Transformers – Then, now and future?

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Birmingham – 14 November 2023

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Transformers

Where are we going?

- Transformers last a long time!
- Examples in this presentation decommissioned between 50-80 years after commissioning
- Basic technology has not changed
- Changes in methods and materials
- Future? Who knows! (depending heavily on how electrical networks evolve)

C. A. Parsons 150kVA 11/0.433kV Distribution Transformer
Built c.1937, Commissioned c.1937, Decommissioned in 2017
Photo Courtesy of Hongzhi Ding

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Transformers in the past

Where have we come from?

- Basic technology:
  - ✓ **Iron magnetic core**
  - ✓ **Coils wound around core – copper or aluminium**
  - ✓ **Solid insulation – paper, cotton, board**
  - ✓ **Insulation fluid – air or oil**
- Basic Design Methods
  - ✓ **Slide rule**
  - ✓ **Empirical formulae**
- Manufacturing methods
  - ✓ **Hot air ovens with or without vacuum**
  - ✓ **Oil filling – under atmospheric pressure**

Current technology

Where are we now?

- Basic technology:
  - ✓ **Iron magnetic core**
  - ✓ **Coils wound around core – copper or aluminium**
  - ✓ **Solid insulation – paper, board, aramid paper**
  - ✓ **Insulation fluid – air or oil, synthetic or natural esters, gas**
- Basic Design Methods
  - ✓ **Computer programs for most calculations**
  - ✓ **Finite element analysis for thermal, electrical and mechanical stresses, losses**
  - ✓ **Much tighter tolerances in clearances**
- Manufacturing
  - ✓ **Tighter tolerances on dimensions**
  - ✓ **Better processes – drying (vapour phase), oil processing,**
  - ✓ **Improved manufacturing of components (insulation, conductor, etc)**

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Transformers in the past

The Crompton Parkinson (British Electric Transformers) 120MVA 275/132/11kV ON/OFB Autotransformer Built 1954, Commissioned 1954 at the Birth of British Supergrid, Decommissioned in 2022

