FEASIBILITY STUDY OF AN ELECTROTHERMAL ENERGY STORAGE IN THE CITY OF ZURICH

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ABSTRACT

In this paper, a pilot project in the city of Zurich, which aims at demonstrating a new concept for electrothermal energy storage (ETES), is presented. ETES is a new type of large-scale electricity storage with potential power ratings in the range of tens to hundreds of MW and storage durations in the range of several hours. Therefore, the ETES is a promising technology to fill the gap between battery storage on the low voltage level and pumped-storage hydropower plants on the transmission level. In this paper a spectrum of possible applications of the ETES and interdependencies between them are analyzed with a focus on urban networks.

INTRODUCTION

The city of Zurich stipulates in its Municipal Code that it pursues a sustainable development by reducing the average continuous power consumption to 2000 W per capita (today's Swiss average is about 6000 W) and by reducing the CO_2 emissions to 1 t per year per capita (today's Swiss average is roughly 6 t) [1]. Furthermore, the city of Zurich declared that it does not want to acquire new shares or purchase rights for nuclear power production. Achieving these goals requires measures for supporting energy efficiency and renewable energy sources. In the light of these municipal boundary conditions and the Swiss energy strategy 2050, which formulates similar goals on the federal level, it is expected that the share of renewable energy sources, in particular solar and wind, will significantly increase in the coming years. The integration of these fluctuating renewable energy sources leads to several challenges for the operation of the power system both from a technical and a market-related perspective.

ewz, the distribution system operator and electricity supplier of the city of Zurich, has to be prepared to cope with these challenges. With increasing levels of fluctuating infeed from renewable energy sources, options for energy storage will play an important role [2]. Therefore, ewz is initiating several pilot projects in this field. One of them focuses on battery storage on the low voltage level [3]. In the pilot project described in this paper a new concept for electrothermal energy storage (ETES) developed by ABB shall be built as a first-of-its-kind demonstration plant and connected to the 22-kV-grid. The ETES concept is based on transcritical CO_2 cycles and allows site-independent storage of electrical energy [4]. Due to this characteristic, ETES systems can be placed close to the production sites and consumers. They can thus contribute to relieve problems in distribution grids caused by fluctuating decentralized infeed. Thanks to its scalability, the ETES technology may be able to fill the existing gap between battery storage on the low voltage level and pumped-storage hydropower plants on the transmission level.

The paper is structured as follows. The following chapter gives an overview of the ETES technology concept. Subsequently, possible application cases of the ETES are outlined and the pilot project ETES Auwiesen is described. Finally, conclusions will be drawn and an outlook will be given.

CONCEPT OF THE ETES TECHNOLOGY

The ETES concept developed by ABB is based on a combination of a CO_2 heat pump for the charging with electrical energy, a hot water reservoir for the storage of the energy and a CO_2 heat engine for the discharging of the storage unit. Figure 1 illustrates the charging process.

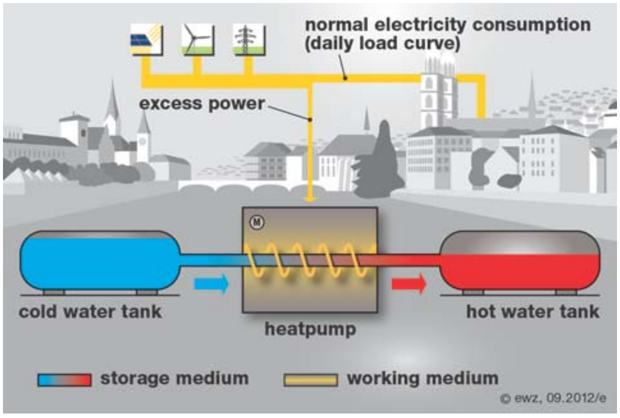

Figure 1: Illustration of the ETES charging process

CO_2 is used as working medium for the transcritical charging and discharging cycles. Water has been chosen as storage medium because it is an environmentally friendly material with very good thermal properties (e.g. very high heat capacity). Furthermore, the temperature profiles of CO_2 and water during heat exchange match very well, which allows for achieving high efficiencies in the CO_2 cycle. At the cold end, an ice storage is used as thermal reservoir. The ice is produced during the charging process and is melted during the discharging process. Using closed thermodynamic cycles, interaction with the environment is minimized and thus a site-independent installation of the ETES is possible. The roadmap of ABB for further development of the ETES technology includes a long-term target of 60 to 70% round-trip efficiency for 20 to 500 MW, i.e. values that are relatively close to the efficiencies of typical pumped-storage hydropower plants. In addition to the high efficiency potential and the site-independence, another key characteristic of the ETES is the flexible scalability with respect to both power rating and storage content. The low environmental impact compared to other storage technologies such as batteries or pumped-storage hydropower plants is a further advantage. A more detailed description of the ETES concept proposed by ABB can be found in [5].

