Feasibility of SF_6 Gas-Insulated Transformers

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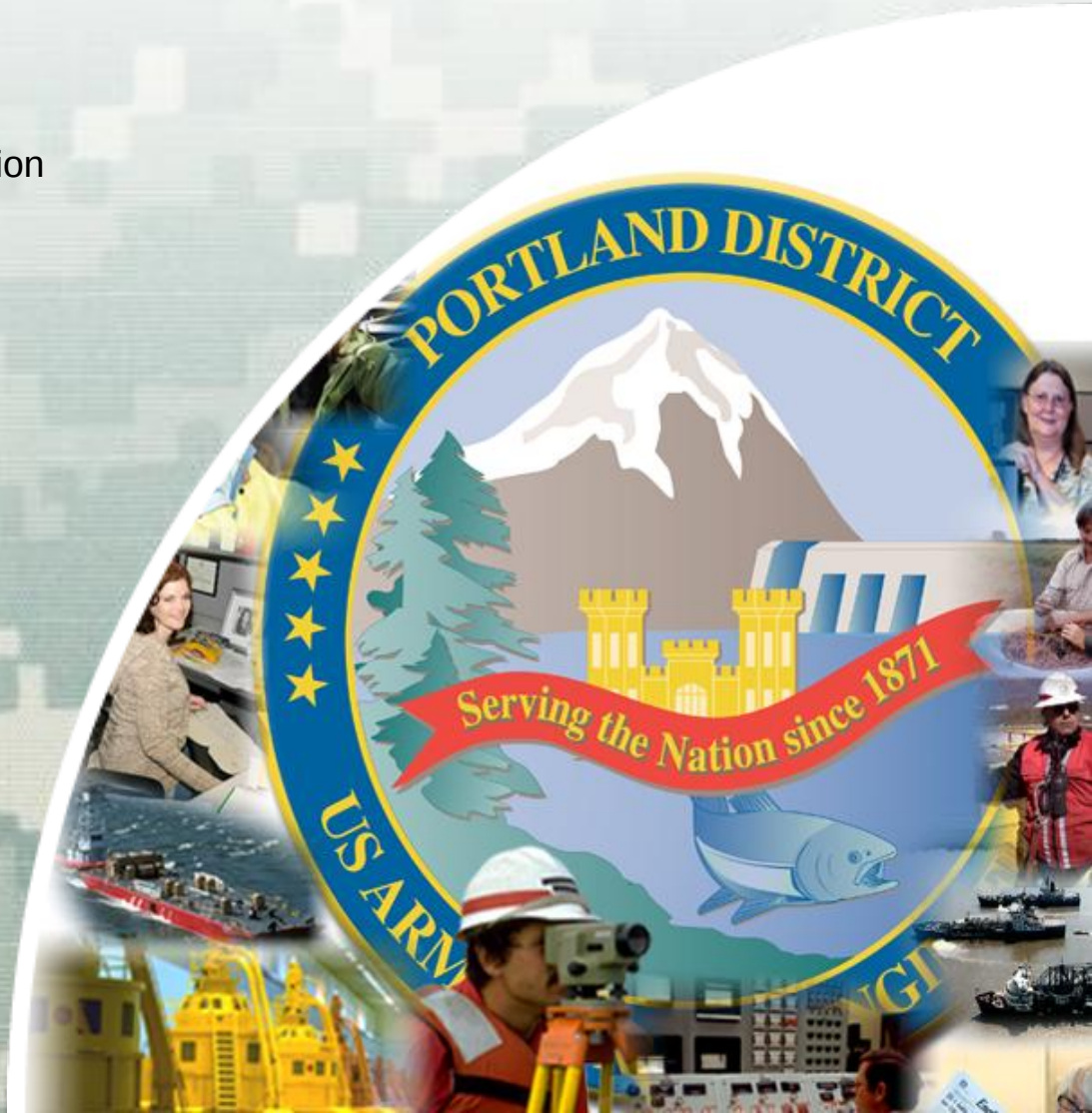

