A2 - POWER TRANSFORMERS & REACTORS
Technical Webinar on behalf of UK Technical Committee

Experience And New Requirements For Transformers For Renewable Generation

Elizabeth MacKenzie

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Presenter

Elizabeth MacKenzie

Elizabeth has spent the last 38 years working in the transformer industry, covering design, manufacture, testing, refurbishment and failure investigation of transformers as well as transformer monitoring.

She holds a BSc and MSc from the Queen's University of Belfast in Electrical and Electronic Engineering.

Her experience of design covers oil-filled transformers from distribution size up to 400kVA, 200MVA. She has managed large engineering departments and quality assurance departments. She is currently an independent consultant where her main interest is transformers from conception to disposal, and she has also been involved in documentation projects for several companies.

Elizabeth is a Distinguished Member of CIGRE and is currently the Additional Regular Member for CIGRE A2 in the UK and is a member of AG2-08. She has been active in the SC 12 and A2 community in the UK since 1998 and was a member of WG A2.44 for a few years.

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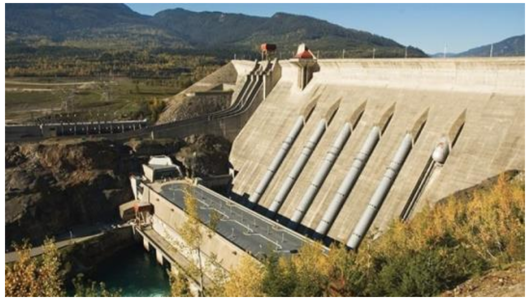
Energy (R)evolution

WIND

Worldwide 837 GW installed, covering 6.6 %[2] of the energy demand (UK 25.7 GW)[1]

SOLAR

1,000 GW installed worldwide, covering 3.7 %[2] of the energy demand (UK 14 GW)[1]



HYDRO

Worldwide 1,360 GW installed, covering 16 %[2] of the energy demand (UK 2 GW)[1]

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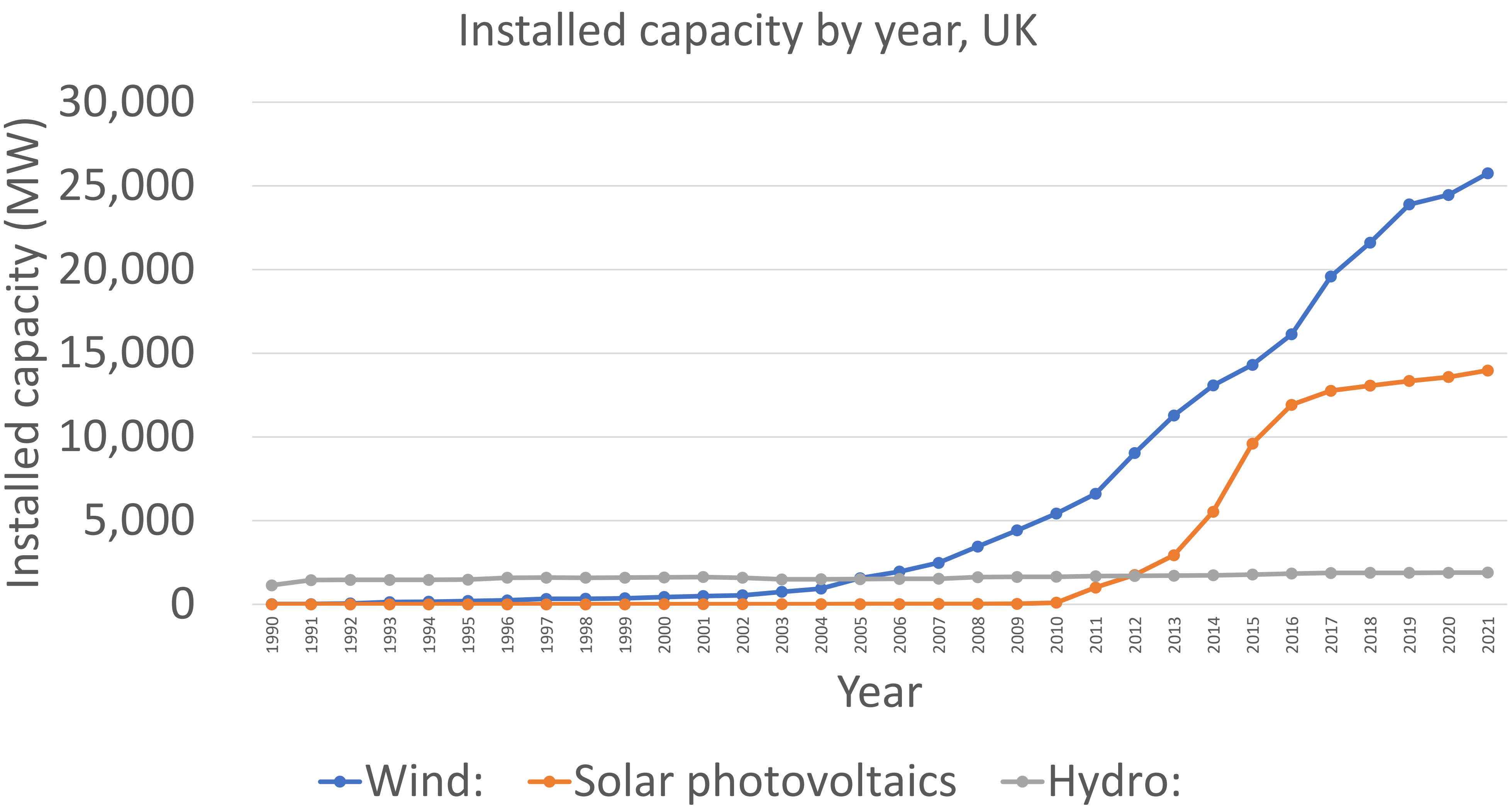
1 https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes (accessed 2/2/23)

