# Smart styring til industrielle varmepumper

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# PROJEKTETS FORMÅL

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Større varmepumper er under hastig udvikling i industri- og i fjernvarmesektoren, hvor det giver god økonomi at bruge dem.

Disse varmepumper driftes typisk ud fra simple temperatur set punkter, som blev fastsat under dimensioneringsfasen, længe før varmepumpen blev fysisk i driftssat, og ud fra historiske energipriser. Varmepumperne bruger derfor ikke de styringsmæssige muligheder, der er tilgængelige i dag, og som kan være med til at sikre en energiøkonomisk drift form, i samspil med de øvrige energisystemer der findes i virksomheden og elnettet.

Projektet vil samle relevante parametre, som har indflydelse på varmepumpens driftsøkonomi, for derved at kunne styre varmepumpen bedre økonomisk og energimæssigt.

Der udvikles en ekstern Smart Kontroller, der kan:

- indsamle data om varierende energipriser
- regulere drift for varmepumpen ved for høj energiudgiftspris
- beregne varmepumpens COP-profil, og derigennem optimere dens driftsform
- flytte energiforbruget til perioder med lav elpris
- give mulighed for ekstern til- og afkobling af varmepumpen ift. el-markedet

## REALISERET FORMÅL

De oprindelige målsætninger er blevet indfriet.

I løbet af projektet opbyggede vi en dybere viden om el-markedets organisering og muligheder og krav i individuelle programmer for deltagelse i Systemydelser, hvorefter fokus blev løftet til at kontrolleren kan formidle fleksibilitet for både Nordpool og Systemydelser.

Ambitionen omkring integrationsmulighederne blev ligeledes øget så enheden kan bruges bredere.

Endeligt ville teamet bag projektet bringe systemet frem til godkendelse for levering af systemydelser.

## RESUME

### DANSK

Projektet er gennemført i tæt samarbejde med test virksomhederne og efter agile metoder med kort sprints. Vi har haft succes med at udvide kredsen af involverede virksomheder, som engagerede sig med et bredere set-up og større kapacitet.

Ugentlig opfølgning med test og udviklingspartnerne, hvor vi konstant har opretholdt fokus på merværdien for de potentielle kunder har været afgørende for projektets succes.

Konkret har projektet skabt et demonstrationsprojekt hvor én af de største fødevare producerende virksomheder kunne overholde de teknisk krav for godkendelse til systemydelser.

S.C. Nordic opnåede godkendelse som fleksibilitets balanceansvarlig under pilotprogrammet, og har efterfølgende løftet denne godkendelse under 2021 kravene.

S.C. Nordic har med udgangspunkt i projektet etableret løbende leverance af systemydelser og arbejder målrettet med bred kommercialisering af teknologien.

### ENGELSK

The goal is to develop a generic controller that as an online service, optimize' s the performance of industrial heat pumps and other industrial appliances.

The technology is developed as an aggregation tool for a pool of appliances and have achieved technical approval for delivery of Demand Response services. Optimization is conducted in accordance with both day-ahead (Nordpool) markets and online Demand side Demand Response (Systemydelser).

S.C. Nordic has continued investing in the technology, and it's since been packaged for several dedicated appliances and being promoted in several countries.

The technology and concept were awarded "Best Technologies to address UN's 17 world goals" in 2021.

## INTRODUCTION

### THE GOAL

The joint vision of the consortium is to accelerate the transition into a dynamic and flexible energy market that can address the challenges of large energy consumers and maximize the use of renewable energy.

Leveraging in intersectoral, multidisciplinary and complementary technological assets and knowledge on customers´ requirements, networks, and routes to market, our ambition is to develop and demonstrate a technology that can aggregate all the energy sectors and optimize customer´s energy consumption depending on the energy demand profile, enabling costs savings and savings in general efficiency.

The initial market validation will be driven from large industrial heatpumps.

## PURPOSE OF THE PROJECT

The Danish parliament has set a target of a 70% reduction in greenhouse gas emissions by 2030. Electrification is defined as a vital tool in the national goal for lowering $CO_2$ emissions. Denmark targets 70% savings by 2030, and 100% neutrality by 2050.

Electrification is based on massive expansion of production from renewable energy sources (RE) – in Denmark mainly wind turbines. The production by RE's is closely tied to wind and solar, which carries their intermediacy forward with the levels of productions.

Further to this decision, the government has established a climate partnership with several large companies (link), where a joint proposal for a roadmap has been prepared.

