Utility-side optimisation

The performance (economic, social, environmental, technical) of the DH/DC network can be improved by optimising its operation. Within the network, the utlity side comprises of all the network up to the end-user substation. The aim is to operate the production and transmission/distribution facilities so as to reach high performance. There are several methods that can help in this process, and 3 of these are presented in this article. First you will read about how thermal energy storage enables to decouple the production of heating/cooling for their use. Then the hourly scheduling of the production assets can be designed in a coordinated way with the dispatch of heating/cooling in order to improve the performance. Finally increasing the integration of thermal energy services with electricity services can yield significant economic and energy savings through active network management and demand response. Smart control integration of hybrid heating systems with Thermal Energy Storage (TES) in current energy systems offers great potential to integrate different energy sources and thermal energy generators to provide heating or cooling direct to end-users or by thermal energy networks as district heating or cooling. The grade of success of this integration, measured commonly in CO2 reductions, energy efficiency and cost of thermal energy production will depend on several factors such as availability of resources, type of technology utilized, size of the TES, electricity prices on the project region, smart integration of the energy sources etc.

The smart integration of the energy sources, energy generators and TES is essential for current and future individual or district heating/cooling systems. The smart integration of these technologies and as well as the interaction with other factors as the liberal electricity market, provides the possibility to integrate renewable energy, waste heat, allow free cooling in a more efficient way. It can help in reducing the size of the heat generators, improve heat plant economics, and so on.

In the following sections, both individual heating systems and district heating integration will be briefly described.

Smart heat storage for solar heating systems

Heat supply (hot water and space heating) for buildings represents about 43% of the final energy consumption in the European Union. In a future scenario with high shares of renewable energy sources, intermittent heat and power generation is expected to increase.

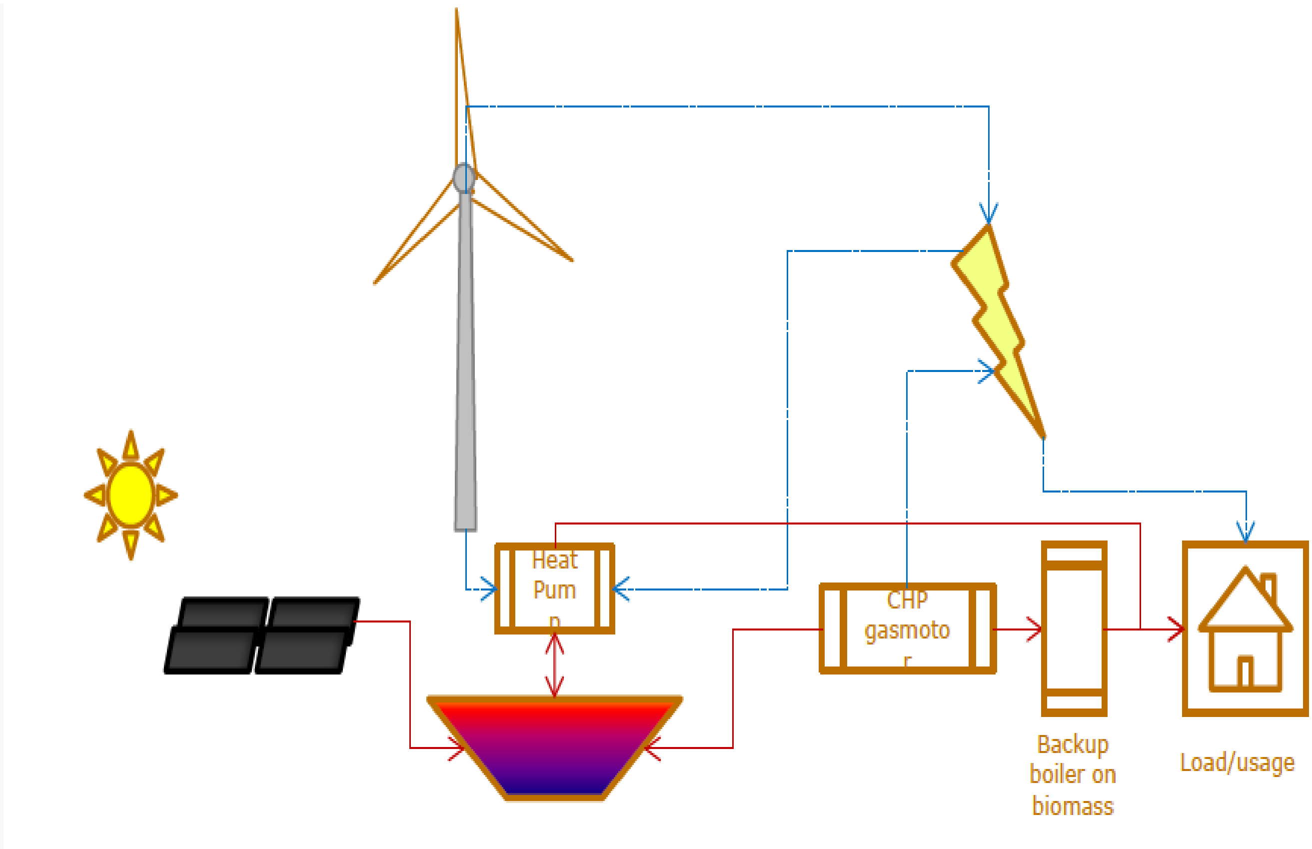

Figure 1: Smart heat storage for solar heating systems

In Denmark for example, during the first semester in 2014, 41% of the consumed electricity came from wind farms and it is expected that by 2050 about 50% of the increasing electricity consumed (including transport and heat pumps, etc.) will be provided by the wind. In the heating sector, it is expected that 15% of the decreasing heat demand will be provided by solar heating by 2030 up to 40% by 2050. From this last figure of 100% solar share, 80% will be provided by solar heating plants and the rest 20% by domestic individual heating systems.

Some of the problems related to these scenarios are the increasing mismatch between the supply and demand as well as the increasing dynamics of the electricity prices on the energy markets. The solution already being implemented in Denmark to tackle this problem is the combination of different energy generation technologies using smart heat storage to integrate them and making the heating plant to interact with the electricity grid (see figure 1).

