CAES

Compressed Air Energy Storage

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Overview

- Design Requirements
- System Overview
- Project Scope Re-statement
- Risk Assessment
- Analysis
- Uses of the System
- Conclusion

Design Requirements

- The focus of this project is to explore the feasibility for coupling wind turbines with small scale Compressed Air Energy Storage (CAES) systems.
- Store wind energy during off-peak hours when the demand for electrical power is reduced.
- Utilize stored energy efficiently on demand.

System Overview

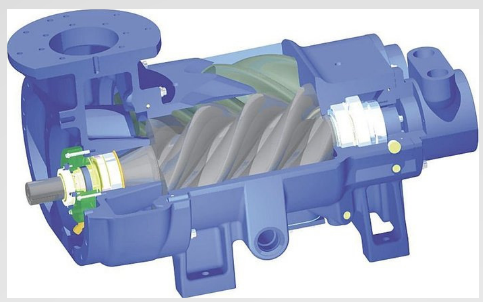
- Compressed Air Energy Storage System
  - Compressor
    - Quincy model #QGV 40
      - Max Pressure = 150 psi
      - Max Flow Rate = 152 CFM
  - Man Made Pressure Vessel
    - Provided by sponsor
      - Volume = 11, 310 cubic feet
      - Max Pressure = 200 psi
  - Air Motor
    - Ingersoll Rand 12kW Air Motor
      - Optimum Operating Pressure = 90 psi
      - Optimum Operating Flow Rate = 425 CFM

System Overview

12kW Air Motor

Courtesy Ingersoll Rand

Courtesy Quincy



Air Compressor

System Demo

Courtesy of IESP

Project Scope

- Wind Data Analysis
  - Data provided by sponsors
- Load Requirement
- Analysis
  - Theoretical system performance based on component selection

Project Work

- Derived governing equations
  - Variable power input
  - Variable power extraction
- Obtained numerical data
  - Compressor power curves for variable power input
  - Experimental wind data
  - Air motor power curves
  - Solve ODEs with numerical data
- Final recommendations

Limitations

- Input Power Range
  - Wind does not blow at constant velocity
  - Mechanically drive air compressor
- Compressor
  - Air end only for mechanical drive
  - Variable output
- Pressure Vessel
  - Size
- Air Motor
  - Minimum Operating Pressure
  - Variable load

Risks

- Wind
- Variable Compression
  - Outlet Pressure
  - Volumetric Flow rate
    - Effects vessel fill time and efficiency
- Pressure Vessel
  - Controls for input/output
  - Air at high pressure
- Air Motors
- Equipment
  - Size of project and equipment
  - Power generation

Governing Equation

Continuity Equation

$$0 = \left.\frac{\partial m}{\partial t}\right|_{CV} + \iint_{CS} \rho V_n dA$$

Ideal Gas Assumption

$$m = \frac{p\cancel{V}}{RT} \Rightarrow \left.\frac{\partial m}{\partial t}\right|_{CV} = \frac{\cancel{V}}{RT}\frac{dp}{dt}$$

Mass through the control surface

$$\iint_{CS} \rho V_n dA = \iint_{out} \rho V_n dA - \iint_{in} \rho V_n dA$$

Governing Equation Cont.

