Improved Prediction of the Energy Demand of Fuel Cell Driven Expedition Cruise Ships

Boertz, C.; Hekkenberg, R.G.; van der Kolk, Richard

Publication date
2020

Document Version
Final published version

Published in
Proceedings of the 12th Symposium on High-Performance Marine Vehicles, HIPER '20

Citation (APA)
Boertz, C., Hekkenberg, R. G., & van der Kolk, R. (2020). Improved Prediction of the Energy Demand of Fuel Cell Driven Expedition Cruise Ships. In V. Bertram (Ed.), *Proceedings of the 12th Symposium on High-Performance Marine Vehicles, HIPER '20* (pp. 214-224). Technische Universität Hamburg-Harburg.

12th Symposium on

High-Performance Marine Vehicles

HIPER’20

Cortona, 12-14 October 2020

Edited by Volker Bertram

Improved Prediction of the Energy Demand of Fuel Cell Driven Expedition Cruise Ships

Clemens Boertz, Delft University of Technology, Delft/The Netherlands,
clemens.boertz@outlook.com
Robert Hekkenberg, Delft University of Technology, Delft/The Netherlands,
r.g.hekkenberg@tudelft.nl
Richard van der Kolk, Damen Shipyards Group, Rotterdam/The Netherlands,
Richard.van.der.Kolk@damen.com mailto:email@address.com

Abstract

Fuel cell systems require a better early-stage prediction of the energy consumption of a ship because they are more expensive, more voluminous and less able to deal with rapid load changes than conventional diesel-powered systems. This paper discusses a model for such an improved prediction of the total energy demand of an expedition cruise vessel. The focus is on identifying the peak loads and load changes under consideration of the passenger behaviour, environmental and operational conditions. The used bottom-up approach builds up a parametric model for the early design stages with limited required input data by using typical operational conditions for this type of vessel. The paper concludes that the method provides more insights into the dynamic power and substantially lower predicted energy use.

1. Introduction

The shipping industry contributes significantly to the global greenhouse gas emissions due to the use of cheap fossil fuels. As a response to the Paris Agreement on climate change, the IMO Marine Environment Protection Committee (MEPC) defined the strategy on the reduction of emitted greenhouse gases and emission of carbon dioxide from ships in April 2018. Following this, the carbon dioxide (CO_2) emission per transport work should be reduced across international shipping by at least 40% on average by 2030 with further efforts towards 70% in 2050 in comparison to 2008. The greenhouse gas emissions should peak soon, together with a reduction by at least 50% in 2050 compared to 2018, as stated in the resolution of the MEPC, *IMO (2018)*.

Meanwhile, the cruise ship industry is forced to reduce the carbon footprint to be able to access remote areas with higher restrictions and as part of their marketing strategy towards more sustainability. The majority of ships under construction, including smaller expedition vessels, still use the combination of conventional fuels and scrubbers or SCR systems in order to eliminate harmful exhaust gases. Alternatively, the additional use of batteries can let the engines constantly run at their optimal condition by providing additional electric power in peak loads, as applied in the latest Hurtigruten expedition cruise vessels, *Silk Bidco AS (2017)*.

Research projects by universities, shipyards and other stakeholders address the use of fuel cells with the purpose of eliminating all greenhouse gases, while reducing the high development costs, *Van Biert et al. (2016)*. The storage of pure liquid hydrogen, at a temperature of -253°C is an important challenge to overcome. Other fuels have to be reformed or pressurized. In general, the volumetric and gravimetric energy densities are lower than those of conventional fuels, which results in larger tanks on board when keeping the same operating range and speed. Next to the physical implementation, fuel cells have additional operational limiting factors, which have to be matched with the power demand. Compared to conventional combustion engines, longer start-up times can be expected as well as a lower dynamic response ability. This conflicts with the dynamic power demand of cruise ships in various operational condition, *Baldi (2018)*. Furthermore, fuel cell systems and the associated fuel storage are significantly more expensive than conventional diesel-based solutions. Therefore, a detailed analysis of the ship’s energy use is required, to keep the size and cost of the fuel cell system as low as possible and to prevent undesirable mismatches between the dynamics of energy supply and demand.

Typically, in the conceptual design phase at a shipyard the energy demand is estimated for all electric power consumers with the load balance approach. All systems are designed for the maximum operational power demand. The actual power demand is calculated based on the absorbed power from the net and additional predefined factors for several different operational conditions. The ‘number in service’ describes the number of running components in the defined operational condition. In addition, the load factor is defined as relative load of the maximum electric power of the component to be absorbed in the actual situation. The third factor, the simultaneity factor, varies between 0 and 1 as well, and describes the mean operational time of the component. Thus, a factor lower than one considers not continuously operating consumers. The last two factors are often combined as utilization factor. The product results in the actual absorbed power per component, which can be summed up to obtain the total power for the given operational condition, as shown in the simplified load balance sheet in Table I, *Klein Woud and Stapersma (2015)*.

