Grid integration and electrical storage – 02

Estimation of the worldwide installed capacity of cold storage with ice and its effect in the electricity grid

Harald Mehling[1]

[1]Consultant, 97074 Würzburg, Germany

[*]*Corresponding email: harald.mehling@gmail.com*

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SUMMARY

The optimization of the electricity system has led to a strong interest in energy storage. One option is storage of the energy form finally used, e.g. cold storage with ice. Before investigating future options, it is necessary to know the current situation. Therefore, information on the storage capacity that has been produced was collected from three large manufacturers: Christopia, BAC, and Calmac. The result shows that they account for about 23.5GWh thermal storage capacity. The ratio of this thermal storage capacity by ice storage to the world-wide electricity storage capacity is about 0.016, and about the same for the installed power. The results indicate that the storage capacity and storage power is significantly larger than estimated in previous studies. In addition, there is still a large number of companies not accounted for in this study. This is the topic of future investigations.

INTRODUCTION

Energy storage in the electricity grid

The optimization of the electricity supply system to increase efficiency and integration of fluctuating renewable electricity sources has led to a strong interest in energy storage technologies. Fig. 1 shows the different options where energy storage can be integrated in the electricity grid.

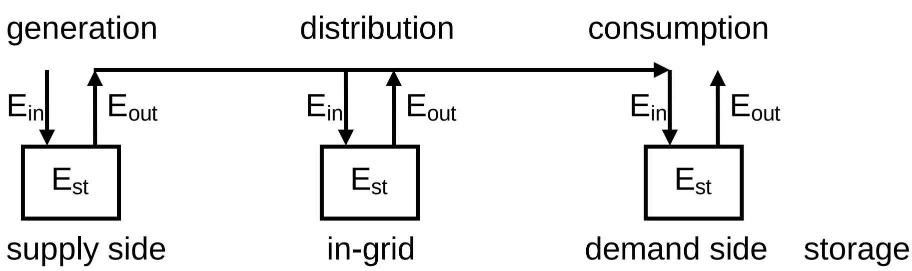

Figure 1. Options where energy storage can be integrated in the electricity grid

In-grid storage in the electricity grid requires that the energy forms of the incoming and outgoing energy, E_{in} and E_{out}, are electrical energy. Because the direct storage of electrical energy in an electrical capacity is not a suitable solution for the requirements of the electricity grid, in-grid storage is practically exclusively indirect storage. In fact, it is to about 99% as pumped hydro electrical storage (IEA 2014a). In pumped hydro, electrical energy is converted to potential energy of water in a high lying reservoir, stored as potential energy, and converted back to electrical energy when needed. Indirect storage where the stored energy E_{st} is as thermal energy storage (TES) like ice storage is not used yet, but under consideration as in the concepts of Electro-Thermal Energy Storage, ETES (La Fauci et al 2013) and the Dual Energy Storage Converter, DESC (Stamatiou et al. 2014). In these concepts, electrical energy is converted by a heat pump to thermal energy, stored in a high and a low temperature TES, and converted back to electrical energy when needed by a thermal engine.

Supply side storage, where electrical energy is generated, requires E_{out} being electrical energy. The stored energy E_{st} can be electrical energy as in a PV power plant with batteries. Thermal energy storage is used at high temperature in solar thermal power plants, and ice storage is used in some cases for pre-cooling of the air of gas turbines to increase their peak power.

Demand side storage requires E_{in} being electrical energy, but E_{out} can be any energy form. When cold is required, it is common to convert the electrical energy to cold by a compression cooler and to store the cold in a TES, usually as cold water storage or as ice storage. This is thus by far the main use of ice storage in the electricity grid.

Applications of ice storage

Conventional air-conditioning is very common today to cool the space in apartment buildings, office buildings, theatres and cinemas, libraries, hospitals, airports, and conference, shopping, and sports centers. A connection to the electricity grid exists such that the cooling machine can be designed to supply the cold demand for cooling and dehumidification at any time. However, doing this is often not the best option and ice storage is added to the cooling machine. Ice storage and cooling machine are used in a combination, optimized to the special conditions. Typically, advantages of using ice storage in the cooling system are a reduction of the size of the cooling machine by 30-70%, the refrigerant charge, and the size of the heat rejection equipment. An improved operation mode can lead to a reduction of maintenance and operation costs, including the costs of electricity if a higher COP is achieved. Due to their high storage capacity, ice storages are very suitable to improve the power supply and demand in cold supply networks. What has been said for conventional air-conditioning therefore also relates to district cooling in many ways because district cooling is just a different way where the cold is produced in a central plant and then distributed for the same application. The main difference is the average size of the ice storage. Ice storage is also used to a large degree for process cooling. Processes with need for cold are common in many industries like the food industry (slaughterhouses and meat industries, central kitchens, bottling plants, dairy industries, breweries …), the pharmaceutical industry, and the chemical industry, as well as in non-industrial applications like ice rinks. Again, it can be advantageous to combine the cooling machine with ice storage for the same reasons as above. Especially in the food industry, the cold demand can be at temperatures far below 0 ℃. In such cases, water-ice cannot be used as PCM anymore; instead, water-salt mixtures (usually with eutectic composition) are used.

