Modeling and Optimization of a Hybrid Electric Ship Power System

By: Eline Bugge Simonsen
Supervisor: Mehdi Zadeh

NTNU
Norwegian University of Science and Technology
ULSTEIN®
DNV·GL

Objective and Scope

The main objective of this master thesis is to investigate the advantages onboard battery storage systems may offer in a hybrid electric power system.
In order to do this an optimization model for determining battery size, and a simulation model accounting for a system's dynamics as response to dynamic load conditions is created.

Motivation

Shipping is considered as the most environmentally form of transport, but being responsible for around 90 percent of the world trade, it constitutes a great source to greenhouse gases. As we now see the emerging consequences of climate change, environmental protection receives increased attention globally. The international maritime organization (IMO) has set a target to reduce total emissions from shipping with 50% within 2050. The urgent demand for sustainable and efficient energy sources drives the initiative to pursue hybrid electric ships. Batteries are identified by the Green Coastal Shipping Programme, a joint program between the Norwegian government and the industry, as one of the most important propellants that may render possible the targeted transition.
The effect of implementing batteries may however vary for different operations and vessel segments. As the maritime battery storage systems have a high initial cost, correct sizing and operation of these systems is therefore essential.

Optimization of Battery Size

A mixed-integer nonlinear programming model (MINLP) is formulated for decision support in order to determine the size of the battery for implementation in a hybrid electric propulsion system. The objective of the optimization is to find the solution that minimizes the cost of the integrated system over the vessel lifetime. The costs involve VOYEX related to fuel consumption and NOx taxes, and OPEX related to maintenance due to wear and tear. The CAPEX of diesel generators and the battery storage system are also considered. Furthermore, due to the short life expectancy of battery systems, a replacement cost is also included.

Acknowledgements

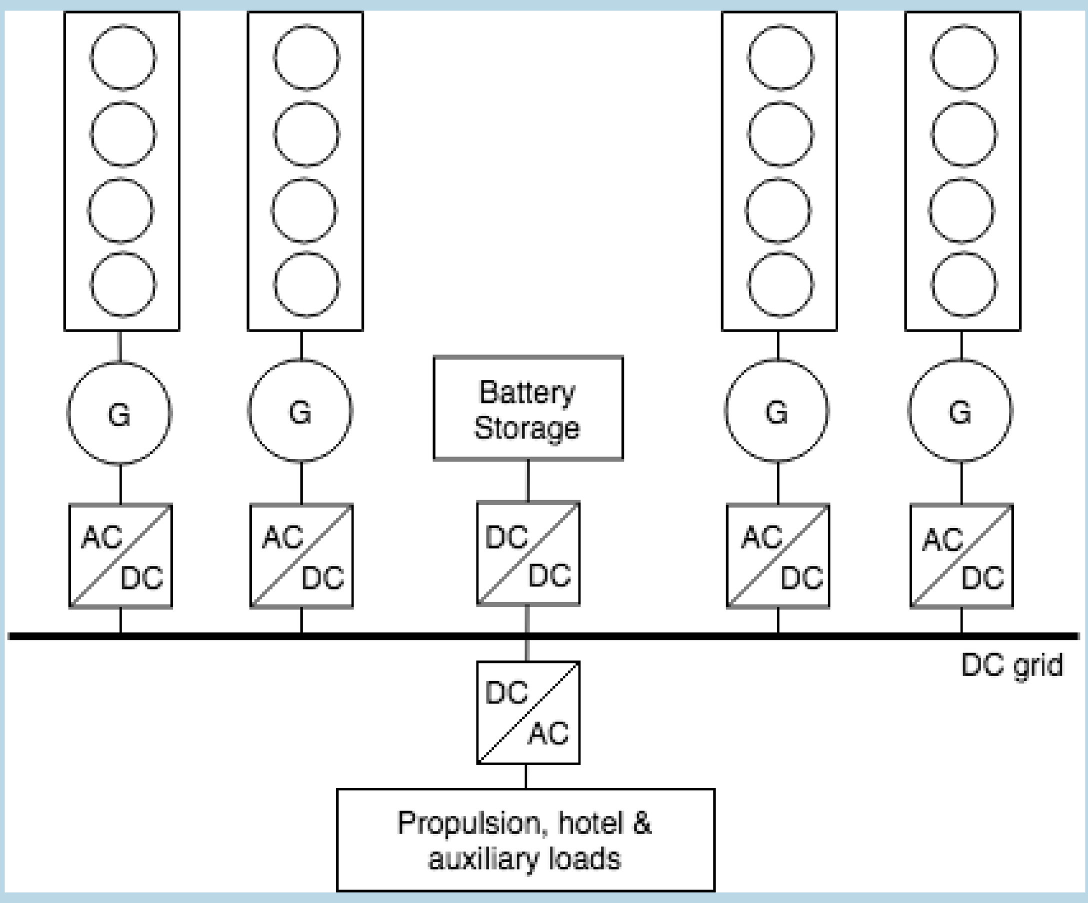
This master thesis was made possible with the help from my supervisor Mehdi Zadeh. Invaluable help to create the simulation model has also been given from PhD candidate Daeseong Park. I am also thankful for the input given from Ulstein Design & Solutions and DNV GL.

