Switching to something better?

A webinar about SF_6-alternatives and a Norwegian researcher's life and career

cigre

For power system expertise

Agenda

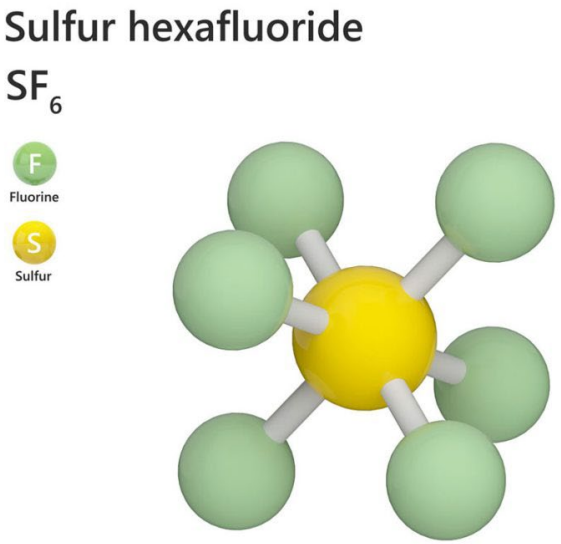
- A short introduction: Nina
- Growing up in a small town
- Moving to Trondheim
- What now?
- Finishing a PhD
- SINTEF Energy Research
- CIGRE
- Research projects: at work and at home
- A short introduction: SF_6
- A growing concern
- Moving to alternatives?
- The challenge of using another gas
- Did you say plus?
- Going higher!
- So many options!
- Restrictions and possibilities

A short introduction: Nina

- Nina Sasaki Støa-Aanensen
- Born in 1987
- Lives in Trondheim, Norway, with a husband and a dog
- Work as a Senior Research Scientist at SINTEF Energy Research
- Norwegian representative in CIGRE Study Committee A3

A short introduction: SF_6

- Sulphur Hexafluoride
- Sulphur: space for six friends
- Fluorine: the most electronegative element
- A “world champion” in:
  - Current interruption performance
  - Electric insulation performance
  - Stable and non-toxic
  - The ideal switchgear gas
  - Highest global warming potential per kg, 24 300 times higher than CO_2



A short introduction: SF_6

- 1980-1990s, SF_6 used for:
  - MV and HV switchgear
  - Cover gas for magnesium / metal industry
  - Window insulation gas
  - Military applications
  - Nike Air Max
  - Luxury car tyres
  - Medical use
- An example from Norway

Table 2: SF_6 consumption in Norway.

Consumers	SF_6 consumption 1990 (kg)	SF_6 consumption 1991 (kg)	SF_6 consumption 1992 (kg)	Estimated SF_6 consumption 1993 (kg)
Magnesium Industry	89 400	84 000	22 800	22 800
Aluminium industry	-	-	3 125	6 000
Secondary foundries	765	550	830	1 610
GIS 145 kV, 300 kV, and 420 kV installation	16 875	1 875	25 625	7 500
GIS 12 kV and 24kV installation	4 500	5 700	6 760	7 760
Sound insulating glass	*	300	700	500
TOTALT	111 540	92 425	59 840	46 170

* The consumption is not estimated.

Navy personnel launch a torpedo powered by SF_6 among other constituents.
Mass Communication Specialist Seaman Leah Allen

https://nilu.brage.unit.no/nilu-xmlui/bitstream/handle/11250/2717927/OR-15-93.pdf?sequence=1&isAllowed=y

Growing up in a small town: Farsund

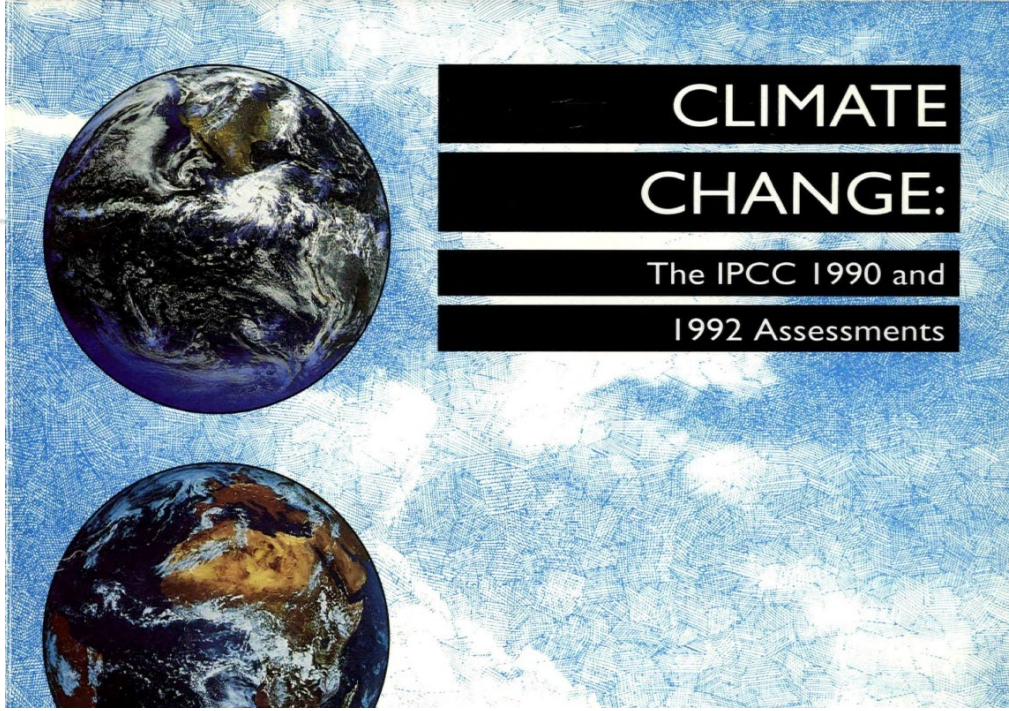
- About 10 000 people
- Peninsula at the south coast of Norway
- Lots of sandy beaches
- A lot of wind
- An aluminium smelter
- A pipe-coating facility

