

# Monitoring systems at the service of ship's energy efficiency: measurements campaign and analysis of the actual electrical absorptions on board

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**Abstract.** The awareness of ship's energy efficiency is undeniably one of the top priorities of ship-owners, designers and operators; the aim is to comply the continuously updated regulations and to optimize the configuration of electrical machineries and their consumptions to reduce emissions and costs. Therefore also monitoring systems, historically connected to the ship structural condition, have been recently employed to assess the energy efficiency collecting information to improve it. In particular, one of the energetic monitoring branches is to monitor the actual electrical absorptions of on board consumers for a selected ship. In order to have impartial empirical information about operating absorption of consumers, a long-term measurements campaign have been organized and carried out with specific instrumentation based on ship's operating availability. The samples acquired during monitoring campaign have been combined with data from ship automation system, integrating the analysis with details of machineries concurrently operating (utilization and contemporary factors). This kind of analysis leads to results suitable for designers to benchmark the foreseen required electrical load on board: the subsequent possible impact on diesel generators' sizing and performance optimization and/or electrical system configuration, could lead to weights, volumes and cost efficiency.

**Keywords.** Energetic monitoring, measurements campaign, electrical absorptions

## 1. Introduction: energetic monitoring and electrical absorptions

Monitoring systems find their first use in the field of the hull stress monitoring, with the aim of continuously control and preserve the capability of the ship to operate safely and reliably. This challenge requires competences and every kind of technologic support in order to reduce the damage risk of ship structures, using different types of sensors and analysis during the ship life.

Next to the first application, still at the top in the ship management, in the last years the monitoring systems have been employed to assess the ship energy efficiency to comply the continuously updated regulations and to optimize the machineries configuration reducing emissions and costs. Minimization of fuel consumption, indeed,

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became one of the top priorities both for owners and operators, therefore a special attention is focused on the choice of machineries and on their operating point, primary cause of the fuel flow. For the designers, the choice of appropriate machineries is a challenge requiring the knowledge of the conditions under which they will operate and the power demand from the connected users: they define the number, the size and the consequent operating point of the engines for a specific purpose.

In particular, one of the energetic monitoring branches is to examine the actual electrical absorptions of on board consumers for a selected vessel, collecting impartial empirical information during a long-term measurements campaign with specific instrumentation. Different class of measures and corresponding analysis can be carried on based on users characteristics and expected operating conditions, distinctive of the different ship type. The samples collection during the campaign, combined with automation data when possible, allows a truthful estimation of the electrical power demand to be used as a benchmark/reference for the load analysis during the design phase. The subsequent possible impact on diesel generators' sizing and performance optimization and/or electrical system configuration, could lead to weights, volumes and cost efficiency.

## 2. Planning and organization of measurements

In order to perform the measurements campaign, a ship in service has to be made available with the cooperation of all involved parts. In the initial phase, once the ship has been identified, the electrical users are studied to understand which of them are suitable and significant for the monitoring purposes.

The starting point for every campaign is usually the electric load analysis. In an electric load analysis the users and relevant loads are listed in groups based on the service they provide as (e.g.) indicated in the Table 1.

**Table 1.** Subdivision of the ship in Groups of Services, in which electrical users are collected

Groups	Services
A	PROPULSION SYSTEM
B	ELECTRIC PLANT
C	NAVIGATION AND COMMUNICATION
D	AUXILIARY SISTEMS
E	ACCOMODATION

Depending on ship type and specific payload, the electric load is differently distributed among ship's services: for example, cruise ships have a demanding electric requirement for air conditioning systems and passenger entertainment (groups D and E), while naval vessels have more important users in Group C and additional groups for defence and armament..

Regardless of payload, a general approach for measurements campaign has been studied, which will eventually require more details when the specific ship and its electrical users of interest will be selected.

These users, main subject of the study, have been divided in two categories, based on the type and the consistent appropriate approach specifically studied for the measurement:

- Single users (direct), recognizable as single machinery (pumps, compressors and similar)
- Group users (subsystems), identifiable in those users operating together in a specific service. For example, the following can be identified as group users: ventilation and air conditioning, galley, lighting.

Concerning the single users, two characteristics allow to portray the situation:

- Running status of the specific machinery (ON/OFF): got from the ship automation system, it also helps to identify the number of active elements of same type which operate together.
- Electrical actual power absorbed, directly measured with specific instrumentation.

The group users, instead, are continuously observed during the long-term monitoring campaign collecting the significant data by means of hardware devices installed on board. The campaign could be also subdivided in more different phases, if all users can not be monitored in the same period. In this event, some group users have been generically monitored during a first phase, the others in the second one and potentially in a third one.

