Modelling of a CHP System with Electrical and Thermal Storage

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Abstract

Decentralised energy generation is increasing in popularity because it provides for higher efficiencies and is consequently more environment friendly than the current centralised solutions. Most of the inefficiencies of centralised power stations lie in the large amount of waste heat. Combined Heat and Power systems overcome this challenge by using the heat as well as the electrical output, but these outputs are generally constant, while any demand would be continuously fluctuating. The only way to deal with this imbalance between supply and demand is through the use of energy storage, and therefore this paper investigates the benefits of combining energy storage systems with a CHP system to determine the potential efficiency improvement from such a combination. A full model of this system, which consisted of several sub-models to deal with the various elements of energy generation and storage was developed in Matlab and used for simulation using some real-life demand data. The results show that through the addition of a correctly sized thermal and electrical storage to a CHP system, the CHP system is able to run continuously at optimal efficiency.

Keywords: CHP; Internal Combustion Engine; Thermal Storage; Electrical Storage

Introduction

The move towards a reduction of greenhouse gas emissions, has led to an increased focus towards improving efficiency. Consequently, decentralized renewable generation are being promoted, especially when these consist of bio-fuelled Combined Heat and Power (CHP) systems. In this manner, a CHP system can benefit from a reduction in fuel consumption of about 35% versus the use of conventional energy supply mechanisms [1]. However, CHP systems would generally still suffer from losses if the demand is lower than the supply, and may at times not be able to fully support the demand. It is well known that energy storage buffers can help to deal with such differences between supply and demand, and while current CHP systems may get fitted with a thermal store, they rarely get fitted with electrical storage, even though that can also bring particular benefits.

The addition of these energy storage facilities, will not only improve the flexibility of a CHP system and its overall efficiency, but such an uncoupling between production and demand through storage allows for this stored energy to be used at other points in time, while excess electricity could e.g. even be sold to the grid when profit margins are most optimal [2].

Model Development

Due to the required system and sub-elements to be modelled, Simulink was identified as the most suitable modelling environment. Through the various add-on environments the full system (See Figure 1) could be developed as sub-models. Unfortunately, the simulator did not allow for all sub-models to be combined directly, in which case they were linked through the use of input/output data of the respective sub-model, these sub-models were: 1) Internal Combustion Engine (ICE) with generator, 2) electrical and 3) thermal storage system.

An Internal Combustion Engine model is used to represent the CHP system, since it is among the cheapest and easiest technologies to install and run. The model used for this simulation is completed using manufacturer's data, and the engine is linked up with an AC generator to complete the CHP system, which provides for 105kW electrical and 47kW thermal output. An RLC load block was used as load to this sub-model, while load changes were implemented through the use of a three-phase circuit breaker combined with different RLC loads.

Any electrical energy, which is not of benefit to the actual load itself, would be stored into electrical storage, for which batteries were used. While there are a large variety of available electrical storage mechanisms, it is well known that battery storage has a high energy and power density, although it may not necessarily form the best solution when the energy storage requirements are large. For this simulation, the lead acid battery model used which includes state of charge characteristics, and therefore allows for accurate simulations over longer periods of time. Considering that batteries normally operate on DC, while the generator and load are AC, a rectifier and inverter are introduced to deal with the necessary conversions. Both of these extra components are added in with the electrical storage sub-model. This electrical sub-model was then combined with the ICE model in order for the generator to supply to the load as well as charge the battery if the demand is lower than the supply, while if the demand becomes higher than the supply then the battery supplies the additional required power.

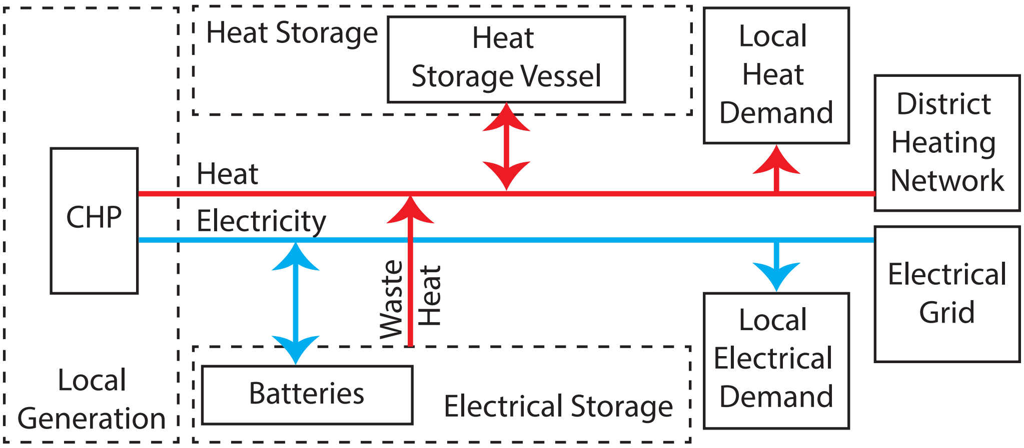

***Figure 1*: Block diagram of a CHP system with thermal and electrical storage**

The sub-model for thermal storage was built around the hot water storage tank model developed by G. Rouleau [3]. The thermal storage uses water as the storage medium due to it being easily accessible, while one can cheaply store water at temperatures up to 200°C in pressurized tanks [5]. The thermal demand in this case is limited to the user's hot water, and so it ignores the space heating requirement, which is on average larger. Secondly, the heat supply only comes from the engine cooling, which is generally of lower temperature than the heat recovered from the exhaust gases. The main design requirement for the thermal storage is for it to be able to minimize the dumping of waste heat. Any heat supplied and/or demanded is stored/retrieved through the use of a heat exchanger, which deals with the heat exchange between the different media. Due to limitations of the modelling environment, the heat supply was provided from a heat flow source block, while any heat losses from the tank through convection and conduction are also modelled using the appropriate components.

Detailed Design and Conclusion

To build a complete system, the individual storage systems need to be sized up, for which one needs to look at the size of the differences between demand and supply. For the demand data used in this setup, a battery capacity of 20 kW and a hot water storage tank with a capacity of 12kW were added in. Through the addition of this storage the efficiency of the CHP system can continuously be kept at its maximum [4], considering that normally if supply is larger than demand, then energy would be wasted and vice versa. The efficiency of a system without storage depends on the amount of energy that is wasted, and could therefore be continuously changing, not to mention that one needs extra energy sources to deal with the case where demand is much larger than the CHP output. Additionally, a well-developed storage system can actually allow for the CHP system size to be reduced and therefore improve on e.g. emissions, while in certain cases one would even be able to buffer electrical energy to sell it when profit margins are highest and therefore make profit on running the system as such.

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