

FOCUS
SMART HEATING – SYSTEM INTEGRATION

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NEW MANAGEMENT SYSTEM FOR DHC NETWORKS

In the Horizon 2020 STORM project, a demand side management system for district heating and cooling networks was developed. The STORM controller was demonstrated in a modern low-temperature 4th generation network as well as in a traditional 3rd generation high-temperature network. In this article, we present the project, the developed controller and the results of the controller performance evaluation.

THE IDEA

The main objective of the project was the development, demonstration and performance assessment of a new type of intelligent demand side management system (DSM) for district heating and cooling networks. The STORM controller makes use of the flexibility present in the thermal capacity of the connected buildings to optimize production and distribution within the grid. Indeed, a lot of thermal mass is present in buildings, consisting e.g. of concrete and furniture. If thermal mass can be 'activated', i.e. by warming up or cooling down this mass slightly (less than 1°C), a lot of energy can be stored or consumed. In this way, the buildings act as a virtual storage buffer, without breaking indoor air comfort limits and indeed without anyone even noticing during normal operations. The harvested flexibility by the activation of the building mass is used for the benefit of the network or energy production plant operation, making it more efficient and more sustainable.

The STORM controller concretizes this through the implementation of three control strategies. Firstly, the controller can shave off peaks in the network power demand, reducing the running hours of often expensive and fossil-fueled peak boilers. This is called the 'peak shaving' control strategy. Alternatively, the controller can also optimize the operation of CHP plants and heat pumps, i.e. enabling them to be switched on at high/low power prices. This control strategy is called 'market interaction'. Finally, the operator is also capable of balancing heat demanders and heat producers in a cluster of a network, maximizing the self-consumption of excess energy in a cluster. This control strategy is called 'cell balancing'. The STORM controller uses these control strategies either independently or in combination to optimize the operations of the district heating or cooling grid.

THE STORM PROJECT

The STORM project (https://storm-dhc.eu/) started in April 2015 and ended in March 2019. During the project, two versions of the controller were developed. This means that, after the development and testing of the first version during a winter period, an update was performed, and the revised controller was tested again for a winter period. In that way, it was possible to develop a very performant, reliable product, ready for commercialization with a short time-to-market.

Figure 1: The production site of the Rottne DH network.

The project was realized by a slim consortium. VITO-EnergyVille, a Belgian research center, was the coordinator of the project, and responsible for the controller algorithm development. NODA, a Swedish company offering smart district heating grid controllers, integrated the algorithms in their hard- and software platform. Additionally, two network operators were part of the consortium as demonstrators. Växjö Energi AB is a Swedish network operator in the main city of Växjö in the South of Sweden (Figure 1). They also operate a small, rather traditional, network of about 200 consumers in the community of Rottne which was used as a demonstration in STORM. This network mainly uses wood chips as fuel, supplemented with expensive bio-oil in their peak boilers. In this network, the aim was to minimize the peak oil consumption by means of peak shaving. The other demonstration network is operated by Mijnwater BV, and is located in Heerlen in the very south of the Netherlands. This is a highly innovative, very low temperature network, making use of water from flooded former coal mines for heating and cooling (Figure 2).

This network also comprises decentralized heat pumps to boost the temperature of the ground water (~28°C), to the required level for space heating and domestic hot water production. The network is organized in clusters of buildings, and a backbone network connecting the clusters and the mines. In this network, the objective was to balance the consumption of the buildings to the available excess heat in the clusters of the network. In that way, the energy exchange with the overlaying backbone network was minimized. The overall goal here is to use the capacity of the backbone better: serving more clusters with the same backbone.

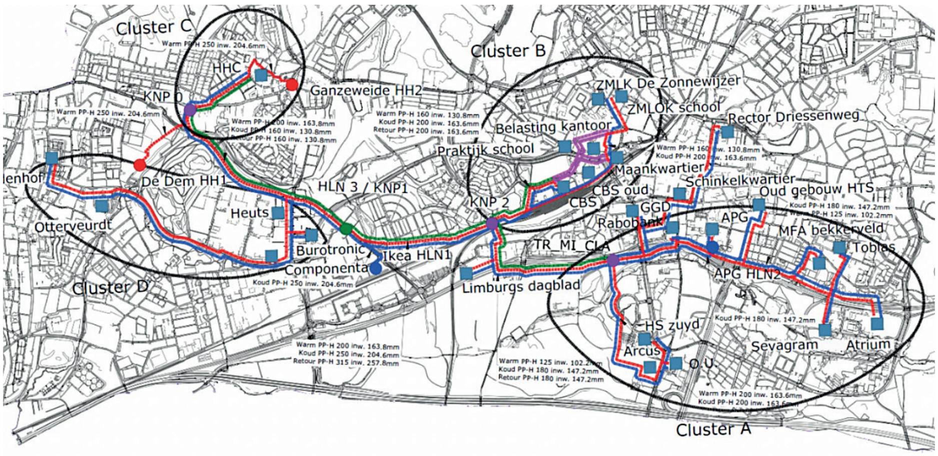

Figure 2: Layout of the Mijnwater DHC network.