Case I. Surplus power to compress air

$$\frac{\forall}{RT}\frac{dp}{dt} = \iint_{in} \frac{p}{RT} V_n dA$$

$\forall = Volume$

$\dot{\forall} = Volumetric Flow Rate$

$p = \Pr essure$

Solve for Pressure differential

$$\frac{dp}{dt} = \frac{1}{\forall} p_{in}(t)\dot{\forall}(t)$$

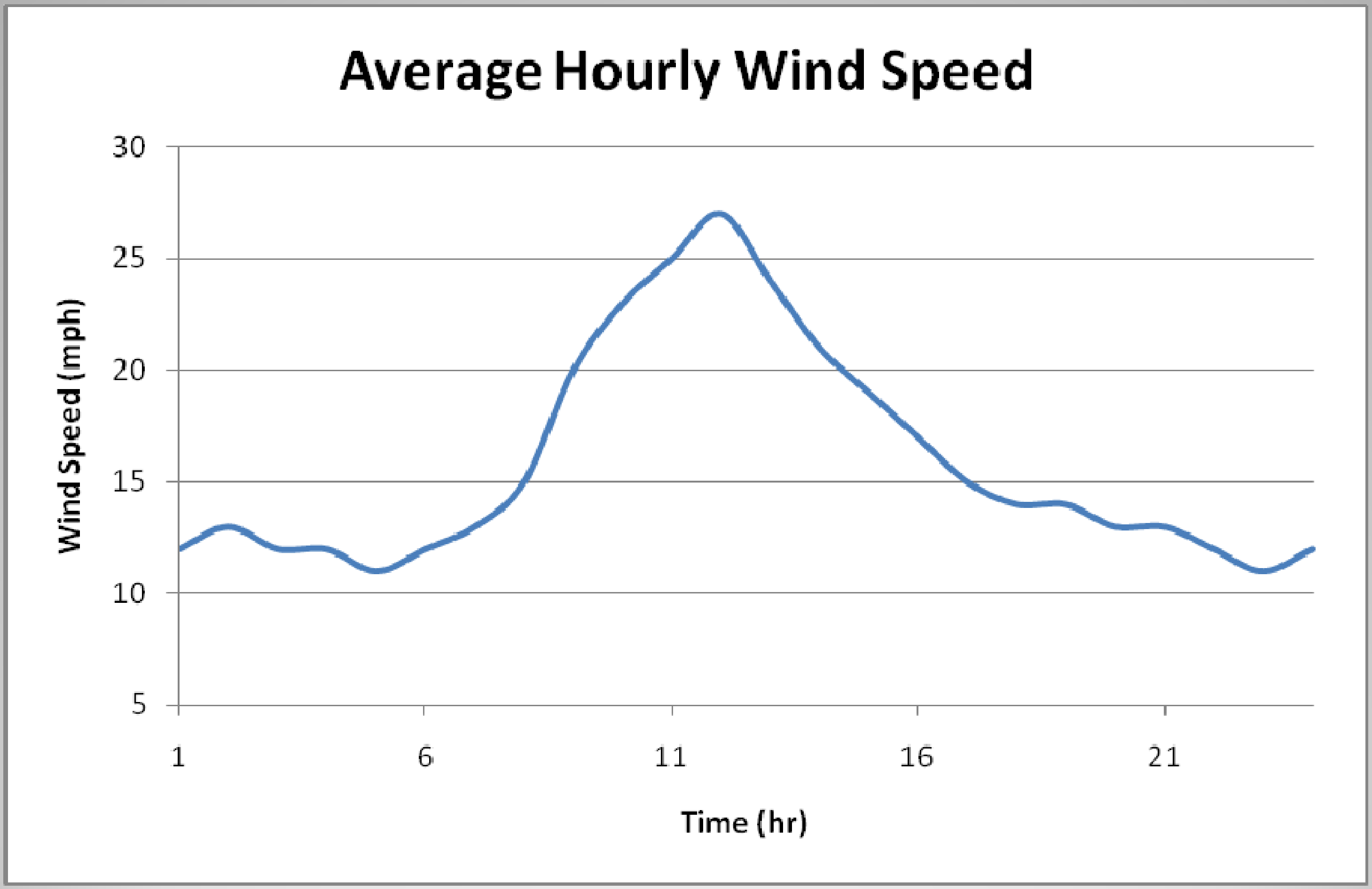
Case II. Peak load – power generation

$$\frac{dp}{dt} = \frac{1}{\forall}\left[-p(t)_{out}\,\dot{\forall}(t)_{out}\right]$$

