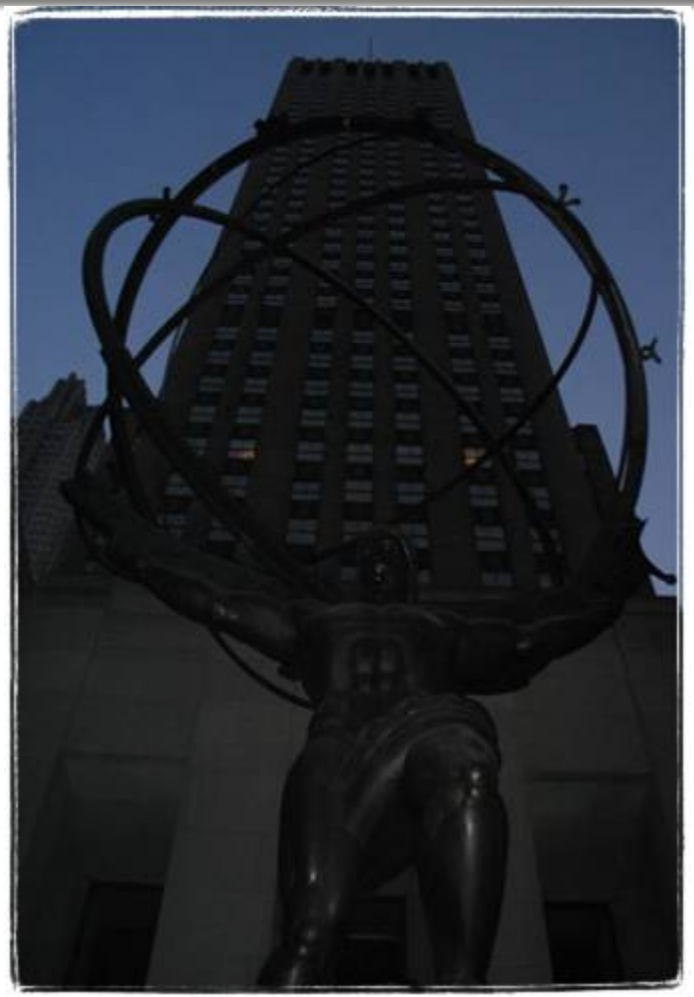
SuperVAR™

August 11, 2006

Edison Shrugged



Things alter for the worse spontaneously, if they be not altered for the better designedly.

TVA

DOE HTS Program Success: Enabling Commercial Rotating Machinery

- First 1600 hp HTS industrial motor (1996-2000, DOE SPI – Rockwell, AMSC)

- AMSC builds on technology from DOE SPI program
- 2005 – AMSC and TVA successfully demonstrate HTS synchronous condenser prototype
- 2006 – AMSC expects to ship first commercial HTS synchronous condenser

- 2003: AMSC delivers 5 MW HTS ship propulsion motor to U.S. Navy
- 2006: AMSC expects to deliver 36.5 MW ship propulsion motor to U.S. Navy in September 2006
- Candidate propulsion motor for DDX-class destroyers in 2010 and beyond

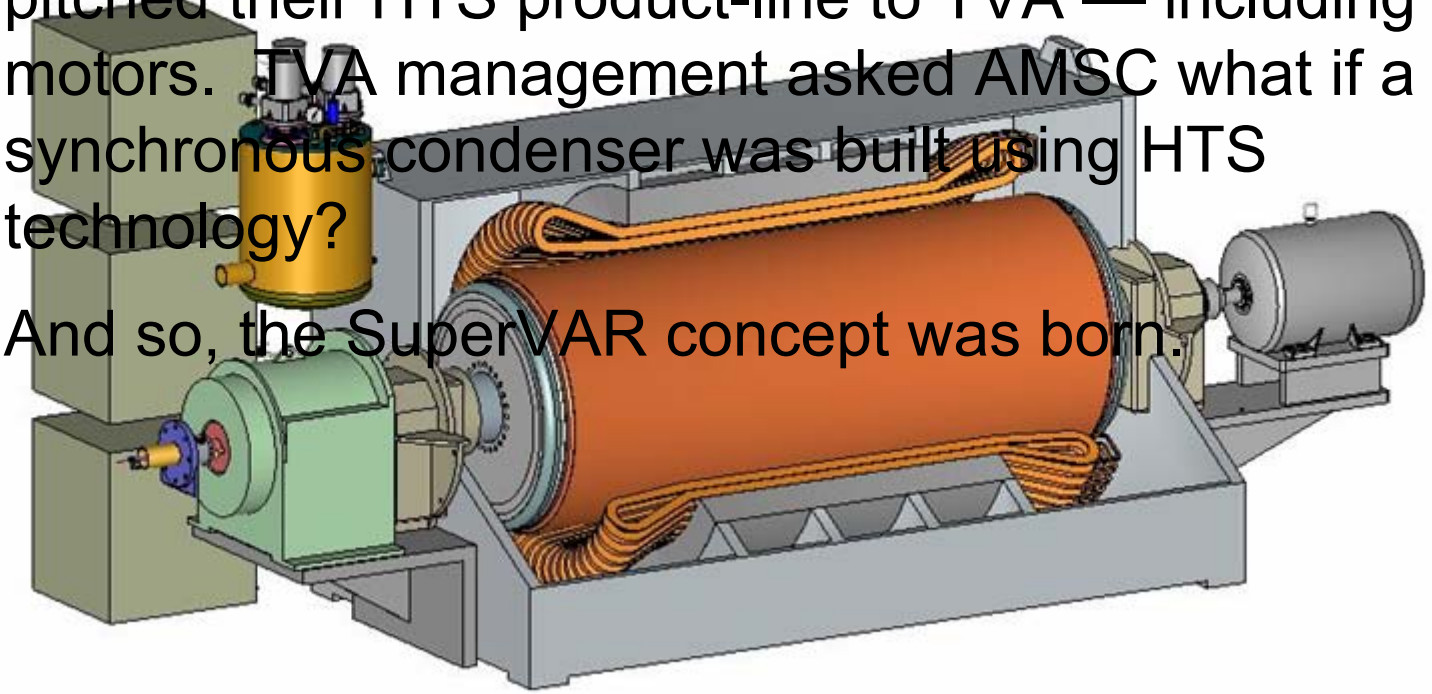
TVA

"If I have seen a little further, it is by standing on the shoulders of Giants." — Newton

SuperVAR born with the question "What if ?"