INVESTIGATED APPLICATIONS

The multiple benefits that ewz can acquire through ETES are spread across various sectors. For example, costs for grid utilization and local grid extension can be reduced. Furthermore, its operation can bring revenues through trading based on price arbitrage using the electricity storage mode and through electricity production from external heat sources (e.g. waste heat). The challenge is to determine the optimal combination of the possible applications. For the purpose of this feasibility study, the focus is on the three following categories of applications: benefits for the distribution grid, trading through price arbitrage and heat conversion to electricity.

Benefits for the Distribution Grid

Through ETES, costs can be significantly decreased by lowering the monthly load peaks and complying with reactive power requirements. Moreover, it offers several operational advantages for the distribution grid such as grid stabilization, prospects for islanded operation, and congestion management capability.

Peak Shaving
ewz is obliged to pay a monthly fee to the transmission system operator (TSO) for the utilization of the transmission grid [6]. The power used to calculate this fee is the highest load of each month measured in quarter-of-an-hour intervals. ETES can be used to reduce the fee by reducing the maximum city load, storing electrical energy during times of excess power or low residual load and discharging during peak load hours. Figure 2 depicts a daily load in the city of Zurich and how the peak shaving concept can be implemented.

Reactive Power Compensation
Apart from the grid utilization fee, ewz has to pay an additional fee to the TSO for the consumption or generation of reactive power when the power factor of the system is lower than 0.90 [6]. Under low load conditions the Zurich network has currently a capacitive character due to its high proportion of cables. With increasing distributed generation, mainly PV, the distribution grid of Zurich becomes more often capacitive with an even lower power factor at the substations (220/150 kV).

Prevention of Grid Reinforcements
Without storage units an extension and reinforcement of the grid would be necessary in order to cover the constantly increasing dynamic loadings of the distribution grid (variable demand and renewable distributed generation) and to optimally operate the network. This would ensure adequate capacity, uninterrupted supply and lower losses, requiring however at the same time labor and funds. Instead of grid reinforcements (extra cables, bigger transformers, and voltage regulating equipment), a local storage unit such as ETES could be used to obtain the same results in appropriate cases. The storage unit can locally operate as a load and this way shave the feed-in peaks. Additionally, it can feed the energy back in the system when needed.

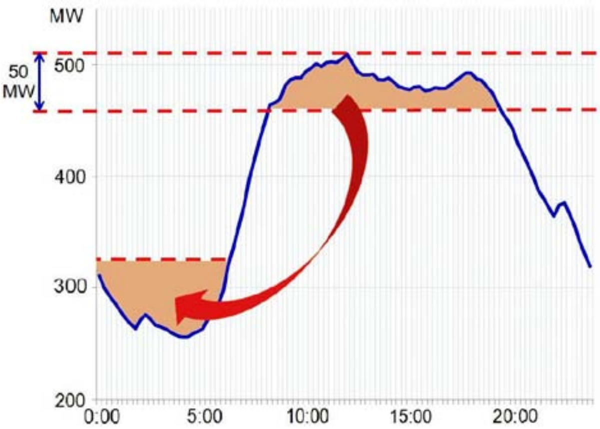

Figure 2: Peak shaving on the daily load of Zurich for a 50 MW storage unit

Trading using price arbitrage

Trading can achieve revenues through the storage of energy by taking advantage of the temporal price spread in the spot market. Electricity from the grid will be used for the charging of the storage unit with electric energy. This process will take place at the hours, when the price in the spot market is at the lowest possible point. For pure storage operation, the decisive factor on whether the unit will incur revenues or losses through trading is the difference in the spot prices between different hours.