They state: The phasing-out of fossil fuels in the energy and utilities sectors and other sectors leads to an increased demand for renewable energy, which the energy and utilities sector must supply for the full transformation of Denmark to be completed. The need for production capacity and infrastructure can be reduced with energy efficiency improvements, flexible consumption, and storage.

Energy demand from renewable energy is expected to increase by 64% to 125 TWh by 2030. To deliver the large amount of renewable energy, offshore wind needs to be expanded from 1.7 to 7.6GW, onshore wind from 4.4 to 6.1GW and solar from 1.2 to 8.8GW. The electricity grid needs to be upgraded to transport much more electricity than at present; including, final consumption from the electricity distribution network is expected to increase from 34 TWh in 2019 to 58 TWh by 2030, and final consumption from the electricity transmission network is expected to increase from 1 TWh to 13 TWh. Flexible consumption and smart solutions may limit the need for expansion, but the increased electricity generation from fluctuating renewable energy sources.

The goal with this project is to demonstrate a technology that delivers the efficiency and flexibility in big demand as the renewable energy production increases, demonstrated with CO-RO, Kopenhagen Fur and one of Denmark’s most prestigious industrial flagships and largest brewery.

Representatives of the entire value chain of the energy community is represented by:

Local distribution by TRE-FOR

Energy trading by EWII

Transmission Energinet.dk

District eating: Dansk Fjernvarme

This technology is a sought-after remedy for the intermittence in power production by renewables, and the projects will be a true enabler in the demonstration of real-world relevant solutions.

## BACKGROUND

Denmark's example, by raising the targets puts the energy markets across the globe under complex and challenging pressure. This project aims at developing and demonstrating various tools for delivering solutions by merging technical, regulative, commercial, and trading platforms.

Flexibility, in this project, is defined a Demand Side Demand Response (Hereafter DS-DR), where large energy consumers (industrial) identify a commercial incentive by utilizing price fluctuation in the market, while still going green, and at the same time help to balance the energy market.

The application is drafted based on a Minimal Viable Product (MVP) developed and deployed with the demonstrators.

## THE POWER GRID – FROM A HISTORIC PERSPECTIVE

Physics dictates that Electricity grids must keep constant balance between production and consumption. The Grid is a system that was invented over 100 years ago and has been improved in a constant process. Historically this has been managed on the production from large generators, but as the production shifts towards renewables i.e. wind turbines and solar panels – which produces as the wind blows – creating situations where their production far exceeds the needs on the consumer side.

Distributed production has created an environment where the productions side has a life on its own, and keeping the balance is becoming an increasing problem. Focus on Demand Response has shifted towards the consumer side – Demand Side – Demand response (DS-DR).

## ENERGY MARKETS EXCHANGE – NORDPOOL

Electricity is traded as a commodity, on an online exchange called Nordpool. The cost of electricity is defined by matching the offered volumes/price for production, and the projected consumption.

Nordpool was developed by the Norwegian energy sector in the 80ties since they wanted to transform it from a monopolistic to open market. Nordpool was adopted by the other Scandinavian countries as the market platform for power trading. Since its adoption it has been expanded to cover Northern Europe:

The markets are managed by the hour, and trading between the countries are conducted under EU legislation


## PRICES FROM NORDPOOL

Due to Grid infrastructure, National Interests, and system wide bottlenecks, the Nordpool area is divided into subsections. Prices are negotiated individually for each region.

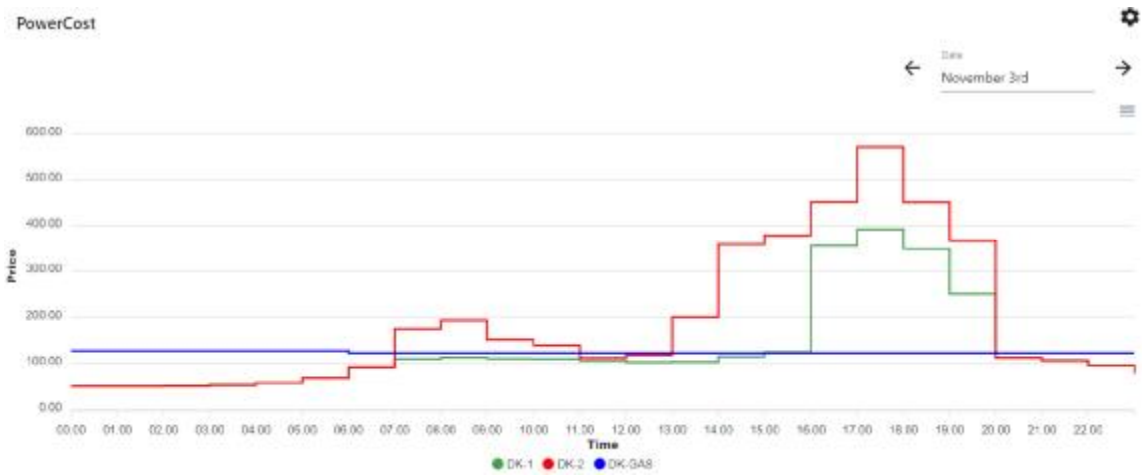
The Authorities in each country works towards level prices and the same prices for each region.Due to the already implemented renewables the prices fluctuations are building, and the differences between markets are also starting to show in the prices. The Frederician Carlsberg factory is placed in the DK1 section, which present some opportunities for taking advantage of the price levels. The DK1 section is influenced by:


