Compressed-Air Energy Storage Systems for Stand-Alone Off-Grid Photovoltaic Modules

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Objective

•Examine the viability of using **compressed-air** storage modules in conjunction with stand-alone, off-grid photo-voltaic (PV) systems for powering individual housing units

Current Energy Storage Systems: Overview

- Pumped Hydroelectric storage
  example: Wivenhoe, Queensland
  •low storage efficiency
- Underground Compressed Air Energy Storage
  example: McIntosh, AL
  •Geological structure reliability
  • Not emission free (fossil fuels used)
- Electrochemical modules [1]
  example: Batteries, capacitors
  •limited life cycles
  •Environmental hazard

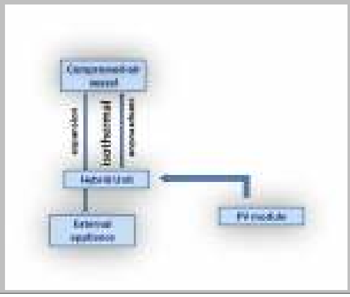
We propose to

➢**Focus** on off-grid power delivery customized for individual household units

➢**Design** a **low-cost, low-maintenance, environmentally-benign, energy-efficient** compressed-air module as an energy storage system

ISOTHERMAL SINGLE STAGE HYBRID COMPRESSOR/MOTOR UNIT

A Schematic Representation of the Prototype



Collaborators:

•**C. Deymier, Butametal sa. France**

•**Ryan Willwater, URIC, University of Arizona**

Key Features of the Prototype

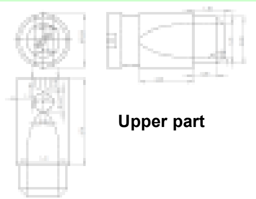
- Hybrid compressor/motor **single-stage** design
  - minimize number of moving parts
- Effective cooling system for isothermal compression/expansion
  - maximize efficiency
- Liquid 'Piston'
  - reduction in dead volume
  - decrease in friction

Unlike heavy duty compressors (> 1000 rpm) that are used under adiabatic conditions, with an emphasis on reducing the time to attain desired (high) pressures, the proposed prototype represents a highly efficient system, with an **emphasis** on **minimizing power consumption** and **losses due to friction** making them ideal as energy storage units when used in conjunction with stand-alone small PV panels

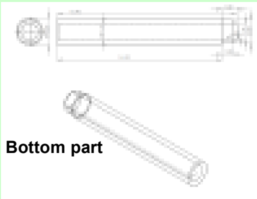
- operates at near quasi-static conditions
- light-duty (~ 60 rpm) - reduction in losses due to friction
- 'ideal' efficiency
- optimized to fully utilize small PV panels power-output

Design

An Engineer's rendition:



Upper part



Bottom part

Includes:

-**Multiple fins to promote thermal conduction**

- **liquid glycerol**

-**Electronically-controlled air regulator in synchronization with the crank-shaft that controls the motion of the piston**

References:

1. G. Bopp et al., Prog. Photovolt. Res. Appl. 6, 271-291 (1998)
2. http://www.theaircar.com/acf
3. S. Lemofouet-Gatsi, These N 3628 (2006), Elcole Polytechnique Federale de Laussane

System Efficiency

Consider *n* moles of an ideal gas. Let V_i be the initial volume of the gas (at atmospheric pressure and temperature T_i) which is compressed to a final volume V_f (at the desired pressure).

Isothermal vs **Adiabatic compression**

Isothermal

$$W^{iso} = -\int_{V_i}^{V_f} PdV;$$

$$P = \frac{nRT}{V}$$

$$W^{iso} = -nRT_1 \ln(\frac{V_f}{V_i})$$

Adiabatic

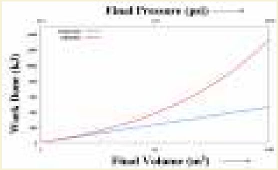
$$W^{adi} = -\int_{V_i}^{V_f} PdV;$$

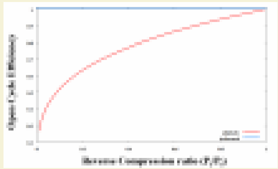
$$P = \frac{nRT}{V}$$

$$PV^{\gamma} = K \text{ (constant)}; \gamma = \frac{C_p}{C_v}$$

$$W^{adi} = -nRT_i \frac{V_i^{\gamma-1}}{1-\gamma}(V_f^{1-\gamma} - V_i^{1-\gamma})$$

Note: The prototype can be represented by an open compression/expansion cycle; here, the pressure of the storage cylinder is maintained by the hybrid unit. The storage and discharge phases are represented by the sums of elementary compression and expansion cycles (or steps)





amount of work required to compress air at a starting volume of $1 m^3$ and atmospheric pressure = 14.7 psi under isothermal and adiabatic conditions respectively

Here, the efficiency is given by

$$\eta = \frac{W_{exp}}{W_{comp}} = \frac{1 - \left(\frac{P_f}{P_i}\right)^{\frac{1-n}{n}}}{\left(\frac{P_f}{P_i}\right)^{\frac{n-1}{n}} - 1}; \quad n_{adi} = 1.4, n_{iso} = 1$$

Numerical Estimations:

Energy density of the compressed air is 4.6×10^7 J/m^3.
If used for 10 hours, will yield 1280 W/hr.

Conclusions

• The compressed-air energy-storage unit proposed in this work is optimally designed to have maximum efficiency and completely utilize the energy derived from solar-powered PV cells.

• The proposed prototype is a low-cost, low-maintenance, environmentally-benign system, especially designed to be used in stand-alone off-grid individual housing units.

• Assuming isothermal conditions, numerical estimations demonstrate the feasibility of the proposed system; specifically, the prototype is designed to work as a hybrid compressor/motor unit, and if used in conjunction with a small-sized PV panel (10 m^2) for 8 hours, is capable of operating any appliance rated at 1200 W for 10 hours.

Future Directions

• Rigorously characterize the deviations from isothermal behavior of the system, by measuring the losses due to friction, thermal effects and use this information to further refine the design of the system.

• Utilize the recent advances made in small-scale compressed-air driven motor technology [2,3] to optimize the efficiency of the prototype.

• Do a thorough evaluation of the reliability, safety and risks involved in the operation under a variety of conditions. (e.g. effect of weather)