CAES

Compressed Air Energy Storage

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Overview

- Project Introduction
- Constraints
- Design Concept
- Component Analysis
- Conclusion

Project Overview

- What is CAES?
  - Compressed Air Energy Storage
- How can we store Wind Energy
  - Compress Air
    - Simple, available, cheap
    - Highly inefficient
- Store the Compressed Air
  - Man made pressure vessel for small scale
  - Larger scales use caverns
- Use the Compressed Air
  - Turbine, air motor or supply air

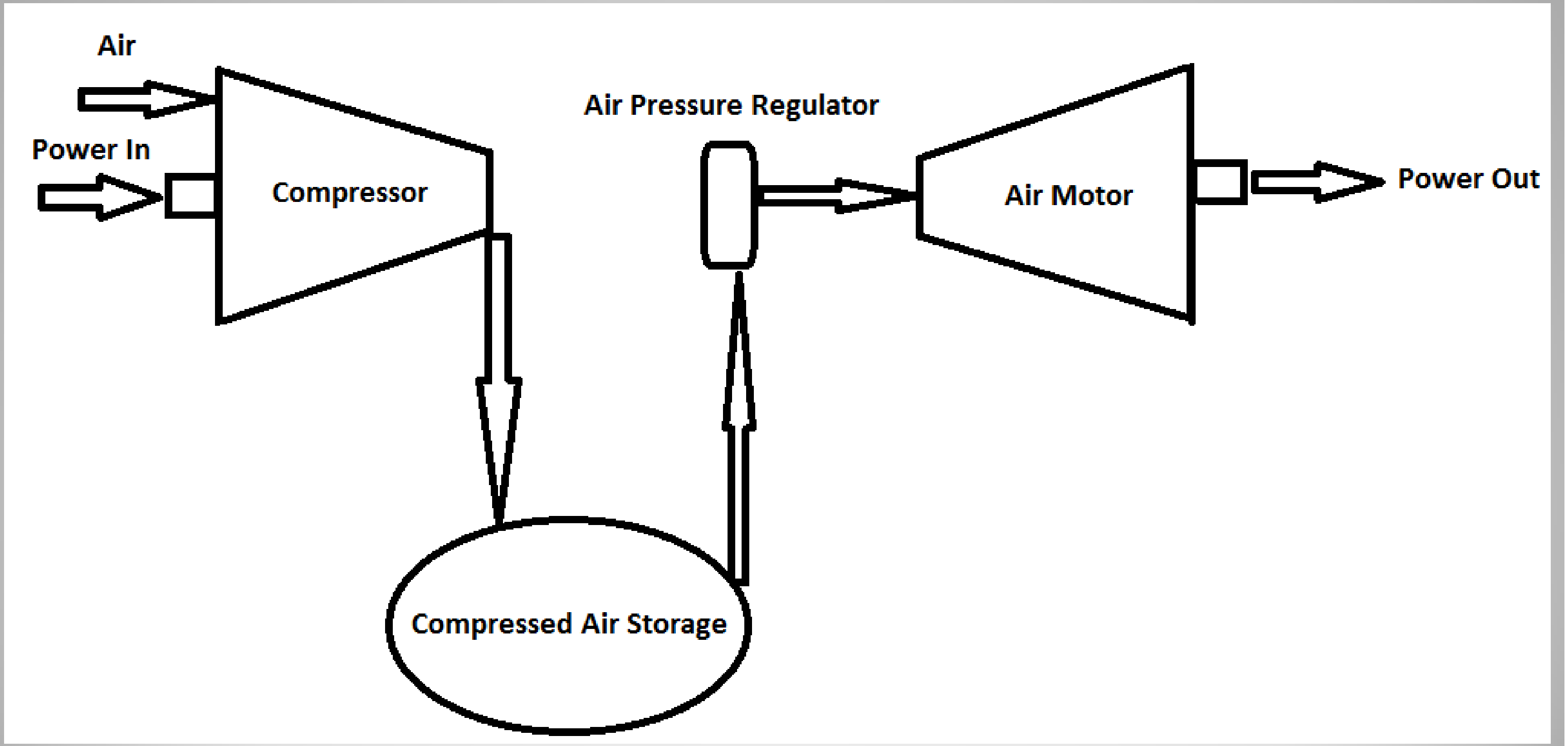
Objectives

- Design small scale CAES systems
  - 20kW, 50kW, 100kW, 250kW
- Connect Existing Equipment in series to create our system
- Perform analysis on:
  - Overall system performance
  - Overall efficiency
- Is this system feasible for small scale?