In 2001, American Superconductor management pitched their HTS product-line to TVA — including motors. TVA management asked AMSC what if a synchronous condenser was built using HTS technology?

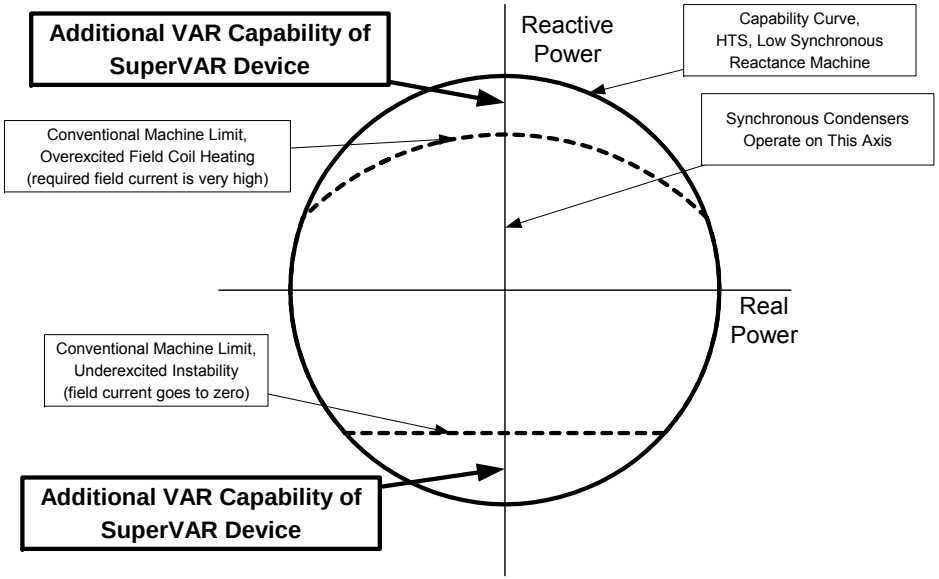
And so, the SuperVAR concept was born.

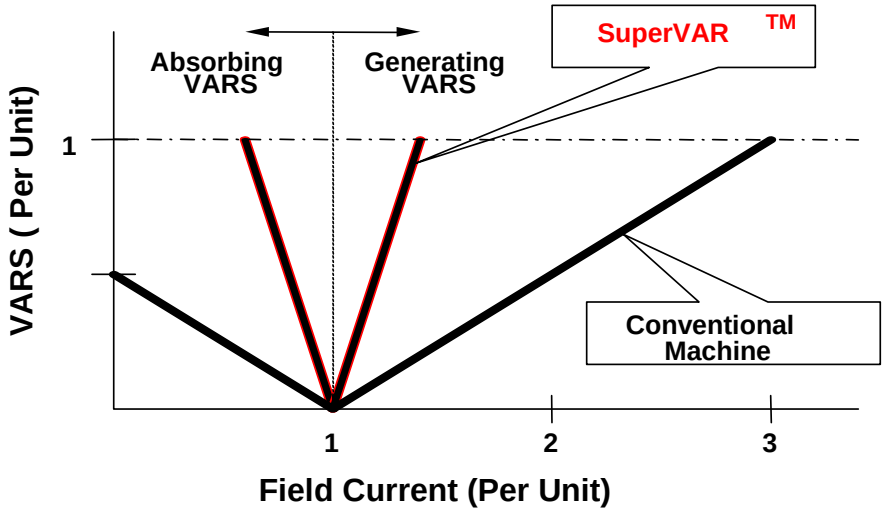


"He that will not apply new remedies must expect new evils; for time is the greatest innovator." — Bacon

TVA

Steady State Benefits of HTS Rotating Machines





- Low synchronous reactance design removes under-excited stability limit of conventional machines
  - Field current is well above zero at full rating under-excited
- HTS field coils remove coil heating limit of conventional machines,
  - Full rating over-excited is possible
- No thermal cycling of rotor coils yields improved machine life, no rotor rewinds projected

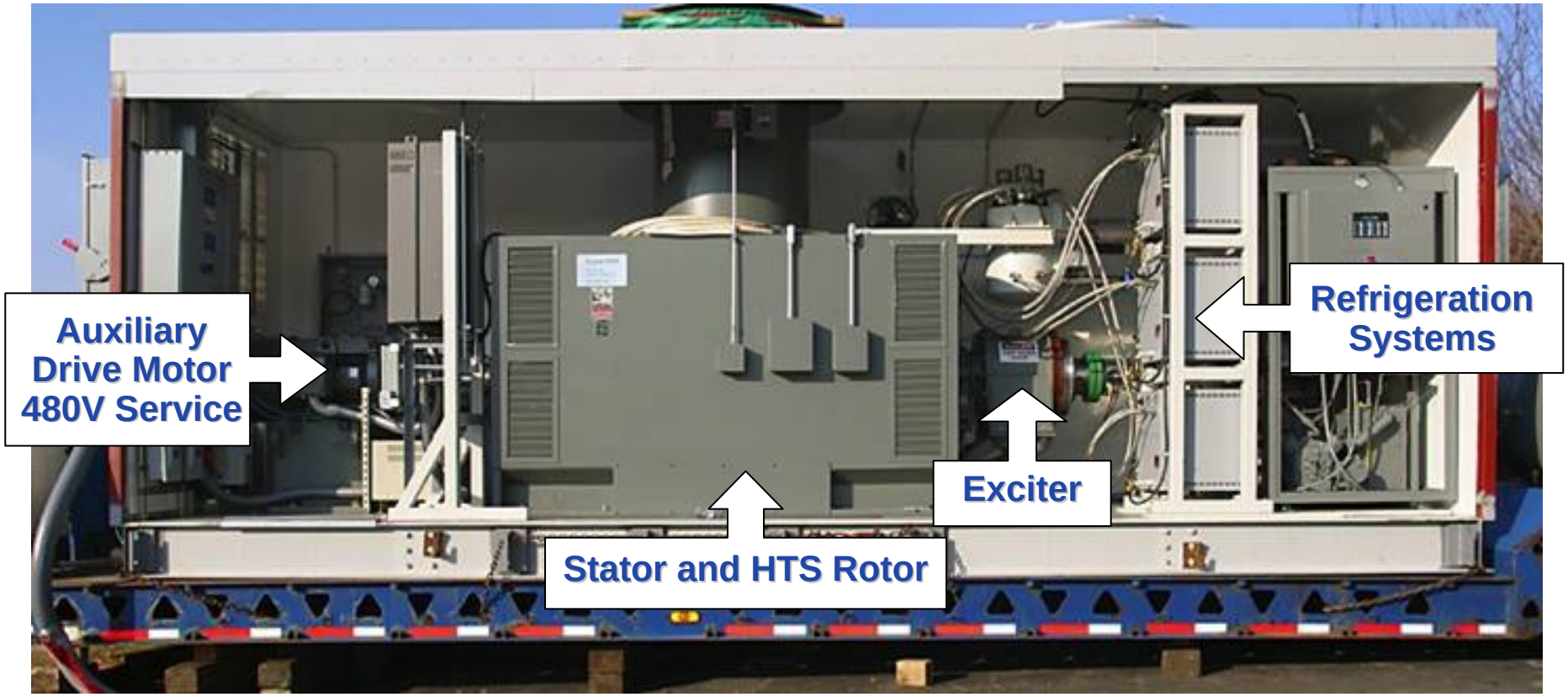
Low synchronous reactance, HTS machines are capable of more reactive output than a conventional device for a given rating machine