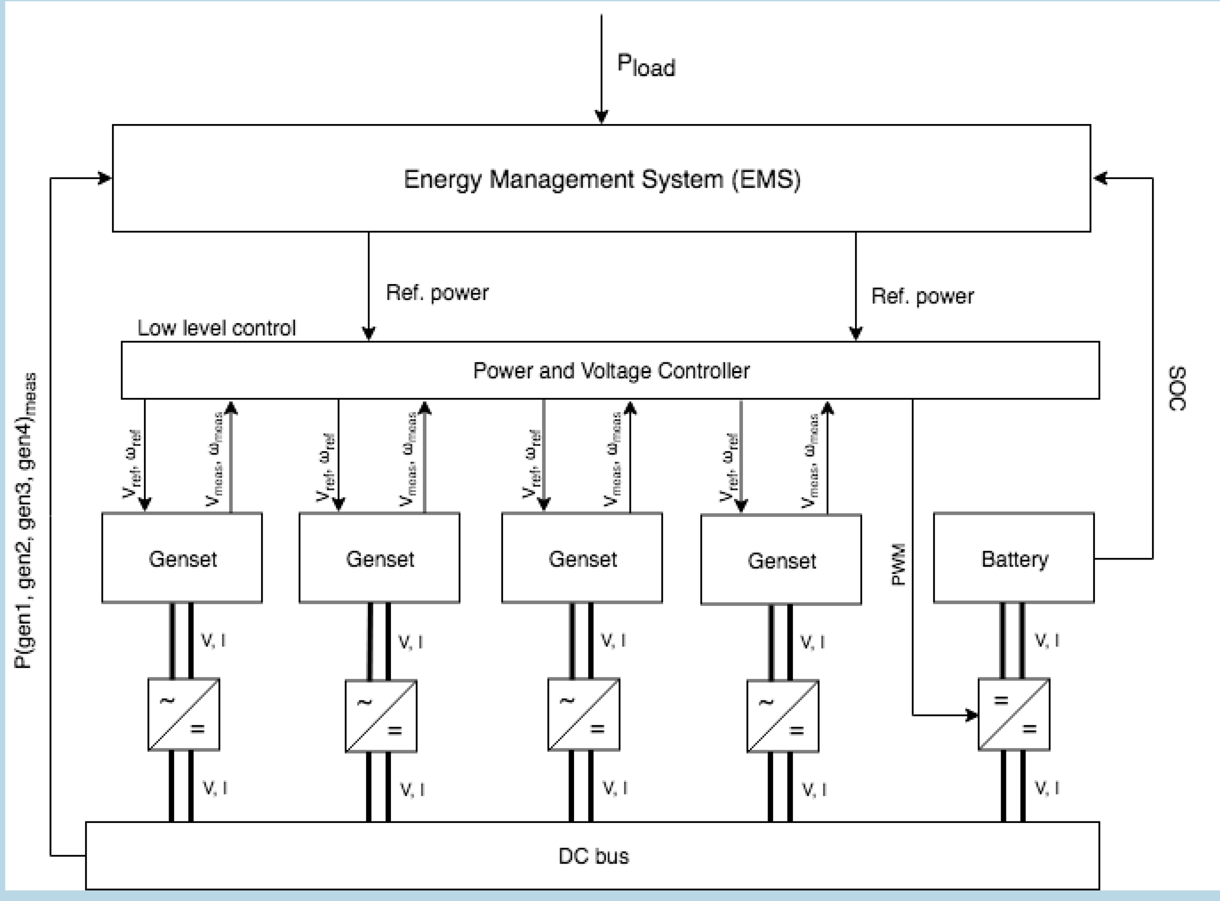
References

[1] DNV GL: *DNV GL Handbook for Maritime and Offshore Battery Systems*, (2016)
[2] IMO: *Third IMO GHG Study 2014*, (2014)
[3] Regjeringen - Ministry of Climate and Environment: *NorwayâĂŹs climate target for 2030*, (2015)
[4] International Chamber of Shipping: *Shipping and World Trade*, [Accessed on 21.02.19 from `http://www.ics-shipping.org/shipping-facts/shipping-and-world-trade`]

Simulation Model

In order to account for the dynamic responses of the total system the hybrid power system is modeled in the MATLAB Simulink platform. The simulation model is designed with a DC grid system where the power is supplied by four diesel generators and a battery as demonstrated in the single line diagram in the figure to the left. As a part of the master thesis, a case study has been performed on a specific vessel and the simulation model is designed based on it's machinery configuration. The model may however easily be adjusted to represent any other machinery configuration.

