NORA – Final Report

Regenerative electric/hybrid drive train for ships

- RENSEA phase II

On behalf of the RENSEA project Group
North Sailing
Icelandic New Energy
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Summary

After a few years of planning, preparation, networking and tendering the installation of all new electric components started at the end of 2014. During the installation process into Opal (the boat to be converted) a handful of small design changes where done so that the new system would work as planned. In general the overall conversion of the boat was successful, but due to the above mentioned changes and late delivery of some components the testing and formal launch had to be delayed a couple of months from the original plans.

In late June 2015 the installation was complete, including:

- 240 kW battery pack, LiFePO4 (46* 60 kW/300 v – in two strings)
    - Upgraded to IP67 (standard) with airthight packaging
- Electric motor/generator – 144 kW, 6900 Nm and 200 RPM
- The old Scania was equipped with a 150 kW generator (when neither regeneration nor land power can be utilised)
- Control system for charging and discharging, BMS, etc.
- New propeller – dimension 1,8 m. (old was1,4 m.)
    - Feathered and designed for maximum efficiency for propulsion as turbine
- Murphy og ARADEX system components
- EMC noise reduction system

After 9 months in the shipyard the boat was tested on Skjálfandi Bay in late June and first days of July. The boat was already scheduled to leave on tours in mid of July so the testing of the equipment was relatively short compared to plans. Fortunately the extensive preparation paid of as all components worked according to plan and the ship got certification for operation from the Maritime Authority in Iceland in the first week of July.

It was the Prime Minister of Iceland hon. Sigmundur Davíð Gunnlaugsson that officially launched the new system on July 12th the day before the first voyage to Greenland. Opal has since then been successfully operating in a very demanding environment with great success.

Even with the optimism in the team the efficiency of the system seems greater than expectations and the regeneration capabilities are working as planned. This indicates that the potential of such systems not only for sail boats but for general hybridisation of ships is greater than originally thought of.

To make exact measurements of the total efficiency of the system a special monitoring system has to be installed. The boat also need to sail longer distances under stable wind conditions. This will be the main task for the next months when the boat will be back from Greenland.

The first findings that need to be confirmed under ideal conditions indicate that distance the boat can travel only driven by electricity from the battery bank is greater than expected. It seems that the efficiency of regenerating electricity with the propeller under sailing is close to what could be expected from the calculations. The first preliminary findings are promising and indicate that the system could have large implications for various boat operations.

The overall project ran very well mainly due to the high commitment of partners. No major incidents were faced during the project period. The project though has gone above original budget but different players and partners decided to increase their own funding to see a successful outcome.

1. Introduction

Since the original application to Orkusjóður the project was enlarged[1] by adding partners from the other Nordic countries and applying for funding from Icelandic Maritime Fund, NORA and Nordisk Innovation (NIC). The tasks of the project has also been enlarged, i.e. from the original concept of only developing a system for Opal to designing the system for other types of boats also. The goal with that enlargement is to increase the commercial viability of the project i.e. that the findings from the RENSEA II project can be utilised in number of different ships of small size, both sail boats and other types of boats.
This final report will only adress the Icelandic part, i.e. the conversion of Opal to a „regenerative plug-in hybrid-electric propulsion“ for a sail boat, which was what was applied to in the application to Orkusjóður.

2. Project coordination and partners

The success of the project can be directly connected to the commitment of project partners. The cooperation in the project has been excellent. As stated in previous status reports to Orkusjóður then the project was enlarged with funding from NORA, the Icelandic Maritime fund and Nordic Innovation which created a relatively large partner group. In the expanded project partners included:

- NaustMarine (ICE)
- Nýsköpunarmiðstöð (ICE)
- Clean-e-Marine (DK)
- Lakeside (FO)
- Bellona (NO)
- ANEL (NO)
- Wavepropulsion (NO)
- Caterpillar Propulsion (SE)

At later stage Lithium Storage (Switzerland) also joined the group as the provide of batteries to the project and contributed to the integration of the system. Also as explained earlier the expanded project involved also activities in Norway and the Faroe Island.

