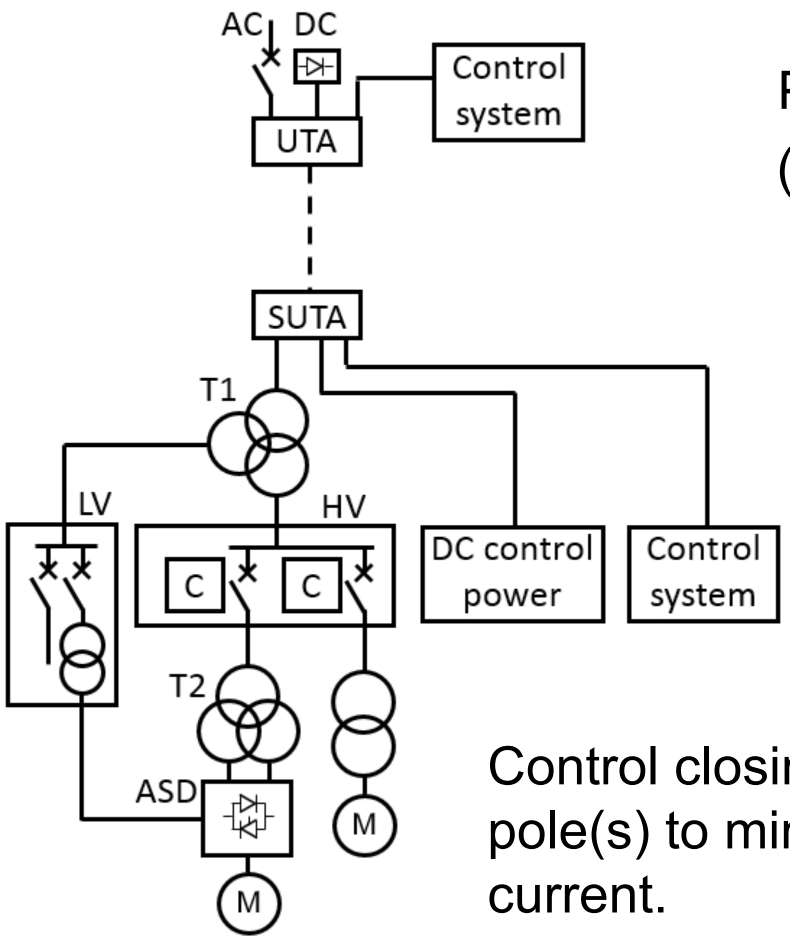
- Order special transformer with low inrush current
- Use preinsertion resistor
- Energize transformer through tertiary winding
  - Synchronize with main supply then connect
- Control closing time of breaker pole(s) to minimize the inrush current



Using preinsertion resistor

- Open Q4 and close Q3
- Close Q1 to energize T1
- Close Q2
- Open Q1 and Q3
- Close Q4

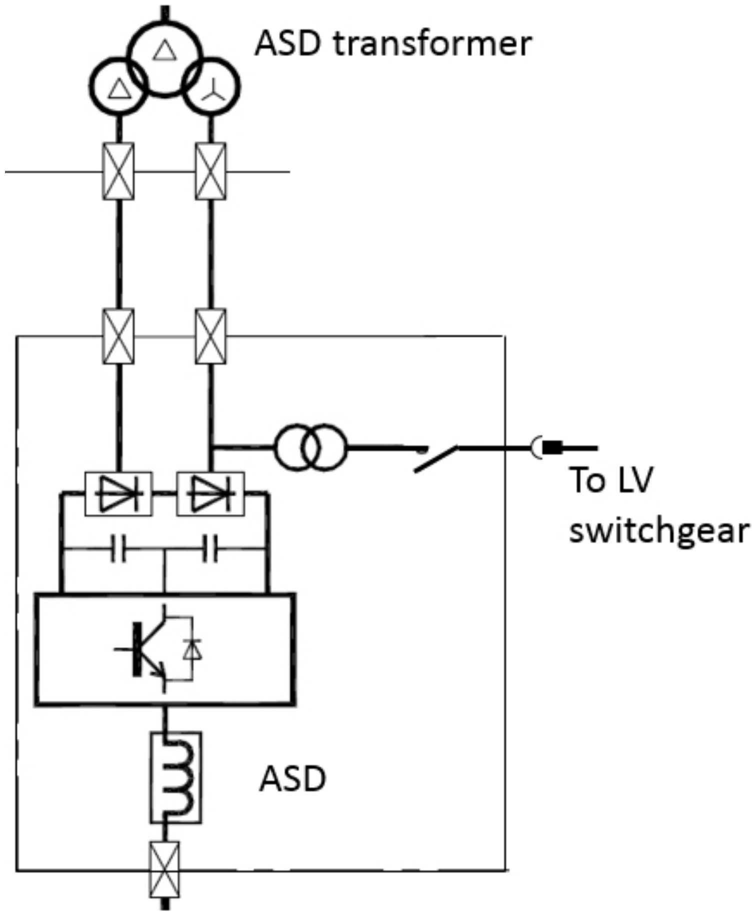
Limiting transformer inrush current 2/2



Presented in PCIC Europe 2016
(ASD = Adjustable Speed Drive)

Control closing time of breaker pole(s) to minimize the inrush current.

Requires specific control equipment



Energization via tertiary winding.