As the possibilities to store electricity are currently not sufficient for the integration of renewable energy sources, especially solar and wind power, it is interesting to investigate whether the storage of the energy form that is finally used (demand side storage), especially as heat or cold, can play a significant role in the optimization of the electricity system. Cold storage with ice is a technology that exists already for a long time; it is reliable, economic, easy to install, and already widespread. Before investigating the future options of this technology, the question of how much ice storage is already installed today and its effect in the electricity grid should be answered. To find this answer, and thereby build a sound basis for future discussion, is the topic of this paper.

METHODS

To make an estimation of the installed storage capacity based on real data from desk top research, the general options are to ask producers, installers, or users. For electrical energy storage in the electricity grid the choice is easy: the users, which are the companies running the grid, need to know the installed storage capacity. This is not the case for ice storage. The most direct approach to estimate the installed capacity of cold storage with ice would be to identify the installations and sum up their storage capacity; this is for example possible for TES in solar thermal power plants. For ice storage this is however not practical because the number of installations is many 1000s and the applications are very diverse. In the case of ice storage there are however few manufacturers producing large ice storages in the world. The survey has thus focused on large ice storages, and information on how much storage capacity was produced was collected from the manufacturers.

The construction of large ice storages follows two basic concepts. In the first one, ice is produced on a heat exchanger coil, and thus outside the cooling fluid cycle, as shown in fig. 2. BAC (Baltimore Aircoil Company) uses this concept; Calmac uses the same one, but with a very different technical design.

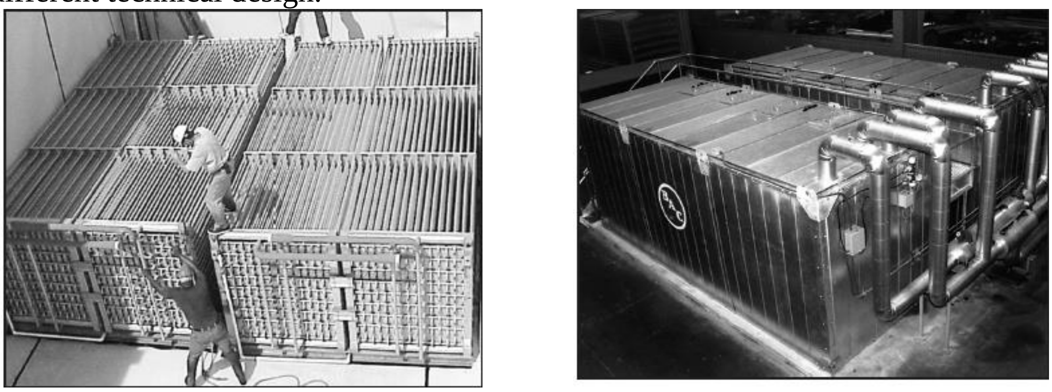

Figure 2. Storage construction concept used by BAC (source: BAC); a single unit holds about 30t of ice.

In the second concept, ice is macro-encapsulated, and the capsules are placed inside the cooling fluid cycle, as shown in fig. 3. Cristopia uses this concept.

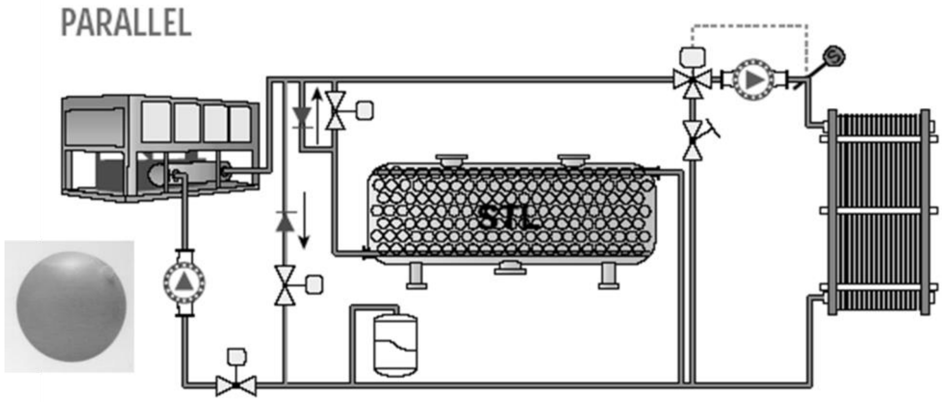

Figure 3. Storage construction concept used by Cristopia (source: Cristopia).

