

Combined Heat and Power Plants with Thermal Storage

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Introduction

Increasing the energy efficiency of our systems helps us to meet our energy related challenges affordable. Combined heat and power plants serves as a strong example of how energy efficient technologies can help us drive business competitiveness and economic growth and jobs, and also helps us in protecting our environment from the harmful greenhouse gas emissions. Combined heat and power (CHP) plants or cogeneration, are unique among electricity producing methods and technologies because they generate electricity and thermal energy in a single integrated system.^{1,2} CHP unlike central station generation, is located at or near the consumers location, thus transmission losses and transportation costs are avoided.³ It utilizes the heat generated by the electric power equipment to satisfy heating/cooling applications of a building or industrial process, which would normally be lost during power generation process. Cogeneration is highly efficient form of energy generation and it can achieve greater energy savings compared to separately generating power, heating and cooling. CHP adds additional flexibility and reliability to the system upon integration with potentially variable renewable energy systems like solar and wind power. Together, the CHP systems results in additional energy savings and carbon footprint reductions. Though CHP is currently underutilized,³ in industries, the market activity is growing, recognizing its benefits and declining natural gas rates.

CHP produces both heat and power simultaneously, but the demand for heat and power fluctuates during the day: Demand for power is typically high during daylight hours; whereas demand for heat is high at night. If the demand for power is met exactly, there may be

excess or insufficient heat; conversely, if the demand for heat is met exactly, there may be excess or insufficient power. Thermal energy storage (TES) systems allow this excess heat to be stored in periods of low demand and used in periods of high demand. This allows the CHP plant to operate at high efficiency without wasting either heat or power. Among the many types of energy storage methodologies being widely used, TES system makes a significant impact in terms of large scale application and costs involved.⁴ TES coupled with a CHP plant, not only improves the efficiency of the system but also proves to be economical and environmentally promising. Although CHP coupled with TES is less common across industries, there is a significant potential for adoption of CHP-TES system to further increase the energy efficiency of Industries.

Overview of CHP

CHP, also known as cogeneration, produces concurrently electricity and thermal energy for heating/cooling applications from a single source of energy. It is a type of distributed generation³ located at or near the point of consumption.

The CHP plant can run on multiple fuels, so the facility is protected from fuel price volatility and supply risks. Also, there are many prime mover technologies used in CHP for generating electricity. The heat generated by the prime mover is utilized to meet the heating/cooling demand of a building or industrial process.

The electricity generated by CHP can be used on-site or can be sold back to the grid if agreements and protocol with the local utility can be arranged. The thermal energy produced is the most valued³ output for most industrial applications. CHP applications operate at a high efficiency² of over 80%, while the conventional methods when separately operated has a typical combined effi-

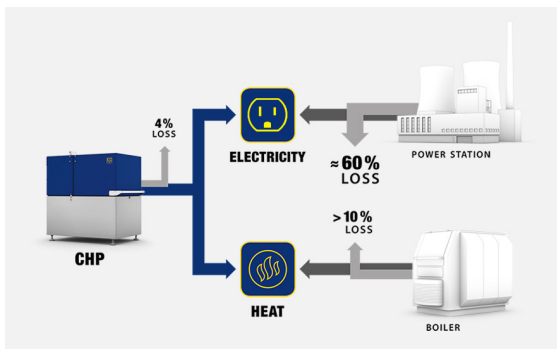


FIG. 1: Cogeneration compared to separate energy generation.⁵

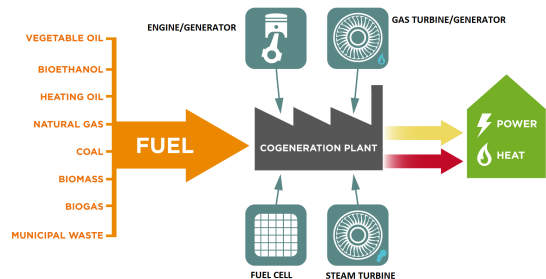


FIG. 2: Cogeneration Principle.⁶

ciency of 45%. CHP reduces the emission of CO_2 and other industrial pollutants, thereby bringing the facility into compliance with the emission standards generally.