In general, specific conditions like harbor mode and sailing mode at maximum and design speed are predicted, but without any dynamically changing situations. This method provides a relatively crude overview of the power and energy demand of a ship and lacks details about their dynamics. For the early design stage of classic diesel-powered ships, this is acceptable but as discussed before, it is not for a fuel cell-based solution, especially in hybrid configurations.

Table I: Simplified format of load balance sheet

Consumer name	Absorbed electric power	In port				At Sea				…
	[kW]	Number in service	Load factor	Sim. factor	Average absorbed power	Number in service	Load factor	Sim. factor	Average absorbed power	…
Component 1										…
…										…
Total	∑				∑				∑	

Previous studies distinguish between the different operational modes and the consequences for the propulsion load while keeping the energy demand of the hotel systems constant, e.g. *Simonsen (2018)*. For hotel systems for cruise ships, usually part of auxiliary systems, this approach is not defendable due to the high contribution to the total power demand. The focus is mostly on improving the energy efficiency by assessing sea monitoring data in a top-down approach in order to lower the fuel consumption, *Howitt (2010)*. Even if *Simonsen et al. (2018)* state that the "bottom-up" approach is more complex, such a systematic approach is necessary to study the dynamic energy behavior of every system. Thus, the operational behavior has to be considered more detailed already in the predictions within the first design phase, *Guangrong (2017)*.

As a consequence, the required power and energy demand of the different systems on board must be further examined under varying operational conditions over time. Considering the starting and transient load response time, the understanding of the load changes is just as important as the total power demand at a certain condition, as normally investigated statically in the load balance approach.

This paper presents a detailed breakdown of the different electrical consumers and subsystems, grouped in propulsion, auxiliary systems and hotel systems. On the basis of predefined typical days of operations (TDO), the operational conditions and passenger behavior are described. The impact of the different environmental conditions is assessed by applying weather profiles for hot, cold and medium conditions. The resulting power prediction for every system focuses on the individual load behavior. The combined energy demand of the typical operational days finally leads to the total energy demand of the entire operational profile. Driving factors of the actual load and additional peak loads can be assessed. The results of the power and energy analysis are finally related to the fuel cell characteristics by identifying more favorable systems to be powered by a reliable fuel cell system.

2. Dynamic Prediction Model

First of all, the varying operational conditions have to be defined. Based on these influencing factors, the dynamic power demand is predicted for the different systems, as identified and grouped in the system breakdown. The varying load is the basis for the following energy prediction of the expedition cruise vessel.

2.1. Operational Conditions

Before predicting the power demand, the operational profile, passenger behavior and environmental conditions over the day have to be defined in the first step. They are also referred to as the three main influencing factors of the load behavior. Although users of the method can define their own settings for these aspects, thus making it suitable for their specific application, the cases as described below are used in a case study to demonstrate the way the approach works.

Cruise ships usually have a very diverse operational profile including a long time spent in part load condition. In contrast to cargo vessels, they do not follow a repetitive daily or weekly schedule. Sailing the whole day might be followed by a harbor day in order to offer land excursions. Alternatively, the ships might also travel at low speeds in scenic areas.

In order to define the operational profile, an activity-based approach is applied to obtain typical speed profiles of expedition cruise vessels. The voyage timeline of several reference vessels could be analyzed, where the actual position and corresponding speed is logged over time by using the Automatic Identification System (AIS). In order to model now the power demand for varying conditions, the obtained speed profile is transferred into five typical days of operations (TDO), similar to the used simplification method in the systematic procedure by *Fazlollahi at al. (2014)*. It considers maneuvering, being moored in a harbor or at anchor and sailing at low, medium, design and high speed, as defined in Table II. The energy demand over a week or the whole year can be estimated in a later step by adding up different days similar to the planned schedule or typical speed profile as obtained by the available AIS data as shown in the table as well.

The first defined typical day represents a port day. In the second day the ship would constantly sail at design speed. The remaining three days describe the mixed operational conditions, considering the varying speed profile and a port call during the day.

