Bachelor's project

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of ICT and Natural Sciences

Nora Sorte

a model for optimising hybrid ships

Bachelor's project in bachelor ingeniør, elkraft
Supervisor: Osen, Ottar; Bye, Robin Trulssen
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SUMMARY

In this project my goal was to create a basic Simulink model that can be used to simulate the power supply of a ship that contains both a battery and diesel electric generators. I started by making a very basic model, and iterated upon it by adding a battery, a second generator, and a simple power management system.

At its most basic the model uses a demand test signal and variable inputs to give us a rough estimate of how powerful the generators need to be in order to supply the system and charge the batteries, as well as how much battery capacity is needed. This is the function of the basic model, but due to its simplicity and high degree of modularity, it has a flexibility that makes it relatively easy to alter for different setups.

TERMINOLOGY

Terms

Peak shaving	filtering a signal so that peaks above a certain threshold are cut off
Excess power	in our case, this refers to power that is either unused (positive values) or needed but not delivered (negative values)
Generator rated max	the maximum power output the generator is expected to deliver consistently without shortening its lifespan
Used power	the power the system needs to deliver
Dynamic positioning	responsible for maintaining the vessels relative position by counteracting forces like currents and wind. Usually manages thrusters, usually communicates with PMS.
Power Management System	Responsible for managing available power. Starts additional generators when necessary, uses load reduction, power limitation and load shedding to avoid blackouts and power shortages.
Power limitation	large users such as thrusters receive a signal from the PMS that determines how much of the system's power they can use.
Load reduction	the PMS sends a signal that asks large users to rapidly reduce power use.
Load shedding	sheds large, lower priority users to maintain power for propulsion and avoid blackout.
State of charge	current battery charge given as a ratio of max charge

Isosynchronous	a generator that maintains constant frequency regardless of load is described as isosynchronous. Technically, the generator does still droop, but the droop is transient in nature and recovers quickly.

Notation

P_e	Excess power
P_N	Generator rated max
P_U	Used power
S	apparent power
U	voltage
I	current

Symbols

Π	3.14

Abbreviations

DP	Dynamic Positioning
PMS	power management system
SoC	state of charge

1 INTRODUCTION

In this project the goal was to create a Simulink model that can be used to simulate the power supply of a ship that contains both a battery and diesel electric generators. The system has been tested both using a single value for generator max, and as two separate generators. In addition to simple test signals, this setup has been tested with data from the NTNU-owned research vessel R/V Gunnerus. See chapter 3.1.1 Gunnerus for more information.

Extended periods of increased power drain, such as navigation during bad weather, should be handled by the generators, as the battery is mainly used to peak shave. Because of the rotor inertia, starting and stopping a generator requires a lot of energy. Using the battery as a buffer saves us energy by allowing us to only start the second generator when it is needed for a longer than the duration of a single spike. This also gives us more time to start the next generator if necessary.

At its most basic the simulation gives us a rough estimate of how powerful the generators need to be in order to supply the system and charge the batteries, as well as how much battery capacity is needed.

Choosing oversized components will waste both money and valuable space, while detracting from the weight of cargo, passengers, equipment etc. the ship can carry and therefore reduce profitability. Meanwhile, choosing a battery and generator that are too small may cause the ship to run low on power in a critical situation, or force the crew to strictly ration energy during periods of high power-consumption.

The model allows input values matching the generators and batteries the user considers using, and output plots that offer an estimate of how well these options would fill the demand.

In the model, power flows from generators to consumers. The battery charges when generator load is under max, and discharges when demand is above max load; this way it serves to even out the fluctuations in demand as seen from the generator, ideally shaving off the peaks in demand.

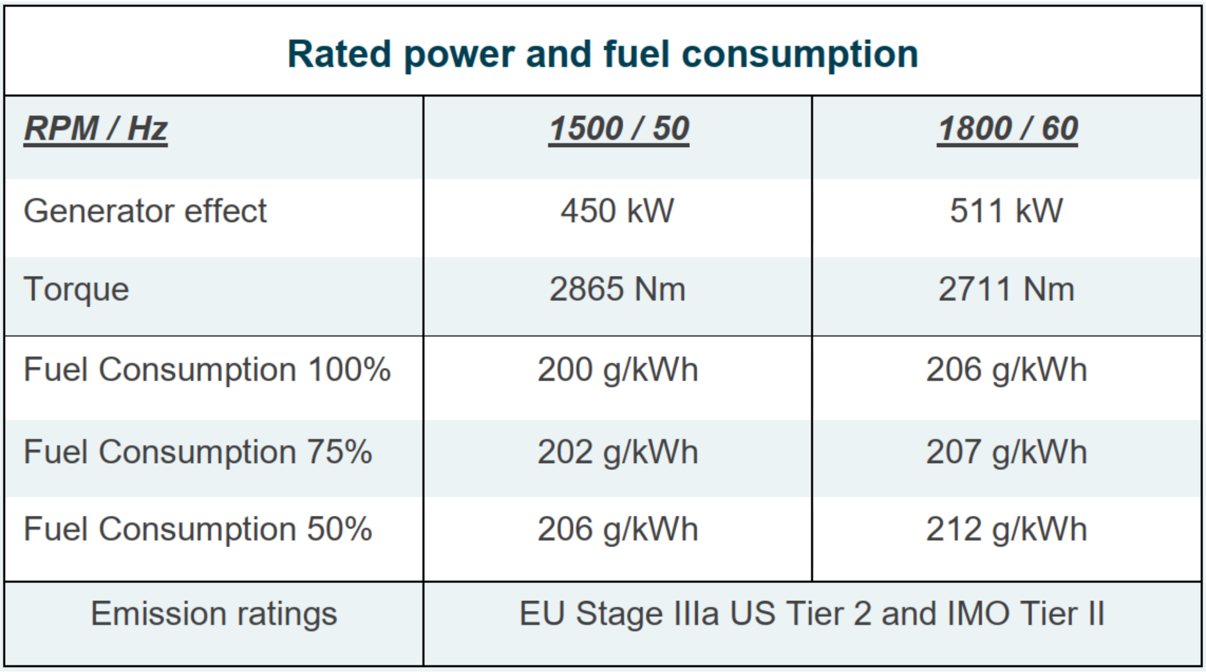
The project faces some challenges. At its most basic, I needed to simulate a battery capable of charging, discharging, and keeping track of its state of charge, and a system that lets us compare available power to demand, while considering the battery state of charge. It needs to take user input and produce output data that can be interpreted by a user, preferably in the form of plots.

Note that the examples in this paper have largely been simplified to two generators. This had been done to make the explanation more comprehensible, and it is possible because once I have proven that I can add an additional generator to the model, adding more is largely a matter of copying my previous work.

2 UNDERLYING THEORY AND MOTIVATION

When using this model, the goal is to find a combination of generators and batteries that avoids power outages or significant unnecessary strain on the generators, while reducing pollution by increasing efficiency. There is a precedent for this; other ships that have undergone hybridisation have successfully reduced average fuel consumption. One example is the Far Sun, which saw an average reduction in fuel consumption of 5.1% (Selen 2018).

The generators experience less load fluctuation and because they don’t need to have the capacity to handle these peaks, they can spend more of their active time running closer to peak efficiency, which tends to be close to max rated capacity, see figure 1.



Rated power and fuel consumption

RPM / Hz	***1500 / 50***	***1800 / 60***
Generator effect	450 kW	511 kW
Torque	2865 Nm	2711 Nm
Fuel Consumption 100%	200 g/kWh	206 g/kWh
Fuel Consumption 75%	202 g/kWh	207 g/kWh
Fuel Consumption 50%	206 g/kWh	212 g/kWh
Emission ratings	EU Stage IIIa US Tier 2 and IMO Tier II	

Figure 1: (nogva.no n.d.)

In figure 1 we see the fuel consumption of a 450 kWh Nogva-scania generator. As we can see, running the generators at 50% load uses more fuel/kWh than running it near full capacity, but in the generators used by Gunnerus the difference is not particularly severe.

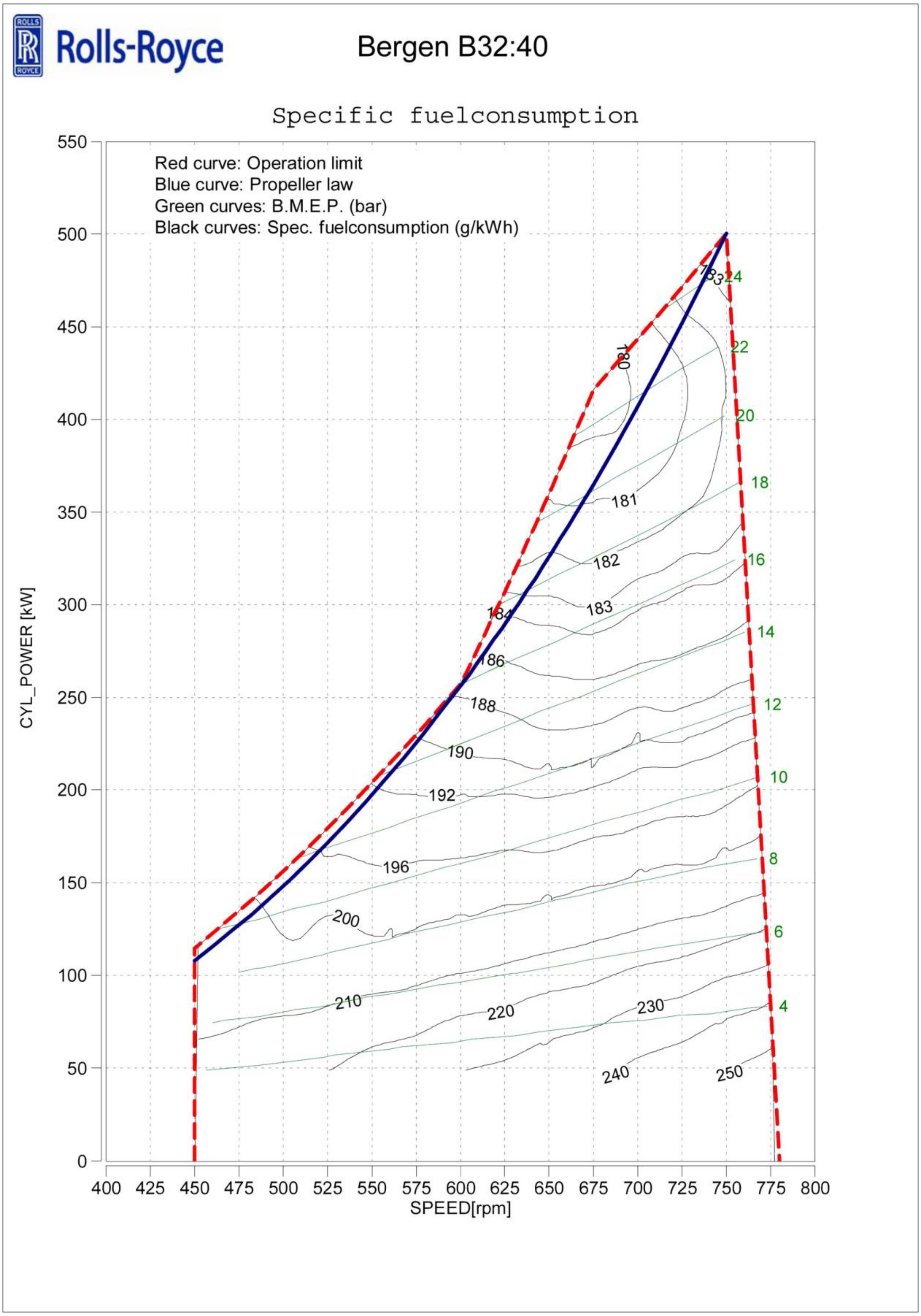


Figure 2: example curves, specific fuel consumption, g/kWh

Cutting fuel consumption is beneficial for several reasons. One reason is that fuel is expensive, so it may aid in cutting costs. Another reason is environmental concerns. Norway is committed to cutting its release of greenhouse gases by 40% by 2030, relative to 1990 (klima- og miljødepartementet 2019).

The equivalent of 52 million tonnes of CO2 was released from Norwegian territories in 2018 (statistisk sentralbyrå 2020).

If the battery is too small, peaks in demand may cause blackouts or noticeable fluctuations in supplied power (lights dimming briefly, etc.). A sufficiently powerful generator can compensate, but using it like this will be more inefficient.

If the generator capacity is too small, the battery will run out during longer periods of high demand for power, and power may need to be carefully rationed.

This is undesirable in any ship, but in certain ships, like ships supplying oil rigs etc, any possibility of compromising the ships ability to maintain an exact position is completely unacceptable.

For shorter periods of time it may be possible to compensate with a large battery, but a battery that can do so reliably during longer trips may be too heavy, too large and too costly.

The consequence of choosing generators and batteries with too much capacity are far less dramatic but important, nonetheless. Inefficient generators waste fuel and pollute more, additional battery capacity is heavy, and both can be costly.