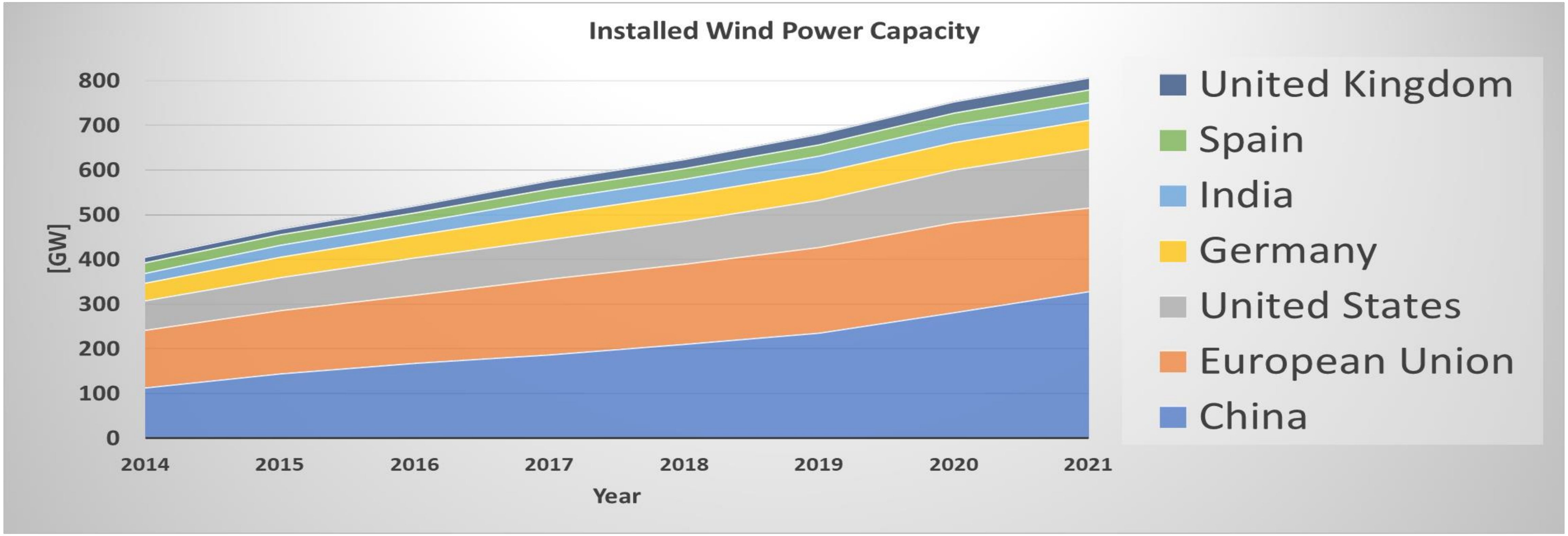
2 https://ourworldindata.org/grapher/electricity-prod-source-stacked (accessed 5/2/23)

Energy (R)evolution



https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes (accessed 2/2/23)

Energy (R)evolution



In UK, installed capacity in 2021 (11.3 GW – offshore, 14.5 GW - onshore) delivered 64.7 TWh - 22% of the energy demand (294 TWh).
(World leader: China 330 GW)

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Energy (R)evolution

WIND

Worldwide 837 GW

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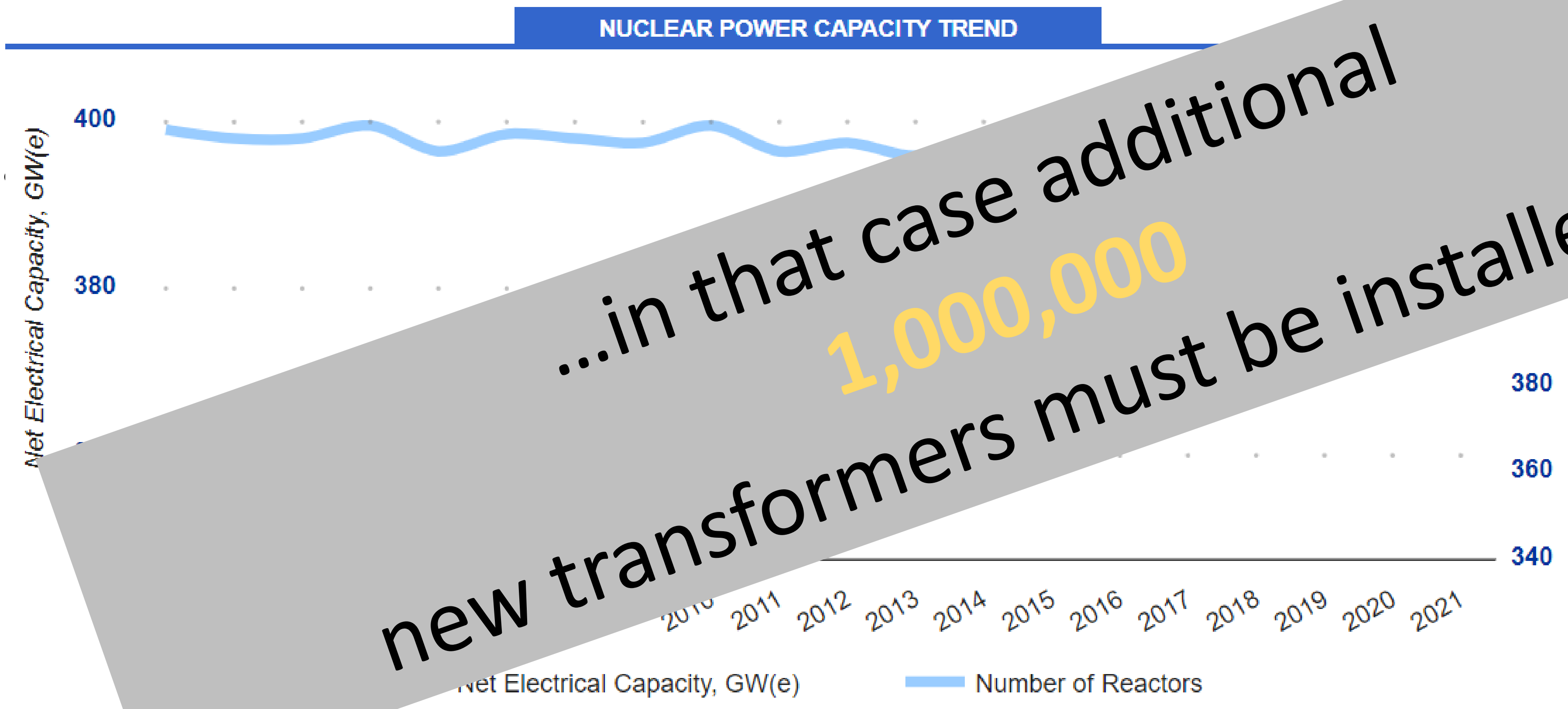
covering 3.7 % of