Table II: Proportion of operations in certain speed ranges as obtained out of AIS data and defined five typical days of operation (TDO)

Speed Range	Defined range (% max speed)	Typical profile (based on AIS)	TDO1	TDO2	TDO3	TDO4	TDO5
Port/Anchor & Maneuvering	<1kn	42%	24h	0h	12h	17.5h	0h
Low Speed	1kn-40%	8%	0h	0h	2h	1.5h	12.5h
Medium Speed	40-70%	27%	0h	0h	6.5h	2h	10.5h
Design Speed	70-85%	25%	0h	24h	3.5h	3h	0h
High Speed	85-100%	4%	0h	0h	0h	0h	1h

The occupancy of a certain area influences the power demand in terms of used facilities and electrical components at a certain time. Thus, the passenger and crew behavior are defined in order to consider this in the predictions later on. The definition is in accordance with the TDOs described above. All spaces are grouped into the main types of areas, like passenger cabins, restaurants, outdoor areas, leisure and public spaces. Additional areas for the crew are defined by the laundry, galleys, crew public spaces and cabins. The occupancy rate of these spaces is formulated as the ratio between actual number of people per zone divided by the maximum number of people on board. For example, the rate of 50% in the cabins would mean, that half of the passengers are allocated in the cabins in the actual time. Every type of area is related to an occupancy rate per specific time step. Fig.1 shows the distribution of passengers exemplary for the third TDO including a port call (8am-8pm).

The distribution per time step of passenger and crew is based on logical assumptions for typical passenger movements and crew working hours. For example, in the night, most of the passengers are sleeping in the cabins. The main mealtimes are in the morning and in the evening. Lastly, while moored in port, most of the passengers are not on board due to excursions or other individual trips.

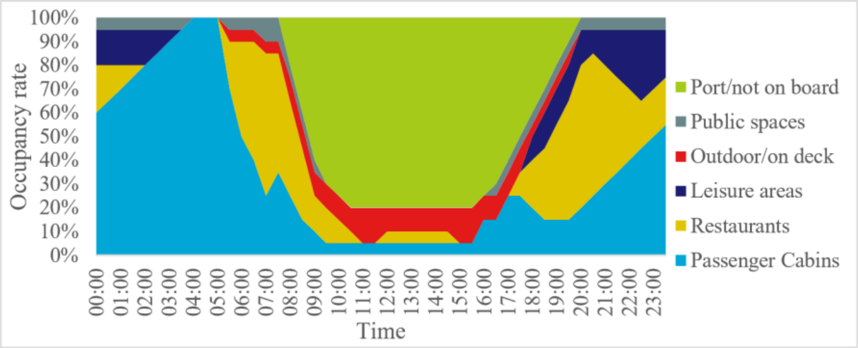

Fig.1: Defined occupancy rate for passengers; TDO3 incl. port call 8am-8pm

Instead of considering only different seasons, varying weather profiles are applied to demonstrate the impact of the environmental conditions on the power demand behavior. The extreme conditions in winter (throughout the day constant at -20°C) and summer (+35°C) are defined by ISO regulations, *ISO (2002)*, as commonly used as design parameter for the HVAC system. For these warm and cold conditions, an example weather profile is considered for Singapore (25-31°C) and Resolute Bay (-16--21°C). The profile of Amsterdam is the third condition as medium weather condition (Amsterdam summer profile used, with varying temperature 17-28°C). In addition, the corresponding hours of sunlight are defined next to a different sea water temperature per location.

2.2. System Breakdown

Before the energy consumption can be predicted, the whole system cruise ship has to be subdivided into the main electrical consumers and subsystems. First of all, the three main groups of systems can be defined. The propulsion systems are the systems which are directly related to the generated thrust to propel the ship. The auxiliary systems are all non-propulsion systems which assist and ensure normal operations. This involves for example the survival systems, including any hazard prevention, detection and fighting systems, like bilge or firefighting system.

Finally, the hotel systems are kept separate from the auxiliary systems due to their high power demand on cruise ships. These systems are more related to the passenger comfort and specific hotel facilities on board. In order to model the different operating subsystems, further grouping of the electrical components is applied resulting in the division as shown in Fig.2.

The subdivision is made on the basis of the belief that if a specific system or component contributes a higher proportion to the overall power demand, temporarily or constantly over time, then it should be modelled with a higher degree of detail, Fig.3. For example, the bow thrusters need a significant amount of electric power while maneuvering. Thus, a more detailed investigation can point out the temporarily high loads.

