Energy Efficient Mobile Electric Trailer Refrigeration Units

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Introduction

- Foods that require precise temperature control are stored and transported in stationary or mobile Trailer Refrigeration Units (TRUs).
  - Spoilage of the load can be very expensive
- Diesel powered TRUs are noisy and pollute the air
- Electric powered Trailer Refrigeration Units (eTRU)
  - Typically save on energy costs, use clean energy and reduce harmful diesel emissions and noise
  - Have less components and are more reliable
  - Limit the dependence on petroleum
  - Increases chances of satisfying future regulations
- Although stationary TRUs can be powered through the electric grid, this is not the case with mobile TRUs
- Hybrid diesel/electric TRUs exist but while in transit, they are powered by diesel engines
- There is a need to develop mobile TRUs that are powered by clean renewable energy sources

Energy Saving Features added to the Customized Stationary eTRUs

- Customizing TRUs allows features to be added that may not be available in currently available TRUs
- Heuristic energy savings algorithms programmed into Intra-Tech's Controller
- Reduce startup surge current
  - Offset the starting time of compressor and fan motors
  - Start compressor in low power mode
  - Allows more stationary units to be powered by the same electrical source
- Increase box compartment space
  - Put evaporator outside box compartment
    - Also reduces damage by bumping when loading cargo
- Can add a wireless energy management system to control energy usage of all trailers
  - Controller will decide how to manage the power
  - Can also be used to monitor and control eTRUs remotely over the internet
- Uses 480vac 3ph
  - direct from power company which eliminates transformer losses
  - less current can use thinner wires
  - Lowers copper costs

Shows 2 eTRUs converted from diesel by New York Truck (NYT). Controller developed by Intra-Tech uses NYT's energy saving heuristic algorithm which makes use of discrete capacity control modes 0%, 32%, 67%, 100% of the Carrier compressor.

Energy Reducing Tradeoffs

Item	Clean Energy Savings (Kwh)	**Polluting Energy Added (Kwh)**	Additional Cost	Energy Cost Savings

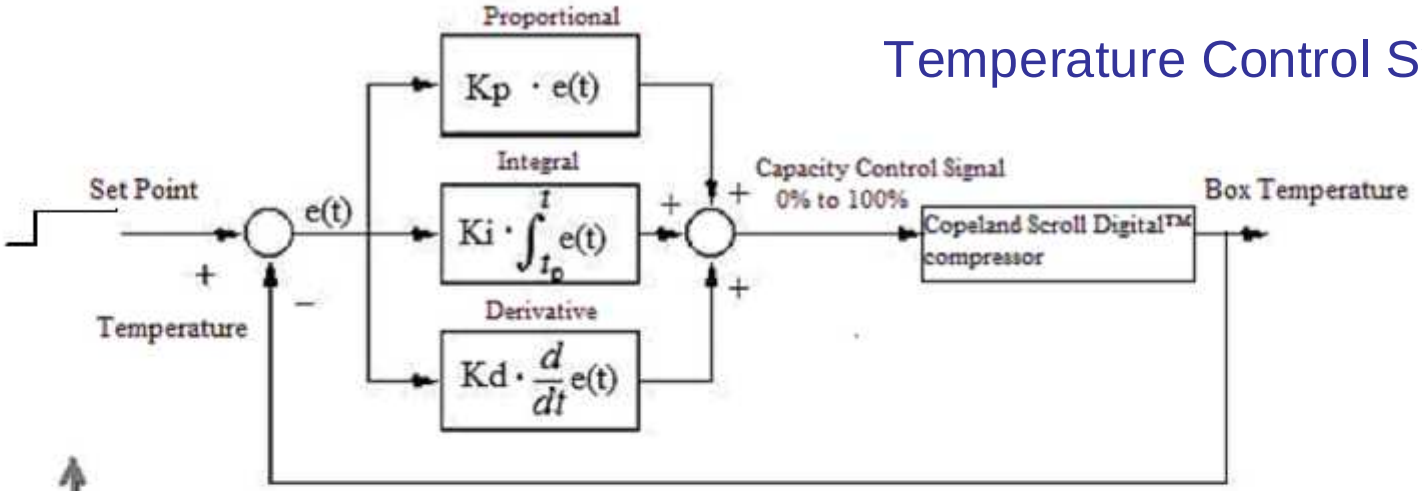
- AC/DC motors versus fan/serpentine belts
- Heating coils versus cooling by reversing refrigeration
- Digital Scroll Compressors – match cooling capacity to load requirements
- Multiple compressors in tandem
- Multiple fans, Variable speed fans, Turn fans off
- Insulation - thicker insulation reduces cargo space but saves energy
- Microstaq's Silicon Expansion Valve (SEV) - Higher efficiency, capacity modulation
- 480 vac 3ph - reduced current, more efficient, thinner wires, less cost