The Icelandic cooperation was at its best throughout the whole project. Regular meetings, roughly two per month, and then larger meetings were held during the whole project period. No coordination issues were phased during the project timeframe and all issues were solved

3. Project key elements

The key activities, with regards to the original Orkusjóðs application, have been identifying components, signing contracts (following quotes), which is then followed by the system design including all battery management systems (BMS) and preparing land connection which can influence the BMS and the system design.

Preparations started some years ago with a pre-project RENSEA and the work from that project eased the work for this. Formal communications pathways were set up with key players and quotes obtained from many different players. At the same time design procedures were in place which influenced the choice of some components. They key components to search for were the batteries, the electric motor/generator, the propeller and other system components, Regarding the generator the final

[1] This has been explained in detail in earlier status reports to Orkusjóður.

decision was then to mount a new generator on the old Scania. There were partners for other key tasks. This search came to an end in late 2014 and the key choosen components are:

- New design of batteries for marine applications: 240 kW battery pack, LiFePO4 (46* 60 kW/300 v – in two strings)
    - Upgraded to IP67 (standard) with air-waterthight packaging
    - Including BMS and chargers
- Electric motor/generator (PMM) – 144 kW, 6900 Nm and 200 RPM
    - The old Scania was equipped with a 150 kW generator (when neither regeneration nor land power can be utilised)
    - Bio-diesel testing on the Scania is being planned[2]
- Control system for charging and discharging and software, etc.
- New propeller – dimension 1,8 m. (old was1,4 m.)
    - Feathered and designed for maximum efficiency

Aligning all of these components together and creating a system and software to operate is the key element in the project.

Batteries

Quotes were obtained from 4 different battery producers. The key objective in the quotes were, physical design, capacity and cost. The key problem with most of the offers obtained was that the physical design of the battery packs where not flexible nor compact enough to fit into the limited space available in an old boat without doing expensive changing, and to avoid taking up valuable space during tour-trips, of the layout on board Opal. Most of the battery producers were not willing to do any redesign of the batteris as they did not see the project a major customer and that the cost of redesigning 200-300 kW battery pack would be very expensive. This created some issues as most of the batteries that could be fitted into the area would only hold 140 – 200 kW which would be too little for a conventional whale watching tour.

Lithium Storage in Switzerland has been developing batteries for the lorry and van market (i.e. vehicles) which were both very competive in cost and they were also willing to redesign the packeging to fit the needs of Opal and maritime use. Following a contract signiture the company redesigned the packaging both to fit into Opal and also to fulfil the needs of certification for maritime use. This flexibility in design makes the batteries more competitive for the marine market – something that future projects can benefit from.

The relationship with Lithium Storage has now been strengthened with the goal to utilise their batteries in more marine applications and in future RD&D projects.

Motor/generator

At the onset the goal was to use the conventional diesel engine as a generator of electricity. The task of identifying the „correct“ generator for the old 210 kW Scania became a bit complicated, mainly the interphases between the generator and batteries. In the end a generator from Leroy Somer was choosen and motor controller from Aradex was chosen to control the current to the batteries.

Baumuller was identified early to supply a Permanent Magnet Motor (PMM). The key to the choice was maximize the efficiency between the motor and the new propeller. To confirm that everything would fit correctly together and no issues would arise the motor was sent to Caterpillar Propulsion where the shaft and propeller were hooked together to see if all was working correctly together. This FAT (factory acceptance test) was very important as the motor and the shaft did not fit 100% together