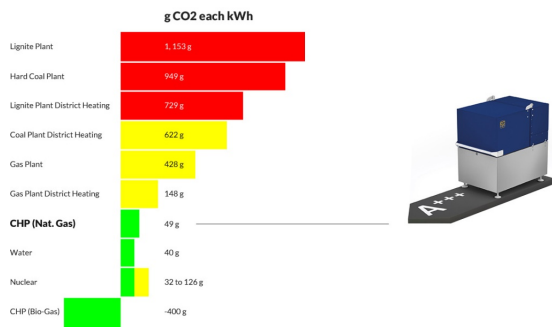


FIG. 3: Comparison of greenhouse gas emissions.⁵

A CHP technology can be deployed quickly and cost effectively after ensuring that the electrical and thermal loads in the facility are as energy efficient as possible. This leads to more efficient generation offering myriad benefits for the end user, utilities and communities. CHP generates significant annual operation cost savings, which enables the consumer to pay back the initial investment in between 3-7 years⁴ depending upon the capital cost per KW, efficiency of CHP plant and hours of operation. CHP enhances energy reliability by providing backup power even when there is a power outage in the grid to facilities where power is mission critical. During and after Hurricane Sandy,⁷ CHP played a key role in enabling hospitals, universities, schools and residential buildings to continue operations when the electricity grid went down in the hardest-hit localities, proving that CHP is a sound choice in making energy infrastructure more resilient in the face of extreme weather conditions. A number of facilities in the commercial, institutional and residential sectors are considering use of CHP, due to its reducing fuel prices and the expanding state and utility incentives available for it in various forms.

Overview of TES

In order to address the challenge of intermittency in renewable energy systems and to make use of the excess generated power going unused, energy storage technology has been recognized as one of the promising solutions to store the energy for use at a later time. Among the many types of energy storage methodologies being widely used, Thermal Energy Storage (TES) system makes a significant impact in terms of large scale application and costs involved. Thermal energy storage is like a battery for a facility where it makes use of its thermal equipment and storage tank to shift all or a portion of its thermal demand to off peak hours. The stored energy is either used the next day or in future to address the facility's demand. TES is a very cost effective method of energy storage compared to other storage technologies that rely

on expensive, sometimes even exotic materials. Its inclusion can dramatically reduce pay back periods, making it employable in a wide variety of applications.⁸ Further, it also improves the share of renewable in the energy mix⁹ by the conversion and storage of variable renewable energy in the form of heat which can be used for space or water heating in facilities.^{10,11} TES systems can be either used in centralised applications such as district heating or cooling, large industrial plants or in distributed systems applied in commercial or domestic buildings to capture solar power for water and space heating/cooling. TES systems have large number of installations in European countries, in places which have a large percentage of renewable. For example, in Denmark, Thermal energy storage has been a vital part of its 100% renewable energy plan.¹² Thermal Energy storage could be sensible, latent or thermo-chemical heat¹³ as represented in Figure 4;

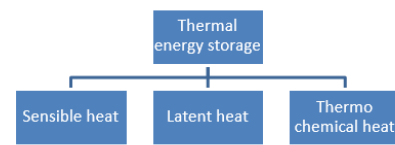


FIG. 4: Thermal energy storage types

Sensible heat storage is the storage of thermal energy by raising the temperature of a solid or liquid medium. Latent heat thermal energy stores by changing the phase of a material. Thermo-chemical heat storage involves chemical reactions to store and release thermal energy. Sensible heat storage is relatively inexpensive compared to other two types of thermal storage. The only drawback is the requirement of large volumes due to its low energy density.

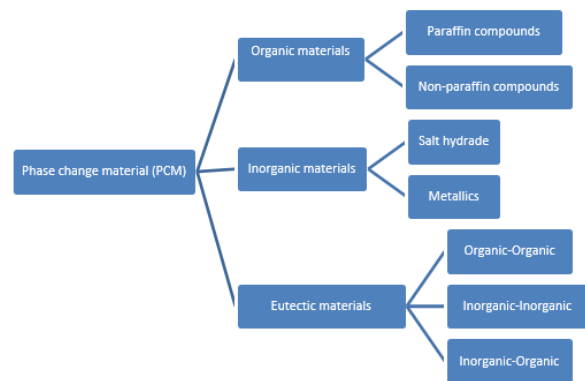


FIG. 5: Classification of Phase change materials (PCM)

Phase change materials (PCM) are latent heat storage materials that absorb and release thermal energy during melting and freezing. It has the ability to store more energy per unit volume than other TES types. PCM finds wider use in improving energy efficiency of building heating, cooling and air conditioning applications.

The ability of PCM to melt and solidify at a wide range of temperatures makes them more attractive for numerous applications¹⁴ of TES systems. Apart from meeting the application requirement, the selection of a PCM depends upon its physical, thermal, chemical and economic factors.¹³

Coupling of CHP-TES

The need for a TES in a CHP arises when the demand for heat and power produced by CHP plant fluctuates during the day: Demand for power and heat varies during daylight hours and at night. Therefore it is important to match the production and consumption profiles.¹⁵ Thermal energy storage (TES) can be used to store the heat generated to help better align these loads. This allows the CHP plant to operate at high efficiency without wasting either heat or power.¹⁶ Adding TES to an energy system improves its economics by downsizing the equipment and its capacity,¹⁷ and also reduces equipment wear. Under certain applications, it can have an immediate impact on capital costs by replacing expensive chilling or power generation unit with a less expensive storage tank.