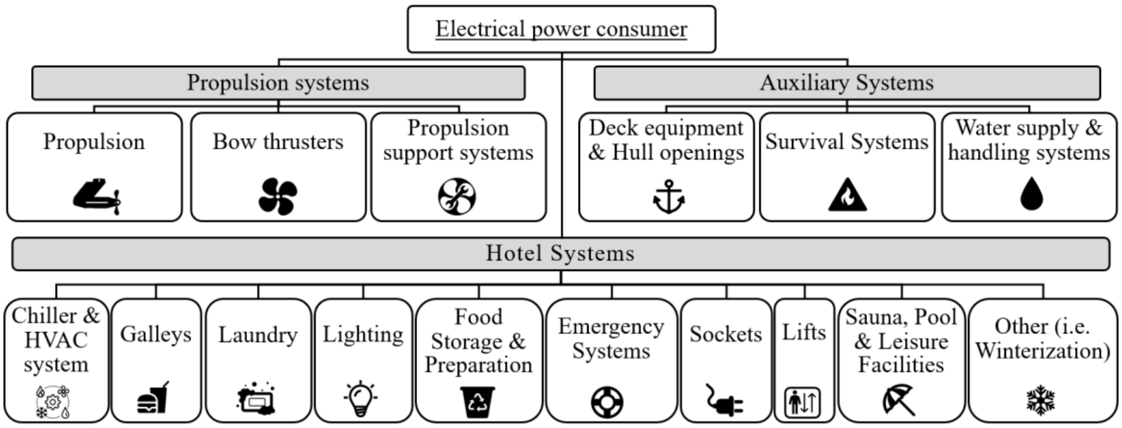

Fig.2: System breakdown of electrical components and systems

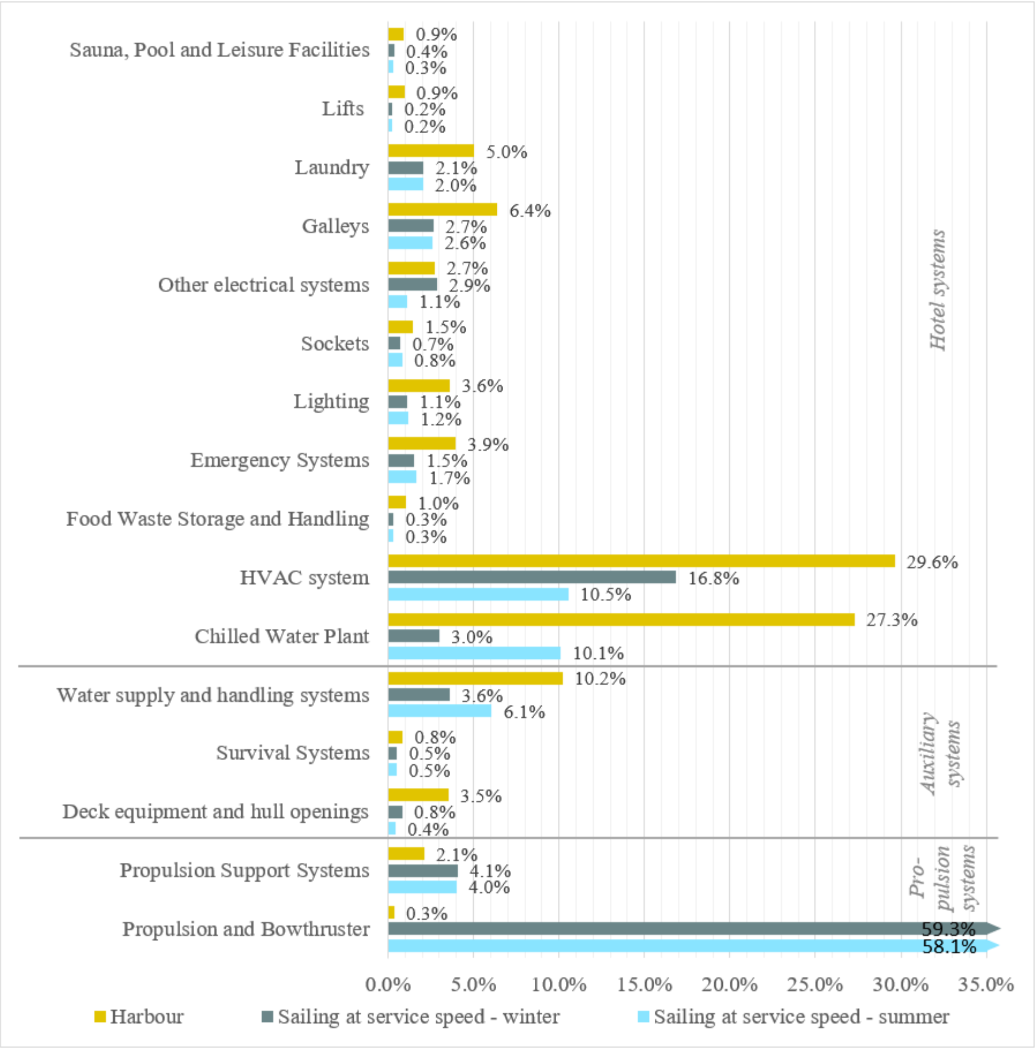

Fig.3: Grouped systems and its proportion of overall power in chosen operational conditions in load balance approach for used reference vessel

Furthermore, some components or systems can be modelled together if they are highly dependent on each other. For example, the HVAC system is modelled together with the chilled water plant even if both systems consume a significant amount of energy. The cooling demand by the HVAC system is directly supplied by the chilled water plant (compare contrary power contribution of HVAC system and chillers in summer and winter in Fig.3). Thus, the systems are directly related and are modelled together under varying conditions.