US Army Corps of Engineers

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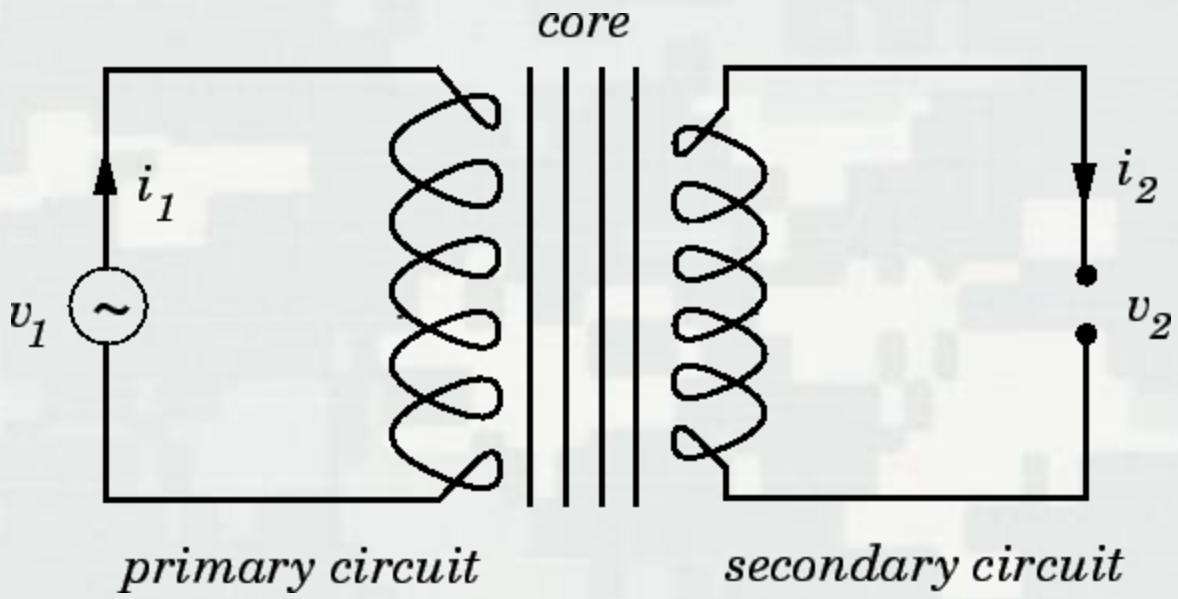
Outline

- Transformer Background & Basics
- Oil-filled transformers
- Oil-filled transformer concerns
- Gas-insulated transformers (GIT)
- Gas-insulated transformer benefits
- Gas-insulated transformer concerns
- Risks and Unknowns
- Questions?

Transformer Background & Basics

- Purpose of power transformers
  - Convert voltage from generator level, to distribution and transmission level, and back to utilization level
  - Using higher voltages decreases losses, which increases efficiency and revenue



Transformer Background & Basics

- History
  - First developed in the late 1800s
  - The transformer design used at most USACE projects was patented in 1887 by Westinghouse

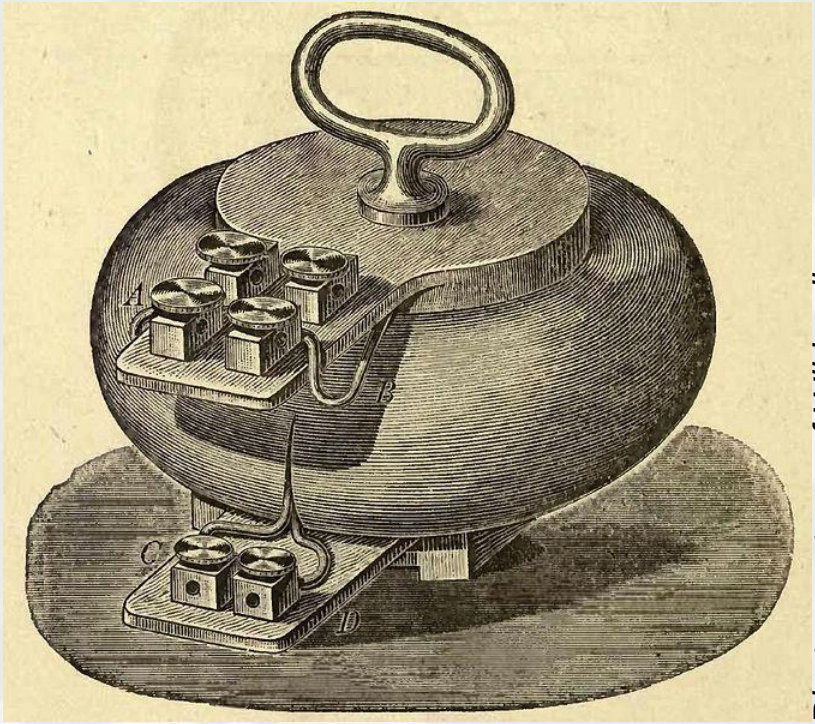


Photo courtesy of Wikipedia

Original 1885 transformer

Transformer Background & Basics

- Procurement lead times from time of PO
  - 24+ months in good economic times
  - Recent (not as good economic times) approximately 13 months