Growing up in a small town: Farsund

- Myself, an older sister and two parents
- Good at school
- Bad at sports
- Music (piano, choir, brass band)
- Wanted a dog, but never got one
- In the nerd category : P
- Enough good friends!
- 1987-2006

A growing concern around SF_6

- The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to provide policymakers with regular scientific assessments on the current state of knowledge about climate change.
- 1997: Kyoto protocol listed six greenhouse gases that we should limit emissions of to slow down global warming, SF_6 was one of them.
- 2006: First F-gas regulation passed in the EU, prohibited use of SF_6 for certain applications



Article 8

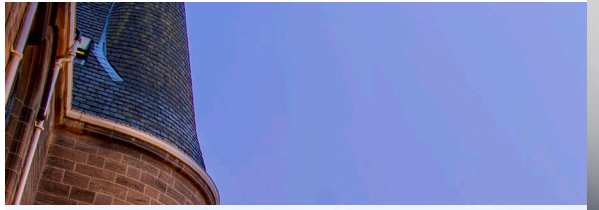
Control of use

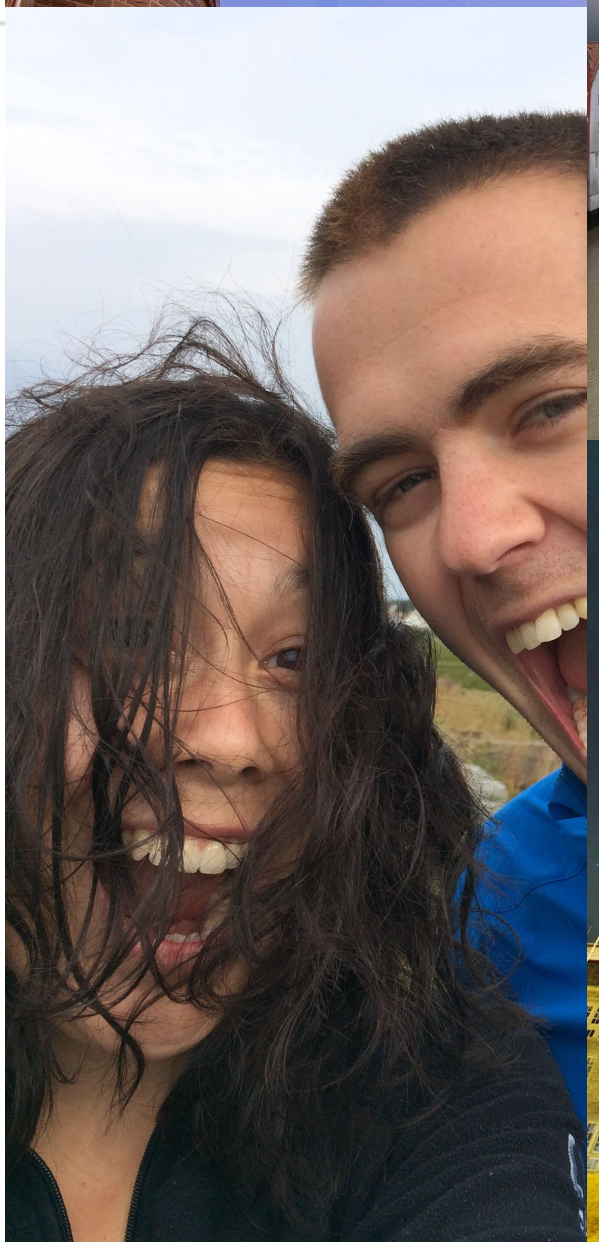
1. The use of sulphur hexafluoride or preparations thereof in magnesium die-casting, except where the quantity of sulphur hexafluoride used is below 850 kg per year, shall be prohibited from 1 January 2008.

2. The use of sulphur hexafluoride or preparations thereof for the filling of vehicle tyres shall be prohibited from 4 July 2007.

Moving to Trondheim

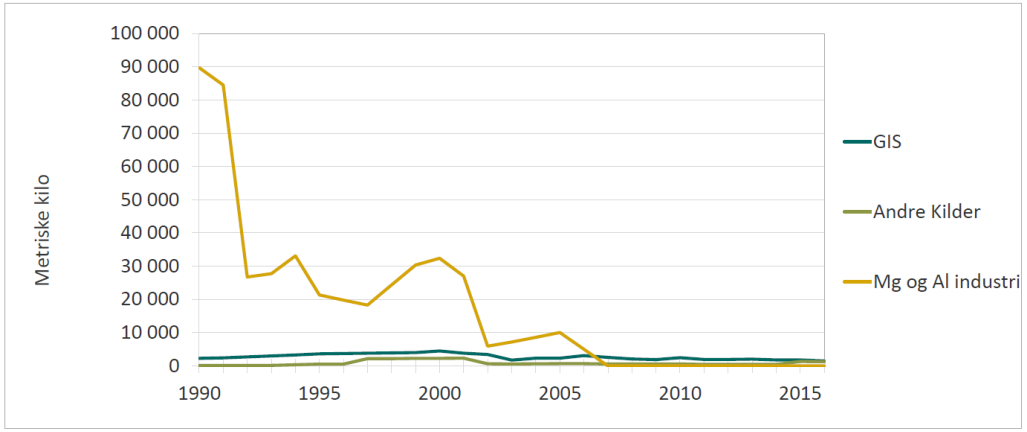
- From 10 000 -> 160 000
- From coast to river + fjord
- More snow, less light during winter (today 09:50-14:30)
- Norwegian University of Science and Technology
  - Norway's largest university, >43 000 students
- Master of Science: Applied Physics and Mathematics
- Lots of new friends, even a boyfriend?!
- A lot of things to learn
- Spent summers in Farsund, working at the aluminium smelter
- One semester in Glasgow, Scotland
- 2006-2011