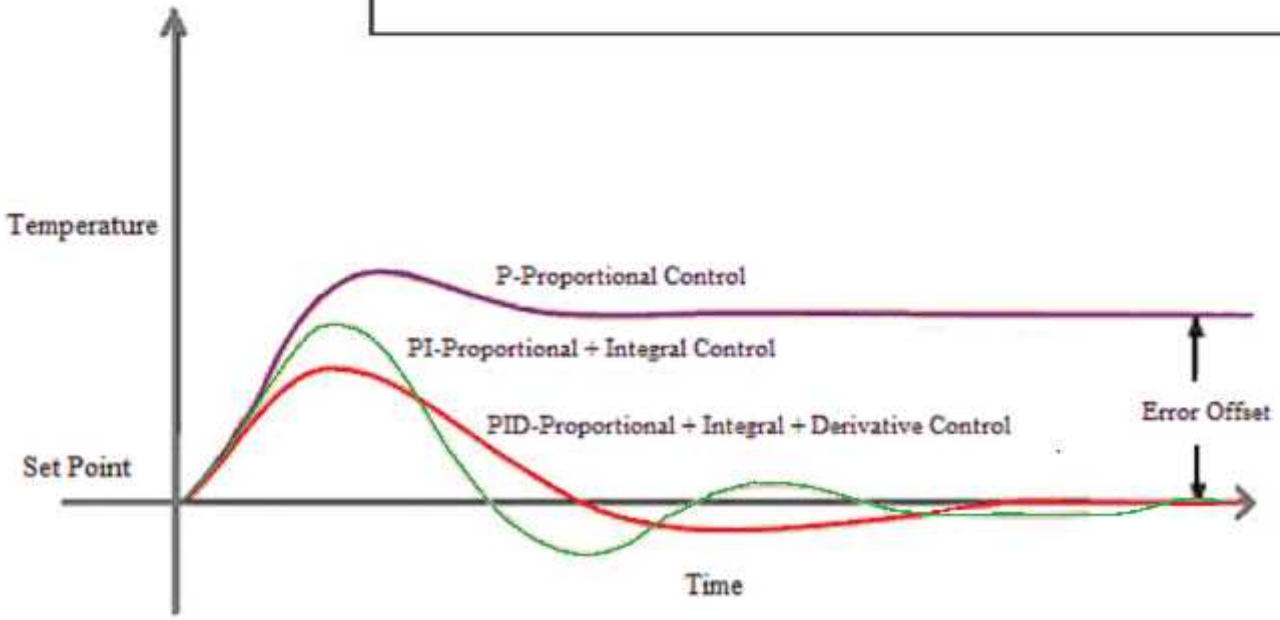
Benefits of Emerson's Copeland Scroll Digital™ compressor

- Has reduced number of mechanical components
- Has reduced maintenance costs
- Requires reduced fuel consumption
- Increased product life
- Linear capacity control from 10%-100%
  - Greatly simplifies mathematical analysis and design of linear control systems
- Amenable to PID control algorithms
- Allows for energy efficient matching of cooling capacity to the load
- 70% fewer moving parts
- More reliable
- Has a longer life span than compressors that use pistons