In a diesel-electric generator, efficiency drops when load is low. Peak efficiency for the generators used in ships is usually close to the rated max; running two generators at 40% load is far more wasteful than running one at 80%. At the same time, starting and stopping the secondary generator is also very wasteful. We need to find a balance between keeping the extra generator online and available and saving fuel by maximizing efficiency. In this case waste is detrimental both to the environment and to our budget, but unfortunately, when the generator is itself the main tool for varying power production depending on load, efficiency is a necessary sacrifice to guarantee safety and reliability. In this case a battery can act as a buffer, covering load peaks beyond what the main generator can handle, but without requiring the secondary generator unless demand is out of bounds for the main generator for long enough that the battery starts running low. The second generator would only have to run during longer periods of increased load, significantly reducing superfluous starts and stops, keeping power generation near peak efficiency for longer in total.

Representing the generators as a single value gives no further insight into how the power is supplied, adding a second generator to the model adds to its quality and flexibility. When several generators are feeding the same network, as is usually the case aboard large vessels, there are several ways to control them.

To start with, running the generators in parallel requires them to have the same voltage and frequency (Kristiansen 2013). The DP system uses data from sensors and other systems, like PMS to predict what it will need in order to maintain dynamic position. For some ships this is mostly about staying on course and navigating safely but if, for example, the ship in question is supplying an oil rig, DP is responsible for keeping the ship completely still within a few metres.

One way to decide when to start the auxiliary generator is to look at the current load on the main generator and start the auxiliary generator if it is over a certain percentage. If the shared load of the generators drops below a certain percentage, the secondary generator is shut down. If we include a battery in this system, we could modify this rule by turning on the secondary generator only if the main generator's load is above the given percentage *and* the battery is drained to a certain SoC. We could then shut down the second generator when load is below a given percentage and the battery is above a certain Soc, or in other words: close to full.

So, how do we distribute the load when several generators are online? Speed droop describes how a generator's speed decreases as load rises. This is often represented with a droop curve. One way that parallel generators are controlled is by distributing the load so that the speed droop is roughly equal in proportion to the power rating of each generator, thus demanding less power from generators with a smaller power rating.

Another way to connect them would be to let one have constant load while the other can vary. This is possible when one generator is isochronous, maintaining constant frequency even as load changes. The isochronous generator handles load changes, while the normally drooping generator maintains constant load. It is common for the main generator to be designed with an iso mode, as the isochronous generator usually handles the higher load (Patel 2012).

Note that the generators still have the same voltage and frequency, and that running two isochronous generators in parallel can make the system unstable.

So how does all of this translate to this project?
One option is to enable the second generator when the first generator maintains a load above a certain threshold, and disable it when total load drops too low. This works just fine, but it fails to use the battery efficiently.

Another option is to enable the second generator when battery is beginning to run low, and disable it when the battery is close to full. This will cause the system to use the second generator only when the average load exceeds what a single generator and battery can handle. In other words: the second generator turns on when there are many high peaks without enough time to recharge between them, and in longer periods of high load. It would also turn on the generator when a single peak is too high for the battery to handle, and we would risk a situation where the second generator repeatedly starts, charges the battery, then turns off when the battery is full. This could be avoided by disabling the generator when the battery is close to full *and* the total load is below a certain threshold.

This could make an interesting project for an automation engineer; designing a good power management system is a field unto itself (Radan 2008). Since the goal of this thesis is to make a simple simulation model that can be extended and improved in the future, the details of power management falls outside the scope of this paper.

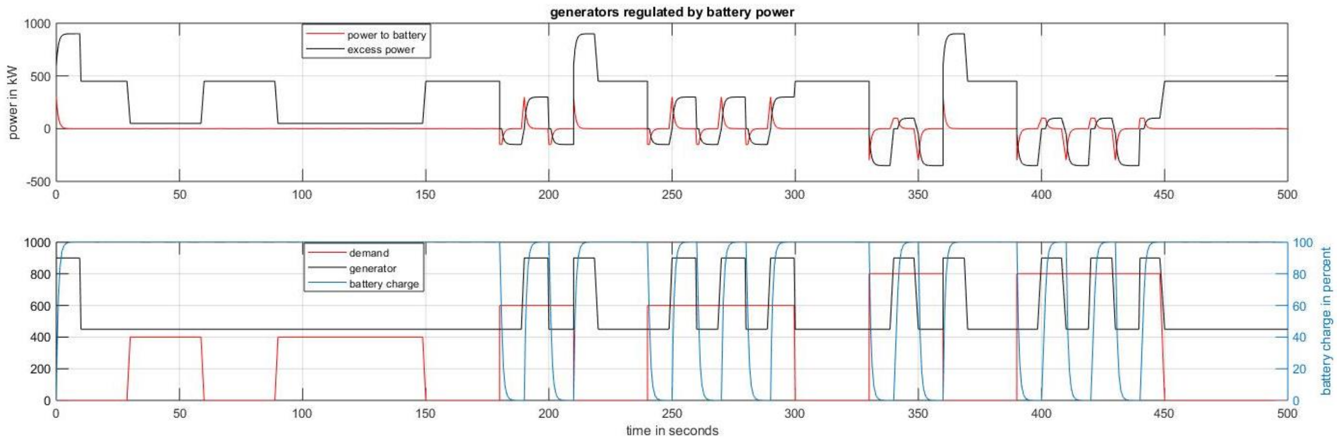


Figure 3: SoC-dependent power managment

In figure 3 we see how the system works when using the battery percentage to control the second generator. As we can see, nothing out of the ordinary happens while demand is low, but during extended periods of increased demand the second generator will turn on and off repeatedly, turning on to charge the battery, only to immediately turn off when the battery is full. For a car this would not necessarily be a problem, but in the generators of a vessel this size the rotor inertia is significantly greater- therefore this runs the risk of increasing fuel consumption quite a bit.

This algorithm is useful for demonstration purposes, but whether it's an improvement for the system depends on the needs of the vessel. Unfortunately, it would be a step in the wrong direction in a lot of situations. The system will likely work better if the second generator stays on as long as the demand is too high for the main generator alone. This way the battery is mainly used for short bursts, and as a buffer when determining when to use the secondary generator, as intended.

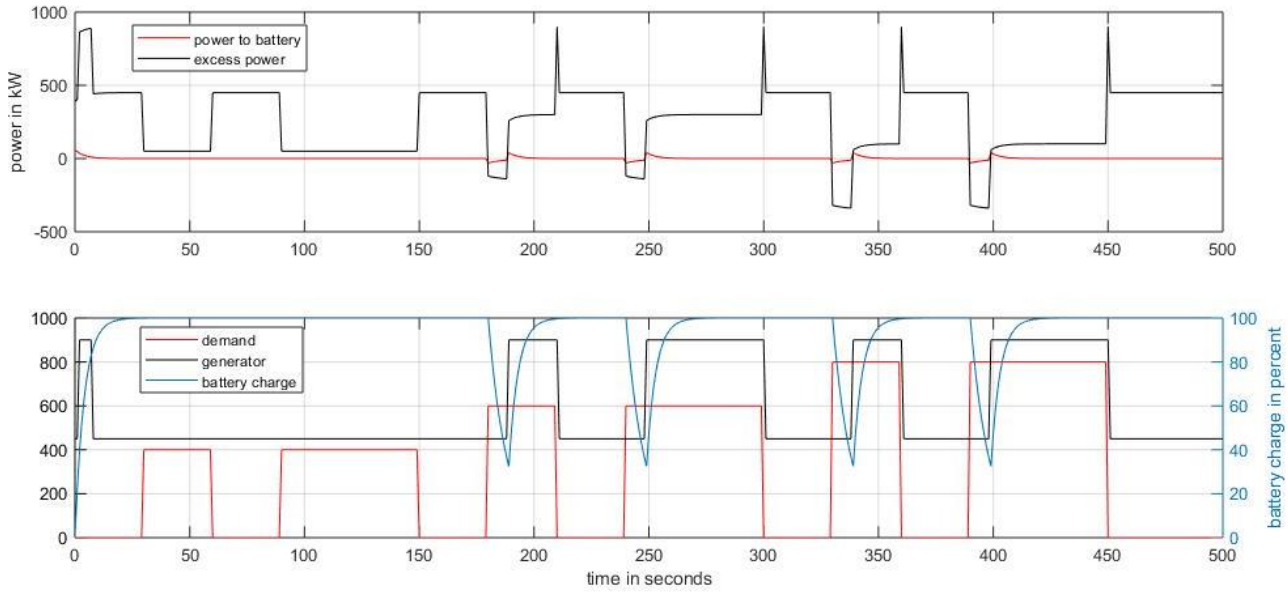


Figure 4: improved power management algorithm

Here, a better algorithm has been introduced, which takes demand into account. The second generator now stays on as long as the demand is higher than 90% of the primary generator rated max. when a peak comes, the battery drains first, before the second generator starts, recharging the battery and covering the demand. There is a spike in available power when the generator turns off, as the demand drops to zero with the second generator active.

3 MATERIALS AND METHOD

3.1 Data

3.1.1 Gunnerus

Figure 5: Gunnerus side view. Photo: Fredrik Skoglund (NTNU.edu n.d.)

The R/V Gunnerus is a research vessel belonging to NTNU. It has been in service since 2006, it has a dieselelectric propulsion system, it is used for both research and educational purposes, and I have used research data from this vessel as the main test for my model.

According to the specifications the vessel has 3x450 kW nogva-scania generator sets. (ntnu.edu 2006) The official website of nogva places these at approximately 1600 kg each. (nogva.no n.d.)

To demonstrate out model, I aim to explore the possibility of replacing one of these generator sets with a battery.

According to a 2010 research article by the Zero Emissions Resource Organisation (zero.no 2010), several types of batteries are useable in ferries. One of the more commonly known types is the lithium-ion battery, which I will be basing my numbers on. Modern lithium ion batteries have the added advantage of being able to accommodate rapid charging.

According to the same article, a lithium ion battery has a maximum energy density of about 120-150 Wh/kg. with approx. 1600 kg of weight available, this puts us at a theoretical max capacity between 192 and 240 kWh, assuming the battery will physically fit.

Implementing a battery model can be made very complicated. The subject of hybridisation could fill a thesis on its own (Selen 2018).

We have opted to keep our model simple, to more easily retain the modularity, iterability and flexibility of the model.

3.1.2 About the data from Gunnerus

We have acquired data from the ship itself, in the form of logged data from a research trip. I received these data from chief engineer Finn Tore Holmeset of the department of Ocean Operations and Civil Engineering, NTNU Ålesund.

In particular, I will be needing the GPS data for context, and information about the power consumed during the trip for use with my model. The goal is to use this set of realistic data to test and demonstrate my system.

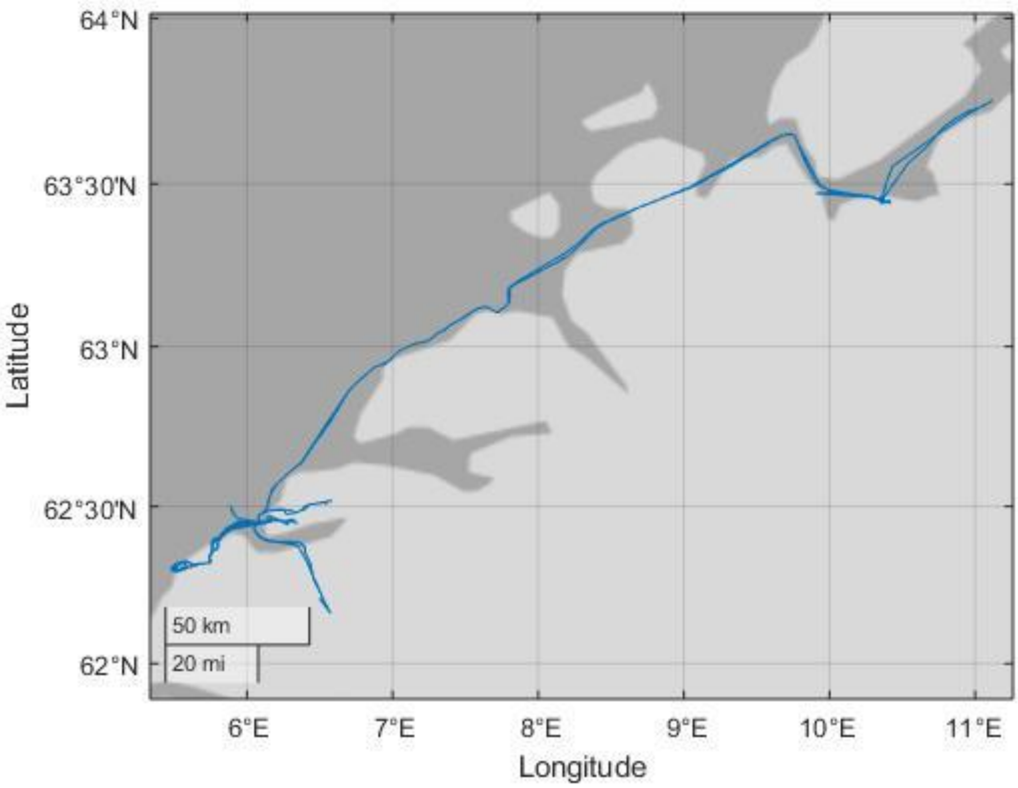


Figure 6: GPS data corresponding to raw demand

Figure 6 shows the GPS data from the ship, during the trip these data are from. As you may notice from the coordinates, the map shows the area around Trondheim.