Incorporation of thermal storage in a CHP plant is essential to increase the systems ability to balance intermittent renewable energies. When there is lot of renewable power available from either solar or wind,¹² CHP-TES can stop producing power and meet thermal loads by discharging TES; conversely, during low power scenarios CHP can run at full load simultaneously generating power and heat. By this way TES improves the flexibility of the system and also maximizes profit.

Results and Discussion

The steady state operation of a CHP plant which has to meet a discontinuous or highly time variable heating load, by coupling it with a thermal storage, will improve the cogeneration system operating conditions and

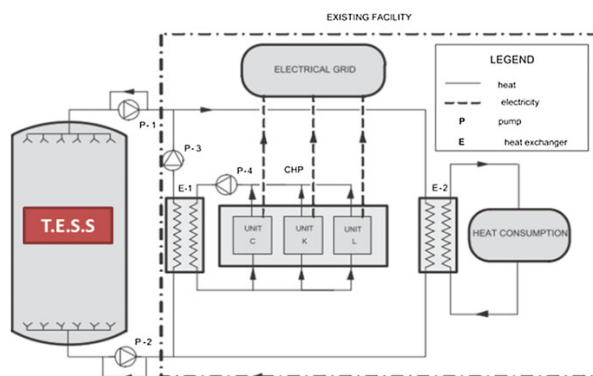


FIG. 6: Combined heat and power plant with Thermal energy storage system.¹⁸

lengthen its operating time. Though it can be concluded that adding thermal storage to a CHP plant has the following benefits like increase in flexibility, improved efficiency, and reduction in energy consumption, equipment costs and emissions, the benefits also depends upon certain key factors. It is important to analyse the thermal energy requirements¹⁹ of a facility before commissioning the system for actual use. It is important to match the requirements with the equipment sizes,²⁰ in order for the system to be efficient. Secondly, the benefits of the combined system vary depending upon the climatic conditions²¹ in which it is employed. For applications in colder regions with high thermal demand like full service restaurant and large hotel^{21,22} will need a separate boiler to meet the heat demand in addition to the thermal storage in a CHP plant. Applications like hospitals and small office facilities have greater demand for electricity than thermal energy. In such cases, adding thermal storage to a CHP plant will not prove to be beneficial. For applications with varying thermal demand frequently, thermal storage contributes to balancing the variation upon thermal energy requirement. Therefore, it is important to properly design and control the CHP-TES system depending upon the application to attain maximum benefits. In general, addition of a thermal storage to a combined heat and power plant does reduce energy consumption and CO_2 emissions over the CHP alone system.

Conclusion

TES carries a lot of benefits and challenges in integrating²³ itself with energy systems. In most cases, TES system presence in a CHP system helps it to match electrical and thermal demands which in other case limit the CHP only system. Installation of large storage tanks allows total stop of the CHP system during non peak hours.²⁴ It has been learnt that apart from an increase in overall system efficiency, flexibility²⁵ and reduction in energy consumption, adding TES to a CHP system also reduces CO_2 emissions²⁶ by thrice compared to a CHP only system. Upon proper optimization and controls, TES-CHP systems operate effectively in district and building heating/cooling applications²⁷ and areas with notable renewable energy penetration.¹¹ The system by shifting electrical peak loads from high cost peak times to low cost off peak times reduces cost of the required additional peaking equipment²⁸ and operating cost thereby allowing users to take advantage of cost savings²⁹ involved. Integration with intermittent renewable energies such as wind and solar power shows their flexibility in balancing the intermittency. Results show that despite fluctuations in available power from renewable energies, a TES system can still produce power at a constant rate.³⁰ TES allows CHP to run more continuously and studies have shown that the longer the operating hours of CHP system, the better the economic outlook of the system. Though it is

said that TES is not very versatile due to its simplicity, In order for the system to be promising and cost effective, intelligent methods to use TES should be developed.¹¹ Development of new materials in the future will lead to increased energy storage and savings. TES systems cost effective technology of storing energy finds users in wide variety of applications. Secondary usage of TES for fire protection water storage benefits the industry in case of fire accidents. TES systems reduce payback periods³¹

greatly in addition to improving the projects return on investment.¹¹

It is important to determine the thermal requirements of the facility before investing in such a system. It is also necessary to take climatic conditions into consideration for the effective functioning of the system. Although CHP coupled with TES³² is less common across industries, there is a significant potential for adoption to increase the energy savings of Industrial facilities.

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