Worldwide 1,360 GW installed, covering 16 % of the energy demand

Due to wind and solar energy more than **1,000,000** new transformers have been installed so far…

Energy (R)evolution



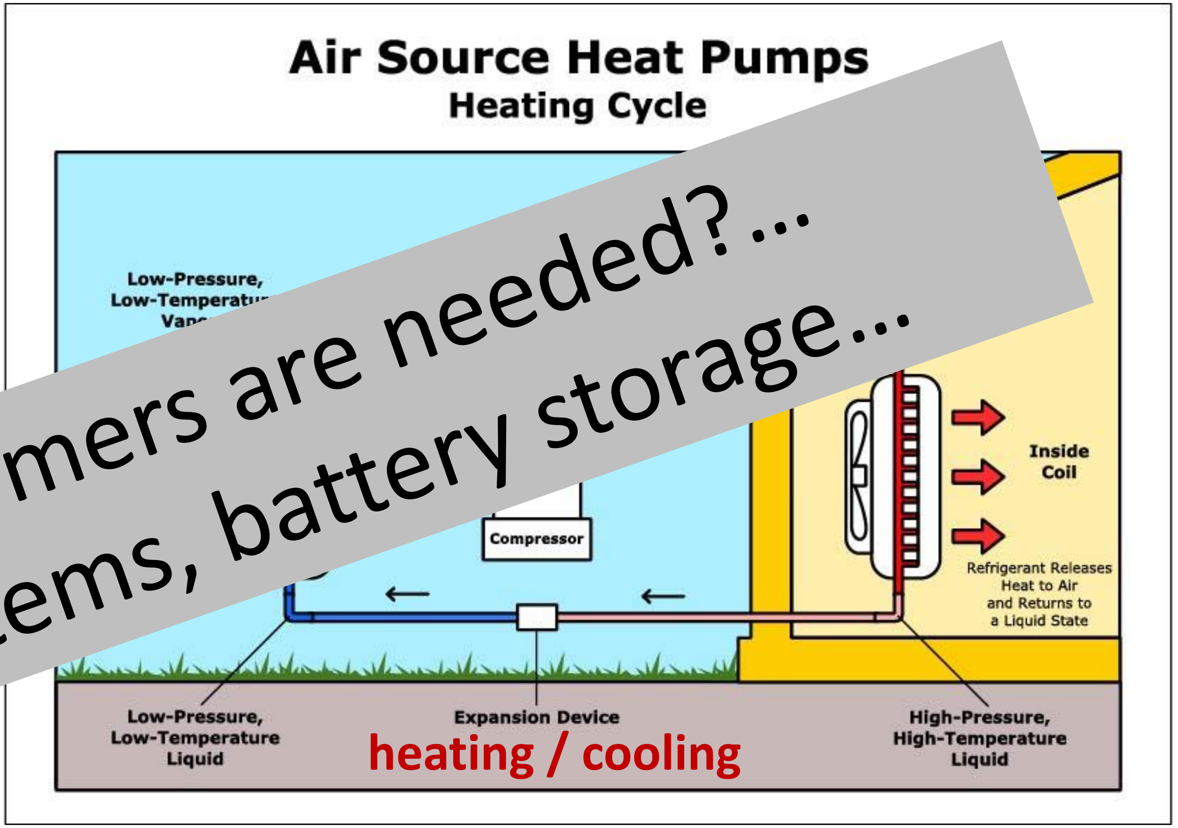
…in that case additional **1,000,000** new transformers must be installed…

...re
...dwide,
... a capacity of
390 GW covering
ca. 10% of the
world's energy
demand
of 24,000TWh.

To rep... the nuclear energy by wind and solar energy the already installed base must be doubled !

Energy (R)evolution

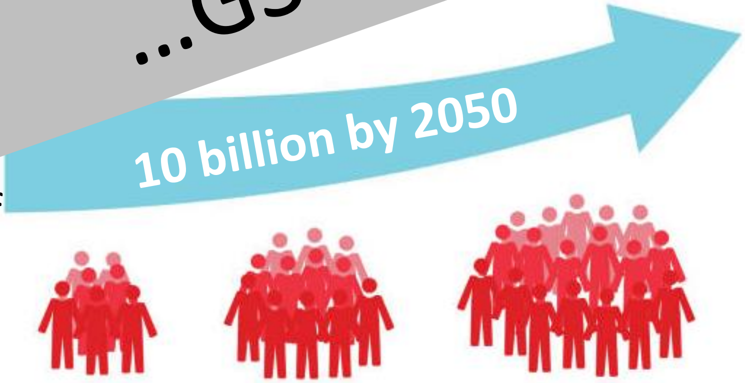
Decarbonisation of the energy economy



…how many transformers are needed? …

…GSUs, charging systems, battery storage…

Around 200,000 heat pumps installed in UK homes since 2000, and around 27,000 are currently being installed each year (2021). Government pledge to install 600,000 heat pumps in homes per year by 2028. [1,2]



Electrification of Africa, Asia, South America

1. https://www.homebuilding.co.uk/news/demand-for-heat-pumps-has-surged-by-28
2. https://www.homebuilding.co.uk/news/heat-pump-sales-in-the-uk-set-to-double-in-2021 accessed 3/2/23