This concept, which is already having succes is the solar district heating using large-scale water pit heat storage (PTES) e.g. the Pit energy storage in Dronninglung plant has a capacity of 62000 m3 of water. It was in 2014 the largest in the world of its kind.

A similar integration of technologies is presented in the Marstal heating plant, a case study about the Marstal SUNSTORE 4 can be found in chapter 5 in Celsius deliverable *D5.6: Concepts for storage and load control*.

Smart solar tanks in combisystems for one family house

The Roadmap Europe 2050 projects an increase in district heating in Europe of 30% by 2030 and of 50% by 2050. Northern European countries such as Sweden and Denmark account with high shares of thermal energy networks. However, there is still a long way to go before widespread thermal energy networks in Europe will exist in locations far away from the dense urban areas where individual heating/cooling systems might be more economically feasible as a thermal network supply.

It is expected that solar and wind energy will cover the majority of energy demand in future energy systems. The fluctuating power coming from wind farms will increase and periods with electricity surplus will be more often. Therefore a concept which integrates both, solar heating systems and electricity power coming from wind is intended to increase the use of these two renewable energy sources.

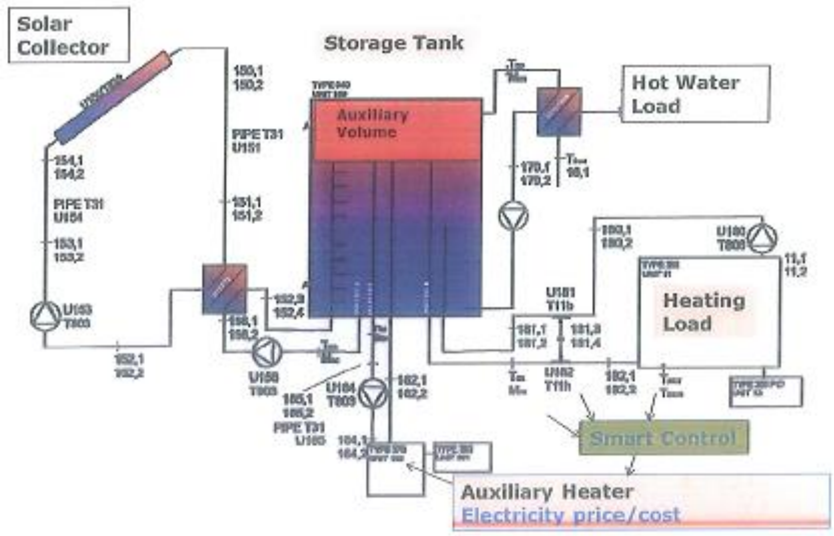

Figure 2:The solar combi system layout. It shows solar collector, auxiliary heater, storage tank and hot water and heating loads in the house.

In these types of heating systems heat is produced by solar thermal collectors in combination with electric heating elements or in combination with heat pumps, which are also driven by electricity (Figure 2). Electric heat devices and heat pumps operate when the heat demand cannot be fully covered by the solar thermal collectors and when electricity prices are low. The system uses a smart tank (with variable auxiliary volume) as well as a smart control system. Therefore heat losses from the tank are minimized and overall performance is increased in comparison with traditional systems.

Other kinds of smart solar storage using latent heat are being developed and investigated by the Technical University of Denmark (DTU). These systems are tested for seasonal storage and cover the heat demand of one-family house. The investigations were carried out with 9m2 surface area and tanks with water capacity of 735l. Part of the heat demand is produced by solar thermal collectors on the roof of a single house, the rest is produce by heating elements or heat pumps. As solar heating cannot cover 100% of domestic heat demand, auxiliary electric heating units can be programmed to supply the rest of the heat when high shares of wind power is generated causing low electricity prices. A complete description of this technology is described in Furbo et.al. paper.

More detailed discussions about the smart control system and its impact can be found in Chapter 5.1 of D5.3 Concepts for intelligent system integration.

Smart Water Heaters as Grid Batteries

Electric-powered water heaters and space heaters have a lot of virtual energy storage capacity and they're already out there in millions of homes and businesses. That makes them a cheap resource for grid storage if they can be managed in a way that allows them to respond to the grid's needs, while still keeping the building at the right temperature.

In North America for instance, there has been commercialy developed so called "Grid-interactive electric thermal storage", for domestic hot water and space heating. These devices help to solve the needs of today's smart grids such as variable generation, variable demand and variable prices.

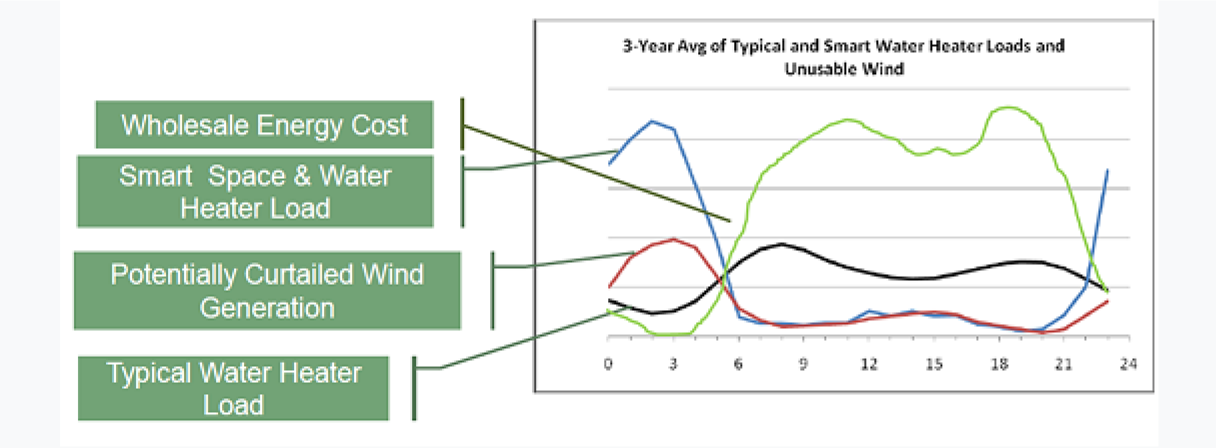

Figure 3:Three- year average of typical and smart water heater loads and usable wind

The system consists of the following components: smart water tank with electrical resistances and smart control. The smart control of these combined systems decides when it is more efficient to charge the thermal storage. This decision is done according three main aspects (Figure 3):

- Electric load demand
- Real time renewable energy production (wind and solar)
- Real time pricing (RTP).

