



SuperPower_{LLC}

A Subsidiary of InterMagnetics General Corporation

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY



Development of High Temperature Superconducting Power Transformers

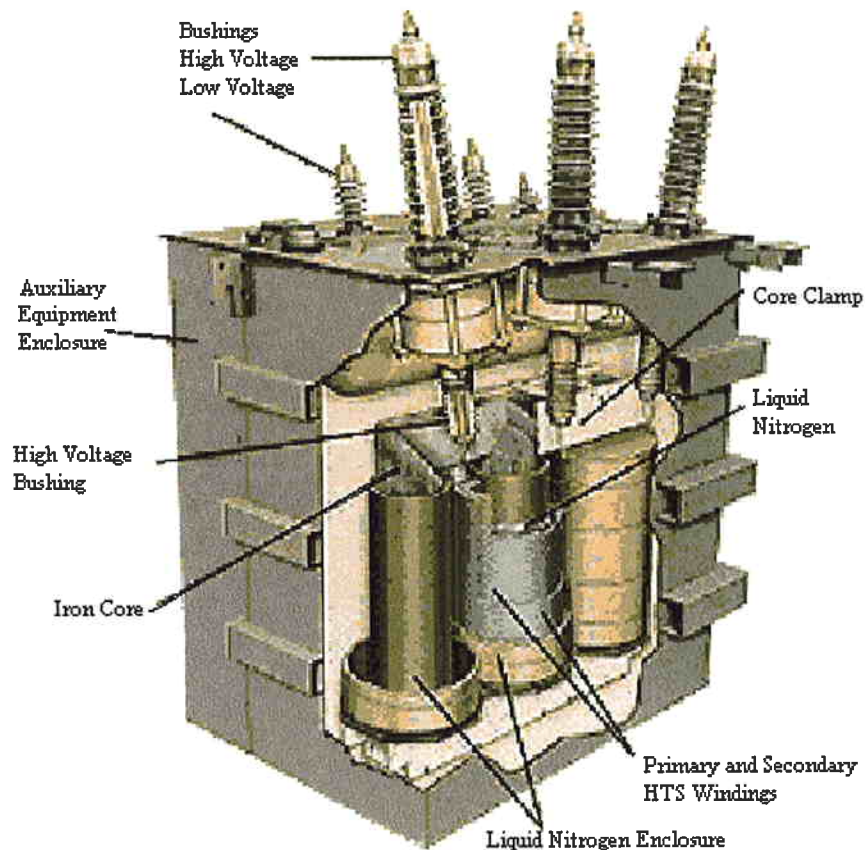
Chandra T. Reis, *IGC-SuperPower, Schenectady, New York*

Sam P. Mehta, *Waukesha Electric Systems, Waukesha, Wisconsin*

Benjamin W. McConnell, *Oak Ridge National Laboratory, Oak Ridge, Tennessee*

Robert H. Jones, *Rochester Gas and Electric Corp., Rochester, New York*

HTS Transformers offer economic, operational, and environmental advantages.



- **Higher efficiency.**
- **2X rating overload capability without insulation damage.**
- **Lower impedance and better voltage regulation.**
- **Potential for fault current limiting capability.**
 - Reduced cost for associated switchgear, breakers, etc.
- **Lower environmental hazard due to lack of oil.**
- **Lighter and more compact than conventional units.**

Higher Efficiency (Lower Operating Losses)

- Core losses
 - Core losses in HTS transformer are comparable to core losses in conventional transformer
- Winding losses
 - No I^2R losses
 - Load losses generated are on the order of hundreds of Watts at cryogenic temperatures
 - Cryocooler compressor power needed to remove at low temperatures on the order of tens of Watts per Watt of loss
 - Present day compressors run continuously and must be sized for peak load
 - For a 30/60 MVA HTS transformer
 - winding losses are like no-load losses
 - due to power needs of cryocoolers
 - around tens of kilowatts at room temperature vs. one to two hundred kilowatts of load loss for conventional transformer

Emergency Overload Capability

- Emergency overload capability up to twice the normal rating can be built into the design
 - Very little heating even during this overload condition
 - Remain in the cryogenic condition
 - No thermal degradation of insulation
 - Designed to handle the added overload mechanical forces.
 - Run for extended periods at overload conditions
 - AC losses are proportional to operating current cubed
 - Refrigeration costs are directly proportional to ac losses
 - Operation in this mode tends to be inefficient
 - Operation above the design limit is not practical

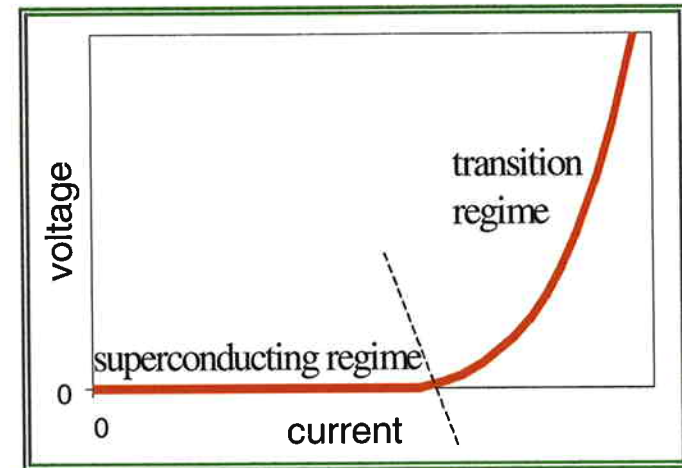


Lower Leakage Reactance

- Lower leakage transformers can be designed because:
 - AC fields are already minimized to reduce ac losses and refrigeration costs
 - Compact windings allowed by high current density
 - May be desirable to incorporate fault current limiting capability so as not to increase system short circuit currents
- Specific benefits to power systems operation are:
 - Improved voltage regulation
 - Reduced impact of faults elsewhere in the system
 - Reduction in required static and dynamic VAR capability
 - Increased reactive power availability from generators
 - Increased availability of real power from existing generators
 - Transformer designs that separate transformer impedance requirements from specific system short circuit current requirements