Kilde: Nord Pool Spot

The figure shows an example of prices for Power (DK1 + DK2) compared to the price of gas, which shows:

- Electrification of gas consumption is possible for some hours, but 07:00 to 20.00 it's not a commercially viable solution.
- Prices ranges from app. 50 to 575 Kr/MWh, documenting the potential in shifting load between hours.

DK1 and DK2 have similar developments during the day, but the prices are significantly different.




The relevance for this project:

1. Establishing revenue from the flexibility in consumption that is offset against the price of power, lowering the green/red lines can increase the number of low-cost hours significantly.
2. Shifting load from high cost to low-cost hours contains a significant potential for savings.

The costly hours from 14.00 to 20.00 depicts a situation where the power grid draws on the costly fossil-based resources.

## HOW ARE PRICES DEFINED?

The market is organized with suppliers and consumers on each side.

Nordpool compiles the predicted need for production on one side and collect the most cost-effective bids on the other side. The classic intersection of prices is the result.

NOTE: Due to their nature, i.e. Wind turbines, some of the producers dictates that they must deliver their production to the Grid. As their capacity builds their impact on the markets become increasingly powerful.

## MARKET COLLAPSE

When the production from renewables exceeds consumption, the market collapses and prices drop below 0, as shown in the figure below in green. This exemplifies a day with extensive production from renewables, where electrified processes are cost effective over natural gas – to the extent that the savings for 23 hours can cover the loss from 17.00 to 18.00.


RE's variance in production combined with the lack of energy storage capacity in the power grid, creates a massive global scale challenge in ensuring a balance between electricity generation/consumption. This challenge, referred to as the need for Demand Response (DR), is the core business platform for S.C. Nordic and our partners.

## THE DANISH ENERGY MARKETS.

Ideen The market is divided into 2 areas DK1/DK2, with different programs:


*Important: note dividing line in Storebælt*, which *divides Denmark into 2 areas DK1/DK2 – Ref Energinet.dk*

The key messages are that the revenue base is closely tied to how fast the systems can react and how long the flexibility is available. For example, the requirement for FCR to adjust automatically with a reaction time of 15-20 sec must be able to handle a maximum of 15 minutes and brings in 200-300.00 Kr/mon.

## PROJECT MANAGEMENT AND ITERATIONS

### MANAGEMENT FRAMEWORK/TOOLSET

The project was managed as an Agile project with short iteraions.

We decided to define the iterations to match the project phases, and not use predefined timeboxing. The average iteraions was 4 weeks.

### ITERATION 1 – ESTABLISH CONNECTIVITY

The initial approach with this project was to establish communication between the Heatpump controller and a central web hosted solution.

With this we wanted to collect all relevant data from the controller and thereby utilize the sensors and data already collected by the controllers.