Transformer Background & Basics

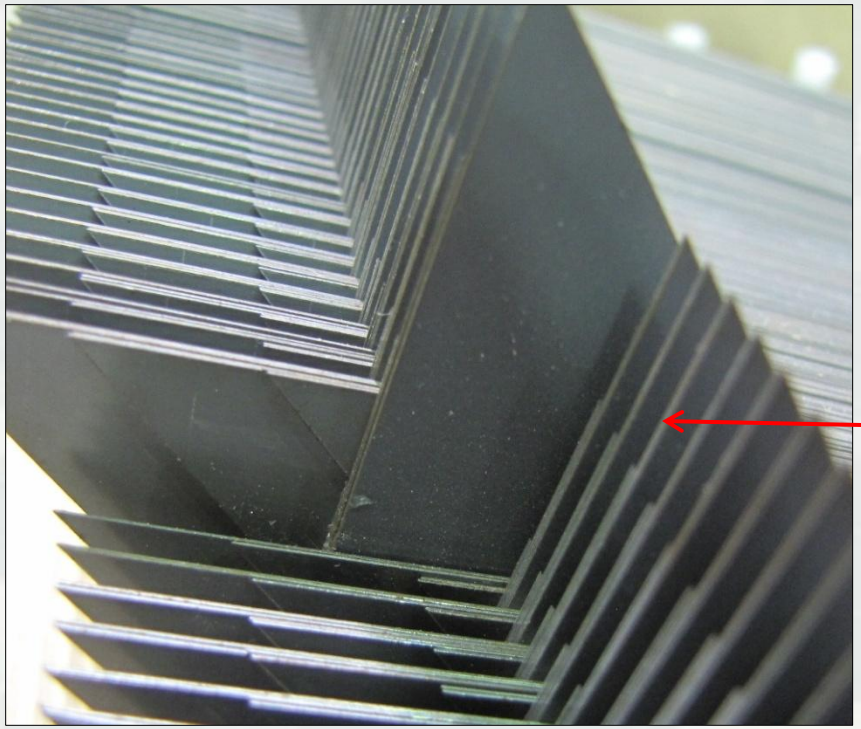
- Cost
  - Misconception that copper is majority of cost
  - 1/5 of cost is typically copper and steel – bids based on commodities indices
  - Transformer manufacturing is VERY labor intensive

