CAES: Combined Compressed Air Energy Storage

Concept Generation and Selection

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Project Introduction

Renewable and sustainable energy sources have become a major topic of interest with the depletion of oil and natural gas supplies. In addition, the need for cleaner and more efficient energy processes are becoming increasingly apparent. Wind energy is an obvious choice when searching for sustainable and environmentally friendly energy sources. However, there currently lacks an efficient means of storing renewable wind energy for later use. Our project is to design a more efficient means of harnessing surplus wind energy by compressing air, storing it, and defining its later use.

The focus of this project is to identify the need for coupling wind turbines with Combined Air Energy Storage (CAES) systems. We will construct and design a system driven by wind turbines and a power generation unit to convert energy to electric power. Analysis will be done on the system performance, efficiency and energy balance. This will be done while keeping the cost and scalability of the system at a minimum while keeping efficiency high.

The CAES system will be comprised of three subsystems: a compressor, a storage device such as a pressure vessel, and an energy generator that will allow the stored compressed air to be converted to electrical energy. The primary focus of this project is efficiency of the system, while keeping the system scalable for use within large and small systems used for power generation. Our system will have a variety of power inputs that range from 20 kW to 250kW.

CAES Background

Currently there are only two power plants in the world that use CAES, one in Germany and one in Alabama. However, both plants do not use a renewable energy source to power the compressor; they use excess grid electricity as a power source. There is currently a project in Iowa that will use wind turbines such as the type our project is focused on. The systems in use currently generate 290 MW and 190 MW respectively. Our system will not generate as much power because our system is focused on more local use rather than power distribution.

The current power plants utilize abandoned mines or empty caverns as their pressure storage area. These vessels are able to store massive volumes of air. For example, the plant in

Germany is able to store approximately 300,000 m^3 of air at a pressure between 700 psi to 1000 psi but operating pressure is around 600 psi. When the extra power is needed, air is released from the cavern and injected into a gas turbine which is connected to a motor-generator. The motor generator functions as a two in one machine; as a motor to drive the compressor during off peak hour then as a generator when the extra power is needed. The air is compressed for around 8 hours and then is able to be used for 2 hours. The total power efficiency of the plant is approximately 40-50%. A simple diagram of the plant is shown below.

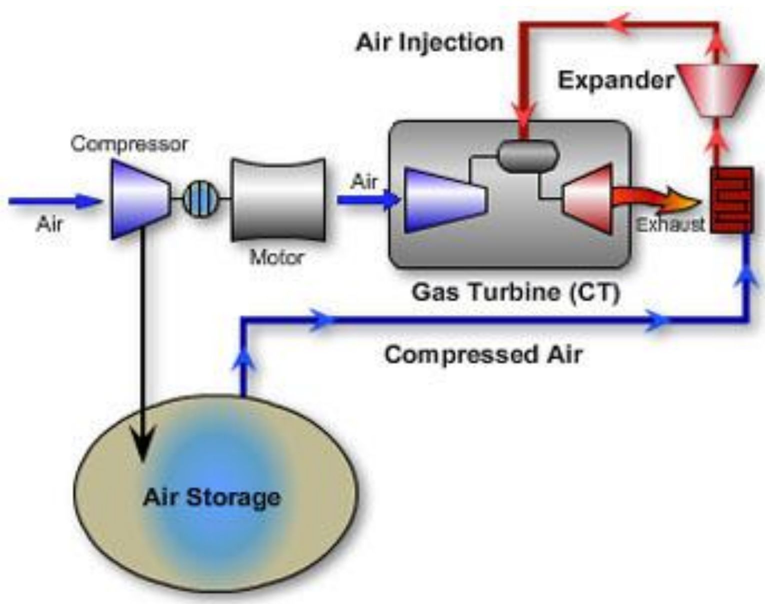

Figure 1 -Diagram of German CAES Power Plant

Wind Turbines

Wind turbines come in all shapes and sizes, from lift based turbines that mimic the profile of an airplane wing to create rotational motion to drag based turbines that rely on the wind to push the blade. The turbines our system will utilize are known as rim based turbines as shown in Figure 2 below. Whereas the larger lift based wind turbine require approximately 12 mph of wind to begin generating electricity and has the generator at the center or hub. The rim based turbines only require approximately 2 mph wind to begin generating electricity and the generator is at the base of the turbine.