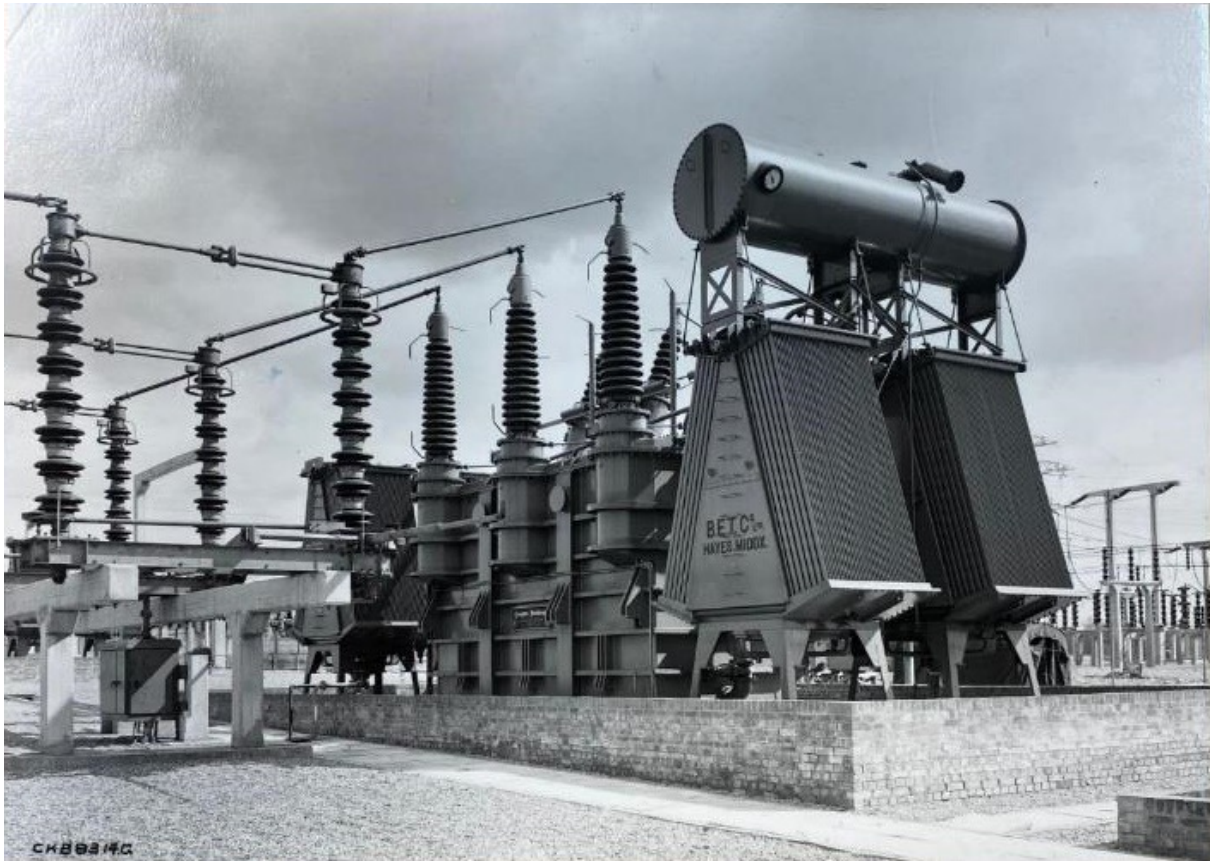

Photo courtesy of Hongzhi Ding

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Transformer losses

Typical values of Peak Efficiency Index (PEI) compared to EcoDesign

- EU Regulations Regulation (EU) No 548/2014 and 2019/1783
  - ✓ **Tier 1 come into force in 2015, Tier 2 in 2021**
- EXAMPLE: Tier 2 for 120MVA, PEI = 99.770 minimum
- Typical PEI for power transformers:
  - ✓ **1963, 120MVA, 132/33kV, No-load loss 101.88 kW, Load loss 636 kW, PEI = 99.576%**
  - ✓ **2017, 120MVA, 132/33kV, No-load loss 23.29 kW, load loss 558.17 kW, PEI = 99.810%**
  - ✓ **2017, 120MVA, 132/33kV, No-load loss 40.3 kW, Load loss 269.14 kW, PEI = 99.826%**
- Some transformers have been replaced on the basis of cost of losses over lifetime which outweighs capital cost of a new transformer