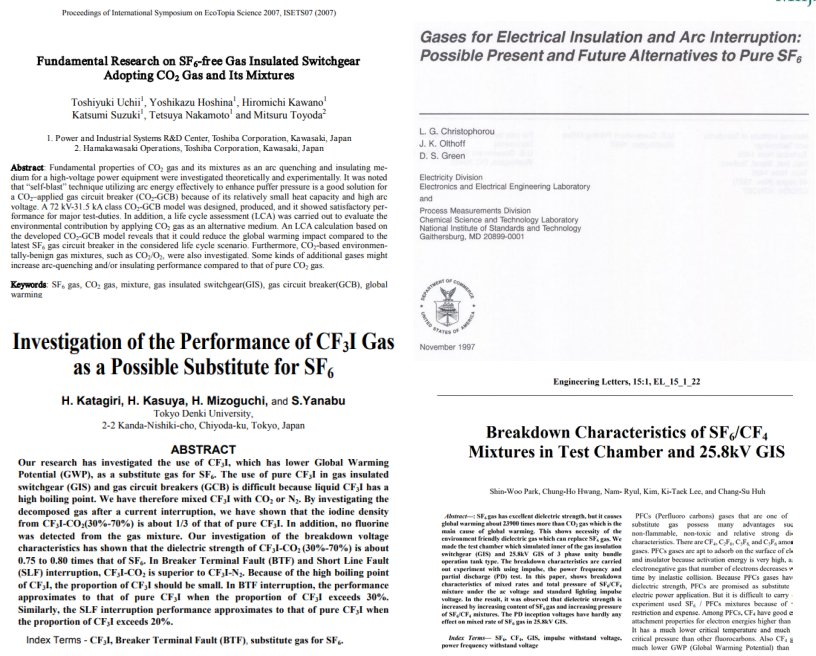


Moving to alternatives?

- The search for something better than SF_6 never stopped, but the Kyoto protocol accelerated the need and motivation to look for an alternative
- The global warming concern, and ban on other applications than in switchgear starts to show effects
- Papers exploring different alternatives (new and old) are regularly published
  - Pressurised air
  - Mixtures with SF_6
  - CF_4
  - CF_3I
  - CO_2
  - (Vacuum technology)
  - …



Miljødirektoratet.no



Proceedings of International Symposium on EcoTopia Science 2007, ISETS07 (2007)

Fundamental Research on SF_6-free Gas Insulated Switchgear Adopting CO_2 Gas and Its Mixtures

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1. Power and Industrial Systems R&D Center, Toshiba Corporation, Kawasaki, Japan
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Abstract: Fundamental properties of CO_2 gas and its mixtures as an arc quenching and insulating medium for a high-voltage power equipment were investigated theoretically and experimentally. It was noted that "self-blast" technique utilizing arc energy effectively to enhance puffer pressure is a good solution for a CO_2–applied gas circuit breaker (CO_2-GCB) because of its relatively small heat capacity and high arc voltage. A 72 kV-31.5 kA class CO_2-GCB model was designed, produced, and it showed satisfactory performance for major test-duties. In addition, a life cycle assessment (LCA) was carried out to evaluate the environmental contribution by applying CO_2 gas as an alternative medium. An LCA calculation based on the developed CO_2-GCB model reveals that it could reduce the global warming impact compared to the latest SF_6 gas circuit breaker in the considered life cycle scenario. Furthermore, CO_2-based environmentally-benign gas mixtures, such as CO_2-O_2, were also investigated. Some kinds of additional gases might increase arc-quenching and/or insulating performance compared to that of pure CO_2 gas.

Keywords: SF_6 gas, CO_2 gas, mixture, gas insulated switchgear(GIS), gas circuit breaker(GCB), global warming

Investigation of the Performance of CF_3I Gas as a Possible Substitute for SF_6

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ABSTRACT

Our research has investigated the use of CF_3I, which has lower Global Warming Potential (GWP), as a substitute gas for SF_6. The use of pure CF_3I in gas insulated switchgear (GIS) and gas circuit breakers (GCB) is difficult because liquid CF_3I has a high boiling point. We have therefore mixed CF_3I with CO_2 or N_2. By investigating the decomposed gas after a current interruption, we have shown that the iodine density from CF_3I-CO_2(30%-70%) is about 1/3 of that of pure CF_3I. In addition, no fluorine was detected from the gas mixture. Our investigation of the breakdown voltage characteristics has shown that the dielectric strength of CF_3I-CO_2 (30%-70%) is about 0.75 to 0.80 times that of SF_6. In Breaker Terminal Fault (BTF) and Short Line Fault (SLF) interruption, CF_3I-CO_2 is superior to CF_3I-N_2. Because of the high boiling point of CF_3I, the proportion of CF_3I should be small. In BTF interruption, the performance approximates to that of pure CF_3I when the proportion of CF_3I exceeds 30%. Similarly, the SLF interruption performance approximates to that of pure CF_3I when the proportion of CF_3I exceeds 20%.

Index Terms - **CF_3I, Breaker Terminal Fault (BTF), substitute gas for SF_6.**

Gases for Electrical Insulation and Arc Interruption: Possible Present and Future Alternatives to Pure SF_6