Transportation issues at same site

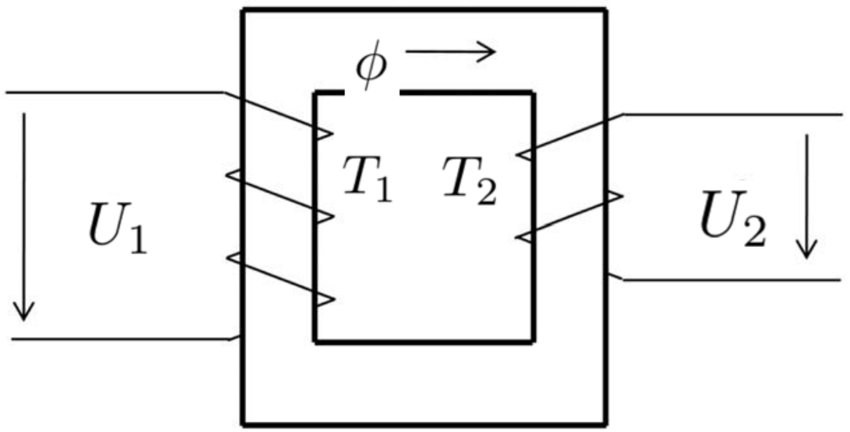
- Two additional transformers for new substation delivered to site
- Transportation by ship to port, then overland on bad roads to site
- High-end shock recorders installed on both transformers
- At site, analysis of recordings showed excessive vibrations and shocks
- Question: What to do?
  - Too expensive to ship transformers back for inspection
  - Impossible to inspect transformers at site for internal damage
- Analysis of data performed by recorder supplier/manufacturer
  - Data not typical of transportation shocks and vibrations
  - Conclusion of manufacturer is that recorder mounting plate on transformer vibrated (resonance)
- Verification of transformer impedance done at site
  - Acceptance test for short-circuit withstand testing IEC 60076-5
  - Result was within limits for short-circuit testing
- Decision: Transformers deemed not damaged and energized. In service since with no issues.

4) Noisy transformer - power plant on an island

- Power station located close to residential area
- Grid connection transformer occasionally exceeded admissible noise levels
- Several other unrelated fault conditions at same site
  - Corrosion
  - Earthquake damage
  - Generation equipment issues
- Client decided to take a look at all issues at the same time

Magnetostriction – major source of transformer noise

Transformer magnetic circuit



$$\phi = \phi_m \sin 2\pi f t$$

$$e = -T\frac{\mathrm{d}\phi}{\mathrm{d}t} = -T\phi_m 2\pi f \cos 2\pi f t$$

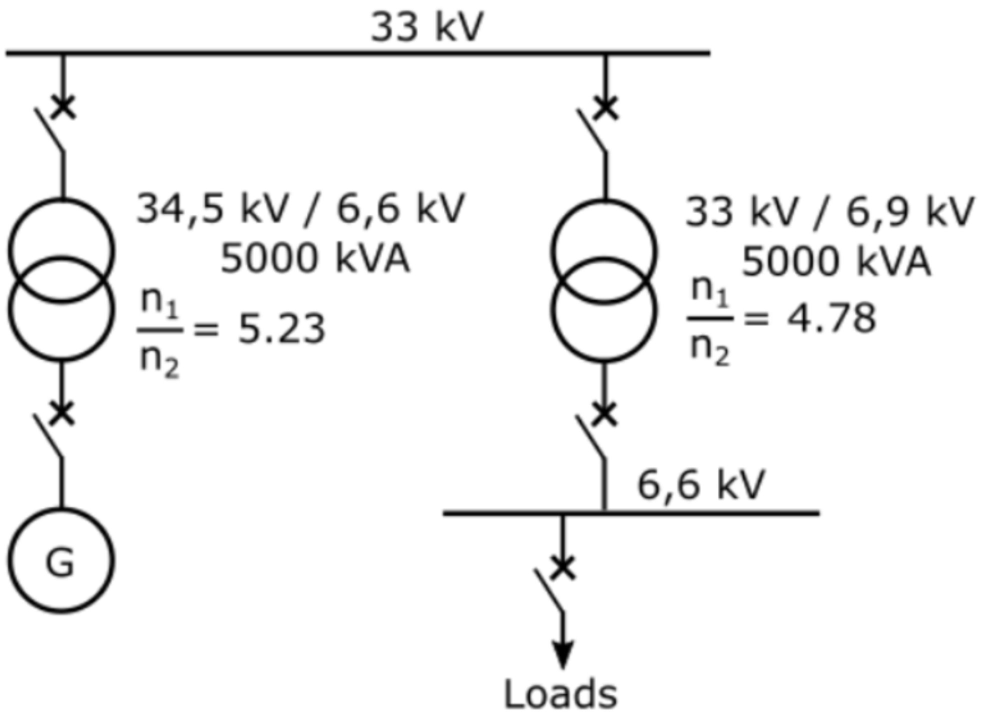
$$U = e_{\mathrm{rms}} = \frac{2\pi}{\sqrt{2}}\phi_m f T = 4,44\phi_m f T$$

$$\frac{U}{f} = 4,44\phi_m T = \text{constant}$$

- Voltage is fundamental design factor
- Voltage proportional to frequency: volts / Hertz = constant
- Flux density = ϕ / core area
- Too high design flux density causes noise
- Design magnetic circuit for all applied voltages

- Occasional noise due to core saturation
- Worst case: Exporting power at low power factor

