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REVIEW OF THERMAL ENERGY STORAGE TECHNOLOGIES INTEGRATION IN SMART GRID

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ABSTRACT

With global warming, governments want to use more and more renewable energy, which are an unstable source of energy. With the strong development of new technologies, energy but especially electrical consumption is growing rapidly. As a consequence, energy policies tend to reduce consumption. In order to achieve an optimum result, the electrical network as well as every distribution network systems will have to undergo major transformations. So as to adapt to new requirements that the present systems do not have. Although the lack of investment and confidence in these technologies, thermal energy storage (TES) is a good way to integrate renewable energies into the distribution network, it will act directly on the heat networks and will have an impact on the production systems and therefore on energy consumption. Indeed, TES systems are necessary tools to participate in demand management. They widely guarantee an improvement of the energy efficiency and a control of the energy. Since TESs are used to manage the relationship between the demand of each consumer and energy availability. The Demand side management (DSM) is a principle of Smart Grid which aims to improve the capacity of the distribution system to adapt to consumer needs optimize demand and consumption.

A study was carried out to show the different TES systems, in order to compare their advantages and disadvantages and the parameters of each of them, in order to finally determine the production technologies, storage system and consumption strategies to be considered and integrated in the Smart Grid for the most optimal result.

Keywords: Thermal energy storage, DSM, Smart Grid



1. INTRODUCTION

The concept of controlling energy demand is designed for the first time in the wake of the oil shocks of 1973 and 1979. Indeed, the affected countries launched energy management programs in such a way as to best consume the available resources. The term Demand Side Management (DSM) was first used by the Electric Power Research Institute in 1980 to encompass the actions of managing the load (load management) of the power grid, energy efficiency and energy saving.

Today the energy system is not optimized to ensure a necessary distribution of the network. Indeed, the use of the production capacity does not exceed 55% and the transmission network is below 50%. In addition, energy production is mainly depend on two types of power stations: the power stations generating the base load and the latter trigger at peak loads.

The power plants to provide the minimum energy load at a load factor of about 85%, while those that decline on the photos work only few hours a year.

These commissioning operations are expensive and emit a lot of CO₂. The network also faces the emergence of non-dispatchable renewable energies, that is to say that it can not be put into service according to the needs of the network, productions must be consumed as soon as they are produced.

The common factor in all problematic issues is the balance that must be struck between supply and demand. This balance is difficult to obtain demand is volatile and can not currently be managed in real time by the network managers. Insofar as basic power stations are very inefficient, the peak power stations are triggered by large variations in consumption.

As described in [1] by conducting DSM actions, it is possible to move or clear consumptions, which has the consequences of linearizing the consumption and thus the energy production. The DSM has several advantages for both the electricity grid operators and the end-user.

In the same line, it is also an opportunity to alleviate the increase in consumption of full hours due to air conditioning in urban areas. In addition to this, space problems related to the installation of more powerful transformers will be solved by the use of cold storage systems.

The fault management will also be more successful, therefore the power grid will be more robust for consumers with critical load. At the customer level, profits are mainly financial. DSM can allow the end user to reduce the cost of energy bills while maintaining the same level of comfort.

Storage is an essential element in controlling energy demand. Some hours of consumptions that take place at full hours are not simply displaced without harming the comfort of the end user. This is the case, for example, with heating and air conditioning. To work around this problem, storage solutions are used. These storage solutions are part of distributed energy resources. Distributed energy resources are the elements that fit into the smart grid and enable the demand for energy to be reached.

Future intelligent networks will integrate a notion of storage to smooth the load curve. In this case, storage is also used for the energy produced by non-dispatchable technologies. The portion of electricity consumption for heating and air conditioning is 35% in the tertiary sector in Ile de France. Domestic hot water and heating have a share of more than 70% in private homes. It is therefore essential to plan consumption items, especially since they are the ones that have the biggest impact on consumer photos. In order to answer this problem we will be interested in the use of thermal energy storage (TES) methods: heat and cold. The study of systems and their most optimal strategies, as well as their integration in Smart-Grid (SG) modeling models.

The goal of the Smart Grid is to improve the distribution system's ability to adapt to consumer needs and optimize demand and consumption.

The distribution systems are not adapted to the stated specifications. It is necessary to use and study the production and distribution methods, and improve the consumption algorithms for the royalty flow, which produces the amount of energy in a given time [2].