The data was in a format where the first two digits are in degrees, the next two are minutes, and the remaining digits are decimal minutes. Plotting these values required extracting the columns that held the latitude and longitude from a larger file and writing a script that converted this format (DM.m) to a format the matlab plot command accepted, namely degrees comma decimal degrees (D.d).

The script divides the coordinates by 100 and rounds them down to get the first two digits, the degrees. The script then multiplies this by 100 so the result can be subtracted from the original coordinates. This removes the first two digits, leaving us with the minutes and decimal minutes. In other words, converting DM.m to D.d uses the following formula:

$$D.d = D + .d = D + \frac{M.m}{60}$$

This leaves the demand. The logged data does not contain a finished estimate of the total power use. Therefore, I have chosen to use the voltage and current of the drive log. Adding port side and starboard together and assuming that

$$|S| = U * I$$

Unfortunately, this does not include hotel etc. The easiest and fastest solution for this is to add a constant value to the calculated demand, assuming this power consumption varies very little compared to the propulsion. According to the source for the logged data, 40 kW is a realistic guess, and this should be precise enough for our purposes. It is assumed that the user has their own test signal or estimate of demand, so the signal I am using for demand is a test value for demonstration.

The drive logs also contained time in milliseconds. I used this to make a timeseries, which served as the test signal in the final phase of the project.

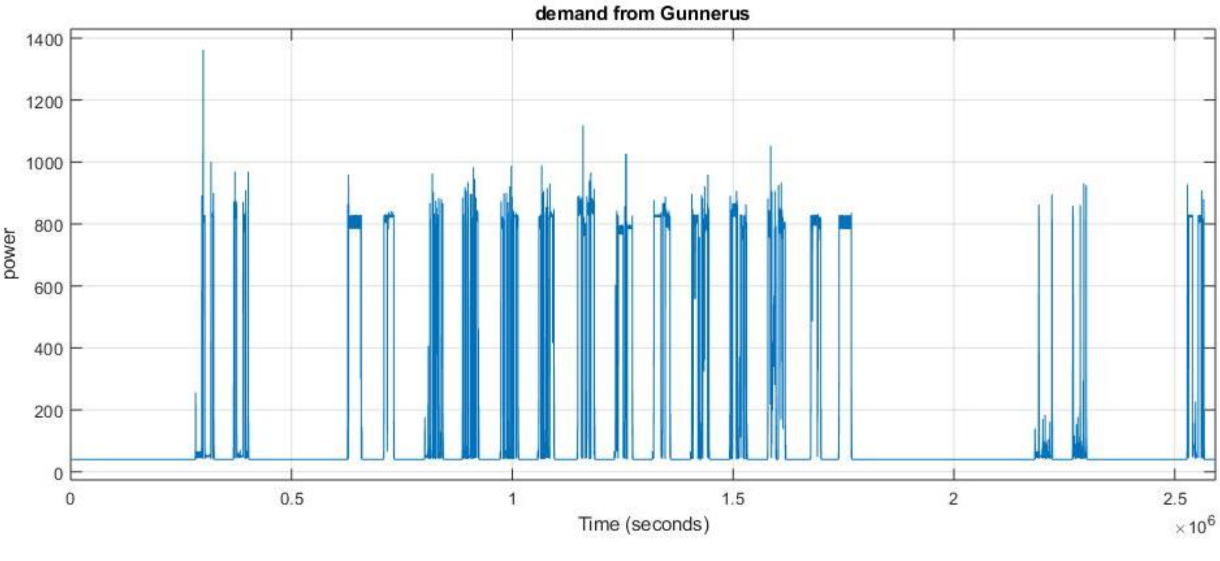


Figure 7: demand from ship, constant of 40kW added to account for hotel

Figure 7 shows the resulting demand. There are 19 shorter "trips", so if we expect to get anything meaningful out of this, the next step is to isolate one of these active periods and examine it more closely. In this illustration I have added a constant 40 kW to the signal to simulate hotel etc. in the remaining illustrations I have not modified the signal.

3.1.3 A closer look at the data

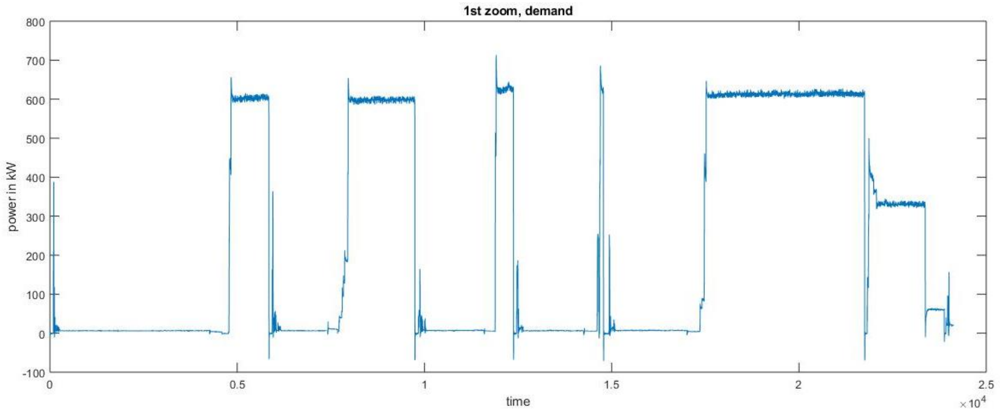


Figure 8: a closer look at the 6th active period of the full demand signal

In the graph above we take a closer look at the signal between t=9.0e5 and t=9.24e5 on the demand graph. This reveals that the signal appears surprisingly binary in nature. It is entirely possible that, rather than a log of the propulsion power use, we are looking at something like a control signal. Unfortunately, examining the logs further reveals no better method of approximation, so we will go forward with these data.

Future users of this model are assumed to use a more accurate analysis of their demand.

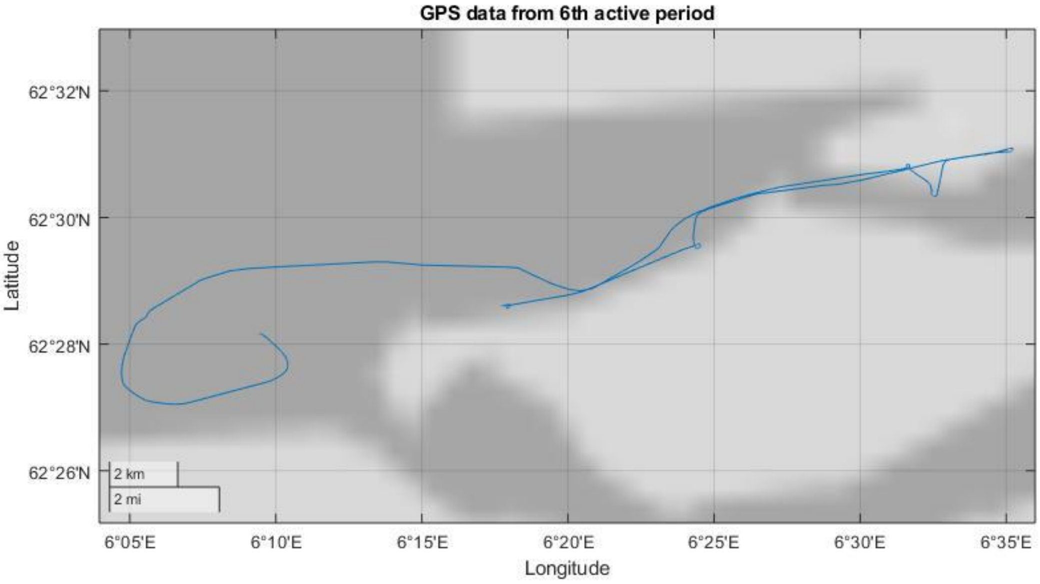


Figure 9: vessel position during 6th active period

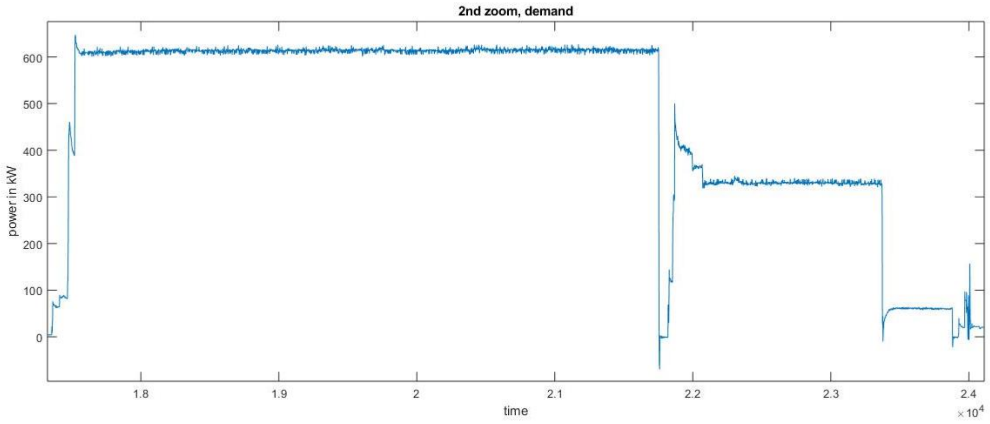


Figure 10: an even closer look at the demand

Figure 10 is a the final third of the 6th active period (see figure 8). As we can see, the signal looks suspiciously digital.

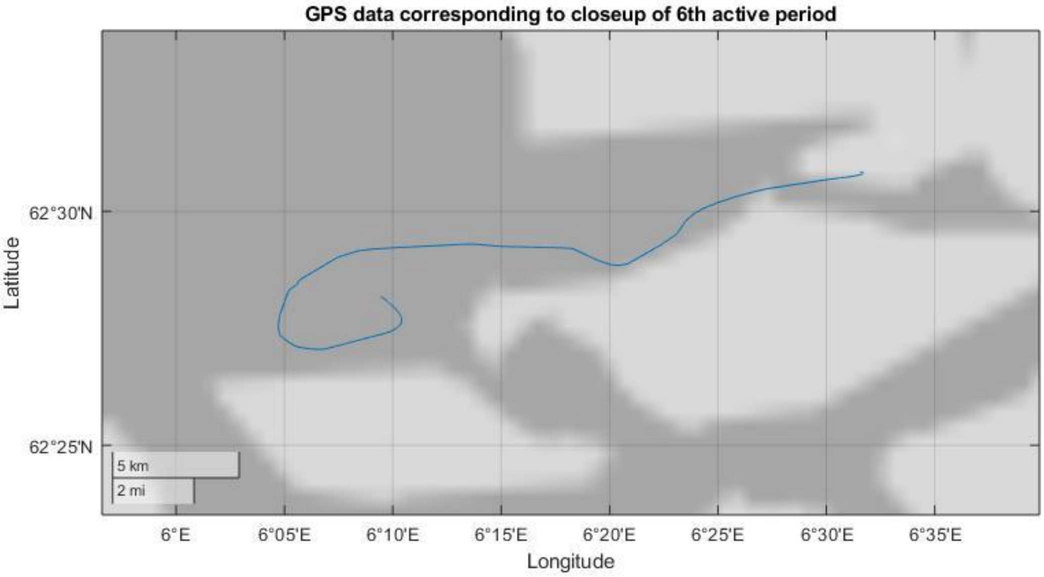


Figure 11: vessel position during final third of 6th active period

Additional information, such as a GPS plot, could help us contextualize the results we get.