TVA

What Is A SuperVAR System?

- A Synchronous Rotating Machine
  - Just like a large synchronous motor or generator
- Armature and Support Equipment Conventional
  - Makes extensive use of off-the-shelf components and technologies
- Rotating Field Winding Is Superconducting
  - Field windings cooled to very low temperatures in a rotating Thermos bottle
  - No thermal expansion/contraction degradation mechanisms
  - No chemical degradation mechanisms (kept in a vacuum)
  - Windings carry electricity without resistance
- Controlled and Transient VAR/MW Provided to System
  - Reactive power continuously adjustable (+/-12MVAR)
  - 2X overload available for up to one minute
  - Voltage regulation or reactive power compensation possible
  - Transient MW/MVAR available (flicker, motor starting, other transients)

Major SuperVAR Condenser Systems



SuperVAR Condenser Technology Base

- Leverages COTS (commercial off-the-shelf) components
  - Stator – standard, air-cooled, iron core stator
    - 100 year old technology
  - Exciter
  - Cooling components
  - Ferro fluidic seal
  - Conventional journal bearings
- Take advantage of technology base developed
  - AMSC 5000HP motor project
  - 5MW Navy program
  - PES, DVAR/DSMES

SuperVAR condenser leverages conventional technology, demonstrated HTS machine features and other AMSC reactive power compensation products

TVA

SuperVAR Condenser Prototype Specifications

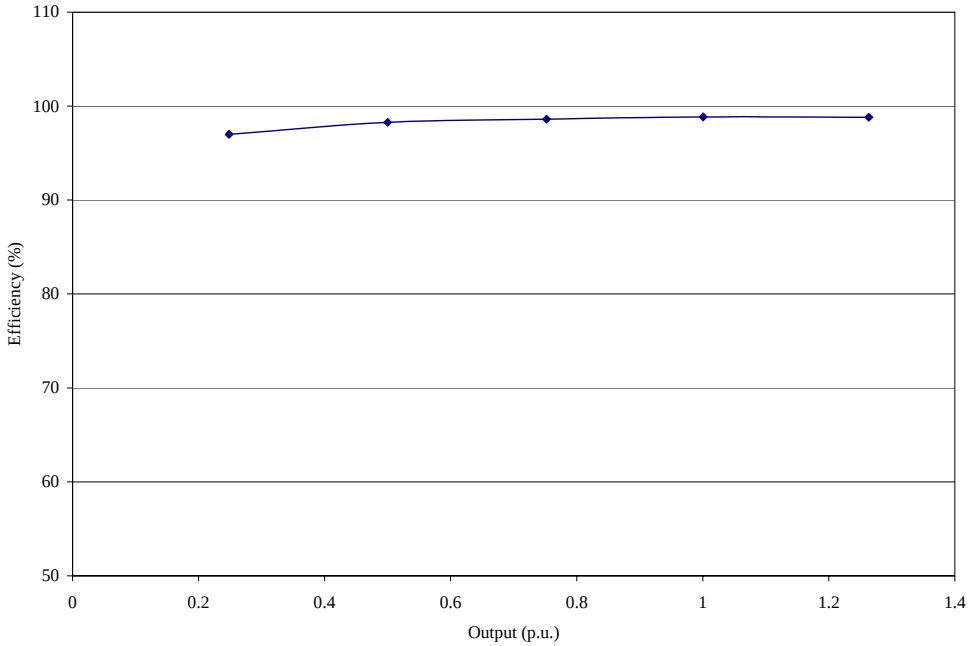
Rating	8 MVAR
Voltage	13.8 kV line to line
Ambient Temp	-30^{o} to +40^{o}C
Losses	1.7% rating at 8MVA
	Including 50kW 480V auxiliary power