To contribute to this system we must consider all possible systems. This is why it is necessary to look at the thermal storage.

The aim of this study is to propose several strategies for controlling production and energy consumption in an intelligent network in order to optimize the configuration and operation of the production and thermal storage devices for the lowest power installed possible. The idea is to move the operation of refrigeration units and heat in order to improve the performance of production systems and take into account the internal and external parameters that come into play.

2. INTEGRATION TES WITHIN A SG

In order to meet objectives of the model Smart Grid The scientific community tried to integrate thermal energy storage on it. The term Smart Grid is to be taken in the broadest sense as "Smart energy system" [3]. Indeed, most of the models emphasize the combination of several sources of energy in order to smooth energy loads and optimize consumption.

A projection between 2004 and 2025 has been studied [4] in order to analyze the impact of the combination of several distribution networks in order to optimize the consumption of each energy resource (Figure 1). This estimation is based on the integration of renewable energies ,previous work [5] [6] [7] the relocation of heat pumps and the impact of DSM strategies.

The study assesses the positive effect of DSM strategies related to the introduction of heat pumps systems powered by the excess derived from renewables energies. The use of heat pumps provides an interesting reduction in the electricity excess, helping to avoid grid stability problems when a large share of renewable sources is introduced.

Futhermore the study of the DSM strategy confirms its feasibility in keeping the users comfort while a proper TES is included in the heating system.

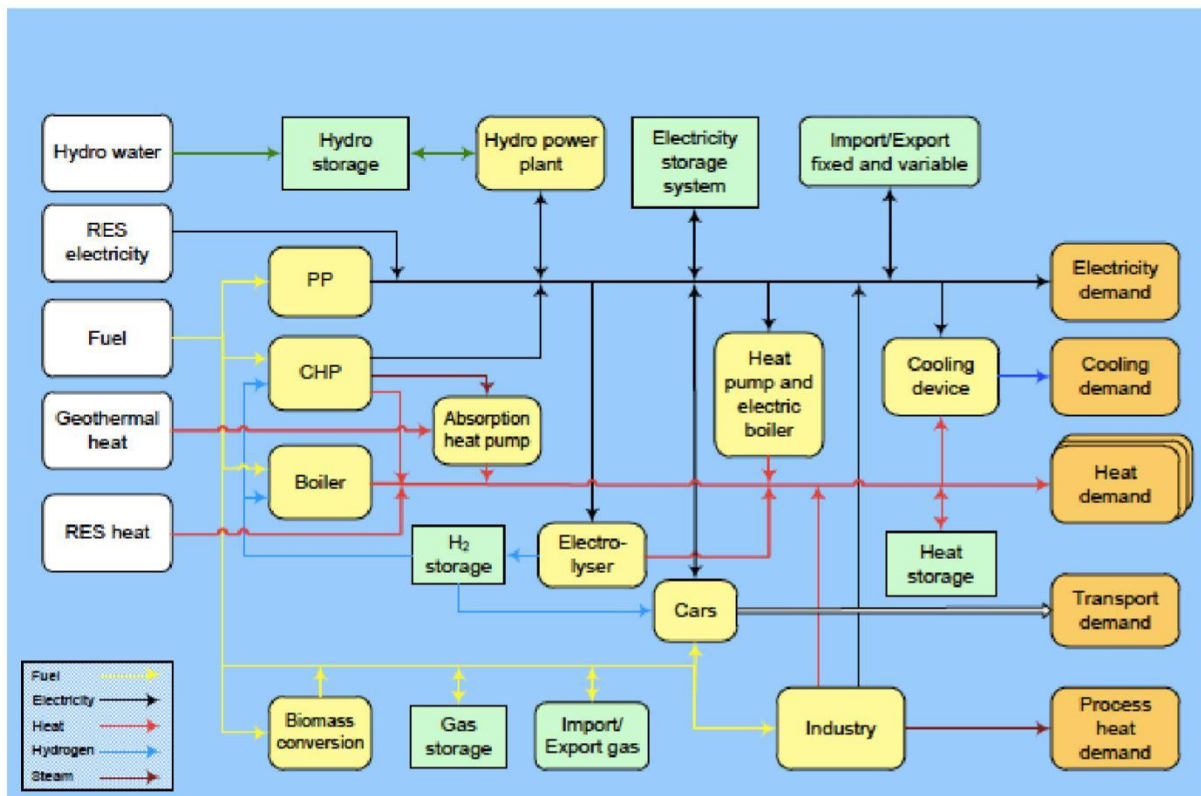


Figure 1. EnergyPlan model

This type of system offers flexibility and interaction between different energy sources and between different production systems.