Electricity is stored as heat in water tanks or well insulated brick core depending on the unit used. Storage occurs based on availability of renewable or off-peak energy or as signaled by the utility for ancillary services. With smart control the grid is affected like other electric storage technologies. The equipment accounts with an on-board microprocessor based control system to regulate charging and discharging.

Thermal Energy Storage and Heat Pumps

Heat pumps provide space heating and hot water or cooling for residential, non-residential and industrial applications in all European countries. Heat pumps are seen as a promising technology for load management in the built environment in combination with the smart grid concept and thermal energy storage. Heat pumps can be coupled with thermal energy storage (TES) systems and shift electrical loads to avoid potential stress in power grids, integrating fluctuating renewable energy (e.g. wind solar) or to produce cheap heat. TES can retain thermal energy by storing hot or cold water or even other materials for a period of time and release this thermal energy again whenever it is needed.

Heat pumps technical advantages and load control

Thermal energy storage brings environmental benefits, as it provides energy savings and asses climate change mitigation. Moreover linking TES with heat pumps can be used to manage electrical loads in dwellings or buildings with heat or cooling demands. This mechanism can be applied for peak shaving or load shifting as follows: from on-peak when the price of electricity is high (typically during the day) to off-peak hours where electricity is cheaper (in most cases during the night), and thus serving as a powerful tool in demand-side management (DSM) strategies.

Some studies have shown that heat pumps together with district heating systems are the best solution for heat supply in existing and future energy systems. The importance of the ability that these systems will provide in future energy systems is mentioned by Hedegaard, K., & Münster "the use of individual heat pumps is expected to grow considerably in Denmark, thereby developing into a significant part of the total electricity demand. The electricity demand of the heat pumps becomes flexible if e.g. investing in control equipment, enabling intelligent heat storage in the building structure and/or in existing hot water tanks, and/or if investing in heat accumulation tanks for space heating”

Balancing the network is a very important technical aspect requiring the consideration of heat pumps and TES. It comes from the increasing penetration of fluctuating renewable energy as Hewitt stated in his research work; “If a large amount of wind energy is to be superimposed onto a traditional fossil fuel fired (or future nuclear) electricity network, the inherent smoothing associated with wind turbines widely dispersed across a geographical region may not be sufficient to manage the dynamics of existing fossil fuel and nuclear plant (in ramping up or down depending on network requirements). Therefore an element of storage is required.” Regarding this aspect of balancing the fluctuating renewable energy with the energy demand, the technical university of Denmark (DTU) has been carried out several studies.

Renewable energy integration with heat pumps and thermal energy storage into district heating systems

Denmark is strongly pushing forward to a 100% renewable supply of energy by 2050. One radical measure taken on April 2013 was, the banning of oil or natural gas heating systems in new buildings. The measure will become more extreme, as even existing oil heating systems should be changed if there is a local supply of district heat or natural gas available by 2016. In order to achieve this goal, “Research work at the Technical University of Denmark aims to find out ways to couple the excess production of wind energy with heat pumps and thermal energy storage, so as to replace a large portion of the thermal energy demand – otherwise met by fossil fuels – in the residential and commercial sectors” and they claim also “we have found that it would be economically feasible to replace almost all the fossil-fuel boilers with a combination of a heat pump driven by renewable electricity and an energy storage system”

Heat pumps show significant potential to integrate renewable energy when achieving successful coupling with thermal energy storage. The performance of the system can also increase and thus, decouple energy supply from energy generation, allowing a reduction in sizing of the heat pump. Furthermore, it is possible to reduce operational costs, when taking advantage of the off-peak electricity tariff and to avoid power stress in the electricity grid in the case of the residential heat pumps. Other benefits that heat storage provides is that it can operate as a backup system when a problem occurs with the heating system.

Integration of heat pumps and Thermal Energy Storage into current district heating systems

Heat pumps linked to thermal energy storage are already part of district heating systems and together with other energy sources, satisfy the heat demand of entire districts in seveal cities. Using large-scale heat pumps into district heating networks is quite commung for example, in Denmark and Sweden. Some of the reasons of using large-scale heat pumps instead of residencial heat pumps are that: "Central heat pumps are more efficient, more compact, cheaper and deliver higher temperatures than individual heat pumps".