3.2 *Method*

3.2.1 Information flow

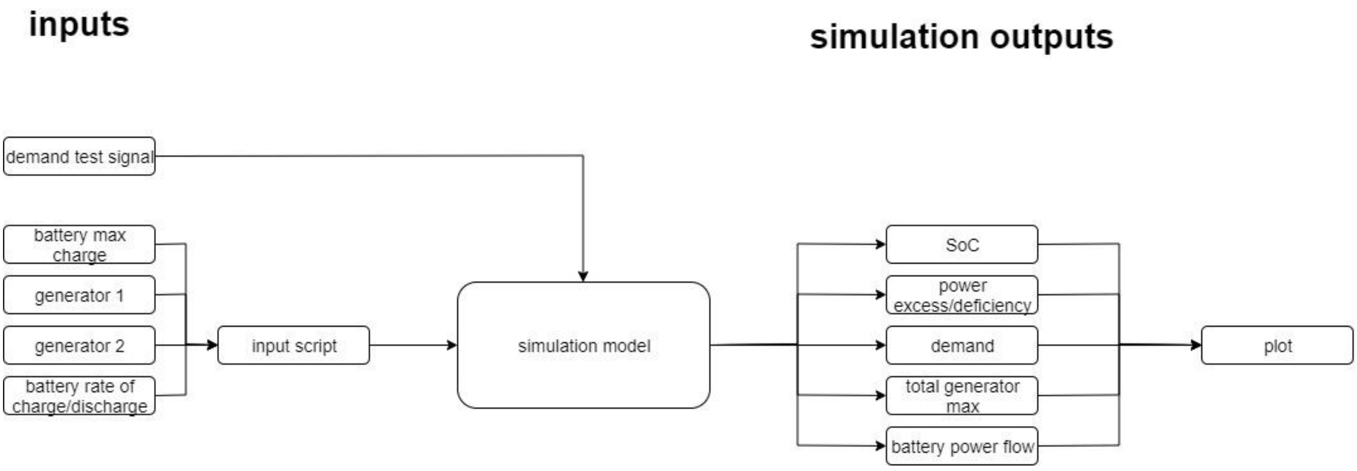


Figure 12: system information flow

3.2.2 Main model, v1

The main model has inputs corresponding to battery max charge, rate of charge and discharge, as well as generator max load. These values can of course be input manually but included in the files is a script for inputting the variables. Currently it inputs the testing values, a good future improvement might be a user interface, with input fields for the information we want the user to be able to change.

Initially, I used a simple sine wave as the demand test signal. It served the purpose of testing the basic functionality of the system in its early stages, but since it only has smooth, regular, long peaks, and none of the sudden, short peaks we want the battery to shave, it was replaced by three separate test signals as v1 neared completion. One test signal ramps up from zero, stays high for a while, then ramps back to zero, the second is a series of short peaks, and the third is a series of longer peaks.

The subsystem labelled “batteryPlusLogistics” uses these to give us the state of charge as a ratio, a signal labelled excessPower that should be equal to spareCapacityGenerator if everything is working right, as well as the net flow into the battery.

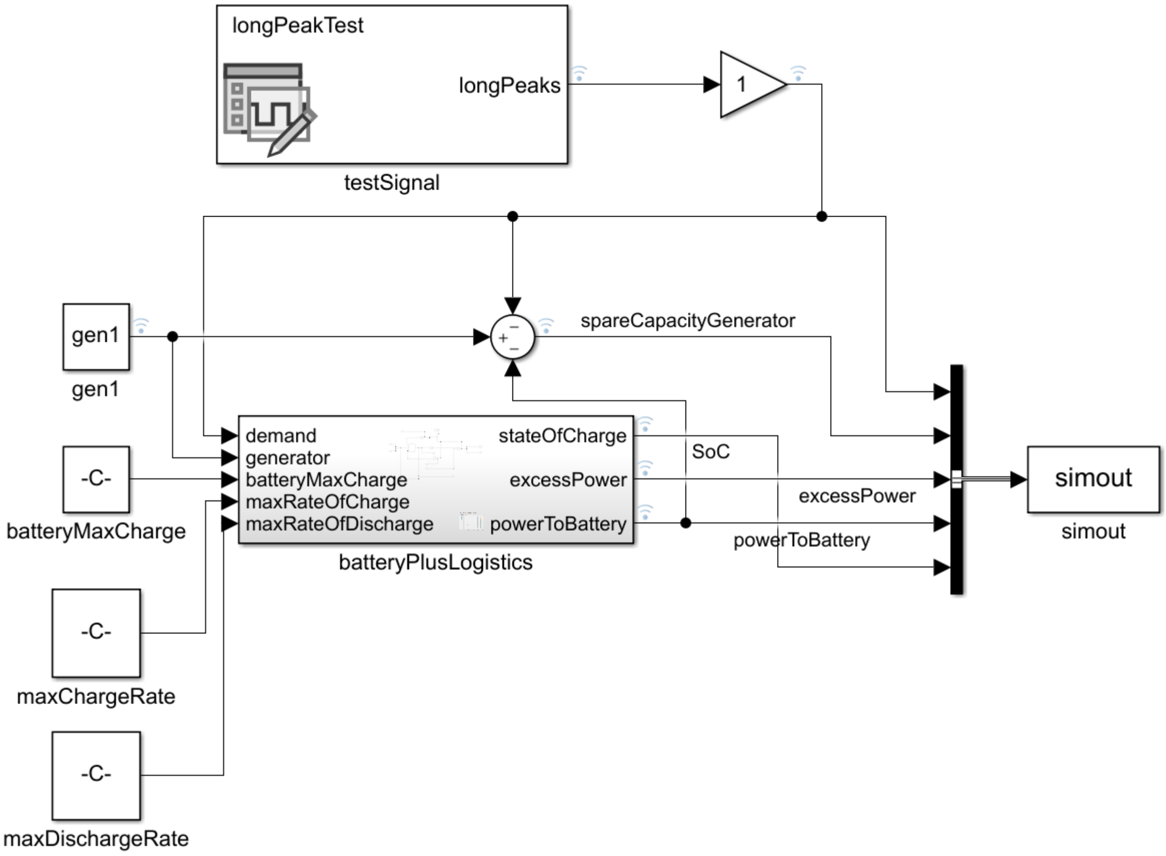


Figure 13: main system (mathworks 2019)

3.2.3 Battery (subsystem)

We originally called this system the battery because that was its original purpose, but in its current form this subsystem handles a lot of signal logistics as well.

The battery takes the inputs “demand” and “generator” and uses these to calculate the remaining available capacity after consumers are accounted for. This signal is then constrained, limited by the state of charge and the rate of charge and discharge. In its current form this is a very basic formula but making this correspond to an actual battery characteristic requires no major changes apart from the formula itself.

The constrained signal represents the power that the battery receives, here denoted as “powerToBattery”.

These values are used to calculate “excess power” – a variable that only deviates from (approximately) zero when we have capacity to spare (positive deviation) or too little generator capacity (negative deviation). When this is positive and the battery is not full, the battery can charge, and when it is negative, the battery will be drained to compensate, if possible.

Excess power is calculated using the following formula

$$P_e = P_N - P_U$$

Where P_N is the rated max capacity and P_U is used power.

The constrained signal is then integrated to get the stored charge. This takes a kW input and gives us stored charge in kWh. The stored energy is then divided by the battery max charge, to get "state of charge" which gives us the level of charge expressed as a ratio. This value is used to moderate the speed of charge and discharge relative to battery level.

The main purpose of a battery is to store power. To simulate this, we need something that gives us an input that corresponds to system power excess (or deficit) in kW, and an output of stored power in kWh. The way we solve this is by integrating "excessPower" with respect to time. This gives us a signal that increases when the system has generator capacity to spare, decreases when there is a power deficiency, and stays constant when the supply and demand are in equilibrium- perfect for this purpose.

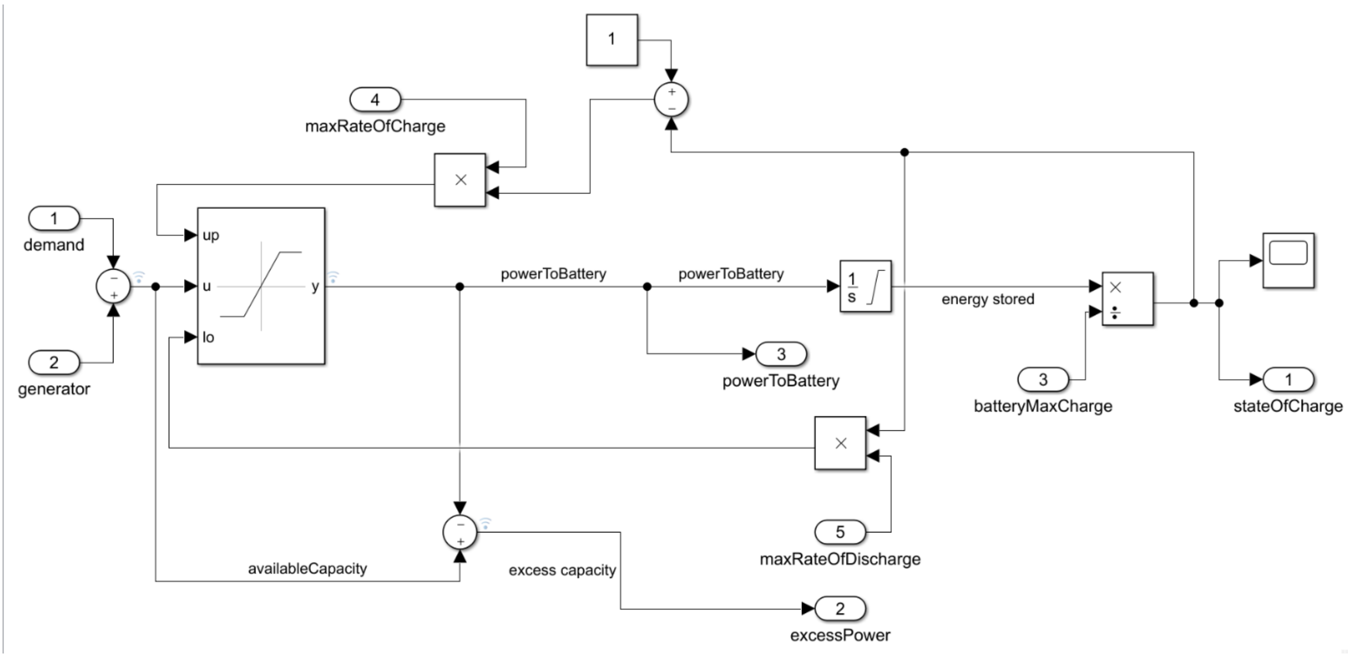


Figure 14: battery and logistics subsystem (mathworks 2019)