Potential Energy Savings per household

Household Electricity Survey. A study of domestic electrical product usage

- in England, the total potential annual electricity saving per household ranges from 491 kWh to 677 kWh depending on the type of household;
- this total potential electricity saving is a minimum value because lighting savings are underestimated;
- the priority actions that should be carried out for demand side management (DSM) concern cold appliances, lighting, audiovisual sites and computer sites:
  - **replacing the inefficient cold appliances with the most efficient models could save up to 358 kWh/year per household;**
  - **choosing a laptop instead of a desktop and reducing standby consumption could save up to 128 kWh/year for the computer site;**
  - **using only audiovisual appliances with a standby power of less than 0.5 W could reduce this consumption of this type of appliance by 111 kWh/year.**

Intertek report R66141 Final Report Issue 4 Household Electricity Survey A study of domestic electrical product usage, May 2012

Energy (R)evolution - decarbonisation

The share of electricity in final energy demand is likely to increase from about 20% today to about 70% by mid-century. To meet this demand, the size of the global power system should be multiplied by 3.5-5, while also shifting entirely to zero-carbon power sources. How can this be achieved in 30 years? In addition, electricity will be used to produce hydrogen, which could be the second biggest form of final energy consumed globally, and hydrogen-based fuels (ammonia, synthetic fuels) to be used in long-distance shipping and aviation.

https://www.energy-transitions.org/energy/electricity/ accessed 28/1/23

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Decarbonisation – electric vehicles

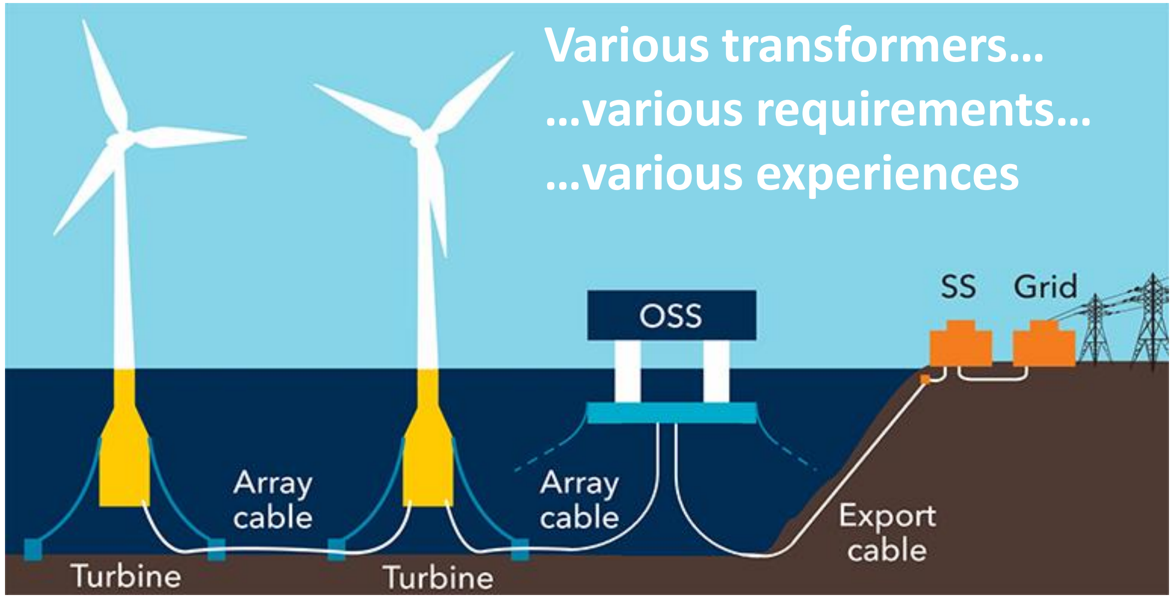
Sandia Lab Studies Vulnerabilities of Electric Vehicle Charging Infrastructure – T&D World

- If roughly half of Americans will have an electric car in less than 30 years as experts predict, that means roughly half of U.S. households will undoubtedly charge these cars at home, doubling their load on regional electric grids. Utilities will not only have to contend with energy supply concerns, but also distribution challenges through their already congested network circuits. A surge in demand in a busy circuit could cause it to overload, wiping out power in an entire neighborhood—or worse.

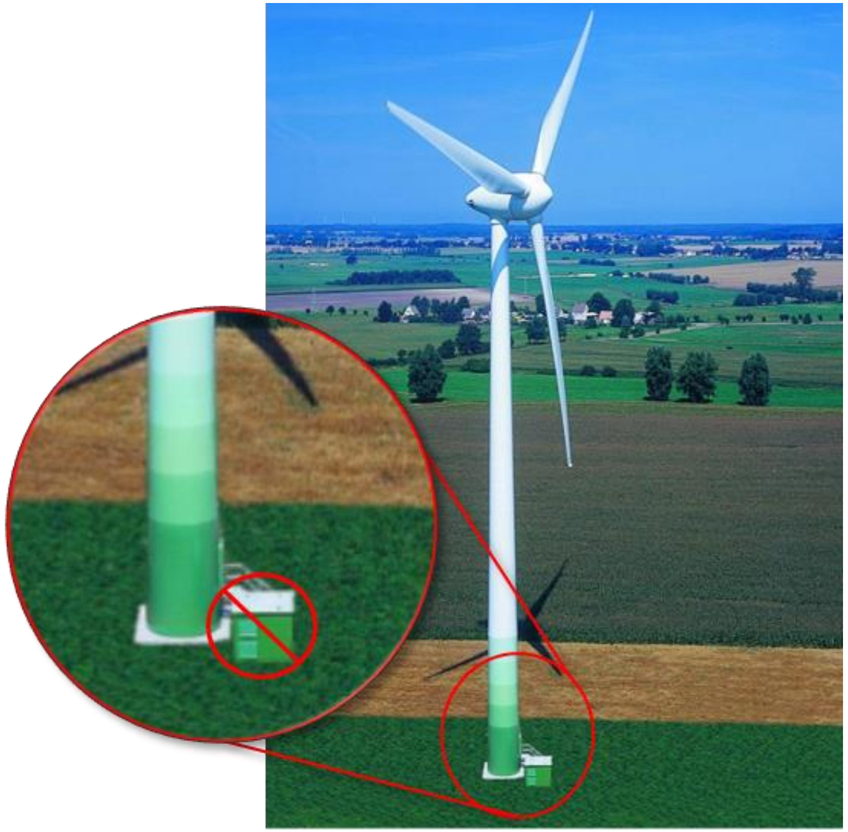
https://www.tdworld.com/electrification/article/21255634/sandia-studies-vulnerabilities-of-electric-vehicle-charging-infrastructure?utm_source=TW+TDW+Distributed+Energy+Resources&utm_medium=email&utm_campaign=CPS221204004&o_eid=3601D2298456F1H&rdx.ident[pull]=omeda|3601D2298456F1H&oly_enc_id=3601D2298456F1H
Accessed 3/2/2023