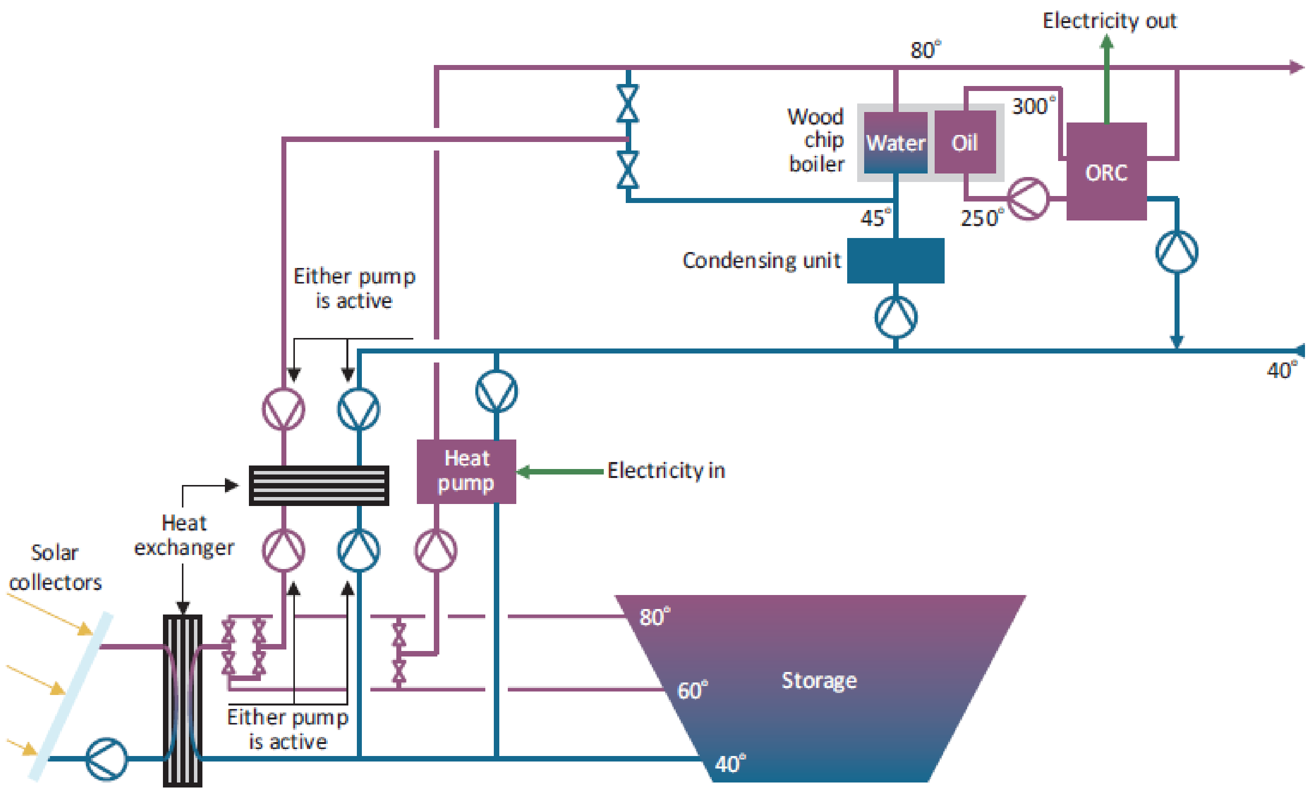

Figure 4:Principle hydronic system of SUNSTORE 4

A good example of the utilization of heat storage in combination with heat pumps and other technologies as solar thermal collectors is the plant at Marstal, Denmark.

As part of the solar heating plant, the thermal energy storage in Marstal is used all year long, due to its large size. The pit thermal energy storage (PTES) is mainly used to store the warm water coming from a solar thermal collector field. The PTES at Marstal is an excavated pit, which is lined by a membrane and filled with 75,000m3 of water. The operation temperatures range from 30 to 90C and its dimensions are the following: 113 m long, 88m width and 16 m depth. The storage is not insulated towards the bottom and the walls of the excavated pit, since the losses through the soil are low. Not so, the top of the storage is insulated and covered by a floating liner.

The PTES allows to integrate and to store hot water coming from the solar field. The hot water is integrated at different highs depending on its temperature. The whole heat demand is covered by the solar plant and the surplus of solar energy harvest is preserved until winter. It also provides all year long the input for the heat pump.

The heat pump has a power of 1.5MWth and uses CO_2 as refrigerant in its multi-comrpessor system. Its COP (coefficient of performance) is very sensible on the inlet temperature on the hot water circuit (corresponds with the gas cooler outlet temperature) but can reach very high hot water outlet temperatures (~ 80°C) without a reduction of COP. These temperatures are: inlet 35°C, outlet 80°C.

Some of the features that the heat pump provides to the solar plant are:

- Utilizes low temperature energy from the bottom of the heat storage
- Heat capacity of the pit heat storage will be increased due to larger temperature difference
- Efficiency of the solar system will be increased due to lower inlet temperature from the bottom of the pit heat storage
- Reduction of heat losses in the pit heat storage due to lower average temperature

- The operation of the heat pump takes place mainly at the end of the winter season in order to optimize the solar efficiency and the solar yields
- The heat pump provides flexibility of the electricity consumption, thus it produce heat during the winter where prices are more convinient for its operation

For more detail about heat pumps in Denmark and Sweden and about this project, a more detailed information and a case study can be found in the D5.6 Concept of Storage and Load Control.

Thermal Energy Storage and CHP

By capturing the waste heat associated with the electricity production, combined heat and power plants (CHP) can produce electricity and heat at the same time, thus reducing operational costs, emissions and primary energy consumption, making them more attractive over conventional separated heating plants for sustainable energy generation. CHP can meet electricity and heat demands of a commercial building (e.g. hotel, school, offices, restaurants, hospitals, supermarkets) or it can be connected directly to the power grid and supply a district heating network. However, a common concern is the mismatch between the electricity and heat production and the electricity and heat demand.

The relation between the electric and heat load demand is called power-to-heat ratio, so CHP installed in buildings with low power-to-heat ratios tend to have a bigger excess of heat production. This excess of heat can be addressed by coupling the CHP generator to a TES system, thus the heat can be stored and used later when it is needed. If heat supply and demand are better managed, the overall efficiency and economics of the system can increase.

One opportunity to optimize CHP operational performance, energy production, and electricity demand is for example, in the UK and northern Europe where these power plants provide the so called “base load heat demand”. Then, there are some periods when the production of electricity is limited by the production of heat, because it is not needed at the moment.
Coupling TES to CHP plants allows storing heat every time when producing electricity is economically attractive even tough heat is not necessarily.

Adding a TES to the CHP plant brings more operation flexibility and permits the plant to operate longer during the year. These benefits can solve the problems confronted by CHP plants in current and future energy systems such as decreasing stock market prices for energy, and decreasing heat demand. The profitability of adding large thermal energy storage to an existing district heating system in Germany with different heat generation technologies can be identified by Groß et al. Within Groß investigation it is also pointed out that “Combined heat and power based district heating is a changeover technology on the way to Germanys full energy supply through renewable energies”.

Control Strategies for micro CHP coupled with Thermal Energy Storage applicable in District Heating Systems

Different control strategies are available in operation for micro CHP coupled with Thermal Energy Storage. A simulation tool was developed by the University of Applied Science in Cologne, Germany linking a CHP and TES, in order to show the different possibilities to control the operation of a small CHP plant when it is coupled with thermal energy storage. This way, it can be seen how flexible, the electricity and heat production of the CHP can become in winter and in summer when heat demand is very variable.

For a very detailed discussion and analysis, please refer to the Section 5.3.1 in D5.3.

Opportunities of new control designs for increased renewable energy integration and recovery of waste heat recovery

It is common to connect a CHP to a district heating network. A combination of all mentioned control strategies provides again more possibilities for more efficient management of the system.