Figure 2-Kueka Wind Rim based wind turbine

Wind Data

The compressed air energy storage system is dependent on the power output provided by the Keuka Wind turbine based out of Interlachen Florida. The power generation of the wind turbine at Keuka is dependent on the wind speed that is available; therefore wind data for the area must be analyzed in order to determine the equivalent power outputs. Wind data that has been averaged over the past 25 years is shown below in Figure 3 for Gainesville Florida which is in close proximity to Interlachen. From the data it can be noted that an average yearly wind speed of 6.3 miles per hour can be expected. So the wind turbine should be capable of producing power in the range of 20 kW to 250 kW as was expected due to the design of the wind turbine. The drag wind turbine is capable of operating at wind speeds as low as two miles per hour, meaning that at our average speed a sizeable amount of power will be created for consumption, and for use within the CAES system during the off peak hours.

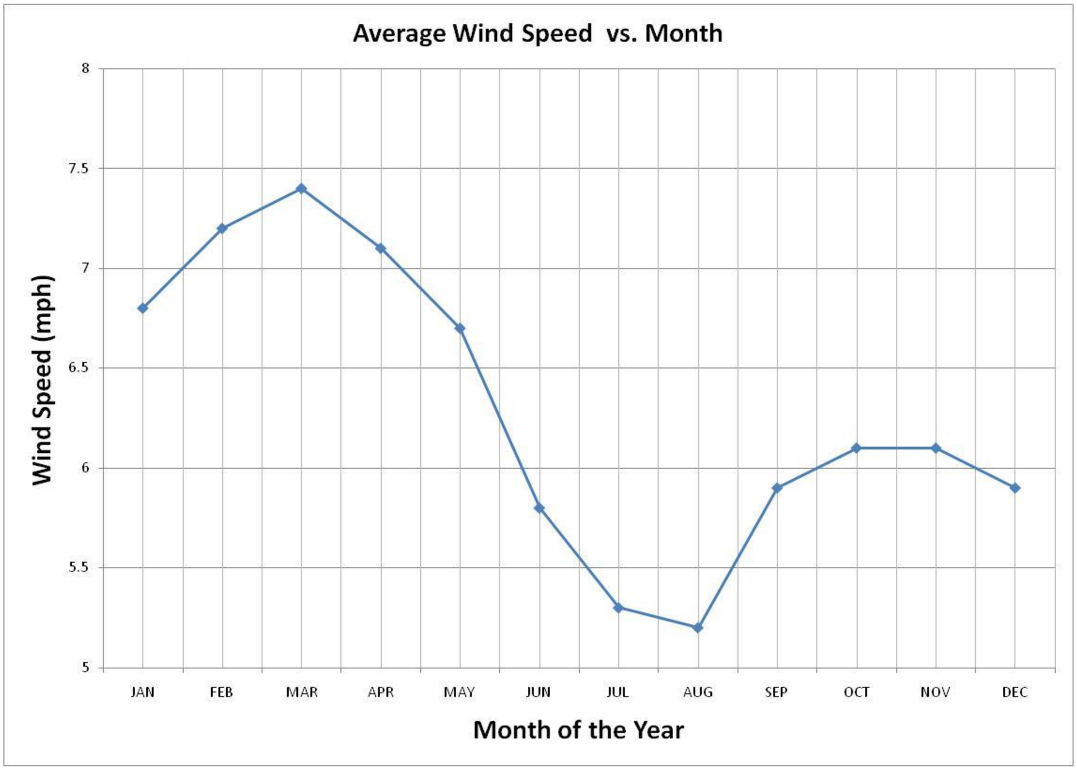

Figure 3- Wind Data for Gainesville Florida

Compressors

For the application of compressed air energy storage the efficiency of the compressor within the unit will define the success of the system. Due to the location of the wind turbine at Interlachen, Florida an average wind speed of 6.3 miles per hour can be expected. Therefore a small amount of power will be usable as energy to run the compressor during the off peak hours. For the purpose of this design project we will design the compressor to be capable of operating at an input power range of 20kW to 250kW. At these power ranges we can expect a low flow rate into the compressor; therefore as can be noted in Figure 4 below a rotary type compressor will be best suited for our system. Within the rotary type of compressors there are two different variations of compressor that will be considered, helical-lobe and sliding vane compressors. However another type of compressor exists that has been created since Figure 4 was created. The guided rotor compressor is a relatively new positive displacement device that has become the industry standard for many compressions applications since its inception in the early 1990's. Each of these three variations will be described below in detail.

