ENSC 461 PROJECT: Development of a new hydraulic regenerative energy storage system

Assigned date: Feb. 21, 2011 Due date: April 11, 2011

Introduction

Traditionally, energy storage has been of high interest, as in the case of the inflexible nuclear or thermal power versus daily cycles. Storing electrical energy after production is a challenge. Integrating electricity storage into the electrical network has been identified by the Electric Power Research Institute as a major opportunity for improving reliability of networks and to optimize generation, transmission and distribution assets. Recently, several new storage technologies have been proposed as alternative solutions to classical electrochemical batteries, among them is hydraulic regenerative system (HRS).

Principle of operation: electricity is used in an electric motor/generator to drive a hydraulic pump/motor that moves hydraulic fluid from a low-pressure reservoir to a hydraulic accumulator during the energy storage mode, see Fig. 1. The accumulator contains pressurized gas, typically nitrogen. In the regeneration mode, the compressed gas pushes the hydraulic fluid back into the low-pressure tank and generates electricity through the hydraulic pump/motor. The HRS concept was put forth in the 70's in automotive industry by GM, where the input power comes from vehicle's powertrain during the brake period and the regenerated energy is transferred back to the powertrain in the acceleration mode. Following the recent increase in oil prices, the HRS technology has received considerable attention from companies such as Ford, GM, and Volvo. The *US Environmental Protection Agency* (EPA) has collaborated with many organizations including Parker-Hannafin Corp and GM to develop hydraulic hybrid vehicles and trucks. While electric hybrid vehicles regenerative efficiency is less than 40%, prototype hydraulic hybrid trucks have achieved efficiencies up to 70%.

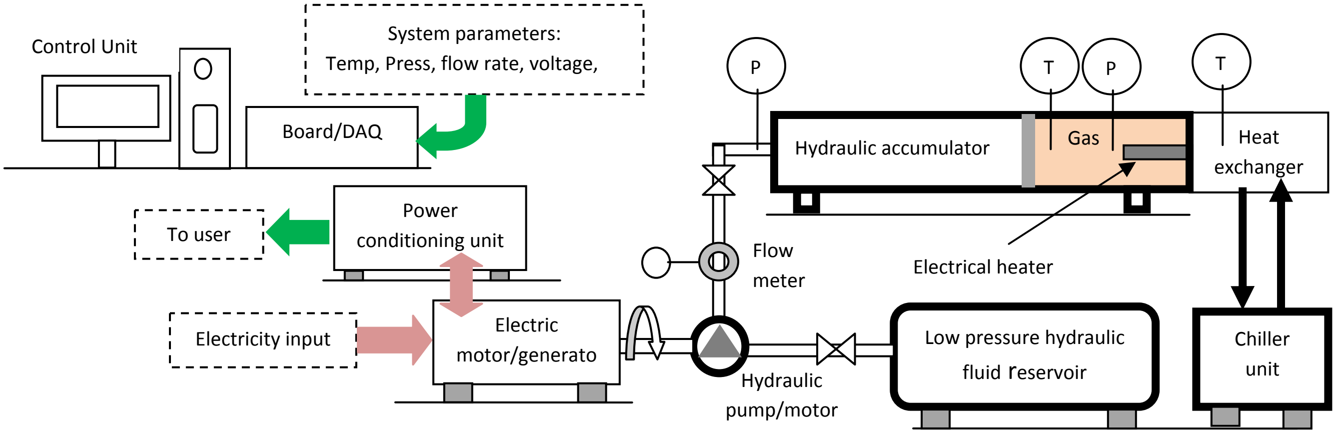

Fig.1: Schematic for the integrated HRS for electricity storage, a laboratory set-up.

For stationary energy storage applications, the HRS technology is not yet on a commercial basis, but it is predicted that it can initially substitute the lead–acid batteries in certain stand-alone stationary equipment applications. The first targeted applications are systems with drives mainly for workshops, food processing, and UPS installations where the HRS performance is comparable with the lead–acid batteries; but HRS remains more expensive. The HRS has the following advantages:

1) Reliability, reduced complexity, low maintenance, and long service life (up to 40 years). Hydraulic systems have a proven record as they have been in use in various industrial and transportation applications for many decades. This is a major advantage for sustainable energy applications, since they are often installed in rural and remote areas.

2) Environmentally friendly: HRS contains no pollutive, hazardous, explosive, or chemical material.

3) Flexible charging-discharging frequency: HRS can handle both high frequencies and high rates of charge/discharge; storage capacity is not affected by age or speed of charge; and unlimited cycling ability, independent charge and discharge rate.

4) No self-discharge. Also service life of HRS is not affected by temperature.

5) Scalable technology: HRS is fully scalable and can be used in all storage capacities in both stationary and mobile applications.

The challenges facing the HRS include: 1) relatively low energy density 5.55 *Wh/kg* at 250 bar working pressure. The energy density increases with the pressure, current systems operate at 200-350 bar; studies are underway to increase the pressure to 1,400 bar; and 2) energy efficiency of 73% which is slightly lower than new lead–acid battery.

Your task

The focus will be on improving energy capacity of accumulators and the efficiency of HRS. The hydraulic storage involves transient thermodynamic processes in the accumulator. As such, development of a thermodynamic model for energy conversion processes in HRS will provide a platform to model and optimize the energy storage.

Consider a 6 kWh HRS system as the base for your analysis. The HRS can be modeled similar to a power cycle with 3 main processes: charge (compression), storage, and discharge (expansion). The ultimate goal is to determine instantaneous energy content, entropy generation rate and their relations with the system parameters such as: gas temperature, pressure, hydraulic liquid flow rate, hydraulic pressure, the energy charge/discharge rate, and efficiency of the system. These functional relationships are vital for the control unit to determine the “state of charge” of the HRS and more importantly to optimize the duration and the sequence of hydraulic and electrical system parameters such as valves, electric motor/generator and heat exchangers. Assuming quasi-equilibrium processes, preliminary model(s) can be developed to investigate the effects of main thermophysical parameters on the performance of the HRS. You may assume an isentropic efficiency of 95% for compression and expansion. A real gas equation of state such as Benedict-Webb-Rubin can be employed to model the high-pressure gas behaviour.

Hint: it is predicated that an isothermal compression can significantly reduce the required energy for compression. Isothermal compression/expansion is ideal because it requires the minimum input work during the compression and maximizes the energy regenerated during the expansion of the compressed gas. Depending on the charging frequency, different strategies can be devised to manage the gas temperature in the accumulator.

Heat recovery and cogeneration solutions: HRS has also the potential to be incorporated in heat recovery or cogeneration solutions. In many instances, a secondary heat source, such as exhaust/radiator thermal energy in vehicles, exists whose energy can be transferred to the compressed gas during the storage period. Heat transfer will increase the temperature of the compressed gas and, proportionally, its pressure which in turn results in a higher stored energy in the accumulator. The heat recovery can be performed using an accumulator equipped with a heat exchanger for the secondary fluid. The effectiveness of HRS for heat recovery solutions can be investigated through performing several parametric studies using the thermodynamic model described above. Note that the cogeneration requires multi-accumulator arrangement, compact heat exchangers, and efficient thermal-control strategy.