Especially the second concept has a significant difference between the storage volume and the ice volume. It is therefore necessary to use data on the storage capacity in energy units, e.g. in GWh, and to convert data in storage or ice volume to energy units.

RESULTS

The following assumptions and simplifications were used, which will be discussed in the discussion section. First, it was assumed that most of the storages that have been produced are still in operation. Second, that a small fraction of the storages uses salt-water mixtures was not taken into account separately. Third, because the production of ice is exclusively from electrical energy, all ice storage is in the electricity grid as demand side storage.

World wide installed capacity of cold storage with ice

The following is the information retrieved from three of the largest companies producing large ice storage systems in the world, and refers to installations worldwide. Christopia (http://www.cristopia.com), according to their catalogue (Cristopia 2015), has more than 3000 customers worldwide, and shifts more than 500 MW of electricity with more than 6 Million kWh = 6GWh of electricity transferred daily from peak to off-peak hours. According to Supawong 2010 the latter corresponds to 10GWh thermal storage capacity daily. According to Cristopia, the technology was developed in 1982. BAC Baltimore Aircoil Company (http://www.baltimoreaircoil.com/) has installed 3.5GWh in 2600 systems with about 30 years of experience (BAC 2015, until 2014). Calmac (http://www.calmac.com/) estimates (personal information) its installed capacity to be about 10GWh in 4000 installations in a time span of about 30 years. Altogether, these three companies thus account already for 23.5GWh of thermal storage capacity in about 10000 installations. Looking just at the phase change, as a rule of thumb, 1t or 1m^3 of ice stores roughly 0.1MWh (0.0925MWh and 93kWh/m^3 exactly). The storage capacity of 23.5GWh thus corresponds to about 250.000t of ice (about 25t per system on the average).

Assuming an average charge and discharge time of 10h, as indicated by the data from Cristopia, the average thermal power is 2.3GW.

DISCUSSION

Check of assumptions and simplifications

The assumptions and simplifications that were made are checked now. First, some of the storages might already be out of order, as all three companies produce ice storages for about 30 years. If the lifetime of the storage is only 15 years, and the production increased linearly over the 30 years, then still three out of four storages would be in operation. Second, that a fraction of the storages uses salt-water mixtures for storage at temperatures below 0 °C seems to be not important: the fraction is probably small, and they are still connected to the electricity grid. Third, that the production of ice is exclusively from electrical energy is a safe assumption because subzero temperatures are practically always produced by compression cooling from electricity. In addition, in the introduction it was shown that practically all ice storage is in the electricity grid is demand side storage.

Effect in the electricity grid

The data up to now all refer to thermal energy. Because the COP of conversion from electrical to thermal energy as ice is in the order of 2.3 to 3.0, this has to be kept in mind when comparing thermal to electrical power or stored energy.

Regarding the amount of energy, electricity generation worldwide was 22668TWh=22668·1000GWh in 2012 according to IEA 2014b. The average generation per hour is then about 22668·1000GWh/8000=2800GWh. The electricity storage capacity world wide is 1500GWh (IEC 2011), just about enough to store the average generation of half an hour. The ratio of the 23.5GWh of thermal storage capacity by ice storage to the world-wide electricity storage capacity is thus 23.5GWh/1500GWh=0.016.

Regarding power, the installed electricity storage capacity worldwide is according IEA 2014 about 150GW. For comparison, the power of an average nuclear power plant is in the order of 1GW. According IEC 2011, it is to 99% by pumped hydro storage (PHS) power plants (over 127 GW), and this is about 3 % of global generation capacity (which is then 127·100/3=4223GW). The ratio of the estimated thermal power of ice storage derived here of 2.3GW to the power of all electrical storage is then 2.3GW/150GW=0.015.

CONCLUSIONS

As the short survey shows, the globally installed storage capacity in large ice storages is quite significant. The data from just three of the largest manufacturers show that they have already installed 23.5GWh of thermal energy storage capacity. This value is bigger than commonly estimated. For comparison, the IEA Technology road map Energy Storage (IEA 2014a) estimates the thermal energy storage capacity in the United States in 2011 by ice storage to be only 1GWh. The ratio of the world-wide installed capacity of cold storage with ice regarding to that of electrical energy is 1.5:100, taking into account the COP it is somewhat below 1:100. The same ratio results for the power. Assuming 10h charging and discharging time results 2.3GW of thermal power, which is much larger than estimated in the IEA Thermal energy storage technology brief (IEA 2013).

While the three companies covered here are among the biggest producers worldwide, there is still a larger number of companies not accounted for, specifically those producing smaller ice storages, such that the total installed capacity of ice storage worldwide could even be several times higher than the value found here. For this reason, a more comprehensive survey has been started already, that in addition collects data regarding to countries, regions, applications, and what the potential for improving the electricity system are.

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