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November 1997

Engineering Letters, 15:1, EL_15_1_22

Breakdown Characteristics of SF_6/CF_4 Mixtures in Test Chamber and 25.8kV GIS

Shin-Woo Park, Chung-Ho Hwang, Nam- Ryul, Kim, Ki-Taek Lee, and Chang-Su Huh

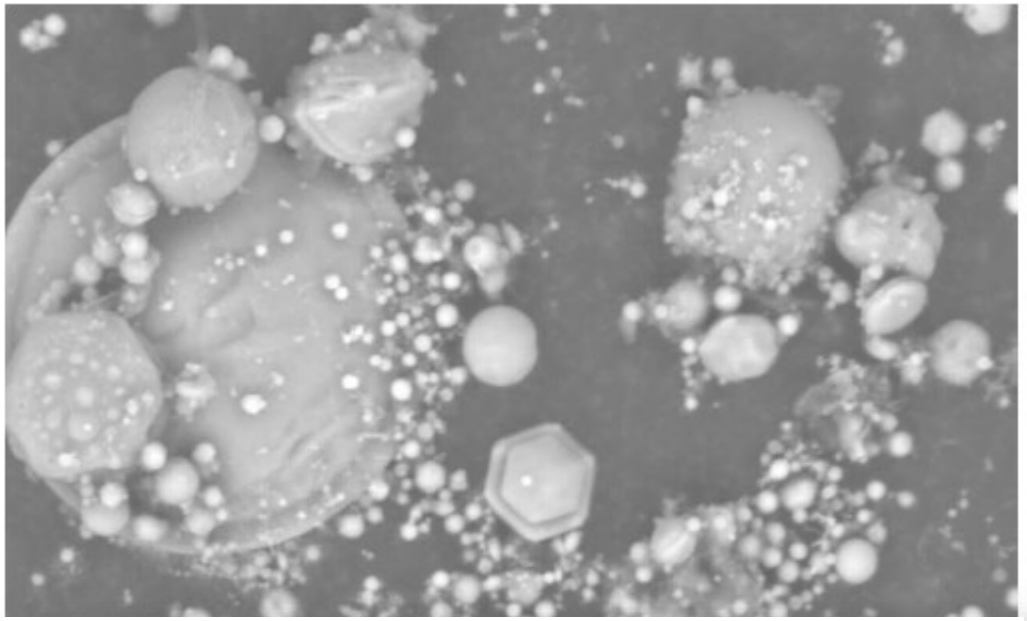
Abstract— SF_6 gas has excellent dielectric strength, but it causes global warming about 23900 times more than CO_2 gas which is the main cause of global warming. This shows necessity of the environment friendly dielectric gas which can replace SF_6 gas. We made the test chamber which simulated inner of the gas insulation switchgear (GIS) and 25.8kV GIS of 3 phase unity bundle operation tank type. The breakdown characteristics are carried out experiment with using impulse, the power frequency and partial discharge (PD) test. In this paper, shows breakdown characteristics of mixed rates and total pressure of SF_6/CF_4 mixture under the ac voltage and standard lighting impulse voltage. In the result, it was observed that dielectric strength is increased by increasing content of SF_6 gas and increasing pressure of SF_6/CF_4 mixtures. The PD inception voltages have hardly any effect on mixed rate of SF_6 gas in 25.8kV GIS.

Index Terms— SF_6, CF_4, GIS, impulse withstand voltage, power frequency withstand voltage

PFCs (Perfluoro carbons) gases that are one of substitute gas possess many advantages su non-flammable, non-toxic and relative strong di characteristics. There are CF_4, C_2F_6, C_3F_8 and C_4F_8 amon gases. PFCs gases are apt to adsorb on the surface of el and insulator because activation energy is very high, a electronegative gas that number of electrons decreases o time by inelastic collision. Because PFCs gases hav dielectric strength, PFCs are promised as substitute electric power application. But it is difficult to carry experiment used SF_6 / PFCs mixtures because of restriction and expensie. Among PFCs, CF_4 have good a attachment properties for electron energies higher than It has a much lower critical temperature and much critical pressure than other fluorocarbons. Also CF_4 g much lower GWP (Global Warming Potential) than

MSc: Check! What now?

- A bit of everything, but not a lot of one thing in particular
- Project work: Identifying by-products from a new method of producing aluminium
- Master thesis work: Non-linear laser-induced deformations at liquid-liquid interfaces
- Is this useful in the real world?
- But then, I found a PhD position
- 2011-2015