Applications

- Installation and handling



Applications



Even for one application
…different challenges
…different designs
…different insulation materials
...different reliability

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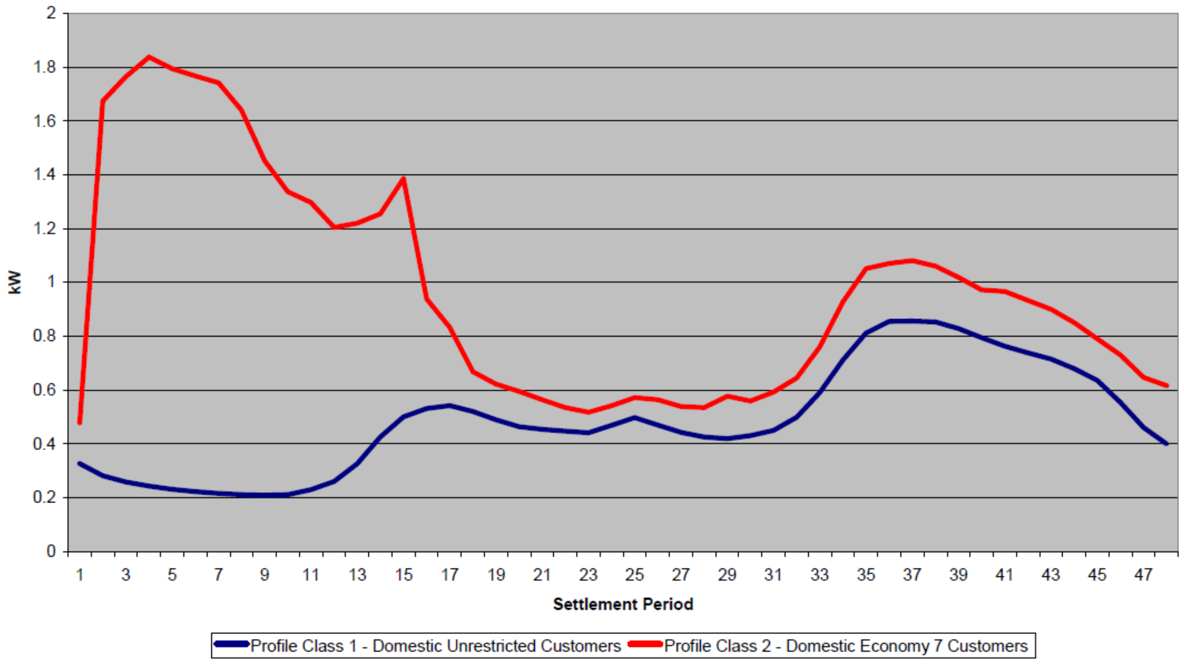
Let’s start at the beginning

Specification of transformers

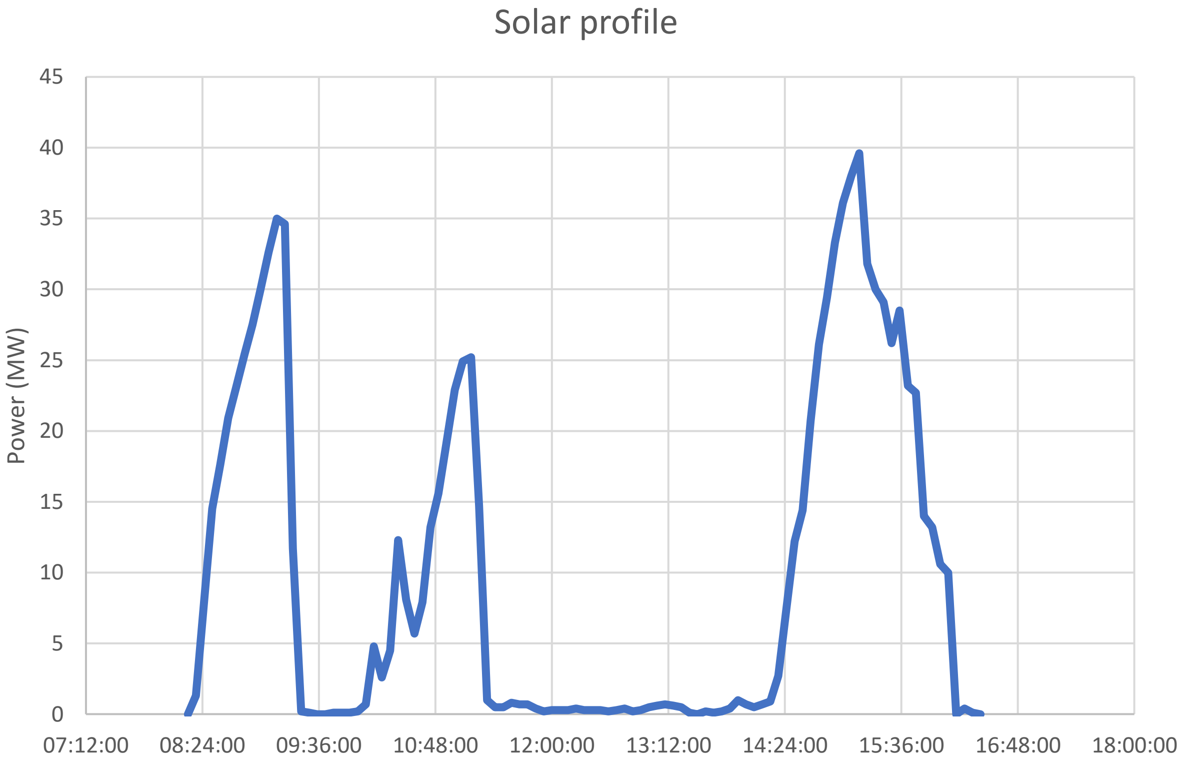
- Some companies which are specifying and installing equipment have no idea of the technical requirements
- IEC 60076-1, CIGRE TB 528 – a few requirements!
  - Any peculiarities of installation, assembly, transport and handling. Restrictions on dimensions and mass.
  - Unusual service conditions
  - Whether a transformer is to be connected to a generator directly or through switchgear, and whether it will be subjected to load rejection conditions and any special load rejection conditions
  - Details of intended regular cyclic overloading
  - Loads involving abnormal harmonic currents such as those that may result where appreciable load currents are controlled by solid-state or similar devices
  - Regular frequent energisation in excess of 24 times per year