High voltage winding

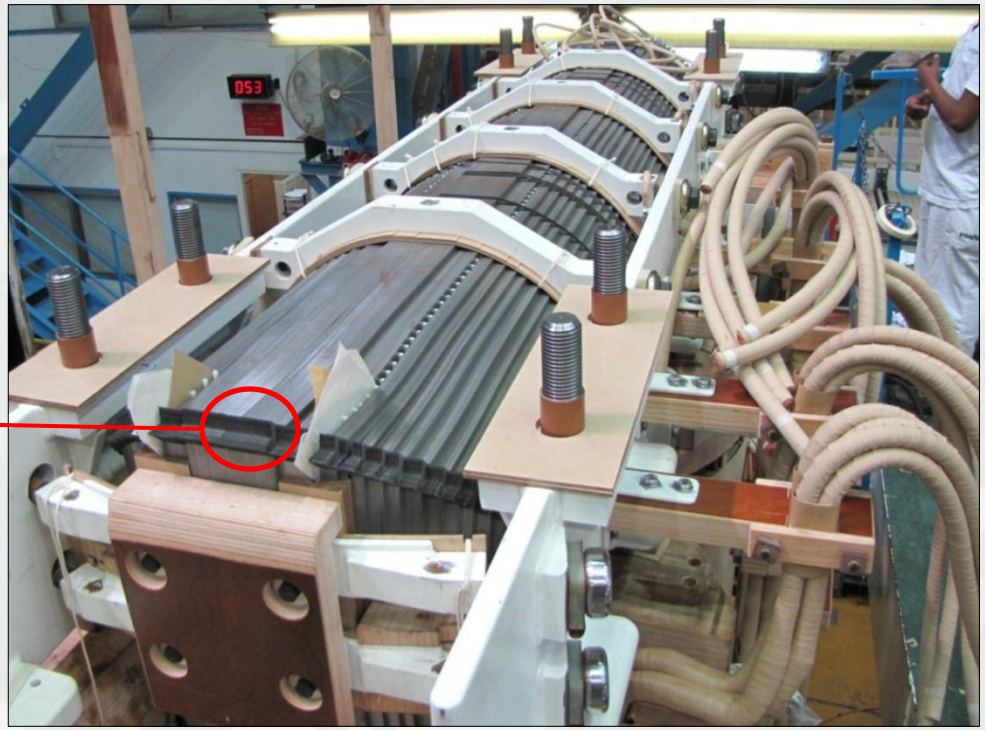
Transformer Background & Basics

Three-phase transformer “active” assembly

Transformer Background & Basics



Detail of steel laminations



Assembled 3-phase transformer top view

Transformer Background & Basics

- Customization
  - Hydro applications are NOT interchangeable
  - Unique interface requirements

Isolated-phase bus connection to generator

Transformer mounted on tailrace deck
Bonneville Powerhouse
Columbia River, Washington

Oil-filled Transformers

- USACE Experience
  - USACE owns more than 350 large oil-filled transformers at hydropower projects
  - HDC experience in replacing approximately 90 transformer in the past 18 years
  - Replacement rate of < 5 per year

Oil-filled Transformers

- Benefits
  - Large U.S.-based service industry
  - Service history with power plants
  - Maintenance personnel experience
  - Mineral oil is an excellent cooling and insulating medium when properly maintained

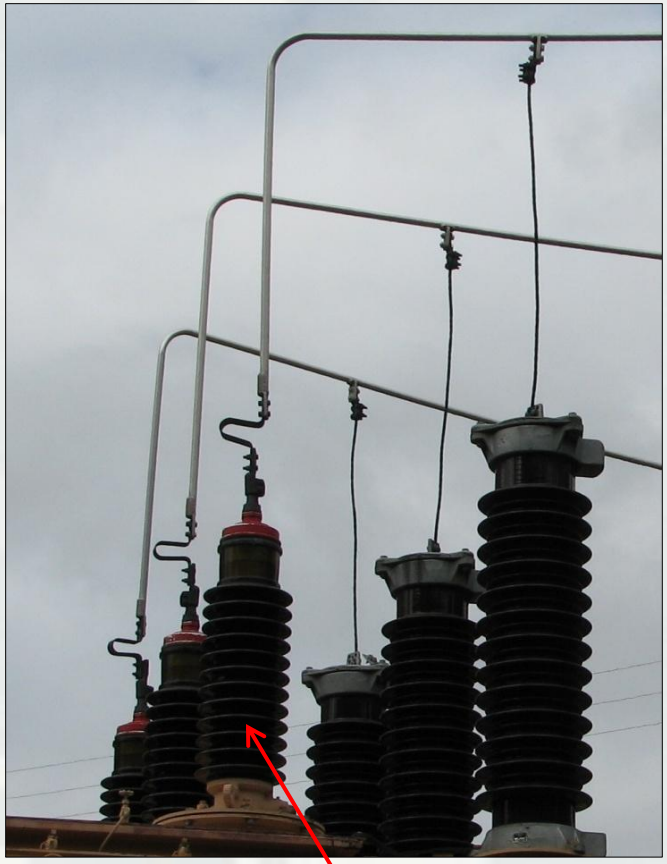
Oil-filled Transformer Concerns

- USACE aging fleet
  - Expected oil-filled transformer life span is 30 years
  - Approximately 100 transformers 50+ years old
  - Approximately 50 transformers 40-50 years old

Substantial oil leaks on radiators

Oil-filled Transformer Concerns

- Failure modes
  - Internal overheating
  - Arcing faults (internal)
  - Bushing failures
- Results of failures
  - High temperatures
  - Catastrophic tank failure
  - Bushing explosion
- Oil Leaks
- PCB contamination in oil