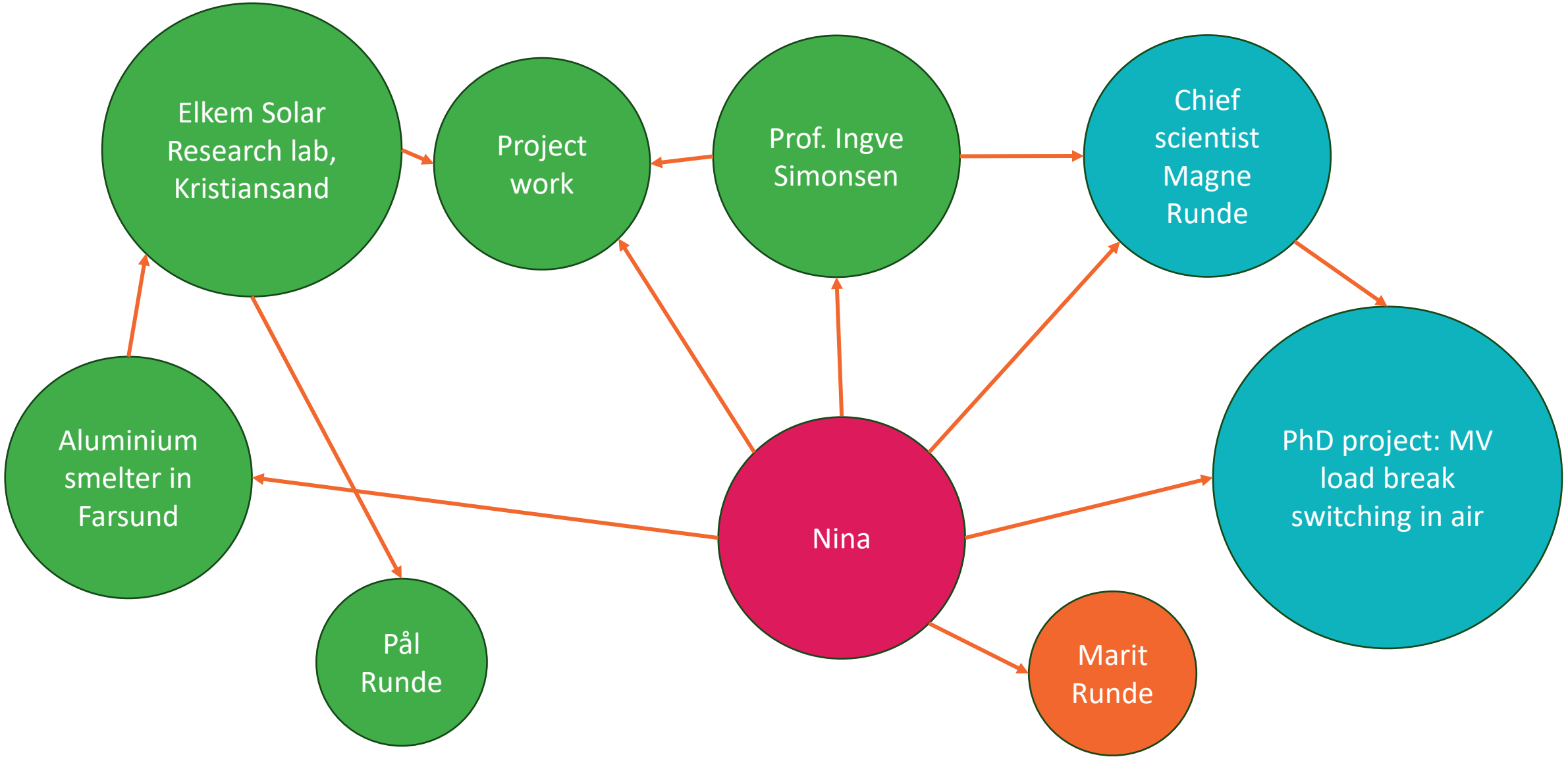


NTNU
Norwegian University of Science and Technology

Nonlinear Laser-induced Deformations and Forces at Liquid-Liquid Interfaces near the critical Point.

Nina Sasaki Aanensen

MSc: Check! What now? (a digression on how small Norway is)

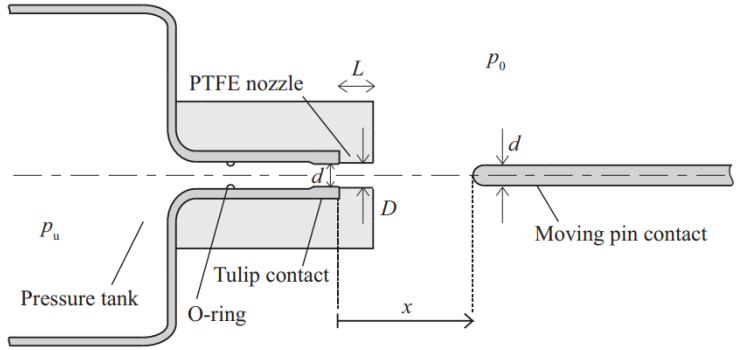


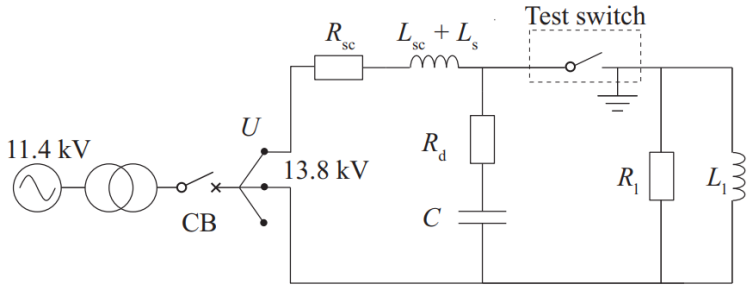
The challenge of using another gas: Is there something better?

- A lot of gases are more environmentally-friendly than SF_6
- But an alternative should also be:
  - A good electric insulator
  - A good electric arc quencher
  - A good heat conductor
  - Stable, non-toxic, non-flammable
  - A gas in the range -40°C – +50°C
  - Scalable up to high voltages
  - +++
- If not taking GWP into account:
  - No gas or gas mixture gets as good overall score as SF_6
- Air: about 30-40% the performance of SF_6
  - Everything else needs to be optimised

The challenge of using another gas: Is there something better?

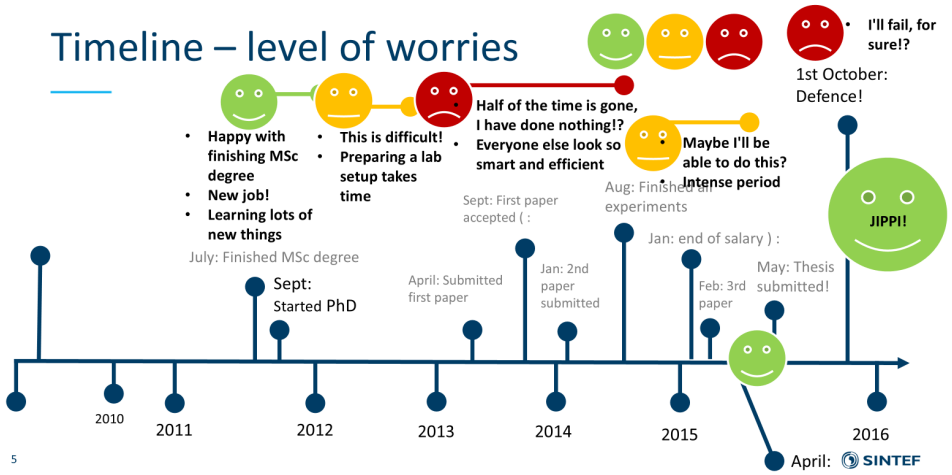
- My PhD work: Investigate design parameters that influence the interruption capability:
  - Nozzle width and length
  - Contact size
  - Over-pressure (and gas flow) vs current
- Experimental work in a single-phase directly powered MV lab in Trondheim
- Not so many females in this field?
  - Have to document it!?





