ELECTRIC THERMAL STORAGE: ETS AS A VALUABLE APPLICATION FOR EXCESS WIND ENERGY IN MICROGRIDS

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RESEARCH TOPICS

• Hybrid Wind-Diesel Power Systems
• Electric Thermal Storage (ETS)
  – Electrical dynamics
  – Heat transfer modeling
  – Thermodynamics and efficiency
OBJECTIVES

I. Background
II. Thermodynamics / Efficiency
III. GETS electrical modeling
IV. Thermal modeling
I. BACKGROUND

Image credit: Fairbanks Daily Newsminer
HYBRID WIND DIESEL (HWD) SYSTEMS

- Diesel Electric Generator (DEG)
- Wind Turbine Generator (WTG)
- Consumer Load
- Secondary Load
HWD SYSTEM MODES OF OPERATION

- **Diesel-Only Mode (DO)**
- **Wind-Diesel Mode (WD)**
- **Diesel off:** Wind-Only Mode (WO)
- **Diesel on:** High Contribution Wind-Diesel Mode (HCWD)

The diagram illustrates the power (kW) versus time for different modes of operation. The diesel capacity and wind turbine capacity are indicated with respective lines. The graph shows the power demand (grid demand) and the diesel and wind contributions over time.
DUMP LOAD APPLICATIONS

- Storage
  - Battery, pumped hydro, etc...
- Immediate use (heat)
  - Electric boiler
  - Resistive load bank
- Thermal storage
  - ETS
ELECTRIC THERMAL STORAGE (ETS)

- Resistive heating elements
- High-density storage bricks
- Air channels
- Blower
- Insulation
- Controller

Photo: www.midcoastenergysystems.com
TYPES/CLASSIFICATION

ETS

Central

Forced Air

Hydronic

Room
II. THERMODYNAMICS / EFFICIENCY

Image credit: www.spotthefrog.net
HEATING WITH WIND

- Is heating with wind “efficient”?
- Efficiency is generally defined as:
  - What you get out / What you put in X 100%
- First law efficiency
- Second law efficiency
FIRST LAW EFFICIENCY

90 + 10 = 100
SECOND LAW EFFICIENCY

Electrical Work → 100% → Heat

Heat → 100% → Electrical Work
SECOND LAW EFFICIENCY
BEFORE STORAGE
SECOND LAW EFFICIENCY AFTER STORAGE

150

210

100

60

100

40

210 + 40 = 250
EFFICIENCY SUMMARY

- First law efficiency: 100%
- Second law efficiency...less
- It would be preferable to store the energy in the form of work potential

Heating Potential Before and After Full Charge Storage vs Outdoor Temperature

- Heating Potential Before Storage
- Heating Potential After Storage
- Actual Heat Supply
III. GRID-INTERACTIVE ELECTRIC THERMAL STORAGE (GETS)

Image credit: www.mncee.org
UNIT CONTROL

• Discharge:
  – Thermostatic control

• Charge: On large grids for load leveling
  – Outdoor temperature probe

• Charge: On small grids for assistance with frequency regulation
  – Power plant via a dedicated distribution circuit
  – Power Line Carrier signal (PLC)
  – *Self regulating ‘Grid-interactive’ ETS (GETS)*
GRID-INTERACTIVE ETS (GETS)

- Each unit measures the grid **frequency** and responds with an appropriate number of heating elements.
- Instantaneous balance of real power is achieved.

**Diagram:**

- Wind increases sharply
- Load decreases rapidly

- **Real power surplus in grid**
- **Frequency rises**
- **GETS Network Responds**
- **Frequency Recovers**
GETS MODEL

- GETS parameters
  - Number of elements
  - Unit kW
- GETS variables
  - Full Response Point (FRP)
  - Zero-order Hold Time (ZHT)
  - ETS Total Network Capacity (TNC)
- Unit synchronicity
IMPROVED FREQUENCY REGULATION

Bus Frequency

Bus Voltage

WTG Real Power

ETS Real Power

No ETS Support
Optimal ETS Support
FINDING THE SWEET SPOT

ETS Network Capacity (pu)
SD(f) [Hz], ZHT=0.005s, Staggered

ETS Network Capacity (pu)
SD(V) [pu], ZHT=0.005s, Staggered

ETS Network Capacity (pu)
SD(f) [Hz], ZHT=0.02s, Staggered

ETS Network Capacity (pu)
SD(V) [pu], ZHT=0.02s, Staggered
POTENTIAL PROBLEM

DEG Real Power

Bus Real Power

ETS Real Power

Power (W)

Time (s)
SUMMARY

• A network of distributed GETS-controlled loads can assist with frequency regulation in WD mode

• An optimal combination of set points exists for a certain set of system parameters

• If the GETS units respond faster than the diesel, they may become part of the primary load
IV. THERMAL MODEL
PERFORMANCE ANALYSIS

• Wind speed patterns
• Electrical load / demand profile
• Heat load / demand profile
• Diesel cost
• Heater output characteristics
MEASURED OUTPUT

Lab Test Results - Steffes 2102

- Graph showing outlet temperature (°C) over time (min) for different conditions.

- The graph includes multiple lines indicating different test conditions.

- The data represents the measured output from the lab test results.
AIR FLOW PATH

Inlet side

Outlet side

- Heating elements
- Air channels
- Simulation region
- Height (H)
- Single brick
- Divider baffle
MODEL GEOMETRY

Upper Surface

Air Inlets

Charging Surfaces

Air Outlets
DISCHARGE CYCLE
VARIABLES CONSIDERED

- Phase change materials
- Brick geometry
- Air flow rate
- Air velocity profile
- Temp gradient (thermal history)
V. CONCLUSION

what do u call a MASSIVE solar energy spill?

a Nice day

Photo: www.quickmeme.com
ETS PROS/CONS

• Pros
  – Wind is a clean source of heat
  – Wind supply and heat demand are decoupled
  – Heat is valuable in Alaska

• Cons
  – Work potential is destroyed
  – Materials are heavy, making transportation expensive
  – Control issues exist
RESEARCH SUMMARY

Combined HWD/GETS Electrical Model

HWD Test Bed Electrical Model

GETS Electrical Model

Measurement and Validation Study - 6/13/2013

IEE Journal of R&SE

Steffes 2102 - 12/24/2013

IEEE Journal of R&SE

AUPEC 2014

ETS Thermal Model

Currently Taking Data

ASME Journal of Heat Transfer

ASME Power 2014