Bushings currently in service: this type is known for catastrophic failures

Oil-filled Transformer Concerns

- Environmental Cleanup from oil spills
- Public perception from oil spills

Typical proximity to river

Gas-insulated Transformers

- Differences
  - No oil
  - Insulated by sulfur hexafluoride gas, SF_6
  - Plastic insulation instead of paper
  - Pressurized

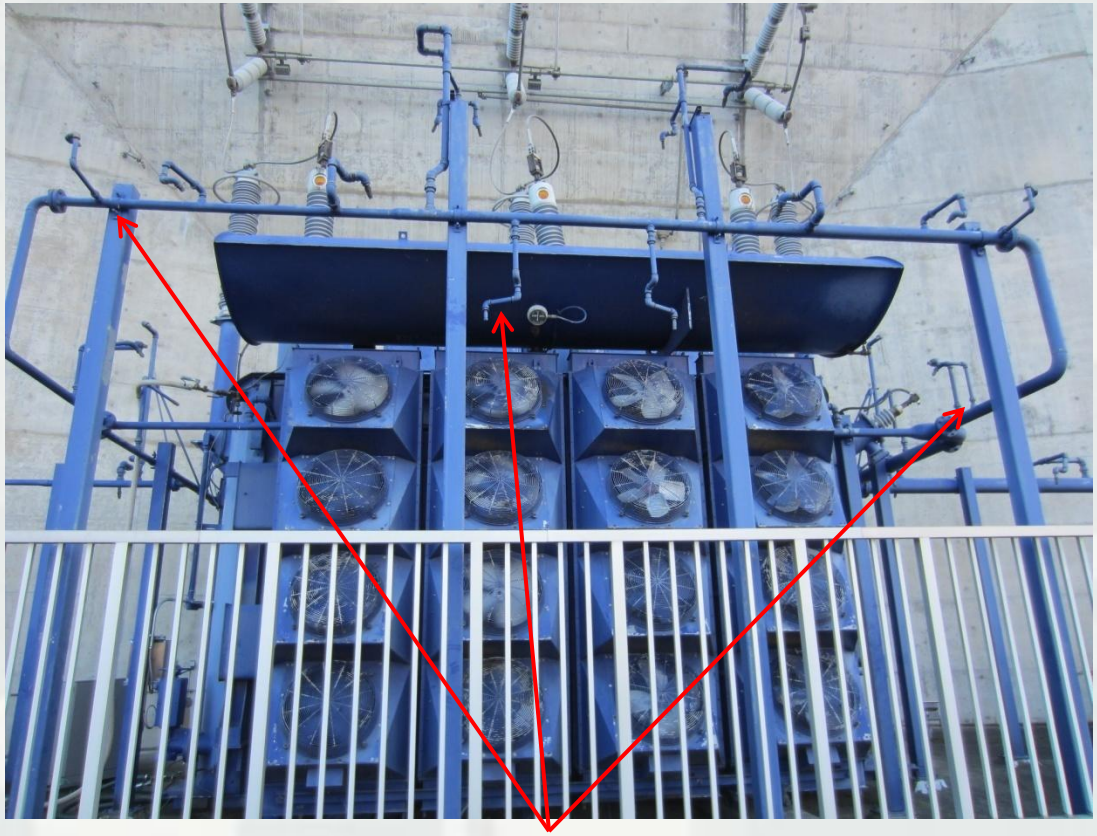
First GIT installation in North America
Osage Powerhouse, Missouri

Gas-insulated Transformers

- Manufacturers
  - Toshiba
  - Mitsubishi
- Experience
  - First unit in commercial operation in 1967
  - Over 10,000 installed, mostly in Japan, Hong Kong
  - One installation in North America at AmerenUE's Bagnell Dam, Osage Powerhouse

Gas-insulated Transformer Benefits

- Containment
  - Not required
- Explosion-proof
- Not flammable
- Fire suppression
  - Not required
- Blast-proof walls
  - Not required



Deluge system for oil-filled transformer

Gas-insulated Transformer Concerns

- Leaks
  - Personnel safety – SF_6 displaces air
- Manufacturers
  - Government procurement – sole source issues
- Longevity
  - 1967 unit made by Toshiba was removed from service after 30 years trouble-free
- Space & weight
  - Different layout for cooling, blowers, support structures
- Plant interface