Fault Current Limiting

- The current-voltage characteristics of a superconductor lend themselves to the possibility of designing the windings to also operate as an intrinsic fault current limiter

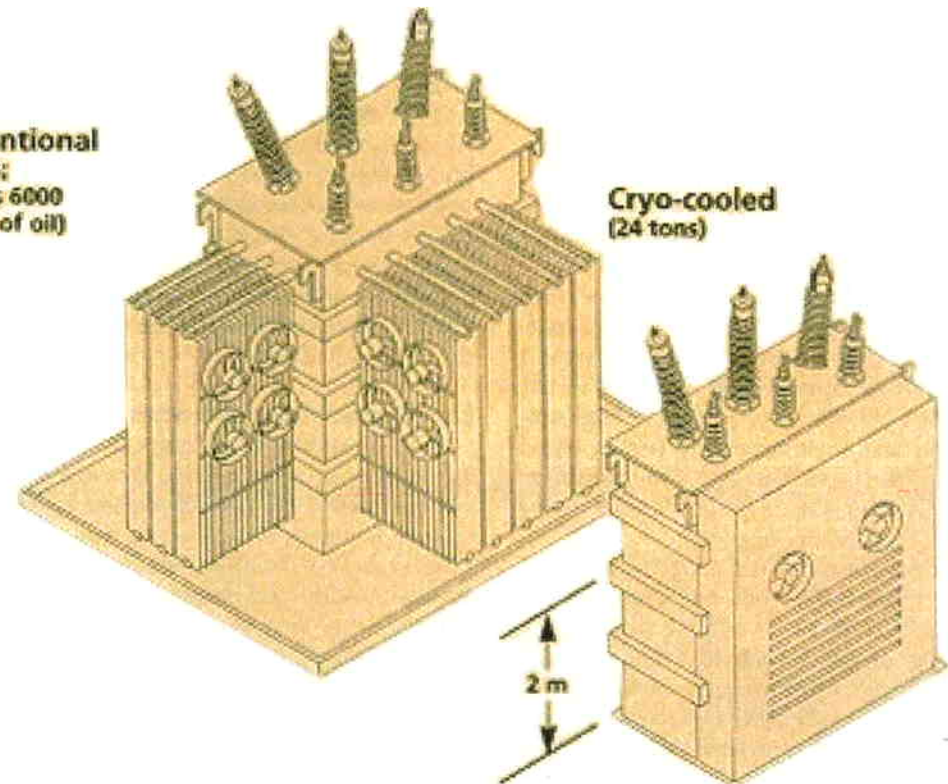


- Feasibility of fault current limiting:
 - Depends on rapidly achieving a uniform transition of the entire length of superconductor to the resistive state
- Benefits to the power system include:
 - Reduction of current interruption ratings for circuit breakers and reclosers
 - Elimination of the need for other current limiting devices

Siting Benefits

- Compact Design
 - Lighter weight
 - Smaller footprint
 - no heat exchangers
 - compact windings
- Environmentally friendly
 - Oil free
 - Non-flammable
 - Benign liquid nitrogen coolant
- Possibility of indoor siting
 - limited mainly by the weight of tank and core

Conventional
(48 tons;
includes 6000
gallons of oil)



30 MVA Transformers

external package of HTS transformer very similar to conventional transformer

High Power Density

- Expected factor-of-two size and weight reductions for a 30/60 MVA HTS transformer compared to a conventional transformer

Example: 60 MVA substation

• Conventional Transformers

- **two 27/36/45 MVA units.**
 - Each nominally operates at 30 MVA
- Either handles full 60 MVA load in emergency
 - only for a short time
 - with significant loss of transformer life

• HTS Transformers

- **two 30/60 MVA HTS units**
 - Each nominally operates at 30 MVA
 - half the footprint
 - Either handles full 60 MVA load in emergency
 - prolonged time
 - no loss of life during overload
- Two more HTS transformers can be added in original footprint
 - double the capacity of substation

Design Approaches

• Liquid Nitrogen Bath Cooled

- Windings immersed in LN₂ bath
 - Use cryocoolers to re-condense, or periodically replenish, boiled-off LN₂
- Advantages
 - LN₂ provides thermal & electrical insulation
 - Very similar to oil
 - Possible to air cool the core
- Disadvantages
 - Operation limited to between 77K (-320F) and 64K (-345F)
 - More of the (relatively expensive) superconductor is needed
 - Vacuum-tight, non-metallic, donut-shaped enclosures for the liquid nitrogen that surround each core leg

• Cryocooled

- Use cryocoolers to directly cool the windings
 - Can run at optimal operating temperature
- Advantages
 - Less conductor needed
 - Reduce conductor cost
 - Only tank wall is vacuum tight dewar
- Disadvantages
 - Energy required for cryocoolers
 - Must have very low ac loss winding design and efficient cryocoolers

Design, Operation and Cost Issues, Dielectrics

- Penetrations through vacuum space
 - surface creep in vacuum, cold temperatures
- Cryogenic temperature operation
 - Desired Properties
 - High dielectric strength
 - Low partial discharge
 - Low dissipation factor
 - Thermal compatibility
 - Mechanical strength for solid materials
 - Thermal conduction
 - LN₂ impregnated paper can be designed to be comparable to oil/paper
 - Measurements underway or completed

however

**Standard solutions for good cryogenic performance
are often incompatible with high electric field**