The third consideration of grouping the components is to take the operating conditions into account. If systems are operating in different conditions, then they should be modelled separately, even if the overall power contribution is low. For example, the emergency systems are only running on stand-by mode in normal operation, while having the higher load in emergency situations.

2.3. Power prediction

In order to estimate the energy consumption, the power demand has to be understood under the operational conditions. This is done by using separate prediction models for the defined groups of systems and electrical components. The focus is on identifying the maximum power demand to assess the power plant (or fuel cell) size. Additional power fluctuations can be analyzed as well, which are critical for fuel cell systems. If an additional peak load cannot be considered within the used time step size of 30 minutes, then it is listed as immediate peak load manually. The prediction models are briefly described and are included more detailed in the master thesis report ‘Energy demand of a fuel cell driven cruise ship’.

The power that is required by the main propulsion system is predicted based on the empirical method of Holtrop and Mennen, *Holtrop and Mennen (1982)*. The main dimensions and gross tonnage are used for the vessel as input data, next to defined form factors for a conventional cruise ship hull. The same holds true for using typical efficiencies to obtain the required brake power at design speed. The propeller law can now be used to predict the required propulsion power for speeds unequal to the design speed. The bow thruster is predicted under consideration of the crabbing criteria and the expected side forces. In general, the passenger behavior and weather condition are not considered in the propulsion power predictions.

The power demand of the auxiliary systems is independent of the speed of the ship and only impacted gradually by changing the operational mode (i.e. port to sailing mode). The number of passengers does play a role in predicting the actual load (mainly water supply system), whereas the daily behavior on board is less influencing this group of systems. Lastly, a different sea water temperature per season affects the heating demand within the water supply system, while the varying ambient air temperature does not influence the load behavior of the auxiliary systems.

Except for the water supply system, the auxiliary power demand is widely constant per operational condition. Thus, next to the predicted installed power, constant utilization factors are applied per operational conditions (sailing or port) as well as for the different seasons (summer or winter). The water systems consider the varying demand of potable water and cooling water for the HVAC and propulsion systems.

Lastly, the hotel systems are discussed. The individual configuration of systems and components depends on the owner requirements. However, within the scope of an expedition cruise ship, the limited number of outfitting, leisure and entertainment facilities can be grouped to enable a rough prediction of the electric energy demand in the first design stage.

The HVAC system is one of the most dynamic energy systems on board of a cruise ship. Separate estimations are performed for every area on board. The passenger cabins are supplied by local fan coil units (FCU) and the public and crew areas by centralized air conditioning units (AHU). They include the electrical components of fans, cooler, heater and humidifier. The automated prediction considers the passenger behavior, as defined for the typical operational days, and the different weather profiles for the ambient air in order to get a power demand different for every time step.

The galleys and laundries are related to typical working schedules to consider the varying load. Lighting is reduced in unoccupied areas and cabins and results in varying load depending on the passenger behavior. Minor systems can be linked to a utilization factor for full operation in sailing condition and lower load in port condition due to less people on board.

2.4. Energy prediction

The time-dependent load behavior during the different operational days is the basis for the daily energy demand per typical operational day. It is the basis for sizing the fuel tanks. The required energy per day is calculated directly from a time-domain integration of the power prediction. The demand for a whole operational profile is obtained by adding different typical operational days. For example, the commonly used three-week transit condition is described by using the second operational day, constantly sailing at design speed. Alternatively, a typical coastal profile can be assembled with the different defined days in mixed operational modes considering a varying speed profile of the vessel.

3. Results

The prediction of the power demand is the basis for sizing the fuel cell on board. Using an estimation under dynamic operational conditions provides insight in the demand of the whole cruise vessel after calculating the load of the individual systems. As a potential design point for the different power plant components, it is important to differentiate between the maximum power load and the base load. The base load describes the minimum amount of power needed over the day and is significantly lower than the maximum load, which occurs only temporarily.

Conventional predictions in the design process, like the load balance approach, focus on the maximum loads to size the main engines.

In order to implement fuel cells, most likely within hybrid configurations, the dynamic power prediction identifies the base load and additional power fluctuations up to the temporary maximum load. This provides more well-founded decisions, how to match the operational points of the different power plant components with the individual load more efficiently.

The highest power is required by the main propulsion in sailing mode, Fig.4 (left). However, expedition cruise ships often operate at lower speeds below the design conditions (see obtained speed profile in Table II), which results in a considerably lower demand most of the time, Fig.4 (right). The highest load changes result from adjusting the speed. In addition, high peak loads are shown in maneuvering condition, Fig.4 (right), e.g. before mooring. The operating bow and azimuth thrusters need high electric power within a short period of time.