Step-up transformers and step-down transformers

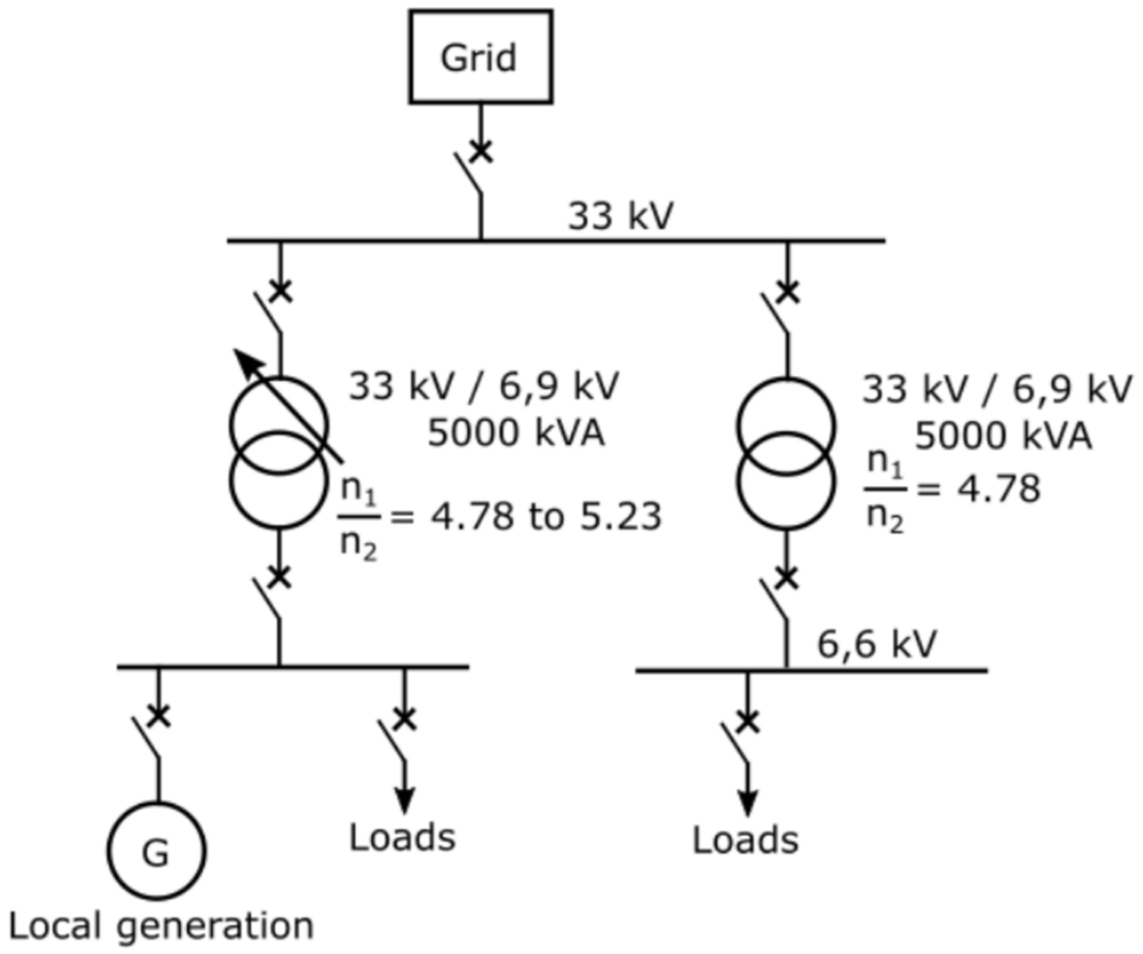


Transformer is a passive device

- Power flow determined only by applied voltage
- Turns ratio will depend on use of transformer
- Step-down:
  - Supply voltage higher than load voltage
  - LV winding no-load voltage increased (voltage drop)
  - Turns ratio is minimum
- Step-up:
  - Supply voltage lower than load voltage
  - HV winding no-load voltage increased (voltage drop)
  - Turns ratio is maximum

- Step-up or step-down transformers normally have only off-voltage tap changer
- Be careful when power flow can change during operation

Power flow in both directions



Normal operation configurations:

- Grid supplies power to all load. Generator off
- Grid off. Generator supplies power to all loads
- Generator transformer must handle both cases without plant shutdown
- May require an on-load tap changer

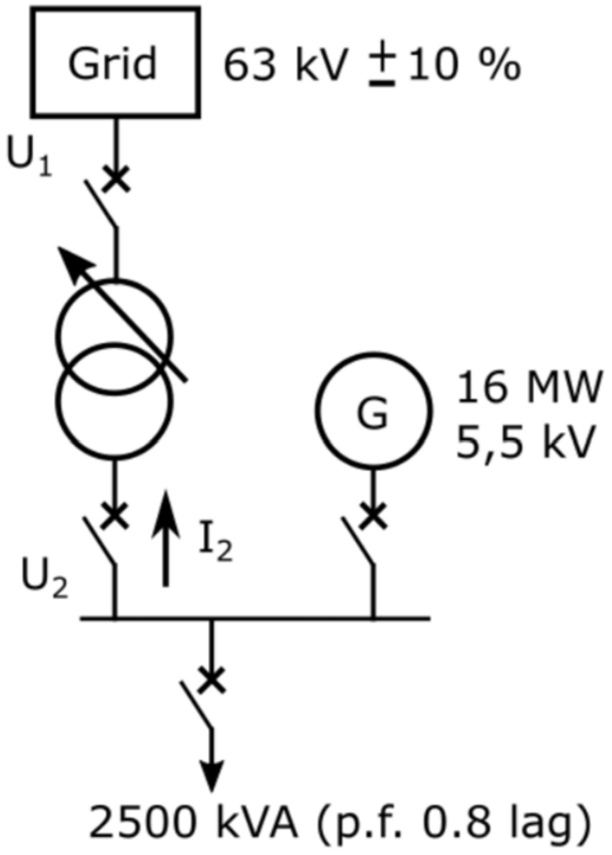
Consequences:

- Transformer design adapted to operations
- Voltage control may require power management system:
  - Regulation by transformer when power from grid
  - Regulation by generator when operating
- Must avoid conflicts between generator and transformer AVRs

Performance requirements

Power plant operation

- Export 20 MVA to grid
- Grid voltage:
  - 69,3 kV max
  - 56,7 kV min
- Generator output voltage:
  - 5,5 kV + 10%
- Load when generator out of service
  - 2500 kVA