Also, part of the consortium was Zuyd Hogeschool, a Dutch university of applied sciences, who developed educational packages on intelligent control of DHC networks. The last partner is the DHC+ Technology Platform, who were responsible for the coordination of dissemination and communication activities.

THE STORM CONTROLLER

The STORM controller is integrated in the NODA Smart Heat Grid solution and is implemented in an AWS cloud platform. Besides the controller core, the product contains functionalities for communication with sensors and control systems by means of various communication protocols. Furthermore, also visualization features are part of the product (Figure 3).

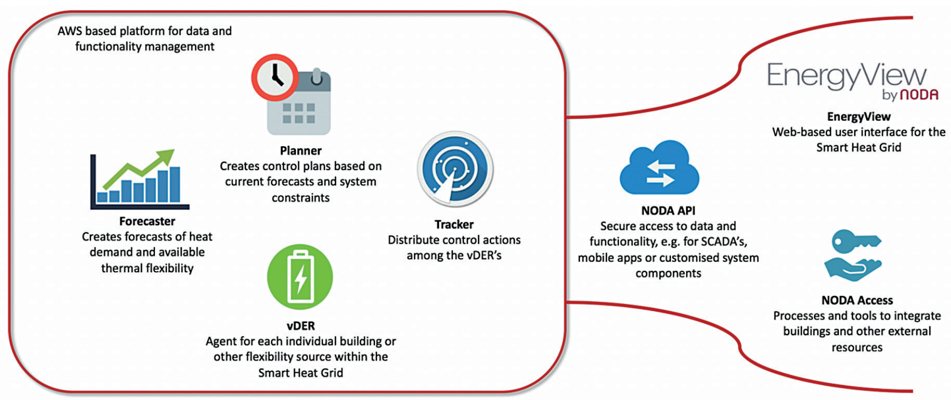

Figure 3: Architecture of the NODA Smart Heat Grid solution.

The controller itself consists of four main modules. First, there is a Forecaster module. It forecasts the energy demand in the network for the upcoming few days based on weather forecasts and the historical behavior of the network. Moreover, it also forecasts the flexibility available in the network, i.e. it forecasts how much energy can be stored or released from the virtual buffer, based on the building thermal mass and the thermal state within the building.

The second module is the Planner, which is like an optimizer. It uses the forecasts calculated by the Forecaster and has a certain objective to fulfill, e.g. peak shaving. Based on these inputs, the Planner will calculate to which extent the demand profile of the network can be shaped towards the objective by using the available flexibility. In this exercise, the comfort constraints of each individual building are always taken into account. The output of the Planner is a control plan, which normally spans the coming 24 hours.

Then, there is the Tracker module, which disaggregates the desired control plan generated by the Planner into individual control power demands for each building. Thereby, it tries to make sure that the actual heat demand curve of the network corresponds as close as possible to the optimized one from the Planner. Because of unavoidable model errors in the building and network models, it acts and reacts in real-time, by constantly updating the power demands sent out to the buildings. While the Forecaster and Planner operates on longer time periods of hours and days, the Tracker will normally operate on near-real-time time levels.

Finally, each building connected to the control signal is represented by a software agent called a virtual Distributed Energy Resource (vDER). The vDER translates the power demand from the Tracker into a control signal able to be used in the control system of the building substation controller or building management system. This control signal makes the building react in the way the controller wants it to, in order to meet the control objective. Each vDER also continuously communicates with the Forecaster to provide the basis for making predictions on the available thermal flexibility.

As explained, the vDER outputs control signals suited for the substation controllers or building management systems. This is a vital feature of the STORM controller, since this means that the existing controllers in the network should not be replaced; the STORM controller is an extra control layer that collaborates with the existing controllers. It coordinates the operation of the individual, independent control systems of the connected buildings, for the sake of a certain global objective to be reached, e.g. by manipulating their setpoints. In this way, the STORM controller connects the demand and the supply sides of the network, which are normally independently controlled.

RESULTS

PEAK SHAVING

As explained, in the Rottne demonstrator, the aim was to reduce the oil consumption by the peak boilers. It should be noted that only 9 out of the about 200 consumers where connected to the STORM controller. However, these nine buildings are nevertheless the largest ones in the network and represent about one third of the total energy consumed in the network. This means on the other hand that two third of the network energy demand was uncontrollable.