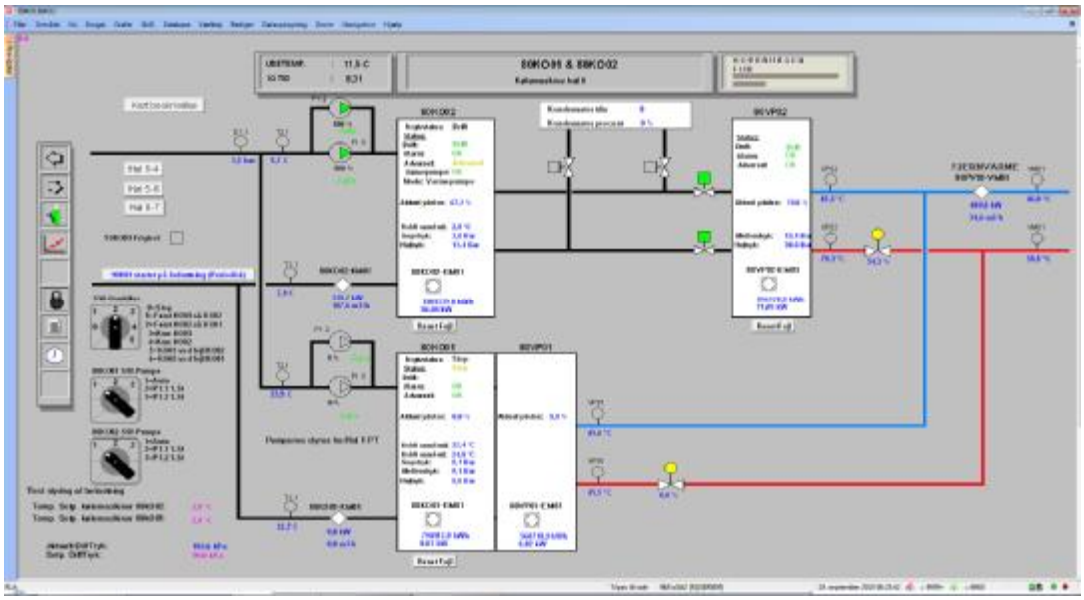
The communication, data format and data collection were defined for vital data in an organized structure highly relevant for software access and optimization, AND a flexible part where customer and application specific data are also collected.

2-way connectivity was established and the data available in the controllers was replicated:

Dedicated monitoring of the power consumption was also established:

The quality of the data was confirmed, and the potential for optimization became evident for the project members.

We also became aware of the needed support by the tech. support staff of the customer, and inherently the provider or manager of the software integration of the cooling compressors or heat pumps in question. This became a concern for the project team since it limited to potential reach of the technology.



Conclusion: The approach is viable, and the quality of the data provided is very high.

It does depend completely on the partners support and direct access to the system software of the controllers and the monitoring/SCADA system its integrated with.

## ITERATION 2 – GENERIC SCADA SOLUTION

In view of the experience and knowhow developed the problem was addressed by developing a 'click-on' solution for the compressors.

We decided to restart the development and develop a basic controller that can:

- Monitor power loads, and calculate consumption from the compressors
- Collect the forward/reverse temperatures and flow, to calculate heat production
- Integrate the data in the local software package so documented COP (performance) are calculated and reported

The secondary objective with this approach was to utilize generic protocol converting and access or listen in on the communication with the sensors already deployed and used by the main controller.

The technology was deployed with the other test partner in DK2, and data was collected, where we used additional censoring on the heat/cooling supply of the compressor..

Conclusion –

Offering an clip-on solution to existing installation does address the dependency of access to the controller and its software.

But the quality of the meter information collected drops, and becomes questionable compared to the logging that the customers already operates with their SCADA system.

## ITERATIO 3 -

Having established secondary monitoring and data collection of the test customers, another evident problem that emerged is: When we know how to optimize, how do we establish an integrated solution with the controller and SCADA system where our technology delivers added value?

A generic protocol converter was acquired from adfWeb and integrated with the central solution. We documented again that connectivity is possible, but also that the learnings from iteration 1 about the dependency of the technical support must be respected.

Conclusion: A generic solutions is not a feasible since it cannot develop customer value.

## ITERATION 4 – MARKED VALIDATION

The solution was adapted for online communication with the controllers.

Recognising the obstacles the group enhanced the controller capacity, and its environment for system integration. We developed a generic communication platform, which supports for industry recognised protocols.

This platform was developed based on knowledge gained in iterations 1-3 but was effectively a complete redesign of the controller.

This enhancement addressed another concern that we had encountered. All technical and IT support staff members were concerned, that if they started to adjust their activities to become flexible, the solution must be secure, stabile and hacker proof. Implementing secure communication, VPN and industry acceptable encryption dictated a steep increase in the processing power and OS selected.

With this redesign it became possible to establish a pilot of the technology with a large brewery in Dk1, and the controller delivered a fully functional pilot.

Conclusion: The protocol suite combined with recognised encryption and VPNs has been developed to a level, where industrial partners can accept integration.

It's the Commercial driver of the Technologies that carries the relevance.