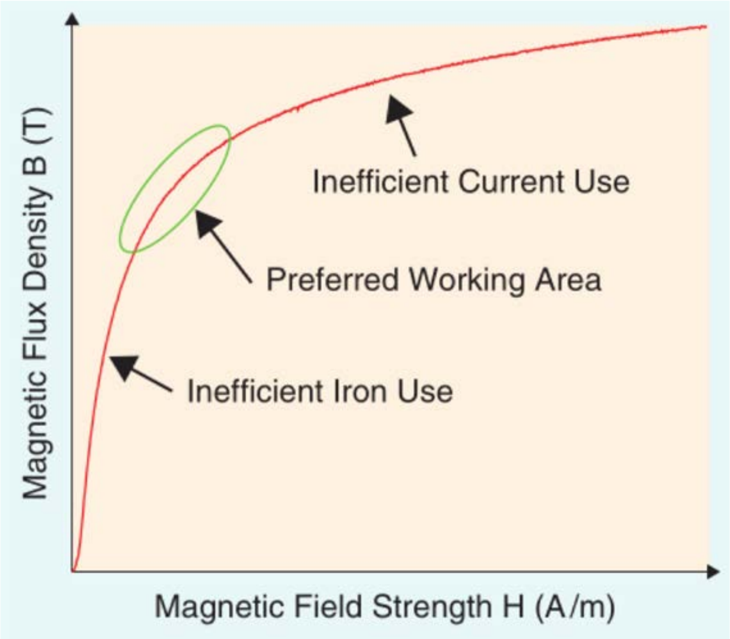


Transformer design

- Export 20 MVA to grid
- Import 2500 kVA
- Meet noise limitation

General design considerations

- Select operating range on B-H curve
  - Identify conditions where flux density is high
  - Determine if other methods could be used to keep B lower
- Taps on HV side
  - Typical design choice due to cost (lower current on HV side)
  - All taps for full power except where voltage exceeds U_m
- Generator operation
  - Should never absorb reactive power (stability issues)
  - Should export reactive power to support grid voltage
  - Use voltage capability to avoid tap changer operations



Comparison with standard step-down transformer

Step-down transformer

- Maximum turns ratio: 63 kV + 10% at no load = 12,6
- Minimum turns ratio: 63 kV – 10% at full load (20 MVA pf 0,8 lag) = 9,7
- Rated voltages:
  - HV winding 69,3 kV, U_m 72,5 kV
  - LV winding 5,75 kV (5,5 kV + 5%)

Step-up/down transformer

- Maximum turns ratio: 63 kV + 10%, 20 MVA export with generator voltage 5,5 kV = 13,2
- Minimum turns ratio: 63 kV – 10% at full load (2,5 MVA pf 0,8 lag) = 10,22
- Rated voltages:
  - HV winding 69,3 kV, U_m 72,5 kV
  - LV winding 6,05 kV (5,5 kV +10%)

Main differences in step-up/down transformer

- Tapping range is the same but average turns ratio is higher
- Rated voltage of LV winding is higher
- Voltage control at 5,5 kV level can be the same or different:
  - Transformer AVR controls voltage range and generator AVR fine tunes it, or
  - Power management system controls transformer tap positions and generator AVR

Conclusions

- Transformer LV winding rated voltage was too low
- Core saturation effects when exporting power at low power factor increased noise

Recommendations

- Number of tap positions must be sufficient but no more than necessary
  - Reduced reliability - more complexity and transient voltage oscillations across regulating winding
  - Higher cost
- Tap changers can be off-voltage or on-load: select what is required for your application
- Possible to combine on-load and off-voltage taps
  - Off-voltage to change operation from step up to step down
  - May make sense for very specific applications
  - Reduces total number of tap positions
- Control flow of reactive power to reduce number of on-load tap changer operations
- Do not use 105% overfluxing safety margin during design. Keep as ”safety margin”
- Clearly define who is in charge of voltage level control

5) Issues in vector group

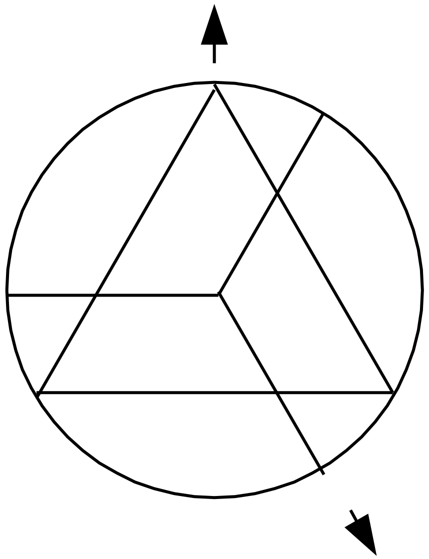
- Can result in ordering the wrong transformer
  - Correct voltage ratings
  - Correct rated power
  - Wrong definition of delta and wye windings

What IEC standards say:

- HV winding is the winding with the highest rated voltage
- LV windings are all other windings
- Rated voltage is the voltage that appears on each winding at no load
- Rated apparent power is the power flowing into the transformer at rated voltage and current
- No mention of “primary” or “secondary” windings

Clock number notation (example Dyn5)