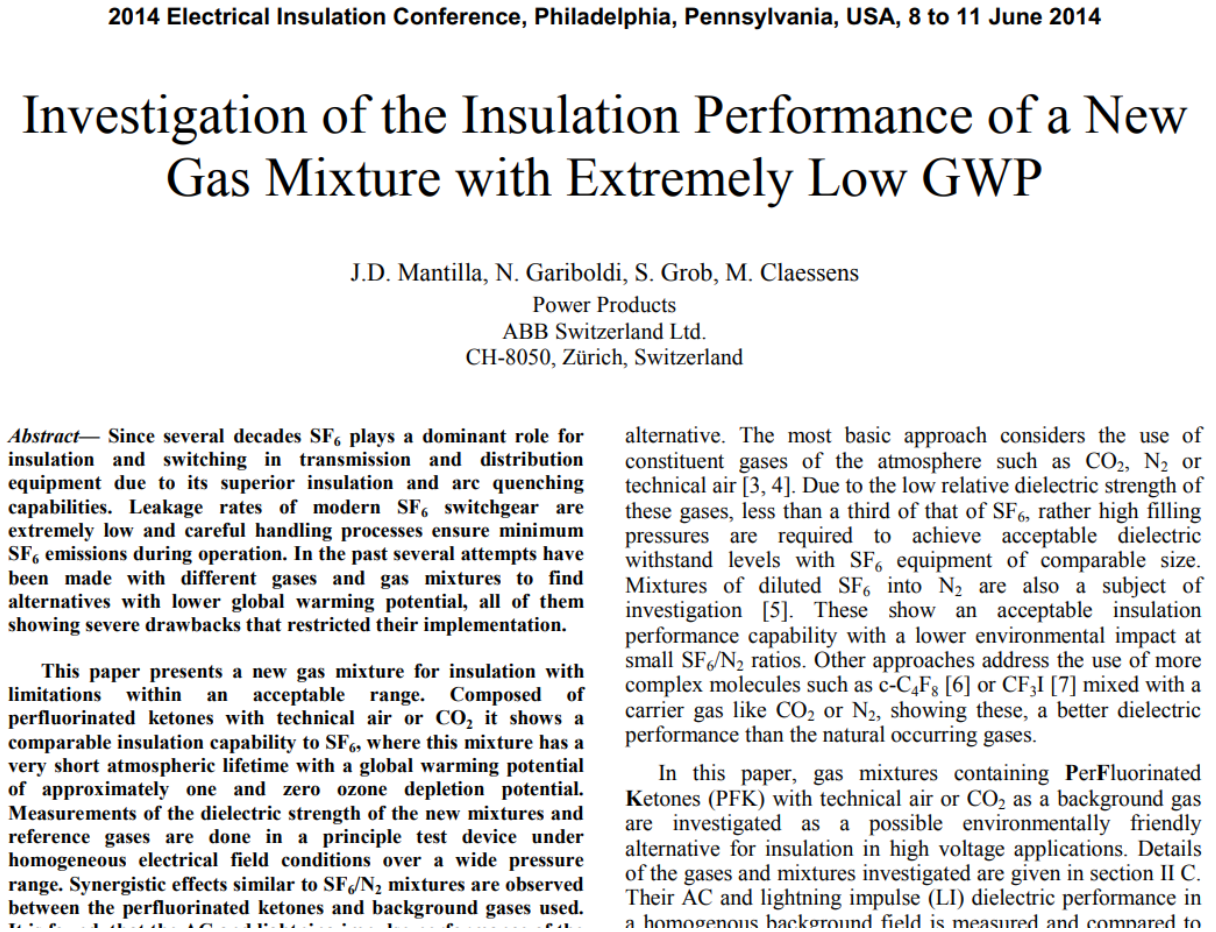
Finishing a PhD

- Working on a PhD can involve some mixed feelings
- Worked on one topic for many years: But still so much you don't know!
- Feeling of "nothing surprising was uncovered"
- And still: What can this be used for?
- Despite all this: Finishing a PhD is a great feeling!
- And: I was lucky enough to get a job at SINTEF Energy Research, where I could continue with research within my topic!
- (Still lack of females)



A PhD on current interruption in air, but did you say plus?

- In one of my last PhD project meetings with ABB, they mentioned that they were considering something else than just technical air : P
  - AirPlus: Technical air with a dash of C5-fluoroketone
- From 2014, papers on new synthetic molecules for switchgear were published



2014 Electrical Insulation Conference, Philadelphia, Pennsylvania, USA, 8 to 11 June 2014

Investigation of the Insulation Performance of a New Gas Mixture with Extremely Low GWP

J.D. Mantilla, N. Gariboldi, S. Grob, M. Claessens
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CH-8050, Zürich, Switzerland

***Abstract*— Since several decades SF_6 plays a dominant role for insulation and switching in transmission and distribution equipment due to its superior insulation and arc quenching capabilities. Leakage rates of modern SF_6 switchgear are extremely low and careful handling processes ensure minimum SF_6 emissions during operation. In the past several attempts have been made with different gases and gas mixtures to find alternatives with lower global warming potential, all of them showing severe drawbacks that restricted their implementation.**

This paper presents a new gas mixture for insulation with limitations within an acceptable range. Composed of perfluorinated ketones with technical air or CO_2 it shows a comparable insulation capability to SF_6, where this mixture has a very short atmospheric lifetime with a global warming potential of approximately one and zero ozone depletion potential. Measurements of the dielectric strength of the new mixtures and reference gases are done in a principle test device under homogeneous electrical field conditions over a wide pressure range. Synergistic effects similar to SF_6/N_2 mixtures are observed between the perfluorinated ketones and background gases used.

alternative. The most basic approach considers the use of constituent gases of the atmosphere such as CO_2, N_2 or technical air [3, 4]. Due to the low relative dielectric strength of these gases, less than a third of that of SF_6, rather high filling pressures are required to achieve acceptable dielectric withstand levels with SF_6 equipment of comparable size. Mixtures of diluted SF_6 into N_2 are also a subject of investigation [5]. These show an acceptable insulation performance capability with a lower environmental impact at small SF_6/N_2 ratios. Other approaches address the use of more complex molecules such as c-C_4F_8 [6] or CF_3I [7] mixed with a carrier gas like CO_2 or N_2, showing these, a better dielectric performance than the natural occurring gases.

In this paper, gas mixtures containing **PerF**luorinated **K**etones (PFK) with technical air or CO_2 as a background gas are investigated as a possible environmentally friendly alternative for insulation in high voltage applications. Details of the gases and mixtures investigated are given in section II C. Their AC and lightning impulse (LI) dielectric performance in a homogenous background field is measured and compared to

Working for SINTEF Energy Research (since April 2015)

- Continued research projects with on MV (and later HV) switchgear
  - On current interruption
  - Short-circuit making
  - Dielectric design
- Building test setups, performing experiments, setting up budgets, writing applications, co-supervising students at NTNU, learning a bit more fluid simulations, writing reports and papers, project managing, presenting research, talking to partners, +++
- Still a lot to learn!

So many options!