Solving Differential Equations

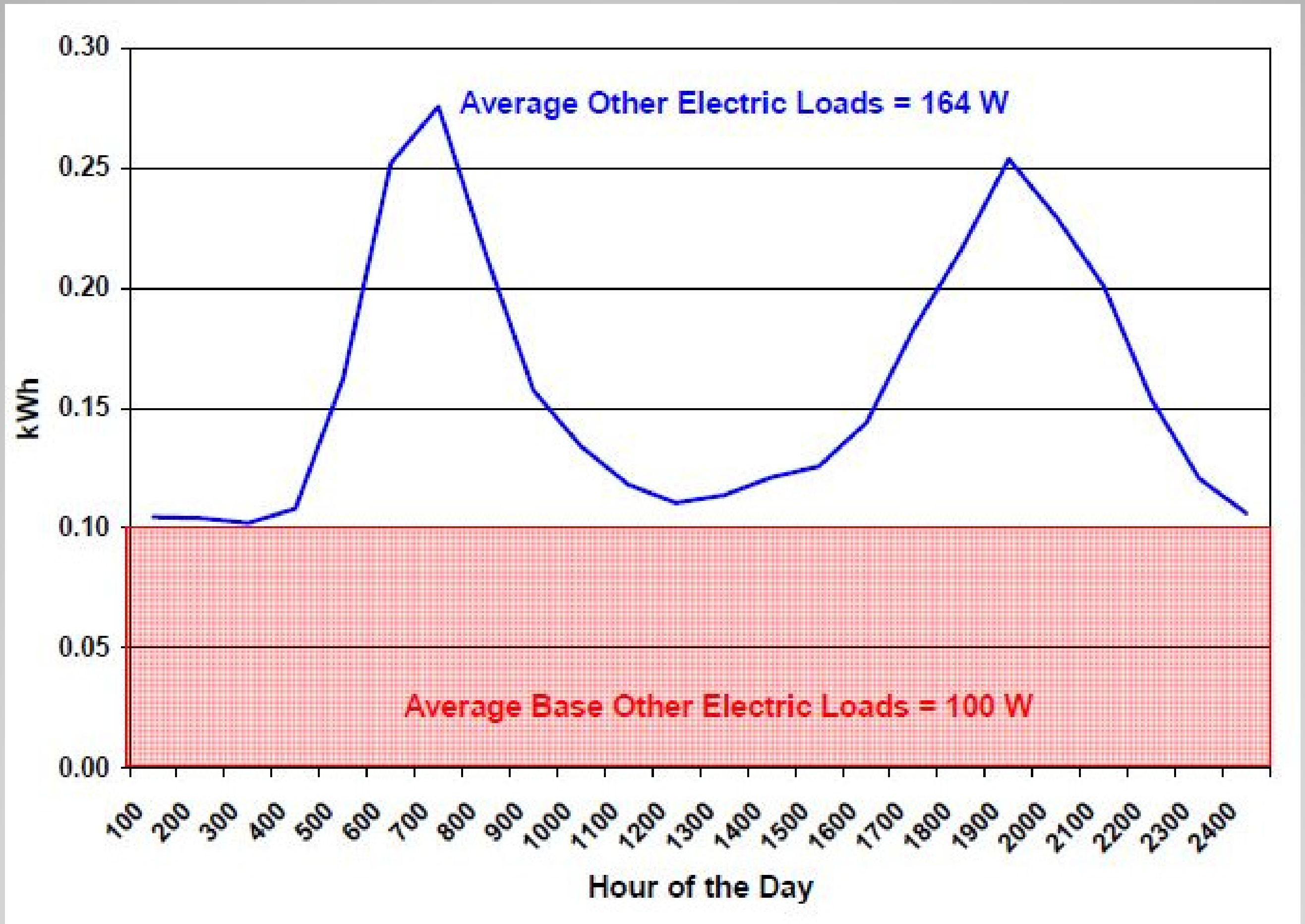
- Experimental data for wind speed over time
  - Power output of turbine using power curve
- Compressor data
  - Compressor power curves for variable power input
  - Flow rate for variable rpm
  - Constant pressure output
- Air Motor data
  - Compute load requirement
  - Throttle motor to match load
  - Variable input parameters
- Numerical integration