Loss values courtesy of SPEN

Bushings – 275kV typical

Porcelain insulator, oil-filled

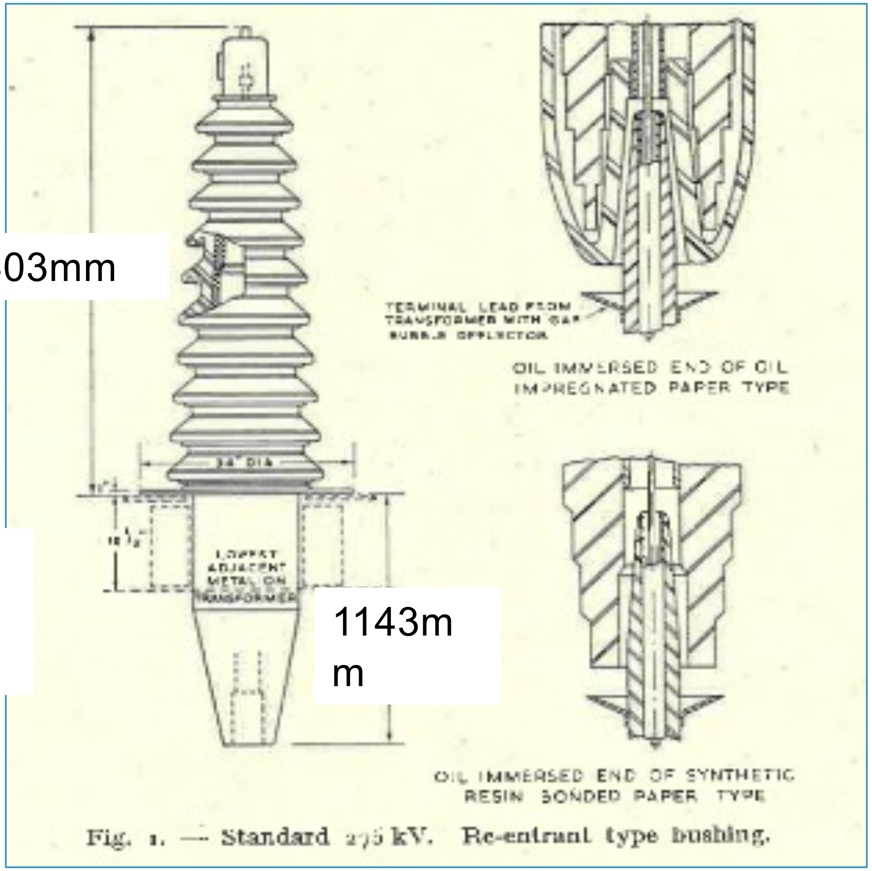


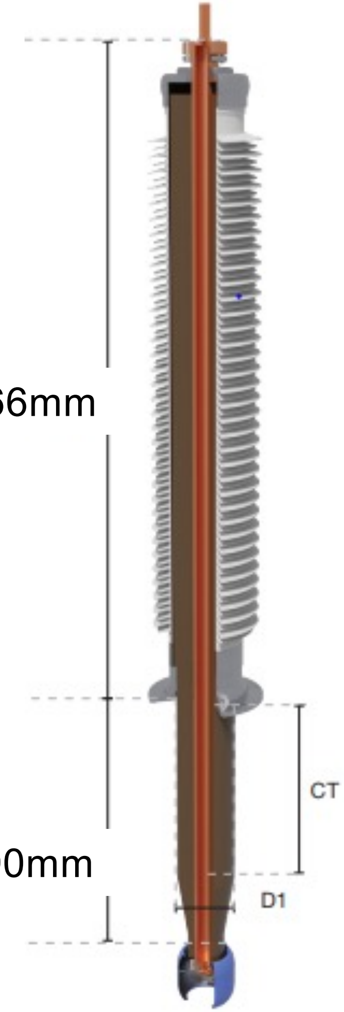
Fig. 1. — Standard 275 kV. Re-entrant type bushing.

3403mm

863mm dia of flange

1143mm

'*Comparison of Designs of British 275kV Transformers*' written by W. Casson and G. B. Harper of Central Electricity Authority published in CIGRE 1958



Silicone insulator, solid insulation

2766mm

500mm dia of flange

1190mm

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Hitachi Energy AirRIP® flex transformer bushing Technical guide