3.2.4 Main model, v2

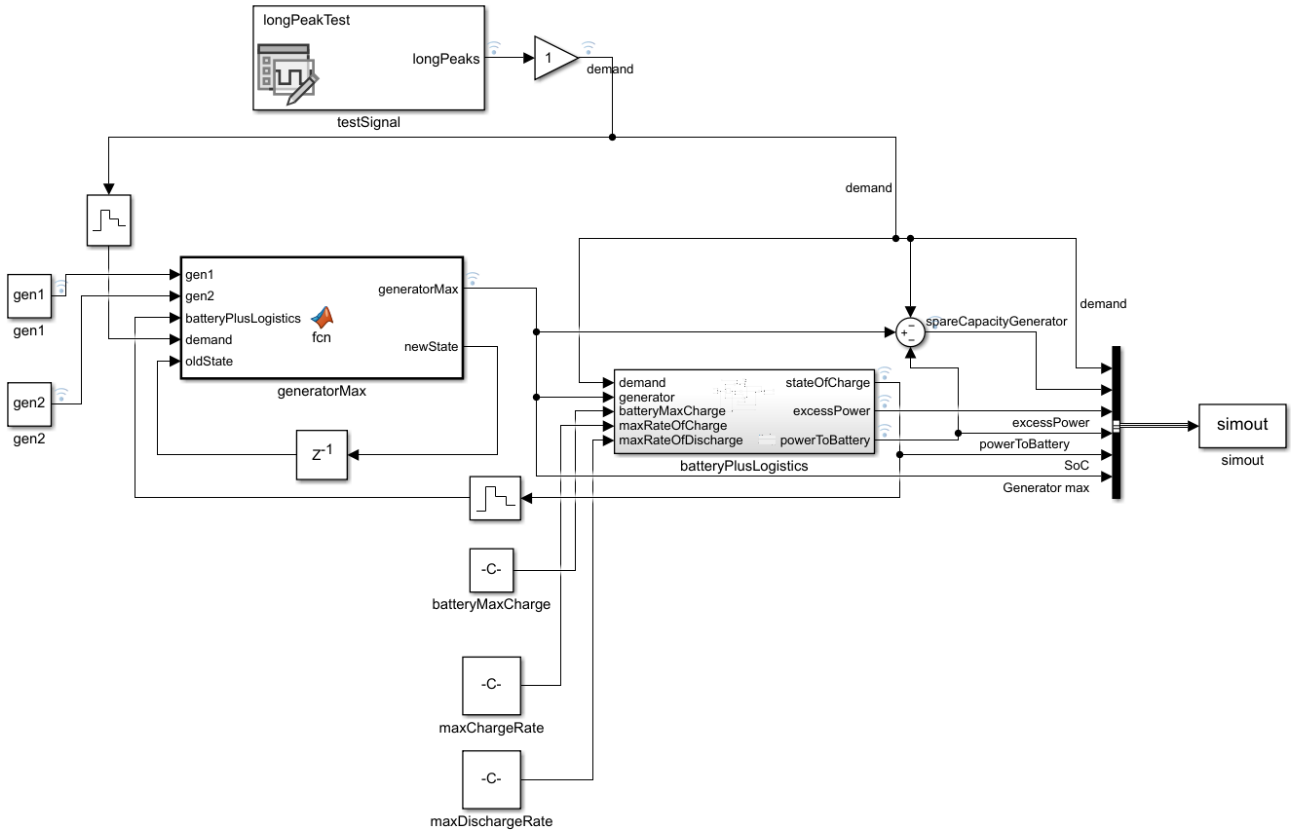


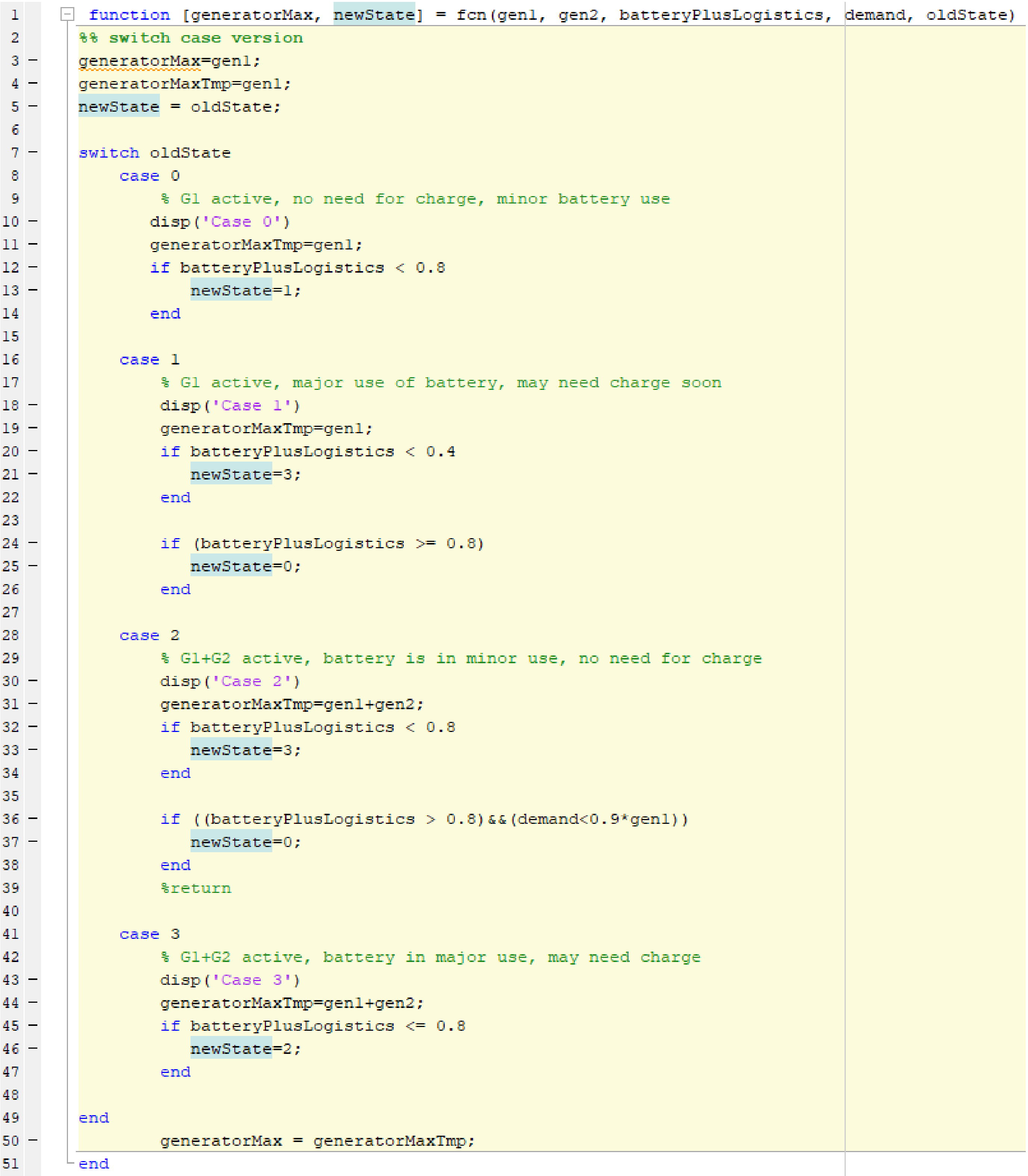
Figure 15: v2 has an additional generator, and an improved algorithm (mathworks 2019)

This version of the model sees an increase in complexity when it comes to the generators. Where v1 had a single max value, this version has two generators in total, and an algorithm that determines when we enable the secondary generator. It outputs the resulting total generator rated max power, a signal that varies depending on how many generators are active.

The highlighted box is the algorithm. As we can see, the inputs are:

1. generator 1 rated max power
2. generator 2 rated max power
3. state of charge, feedback from battery + logistics
4. our test signal for demand

this model uses the output of the generatorMax function where v1 used gen1 directly.



```
function [generatorMax, newState] = fcn(gen1, gen2, batteryPlusLogistics, demand, oldState)
%% switch case version
generatorMax=gen1;
generatorMaxTmp=gen1;
newState = oldState;

switch oldState
    case 0
        % G1 active, no need for charge, minor battery use
       disp('Case 0')
       generatorMaxTmp=gen1;
       if batteryPlusLogistics < 0.8
           newState=1;
       end

    case 1
        % G1 active, major use of battery, may need charge soon
        disp('Case 1')
        generatorMaxTmp=gen1;
        if batteryPlusLogistics < 0.4
           newState=3;
        end

        if (batteryPlusLogistics >= 0.8)
           newState=0;
        end

    case 2
        % G1+G2 active, battery is in minor use, no need for charge
        disp('Case 2')
        generatorMaxTmp=gen1+gen2;
        if batteryPlusLogistics < 0.8
           newState=3;
        end

        if ((batteryPlusLogistics > 0.8)&&(demand<0.9*gen1))
           newState=0;
        end
        %return

    case 3
        % G1+G2 active, battery in major use, may need charge
        disp('Case 3')
        generatorMaxTmp=gen1+gen2;
        if batteryPlusLogistics <= 0.8
           newState=2;
        end

end
        generatorMax = generatorMaxTmp;
end
```

Figure 16: the code for the power management algorithm. (mathworks 2019)

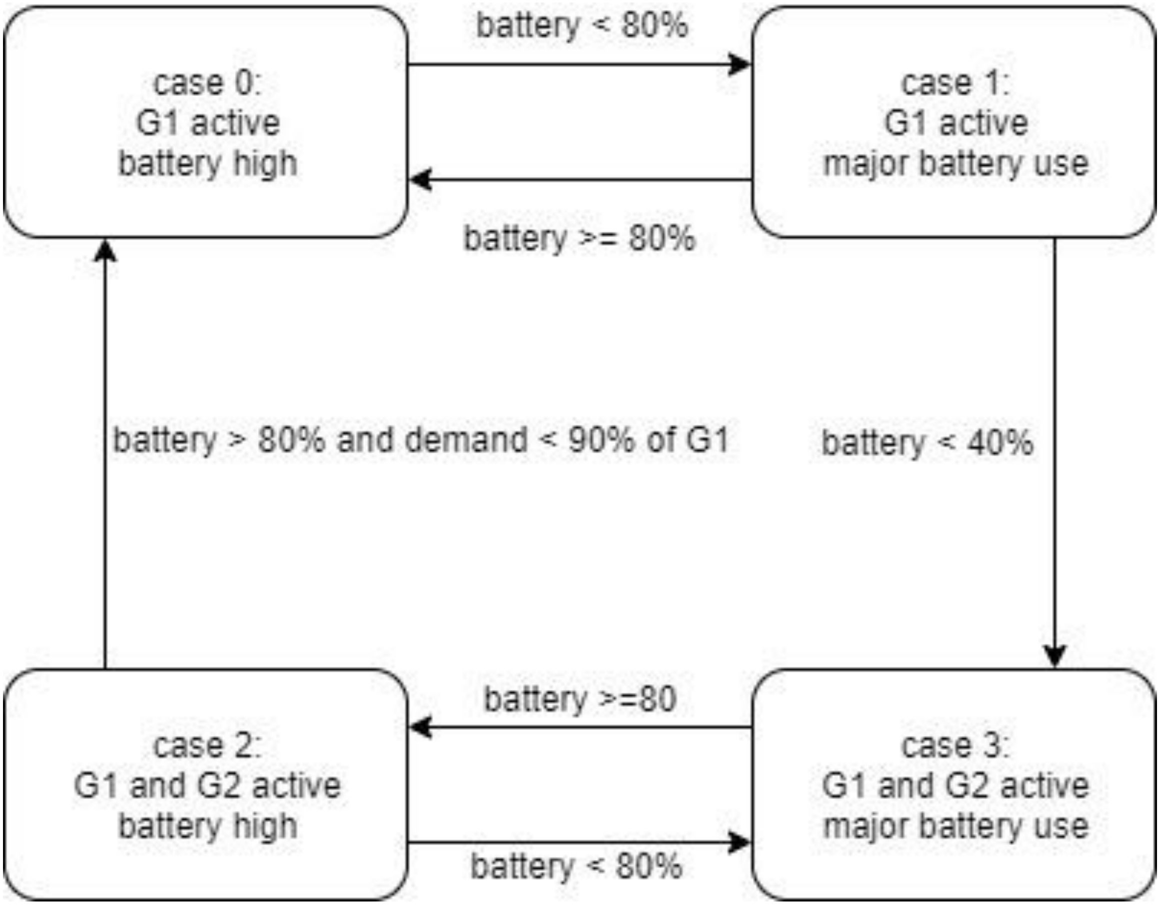


Figure 17: case diagram, power management algorithm

When demand is lower than one generator can handle on its own, we mostly stay in case 0. As soon as demand rises above that, the battery begins to discharge (case 1), making up for the difference. If the battery is allowed to recharge, we return to case 0. When the battery is in danger of running low, we enter case 3, where both generators are active and battery is low, but as long as the demand is less than the total max output of both generators, the battery will charge. Once the battery nears full, we enter case 2, where the battery is near full and both generators are active. If the battery drains to below 80% we return to case 3, and the battery should be charged before we can disable the second generator. from case 2 we disable the second generator, returning to case 0, if the battery is full and demand is low enough for generator 1 to fill.

This serves our purposes well, but a more specialized engineer would no doubt find a better, more elegant solution.

4 RESULTS

4.1.1 About the test signals

For the ramp and peak tests, values have been chosen with demonstration in mind, meaning some degree of realism has been sacrificed to assure that the plots can be read easily. This means that the values used, particularly battery capacity and generator max load, may not be completely realistic.

Likewise, the test signals have been chosen to display system response, and do not represent a real situation.