Wind Data

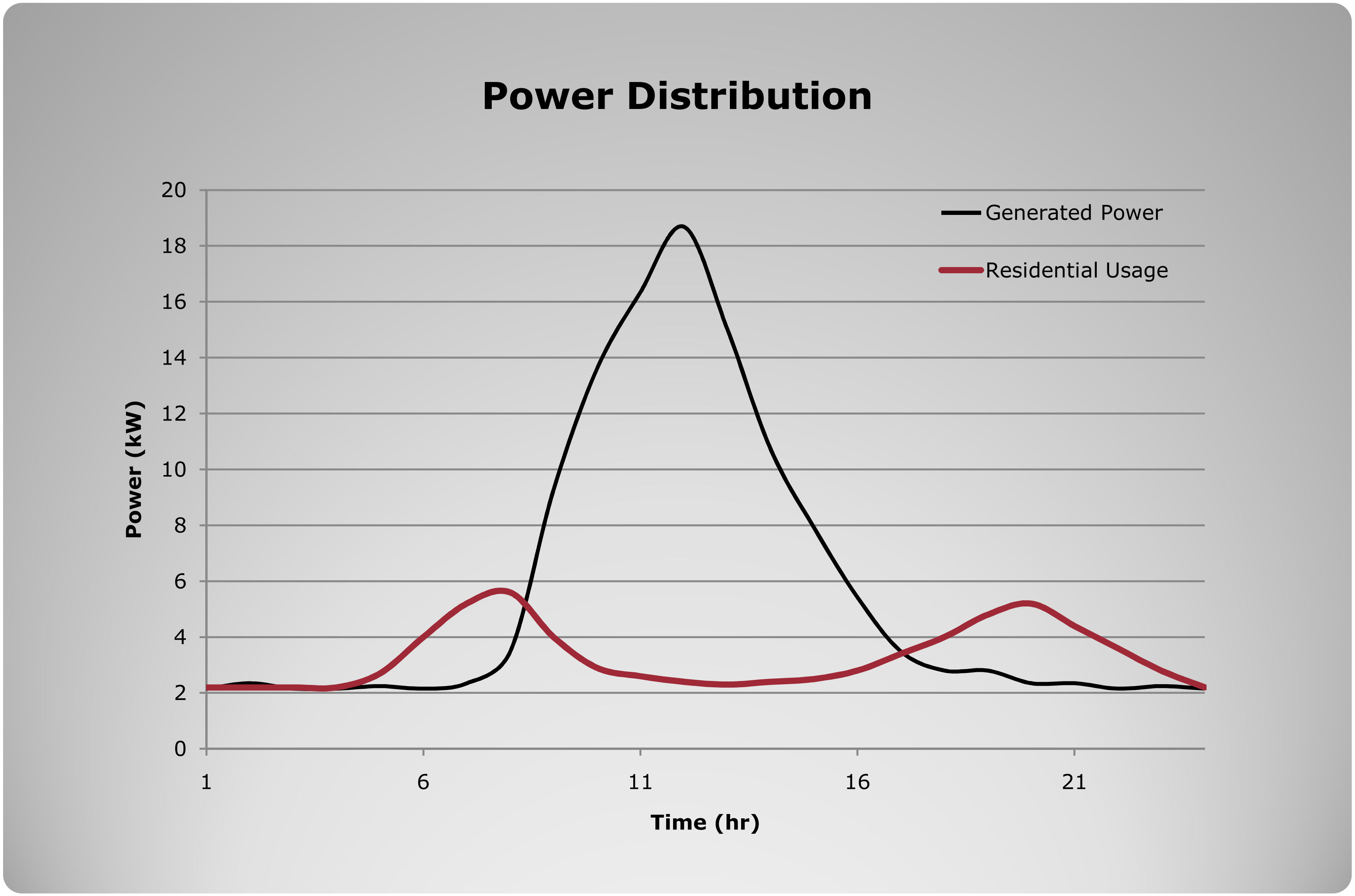


Average Hourly Wind Speed
30
25
20
15
10
5
Wind Speed (mph)
1
6
11
16
21
Time (hr)