[2] Was not possible to execute on the maiden voyage to Greenland

and all junctions could be corrected before all the components were shipped to Iceland. After the installation of the motor the team was faced with problems connected to EMC noise. This is a know problem when adding together different components and can become a major obstacle if it is not possible to isolate the EMC vaves and reduce them so that the system functions accordingly. Fortunatelly the issue could be solved quicly by changing the control unit within the motor with a control system from Aradex. Following this solution and some rewiring of the system the EMC issue was eliminated and the system worked according to plan.
The installation in Husavik went very well and the system has proven its functionallity as an extreamly efficient. To get exact numbers special monitoring system has to be installed to collect date that can be used to optimize the system. Based on collected date the plan is to develop software that can have automatic functions to run the system in a optimal way under different conditions, i.e. a better EMS (energy management system)[3]. The calculations based on the towing test from February 2014 estimated the main electric motor to use 32 kw to sail the boat at 6 knots and 46kw reach 7 knots. The experience from the first trip to Greenland indicates that the energy use is lower than that. When sailing only with sails at 5 knots testing show that it was possible to regenerate 4-5 kw. That seems to be close to the calculations. The first experience with the regenerating also indicates that the motor controller has to by programmed differently when regenerating compared to propulsion. When Opal is back from Greenland second half of September the team of the experts will start working one the optimization of the system[4].
The overall outcome is therefore beyond expectations and shows that there is a huge viability to install similar systems in various boat types and for various operations.

The fuel consumption when electricity is produced with generator seems to vary a lot due to operational profile. To find exact figures for fuel consumption further testing needs to be done over time and under various circumstances. But as stated above it is important to improve the EMS system, install a sea-log and upgrade the BMS to be able to monitor the losses in the different system components.

Propeller

At the project beginning a new propeller design was identified as the key to maximize the system´s efficiency. When the project expanded into a Nordic project Berg Propulsion (SE) which later in the project became Caterpillar Propulsion in cooperation with Wave Propulsion in Norway, took on the task of designing a propeller for Opal. The team wanted to have the propeller as large as possible and with a controlable pitch. In short – to maximize the efficiency the propeller should be large and have a much lower RPM than a conventional propeller for a diesel motor. As stated earlier Caterpillar Propulsion did a FAT test with the propeller and the motor which saved a lot of time during installation and also proofing the functionallity of the motor and propeller, as during the FAT test a new mechanical adapor/flange to connect the propeller and electric motor was designed at Caterpillar Propulsion site.

The feathered design came early on the drawing board so that the utilisation of sails could be maximized, i.e. the blades can be flat during sailing with strong wind. But just as important was to be able to control the possible regeneration (like regenerative breaking) of energy during sailing with sails. In the first trips all of these features were tested with results better than expected (see above: motor/generator).It proofs that all components have to be evaluated when maximizing the total efficiency of a system. Of course all the design parameters of the propeller do not have to be used in applications when f.ex. there is no regeneration possibilities.

[3] This is now a priority for the future development and needs to be fully solved before next systems are installed at Northsailing or other applications.
[4] Further development of the BMS is also a key priority for next steps.

The use of the new propeller is one of the most exciting component regarding efficiency gain. There are indications that the efficincy of a propeller can almost be dobled with a new design saving drastically on diesel consumption. This though needs to be research further for example if it is economical to actually convert the conventional fleet of Northsailing only by changing the propeller – would the fuel savings match the investment cost of intalling a new propeller.

Control system

As can be understood from above then most of the componets were not specially designed for the project. However to get them all to work correctly together it was necessary to design the control system. This became a more time consuming part of the project and more complex than anticipated in the beginning, which is very common in such projects.

A lot of learning had to be done by doing and mistakes had to be corrected ASAP. During the original testing of the boat and later the first voyage to Greenland it became evident that the control system can be made better and have a simpler functionality for the crew. Despite some flaws in the system it works as indended but it has needed a bit more attendance than originally planned.

During the first months of operation the team has already identified the key flaws which will be corrected in the near future so as stated earlier the future success of the project is to develop a better EMS and BMS for the boat. This indicates that the components are not the problem but the systems.

Certification

Certification is a very important feature. Early in the project the project group involved Lloyds Registry for the certification of the system. They did the original certification for Opal and therefore it is an advantage to use the same players for the next step. They were fed with information as they became available so that they could recommend changes or necessary safety equipment and in that sense avoiding that at the final stage there will be issues with certification.