HV winding phase
voltage at 0°



LV winding phase voltage at 5 o'clock
lags HV by 5 x 30° = 150°

D, d: delta connection

Y, y: wye connection

N, n: connection to earth

Upper case: HV winding only

Lower case: LV windings

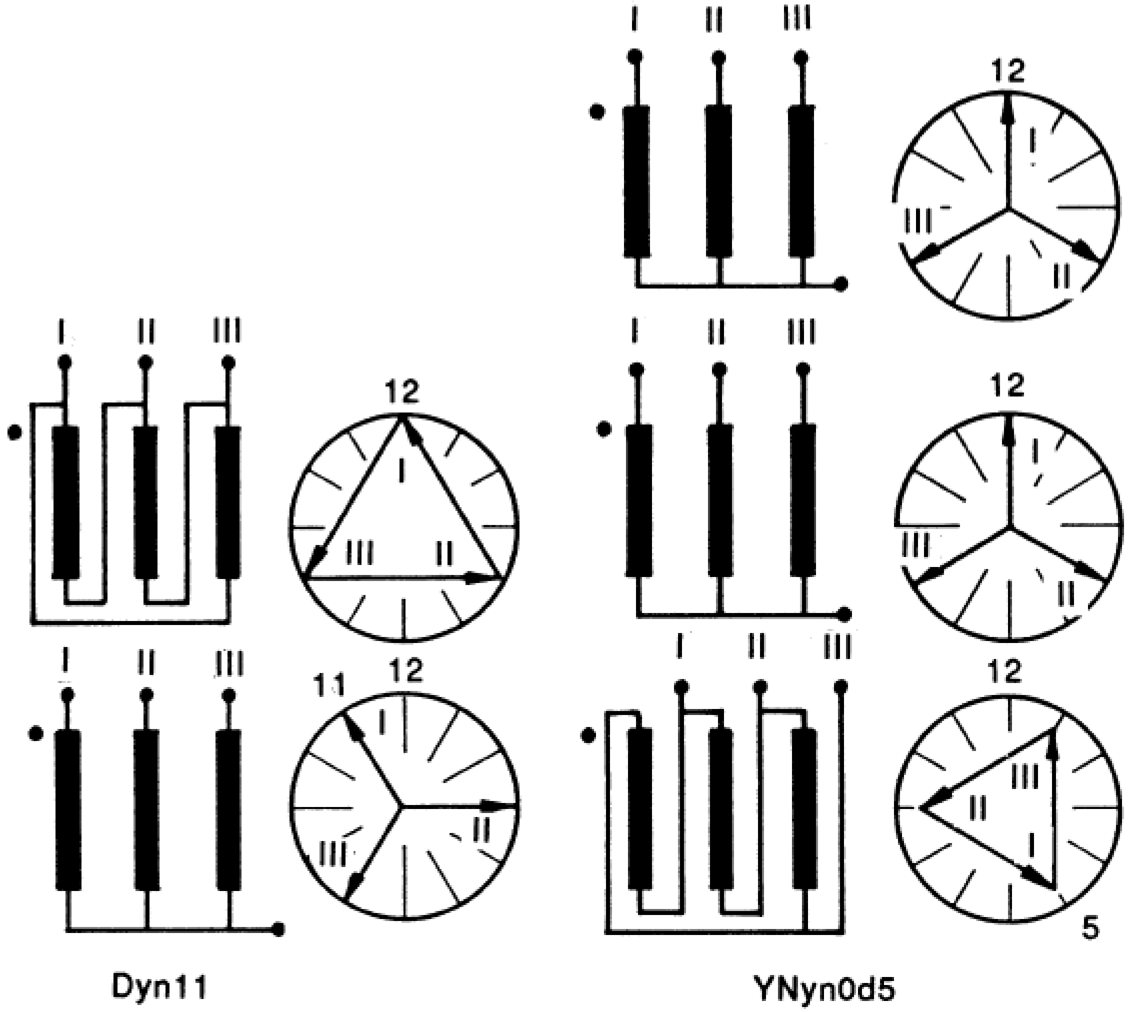
Depends on national preferences:

France, China: Dyn11

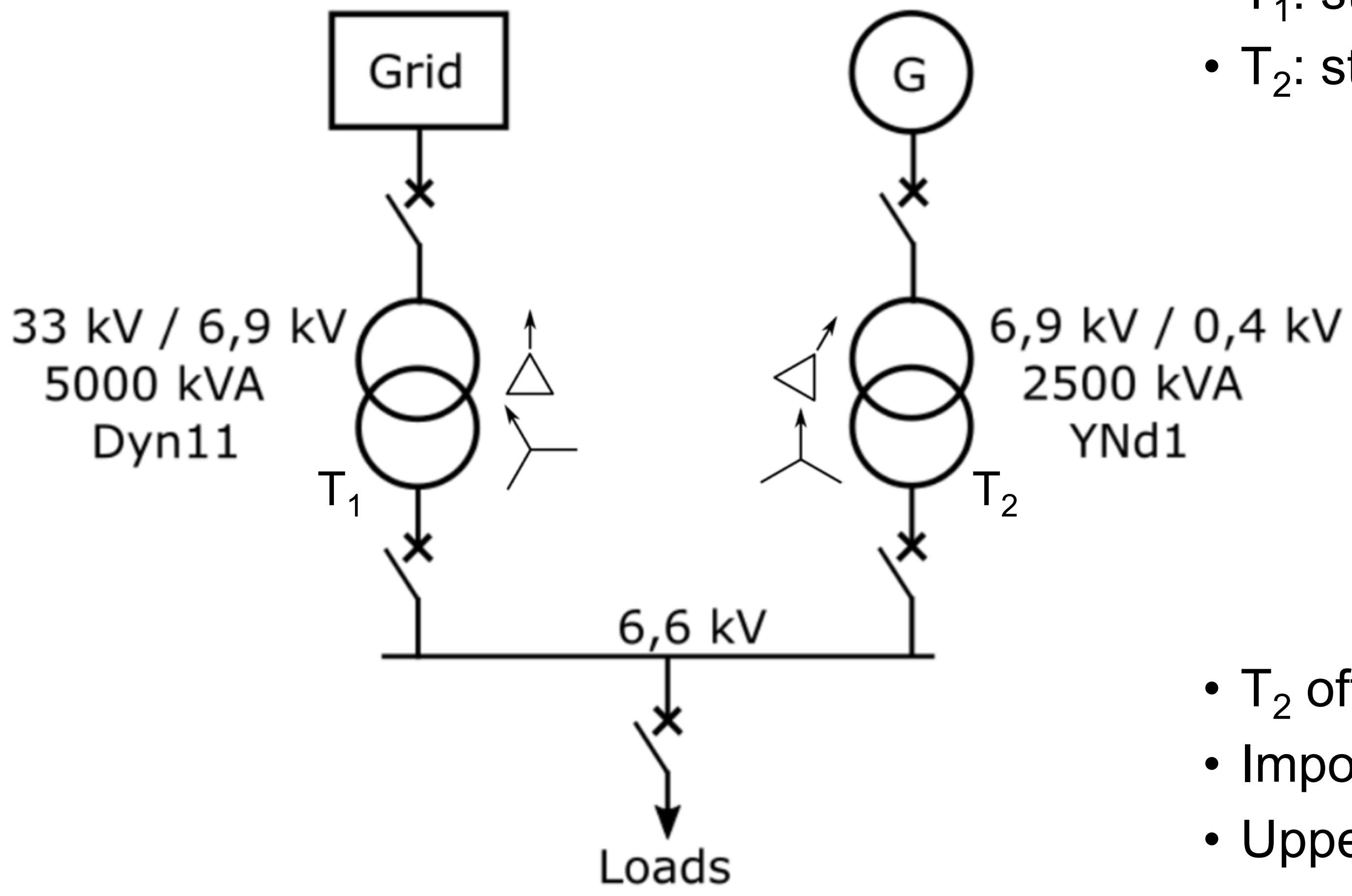
Germany, Egypt: Dyn5

no technical reasons for choice

Example from IEC 60076-1 § 6



Be careful of vector groups



- T_1: step-down XFMR feeding 6.6kV system
- T_2: step-up XFMR feeding same 6.6kV system