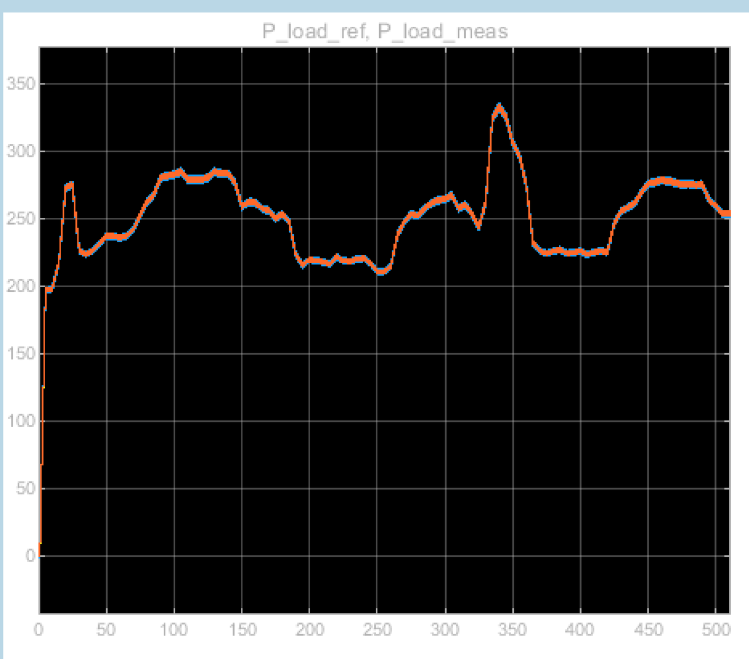


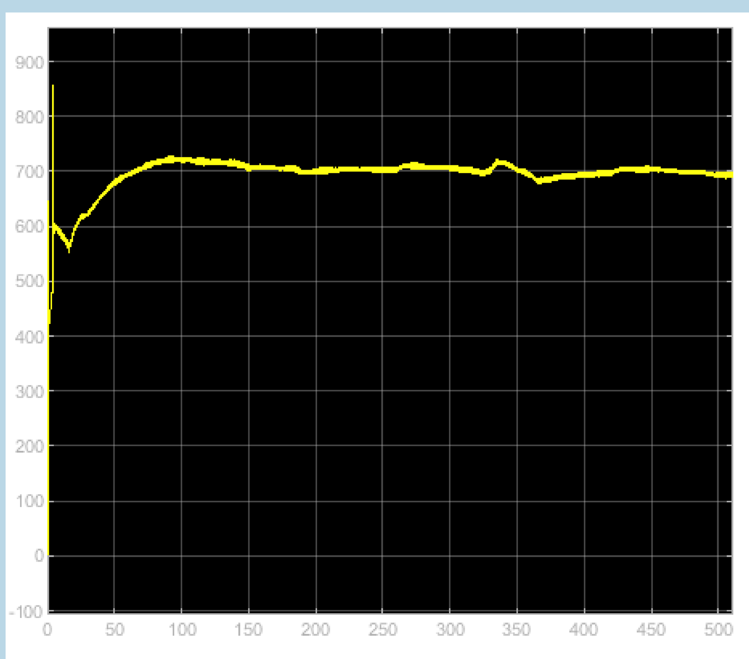


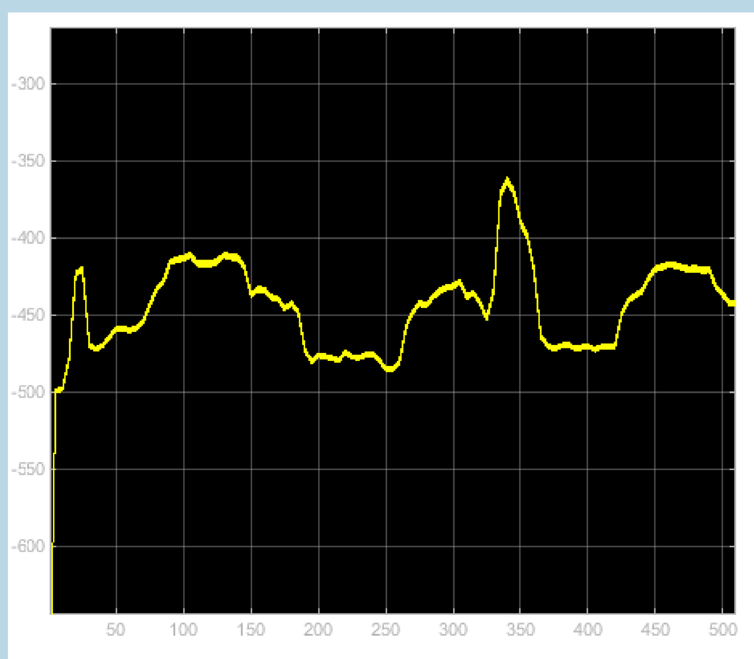
The block diagram to the right demonstrates the model's control system hierarchy. An energy management system is designed in order to optimize the power flow. Based on the current power demand and the battery state of charge, the energy management system determines the reference power to be provided by the different diesel generators and the battery. These references are then communicated to the power and voltage controller for further distribution. The power and voltage controller translate the signals into source specific signals, such as current and voltage levels. The diesel generators and the battery will then produce power according to these signals. The generated electric power is then fed via power converters into a common DC bus that distributes the power to the consumers.
The model calculates the fuel consumption based on the loading of each diesel generator. From this the cost of fuel and the accompanying NOx tax is calculated. Based on the diesel generator type, and how it is operated the maintenance cost may be calculated.

Results and Conclusion

The battery is intended to optimize the operation of the generators in various ways. **Load levelling** is characterized by the smoothing an engine load by charging the battery during low power demand, and discharging when the demand exceeds the power generated by the engine. This enables the engine to operate at the point where specific fuel consumption is minimized, while simultaneously reducing wear and consequently the need for maintenance on the engine. Moreover, batteries, with its high power density are efficient in absorbing sudden peaks in the load demand, so called **peak shaving**. Through this the battery spare the engine from overloading with the potential of blackouts. Moreover, an additional function is to serve as a **spinning reserve** which is a requirement related to redundancy in certain operations. Finally, the battery may **prevent the generators from operating at damaging load levels**.
The simulation model demonstrates how the battery may improve the operation of the diesel generators. An example is through load levelling as demonstrated in the figures below. The figure to the left shows how the load demand fluctuates over time. The figure in the middle and to the right shows the power produced (or consumed) by the generator and battery, respectively. As these two figures demonstrate, the battery is able to absorb the load transients, in this case by charging (negative values), making it possible for the generator to operate at a steady load level.







A case study focusing on economical performance is executed for the PSV 'Blue Queen'. In the case study, Blue Queen's machinery system is compared to a hybrid electric system consisting of the same diesel generators and a battery.
The results of the case study indicate that the battery has great potential in reducing both emissions and VOYEX costs as a result of reduced fuel consumption. Moreover, a substantial reduction in maintenance need is also observed.