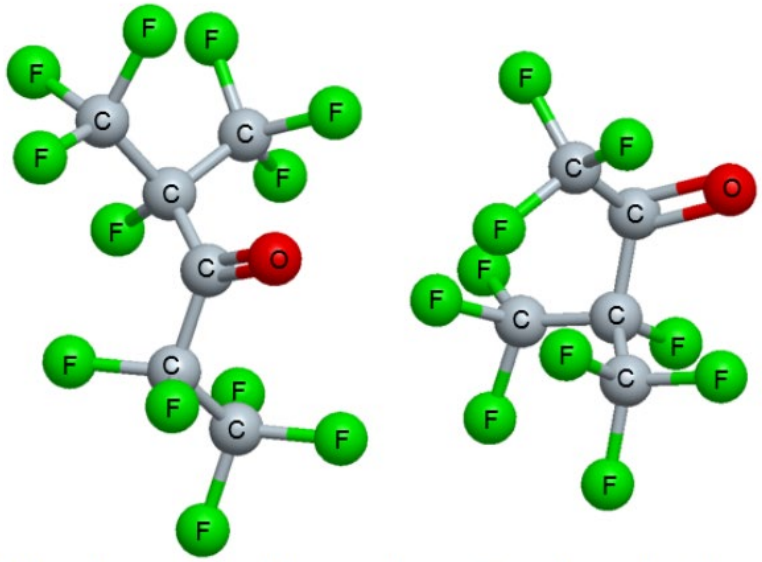

Figure 3. Molecular model of the two investigated perfluorinated ketones $C_6F_{12}O$ (left) and $C_5F_{10}O$ (right)

HFO1234zeE

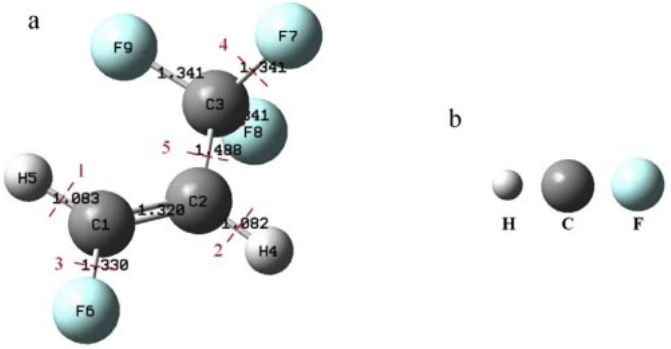

Fig. 5. Schematic diagram of Molecular structure: (a) HFO and (b) Atom involved later.

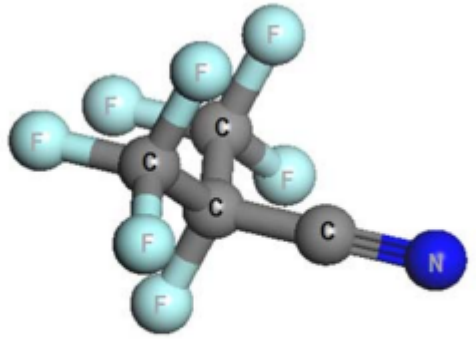

Figure 1. Molecular structure of the Novec™ 4710, 2,3,3,3-tetrafluoro-2-(trifluoromethyl) propanenitrile.

SF_6 Alternative Development for High Voltage Switchgears

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Todd IRWIN

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Charleroi, PA, USA

***Abstract*— The modern transmission and distribution network relies on SF_6 technology because of its remarkable arc quenching properties and dielectric insulation (approximately 3 times greater than air). However, even if SF_6 Switchgears are safe for the environment, the SF_6 insulating gas has potential significant environmental impacts if it leaks into the atmosphere. Indeed SF_6 is one of the six gases listed in the Kyoto Protocol, with a global warming potential that is 23500 times greater than CO_2.**

Alternative solutions to SF_6 have been researched for a long time. Up to now, no significant success has been achieved in solutions for the transmission network. This paper presents the research conducted with fluorinated compounds to qualify a new gas to be used into high voltage equipment as SF_6 alternatives with properties significantly improved with respect to typical SF_6/N_2 mixtures or others already in use.

Nevertheless, SF_6 has the major drawback of presenting a global warming potential (GWP) of 23500 (relative to CO_2 over 100 years), and it has a lifetime in the atmosphere of 3200 years, thus placing it amongst the gases presenting the most potent greenhouse effect [1]. Therefore, 1kg of SF6 released into the atmosphere has therefore the equivalent global warming impact as 23.5 tons of CO_2.

SF_6 was thus included by the Kyoto Protocol (1997) in the list of gases for which emissions need to be limited and the best way of limiting emissions of SF_6 consists in limiting the use of said gas, which has led industry to seek alternatives for SF_6.

II. EXISTING ALTERNATIVES

Research was done in past decades on substitutes to SF_6, covering different candidates including common gases (Nitrogen, air, CO_2), perfluorocarbons, and vacuum. All these

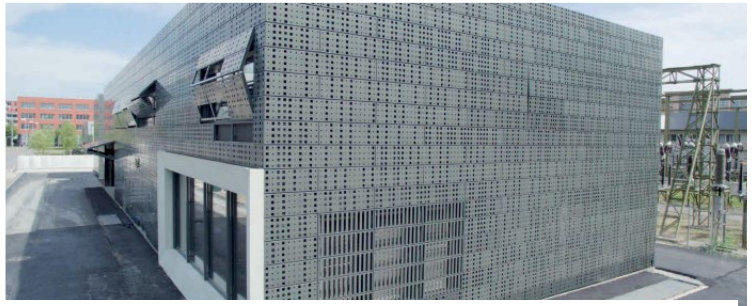
My introduction to CIGRE

- 2018: Magne Runde (my PhD supervisor, now my colleague) told me that I should travel to Paris as fast as I could
- Joined WG A3.41 (TB 871)
  - (I think they needed some females here as well)
- Later, became the Norwegian representative for SC A3
- Active in workshops and discussions related to SF_6-alternatives

Going higher!

- New SF_6-free switchgear launched every year
- Higher ratings
- More and more manufacturers
- More and more countries
- A lot of fancy names
- A lot of new knowledge to collect and compare
  - Good to have CIGRE!