By controlling those 9 buildings, the peak-shaving tests resulted in a reduction in the peak consumption of 3.1% compared to the reference scenario without the STORM controller active (Figure 4). This peak heat reduction has been achieved despite an overall heat demand increase of the large uncontrolled part of the building stock in Rottne. If this influence is corrected for, then a peak heat reduction of 12.7% was determined (Figure 5).

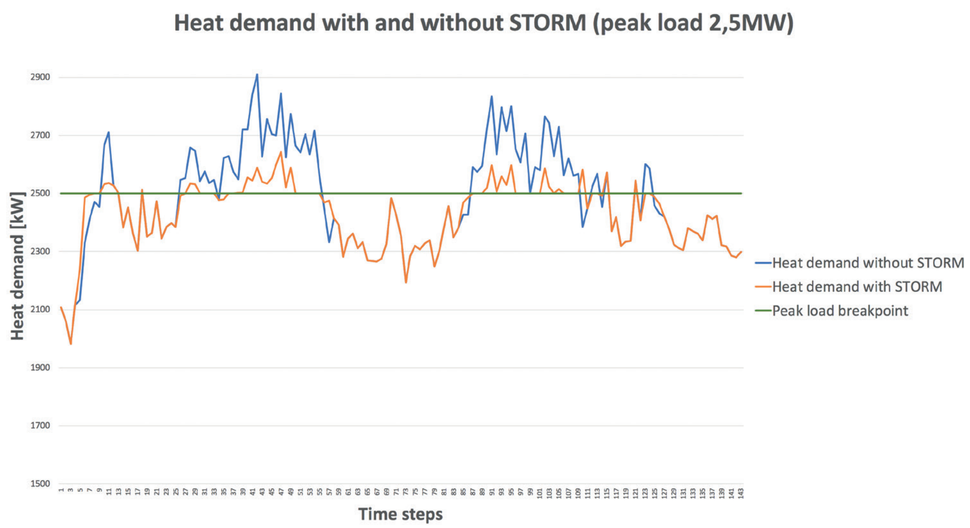

Figure 4: Comparison of the Rottne network heat load with and without STORM controller.

In the Mijnwater system in Heerlen, cell balancing was the main control objective. However, by balancing the demand to the excess heat production in the cluster, less flow is extracted from the backbone network. Therefore, this results in hydraulic peak shaving on the backbone network, and an increased dT in the system. It has been found that the controller was able to reduce the flow over the entire test period for a long time without jeopardizing the energy delivery to customers. From the evaluation of the results, a peak shaving potential of 17.3% could be determined with, as a derivative, a simultaneous capacity increase of 42.1% (see results on cell balancing below).

MARKET INTERACTION

The market interaction strategy was emulated in the Rottne demo site. Despite the lack of a real CHP, the STORM controller used input from the wood chip boilers as if they were a CHP, as a proof of concept. Based on the electricity price forecast on the power market, the STORM controller tried to move heat demand to match higher spot prices, thereby increasing the financial gain of selling electricity while still ensuring heat delivery. The primary conclusion is that the STORM controller indeed has the ability to both charge (increase heat demand of the buildings) and discharge (decrease the heat demand) alternatively in order to track the requested behaviour from the earnings/cost forecast. The ability to charge and discharge has been shown to range between 30-50 % in short-term demand on individual building level: this means that, on average, a building can modulate 30-50 % more or less energy than it normally would for a short period of time (a few hours), without people or thermostats noticing it. If this individual control ability is then coordinated among several buildings, the combined flexibility is substantial in both time and intensity.

Apart from CHP optimization, there are other benefits of market interaction. If in a district heating grid with high electricity costs (e.g. those including heat pumps), the situation where the highest peak values can be flattened to the average values, this would mean a 15% price reduction on the electricity purchase during this short period of time. Combined with the ability of the controller for charging and discharging of 40 % on average, the conclusion would be that the procurement costs of electricity could be lowered with 6 %. For the Rottne demo site, the electricity costs represent 5.9 % of the total system costs. This means that with the market interaction feature of the controller, the total operational costs can be reduced by 0.35 %. For the all-electric DHC system in Heerlen, the purchasing costs for electricity represent 21 % of the total cost price. On the basis of the same principles, a saving of approximately 8.4 % on electricity purchases could be achieved.

This option of the controller will be of great importance, especially for all electric systems such as that of Mijnwater, especially when sufficient thermal buffering has been provided in the system, making it possible to charge energy independently of the energy demand at times when the electricity price is most favourable.

Finally, it should be noticed that the market interaction control strategy can also be used for DHC systems without CHP, in which case the purpose is to avoid high production costs and premiere low costs. This versatility makes market interaction a powerful control strategy, and it now forms the foundation of several commercial spin-off projects based on the STORM technology.

CELL BALANCING

Although cell balancing was specifically developed for and studied in the Mijnwater demonstration case, the concept is also viable for more general distribution optimisation in generic grids in order to facilitate a more balanced distribution behaviour.