When oil-filled bushings have a problem……

Photo courtesy of Elizabeth Mackenzie

Tapchangers – over the years

Original MR tapchanger 1929

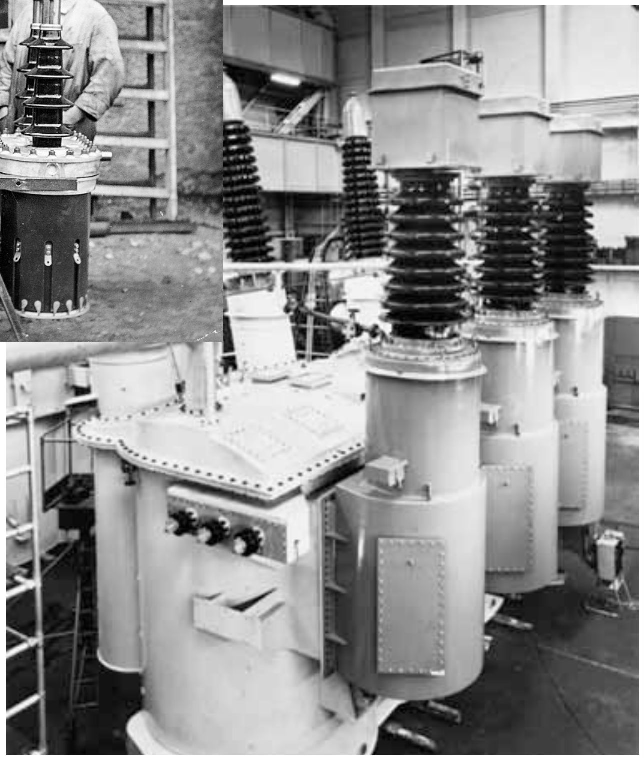
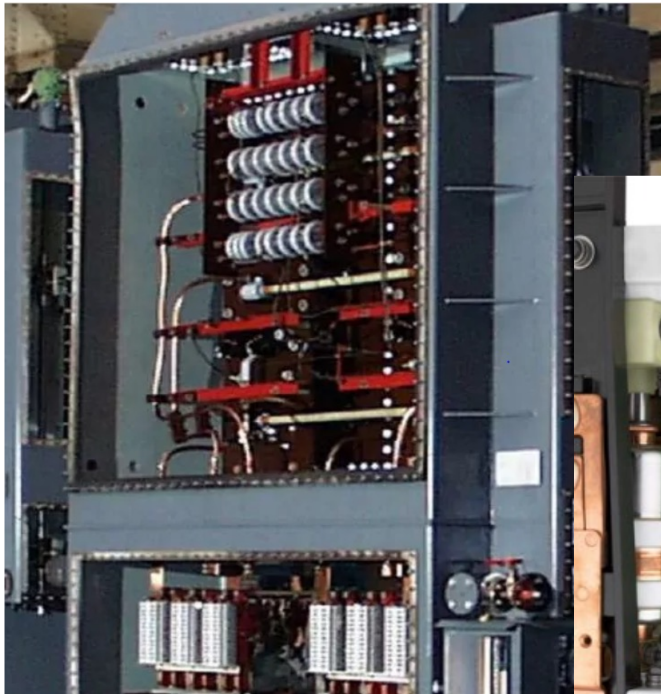
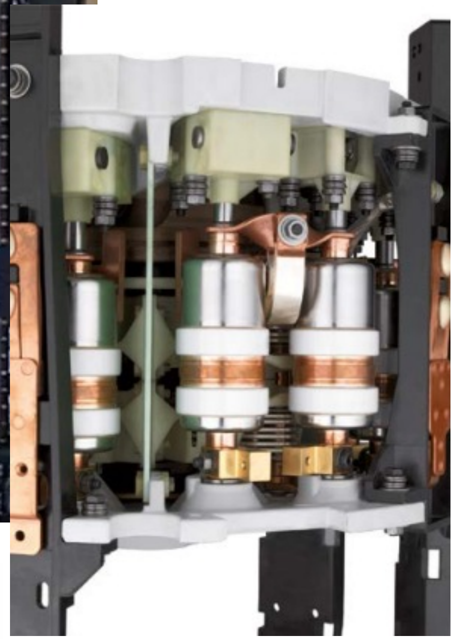