Typical load curves



Typical household loading
Red = economy 7
Blue = non-restricted

Solar power availability, New York, 1 January 2006



https://data.ukedc.rl.ac.uk/browse/edc/efficiency/residential/LoadProfile/Load_Profiles.pdf Accessed 3/2/2023

https://www.nrel.gov/grid/solar-power-data.html
Accessed 2/2/2023

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Transformers for renewables

Specification of transformers

- Many of these are small transformers <10MVA, ≤33kV. Looked upon as "standard" transformers.
- Expectation - delivery time 2-3 months, "off the shelf". No recognition that these are bespoke products.
- System parameters – harmonics, DC bias, load – all have an effect
- Lack of information in specification, lack of knowledge about what is required.

Typical transformer specification

Item	Description	U	
1	A Brand New Step Up Transformer for SITE NAME - 1000 KVA 60 Hz, 480V/13.8KV		
2	A Brand New Step Up Transformer for SITE NAME - 1000 kVA 60 Hz, 2.4 KV/13.BKV		01

Further Details of both Transformers

-Hermetically sealed. Outdoor type, for grou

-Suitable for use in sandy desert cli 55°C

-Complete with skid under b UV radiation, temp, indicator, plugged --filling hole,

-drain valve and pl

-Color to b have an insulation level of not less than 33 kV.

Pr illed cable box, to be drilled on site for cable entries.

…standards, impedance, cooling/fluid type,…

…number of phases, tappings, connection symbol…

Earthing Transformers

Required in most instances where there is a delta-connected main transformer

- Traditionally, seen as providing an earth point on the delta and limiting the earth fault current on the system for single-phase-to-earth fault
- Nice-to-have 200kVA auxiliary (LV) winding for local supplies
- No particular positive sequence impedance requirements (2-5%)
  - Flexibility for manufacturer
- NOW…. Larger and larger auxiliary windings – up to 1000kVA
- Very specific positive sequence impedance with tight tolerances
- LV zero sequence impedance tightly specified to limit fault current
- Impedances related to physical dimensions – change one, change the other
- All requirements cannot always be met in one single transformer
  - Very difficult for manufacturer

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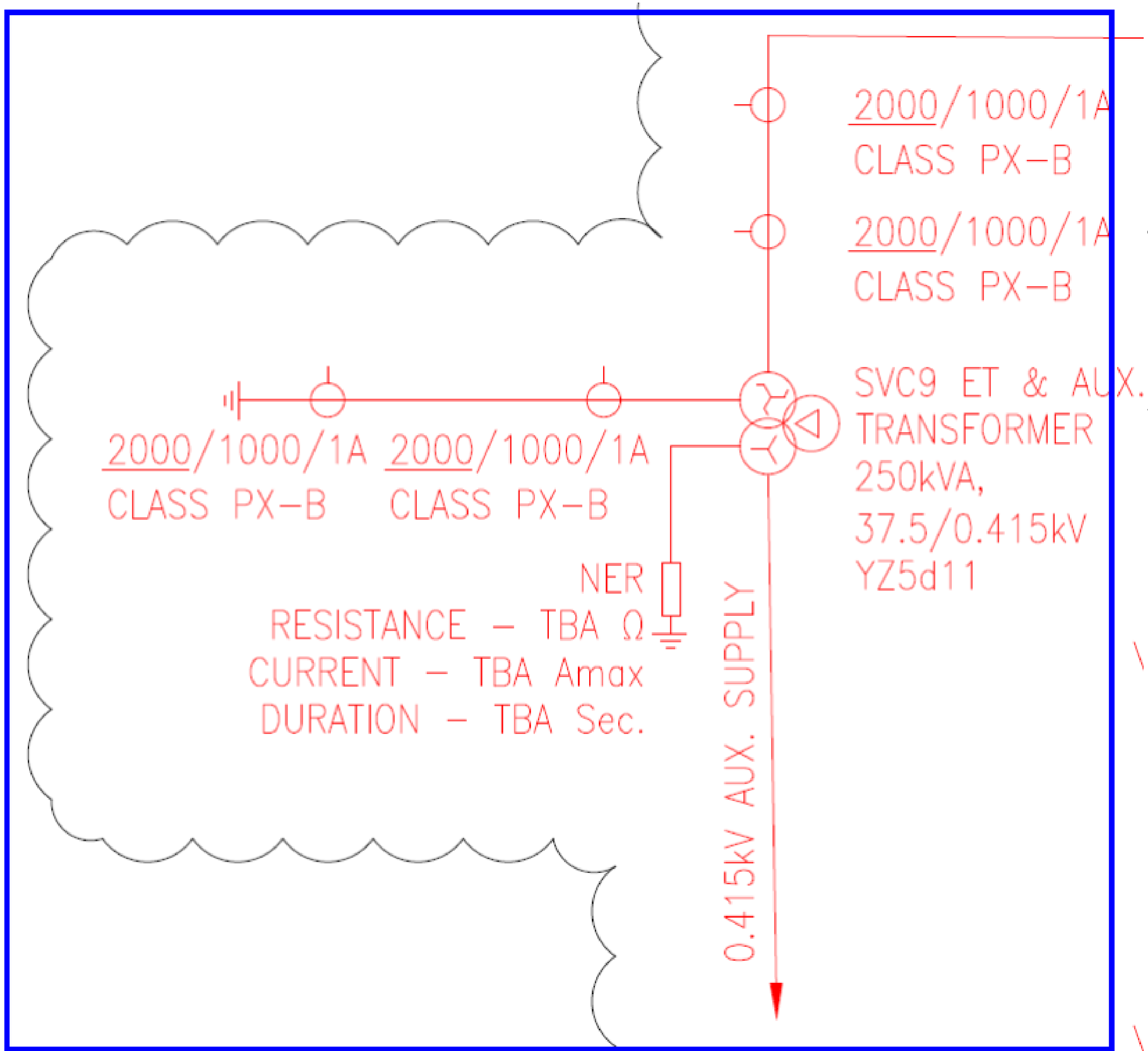
Typical transformer specification