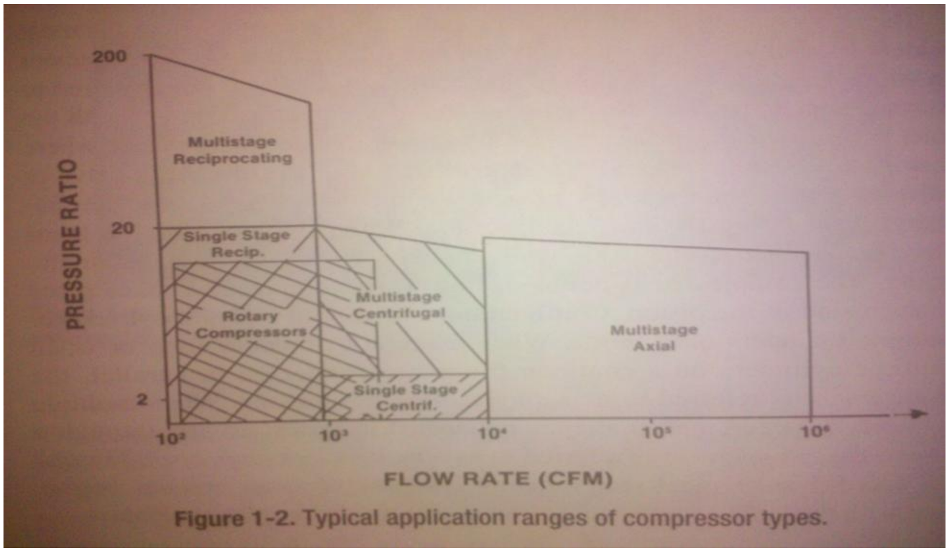

Figure 4-Typical application ranges of compressor types

Helical-Lobe Compressors

Helical-lobe compressors are a positive displacement type of compression device they utilize rotating helical screws in mess to compress the gas. Typically these compressors are referred to as a screw compressor due to the design which can be seen below in Figure 5. Helical-lobe compressors come in two forms dry and flooded. In the dry form a timing gear set is required to reduce wear on the rotors; the flooded form utilizes a liquid media to keep the rotors from contacting one another. The dry configuration has a capacity range of approximately 500 to 35,000 cubic feet per minute (cfm). Discharge pressure is limited to 45 psi in single stage configuration with atmospheric suction. However, supercharged or multistage applications have an obtainable discharge pressure of 250 psi, with a maximum obtainable pressure ratio of 21 to 1.

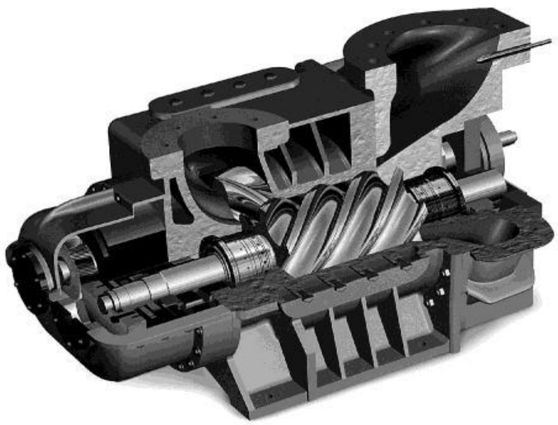

Figure 5- Helical-Lobe Compressor

Sliding Vane Compressors

Sliding vane compressors are another form of a positive displacement compressor, they use a single rotating element to compress gas. The rotor of the sliding vane compressor is mounted eccentric to the center of the cylinder portion of the casing and is slotted and fitted with vanes which can be seen below in Figure 6. The vanes are free to move in and out within the slots as the rotor revolves. Gas is trapped between a pair of vanes as the vanes cross the inlet port; the gas is then moved and compressed circumferentially as the vane pair moves toward the discharge port. The port locations control the pressure ratio. The design requires an external source of lubrication to ensure efficiency.