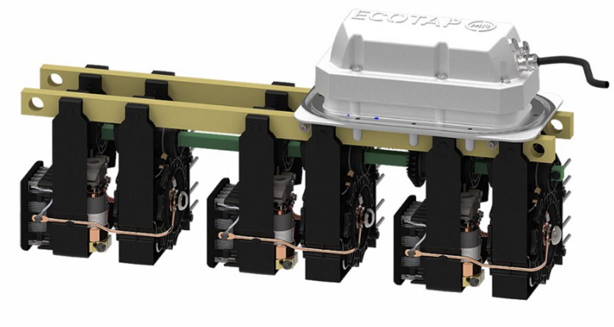
Figure 4.63(a) Three single-phase, fully insulated tapchangers fitted to the 132 kV tapping points of a 240 MVA, 400/132 kV autotransformer (Hawker Siddeley Power Transformers Ltd)



Bolt-on tapchanger, www.brush.eu



Vacuum diverter switch for OLTC, www.Reinhausen.com



Distribution transformer OLTC, www.Reinhausen.com

Internals

Windings, core, insulation, fluid

1950s

Copper strip, paper or cotton covered

Varnished copper strip

Paper and pressboard insulation

Hot-rolled steel

Mineral oil

Askarels (CI

2020s

Copper or aluminium conductor

Continuously transposed conductor

Paper and pressboard insulation

Aramid paper and board insulation

Cold-rolled steel, laser etched

Amorphous steel

Mineral oil

Synthetic and natural esters

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Winding types

1950s

Plain disc coils

Layer coils

Helical coils

2020s

Plain disc coils

Interleaved disc coils – improved impulse withstand

Shielded disc coils – simpler construction than interleaved

Layer coils

Helical coils

Foil winding – distribution transformers, mainly LV

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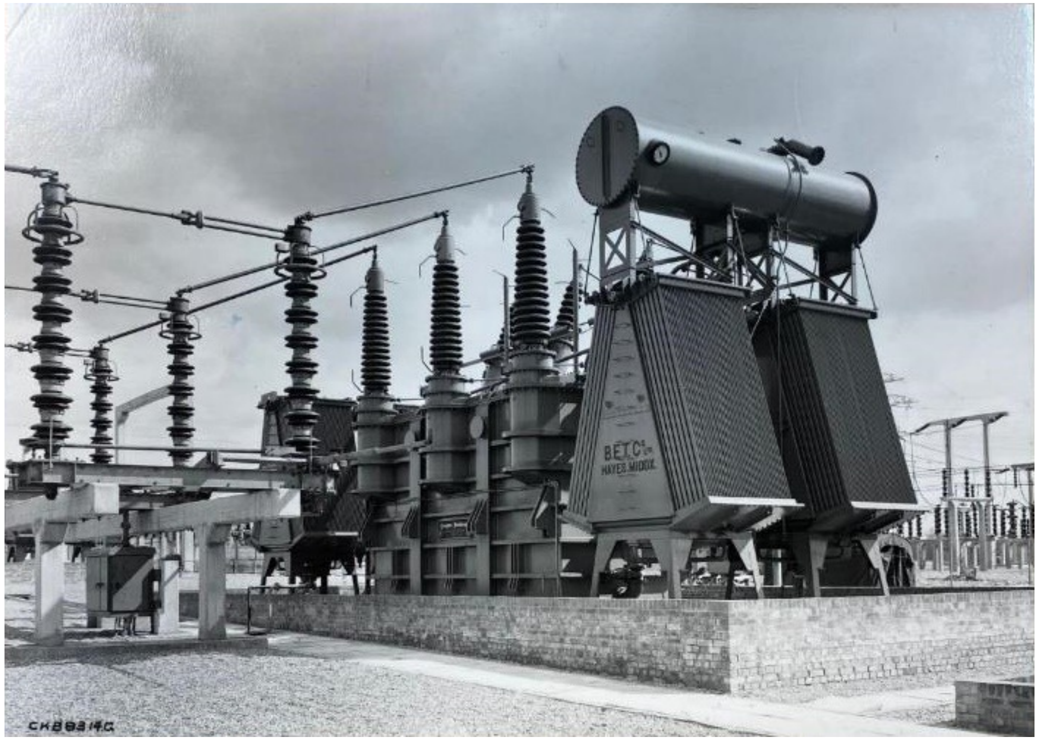
Old vs. New