Or lack of it….

What is the HV fault current limit and duration?

Is this NER to limit the LV fault current?



Class PX CTs – no details to be able to price these

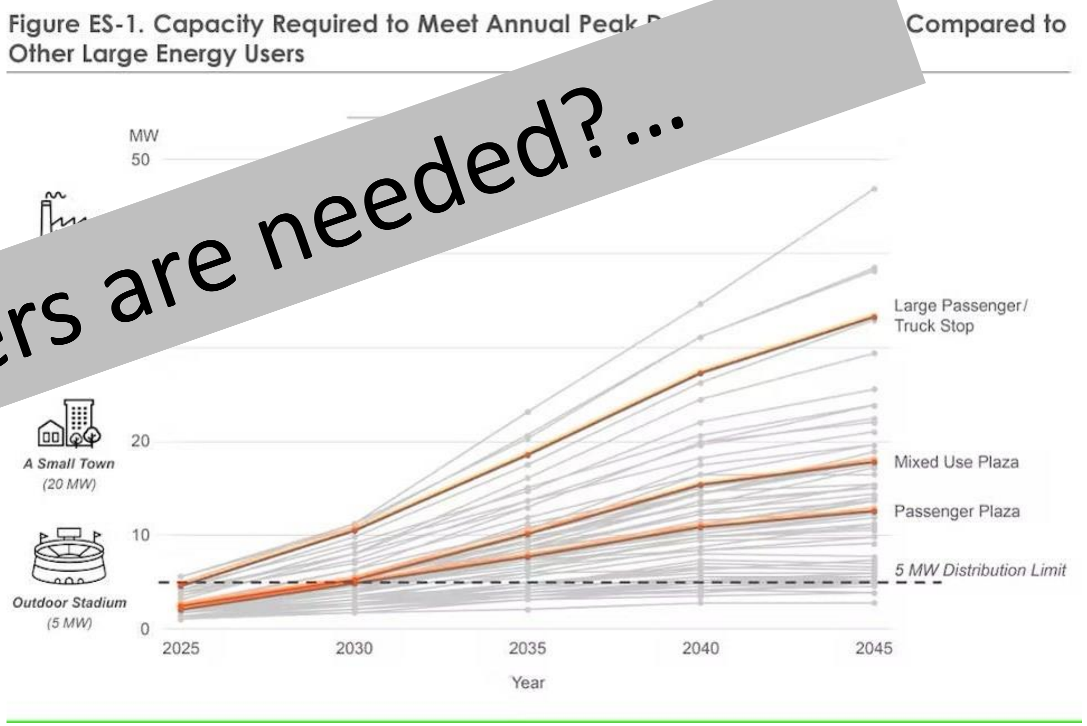
Vector group

ZNyn5+d

Load Growth

- Electrification in the global South
  - Demand for electricity in Africa, Asia, South America, etc.
- The share of electricity in final energy demand is likely to increase from about 20% today to about 70% by mid-century. T meet this demand, the size of the gl power system should be mu 5, while also shifting carbon power sources. be achieved in 30 yea
- El es – personal vehicles, light go ehicles, heavy goods vehicles
  - The charging capacity required to supply a large passenger vehicle travel center/truck stop site will be "roughly equivalent to the electric load of a small town."[2]

…how many transformers are needed?…



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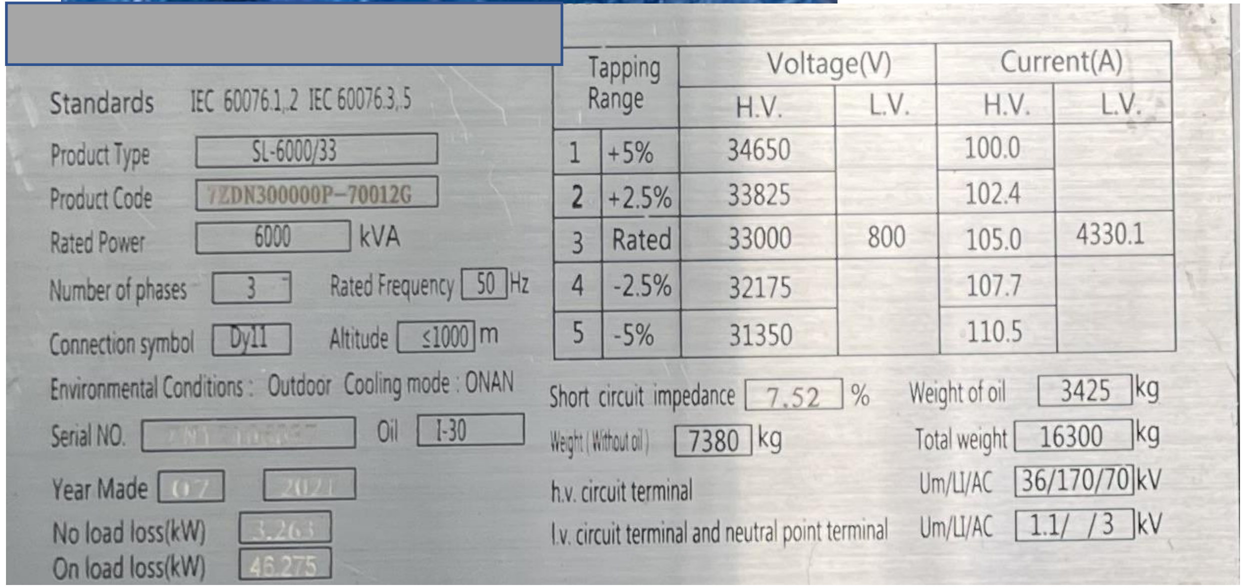
1. https://www.energy-transitions.org/energy/electricity/ accessed 28/1/23 https://www.tdworld.com/electrification/article/21255376/power-grid-is-not-prepared-for-electric-truck-avalanche accessed 3/2/2023

Manufacturing

Are suppliers providing good product?