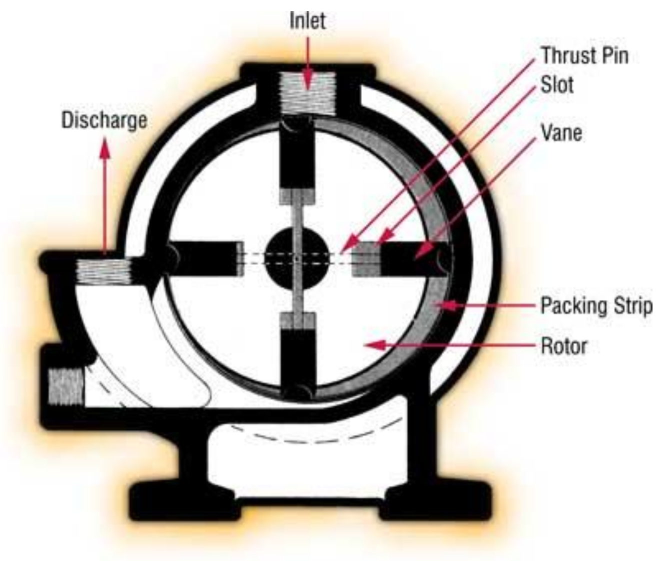

Figure 6- Sliding Vane Compressor

Sliding vane compressors are commonly used as vacuum pumps as well as compressors; with volume flow rates from 50 to 6,000 cfm. A single-stage compressor is capable of generating discharge pressures up to 50 psi, while in booster service units can produce up to 400 psi.

Guided Rotor Compressors

The guided rotor compressor is a rotary positive displacement device that utilizes a trochoid curve to define its basic compression volume, trochoidal design can be seen below in Figure 7. A single rotor compressor assembly is made up of a trochoidal housing, a rotor, roller seals, suction side plate, discharge side plate, crankshaft, rotor bearing, main bearings, end covers, and a ceramic face seal. The guided rotor compressor does not require a timing gear and does not require speed increasers to achieve cost effective delivery. Guided rotor compressors are capable of high adiabatic efficiencies ranging from 75% to 88%, at pressure ratios ranging from 2.8 to 4.6. Also, in comparison to helical-lobe and sliding vane compressors the guided rotor compressor is much smaller in size as well as being a quieter running device due to its balanced design.

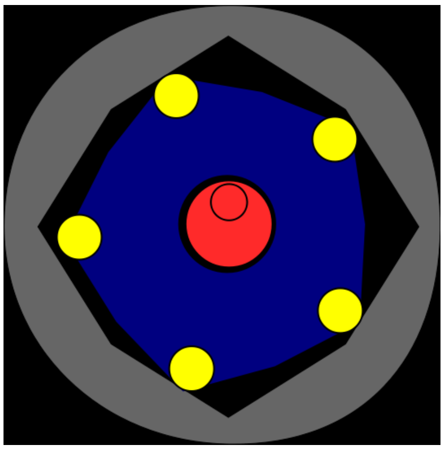

Figure 7- Trochoidal Design

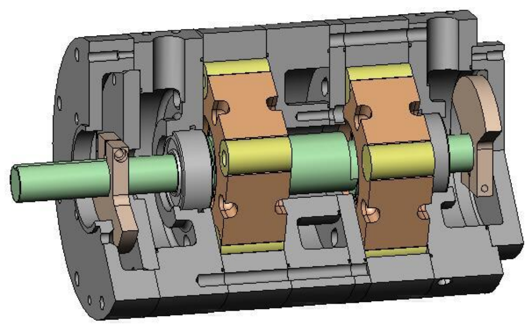

Figure 8- Guided Rotor Compressor

Compressor Decision

In order to fulfill the requirements of the system the compressor chosen must have a high adiabatic efficiency, a good pressure ratio, and be within our budget. Since a compressor is available for use at the Keuka wind facility it may be used if it fulfills these requirements, however due to the lack of information on the compressor this research on compressors has been completed. From the results of our research it has been determined that the helical-lobe compressor would be the best fit for our application due to its variable input power range and excellent pressure ratio. The guided rotor compressor does boast equivalent statistics to the screw compressor however due to its relatively recent conception the cost of such a device is well out of our price range. Therefore ideally a Helical-Lobe or screw compressor should be integrated into our system to compress air for storage.

Generation

For the smaller scale applications of 20 kW and 50 kW we believe that due to the constraints of the provided pressure vessel, a gas turbine would not be feasible to operate due to high pressure and volume requirements. For these power ranges we believe the proper type of generation would be to use an air motor. Then for the larger power ratings of 100 kW and 250 kW, more research and data needs to be investigated in order to determine if a small gas turbine would be feasible or to continue using an air motor.

