ENERGY STORAGE BY COMPRESSED AIR

George C. Szego

Intertechnology Corporation
Warrenton, Virginia

I/would like to discuss with you some of the general attributes of the compression of air as a means of storing what I call off-peak, central station, baseload power for peak use. But exactly the same concept can be used to store wind power.

There are essentially three components to the system: a compressor, a motor, and a turbine. To store the energy, a motor drives the compressor, which, of course, compresses the air. To extract the energy, the air is run through the turbine, which drives that same motor, which is now an alternator. This is the same situation as the pump-turbine and the motor-alternator in a pumped hydro system.

In this system the compressed air is stored underground in caverns or aquifers. The use of caverns requires a water piston and a surface lake to recover flow-work, the PV term, which normally isn't recovered when pumping into an inflexible tank, for example. It also requires the use of surface area. I like very much better the use of an aquifer to store the compressed air because the water in the interstitial spaces would act as the piston and thus no surface area would need to be used.

If you used pumped hydro to store wind energy, you'd get about 0.67 efficiency. If you put in 3 kilowatt-hours, you get out 2 kilowatt-hours. The use of pumped hydro also entails an almost $200 per kilowatt capital investment, substantial land use, and the inability to put it where you want it. Suitable sites are usually far from load centers; therefore, transmission and the capital costs of transmission are involved.

Now, a normal gas turbine system uses up about three-fourths of the total output of the turbine in the compressor; therefore, a 1-kilowatt gas turbine system normally is a 4-kilowatt turbine, a 3-kilowatt compressor, and a 1-kilowatt alternator. (By the way, those systems cost about $110 or $115 per kilowatt. They are enormous spendthrifts of energy, of fossil fuels specifically. Their heat rates are near 17 000 Btu per pound and up. They have the advantage, though, of quick installation, which is why they are used widely by the utilities.) Obviously, it is to our advantage to increase the pressure ratio. Presently, we are considering a 40 to 1 compressed air to atmospheric air pressure ratio for our compressed air storage system.

There is an additional factor. When you operate a separate turbine and compressor for some tank storage system, be it underground cavern, surface tank, or the aquifer, you have two choices:

(1) You can extract the air from storage and run through the turbine cold, in which case the performance is exactly the same as pumped hydro, that is, 0.67 efficiency or 3 kilowatts into storage and 2 kilowatts out.

(2) Or you can burn a small amount of any fuel and heat the air before it enters the turbine.

If this is done to about 4000 Btu per kilowatt-hour, roughly 40 percent of the normal heating rate, the output of the system doubles at a fairly small cost. In other words, 3 kilowatt-hours in and 4 kilowatt-hours out. This is an apparent efficiency of 133 percent, but, of course, you're expending some energy (heat) to get it.

With respect to the combination of windpower and compressed air storage, I hesitate, without making a detailed technical and economic analysis, to say why this is an applicable concept. Certainly it is physically feasible. If there were a battery of wind machines in a given area with an installed area output of, say, 50 or 100 megawatts, I believe the underground storage of compressed air would be the most attractive concept that you could consider.

Another very important characteristic of the underground storage of air is its unique flexibility. In pumped hydro, in a battery, or in a flywheel, when you are up to full storage that's all there is - there isn't any more. And what you have depends on how much money you spent. Air, on the other hand, being a compressible fluid, is quite flexible. For instance let's say we've stored 2 or 3 days worth of power, or air, at 600 pounds per square inch. If we chose to store a week's worth, which surely you cannot do with pumped hydro (pumped hydro is only stored overnight because it is so expensive and because it is inflexible) you can simply continue compression to perhaps, 650 pounds per square inch. The air will be pushing the aquifer up closer to the dome, and you will be getting the piston action simply by the air being more compressed. Because air is a compressible fluid, more energy can be put into it by increasing the pressure, or by pushing back more of the interstitial water in the aquifer.

This storage system concept has the reheat flexibility. It has the lowest capital cost of any storage system of which I'm aware, and certain beneficial environmental advantages that includes not using surface area.

DISCUSSION

Q: Why 50 megawatts as the lower limit cutoff?
A: Well, the reason for that is fairly simple. You've got to sink some wells, for both the cavern and aquifer storage systems. A rough trade-off analysis indicates, at least for commercial utility use,

that the better part of a hundred megawatts is necessary to make the machinery and the attendant structures pay.

COMMENT: My calculations show that the type of flywheel I am considering is comparable in cost and size to your system.

Q: Is there any reason why this power storage system could not be used in off-shore locations several miles off the continental shelf?
A: No, and that opens up an entirely new opportunity not present on land. The ground under the water can, of course, be used. You can also use a membrane or bag lying at the bottom of the water or at a suitable depth. Pump the air into it, and let the water pressure push it back up to you. The use of the membrane is possible only in deep water.

Q: What if aquifers are needed for other purposes, like furnishing water?
A: I don't think I'm a sufficiently good geologist to answer that. But I'll try. I think the aquifer itself would resolve that issue. There are, I believe, few fresh water wells that go down to 2000 feet. So aquifers that are 175 feet down might be used as wells or for water storage, and those 2000 feet down for power storage.