The SuperVAR condenser prototype has industrial class specifications

TVA

Losses and Efficiency

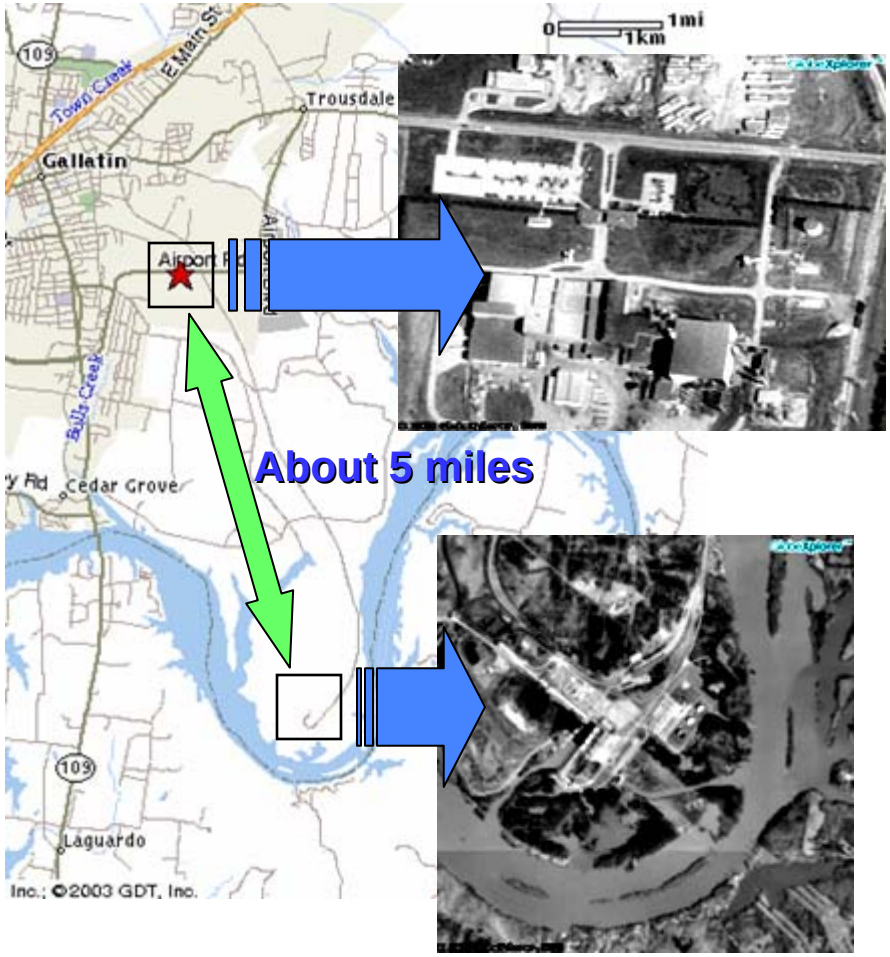
- Auxiliary loads measured
  - System on-line, pony motor coasting, all other systems operating
  - 480V measured with true RMS clamp-on probe at site: 49kW
  - 480V measured in factory test with power analyzer: 46kW
  - Contract specification: 50kW
- Losses at no load measured
  - 54.52 kW measured in factory test
  - Contract specification: 136kW



SuperVAR system auxiliary loads and losses meet contract specifications

TVA

SuperVAR Prototype Installation at Hoeganaes Corporation



- Steel Mill
  - 45MVA arc furnace, 13.8kV load
  - Nearly continuous operation
  - Multiple large voltage transients per melt cycle
  - Many melt cycles per day
- Gallatin Fossil Plant
  - Four coal-fired generating units
  - Construction was completed in 1959
  - Peak capacity is 988 MW
  - Consumes about 7,400 tons of coal a day
  - About 5 miles from Hoeganaes
- Machine Installed at Hoeganaes
  - Machine operating in conjunction with arc furnace

SuperVAR prototype was operated in a demanding industrial application

TVA

HOEGANAES

Prototype SuperVAR System Operation

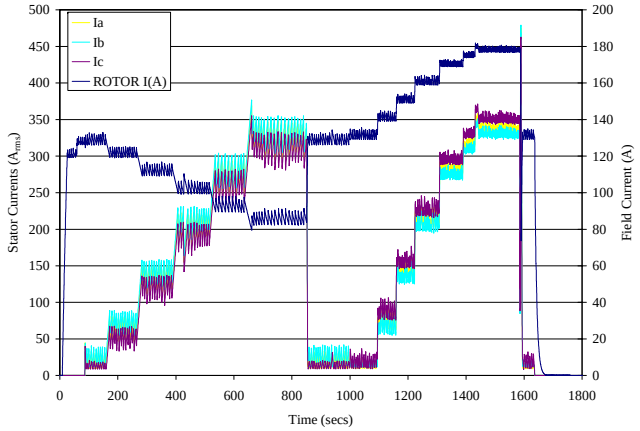
- Operation during over 2000 arc furnace melt cycles
  - Over 260 million pounds of steel melted
  - Equivalent to melting 90,000 Porsche Boxsters
- Over 5 million load transients
  - 40 Porsche Boxters simultaneously accelerating from 0 to full power, 5 million times

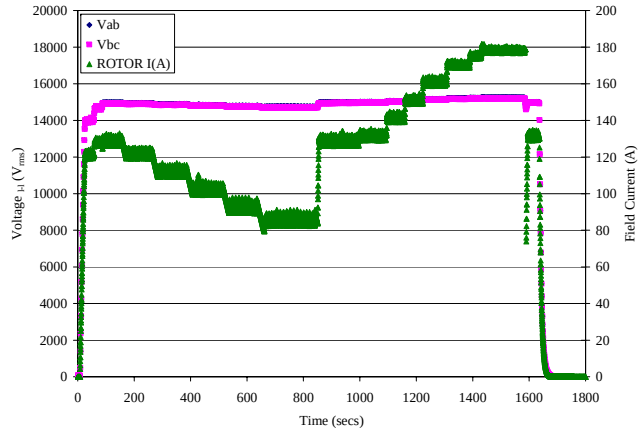
SuperVAR prototype was operated in a very challenging environment

TVA

On-line Results

- Without arc furnace in operation
- Synchronized system and placed on-line
- Adjusted field current for over-excited and under-excited operation
- +/- 8MVAR was demonstrated
- Line voltages were slightly elevated and depressed as expected