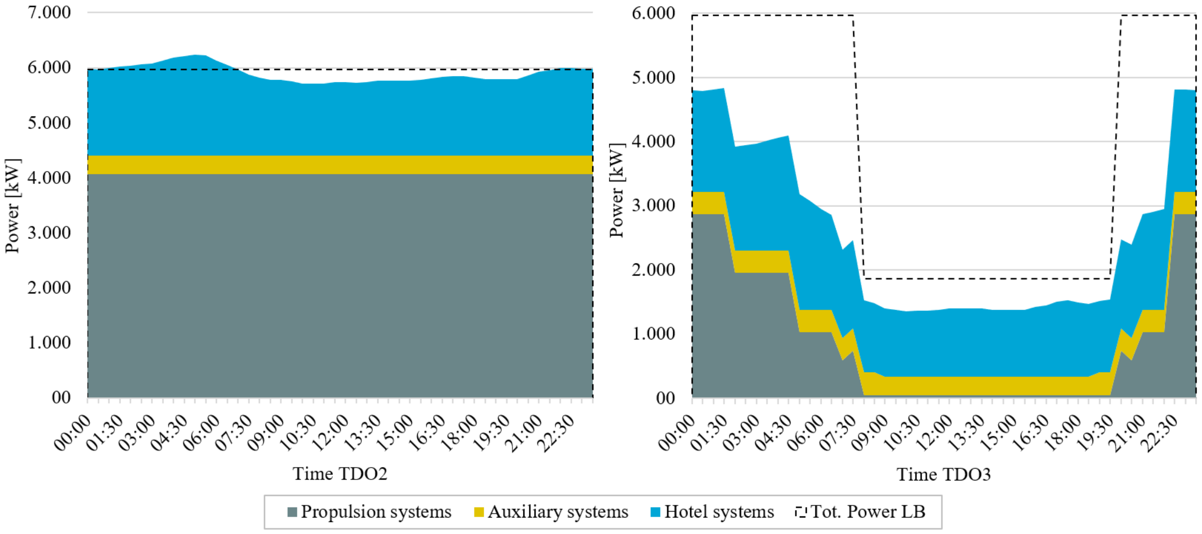

Fig.4: Electric demand of propulsion, auxiliary and hotel systems in winter season, for sailing day constantly at design speed (TDO2) and day including port call, 8am-8pm (TDO3)

In contrast, the power demand of the auxiliary systems is relatively constant close to its maximum load in sailing condition. Only gradual load changes occur by changing the operational mode for example from sailing to port condition. The maximum load of the hotel systems always appears in the morning, when all passengers are on board and several components ramp up from the lower night mode. In general, the power demand is higher in summer, followed by winter condition. This is due to high heat loads or cooling resulting in a higher electrical load within the HVAC system and chilled water plant. The medium weather condition results in the lowest hotel power demand since no extreme cooling or heating is required. Galleys demand the highest amount of electrical energy in their working hours during the day in mealtimes, while the laundry is often running during the night. The remaining and smaller systems are negligibly impacted by the environmental conditions.

Fig.5 shows the power fluctuations for the hotel systems for the used reference vessel. The power fluctuations are mainly influenced by the passenger behavior. Disembarking in port (see right graph in Fig.5, e.g. arriving in port in the morning) causes the highest changes due to a lower actual utilization in port condition, of several systems that normally ensure the high passenger comfort. Thus, they can run on lower design conditions. For example, the galley provides fewer meals and the running HVAC system can be reduced in unoccupied areas.

Fig.5 shows also the predicted power for the hotel systems out of the load balance approach. The demand has its constant value for sailing and port condition and differs significantly from the dynamic approach. The maximum demand is reached only temporarily, while most of the time the load is lower. As a consequence, the static approach in the load balance analysis results in an overprediction of the electric power demand of the hotel systems under consideration of the passenger behavior and environmental conditions.

