Storing electricity

The 'City Block' concentric heat store design lends itself to the storage of electricity on a large scale. Storage makes it easier to employ intermittent power sources like wind turbines and to handle fluctuating loads.

The 'City Block' design has a hot core region surrounded by a cooler outer region. If you move heat from the outer region to the core that does not change the total amount of energy but it does raise its exergy (the capacity to do work). Both the exergy and the energy can be stored for long enough periods of time to handle seasonal load variations so that you can accumulate heat during the summer in the outer zone, move some of that heat to the core with a heat pump, and subsequently recover that exergy and the heat in the winter. The recovery of the exergy is accomplished by reversing the process - moving heat from the hot body to the cold body using a heat engine such as a Stirling cycle engine, or alternatively you can recover both the heat and the exergy by using the heat for an external application such as space or hot water heating.

Conceptually you could use electricity to drive the heat pump, thus converting the electrical energy to stored exergy that could then be converted back to the electrical form using a Stirling cycle engine, so the system would perform like an electrical battery. However, the temperature difference between the two bodies is very small compared to the difference normally employed with power generation equipment so the Carnot cycle efficiency would limit the conversion efficiency to about 7% in the best case. It is much more practical to avoid the re-conversion step and use the exergy in the form of heat so there is no conversion loss. That can be accomplished by using the heat from the core for applications like space or water heating. You are still storing the electricity (in the form of exergy) but you are recovering the exergy by displacing the use of electricity for tasks like heating hot water or operating a heat pump for space heating. We use so much electricity for such tasks that this method of recovering the exergy is generally practical.

Note that the injection of heat into a 'City Block' store and the injection of exergy are separate steps that can be done at different times and that could be controlled by different people. The building owners who are served by the 'City Block' system could control the injection and recovery of heat in the normal way while the power grid operator could independently and asynchronously control the injection and recovery of exergy (effectively storing the electricity that was used to drive the heat pumps). Normally a 'City Block' system extracts heat from the outer zone for space heating and that has little effect on the stored exergy, but when required the heat could be extracted from the core instead and that drains (i.e. recovers) the exergy so the grid operator can control the recovery of the exergy by switching the heat source. The space-heating heat pump will have a much shorter duty cycle when the hotter source is employed, reducing its average power demand and in effect recovering the electricity.

The upshot is that a 'City Block' system can concurrently serve two different purposes, meeting the thermal needs of the buildings it serves and simultaneously storing electricity to handle both supply and demand fluctuations of the power grid. The storage capacities are roughly similar for both (circa 1 MWh) and the power levels are also comparable (about 100 kW per store). The two functions are not completely independent but with proper planning they should not seriously interfere with or limit each other. The dual function requires the addition of the heat pumps that transfer the heat but by raising the temperature of the core the size and cost of the borehole field is reduced and that should more than compensate for the cost of the heat pumps. The exergy recovery stage is advantageous to both the grid operator (because the load is stabilized) and the building owners (because their electricity bills are reduced). The amount of electric energy conserved during the exergy recovery stage should be limited to the same amount of energy as was used by the upgrade heat pumps to ensure that the intended amount of heat will be available for space heating and DHW.

The question of who should pay for the capital costs needs to be resolved. One option might be for the power company to build the heat store components of the 'City Block' systems but charge the cost of running the upgrader heat pumps to the building owners to offset the demand reduction at the recovery stage. That would result in a neutral net operating cost for both parties and also a much lower capital cost for both. The building owners would not pay for the capital cost of the heat store and the power companies would not need to upgrade the supply and grid capacity to handle peak loads. The capital cost of the stores would amount to a few hundred dollar per kW compared to $5,000 or more per kW for increasing the peak supply capacity. For a store that has an exergy capacity of 100 kW that works out to a capital saving of about $470,000 per store that would be realized by the power companies. In addition they would be able to utilize intermittent power sources like wind turbines and they could couple fixed output generators like nuclear stations to the variable demand loads. Providing storage would be a much cheaper solution than trying to boost the overall supply capacity to match the peak loads.

That is only half of the story. In Ontario there are two large power demand periods - in the summer the power demand for air conditioning creates one demand peak and in the winter the need for heat for buildings creates the other large peak. Both of those peaks are reduced by using 'City Block' systems for heating and cooling the buildings. The two effects are additive. The thermal energy storage reduces the power demand peaks and the exergy storage independently shifts the power load. Between them the cost benefit is roughly one million dollars per 'City Block' system. On a national basis the implementation of this concept could reduce the demand for electricity to the point where the existing hydro power could meet our needs for many years to come. In the process the GHG emissions from both heating applications and power generation could be progressively eliminated.

It should be noted that the thermal storage cycles are not the same for heat storage and exergy. Over an annual cycle much of the heat injected into the core will escape to the outer zone. That is not a problem for space heating applications because the escaped heat will still be recovered and put to good use. However, for the exergy calculations the escape results in a loss of exergy that must be accounted for. There is no such loss for heat injected in the winter because at that time the temperature gradient in the core falls as you approach the center. Heat cannot flow "uphill" so all of the winter injection is stored losslessly. That makes it attractive to maximize the winter injection.

The dual function design is particularly attractive for systems that use air-heat exchangers to extract heat from the summer air and store it for winter use. You can use such heat exchangers to warm the ground around the injection holes during the daytime and then extract that heat with the upgrader heat pumps at night, moving it into the core. That chills the outer boreholes which makes it easy to recharge them with heat the following day. The air is effectively an unlimited source of energy and the direct extraction of its heat is the cheapest way to collect energy but in single-function systems the efficiency falls off as the ground gets warmer, an effect that is greatly reduced in a dual-function system.

If the grid operator is not interested in using electricity storage then the system should use solar thermal collectors for charging the central zone. This note is intended to explain the basic principles without delving into the details.

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