- T_2 often mistakenly labeled Dyn11
- Important consequences for system earthing
- Upper case for HV winding, not “primary winding”

6) Errors in rated voltage

1) Incorrect U_r

- U_m specified as 7,2 kV (IEC insulation class voltage)
- U_r specified as 7,2 kV instead of 6,6 kV (silly mistake)
- XFMR manufactured as 7,2 kV/0,420 V Dyn11
- XFMR supplier did not question specification
- XFMR replaced (initial one given to a university)

2) Manufacturing error

- HV winding specified as 220 kV delta (each winding rated at 220 kV)
- Manufactured as wye (each winding rated at 127 kV)
- Windings manufactured again
- HV windings often wye connected (cost effective)

7) Rated power

- Rated power of each winding is $\sqrt{3}\ U_r\ I_n$
- Where different cooling means used, rated power is the highest value

Example: 6,6 kV / 0,420 kV 1250 kVA

- HV winding: Power in = 1250 kVA, rated current = 109,4 A
- LV winding: Rated current = 1250 kVA / ($\sqrt{3}$ x 0,420 kV) = 1718 A
- Power to loads at service voltage 0,4 kV = $\sqrt{3}$ x 0,4 x 1718 = 1190 kVA

Customer said he had ordered a 1250 kVA XFMR and expected to load it at 1250 kVA.

You get what you specify, not what you want

- Transformer manufacturers supply transformers as "loose items", not part of a system.
- Do not assume they know what you want - they only know what is specified.
- Referring to standards is only the first step. Know:
  - what the standards require ("shall")
  - what they recommend ("should")
  - what they don't mention.

Recommendations

- Inform supplier what the XFMR is used for.
  - Some standards mention specific information for such applications
- Have kick-off meeting at supplier’s plant.
  - Access to engineers to answer most questions
  - Review all aspects of XFMR: design, testing, packaging, shipping, installation, commissioning
- Clearly define who is responsible for what

8) Transportation damage

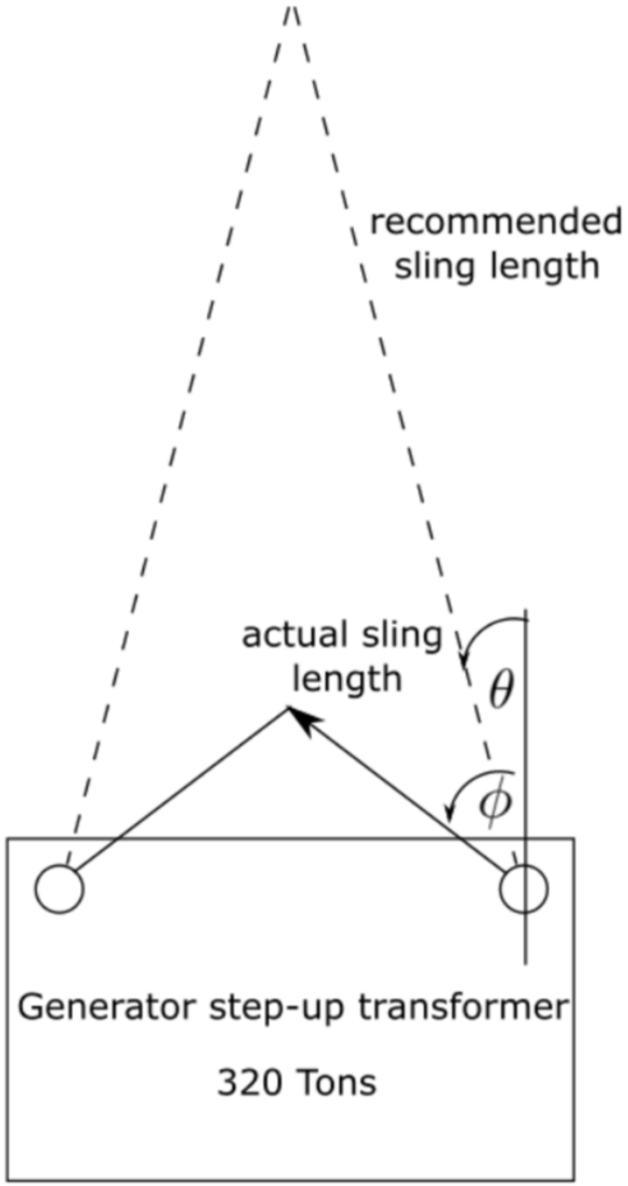
Several examples of damage due to transportation and handling

- Paper mill transformer in Canada
  - Shipped by rail during spring: roads unsuitable for heavy loads during spring thaw
  - Freight train shock absorbers are useless
  - Transformer subjected to many lateral shocks causing severe internal damage
  - Transformer shipped back to Europe for repair
- 300 MVA Generator transformers at large power station in Singapore
  - Shipped from Europe by boat and barge to site
  - Slings were too short: transformer tank was bent at lifting lugs
  - Finally decided to energize as were: no issues afterwards (luck more than anything)
- Use of shock recorders
  - Recommended for larger transformers
  - Be careful with the installation and evaluation of the results
  - If transportation delayed, switch off recorder until transformer shipping really starts

Importance of sling length

Forces on transformer lifting lugs

- Weight on each lug is 80 Tons (1/4 total weight)
- Recommended sling angle ≈15° Force on lug increased by $1/\cos\theta \approx 1{,}04$ = 4%
- Short slings used at angle of ≈ 50° Force on lug increased by $1/\cos\phi \approx 1{,}55$ = 55%
- Force exceeded capacity of lifting lugs
- Result was deformation of transformer tank at lug location