## ITERATION 5 – PILOTING

With the newly developed platform we were given an opportunity to pilot the technology with a very large brewery in Fredericia.

In view of the Corona lockdown, and the fatal development for the industry that Kopenhagnen Fur represents, this was a highly valued opportunity.

The V2.00 controller was the focal point and was piloted for some time.

The conclusions of the pilots:

1. It is only possible to deliver real value for the customers if the technology is integrated with their existing controllers and SCADA system. Any attempt to override system settings will both fail and trigger system alarms
2. is vital that the technology is online for both day-ahead markets as Nordpool, and online markets managed by the TSO, I.e., Energinet.dk
3. Large compressors, as in heating or cooling applications, is not a prime candidate for a lot of fast flexibility. Their physical design and inertia prevent them from reacting at a pace of fast demand response programs
4. The clients must be given sufficient confidence of the technology offered, to even consider it. The potential losses from hacking or breaks down in the core activities FAR exceeds potential savings and revenue from Demand Response technologies
5. The key to success lies in the commercials, not the technology.

## KONKLUSION (IN DANISH)

Projektet har gennem det tætte samarbejde og støtte fra én af 'de store' industrielle forbrugere leveret et referenceprojekt for industriel fleksibilitet på forbrugssiden.

Konkrete resultater:

- Varmeforbruget til rumvarme er nedbragt med 50% på den pågældende fabrik (uden nævneværdig komfort tab)
- Driftsomkostningen på kølesystemer nedbragt med 8-10%, og driftsomkostningen bidrager med yderligere besparelser
- Aggregeret drift af en række forskellige forbrugsenheder har sikret at deres individuelle fleksibilitet kan indgå i en samlet pulje. Individuelt kan de ikke levere i forhold til de tekniske krav om kapacitet og reaktionsmønster
- Automatiseringen af markedsintegrationen for systemydelser har skabt en økonomisk platform for bred udrulning af DS-DR.
  "Demand side Demand response")
- Tæt integration med markeder, kombineret med aggregering af forskellige enheder har dokumenteret et klart markedspotentiale.
- Indholdet af reel grøn Strøm er løftet ed 15-25% i det forbrug styres 'mod' billige timer med et stort indhold af vedvarende produktion.

## PERSPEKTIVERNE

S.C. Nordic har gennem resultaterne og de opbyggede erfaringer, skabt platform for etableringen af en Vækst- Iværksætter virksomhed.

Teknologien vil løbende blive videreudviklet og bredden af pakker til individuelle typer af forbrugsenheder vil blive udvidet.

Efter afslutningen af projektet er der etableret yderligere projekt i andre industrier, og der er etableret internationale aftaler om fælles tilbudsgivning.

## FORMIDLINGSAKTIVITETER I PROJEKTPERIODEN.

Projektgruppen har løbende arbejdet med formidlingen af projektet og dets umiddelbare resultater. Konkret:

- Deltagelse og præsentation af projektet 2 gange i iEnergi.dk fora
- Nyhedspræsentationer udarbejdet ved Carlsberg som den primære test partner
- Linkedin opslag og promoveringer
- Nyhedsopslag på facebook side
- 2 siders præsentation i Skive Folkeblad i forbindelse med vundet pris

## BILAG TIL SLUTRAPPORTEN

Oversigt over:

Publicerede videnskabelige artikler skrevet i projektperioden

- Projektet har ikke haft et videnskabeligt indhold eller fokus

Dokumenter og konference indlæg skrevet og afholdt i projektperioden

- https://www.linkedin.com/posts/mogensbirkelund_klimatosse-activity-6798892991240052736-OIlv
- https://www.linkedin.com/posts/lars-c-christensen-647b4064_carlsberg-activity-6728037752232837120-iaCp
-

Artikler med angivelse af i hvilke magasiner (med datering)

Skive Folkeblad: https://app.retriever-info.com/go-article/03503820210512431eec73bb9732ed733e19f818ed7bc4/517383/monitor/search?type=jwt

Links til videoer m.v. (med datering)

https://www.linkedin.com/posts/mogensbirkelund_vi-leverer-en-konkret-l%C3%B8sning-for-co2-neutral-ugcPost-6537257006116421632-4-Oa

Øvrige formidlingsaktiviteter.

Temadag om elforbrug til varmepumper i fjernvarmen
Dato: 24. juni 2019
Sted: Fjernvarmens Hus, Kolding
Mødeleder: Nina K. Detlefsen, Grøn Energi