Gas-insulated Transformer Concerns

Equivalent oil-insulated (left) and gas-insulated (right) at AmerenUE Osage Powerhouse

Gas-insulated Transformer Concerns

- Experience
  - Personnel training for testing

Gas sampling bag and syringe for gas chromatography

Gas-insulated Transformer Concerns

- Experience
  - Very little U.S.-based experience
  - No service facilities in the U.S.
  - North American fleet is only one unit, one more currently being procured

Risks and Unknowns

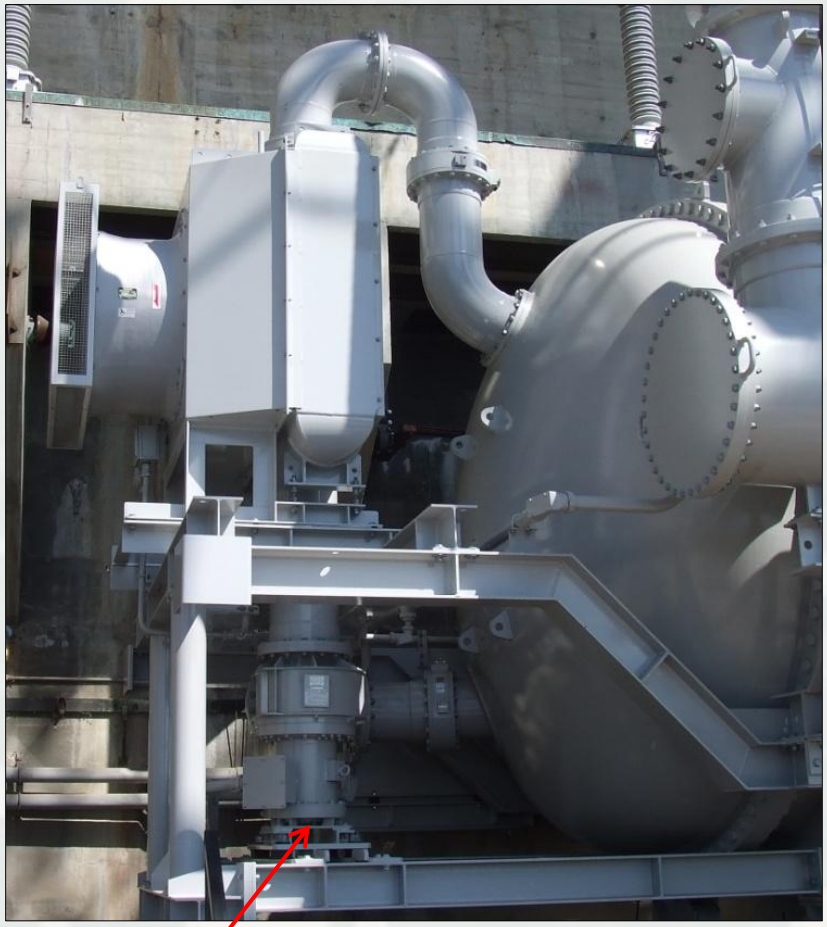
- Environmental
  - EPA recognizes SF_6 as a “High Global Warming Potential gas”
  - 23,900 times more global warming potential than CO_2
  - Leakage reporting is currently voluntary
  - No U.S. fines or regulatory measures
  - The only usage NOT banned for SF_6 in the European Union is high voltage switchgear

Risks and Unknowns

- Government Procurement
  - Sole-source justification might be required with only two proposals expected
  - Specifications need to be reworked
  - North American fleet is only one unit, one more currently being procured
  - No IEEE or industry standard practice guidance in North America

Risks and Unknowns

- Costs
  - Long-term costs unknown
  - Specialized replacement parts need to be ordered from Japan
  - Specialized replacement parts are expensive. For example: a new blower is approximately $30k



Specialized SF_6 gas blower assembly

Risks and Unknowns

- Cost
  - 2 – 3 times as much as equivalent oil-filled
  - Are quotes realistic for long-term? Or based on gaining market share?
- Future cost
  - Leakage fines from EPA?
  - What would a “carbon tax” system do to the cost of SF_6?
  - Lifecycle costs compared to oil-filled

Questions?

GIT tank only