PID Control

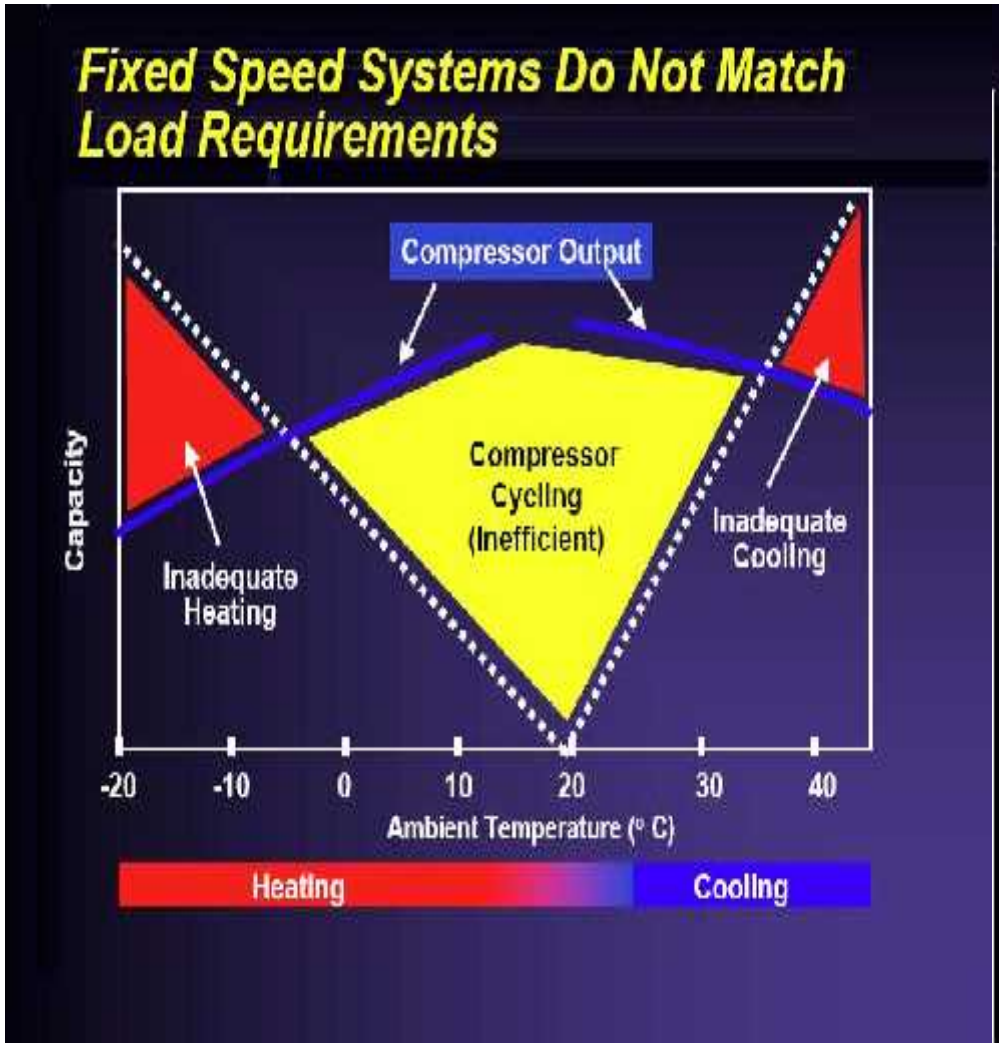
Temperature Control System

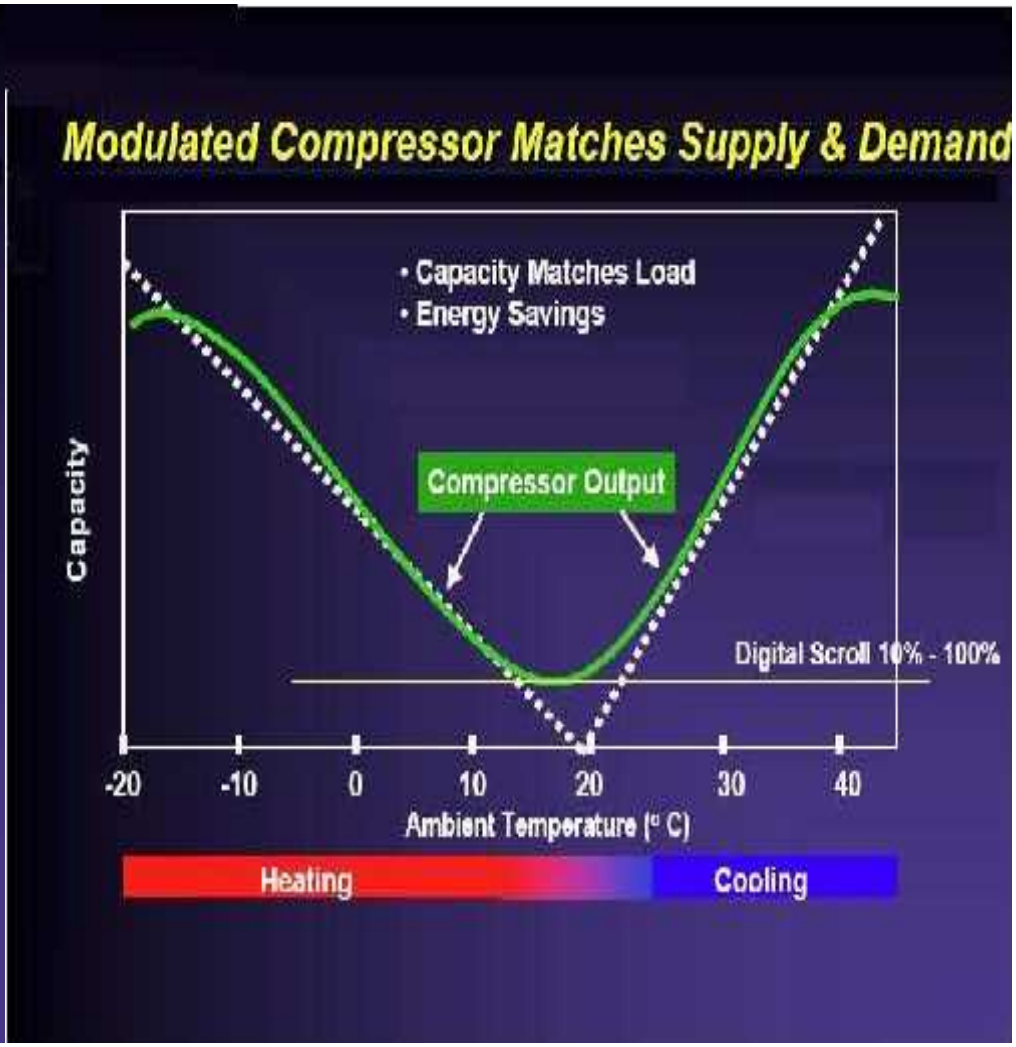




Typical response curves of a Temperature Control System using PID control methods. Using Proportional Control alone results in a steady state error.

General Behavior of Fixed Speed Systems vs Digitally Modulated Compressor





Prototype eTRU using Emerson's Copeland Scroll Digital™ compressor

Demo eTRU using a Copeland Scroll Digital™ compressor and Intra-Tech's prototyped controller

Intra-Tech's prototyped controller LCD display with membrane keys

Control System Ideas

- The eTRU can be treated as dynamical control system
    - Temperature Control System using math models
    - Perform computer simulation of designed system before building prototype
        - Model energy usage behavior using Stochastic Processes and Monte Carlo method
- Kalman Filter
    - Estimation and prediction of box compartment temperature
    - Prediction of discharge temperature
        - Add a mode to limit discharge temperature to prevent damage to load
- Optimal Control
    - Minimize cost functional subject to constraints
    - Find Control Strategy to approach set point temperature using minimum energy
- PID control of each subsystem to obtain desired set point temperature
    - Digital Scroll Compressor
    - Fan Speed Control
    - Expansion Valve Control

Approach to Clean Energy Mobile TRUs

- Start with a stationary Electric Trailer Refrigeration Unit (eTRU)
- Improve the energy efficiency of the eTRU