Since the Mijnwater system consists of a number of clusters connected to the backbone with all buildings connected to those clusters, there is the possibility of influencing supplying flow at both cluster level and building level (peak shaving). As a result of this, due to the higher activity of the heat pumps in the power plants, the temperature difference and thereby the capacity of the system (i.e. the clusters and/or backbone) increases. This capacity increase not only creates room to connect more buildings to the system, but also offers the possibility of influencing the mutual exchange rate between buildings and/or clusters, in other words it facilitates cell balancing.

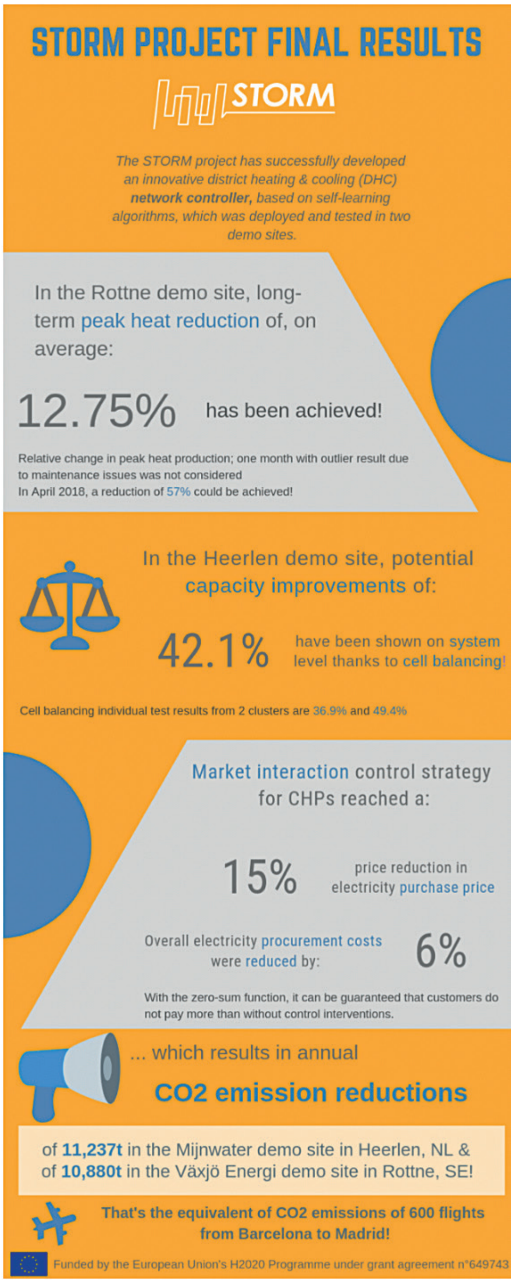

Figure 5: The final results of the STORM controller.

From the evaluation of the tests performed, an improved capacity could be derived ranging from 37% up to 49%. The determined median value was 42.1% on capacity improvement. In the Mijnwater case, cell balancing and peak shaving will have a simultaneous effect that leads to a combined capacity improvement of 52% which corresponds with a total potential.

CONCLUSIONS AND FUTURE PERSPECTIVE

It is clear that demand side management in DH networks, as achieved by the STORM controller, will become increasingly important in the coming years during the transition towards 4G DH networks. The integration of sustainable heat (such as heat from fluctuating renewable sources or excess heat from industry) can only be exploited to its full extend, when DH networks are controlled in a smart way. Demand side management is a form of smart control, by which the connected buildings are used as a source of flexibility. The benefit about this form of smart control, is that large investments in additional installations (like large water storage buffer tanks e.g.) can be reduced: it makes use of already existing thermal capacity.

One of the vital goals of the STORM project was to build technology that could be used in a practical setting. As a result of this, STORM technology was already deployed and used in commercial projects throughout Europe, even before the project actually ended. This shows not only the flexibility and adaptiveness of STORM, but also the actual market demand for this type of technology. An important part of the STORM development process was to create modular components, which was primarily materialised in the project as the Forecaster, Planner and Tracker. Each such individual component forms an important advance in technology for innovative district heating, and they can be deployed either separately or combined as a full STORM controller. Technology relating to the Forecaster was the first component to reach maturity in the STORM project, and consequently deployed in commercial projects. The Planner and Tracker followed thereafter, and all components are now mature enough to deploy in industrial settings.

Although the STORM controller is a market-ready product, future developments are foreseen. Not only the additional control features are prepared, but with the same platform steps are taken into the field of analytics. As such, in the Horizon 2020 TEMPO project (https://www.storm-dhc.eu) fault detection functionalities for substations are added to the platform. With this it is possible to detect and diagnose substations in the network that do not perform optimally.

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