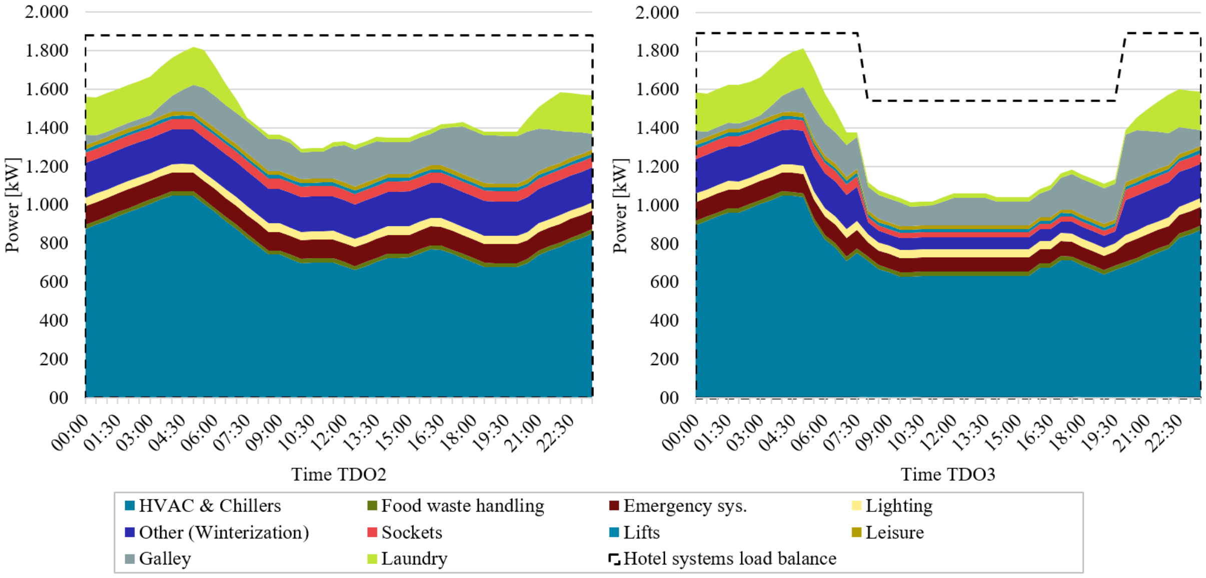

Fig.5: Electric demand of hotel systems in winter season, for sailing day constantly at design speed (TDO2) and day including port call, 8am-8pm (TDO3)

Comparing the total power demand shows that the load changes caused by the hotel systems gets smaller in relation to the changes within the propulsion system as soon as the speed varies, Fig.4 (right), in mixed operational conditions. In port condition, the auxiliary load, including the hotel systems, remains and describes the baseload throughout the day, Fig.4 (right), during the day. Furthermore, comparing the varying load with the load balance approach, the dynamic prediction clearly shows the usually oversized power plant components. In typical costal operations with a varying speed profile, the average load is mostly lower than 50% of the predicted load at design speed (compare sailing day at design speed, TDO2, with mixed operational condition in coastal profile, TDO3, in Fig.4).

The energy demand of the different operational days is predicted for the different considered seasons. Due to the widely constant power demand of the auxiliary systems, the daily energy demand does not vary significantly as well. Different seasons have an impact on the hotel systems due to a different heating or cooling demand of the HVAC system. However, the driving factor for the overall load is the varying speed, which impacts the propulsion system and lowers the energy demand significantly compared to the demand predicted using the load balance approach. The power fluctuations within the hotel and auxiliary systems, as discussed earlier, have a lower impact on the energy demand. They are averaged out due to partly higher and partly lower loads during the day.

The defined operational days are now used to predict the energy demand of a typically used transit profile and an alternative coastal profile of the same endurance of 3 weeks under dynamic operational conditions. An example 21-day cruise is used as case study based on a planned trip by a cruise line. The total energy demand prediction is reduced by around 40% for the reference vessel, mainly driven by the speed reduction and lowering the corresponding propulsion energy by 60%. The energy demand of the auxiliary and hotel systems is only reduced by around 10% in the coastal profile.

Generally, the dynamic prediction clearly shows the potential to better estimate the required power and energy, if varying operational conditions are considered. Optional fuel cells could be designed more efficiently for specific part loads, like the auxiliary and hotel systems. The varying load with its expected gradual load changes can be quantified and covered by fuel cells, rather than the propulsion systems. Conventional combustion engines or balance of plant components, like batteries, can be designed and optimized for the remaining systems with their high loads and temporarily high power fluctuations. A multi-criteria decision analysis on the power supply side can build up on the required energy and power demand of a certain part load to design a hybrid concept. Especially the impact on weight, volume and costs has to be considered. The required fuel cell size can be quantified based on the estimated maximal load and the fuel tanks by considering the predicted energy demand of the specific group of systems or operations.

4. Conclusion

The electrical consumers could be grouped to analyze the individual power demand behavior in varying operational conditions, under consideration of the dependencies and operating time windows. The situations are modelled in five typical days of operations, which present all usual operational modes of an expedition cruise ship.

The following dynamic prediction shows the varying power demand of the individual systems under varying operational conditions, while the total energy demand is still mainly driven by the variation of speed. Looking only into the auxiliary systems including the hotel functions, the fluctuating load is influenced by the passenger behavior and the operating mode, like port or sailing condition. The different weather season impacts the level of the actual electric load, while the daily varying temperature has a lower influence.

The method supports a well-founded decision on the power supply configuration, if it comes to hybrid systems including different power supply components and their operational characteristics. The individual load of systems can be quantified including expectable power fluctuations, which limits the serviceability of fuel cells for certain loads. In addition, the corresponding fuel tanks can be sized for an energy demand of certain systems and operating time windows considering different operational profiles such as ocean-crossing or coastal operations in more sensitive areas.