4.1.2 Ramp test for v1

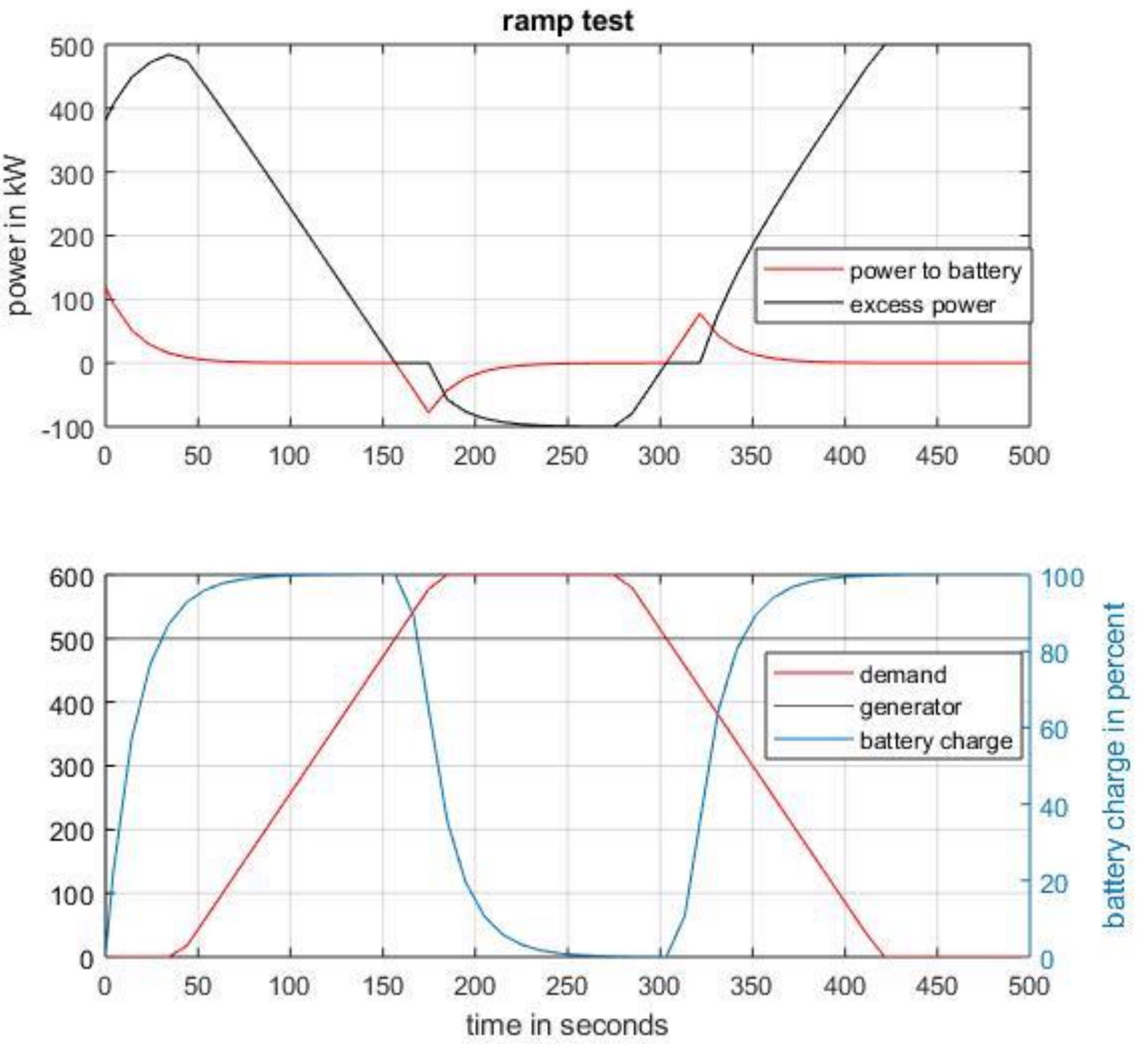


Figure 18: system test, ramp input

The initial demand test input was a sine wave. This is somewhat more realistic than a ramp input, but it also offers less clarity. The above graph shows the system response to a demand that ramps up to 600 kW, stays constant for some time, then ramps down to zero. These test values were made by choosing a realistic value for the generator max capacity, choosing a max value of 120% of the generator for the demand test signal, and choosing a battery capacity that displays the system dynamics. Naturally, these values are for testing purposes only.

Initially, the battery is receiving charge, and excess capacity is high. Because the demand is low, the generator has energy to spare even while charging the battery at its max rate of charge. As demand rises, spare capacity quickly stops rising. The battery fills to max state of charge while demand is still below generator max.

At t=160 seconds the demand surpasses generator max and for approximately 20 seconds, the battery delivers the extra power. The battery then delivers less and less power as it runs out, and at roughly t=230 seconds it is completely empty. Between t=130 s and t= 300 the generator has to run above max to supply power. Realistically speaking, load shedding or similar measures would begin before we reach this point.

At t=260 seconds the demand starts ramping down. At t=300 seconds the demand sinks below generator max and the spare capacity plateaus briefly as the battery starts charging. At t=320 seconds the spare capacity resumes rising as the battery stops accepting charge.

At t= 400 seconds the battery is full, and demand reaches zero soon after, at t=420s. With nothing left to drain power, excess power reaches generator max = 500 kW, and will stay at this value until demand rises again.

4.1.3 Test signal: short peaks, v1

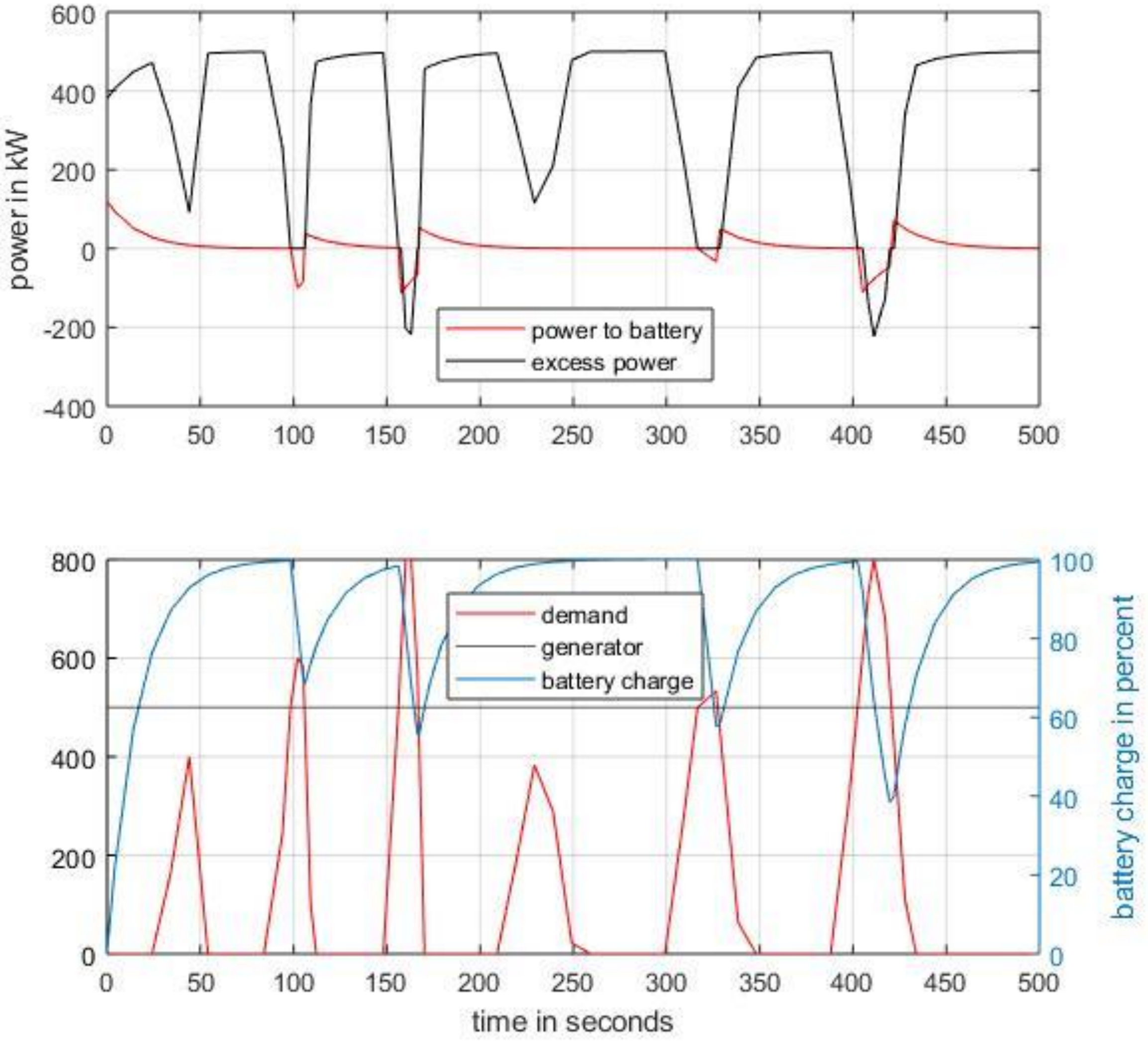


Figure 19: system test, short peak input

This test signal is created to highlight the system's behaviour in response to peaks of varying heights.

As we can see from the plot, the battery covers the second peak just fine, and recovers almost completely in the time between peak 2 and 3, but at peak 3 the available power, here labelled "excess power", goes into the negative. In this case the battery has the power to cover the peak, but cannot supply it fast enough.

The same is true for peaks 5 and 6. Peak 5 is covered quite easily, but peak 6 needs more power per second than the battery can provide. In our current model the rate of charge and discharge can be changed, but due to time constraints this feature has not been fleshed out.

4.1.4 Test signal: longer peaks, v1

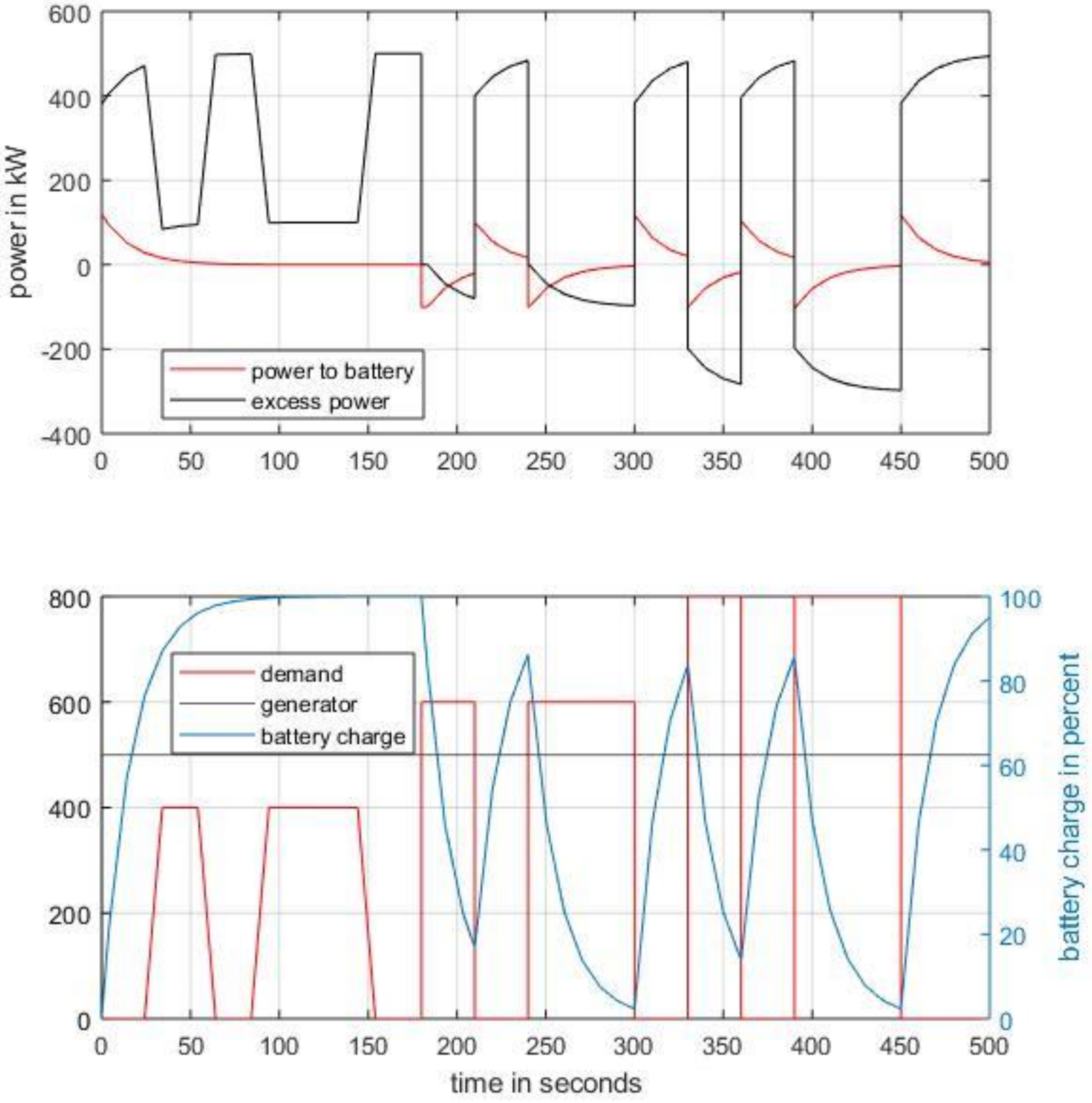


Figure 20: system test, long peak input

This test signal features two signals each of three different intensities, the second peak of each intensity is longer than the first. This plot shows how the system responds to being repeatedly drained. As we can see, the first two peaks are well below the generator max and create dips in available power. The generator covers these with ease. The next two peaks drain the battery quite a bit. Here, we see the battery drain slower as it starts to run low, and excess power dips below zero. The battery does not have time to recharge completely before peak number 4, and is almost empty at t=300 s. this process repeats itself for peak 5 and 6. The battery drains fast, but not fast enough to cover the demand, it does not have time to refill between peaks, and it lacks the capacity to completely compensate for the drain.