Capitalization of losses – used with generator transformer

Often applied for utility transformers, or electrolysis installations

Bidding phase, price of transformer is Cost + *a*€/kW x iron losses + *b*€/kW x copper losses

- Values of x and y determined by type of use of transformer
  - Normally operating at base load $\Longrightarrow$ *a* is low and *b* is high
  - Standby operation $\Longrightarrow$ *a* is high and *b* is low
- In some bids total cost was too high even if transformer given away
- During testing, meeting values of iron and copper losses are acceptance criteria

Oil theft

- Several substation transformers delivered to Iraq
- Shipment by truck to site
- After installation at site, discovered that oil had been stolen
- Required inspection at site, and refilling
- Risk involved was possible moisture ingress
- Recommend means of theft prevention, or at least immediate identification of theft
  - The quicker oil loss is discovered, the quicker that corrective action can be taken

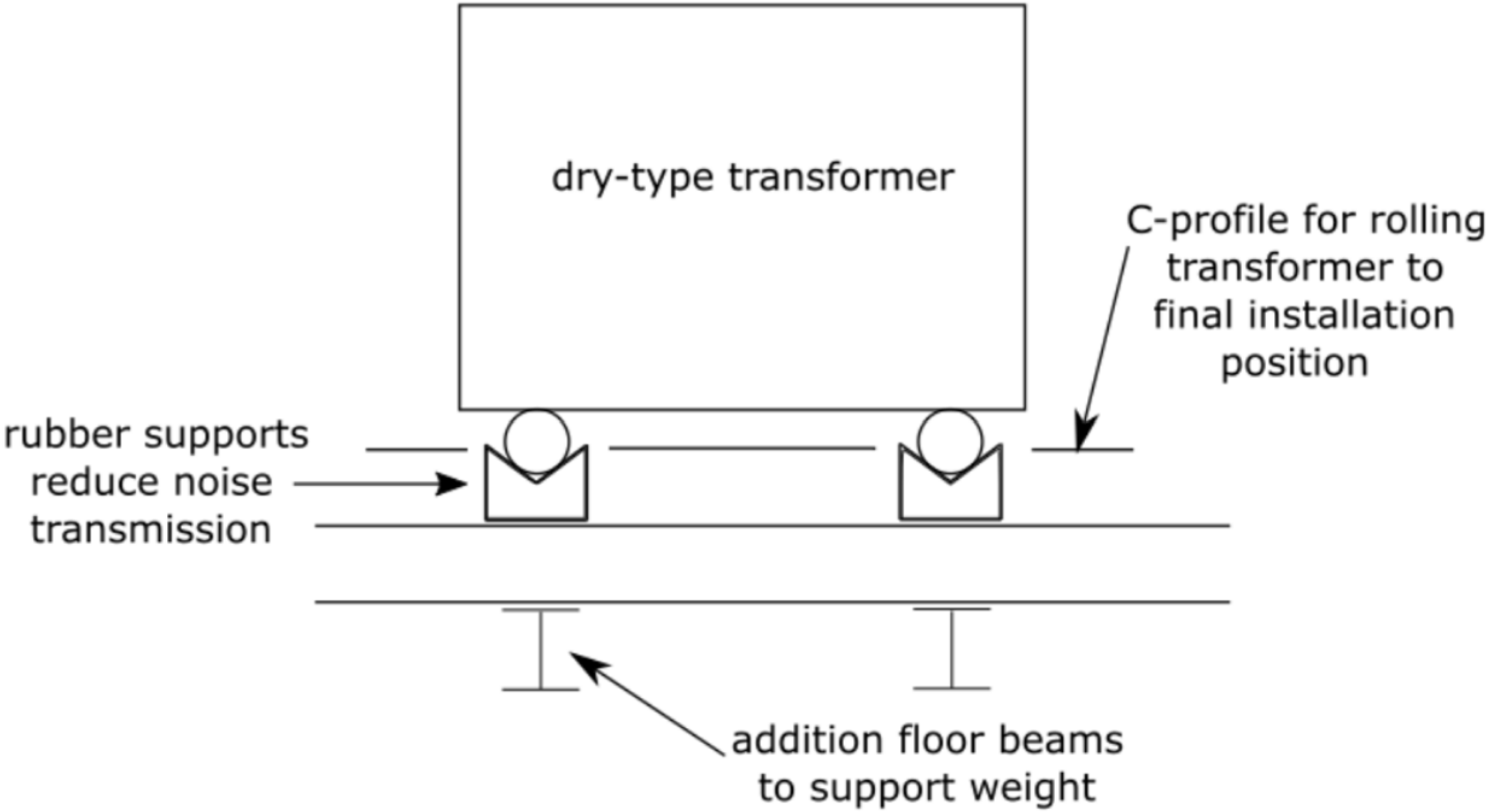
9) Installation issues

Transformers are often large and heavy

Installation must be carefully engineered to avoid problems

- Installation of dry-type transformers in upper floors of buildings
- Noise transmission
- Interfacing to other equipment

Installing dry-type transformers in buildings



- Weight concentrated at 4 points
- Additional floor beams could be required
- Direct installation on floor would cause unacceptable noise transmission
- Use of rubber supports to dampen noise transmission
- C-profile used for installation
- Ensure capability of lifting equipment and access to rooms where transformers are installed

Interfacing to other equipment

14 dry-type transformers provided for same project: 630 kVA to 2000 kVA, but many different connection types required