In addition to the CHP system - which is connected to the district heating network - a storage system waste heat plant could also provide heat, charge the storage or supply the network. Several options are possible nowadays. Thermal storage installed nearby to the CHP or networks enable the use of waste heat or peak shaving methods. One possible scenario in summer could be that during the summer period, where the heat demand is shrunk to the demand for domestic hot water, the waste heat plant connected with a heat pump (HP) could charge the store while the CHP is switched off. Depending on the primary use of the CHP the situation could be vice versa. Another scenario could be to load the store during the night and provide additional heat during morning peaks in order to shorten the operation period of peak boilers or even to turn off the boilers completely.

Demand Forecasting and Despatch Optimization at Warmtebedrijf Rotterdam

Warmtebedrijf Rotterdam (WBR) (Dutch for "Heating Company Rotterdam") is an energy company that has started the transport of residual heat, derived from a waste incinerator, to the district heating networks in the city of Rotterdam since October 1, 2013. Formally WBR consists of two companies: i) WBR Infra NV which owns and maintains the network. Its shareholders are the City of Rotterdam (88%), Woonbron (4%) and the Province of Zuid Holland (8%), and ii) WBR Exploitatie NV, which is responsible for the commercial exploitation and delivery of heat. The shareholders of WBR Exploitatie NV are the energy company E.ON Benelux (50%) and the City of Rotterdam (50%).

WBR owns and operates the transport district heating network in Southern Rotterdam, which is connected to the Northern Rotterdam network (owned by Eneco), at the Heat hub at node 4 in Figure 5 below. WBR's main energy generator is the waste incinerator at AVR Rozenburg. A total of thermal capacity of 105 MWth is available for WBR. As WBR is actively discussing opportunities with other supplier of waste heat in the Rotterdam Harbour area, the total available capacity to WBR is expected to increase in the coming years.

Figure 5: The district heating network of Southern Rotterdam, owned by WBR

WBR does not directly supply heat to residential customers. In Southern Rotterdam it delivers heat to the local distributor Nuon, who will further supply it to its customers (residential, hospitals etc.). In Northern Rotterdam, WBR delivers heat to the distribution company Eneco and any excess heat that WBR has available to E.ON.

As further assets/objects WBR owns a physical heat storage with a capacity of 185 MWh at the Heat Hub. It is common practice that a buffer is situated next to a production facility where it serves as pressure control. The buffer at the Heat hub does not hold this function and was strategically placed in order to optimize the capacity of the distribution network and serve as back up capacity. Furthermore there are several boosterstations for regulating the pressure in the distribution network. WBR also owns the heat storage at AVR with a capacity of 270 MWh.

This device maintains and controls the pressure in the WBR network but is also used for economic optimization.

Figure 6: The heat storage of the Heat Hub located at the Brielselaan

WBR’s primary responsibility is to continuously supply heat to its customers in Rotterdam. In Southern Rotterdam, WBR is the sole supplier of heat into the distribution network. In Northern Rotterdam, next to WBR, E.ON and recently Eneco supply heat to the distribution network. E.ON owns the conventional production assets in Northern Rotterdam. The assets owned by E.ON include several boilers, gas turbines, a CHP, and a heat storage.

WBR and E.ON perform the dispatch of district heating of both Northern and Southern Rotterdam together. This means that the dispatch is jointly optimized. In practice this means that heat of the more efficient (from an economic and environmental perspective) waste incinerator of WBR is used to meet demand in Northern Rotterdam instead of heat supplied by the conventional assets of E.ON.

The joint production of heat and power, the variability in the power price, the cost of production and the opportunity to use the heat stores, form together a mathematical optimisation problem. The price of heat is constant/exogenous in the optimisation horizon (of a week), so the optimisation objective function is maximize the power revenues minus the production costs of both power and the heat of the combined Northern and Southern part of Rotterdam.

Forecasts of the prices of power, gas and the emission rights are input for the dispatch optimisation. Forecasts of the heat demand, which is dependent on weather and behavioral/seasonal factors, are input for the dispatch optimisation as well. Heat demand is measured per district and it enters the dispatch optimisation at an hourly level.

In the first section below the measured data by WBR, and other relevant data that is collected for the dispatch optimisation process are described.

Data and Measurement

Measurement of demand data occurs on a district level. At various points in the network variables such as flow, flow temperatures, return temperature and supplied heat are measured. The heat is measured and calculated by compatible flow meters (e.g. Figure 7) and temperature sensors. The variables are measured continuously and read out on a quarterly basis.

Figure 7: One of the meters

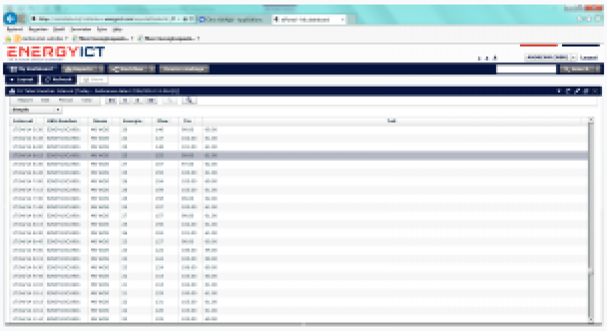

Figure 8: The Energy ICT portal

The heat related data become available through a portal named Energy ICT (see Figure 8). This portal can be used for real-time observation and decision-making. For more long-term analysis measured data are exported through ftp to a more extensive data-warehouse environment.

Other data that are necessary for the dispatch optimisation collected to the data-warehouse as well. These include weather data for making heat demand forecasts, and market prices of power, gas and carbon.

With the history of these data a forecasting of demand and prices are done for a horizon of a week. With these forecasted data dispatch is optimised. The optimisation process is repeated daily for the coming day with newly available data.

In the following section the dispatch optimization and the tool that is developed for it are reviewed.

Dispatch Optimization

Background

E.ON and the WBR are together responsible for the dispatch of the district heating of the Rotterdam area. (See Figure 9 for a network representation.) A joint optimisation is performed for both Northern and Southern Rotterdam areas.

The heat-demand districts to supply for WBR are the Hoogvliet, Maasstadziekenhuis, Brielselaan and Eneco-Noord districts, and for E.ON the Stad-Kop van Zuid and Bdriehoek-Capelle districts. WBR supplies its own Southern districts and the remainder is sent over the "Heat-hub" to the Brielselaan on the North side. As AVR is the most efficient generator, it will be used most of the time, and it will supply a considerable part of the North side.