- Old 120MVA autotransformer



- Modern 240MVA autotransformer

Photo courtesy of Paul Jarman

Old vs. new – like-for-like replacement

1967, line end tapchangers on top of bushings

2022, line end tapchangers in-tank, 3-column

275/132kV 240MVA with 33kV 60MVA tertiary

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Photos courtesy of Jose Quintana

Old vs. new

Earthing transformer, 200kVA, 33kV/415V

New, 2023

Old, c1953

Photo by Andrew John, via Linkedin

Future?

- High temperature materials
  - ✓ **High temperature solid and liquid insulation**
  - ✓ **Better use of copper and core steel, less weight for same rating**
  - ✓ **May cause safety concerns due to tank temperature**
- Carbon footprint
  - ✓ **Just starting to be a requirement**
  - ✓ **How do we improve?**
- Lower losses? Tier 3? Have we reached practical limits?
- GIT – replace liquid with gas
- Digitalisation
  - ✓ **Use Finite Element/Computational Fluid Dynamics software to design transformers**
  - ✓ **Use more modelling techniques for condition assessment**
  - ✓ **Apply machine learning and AI in diagnosis**

  Digital Twin
- AC/AC electronic transformers
- Solid-state tapchangers – increased losses

Alternative future?

- DC grids
  - ✓ **Has been suggested, AC/AC transformers would be redundant**
  - ✓ **Would require a complete change of infrastructure**
  - ✓ **Impractical?**
- Transformers wound with XLPE cable
  - ✓ **Has been tried but there were issues in testing**
- Superconducting transformer
  - ✓ **Has been tried**
  - ✓ **Complexity and cost of cooling may be prohibitive**
  - ✓ **Benefits outweighed by cost?**