All the activities to be conducted onboard (e.g., hardware installation and removal, measurements, data download) have been planned and carried out according to ship availability and operations.

### 3. Execution of measurements

As announced in the previous paragraph, to split the electric loads in two categories affects the execution of their measurements and the employed instrumentation.

#### 3.1. Measurements of single users

Single users have been measured depending on their ordinary use: due to practical reason, whenever the operation of the user is properly permitted even with the ship stopped, the measurements have been carried out on board the ship at dock. Otherwise, the activities have been performed during navigation for those users related to auxiliaries propulsion, compatibly with the vessel needs and operations.

A portable network analyzer has been employed during the activities for measuring various electrical parameters: current and voltage (peak and steady values), absorbed power, power factor ( $\cos\phi$ ). The Figure 1 illustrates the portable network analyzer used for this purpose.



**Figure 1.** Fluke 435 Network Analyzer (resolution:100 mA, 0.01 V, 0.1 W).

Hundreds of single users can be identified as relevant on board the ship among the services of various groups, depending on provided services. The single point measurements require a technical operator which manually perform them.

### *3.2. Measurements of group users*

For the group users, a continuous data collection has been prepared and arranged. The feeders of each group have been equipped with network analyzers, suitable for use in single-phase and three-phase systems, through which it has been possible to continuously measure the electrical parameters saving them in dedicated mass storage (data logger).

In addition, openable core current transformers, opportunely chosen based on nominal current values, have been employed. They have been arranged in a number of two for each three-phase user, taking advantage of the Aron insertion [1]. The Figure 2 illustrates the specific instrumentation for this kind of measurements.



**Figure 2.** Instrumentation for group users: openable current transformers (left), network analyzer MPM4 (center), data logger (right).

If the number of available devices and the one of users and feeders did not match, there would be the necessity to consider two (or more) different phases during the monitoring campaign measuring some users in the first phase and the others in the second one. In the meantime between phases, the collected data will be downloaded and the hardware removed from the first feeders to be moved to the second ones.

## **4. Results: how to analyze them**

Following the division customized for the planning, organization and execution of measurements, the results as well need to be presented in different ways for the single users and the group ones. For both of these categories, the collected data can be later reported in comparison with the electric load analysis.

#### 4.1. Results for single users

The portrait of the situation about the single users is given by the actual absorbed electrical power, measured through portable network analyzer, and information derived from the ship automation system about their running status. The power required by users can be expressed as:

$$P_{required} [kW] = P_{absorbed} \cdot contemp factor \cdot n \quad (1)$$

Where:

- $P_{absorbed}$  is the electrical absorbed power (manufacturer data or direct measurement through analyzer).
- *contemp factor* is the contemporary factor, here defined as the ratio between time in ON status of the user and the reference time, the daily time during which the operating condition of interest has been maintained. It assumes specific values in each operating condition of the ship.

$$contemp factor = \frac{ON time}{Reference time} \quad (2)$$

- $n$  is the number of same type elements running together (e.g., if two of the three pumps installed for the specific purpose are simultaneously running,  $n=2$ ). As the previous one, this coefficient depends on the ship operating condition.

A first comparison about the absorbed power between the empirical values and the design ones leads to evaluate a difference expressed both in kW (3) and in percentage form (4) as the following formulas:

$$\Delta_{absorbed} [kW] = P_{measured} - P_{design (absorbed)} \quad (3)$$

$$\Delta\%_{absorbed} [\%] = \frac{P_{measured} - P_{design (absorbed)}}{P_{design (absorbed)}} \quad (4)$$

Thanks to this comparison, calculated for each user and for each considered group of users, it is immediate to understand if the empiric values are in line with the design ones or if there have been some discrepancies..

The analysis shapes ship operating conditions of interest: in the design phase the required power estimation for every users (1) is different for each of the ones considered for the specific type of vessel. For an example, could be reasonable to focus the attention on:

- NAVIGATION A, characterized by the use of a specific propulsion engine and a corresponding speed during the season of interest (e.g., winter). This operating condition can be assumed as the reference for the period spending in navigation during the campaign.

- AT DOCK B, for the intervals with the ship at dock during the campaign. Also in this case, a distinction can be defined depending on seasons, which influences the workloads of some users (e.g. air conditioning system).

The automation data helps to point out the information about users running status in the specific required cases: starting from the list of the automation selected signals, the contemporary factor is daily evaluated for each of them, and an average value is estimated considering all days of the campaign. In this way, every users have a specific contemporary factor value. In case of same type users (e.g., two bilge pumps), automation states how many of them are simultaneously in use, in order to evaluate the coefficient  $n$  (1).