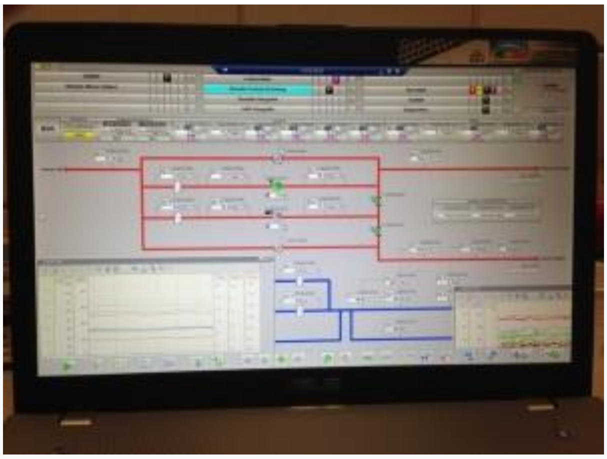

Figure 9: An operator screen displaying a representation of the network

Other assets to produce heat are the ROCA-1 and ROCA-2 (gas turbines), the ROCA-3 (a CHP), the boilers of WSG, Blekerstraat, Delftsevaart-KopVanZuid and ROCA. These production assets use gas as fuel and emit carbon dioxide.

Furthermore there are the AVR, WBR and WSG heat stores, which can both be used for economic optimization and as back-up in case of failure.

The selling-price of the heat demand for WBR does not vary in the optimization horizon of a week, so the revenues of heat demand are not taken up in the objective function of the dispatch optimisation, and therefore the objective function reduces to maximizing the power revenues minus the costs of heat generation for the Rotterdam districts and the generated power. This mathematical optimisation is performed with AIMMS, which is a mathematical modeling and optimisation tool.

The dispatch optimisation is performed daily for a horizon of about a week. While this is a theoretical optimisation, which is based on forecasts, and practice is always different, operators are always busy to improvise as much as possible.

The dispatch optimisation tool is updated if new information about the production assets or heat stores becomes available. When a new asset or demand district is added, or the network structure is changed, a redesign of the tool is necessary.

Necessary input for the dispatch optimization tool

The optimisation tool needs the following parameters as input:

1. The characteristics of the production assets such as producible heat and power combinations and their fuel usage, availabilities, ramp ups and ramp downs, minimum up and down times, some history on on and off, and other additional production costs.
2. Characteristics of the heat stores such as start and end levels, maximum storage levels, availability and heat losses.
3. Network characteristics such as pipe capacities and heat losses.
4. The forecasted hourly values of the price of power, gas and carbon, and the forecasted hourly values of demand per district, (see the paragraph below for more in-depth comment).

Solving by the Dispatch Optimisation Tool

The dispatch optimisation tool was developed in 2013 in the modeling environment AIMMS 3.13. Besides solving, AIMMS has the advantage of model visualisation and comprehensive data presentation (see Figure 10).

AIMMS has a variety of solvers to solve Linear and Integer Programming problems. As there are a number of on/off decisions in this situation, the type of problem is a mixed-integer program (MIP). CPlex 12.5, which is a very common solver, is used to solve this MIP.

The objective function for the dispatch optimisation tool is to maximize the power revenues minus the cost of power and the heat generation.

The main restrictions for the optimisation problem, in terms of equations and inequalities, are the restrictions of the pipe capacities and their losses, the production restrictions of the assets, the restrictions of the heat stores, and the hourly demand to be supplied to the districts.

When making a few assumptions on production restrictions, it is possible to find the optimal solution within an hour of solving time on standard laptops.

Output produced by the Dispatch Optimisation Tool

The output of the dispatch optimization tool can be summarized by:

1. The value of the objective function (and its breakdown in hourly power revenues and production costs).
2. The hourly production scheme of the assets.
3. The behavior of the heat stores.
4. The hourly flows of heat over the pipe network.

In the next section an overview of the forecasting process is given.

Forecasting

For the dispatch optimisation tool a number of forecasted values are required. These can be categorized in the prices of power, gas and carbon, and the heat quantity required to meet the demand in the different districts. Power is a gain that comes as an additional product from the heat production process, gas is a cost that is made in the production process of some assets, and "carbon" are the costs for the rights to emit the carbon that comes free from gas-firing. The forecasted heat demand is important for production planning, and for the quantities of heat that E.ON on the North side of the Heat-hub can expect from WBR.

The values for the forecasted variables enter the mathematical optimisation problem at an hourly level.

Price Forecasting

The main method for forecasting the spot prices of power, gas and carbon is to estimate a week-shape of these prices out of a representative history, where the market structure is comparable to the current market.

The week-shape is found by inspecting relative behavior of market prices within a week, and then to average this behavior over the entire period of history.

In the final step, this obtained (average) week-shape is fitted into the available forward prices for the upcoming period/horizon.

In Table 1 an overview of the used spot and future data for the forecasts is given.

	Power	Gas	Carbon
Spot data	APX	TTF	EUA
Forward data	Dutch Power	TTF	EUA

Table 1. Sources of data for forecasting

Demand Forecasting

As every district has its own building types and their users have different purposes and behavior, heat demand is forecasted per district.

For heat demand forecasting, a history of hourly heat consumption per district, and a history of weather-related data for this area are necessary. The aim is to estimate a relation between heat consumption and the weather-related variables. In this relation the weather-related variables are the explanatory variables, and heat consumption is dependent. As weather-related variables temperature, wind, sunshine, clouds and humidity are taken up. The data of these variables for the Rotterdam area are obtained from Meteo Consulting.

Since the start of WBR on October 1, 2013, a regression model has been used to estimate this relation for every week-hour with an extra stratification on self-defined seasons within a year. The main method has been to relate heat consumption to a cubic polynomial in experienced temperature, which is extracted from wind and temperature, and the addition of a subset of the remaining weather variables.

While this method was sufficient for its purposes in the start-up period, WBR is currently improving on this by remodeling heat demand forecasting with a neural network model, which is planned to be ready by March, 2015.