The commonly used approaches with its static utilization factors for specific operational modes lead to an overprediction of the power plant components. This gets intensified for fuel cells considering lower volumetric and gravimetric energy densities in relation to conventional diesel-based solutions. The maximum condition is only reached temporarily. Especially cruise vessels are mostly running in part load conditions, for which a hybrid system can be optimized by using the proposed dynamic prediction method.

4.1. Recommendations for further research

Simplifications are made within the power prediction, which leads to further room of improvements. Predefined design parameters (e.g. air changes within HVAC system) simplified the load prediction based on common configurations for an expedition cruise ship. However, further investigations into demand-controlled systems (e.g. using sensors) could further lower the energy demand. The dynamic prediction could be also used to assess energy saving strategies (e.g. varying air recirculation rate in HVAC system). The total power demand could be lowered and load changes further reduced.

In addition, the study focused on the electrical demand of a cruise ship as a basis for a sufficient power supply. Fuel cells could replace the commonly used diesel-powered systems. At this point, it is important to consider further thermomechanical consequences as well. The heat in the exhaust, produced by the combustion process, is normally used by the exhaust gas boiler, heating up water directly or any other heat recovery system. The required heat in the other systems has to be balanced by fuel cells or potentially additional electric heaters or boilers.

Lower exhaust temperatures are expected for some fuel cell types, while additional heat could be taken out of the produced water after the chemical process in the stacks. On the other hand, the liquefied chilled fuels in the tanks (e.g. hydrogen and LNG) have to be preheated as well, before bringing them into the fuel cell membrane. This requires additional heat in relation to the commonly used MGO in liquid phase in ambient condition. Meanwhile, the fuel cell modules require less cooling while operating. The reduction of cooling water and additional ventilation can further be optimized.

Overall, a thermal load balance under dynamic condition should be performed as well to prove the heat balance on board. Alternatively, additional heat has to be produced, for example electrically impacting the electric power prediction.

After having studied the power demand side, the supply side has to be designed under varying conditions as well. As briefly mentioned earlier, different options are available for a hybrid configuration. Next to the conventional combustion engines, batteries are already in use in the maritime industry to balance immediate peak loads on smaller ferries. A reliable power plant can be optimized in terms of different parameters like volume, weight or costs. The different power sources have to be considered with their different advantages. For example, batteries are comparably heavy and expensive, which limits the application. Next to the initial investment costs, the expected operational costs over its lifetime have to be considered as well. Thus, the right combination has to be analyzed for the specific ship in a multiple-criteria decision analysis supported by the proposed dynamic prediction method of the energy demand.

References

BALDI, F.; AHLGREN, F.; VAN NGUYEN, T.; THERN, M.; ANDERSSON, K. (2018), *Energy and exergy analysis of a cruise ship*, Energies 11(10)

FAZLOLLAHI, S.; BUNGENER, S.L.; MANDEL, P.; BECKER, G.; MARÉCHAL, F. (2014), *Multi-objectives, multi-period optimization of district energy systems: I. Selection of typical operating periods*, Computers and Chemical Engineering 65, pp.54-66

GUANGRONG, Z. (2017), *Ship energy efficiency technologies − now and the future*, VTT Technical Research Centre of Finland Ltd., Tampere, pp.47

HOLTROP, J.; MENNEN, G.G.J. (1982), *An approximate power prediction method*, Int. Shipbuilding Progress 29(335), pp.166-170

HOWITT, O.J.A.; REVOL, V.G.N.; SMITH, I.J.; RODGER, C.J. (2010), *Carbon emissions from international cruise ship passengers' travel to and from New Zealand*, Energy Policy 38(5), pp.2552-

2560

IMO (2018), *Initial IMO strategy on reduction of GHG emissions from ships,* Res. MEPC.304(72) - Annex 11, International Maritime Organization, London

ISO (2002), *Ships and marine technology -Airconditioning and ventilation of accommodation spaces - Design conditions and basis of calculations*, ISO 7547:2002(E), International Organization for Standardization, Geneva

KLEIN WOUD, H.; STAPERSMA, D. (2015), *Design of Propulsion and Electric Power Generation Systems,* The Institute of Marine Engineering, Science and Technology, London, pp.66-68

SILK BIDCO AS (2017), *Annual Bond report 2016 Hurtigruten*, Tromso, pp.2-4

SIMONSEN, M.; WALNUM, H.J.; GÖSSLING, S. (2018), *Model for estimation of fuel consumption of cruise ships,* Energies 11, pp.26

VAN BIERT, L.; GODJEVAC, M.; VISSER, K.; ARAVIND, P.V. (2016), *A review of fuel cell systems for maritime applications*, J. Power Sources 327, pp.345-364