However, to improve this flexibility and energy efficiency the insertion of thermal storage is studied for cogeneration, since heat demand can be decoupled from production because one has this flexibility to produce electricity by simultaneously storing thermal energy.

Combined Heat and Power (CHP) is a particularly attractive production system for a distribution network adapted to the Smart Grid because there is a possibility of interaction between gas distribution systems and electricity distribution systems. It simultaneously produces thermal and electrical energy, which is why it features a gas boiler and a heat pump. With such a system there is an optimization of the consumption of different sources of energy.

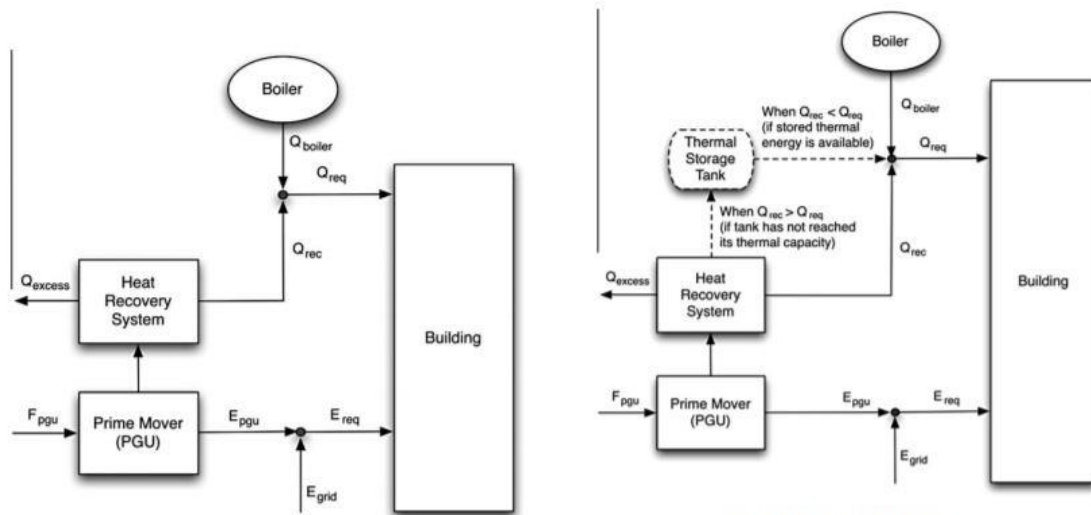


Fig. 1. CHP system schematic.

Fig. 2. CHP-TS system schematic.

Figure 2. CHP without and with TES [8]

Since thermal energy storage is an additional cost to a cogeneration device, the addition of cogeneration to cogeneration must provide an economical advantage and efficiency as well as a positive efficiency. This is why such a device must considerably reduce or eliminate completely the need for additional heating with another thermal production.

Smith *et al.* [8], carried out a study on insertion of CHP and TES on different buildings (Figure 2). Their calculation is based on an ideal device, their result is therefore not general and varies according to several parameters (type of boilers, type of storage, external climate). Their results showed that the storage of heat energy does not provide an advantage in addition to cogeneration. Since the buildings concerning this study are hospitals, hotels that requires much more electrical energy than thermal energy.

To evaluate the energy efficiency of such technologies there are several parameters considered, a building located in a colder climate will have better result regarding this efficiency since the demand will be greater. However, the demand also varies over time during the year and the seasons the climate is not the same from day to day, there is a change in temperature and which is even more important between day and night.

J.Vandewalle *et al.* [3] is directly concerned with the impact of storage by first comparing a gas demand reference with a simulated gas demand. Then it was interested at the size of the tank and way to store, when and how to store thermal energy.

Their results showed that TES increases the electrical revenues of cogeneration: 25% decrease in cost compared to the case without thermal energy storage 50% decrease compared to the case without storage and cogeneration.

3. USE OF TES IN SG

3.1. Indirect electrical storage

The TES applications should be studied, their operation is influenced by the demand of the user. Buildings in Europe account for 40% of the consumption of heating and hot water. It is necessary that these needs be adapted and controlled to meet demand and optimize power consumption. By carrying out actions of DSM, it is possible to move or delete consumptions, which has the consequences of linearizing the consumption, and therefore the production of energy. The DSM has several advantages for both the electricity grid operators and the end-user. Controlling energy demand is an opportunity for system operators to reduce marginal costs of production. Indeed, as part of the consumption at peaks is offset, the most expensive and most polluting power plants no longer have to be put into service. However, it depends very much on the behavior of the end user.