Background

UK Power Networks is trialing low carbon innovation technologies and reshaping commercial processes, seeking the best solutions for integrating these into business as usual. As part of Low Carbon London, a four year programme of demonstrator trials, UK Power Networks trialed Demand Response (DR) extensively and is therefore well placed to develop on this learning to find long term solutions to security of supply.

Brief description of the demonstrator

The role of UK Power Networks in this work package of the Celsius Project is to provide DR to alleviate network constraints and faults. At times of high network demand, the transformers in substations can reach loading levels outside of operational guidelines. While this is not necessarily dangerous, when a transformer has exceeded statutory limits it can lead to thermal and load faults. In both cases the operation of the transformer will either automatically trip out or need to be temporarily suspended. If DR can be used to reduce the demand on the substation, reducing the loading, the number and magnitude of these faults may be reduced or avoided. Times of elevated loading are referred to as a ‘constraint.’ When normal network running arrangements need to be reconfigured due to, for example, a damaged cable or blown fuse, this is referred to as a ‘fault.’ In this case the surrounding substations will need to meet any shortfall in electricity distribution, elevating their load levels which can then result in them being constrained. This is where DR can help. By providing a supplementary supply within the local network known as a Distributed Generation (DG) asset, the load on the substation can be reduced.

UK Power Networks will be working with Islington Council who own the Combined Heat and Power unit (CHP) at Bunhill Energy Centre (BEC) to contract DR services as part of the Celsius project. The aim of this exercise is to learn how best to incorporate CHP-generated electricity at times of network need. Along with operational learning will be contractual learning, most notably from running BEC during the colder months, when there is not the same flexibility as in warmer months.

The events will be autonomously dispatched via a system developed by UK Power Networks and Smarter Grid Solutions (SGS). This Active Network Management (ANM) system will initiate events as required by the network, triggered by a breach of substation load threshold.

Technical Solution

Monitoring

There are several stages to undergo in order to set up a Demand Side Response (DSR) resource. UK Power Networks has undertaken monitoring of BEC to assess the capacity to parallel to the network at varying times, from a diurnal to annual scale. In conjunction with this is the assessment of substation loading which will provide times at which DR may be needed.

ANM Interface

This monitoring could not have taken place without the ANM equipment in place. The ANM equipment is capable of monitoring substation loads and dispatching DR events when the network is in need. A diagram of the ANM interface is shown in Figure 11, components and measurements are also detailed below.

Thresholds

Extensive monitoring of substation loads has been undertaken to find a suitable level at which to place the thresholds for event dispatch. Factored into the ANM configuration are variables which ensure events are not triggered unnecessarily. For example, when the threshold is breached momentarily, an event is not triggered until loading has exceeded this level for a certain period of time. Similarly, when the load dips below the threshold, a lower threshold must be reached and the load held below this for a certain period before the event has ended.

Durations

The duration of each event depends on the trigger. If the network is under fault then the event could be as long as technologically and contractually possible. If the event is due to high substation loading the event may be shorter; lasting until the period of elevated loading passes. Similarly, if the event is dispatched manually (still using the ANM interface but triggered using a Human Machine Interface (HMI) rather than substation load), the event may be of a longer duration than normal as this scenario will usually be in the case of a severe network fault. In any case, events will typically not last longer than 3 hours, as the filling of the thermal store inhibits further use.

Commercial Aspects

There are a number of commercial agreements to be made to enable the use of BEC for Celsius in a way that will benefit all involved. Current technological restrictions limit the length of events but alterations can be made to the infrastructure to accommodate longer events, bringing value to the Distribution Network Operator (DNO) and increased learning of new contractual processes to benefit the Celsius Project. The possibility of longer duration events is explored in the last section below.

Event Dispatch

In theory there should be one method of event dispatch. ANM is the most future proof as it is autonomous and reactive to the needs of the network. Once thresholds have been incorporated into the ANM system and these changed when necessary dependent on month (or season) due to load fluctuations, there should be little human intervention. In a trial scenario this is somewhat different. To test event responses (more specifically the capacity to respond at a certain time, for the duration required), events can be manually triggered. This still uses the ANM interface to send the dispatch signal; the trigger is not a breach of threshold but a human choice and the signal is sent using an HMI. This will enable a higher number of events to take place in a trial period to maximise learning.

General layout

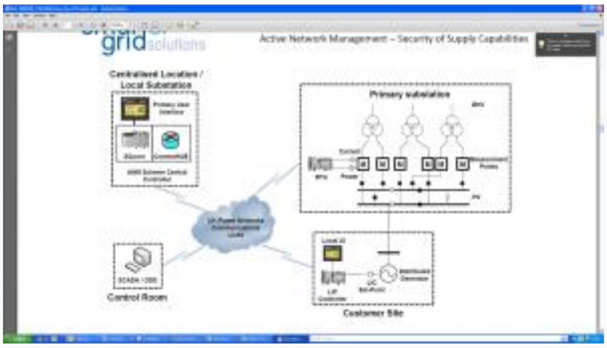

Figure 11: ANM and DR outline design

Main components

The ANM infrastructure operates based on four sets of functional components collectively interacting at any point in time, as seen in Figure 11. These elements have a degree of autonomy whilst interacting with each other in a structured manner. The key operational element in ANM is the SGS power flow software application that resides in the SGS core hardware. SGS power flow is an autonomous algorithm that performs real-time management of energy producing and consuming devices to maintain power flows within the constraints of the network.

The ANM components consist of:

- SGS core – This runs the SGS power flow application that performs ANM and collects data from and passes data to the SGS comms hub.
- SGS comms hub – Collects data from and passes data to SGS core, SGS connect, and Measurement Points (MP). The SGS comms hub also provides an interface to the UK Power Networks Operational Data Store (ODS) and to UK Power Networks SCADA system.
- SGS connect – Provides an interface to the DG load native control system to regulate the import and export of energy from the DG load and ensure fail-safe operation of ANM.
- MP – This can be a value (or values) collected directly from a measurement device monitoring current and power flow at a single constraint location on the network or from a Measurement Point Controller (MPC), which itself collects values from a measurement device.
- Primary/Local User Interface (UI) – User Interfaces are located at the Central Controller and each SGS connect. The Primary UI allows network operators to interact and supervise ANM | DR from the location of the central controller. The Local UIs allow network operators to interact with the relevant SGS connect.