As the project was delayed and the communication with the classification societies become more complex and a formal certification from them was not necessary to get operation licence the work with them was postponed. With a marine approval for the batteries the Maritime Authority in Iceland inspected the installation, drawings, design, etc. and approved of the ship´s operation.

This is another learning step for the project partners and something that has to be worked on the the coming months if similar systems are to be put into ships. Already Lithium Storage and other partners in this project are working with the classification societies to get a formal certificate for marine operation on the batteries so that they can be marketed directly for other ships.

4. Budget

The original budget of the project for the Icelandic part was underestimated. However the budget was partly corrected with the expansion of the project, i.e. with Nordic funding. Again this issue was solved with the strong commitment of the partners as most players were willing to inject increased own funding into the project and close the gap in that way. In this case the main cost increase was for Northsailing, but their commitment to see the project through is admirable. The Nordic part of the project is not fully finalised but the total budget with the Norwegian and Faroese project was around ICEKR 120 Million. The estimated total cost for the project is now closer to ICEKR 150-160 Million mainly due to increased cost of the conversion of Opal. Other parts of the total project have much less risk as they are design and research only. The overall cost of Opal was therefore probably around 30% higher than originally planned.

The group though values the increased cost partly as assets and the goal it work further together towards creating new initiatives and projects and in that sense potentilly recover some of the extra investment done in the project.

5. Dissemination

The launch of the project in early July was very successful. The local coverage in Iceland was very good and many did not realise what the team had accomplished. It was also very important for the project to have many high level stakeholders participating and of course to have the Prime Minister of Iceland to launch set a high profile on the event. Added to the local coverage the commitment of partners and even indirected partners like Landsvirkjun news agencies in many countries were activated. Just to give a couple of examples:

http://www.businesswire.com/news/home/20150713005345/en/North-Sailing-Milestone-Eco-Friendly-Transportation

http://icelandnaturally.com/article/north-sailing-a-milestone-eco-friendly-transportation

http://www.reuters.com/article/2015/07/13/north-sailing-idUSnBw135345a+100+BSW20150713

https://collectively.org/en/article/carbon-free-boat-tours-iceland/

The dissemination of the project in far from being over. If anything the attention on the project is increasing. As reported earlier the group will therefore decided to demonstrate the technology to wider audience in the North Atlantic arena. Already Opal has been in Iceland for testing and is currently on tours in Greenland. It is demonstrated on the East coast of Greenland to show how green technologies can perfectly harmonize with the fragile nature of North. Following a return via Iceland Opal will then be taken to the Faroe Island and from there it will travel the West coast of Norway all the way to Oslo and then to Gothenburg, Sweden where the final demonstration and dissemination will be done at a specific conference (http://mmag15.com/) and from there the ship will be going to Denmark and potentially other European countries[5] before returning back to Iceland (4 last destinations are not confirmed). The tentative schedule was:

Dissemination				2015				
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Iceland								
Greenland								
Faroe Island								
Norway								
Sweden								
Denmark								

A handful of presentations have already been given on the topic:

- Árni Sigurbjarnarson “RENSEA – electrically powered whale watching boat”. Presented on September 17, 2014 at the seminar “Sustainable transport” in Reykjavík.
- Fredric Hauge “Market opportunities for marine environmental technology”. Presented at the Norwegian shipyard association annual conference in Ålesund on November 4 – 5, 2014.
- Jón Björn Skúlason: Utilising regenerative plug-in hybrid-electric propulsion on a sailboat. Presented at the Electric & hybrid marine World Expo, June 23-25th 2015 in Amsterdam.

[5] To be confirmed

- Árni Sigurbjarnarson “Opal – regenerative plug-in hybrid electric propulsion“. Presented at the Making marine applications greener, Gothenburg 21-22 October 2015

Already a documentary has been made which will be aired at the final event of Opal in Gothernber 21-22nd of October 2015. This will be a big conference where key players meet[6]. This documentary will be available on different web sites along with other stories of the ship and the accomplishment of the project. Also public reports will be made available. The group has felt an increasing interest for the ideology and is convinced that the solution being developed in the project will have an important role regarding environmental sailing in the future.