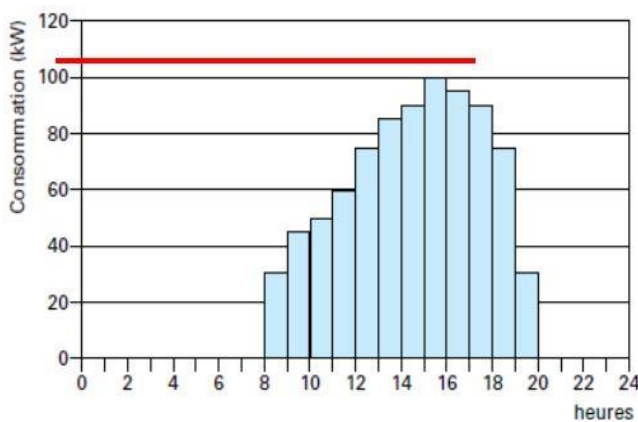


Figure 3. Consumption histogram (Dumas, 2002)

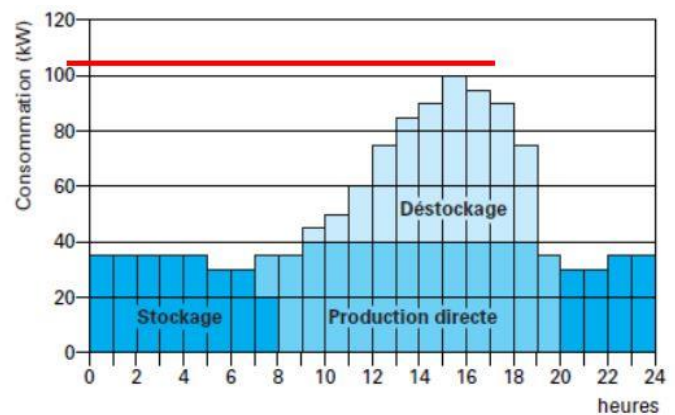


Figure 4. Consumption histogram with storage (Dumas, 2002)

Demand-side management is a method of matching energy production and demand. DSM programs can be directed to peak clipping, valley filling, load shifting and strategic conservation (Figure 3, Figure 4). Among the means of DSM, the TES can be used for this load distribution. By projecting in 2025, C.Brandoni et.al. [4] shows with a numerical model that the use of heat pump linked to thermal storage allows to reduce the electricity consumption, with more than satisfactory results taking into account well all the regulations that will evolve until 2025.

DSM strategies aim to flatten the consumption curve, so be careful not to shift consumption peaks, ie to apply the same strategies for different production systems and TES. For example, moving all refrigeration productions at night because the temperature is lower, so the efficiency of these production systems is better. But such a strategy could cause a peak of consumption at night.

Four criteria are important for DSM [9]:

- Energy-efficient end-use device
- Supporting equipment and systems to allow the shaping of the load distribution.
- Control system to start or stop (manage strategies) end-use devices as required.
- Communication system between end users and external parties.

The TES technologies, their characteristics, strategies and existing tests to meet DSM expectations must be determined.



3.2. Choice of a Thermal Energy Storage Technology

For thermal energy storage to be as optimal as possible there are several important parameters to consider in order to evaluate the efficiency of such a system:

To satisfy this optimization, it is necessary that the system meets several criteria. The storage capacity must be taken into account, the amount of energy available in a storage system after unloading it is important in order to define the energy that can be used.

This is why the maximum amount of energy accumulated per unit mass or volume plays a role on the storage system, which represents the mass and volume density of the energy. Important criterion due to space constraints in buildings.

Performance such as charging and discharging time is also not negligible, efficient and fast charging and discharging times will be more interesting for a consumer.

The reliability of a storage system affects the relationship between its installation and its performance over time, since its durability determines the energy savings or even the financial savings that can impact this system. The number of times or the storage unit can release the energy level for which it was designed after each recharge determines its durability and thus the reliability of this storage.

The available power, ie the maximum power of charge or discharge, is an important criterion that will influence the efficiency, as is the energy efficiency which is the ratio between the released energy and the stored energy.