Measurements available

The ANM system measures at the substation and at the DG asset. A Remote Terminal Unit (RTU) at the substation reads load values and the ANM box connected to the DG asset measures the output of the generator.

The measurements at the substation are:

- Real Power (kW)
- Max Real Power (kW)
- Real Power set point (thresholds) (kW)
- Reactive Power (kVAr)
- Reactive Power Set Point (thresholds) (kVAr)
- Voltage (V)
- Power Factor (-1 to 11)

- Max positive Power Factor (0 to 1)
- Max negative Power Factor (-1 to 0)
- Current (A)
- Major fault indication (I/O)
- Capacity available for ANM dispatch (kW)

Measurements at the DG asset are:

- DR availability (kW)
- Real Power (kW)
- Voltage (V)
- Curent (A)
- Power Factor (-1 to 1)
- Reactive Power (kVar)

Expected impact on Energy Efficiency and the Environment

Quantifying the impact of BEC's contribution to the Celsius project is no easy task. The emphasis is less on energy efficiency and more on security of supply. The benefit of this increased security of supply and the carbon impact is entirely dependent on the number of events and their duration.

Energy indicators

The operation of BEC as a DR asset is to provide ancillary electricity supply to the network at times of peak demand when the loading on nearby City Road has reached levels where action needs to be taken to protect the transformer(s) from constraint or fault. The most ideal situation is for BEC to be automatically dispatched at times of need and the locally connected customers not notice any change to their supply. This is the value case. Not only can UK Power Networks reduce their maintenance and equipment upgrade costs, potentially deferring this into the next regulatory price control period* but they can also avoid paying fines to the industry regulator Ofgem, in instances of fault or outage.

Not accounting for losses, the effective drop in substation load should equate to the output of BEC, approximately 2MW. This could be argued as an energy efficiency measure as this much electricity is not drawn into the DNO network from the National Grid. It would however, be lost in the noise due to its relative insignificance and would fail to register with electricity generators or procurers. If this technique were to be deployed on a larger-scale, city-wide, then this would not be the case but Decentralised Energy (DE) is less efficient than large-scale generation, resulting in a net increase in energy used. Due to this reason one could argue there is little energy efficiency in the operation of BEC but it is the value to the customer through increased security of supply and cost saving through deferral of network upgrade which holds the benefit.

Environmental indicators

Assessing the environmental impact of DR events at BEC is not simple and subject to the number of events, set against standard use. The normal operating hours will have to be assessed and any events which land outside these times will need to be quantified. It is these events which will contribute to a carbon assessment. An example of a CHP event is shown in Figure 12, portraying a typical event time and duration.

Economy

The contractual aspects of BEC are still being defined with the London Borough of Islington. A summary of the envisaged payment structure and the cost to the DNO is given below.

Payment Structure

Through previous work with DR contracts in the Low Carbon London Project, UK Power Networks has offered payment to DR providers in the form of availability payments and utilisation payments. The DR provider is paid an ‘availability payment’ for the hours and days they are available to offer their services to the DNO. They are also paid a ‘utilisation payment’ for the hours they have supplied their service.

Currently this method of payment is not economically sustainable and has been used in trial settings. In the future, theoretically, a DR provider could be available every day of the year, resulting in a huge cost to the DNO which does not hold up well to the business case of customer benefit through cost saving.

It is envisaged in this project that the availability payments will be dropped and the utilisation payment will be of a higher value. Price modelling is currently in progress and shown to be less wasteful. This holds up as future-proof as the DNO looks for more economically sustainable ways to increase security of supply.

Customer Value

Customer value is one main driver of the change in payment structure. If bills can be reduced (in real terms) while providing a more secure electricity supply going forward, then UK Power Networks has succeeded in one of its core values; to be ‘Sustainably cost efficient.’ If this can be achieved through the development of complex commercial and operational contracts with DR providers, the beneficial learning can be scaled-up to other areas in the DNO’s licence areas, providing the same benefits.

DNO Value

Calculating the value to the DNO is a long and involved task which will be undertaken at a later date for Celsius. This can however, be summarised as follows:

- Deferral of network reinforcement through the value of ‘lost load,’ offsetting reinforcement and replacement costs through load reduction measures (DR events).
- The reduction in number and cost or the avoidance of fines payable to Ofgem and customers through increased security of supply.

Although the figures in this example are not on a par with that at City Road and BEC, the principle is the same. The current primary substation at Whiston Road (11 kV) is due to reach its peak load due to organic load growth in the area and will need upgrading to accommodate this. There is not enough space at the substation for the upgrade to take place and therefore a new substation will need to be built and the load transferred; the new substation is proposed to be built in Hoxton nearby. The use of DR has been investigated at Whiston Road and found to enable UK Power Networks to defer the build of a new proposed substation out of RIIO ED1 while helping to manage the network constraint at Whiston Road. Contracting 5 MVA of DR between 2021 and 2025 (inclusive) for £293,640.00 will defer the new substation cost of £13,125,000 therefore saving a total of £12,831,360.

Lessons learned

Invaluable learning, both contractually and operationally will be taken from events at BEC. As the relative cost of customer electricity bills increases, DNOs are working to provide security of supply in the most economically sustainable way. DNOs are entering a time of change, becoming Distribution System Operators (DSOs) whereby they are actively controlling customer demand for mutual benefit. Contracts with Decentralised Generation (DG) providers providing ancillary supply will become commonplace and by trialing and improving the service provided, incremental improvements can be made and built upon for future contracts with other DG providers. When scaled-up, this form of energy efficiency and security of supply can provide real benefits to the DNO in the form of network reinforcement deferral and the avoidance of fines. At the same time, customers benefit from lower bills and more secure supply.

Operationally there are many complicating factors to manage with DR events. This number is greater when dealing with CHPs. For example, there are constraints on the duration of events due to the filling of thermal stores. Once full the generator has to turn off. This can be circumvented through retrofitting a heat dump, enabling the supply of ancillary electricity supply without filling the thermal store. Given the business case, the DNO may wish to contract this from the DG provider and this facility may well be something which is retrofitted to BEC if it has value. Network faults often last for many hours or several days. If this ancillary supply can be contracted at duration there is significant value to the DNO and its customers.