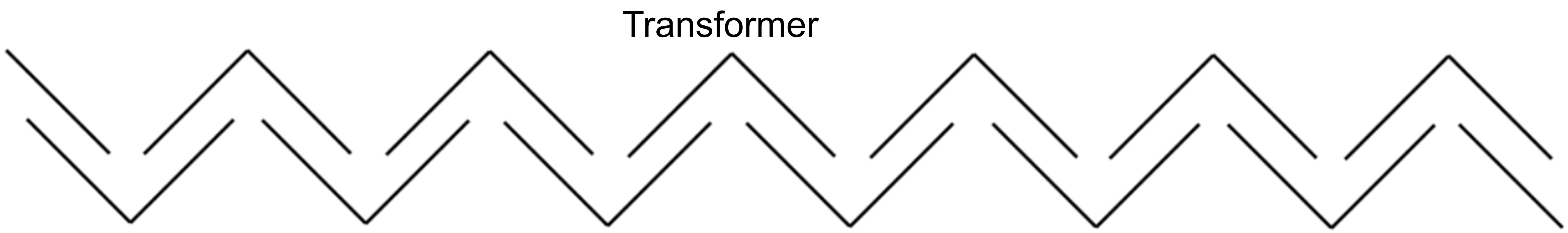
- Horizontal busduct connection to switchgear, left or right
- Vertical busduct connection for isolated transformer
- LV cable connection via top entry

To “simplify” engineering, project engineer made only one drawing showing all options.

Notes on drawing indicated what options applied to which transformers. Results:

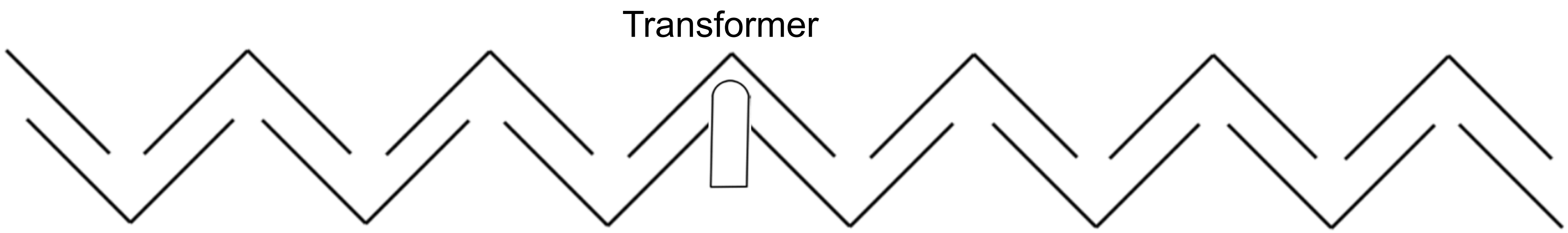
- Many transformer connections were manufactured incorrectly and had to be replaced
- Major delay in commissioning transformers
- Specific drawings per transformer connection type would have been much better

Transformer housing IP



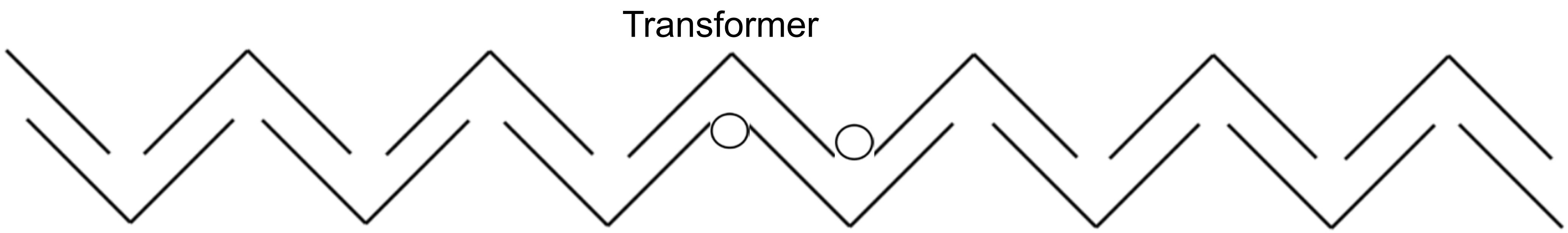
- Housing wall construction used chevrons providing good ventilation

Transformer housing IP – IEC IP20 finger probe test



IP20 finger probe test successful – chevron interlocking prevents touching live parts

Transformer housing IP – IEC IP20 ball test



IP20 ball test failed – ball could enter enclosure between rows of chevrons

- Additional mesh installed inside transformer to meet IP20 requirement.
- Installation in a tropical country where ingress of vermin is a big problem.

General information about dry-type transformers

Dry-type transformers often have cast resin protection for the windings.
Specific points to consider for such transformers:

Overload capability is much different than for oil-filled transformers

- Maximum short-time current is limited by IEC standard
- Problem with wind turbine transformers due to extreme high currents during commissioning
- Transformer resin was cracked leading to premature failure of several transformers

Cast resin is used to provide dielectric strength

- The more cast resin used, the better the insulation
- However cast resin increases temperature rise since thermal insulation
- Design optimization = enough resin for dielectric strength but not too much for heat rise
- Some premature failures due to excessive reduction of resin

Generator step-up transformer interface

The generator is a steam-turbine horizontal shaft machine

- To prevent shaft deformation, the generator is slowly rotated when deenergized, similar to the kiln at cement plants
- The 300 MVA generator transformer has an off-voltage tap changer
- The generator transformer is close coupled to the generator terminals – no switches
- During the slow rotation, the remanant magnetization of the generator stator induces a small voltage that appears on the generator terminals.
- The off-voltage tap changer can be operated only when there is 0 V.

- The problem ended up being solved, but I don’t know how.

10) Conclusions

Transformers are engineered products

- Specification: There are many things to look at: you get what you specify
- Accessories: Little in standards on this subject: include all accessories in specification
  - Access to accessories such as instrument transformers to be described
  - Specify materials for accessories suitable for site ambient conditions (pollution, salt etc.)
  - Pay close attention to cable connections: sizes, gland plates …
- Testing: Be sure that what goes to site meets your requirements
  - Testing normally done without radiators: specify with radiators if deemed necessary
  - Do DGA analyses before and after testing: important difference could indicate problems
- Transportation: Install shock recorders: will not prevent issues but helps making decisions
- Installation: Define all requirements to be sure that installation done correctly
- Maintenance: Define your maintenance program during specification phase
  - Transformer must be equipped to allow the type of maintenance needed

Questions??

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