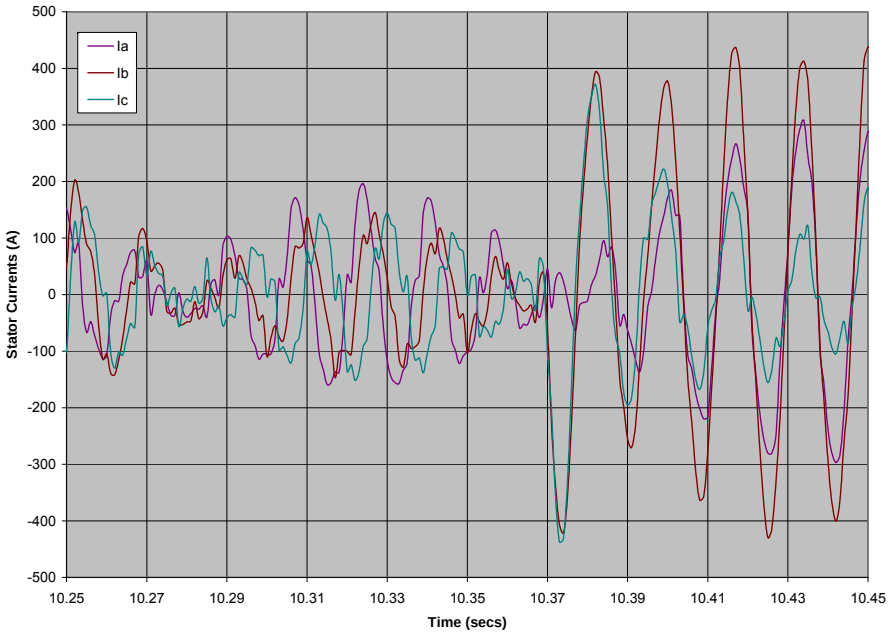




System was operated on-line to verify full +/- 8MVAR operation

On-line Transient Results

- Machine successfully operated through extreme transients to support voltage
- Reacts on the sub-cycle timescale
- Transient output observed in excess of machine rating
- Significant real *and* reactive transient output observed
- 10^6 to 10^7 major transients