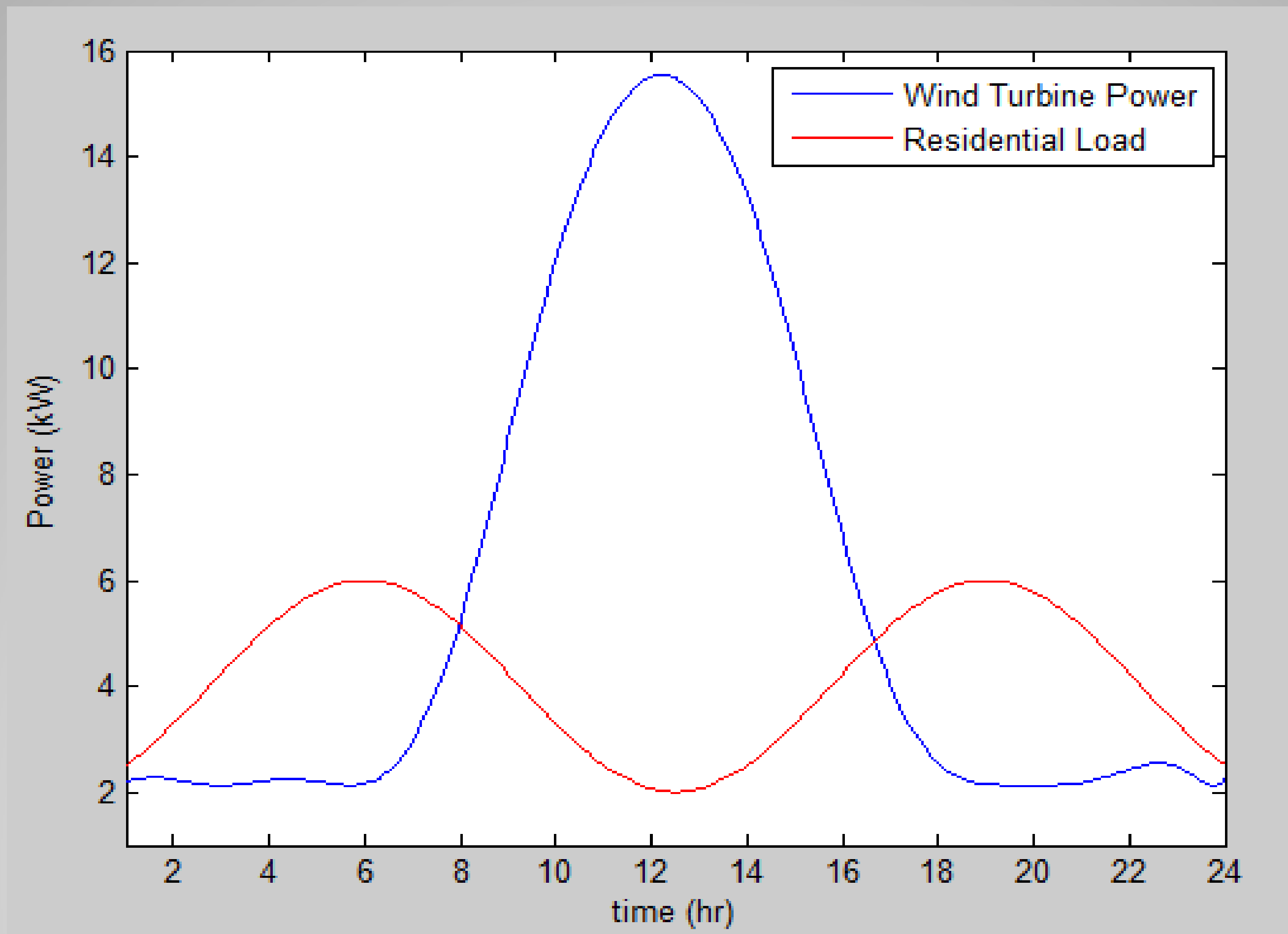
Residential Average Load



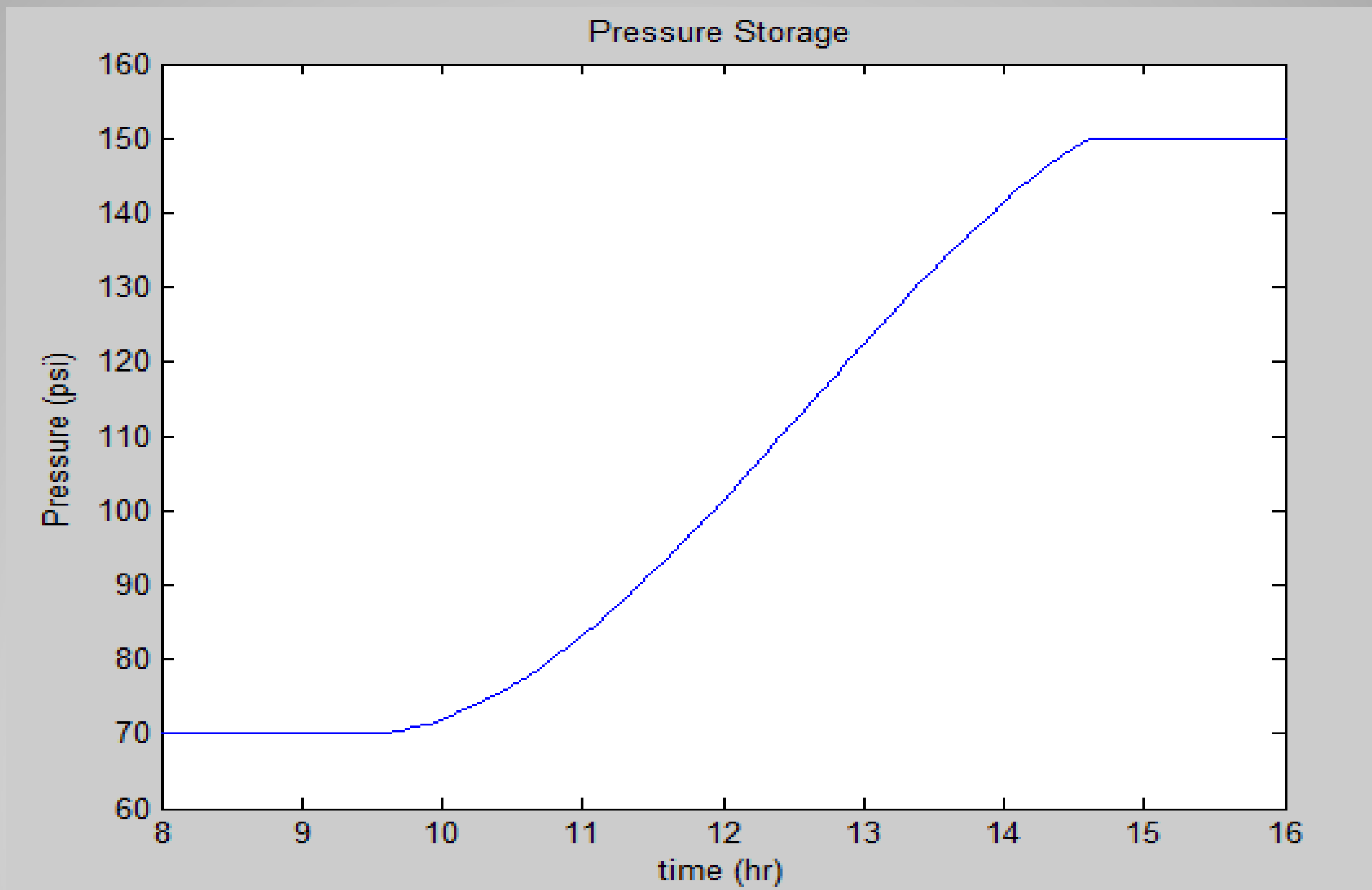
Courtesy: NREL/ Habitat for Humanity Zero Energy House


Power Distribution
Generated Power
Residential Usage
Power (kW)
20
18
16
14
12
10
8
6
4
2
0
1
6
11
16
21
Time (hr)