Air Motors

Air motors come in several different varieties such as vane, piston and turbine. Vane motors operate similar to a rotary internal combustion engine. A slotted rotor rotates eccentrically in the chamber formed by the cylinder and cylinder end plates. Since the rotor is off-center and its diameter smaller than that of the cylinder, a crescent-shaped chamber is created. This is shown in Figure 9-Vane Air MotorFigure 9 below where 'a' is an intake port and 'b' and 'c' are exhaust ports, rotation is clockwise. The Vanes are the brown slots and are allowed to extend to provide a seal between the cylinders inside surface. These motors are best suited for low to medium power outputs and have operating ranges of 100 to 25,000 rpm but they provide more power per weight than a comparable piston air motor.

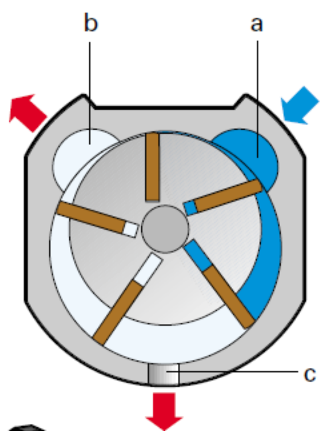

Figure 9-Vane Air Motor

Piston air motors operate just like their internal combustion counterparts except they replace the fuel for compressed air. Piston air motors are best suited for applications requiring high power, high starting torque, and accurate speed control at low speeds. With the speed control however, cost can rise due to the complexities involved. Also, these motors require excellent lubrication and higher maintenance due to size and number of parts involved. But they can output as much as 23 kW if the supply pressure is sufficient. Shown below is a current model of radial piston air motor from Huco Dynatork that has been shown to use up to 80% less air than a comparable vane air motor.

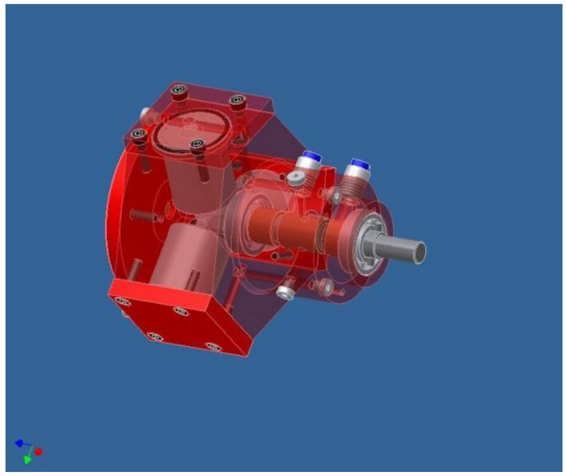

Figure 10-Huco Dynatork Radial Piston Air Motor

Performance of all types of air motors is highly dependent on the inlet pressure. Maintaining a fairly constant inlet pressure will assure the highest efficiency possible for the air motors. This will be done by selecting the proper operating pressure according to the ability of the pressure vessel selected. Once that is done, a pressure regulator will be chosen to ensure proper pressure is maintained for the chosen application.

Concept

Our project will not be to the scale of these plants. Our compressor will be connected to a motor which is connected to a rim based wind turbine. During off peak hours, the compressor will compress air into a large pressure vessel. Once the optimum pressure is reached, one that we deem necessary, it will be released into some power generation device. The power generation device will depend on the pressure we are able to attain in the pressure vessel. The two concepts for power generation are to either use a gas turbine or an air motor. Current CAES plants mix the compressed air with fuel to improve the efficiency of large gas turbines. This is for large scale applications with minimum pressures of about 650 psi. Therefore, for our project, we will likely be focusing on air motors as the source of power generation. They operate on a much lower pressure, which will be in the range attainable by our compressor and pressure vessel combination.

Cost Analysis

The majority of our $2500 budget will be dedicated to the integration of a CAES system. The compressor and pressure vessel is already provided, or will be recommended by us if they are found to be inappropriate. Therefore, the bulk of our budget will be reserved for the power generation component, or the air motor, which range from approximately $300 to $2000. The remainder of the budget will be used for traveling back and forth to Interlachen, FL, where the facility is located.

Conclusion

The main focus of this project is the integration of the components of a CAES system. We will now be determining if the available compressor and pressure vessel at the Keuka facility is applicable for a CAES system. We have yet to find out the specifics of the available components but will be visiting the Keuka facility to inspect the compressor and pressure vessel tentatively the week of October 17. Once we visit the facility and obtain physical data for the compressor and pressure vessel, we will be able to begin calculations for the integration of the CAES system. This will specifically include the compressor pressure output and the pressure rating for the pressure vessel. Once this is determined, we can select an appropriate power generation component, or air motor, for the system. Then the integration of the components to a single working unit will follow next semester.

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