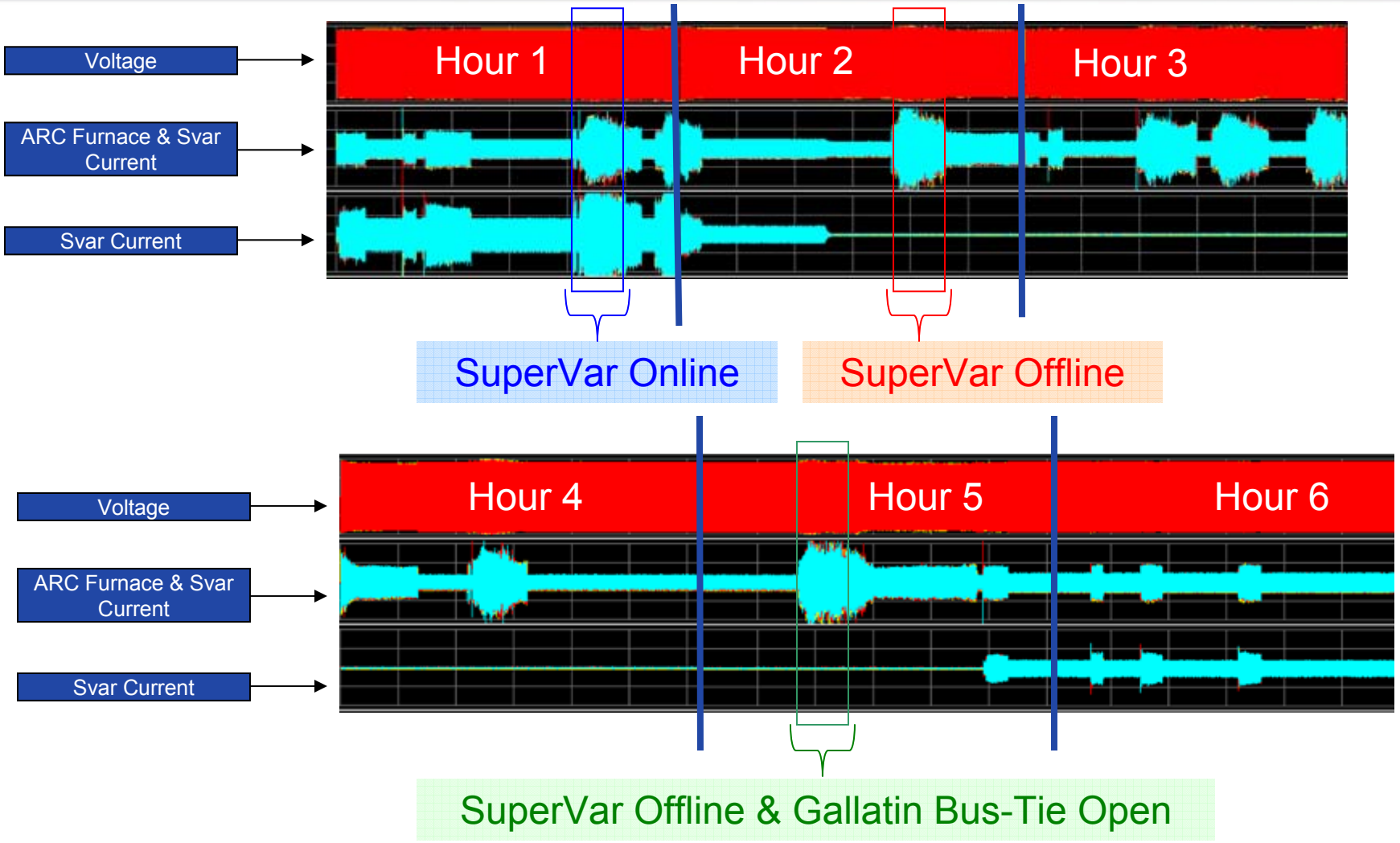


Results show dramatic, transient behavior providing support to furnace

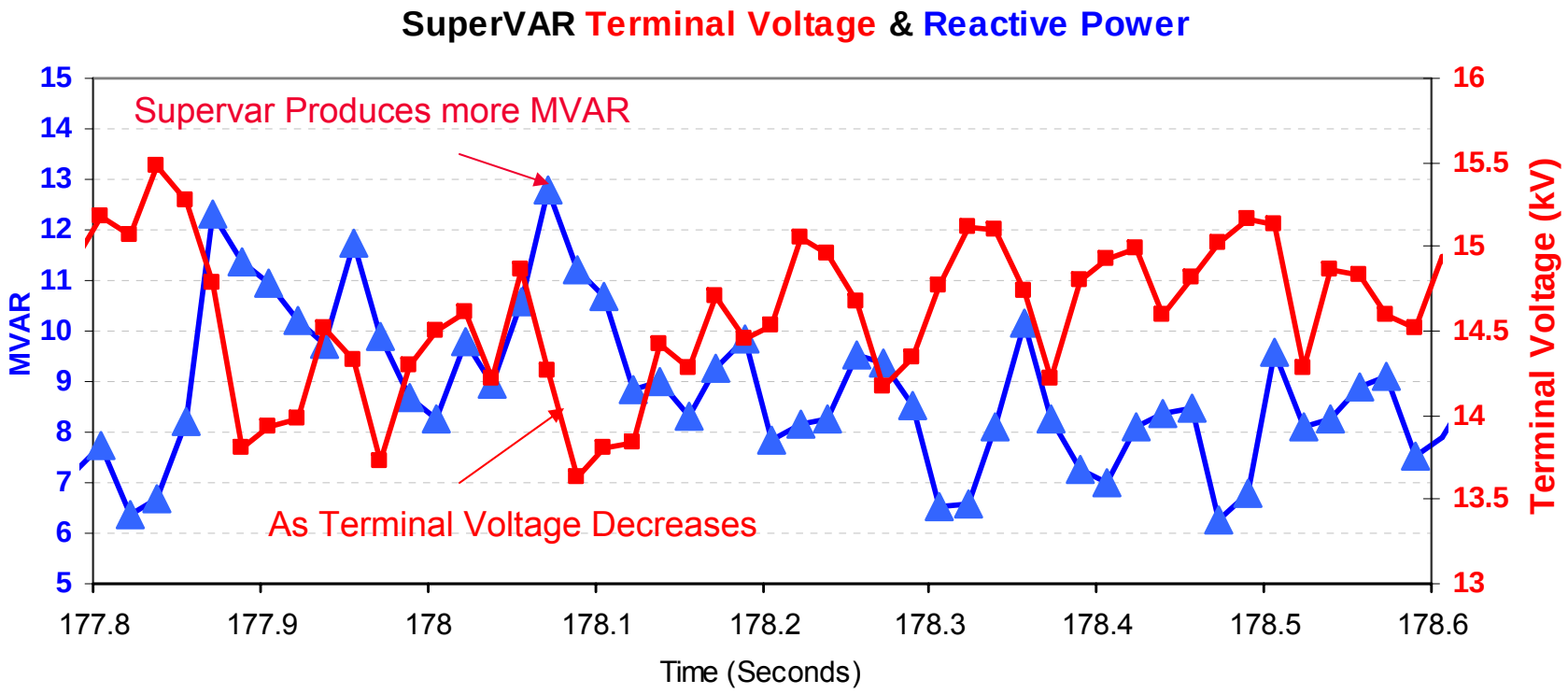
TVA

On-line Results

Total Measurement Period (03-21/22–2005) 9pm – 3am



Cycle by Cycle Response of SuperVAR



This characteristic of SuperVAR is beneficial in minimizing voltage fluctuation due to rapidly fluctuating loads such as arc furnaces

TVA

Graph based on electrical data collected by TVA and EPRI Solutions during 03/21 and 03/22 Gallatin Test

What does it all mean?

- Using appropriate statistical parameters, SuperVAR impact can be measured even though the condenser size is much smaller than the arc furnace and the Gallatin generators.
- Reducing voltage/MVAR fluctuation at Hoeganaes results in a more stable arc and increases the operational efficiency of the arc furnace.
- Reducing the voltage/MVAR fluctuation at Gallatin Steam Plant results in a more efficient operation of the generators.

In theory there is no difference between theory and practice. In practice there is. — Dr. Y. Berra

TVA

489 Relay Event Log Data

- 489 Event Log captures alarm and trip parameters
- Alarm events used to obtain a summary of machine response
- Peak values measured are shown to the right

	Peak 489 Data Logged to Date	**Note:**
Negative sequence current	70%	Response to AF operation
MVAR supplied	13 MVAR	Response to AF operation
MW supplied	11.7 MW	Response to AF operation
MVAR consumed	33.5 MVAR	Response to cap bank switching
Phase current	988 A RMS	Response to cap bank switching
Phase voltage	19,879 V RMS	Response to cap bank switching

SuperVAR system response of real AND reactive power noted of about 12 MVAR or 1.5 PU to arc furnace transients

Flicker analysis by site recordings

Independent analysis by EDF

Waveform recorded during the tests "arc furnace + SuperVAR compensator"