The evaluation of these two factors, not achievable if automation data would not support the analysis, leads to an assessment in comparison with the corresponding design values: the empiric behavior could be similar or different from the expected one, depending on obtained values. Table 2 reports an explicative situation where the empiric behavior proves to be different from the design prediction, both in terms of contemporary factor and active elements running together.

**Table 2.** Example of different behaviors (empirical vs. expected) for electrical single users

	<b>Expected behavior (design)</b>	<b>Empiric behavior (measurements campaign)</b>
Sample user n. 1	1 (of 2) @ 40% $n = 1$ , $contemp. factor = 0.40$	1 (of 2) @ 100% $n = 1$ , $contemp. factor = 1.00$
Sample user n.2	4 (of 4) @ 20% $n = 4$ , $contemp. factor = 0.20$	2 (of 4) @ 50% $n = 2$ , $contemp. factor = 0.50$

The observed results, with different behavior voice by voice, can be a constructive starting point for a discussion between ship designers and operators concerning how, on one side, it has been intended in the design phase (and consequently, how the electric load analysis has been carried out) and on the other side how the electrical consumptions actually evolve during the ship operations.

#### 4.2. Results for group users

The continuous measurements for the group users allow different kind of analysis due to the extended amount of data. In particular, a first look can be given to the daily behavior of each user, in order to evaluate the ones which depend on time (differently used along the day) and the ones consistently employed all the hours. For example, probably the galley users rationally depend on times of meals preparation and service, meanwhile other kind of users could register repeated workloads along the 24 hours per day.

Likewise for the single users, the electrical absorptions are also here studied combining them with the automation data about the ship operating conditions of interest, in all operating conditions selected for the specific case.

Limited to the absorptions referred to the specific conditions, the analysis starts with the estimation of the average daily use of electrical power, leading to have each day characterized by a specific value.

Then, a further average estimation leads to obtain a value referred to the condition A and one for the condition B, in comparison with the design values for the corresponding conditions: potential differences are evaluated through the (3) and (4) for an immediate feedback, as respectively reported in percentage form in the following Table 3 and Table 4. A negative value of the indicator  $\Delta$  means a more demanding expected behavior, vice versa for the positive one.

**Table 3.** Comparison between empiric and design behavior for group users (condition NAVIGATION A).

Group users	$\Delta$ [%] - NAVIGATION A
Sockets	11%
Laundry	-79%
Lighting	-8%
Galley	35%

**Table 4.** Comparison between empiric and design behavior for group users (condition AT DOCK B).

Group users	$\Delta$ [%] - AT DOCK B
Sockets	-8%
Laundry	-90%
Lighting	15%
Galley	-84%

The sockets group results to be used approximately as expected both in this particular condition of navigation and at the dock, while the opposite appears for the laundry: the design values are higher than the empiric ones in the analyzed situation. It is a particular circumstance where the management by on board personnel is different from the ones predicted during the design phase. Concerning lighting group, the comparison remarks difference about 10% on average, with lower expected values at dock and higher in navigation. Also for the galley group the divergence is notable, probably again due to a different employ of these services.

In case of a same group user was partitioned in phase 1 and phase 2 of the monitoring campaign, it is important that the environmental conditions which can influenced the system do not change. Otherwise, there could be the unfeasibility to put together the results coming from the separated phases and portray the behavior of that user in comparison with the expected one.

## 5. Additional results and future improvements

The same investigation here presented for the condition NAVIGATION A can be equally carried out for the other operating conditions contemplated for the specific ship, supported by those automation signals which help to identify the reference time frames and evaluate the actual electrical absorptions to be compared with the expected ones. In addition, it is fair to underline that the operating conditions considered for the electric load analysis cannot be exactly achieved with ship in operation due to the intrinsic characteristic of the load analysis.

Moreover, in case of group user with a considerable number of users (and a consequent demand of network analyzers), could be better to set a specific measurements campaign for that system in order to evaluate the effective electrical absorption of all these users with same environmental conditions. A focused analysis

would be more effective and significant if these users represent a sizeable part of the electrical power demand on board.

## **6. Conclusions**

The added value of this measurements campaign has to be seen as a precious opportunity to discuss these results among ship designers and ship operators in order to fine-tune the method for electric load analysis in design phase with the management of electrical resources on board during ship life.

## **7. Acknowledgements**

For this type of measurements a fundamental contribution is necessary by the ship owner, whose availability in terms of ship, crew and resources prove to be undeniable and helpful during all stages of the campaign.

## **References**

- [1] A. Brandolini, A. Gandelli, *ELECTRICAL ENGINEERING – Vol. II – Power and Energy Measurements*, Eolss Publishers Co. Ltd., Oxford, United Kingdom, 2009.