4.1.5 Ramp test, system v2

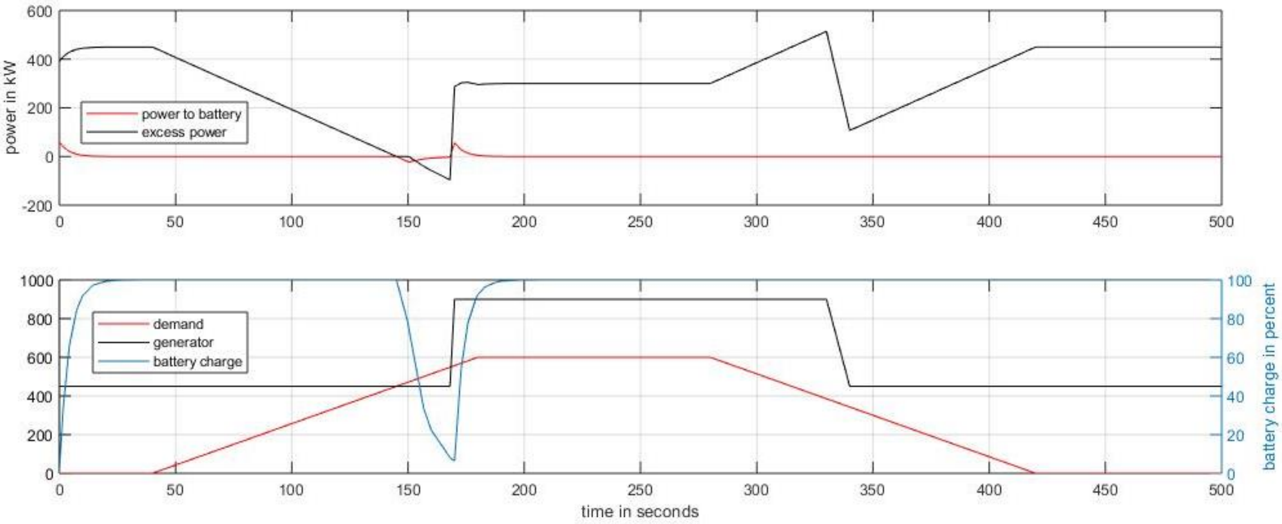


Figure 21: ramp test on improved algorithm

in figure 21, we've tested the improved algorithm with our ramp test. As we can see, the battery starts draining when the demand rises above the primary generator's max capacity, until the second generator kicks in and recharges it. When the demand ramps back down the excess power rises again, until demand drops below 90% of primary generator max, and the secondary generator is shut down.

4.1.6 Long peaks, v2

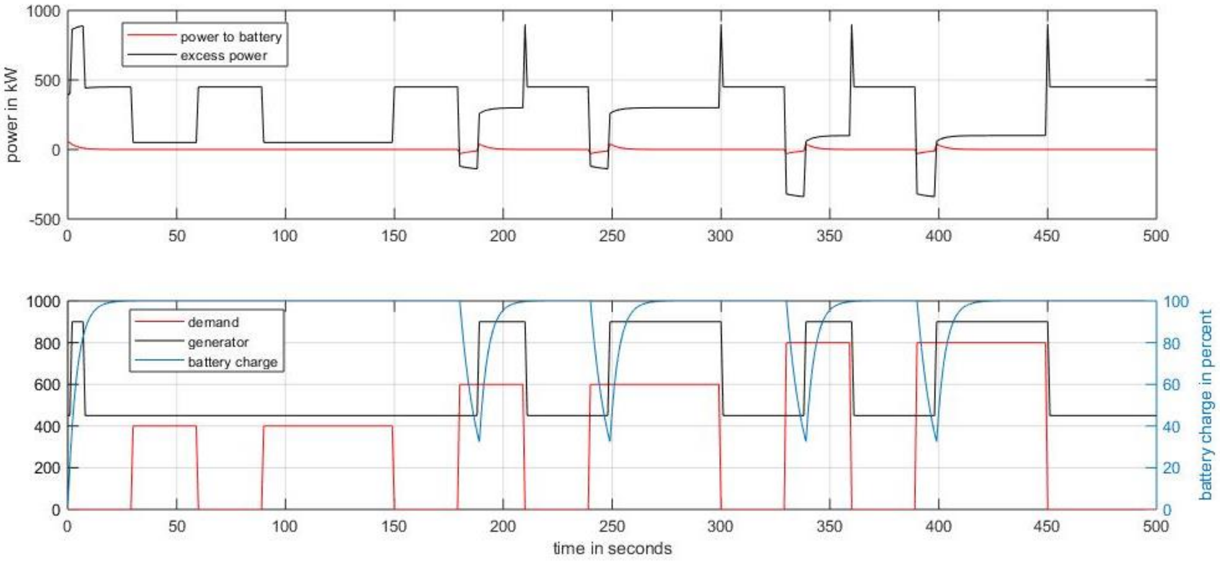


Figure 22: long peaks test, v2

In this version of the system, we see the second generator start as the SoC drops below 40%, and turn off shortly after the demand drops to zero. Because of the small delay between the delay drop and shutting down the generator, we see a spike in excess power when the delay drops. Due to the limitation on battery discharge rate, there is still a power deficiency before the second generator starts.

4.1.7 Short peaks, v2

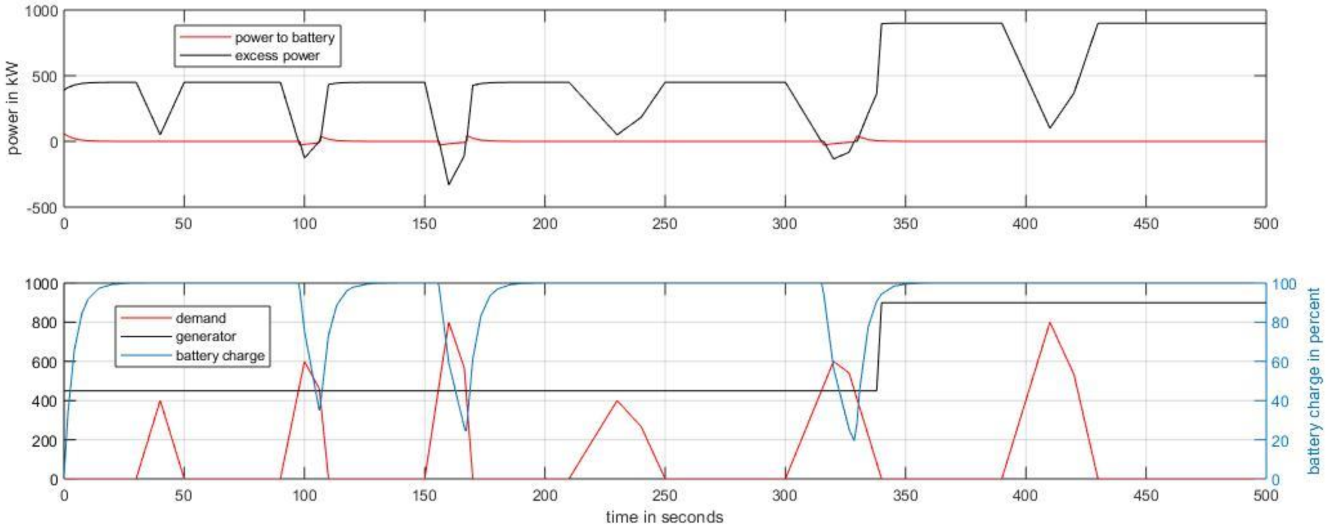


Figure 23: short peak test, v2

In figure 23, there appears to be a problem with the power management system. After the 5th spike the second generator is not disabled, even when the battery is full and the demand is well below the threshold.

4.1.9 System response with logged data

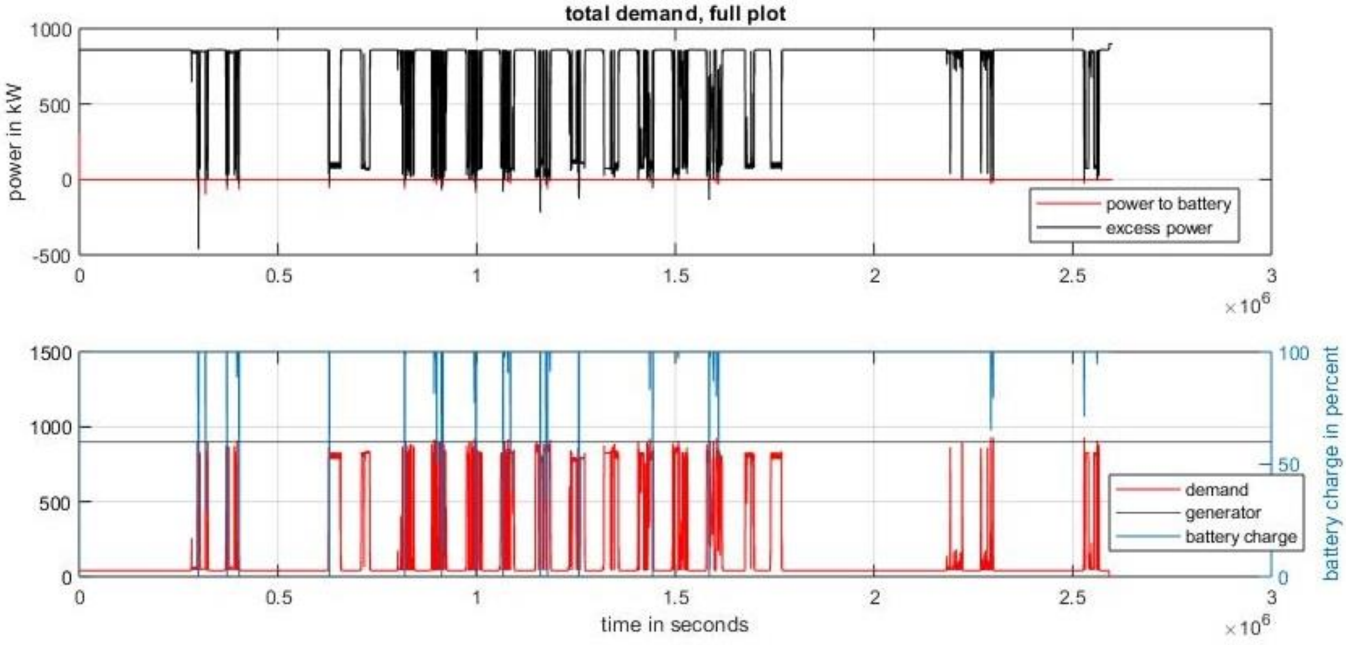


Figure 24: system response for the full demand signal

The pauses between the active periods are roughly seven hours long, so it’s likely that these are day/night cycles where the system only uses power during the day.

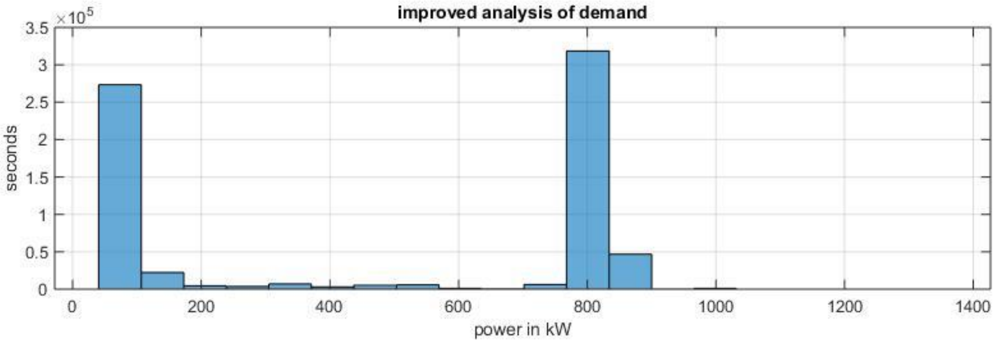


Figure 25: distribution of demand from full signal. Values close to zero intentionally left out.

As we can see from figure 25, a lot of time is spent below 200 kW, less than half the rated max of one of the generator sets. This certainly uses more fuel, but according to the fuel consumption data from nogva, this isn’t actually that much more inefficient. (nogva.no n.d.)

The most common rate of power consumption is 700-900 kW, which is just below the rated max of the generators.

Values above 900 make up a very small portion of the full signal, however, it is still significant enough to be cause for concern. Assuming that my suggestion is to replace one generator set with a battery, this offers a max capacity of approximately 240 kWh and reducing total rated generator max to 450*2=900 kW. This amounts to about half the capacity of a full generator set for one hour. This sounds quite substantial but as we can see, the battery drained completely several times, which indicates that it ran dry while the system was still in an energy deficit. In some modes of operation this may be enough, in the final three active periods the battery never drains completely, but some modes will require additional battery capacity.

The usefulness of adding a battery to a dieselelectric system depends largely on vessel and operation mode. But an analysis of power production and consumption should reveal the viability of such a conversion regardless. In this case, the spikes that exceed capacity are uncommon enough that it seems wasteful to start a third generator to deal with them.

Note that in this version of the model, the max load is not divided into two generators, so the battery charges nearly constantly, and discharges very little. It also lacks the ability to use the battery and one generator instead of turning on the second generator.