Limitations Encountered

- Mechanical or Electrically Driven Compressor
  - Electrical most widely available
  - Compressors are made for non-variable electrical inputs
    - Limits our range
    - May need to normalize power input from wind turbines
- Compressor input Power limited to ±5%
  - Outside of this range, operation is extremely inefficient and damaging to compressor
- We have too wide of a Power Range for one or two compressors for each rating
  - Must use one compressor for each rating
    - Otherwise price gets outrageous
- Pressure Vessel
  - Very limited on range (max 200PSI)

CAES Design


Air
Power In
Compressor
Air Pressure Regulator
Air Motor
Power Out
Compressed Air Storage

Compressor Type

- Twin Screw Air End
- High Adiabatic Efficiency
- High durability
- Expected lifetime of 100,000 hours with routine maintenance every 4,000 hours.
- Quieter operation in comparison to piston type compressor.

Courtesy of Quincy

Power Input

Power Input(kW)	20	50	100	250
Power Input(hP)	26.8	67	134	335
Available Power Input(hP)	25	60	125	300

- From our customers needs the available power inputs from the wind turbine are listed in kilowatts on the top row of the above table.
- Manufactured compressors are sold with power input listed in horsepower making an exact match difficult.
- The last row in the above table shows the readily available power inputs in horsepower, these will be the values used for our analysis.

Compressor Data

Compressor Model	QSB/T 25	QSI-250	QSI-540	QSI-1400
Power Input(hP)	25	60	125	300
Full Load Pressure (psi)	150	125	125	125
Maximum Pressure (psi)	165	150	150	150
Full Load Capacity (acfm)	87	256	540	1400
Compressor Manufacturer	Quincy	Quincy	Quincy	Quincy

- Each compressor model above is a Quincy manufactured air end, packaged with a motor of the specified power input.
- As can be noted the volumetric flow rates increase with each increase in power input.

Pressure Vessel

- Steel pipe welded caps
- 12 ft diameter
- 100 ft length
- ¾" thickness
- Yield stress of 30 ksi
- Allowable stress of 16.9 ksi (ASME standards)

$$\sigma_{hoop} = \frac{P * r}{t}$$

$$P = 312.5\, psi = P_{fail}$$

$$P_{allow} = 176.25\, psi$$

$$\sigma_{long} = \frac{P * r}{2 * t}$$

$$P = 625\, psi$$

Pressure Vessel

- Assumptions:
  - Ideal gas law
    - Compressibility Factor=0.99
  - Temperature change negligible
  - Initial fill with P = 0 psi
- Secondary Fill
  - Tank pressure 70 psi
  - Refill to 150 psi