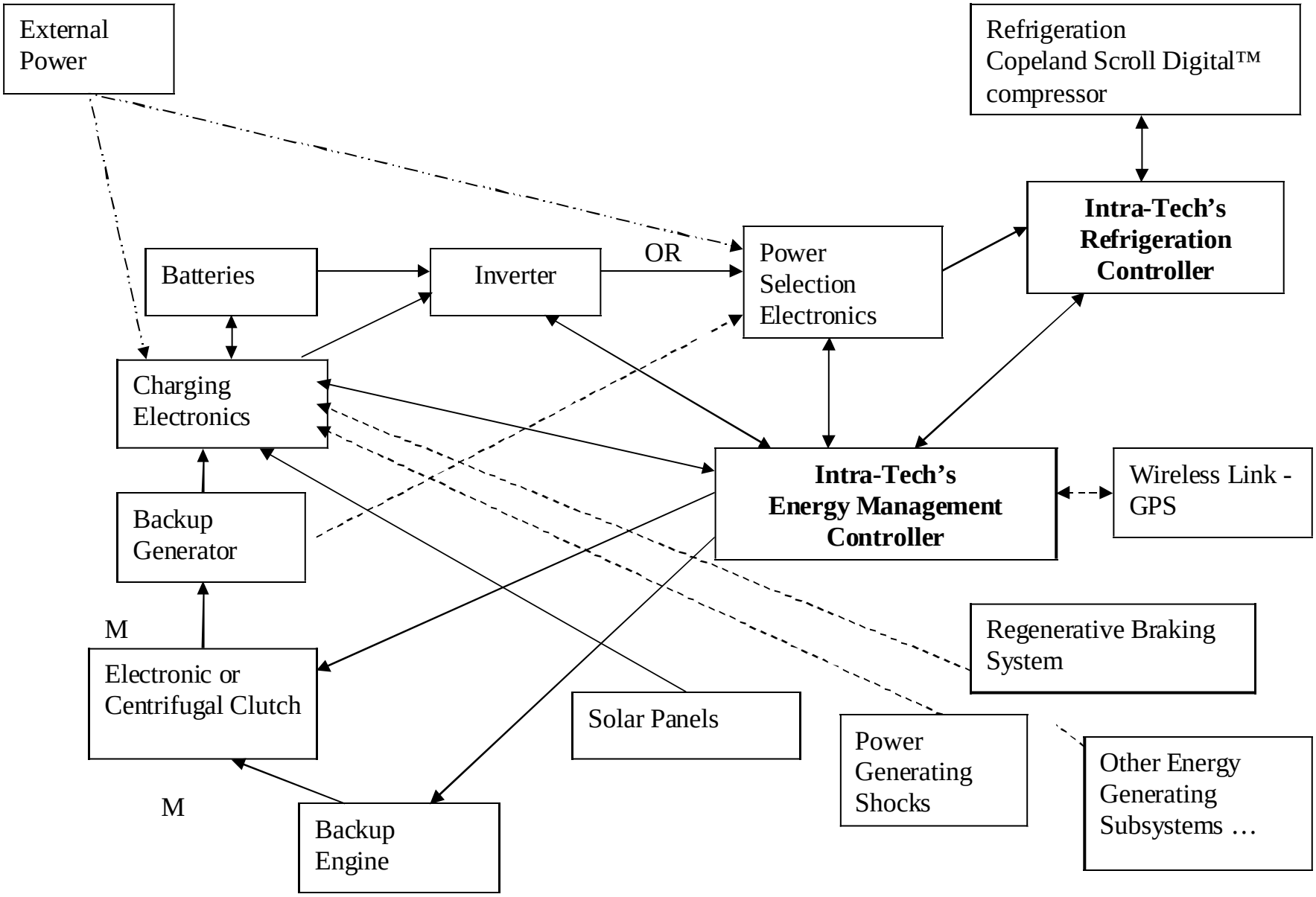
Transition to a Mobile eTRU

- Use clean energy sources such as batteries and solar panels to power the units while traveling
- Before starting the trip, plug the eTRU in and wait until the temperature of the cargo reaches the “set point” temperature and the batteries are fully charged (“pull down” mode)
- During the trip, the eTRU will be in “temperature maintenance” mode, requiring much less energy to keep the cargo at set point temperature
- Develop a Controller to efficiently manage the energy usage of the eTRU

Some Sources of Clean Energy

- Rechargeable Batteries
- Solar Panels
- Regenerative Braking
- Power-Generating Shock Absorbers

Intra-Tech's Energy Efficient & Reduced Emissions Mobile Refrigeration System High Level Block Diagram



Intra-Tech's Energy Management System (EMS)

- Monitor the temperatures, charging rates of the battery, energy demands of the eTRU and the heat transferred between the inside and outside of the box
- Determine if the battery capacity is sufficient to power the predicted refrigeration energy demand
- Communicate with the charging electronics to determine the state of the batteries and the charging rate
- The inverter converts the DC battery voltages to compatible AC voltages required by the refrigeration system. Currently, it will be 480vac 3 phase. The controller will turn off the Inverter when it is not needed
- The Power Selection Electronics will select the refrigeration power source as external, from the inverter or from the backup generator
- Among others, regenerative brakes and power generating shock absorbers will be considered in the future as a source of clean energy
- Will monitor and control the whole system and determine if a small diesel powered backup generator should be turned on for a short time
- When more electrified truck stops become available, using a wireless GPS interface, the EMS may direct the trailer operator to rendezvous to a nearby truck stop for charging and powering the eTRU or to just start the backup generator

Conclusion

- eTRUs reduce harmful diesel emissions, can save energy and can reduce energy costs
- Transitioning from stationary to mobile eTRUs can be done by making the eTRUs more energy efficient and powering them by clean energy sources
- Digital Scroll Compressors can match cooling capacity to the load which improves energy efficiency and are amenable to developing PID algorithms since the capacity can be controlled linearly
- Emerging technologies can make clean energy mobile eTRUs cost effective