Heat Conversion to Electricity

Another possible application is the usage of heat to produce electricity using the ETES facilities in order to reduce costs. The heat can come from waste heat recovery, geothermal energy or other sources. Apart from the revenues from the electrical energy produced through heat conversion, there can be extra revenues through the trading of guarantees of origin for the energy produced from renewable sources, e.g. biomass. Those certificates reflect the ecological added value of the produced energy. Technical challenges with regard to the combination of heat conversion and storage operation remain to be examined.

Combination of Applications

Regarding the three main applications it has to be kept in mind, that they cannot be regarded separately, as they are strongly interdependent, either generating synergies or leading to incompatibilities. The interdependencies are graphically depicted in Figure 3.

When peak shaving is planned, the storage has to provide power as soon as the load curve attains a defined power level. This means that the storage has to be sufficiently large and filled by this time and that the energy fed into the grid for peak shaving energy has to be sold concurrently, leading to obligations and constraints for operation and trade.

Furthermore, target functions of the different applications may change in the future due to development of the market, legislation and other conditions (Figure 3).

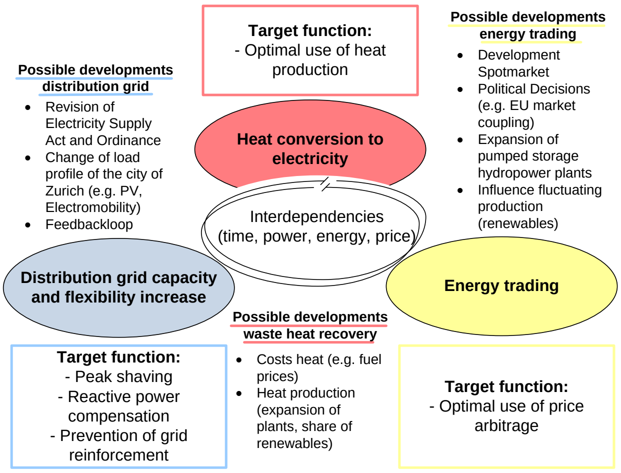

Figure 3: Interdependencies and future developments

PILOT PROJECT ETES AUWIESEN

Topology

The pilot project is planned to be built in the outskirts of the City of Zurich. Figure 4 shows the plan of the yellow framed building area and its surroundings. The area is close to the substation Auwiesen (220kV/150kV) and to the substation Aubrugg (150kV/22kV) which facilitates the electric connection of the ETES Auwiesen to the distribution grid. The biomass power station Aubrugg is located next to the building area and the heating pipeline crosses it in the north-eastern corner. Therefore, the connection to the heating pipeline to enable the waste heat recovery is simple.

Technical Details

In the current planning phase, the ETES Auwiesen has a target size of 5 MW_{el} for six hours charging and three hours discharging. The maximal round trip efficiency is expected to be 40%-45%. The working fluid CO_2 will be operated between 30 and 140 bar. The temperature of the storage fluid water will be maximally 120 °C and minimally 0 °C. The water tanks will have a volume of several thousand cubic meters.

Option for waste heat recovery

After stage 1 of the project in which the ETES Auwiesen is used as a storage for electricity, further utilization of the ETES plant will be analyzed. Stage 2 comprises the possibility of waste heat recovery from the district heating system, together with the waste disposal and recycling operator of the city (ERZ), (see Figure 4).

The excess heat of ERZ originates from waste incineration or biomass units. The available amount of energy depends on the weather conditions, mainly temperature, and the operation constraints of the thermal power units. Waste heat can be stored in the water tanks of the ETES Auwiesen and converted to electric energy when required.