$$t_{20kW\_initial} = 103.8\ min = 1.73\ hr$$

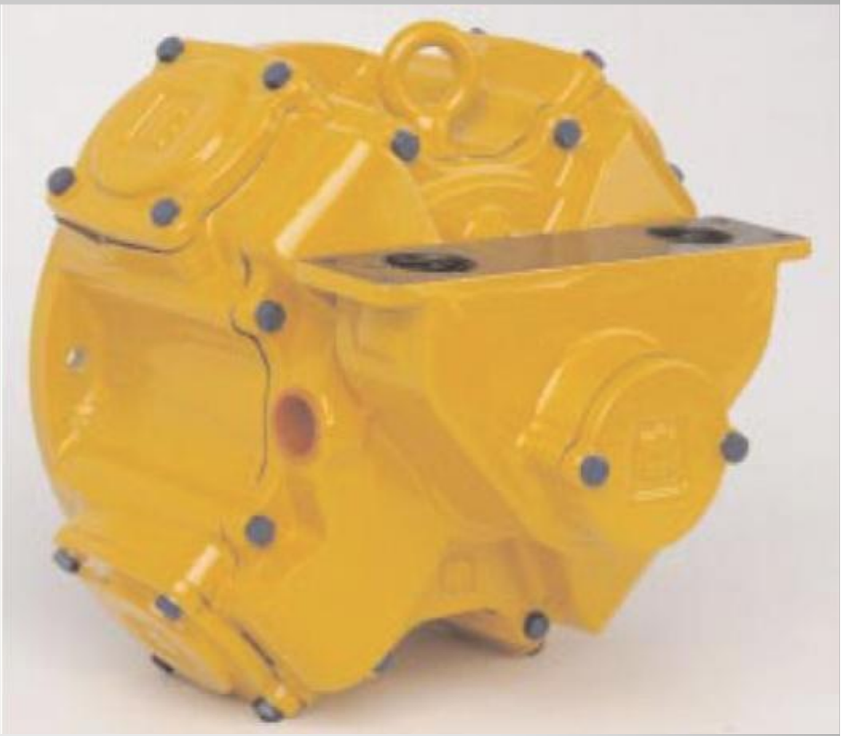
$$t_{20kW\_refill} = 55\ \mathrm{min} = 0.92\ hr$$