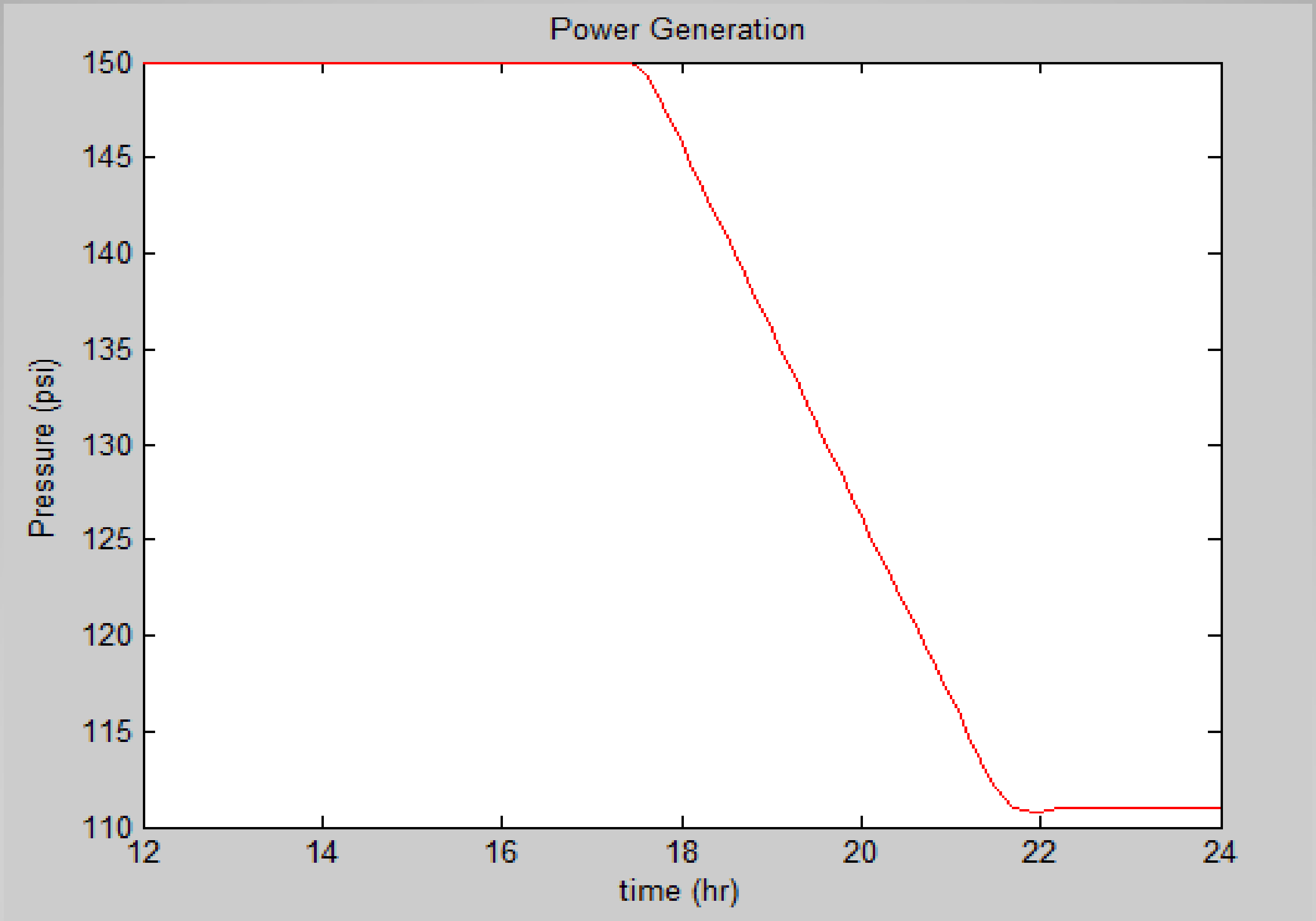
Theoretical Power Distribution



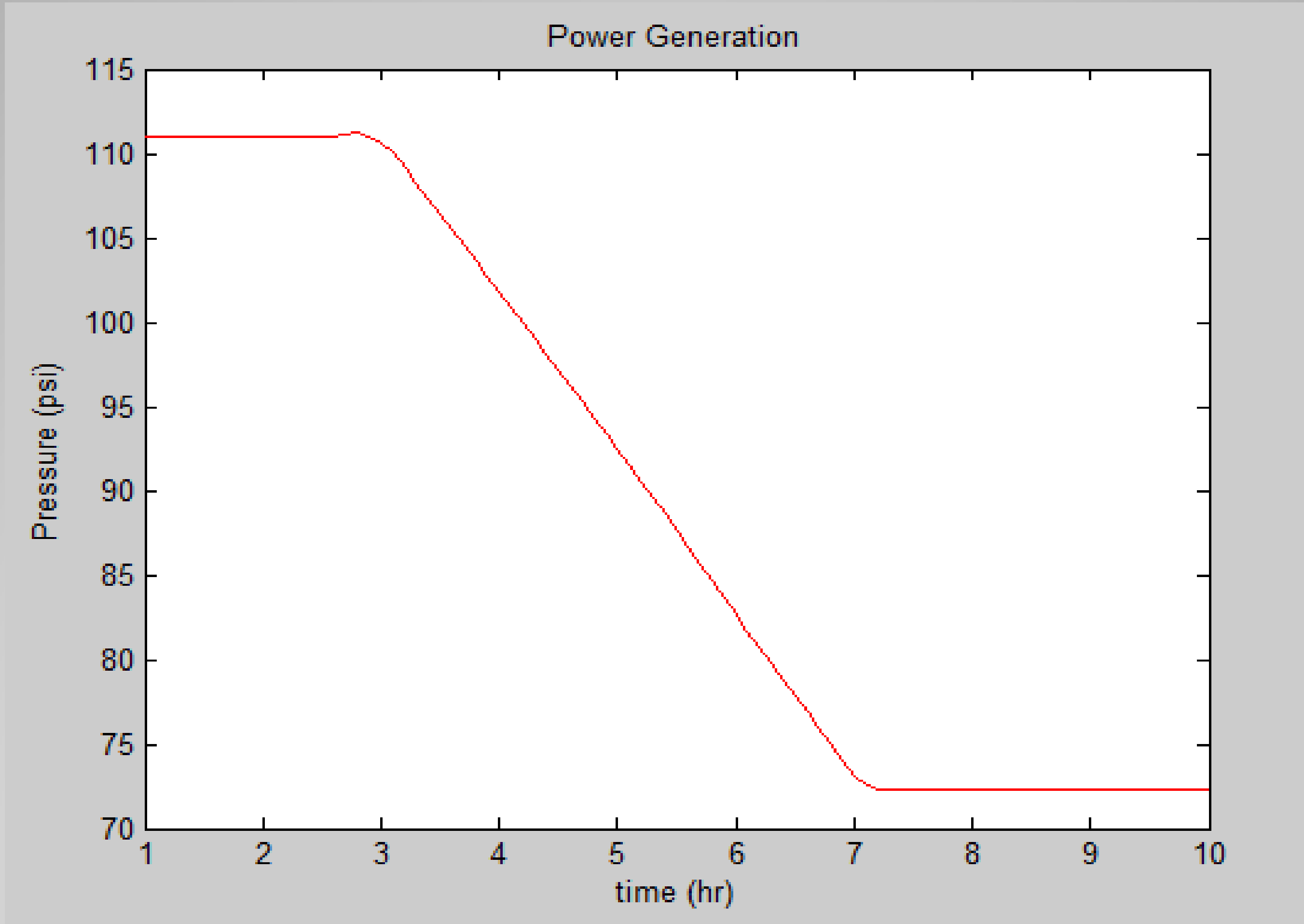
Surplus Power Pressure Storage



Hourly Pressure Variation



Hourly Pressure Variation



Uses of small scale CAES

- Can supply power for a small community of Zero Energy houses
  - NREL/ Habitat for Humanity Zero Energy House
- Eliminates Electric Bills
  - Can get the Electric Company to Pay YOU.
- Free Energy that is used and if not stored for later use

Drawbacks

- Sustainability
  - Variance between power demand and average wind
  - Need to increase storage volume
  - Pressure in vessel will settle after a few hours & overnight
- Price
  - Compressors >$4000
  - Air Motors ~$9000
  - 2 Control Valves, 2 Solenoid Valves, ~$1000
- Cost Benefit Analysis needs to be done

Conclusions

- Project feasible on smaller scale
- Will require larger compressor
  - Multi-stage compressor with higher pressure output
  - Maximize flow rate for minimum fill time
  - Increase power input
- Will require larger capacity vessel
  - Three times larger than current vessel
- Air motor needs to be throttled down to 7 kW
  - Provides longer run time
  - More sustainable power output for required load

Sponsors

- Dr. Srinivas Kosaraju
- Dr. Rob Hovsapian
- Keuka Wind

Questions?