- Low-cost product
  - Rust
  - Shotblast inside tank
  - Quality?
- CE (UKAS) marking
- TB530 - Guide for conducting factory capability assessment for power transformers



Photos courtesy of Ian Naylor, Andy Davies

Suitability for Service?

Photos courtesy of Ian Naylor

Installation of transformers

- Inside wind turbine tower, in nacelle, in enclosures, recessed into ground
  - Increased ambient temperature
  - Lack of ventilation
  - Access for maintenance
  - Type of fluid
  - Information on rating plates

Cooling fins

Drain plug for sampling

Edge of bund

Photos courtesy of Andy Davies

Is it Gas-to-liquid mineral oil or ester fluid?
No information on website!

???

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Possible causes of failure

- Poor specification, poor workmanship
- Installation in enclosed spaces - overheating, humidity
- Harmonics
- DC bias
- Load profile, sudden load changes
  - **Thermal and mechanical stress**
- Interaction with the system
  - **Connection by long cable, resonance**
- Frequent energization
  - **Inrush current**

WHAT COULD BE THE OUTCOME?

- We could have a large number of transformer failures in renewable energy installations in the next 7-10 years
- Those transformers may need to be replaced if the failure cannot be repaired
- There is already a long backlog in manufacturing of transformers and the number required in the near future for network growth (without replacement) could increase
- CIGRE can only do so much – technical investigation and recommendations
- There are more questions than answers…….

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Actions Needed

- Purchasers need to be made aware of the types of information required in specifications for transformers
- Purchasers also need to be made aware that these are not standard, off-the-shelf product
- Maintenance needs to be a factor taken into account from the project inception, not an afterthought
- Installers also need to know the requirements for cooling, maintenance, etc
- Is there a requirement for legislation?
  - **Does OFGEM need to have some input to the requirements?**
  - **Should the DNOs be more involved?**
  - **Database of "approved suppliers"?**
  - **Does the Government need to legislate?**
  - **Who would police it?**

Failure Survey

New working group A2.68

- AG2.08. Lower voltage transformers advisory group.
  - Perception that transformers used in renewable energy generation have higher failure rate than most transformers. Anecdotal evidence.
- Other issues discussed: new materials – liquid insulation, solid insulation, core materials, etc.
- Monitoring and diagnostics for liquid and dry transformers
- Design challenges for transformers for lower voltage applications
- Effect of harmonics and repetitive impulses superimposed on AC voltage in the insulation system of transformers
- Start with failure survey – get the facts. What are the most critical factors? Then look at the issues and recommend working groups around the main causes of failure.

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Failure Survey

Terms of Reference

Scope and aim

1. Design a questionnaire for getting data from wind and photovoltaic park operators taking into account different designs as well as insulating and feeding systems of installed GSUs considering the following CIGRÉ contributions:

   a. WG A2.62 Analysis of Transformer Reliability.

   b. A2 TBs 642 (Transformer Reliability Survey), 755 (Transformer Bushing Reliability) and 528 (Guide for Preparation of Specifications for PowerTransformers).

   c. An International Survey of Failures in Large Power Transformers in Service, Final Report of the CIGRÉ Working Group 12.05, Électra, 1983, Nr. 88, S. 21- 48.

   d. D1 TB 507 (Guidelines for the use of statistics and statistical tools on life data)

   e. Final Report of the 2004 - 2007 International Enquiry on Reliability of High Voltage Equipment (TBs 509 to 514).

2. Identify and convince operators all over the world to share their data from GSU failures and population information in wind and photovoltaic plants anonymously.

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Failure Survey

Terms of Reference

3. Analyze the gathered data in order to estimate failure rates for:
   - **a. applications in wind and photovoltaic parks**
   - **b. various key parameters like power and voltage class**
   - **c. different insulation systems (dry or liquid with different paper types)**
   - **d. different integration environments (e.g. where is the transformer installed, tower or nacelle of a wind turbine, onshore, offshore, climate-zone, how is the transformer fed)**
   - **e. additional design specialities**

4. Identify main failure root causes for different GSU technologies.

5. Provide information concerning how to identify failures in an early stage and how they might be avoided or which measures can be taken to improve the condition of the transformer.

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Failure Survey

Terms of Reference

6. Provide information concerning best practices of design of GSUs for future applications, or improved testing to demonstrate good performance.

7. Consider how these information can be transferred for transformer applications with similar operating conditions needed in the future, e.g. transformer for e-mobility (or other applications in the area of renewables like battery storage transformers), charging stations (highly fluctuating load), for which million units will be installed in the future. This can lead to avoid specific problems by optimizing the design for such systems based on the WG recommendations in advance, which will have an enormous impact.

8. Recommend to start additional working groups to analyze failure root causes in depth that appear more often in order to better understand the background and to develop more detailed recommendations.

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Conclusion

Renewables require millions of new transformers

Existing grid needs to be adapted accordingly

Many questions are still open

Requirements must be made more precise based on experiences

Experiences need to be collected, evaluated and communicated

New WG about failure survey on GSUs for renewables might lead to helpful information

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Thanks

For help in preparing this presentation

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- Janusz Szczechowski, secretary of CIGRE AG2.08
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- Ian Naylor, Threepwood Consulting Ltd

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Any questions?