Finally if the investment on the installation does not have an economical and efficient return such a device is unnecessary for the consumer. Capital and operational costs must therefore be taken into account for the entire life of the system. Some comparisons according to some of these criteria are performed [10].

The power available during the discharge is another aspect to be taken into account. While the amount of stored thermal energy is determined by the storage size, the heating or cooling power is mainly due to the storage model. For a laminated water tank, the power is strictly related to the flow of the tank, which can not be too high so as not to reduce stratification and reduce storage efficiency. For a latent TES, the power is related to the system model and to the thermal conductivity of the material, generally not too high.

However, Phase Change Material (PCM) are a good option [11] [12]. A PCM is a material with a high heat density which, melting and solidifying in a range of temperature, is able to store or release large amounts of energy. Future developments in TES are limited and the only opportunities are related to the development of phase change materials and their integration into the system [13]. The presently studied PCMs have melt temperatures between 22-25 °C, whereas there is a lack of PCM in the temperature range below 15-20 °C [14]. Thermochemical storage systems are being developed and only prototype systems are available.

N.J.Hewitt carried out a study on response times was done on PCM [15]. The loading and unloading times are influenced by the integration of the storage with the Demand-Response.

Among the thermal energy stores, laminated water tanks represent the most fully developed, commercially available technology with good efficiency at low cost in the temperature range for buildings.

3.3. Strategy for DSM

Such a distribution system is strongly influenced by its behavior, and therefore by the application of strategies. But we must not neglect the influence this may have on thermal comfort. The TES allow these consumption strategies to be applied and to maintain user comfort even when they are stopped by using thermal storage (Figure 5). In order to allow such a management of the strategies and regulation of the loads it is necessary to start to explain it [16], intelligent controllers for the buildings of each micro-grid.

DSM strategies typically include...

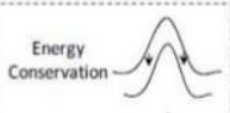

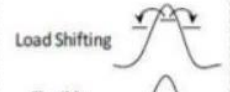
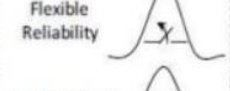
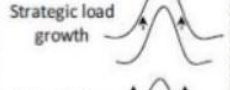

	Aim	Impact on peak demand	Impact on energy demand
 Energy Conservation	Reduce the overall energy demand (<i>energy conservation</i>)	↓	↓
 Peak Clipping	'Clip' demand at peak load periods (<i>load levelling</i>)	↓	↓
 Load Shifting	Shifting to off peak hours (<i>load levelling</i>)	↓	No change
 Flexible Reliability	Induce change in load as per supply (<i>load controlling</i>) also known as flexible load shape	↓	may reduce
 Strategic load growth	Promotion of applications requiring electricity – electric vehicles	may increase	↑
 Valley filling	Increasing load during off peak hours (<i>load levelling</i>)	No change	Increases

Figure 5. DSM Strategies 1

In order to optimize the consumption of the TES, it must be able to function in an intelligent way, such as automata. They must be able to evaluate their consumption in real time according to various predefined parameters such as temperature, the price of production of the energy market to avoid peaks of consumption. In order to be able to respond to such an operation, it is necessary to apply the most appropriate consumption strategies according to the situation, the parameters and the type of appliances. Guérard *et al.* present the different strategies possible according to any type of device if it is about consumption or storage or both [1].

4. CONCLUSION

This paper shows the impact and importance of integration of TES for a more optimal heat network. It presents some model based on this kind of configuration and its advantage to use it in an intelligent network. The thermal energy storage is necessary in order to optimize future distribution networks. But in order to understand this approach, we must define the objectives of this system and these advantages:

First point to highlight is the energy management. Indeed, the thermal energy storage makes it possible to have a better control of the system production operations. This optimization is the reflection of the consumption cut-off explained in the paper. In this case, there is an improvement in the flexibility of the distribution. This can involve a reduction in the installed capacity of 30 to 70%. Second point thermal storage then improves the efficiency of the production system. This management involves moving the refrigeration units (at night) or hot groups (in the middle of the day) at their most favorable time to produce thermal energy. This process improves the performance of the condenser or compressor due to climate conditions. There is therefore an improvement in energy efficiency.

However, a wider study of the problem will have to be accomplished by applying the TES in a model that is constrained to the objectives of a Smart Grid model.

¹<https://www.slideshare.net/TataPowerDDL/demand-side-management-61048795>



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