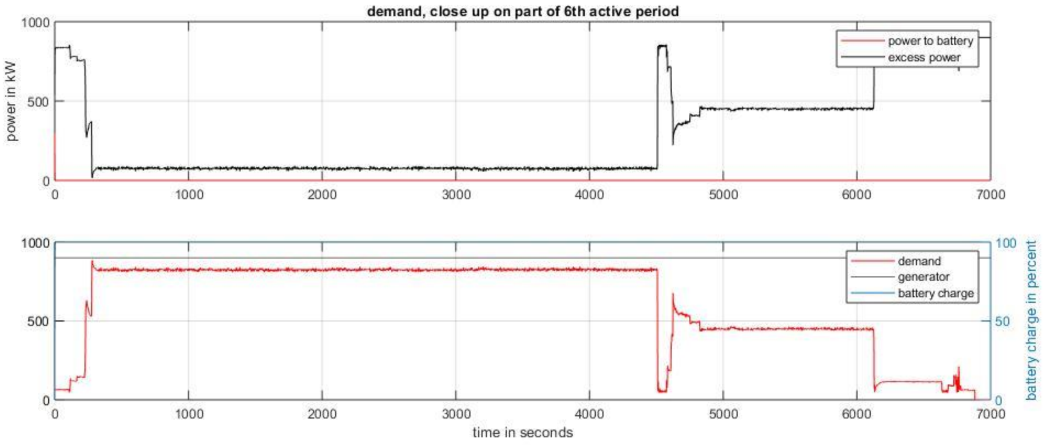


Figure 26: system response to final third of 6th active period

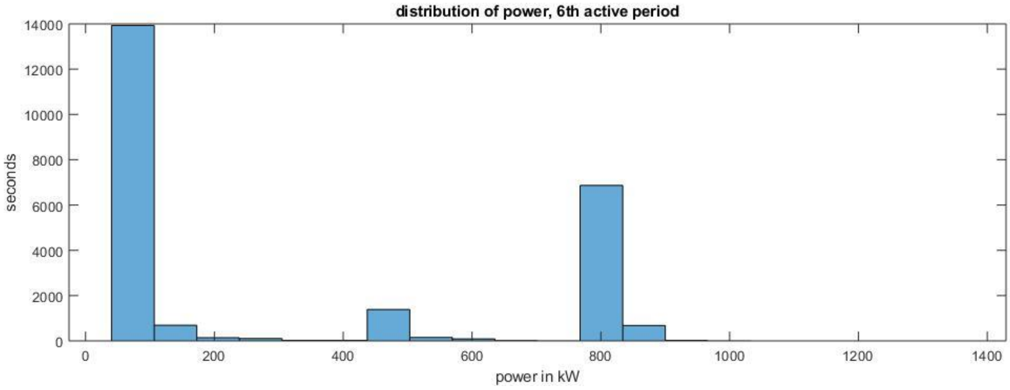


Figure 27: demand distribution for the signal in figure 26

In figure 26 we see a close up of the demand signal, and like most of the signal, this stays in range of what the generators can supply. Roughly two thirds of this time is spent using less than 200 kW, this is after values close to zero have been removed. If boosting efficiency is a major concern, this might be worth addressing.

assuming these data are representative of the typical power consumption, the idea of trading a generator for a battery is plausible, but some modes of operation would require far more battery capacity. The fact that Gunnerus' generators do not use that much more fuel when run at 50% capacity or lower means that while cutting down on fuel consumption is an ecological improvement, and it may not be particularly economically beneficial.

4.1.10 System v2 response with logged data

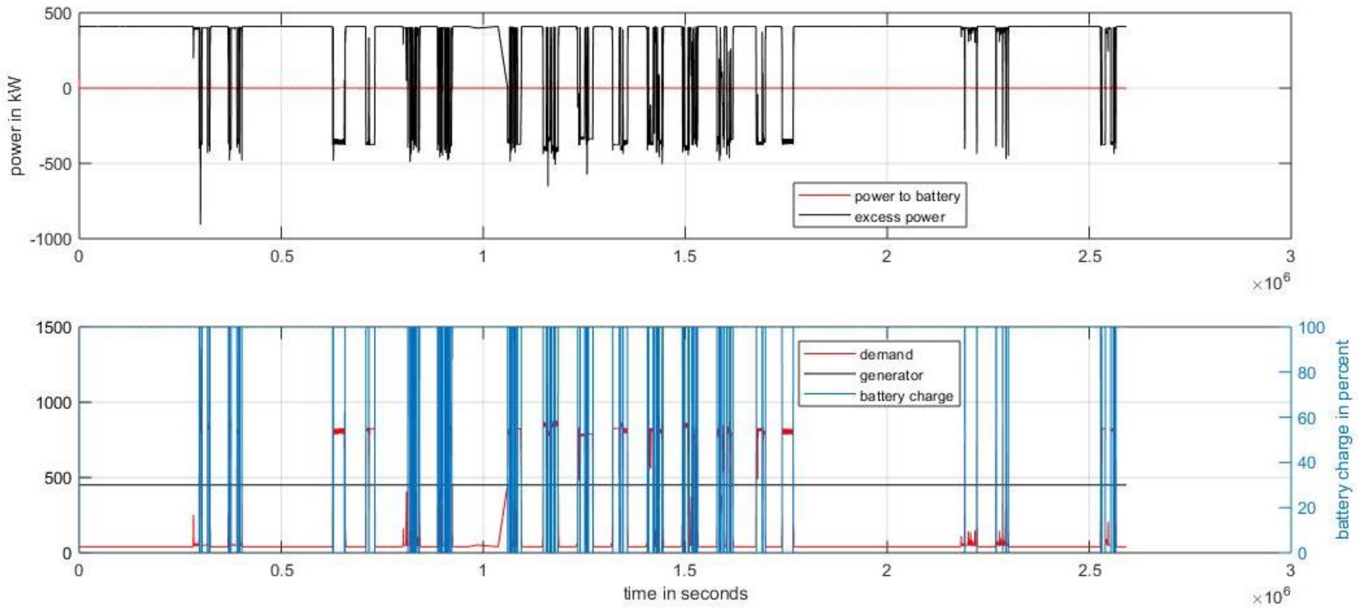


Figure 28: system v2 response with full demand signal

Unfortunately, this doesn't tell us much. There is far too much going on in this plot to get a good interpretation, and smaller variations do not show. If we want a good look on how the system behaves, we need to take a closer look.

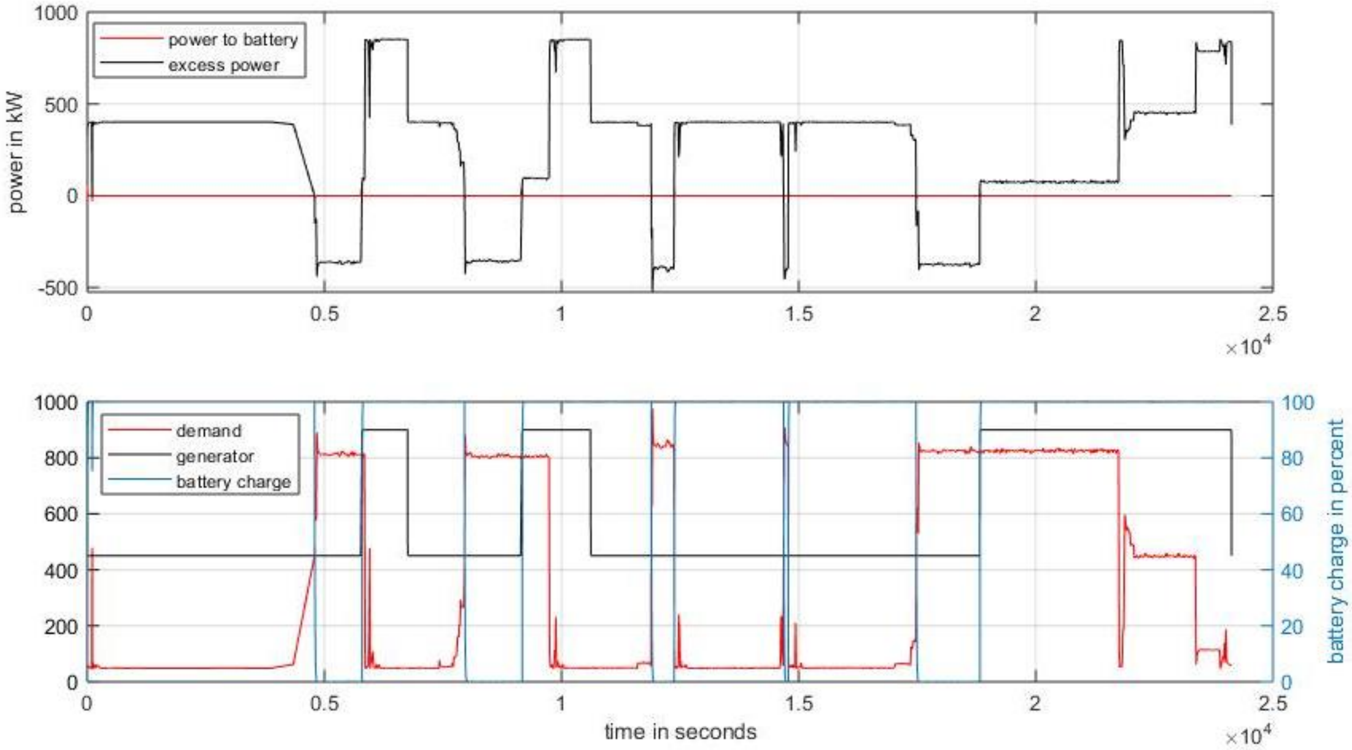


Figure 29: closer look at 6th active period. System v2.

In the sixth active period we have several plateaus that exceed the power one generator can produce. In the first we see the second generator start just as the demand drops. In the second plateau, the second generator starts when the battery empties, but notice that the second generator tends to stay on a while after demand has dropped. The third and fourth are completely covered by the battery. Notice that in the final plateau, the generator does not shut down after the demand drops to about 450 kW, likely because it's above the 90% limit. It is entirely possible that the battery and primary generator could have handled this, but if generator 2 shut down here, we would risk having to immediately turn it back on again. The second generator shuts down after the demand drops further.

In some modes of operation, Gunnerus could benefit from this change, but in other modes it would not produce enough power. For this to be beneficial, it might be necessary to cut power use in the most demanding modes.

5 DISCUSSION

5.1.1 Summary

In the opening chapter of this report I established my goal of using Simulink to create a model that can simulate the power supply and battery capacity of a ship and give us a rough estimate of how well these will cover the power consumption.

We have created a model capable of taking user inputs for generator and battery capacity as well as a signal or timeseries representing demand, simulating the system and outputting the results as a graph that offers the user a rough estimate of the expected performance with the given parameters. The system has been tested both with combined and separate generators.

5.1.2 General

The system simulates the generators and battery of a ship, and tests them with a test signal representing the expected load. I assumed that the estimate in question mainly needs to focus on the generators and battery, ignoring external power sources. I also assumed that the battery is mainly to be used for peak shaving, aiming to cut down on unnecessary starting and stopping of generators. The system gives the user a rough estimate of the available power at any given time, as well as total power deficit. The information is presented in the form of a graph, letting the user examine their system in terms of max generator power output, demand or test signal, battery SoC, and power excess/deficit. The user can input battery capacity, and rated max for each of the generators by editing a script, adding some rudimentary user interface would be a substantial improvement, though not a priority for this paper. Another thing that would boost the model's usefulness is adding the ability to input several different values at once for each variable. The model would then return one plot for each set of values, as well as a summation of the overall power excess and deficit of each, for comparison.

In its current form the battery is fairly basic. The max charge and discharge rate are only a rough estimate, the formula for charging and discharging speed relative to SoC is very basic, and the battery in this model does not discharge over time. While I have not prioritized this, the model is easy to change and add to, so adding improvements like nonlinear curves for the relationship between SoC and rate of charge/discharge, or adding self-discharge to the simulation is entirely achievable.

We have added the ability to use a second generator, and a simple power management system that takes both battery SoC and demand into account. Given more time we could correct some flaws and tweak the performance, but improving this algorithm much further lies outside the scope of this paper. It might be an interesting project for a student of automation.

Some of the tools used to display the data could be significantly improved. I consider this less important than improving the model, but in particular the map displaying the GPS data is difficult to interpret due to its low level of detail.

6 CONCLUSION

Initially the aim of this project was to use Simulink to create a basic simulator that can be altered to simulate different configurations of generator sets and batteries. I started with a system that simulated one generator and a battery, and expanded this to include a second generator.

Since Simulink makes it easy to keep the program modular and iterable, adding one extra generator proves we can add more if needed.

We have created a model capable of taking user inputs for generator and battery capacity as well as a signal or timeseries representing demand, simulating the system and outputting the results as a graph that offers the user a rough estimate of the expected performance with the given parameters. I have tested this system both with combined and separate generators. In the process, this project has challenged my understanding of Simulink and Matlab, and taught me a lot about both.

The system works well, it offers a decent estimate using a fairly basic representation of a battery, and representing the generators as max values regulated by a simple power management system. The system has a high degree of modularity, making it easy to change and iterate upon.

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ATTACHMENTS

attachment 1	final model created in simulink for matlab 2019a, test files incuded

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Science and Technology