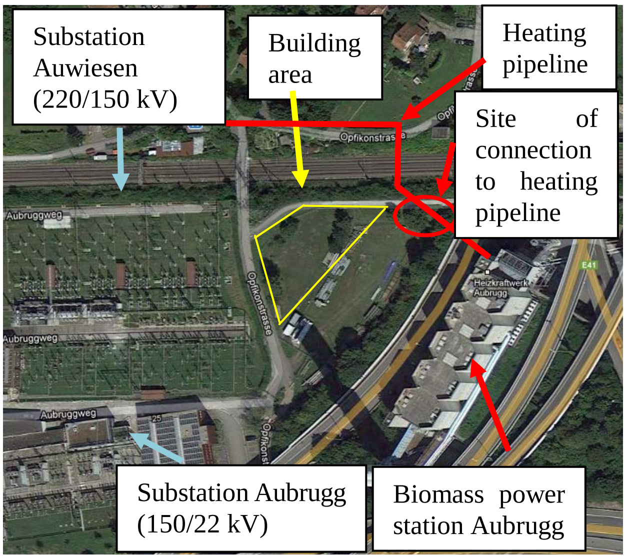

Figure 4: Topology of the building area

Benefits for the city of Zurich

The city of Zurich has many benefits of conducting this pilot project: It can gain experience with a storage which has the potential to facilitate the integration of renewables in the distribution grid. The experience can be used for storages with a size of up to 100 MW_{el}. The water tanks have a double use as an emergency water supply for the district heating system. Furthermore, the device can be adapted to convert waste heat from the district heating to electricity.

Technology Demonstrator

The pilot project is a technology demonstrator for a commercial system size. Due to the pilot character of the project profitable operation is not expected. After the test period, an adequate utilization of the ETES Auwiesen will be determined. The minimal requirement is to integrate and to maintain the water tanks in the district heating system.

Economic Analysis

Several versions have been studied to assess the combination of the applications. The analyses shows, that trade alone is no optimal solution. Grid optimization in the broad sense becomes the driving force of the storage use. In the first stage of the project ETES Auwiesen will be operated as a pilot storage power plant. Possible applications include peak shaving, reactive power compensation and trade. In the second stage of the project, it will be considered to recover waste heat and convert it into eletricity. As the ETES Auwiesen is situated next to a substation, there are no cost reductions due to prevented construction measures in this specific case and also due to the pilot nature of the project.

Stage 1 Grid optimization and trade

Ideally the dimensioning of the ETES Auwiesen has a nominal power (MW_{el}) / energy content (MWh_{el}) ratio, which allows peak shaving of the load curve by the nominal power of the ETES and reactive power compensation. Peak shaving has to be done consistently in order to lower the monthly maximal quarter of an hour values, which determines the demand charge from swissgrid.

For the estimated cost savings and revenues through ETES the present load curve for the City of Zurich and the revenue potential expected today have been considered. As peak load occurs currently at midday, trade is done under the constraints that the storage is sufficiently loaded by midday and that energy is delivered and has to be sold during peak shaving (Figure 2).

Stage 2 Grid optimization, waste heat recovery, trade

As mentioned above reconstruction of the ETES Auwiesen to enable waste heat recovery will be investigated for stage 2. Waste heat recovery will be an additional functionality and increase the complexity of operation which already comprises trade based on storage operation and other applications. It is technically impossible to simultaneously operate the waste heat recovery and the ice tank, pre-requisite for the ETES operation. Furthermore, the balance between charging and discharging the heat tanks over the ice tank must be always kept, creating extra requirements for the operation. Therefore, one approach would be to do waste heat recovery during the summer period and trading based on price arbitrage using the storage mode during winter. However, the analysis shows that total revenues could be nearly doubled if both modes could be operated all year long. This results particularly from the prospective income through trade with guarantees of origin.

From an economic view point the estimations show so far, that about one third of the revenues can be generated by trade, peak shaving and compensation of reactive power respectively. With waste heat recovery the revenues potentially double if trading with guarantees of origin for renewable power is considered.

Risks

The risks of the project comprise various factors: the operation of the ice storage in the system has to be confirmed, the large sized turbomachines are prototypes, the reaction time of the system from charging to discharging determines its value, the heat exchangers have to work efficiently for charging and discharging and the high pressure of the CO_2 requires a high safety standard of the system. Furthermore, typical project risks as costs and delays must be considered.

CONCLUSIONS AND OUTLOOK

The project team showed that the pilot project is feasible and recommended its realization. The pilot project will be a technology demonstrator for an ETES of commercial size and provide findings concerning design and operation. Currently, the pre-engineering of the ETES Auwiesen is being conducted, which will provide a sound cost estimate and operational details. The completion of the pre-engineering is the next milestone of the project. Further planned steps are to receive the building permission of the ETES Auwiesen, followed by its construction and testing. The current project plan schedules commissioning and a first testing phase in 2015.

Apart from the applications studied here, it could be examined what benefits ETES can bring both to power flow control and applications in combination with wind parks, e.g. to compensate the stochastic character of the production.

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