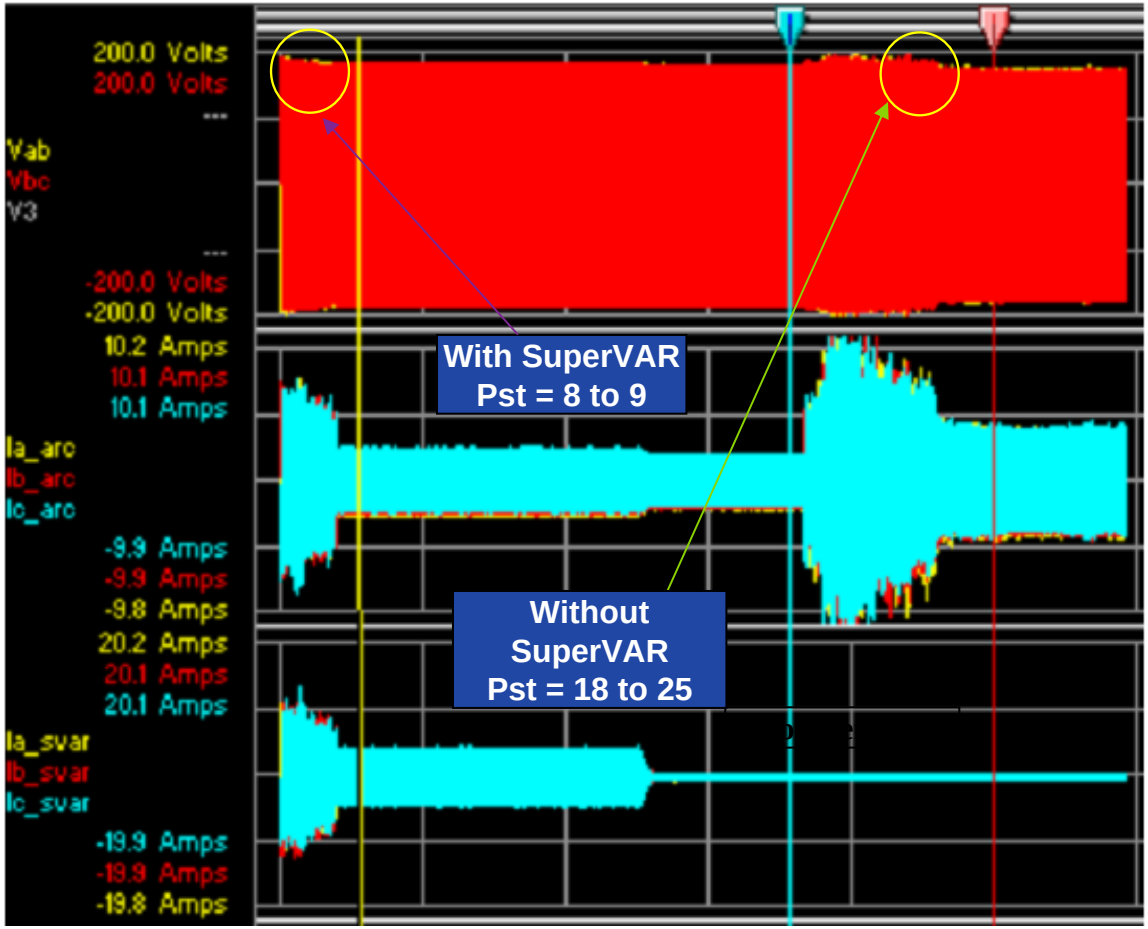
-Extract of line voltage waveform from raw binary file.

- Sampling frequency: 6.4kHz

- Flicker calculation by Flickermeter software: Pst during 10 min

Conclusion:

Flicker reduction is significant by using SuperVAR.



Flicker is the amplitude modulation of the fundamental frequency voltage by one or more frequencies.
At some magnitudes, this modulation causes a visible brightening and dimming of lights connected to the modulated voltage, hence the term flicker.

Summary Specifications of Production Units Incorporating Prototype Lessons Learned

Specification	Prototype	Production Unit	Notes
Rating	8MVAR	12MVAR	Rating achievable without major rotor design changes
Transient	8PU	4PU	Limit fault torques to those proven in prototype
Excitation Speed	60 seconds	1 second	0 to full rating output for voltage collapse applications
Mounting	Trailer	2 Skids	More secure mounting to withstand vibration, separate auxiliaries
Cooling	Neon	Helium	Simplify operations
Controls	Custom	DVAR Derivative	Simplify operations and maintenance
Compressor	Water cooled	Air cooled	Eliminate chiller to simplify operations

Machine Type and Specifications

- Synchronous Condenser
- Superconducting field windings
- Conventional armature
- Exciter based on conventional components

Specification	Value
Continuous Rating	12MVAR leading or lagging
Overload Rating (≥1 minute)	24MVAR leading or lagging
Transient Rating	12MVAR/MW to 50% sag
Voltage	13.8kV
Commanded Response Time	≤1 second (0 to rated MVA output)

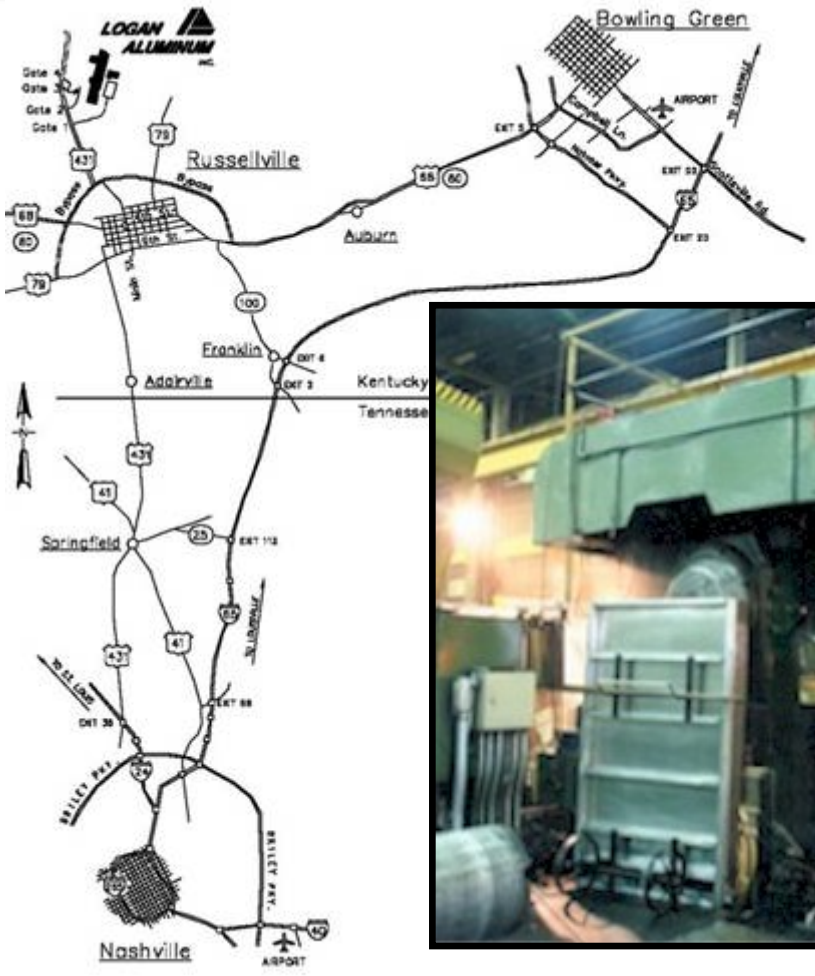
Physical Attributes

Characteristic	Synchronous Condenser	Auxiliary Equipment Skid
Length	20 feet	10 feet
Width	8 feet	8 feet
Height	8 feet	8 feet
Weight	90,000 pounds	10,000 pounds