6. Results

The project key was actually able to set sails with a fully hybrid regenerative system. This was accomplished on July 12th this year. The preparatory work had been well executed but time of getting all components to Iceland and installing them took 6 months longer than estimated. This delayed the project and due to this delay it was not possible to collect all the data which the partners had planned during the summer of 2015. However the operation of the ship has been very successful and as stated earlier in the report the main flaws in the whole project was that the EMS and the BMS did not function in an optimal way. This also made data collection a bit difficult, for example with the current EMS the team is not able to calculate and obtain data where possible energy losses are in the system which is very important so that the team can maximize the benefit of the project. However there are indications that drastic cost reductions can be obtained and major CO_2 savings.

Fuel consumption Opal				
Typical 4 hour whale watching trip				By electrification
		ICE KR	250 trips/yr	
Diesel consumption l.	100	13.800	3.450.000	
Electricity consumption Kwh	170	1.870	467.500	
			2.982.500	**ICE kr saving**
Total diesel consumption l.	25.000		**66.000**	**kg CO2 saved**

It should be noted that these calculations are based on limited testing of the electric system and that all electricity used in the trip of the converted Opal comes from land connections. For longer trips, i.e. where electricity needs to be produced from the diesel gen set the gain is much less (between 20-50% depending on condistions). Further measurments with an opgrated EMS needs to be done to verify the figures.

Already an updated BMS system is being installed into the ship which will support the system operation and currently the team is discussing with parners in the project as well as new partners to work on an updated EMS system. This will enhance data collection and maximize the efficiency of the project. At the same time Northsailing is evaluating the option of actually removing the „old Scania“ and installing a smaller generator which will reduce fuel consumption on long haul trips when electricity generation is needed.

The operation success has been demonstrated as the ship sailed from Húsavík to Greenland in July and was operated there on commercial tours for 9 weeks and then it sailed to the Nordic countries for other demo activities.

This success did not go un-noticed as Northsailing has already won two awards due to the success of the project, i.e. the Environmental Tourism Award in Iceland 2015 and the Silver Award for Best Innovation in Carbon Reduction at the World Responsible Tourism Award 2015. This is a recognition of the great success of the project and highly celebrated by the project partners.

System design for other operators[7]

In the project description emphasis was put on that the design for Opal should be applicable to other boats, i.e. like boats not with sails. For this purpose Lakeside Excursion (Faroe Island´s) was a member of the project grop evaluating if the same or similar system could be used for their boat operations.

A special report has been made by the project group on utilising same/similar design´s for the Lakeside boat as for Opal. In general no major changes in the design have to be made. All key components can be applied to other boat applications and same or a more simpler systems (as such boats do not require regeneration). One of the learning from the RENSEA project is that the BMS and EMS have to be redesigned. It is important that during this redesign phase that the systems will be easily adoptable to applications that do not need regeneration. With that all the design features and learning from the RENSEA project should be applicable to all alternative marine applications.

7. Conclusion

RENSEA II is one of the most ambitious projects in its field currently running in the North Atlantic. It is evident that it can contribute important findings and solutions to reduce fossil fuel consumption in small, and mediums sized, vessels even in the harsh and fragile environment of the North Atlantic.

The interest in the project has increased after the launch of the project in July and the partners are convinced that the results can be utilised for a larger audience and that the developed solution can fit perfectly within a very large market – even larger than anticipated in the beginning. Due to that the group would decided to expand the planned dissemination of project results even though this done totally on the own funding of the partners. The group is also evaluating in what way the new design can be made available for future markets and has initiated a side activity to evaluate that part of the project.

So far the system has more or less performed as planned and with a slight adjustment of the control system the solution is close to be ready for the market. Of course further data collection has to be made during the months to come but until now there are extremly promising results.

[7] A separate report specifically on the Lakeside boat is handed in to NORA with other available reports which have been produced through the whole project.