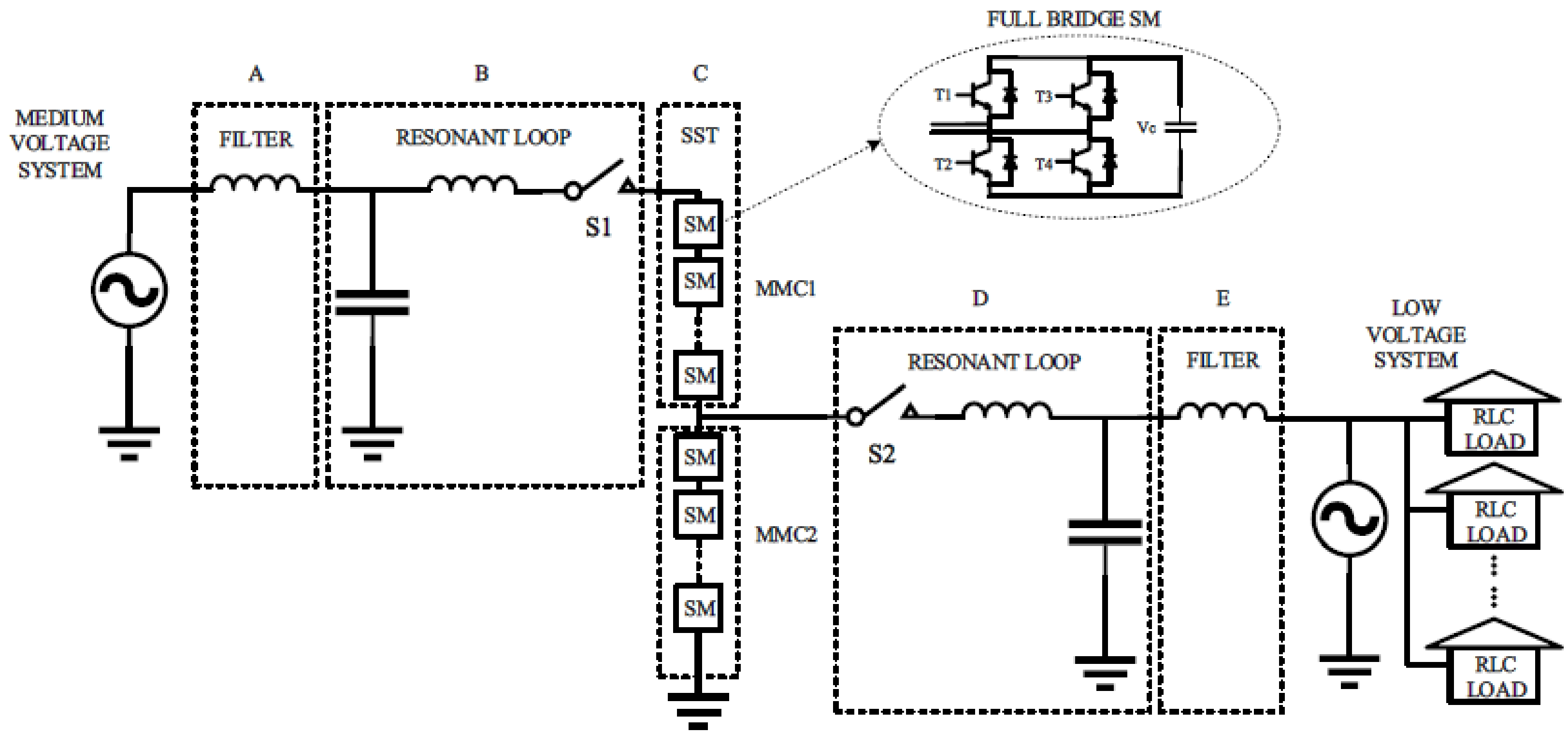
Gas Insulated Transformer - Edinburgh

Photo courtesy of Elizabeth Mackenzie

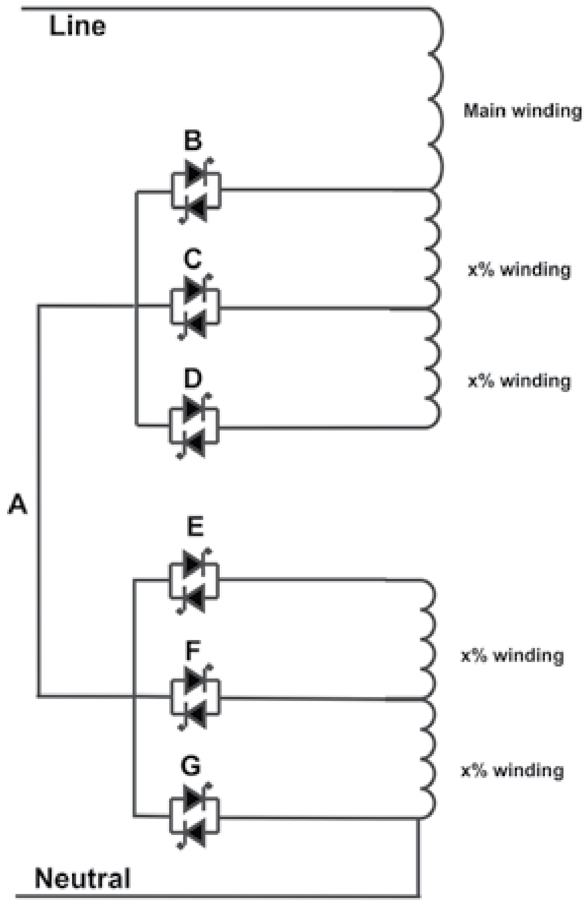
- Underground substation
- Under the streets of the city
- Reduced fire /explosion risk
- SF_6 gas
- Other gases becoming available

AC-AC Solid-state Distribution Transformer

CIGRE SC B4, 10264, Session 2022



Solid-state tapchanger



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