SuperVAR Assemblies Will Be Delivered With Minimal Site Work Required

TVA

Next stop: Russellville, Kentucky



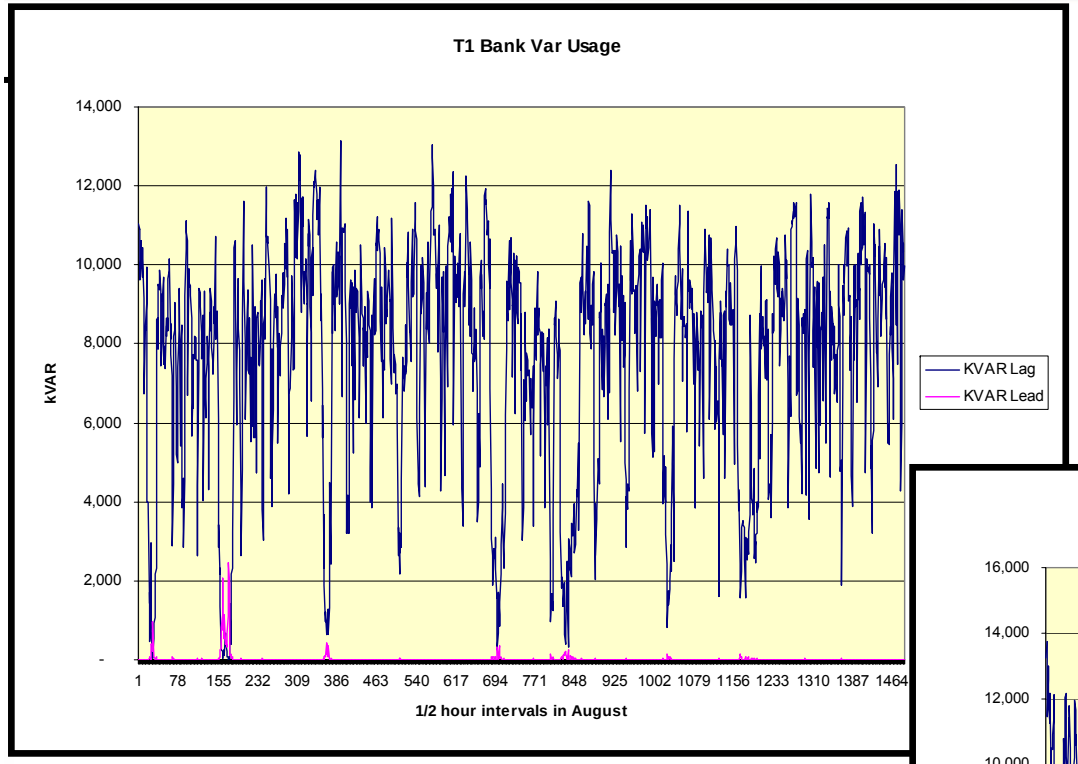
Logan Aluminum premier manufacturing facility with modern high-speed equipment, operational areas include ingot casting, hot rolling, cold rolling and finishing.

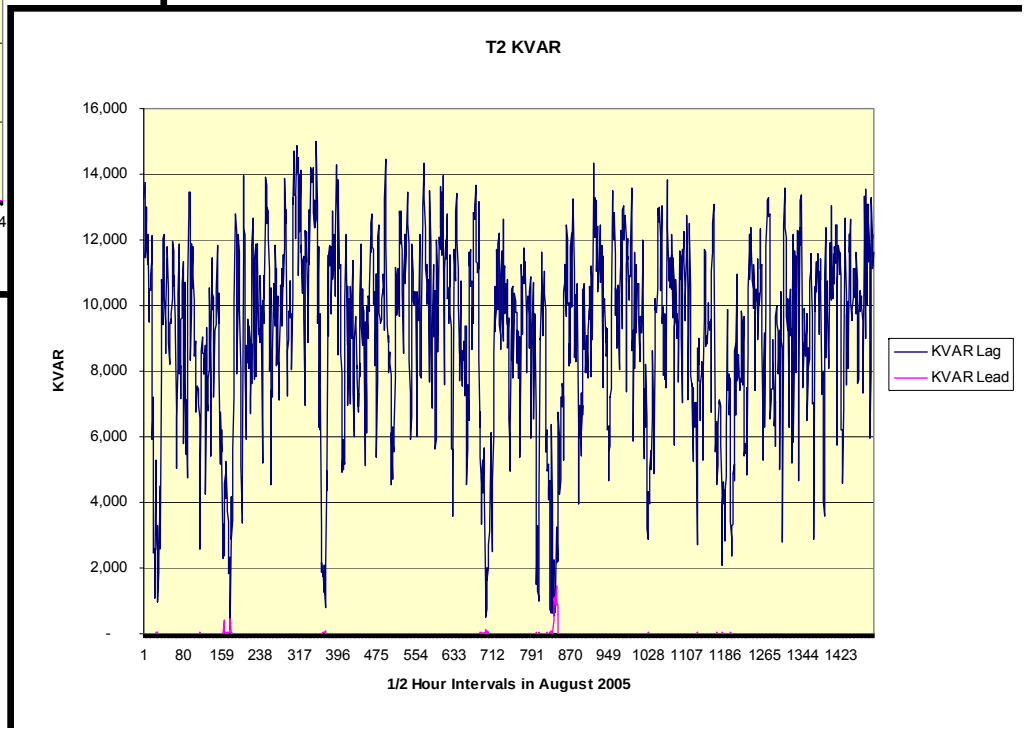
Anything that won't sell, I don't want to invent. Its sale is proof of utility, and utility is success. — Edison

TVA

LOGAN ALUMINUM INC.

T3 Contributes Significantly to Var Injection (Low Loading Condition)





Sir Francis Drake, 1577

Disturb us, Lord, when
We are too well pleased with ourselves,
When our dreams have come true
Because we dreamed too little,
When we arrived safely
Because we sailed too close to the shore.

This R&D engineer's prayer …