$$t_{50\,kW\_initial} = 33.76\ min = 0.56\ hr$$

$$t_{50kW\_refill} = 18\ \mathrm{min} = 0.3\ hr$$

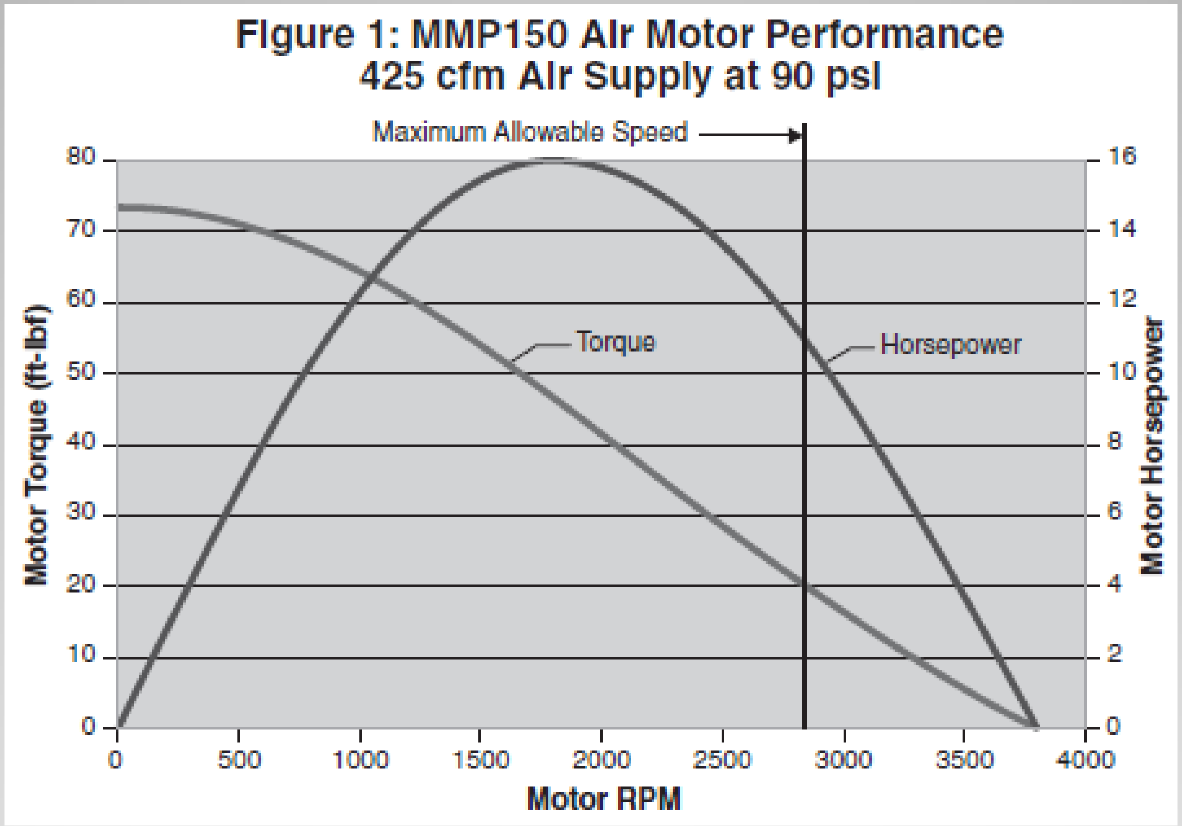
Power Generation

- Ingersoll Rand MMP150
- 16 HP (12kW)
  - Max Air pressure 90 psi
  - Max Flow Rate 425 CFM
- Free Speed RPM 3800
  - Speed at Max RPM 1800
- Torque 61 lb-ft



Courtesy Ingersoll Rand

Air Motor Power Curve



Courtesy Ingersoll Rand

Power Generation

- Operating Pressure will be 90 psi
  - Most power out
- Cut off Pressure will be 70 psi
  - Recommended by manufacturer
  - Efficiency of motor reduces

$$P_{max} = 150\ psi \qquad V = 11{,}310\ ft^3$$

$$P_{min} = 70\ psi \qquad \dot{V} = 425\ \frac{ft^3}{min}$$

$$P_{in} = 90 psi$$

$$dP = \frac{P_{in}}{V} * \dot{V} * dt$$

$$t = \frac{(P_1 - P_2) * V}{P_{in} * \dot{V}} = 23.6\ min = 0.39\ hr$$

Calculation of Run Time for 20kW Power Rating

Power Generation

- 50kW Power rating
  - Tonson M18 Air Motor(23kW)
  - 900 CFM, 1500RPM, 110 ft-lb
- Higher Power Requires
  - Air Flow > 1000CFM
  - Run Time reduced
  - Low Efficiency
- Limited by Vessel

$$P_{max} = 150\ psi \qquad V = 11{,}310\ ft^3$$

$$P_{min} = 70\ psi \qquad \dot{V} = 900\ \frac{ft^3}{min}$$

$$P_{in} = 90 psi$$

$$dP = \frac{P_{in}}{V} * \dot{V} * dt$$

$$t = \frac{(P_1 - P_2) * V}{P_{in} * \dot{V}} = 11\ min = 0.19\ hr$$

Calculation of Run Time for 50kW Power Rating

Efficiency

- Energy is defined by kW-hr
  - We know kW-hr as Joule
  - Power used multiplied by time
- Assumptions
  - Ideal Gas Law
  - Vessel has constant temperature

$$\eta = \frac{Power_{out} * t_{air\ motor}}{Power_{in\_compressor} * t_{fill}} * 100$$

$$\eta_{20kW\_initil} = 11.6\%$$

$$\eta_{20kW\_refill} = 21.8\%$$

$$\eta_{50kW\_initial} = 13.17\%$$

$$\eta_{50kW\_refill} = 24.7\%$$

Cost Analysis

Item	Description	Quantity	Price
QSB/T 25	25 HP Air end	1	$5,486.00
IR MMP150	16 HP Air motor	1	$9,463.00
Tonson M18	31 HP Air motor	1	~$12,000.00
	Flow Regulator		
Travel to Kueka		1	~$100
		Budget	$2500

Future Work

- Recommend the chosen compressors and Air Motor to Kueka Wind for the chosen Power Ratings
- Take a trip to Kueka Wind Farm
- Analysis for variable power input
- Integrating components for CAES system
- Testing at Kueka Wind

Sponsors

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

Questions?