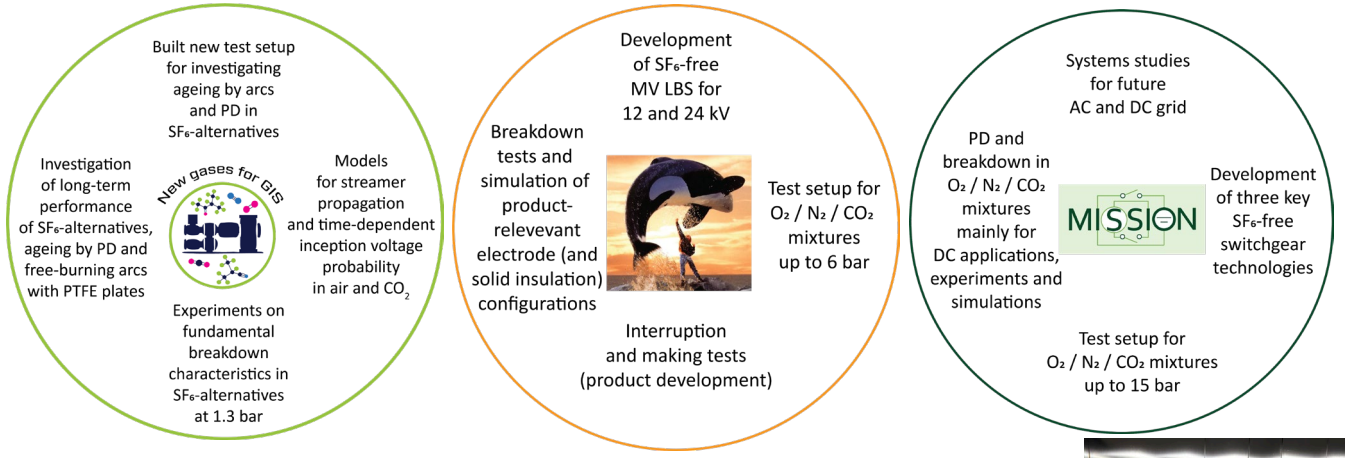
(a) 252kV VI (b) 252kV VCB



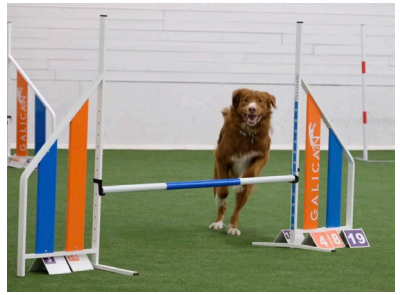
Hitachi Energy to provide world's first SF_6-free 420 kV gas-insulated switchgear technology at TenneT's grid connection in Germany

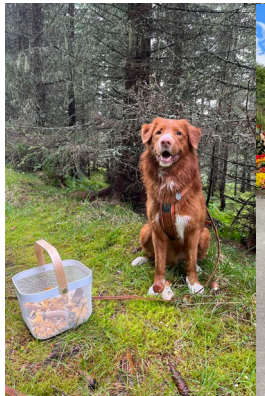
Research projects, at work and at home

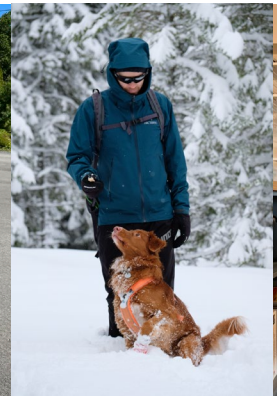
- Projects at work: direct projects with partners in Norway and abroad, Norwegian R&D projects, EU projects
- Side topics: Electrification of vessels, Senior safety representative
- At home: Dog training (a lot of research needed!), gardening, forest walks, friends and family



Sea Zero is designed to carry passengers and cargo VARD Design







Restrictions and possibilities

- Product development, marked requirements and political regulations still drive changes
- The transition to SF_6-free is far from over!

SF_6-alternatives

From a CIGRE colloquium in Birmingham 2023

Medium voltage (<52 kV)	High voltage (>52 kV)	
Switchgear medium (with / without vacuum)	**Interruption medium**	**Electric insulation**
N_2 / O_2 (or dry air)	CO_2 / O_2	CO_2 / O_2
C5-FK / O_2 / N_2	C4-FN / CO_2	C4-FN / CO_2
C4-FN / CO_2	C4-FN / CO_2 / O_2	C4-FN / CO_2 / O_2
N_2 / O_2 / CO_2	Vacuum technology	N_2 / O_2
		C4-FN / N_2 / O_2

- Other alternatives explored during the years, such as HFO-1234ze, C6-FK, and CF_3I
- Some variations in gas mixing ratios

SF_6-alternatives

Medium voltage (<52 kV)	High voltage (>52 kV)	
Switchgear medium (with / without vacuum)	**Interruption medium**	**Electric insulation**
N_2 / O_2 (or dry air)	CO_2 / O_2	CO_2 / O_2
N_2 / CO_2	C4-FN / CO_2	C4-FN / CO_2
N_2 / O_2 / CO_2	C4-FN / CO_2 / O_2	C4-FN / CO_2 / O_2
C4-FN / CO_2?	Vacuum technology	N_2 / O_2
		C4-FN / N_2 / O_2

- Other alternatives explored during the years, such as HFO-1234ze, C5-FK, C6-FK, C3F6O, and CF_3I
- Some variations in gas mixing ratios

Agenda: Check!

- A short introduction: Nina
- Growing up in a small town
- Moving to Trondheim
- What now?
- Finishing a PhD
- SINTEF Energy Research
- CIGRE
- Research projects: at work and at home

- A short introduction: SF_6
- A growing concern
- Moving to alternatives?
- The challenge of using another gas
- Did you say plus?
- Going higher!
- So many options!
- Restrictions and possibilities

So: are we switching to something better?

- I believe yes: because all released SF_6 will leave a permanent change in the atmosphere
- Still, the optimisation challenge is not completed yet, so we better keep working
- And, remember yourself in this “chaos”:
  - Make sure you actually like your job!
  - Make sure you have something that makes you curious and happy outside work!


Thank you so much for your attention!
cigre
For power system expertise