The User Experience as a Demand Response Action in Large All Electric Ships

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***Abstract*— In the global warming context, the newest All Electric Ships are to be designed to pursue efficiency and system sustainability. As in land power grids, also in shipboard applications the Demand Response is an efficient approach to achieve these important goals. Indeed, it can ensure a considerable reduction in the real-time demand of onboard loads, thus helping in avoiding power unbalances and consequent black-outs. From the digital world, the User Experience (UX) is coming as innovative strategy to smartly train the Demand Response (DR) actions. By several mechanisms, like incentives or gamification, the UX can greatly support the Demand Response in limiting the power requests from onboard users. The paper is conceived to give a short recap on DR, while raising the curtain on new UX methodology.**

***Keywords*— Demand Response, User Experience, All Electric Ships, load reduction, sustainability**

I. INTRODUCTION

In marine sector, the reduction in pollutant emissions is nowadays one of the most important goals to be achieved. Such a limitation constitutes a challenge for designers and researchers both for the operations in the port (i.e. shore connection) and for navigation in coastal areas. Here, the ships maneuver and sail at slow speed, thus in operative conditions that are far from the engines optimal working point. In respect to the open sea sailing, a notable increase in pollutant emissions is the resulting effect. On the other hand, the harbors are usually located near, or even into, urban areas, then making the port electrification issue both troubling and challenging at the same time. To explain the importance of this aspect, also in the new Smart Cities paradigm [1] such an expected reduction of emissions in port areas results mandatory. In a world with an increasing attention on environmental issues and impact of pollution on people health, also the regulatory bodies are enforcing restrictive international regulations on pollution [2]. These new rules are imposing the shipping industry to adopt “green” solutions for the new vessels, or to refit the propulsion system of the existing ones, in order to improve their sustainability, thus limiting their environmental impact. At present days, three strategies are technically feasible to achieve these goals. The first option is to use an ecological fuel for supplying the main and/or auxiliary engines. The second option is to install onboard equipment dedicated to the exhaust gas treatment. The third option is to rely on the vessel’s electrification, thus shifting all onboard energy users towards electrical power.

Electrification in particular is the most promising solution, due to its capability of providing flexibility on different levels, being in fact considered as an enabler for the maritime sector sustainability. However, the final effect in term of emission reduction and onboard energy usage is strongly influenced by the operative profile of the vessel. The operative profile is made up by the power needed for propelling the ship, which can only be marginally varied after ship design (it is mostly defined by the combination of ship hydrodynamic, propulsion system design, route selection, and weather), and by the power dedicated to the other onboard loads. The latter can be further broken down in loads dedicated to supporting the ship navigation and loads dedicated to manage onboard guests and/or cargo. All these loads have different profiles and are required in different timeframes, generating an overall load profile for the entire ship energy consumption. By smartly managing all the onboard loads, it becomes possible to modify such a load profile, to optimize energy sources utilization and minimize overall energy consumption. This can be obtained by applying the Demand Response approach, like in land-based applications [3]-[6]. However, in some applications, like in cruise shipping, such an approach must face the issue of guaranteeing a minimum level of satisfaction for the customers, while at the same time pushing them towards a more aware use of the onboard energy (to promote its reduction). This can be obtained with a suitable application of the concept of User Experience (UX) as in [7]-[9].

This paper discusses on the UX in All Electric Ships context. The complete definition on UX features is provided to facilitate its adoption on the reduction of shipboard loads.

II. DEMAND RESPONSE

In today's global energy landscape, efficient management of electrical power resources has become an inescapable priority. With the urgent need to mitigate carbon emissions and optimize the use of energy resources, new strategies and methodologies are emerging. One of these, the Demand Response (DR), looms as a promising solution to address contemporary energy management challenges. The Demand Response is not simply a mechanism for regulating consumption; rather, it represents a systematic and dynamic approach to adapting energy consumption to changing conditions in the electricity market. This strategy goes beyond mere automation, proposing intelligent orchestration of different energy resources in response to the evolving needs of the energy grid.

A. *Maintaining the Integrity of the Specifications*

The DR promotes energy decentralization through the rise of "prosumers," individuals who produce and consume energy, often from renewable sources. This decentralization enables agile peak demand response, reducing dependence on large power plants and incentivizing the use of renewable resources. The real strength of DR lies in integrating technology and human behavior, with incentives such as complementary currencies to stimulate adoption. To give a short summary, DR benefits include:

- *Resource optimization*: efficient energy management, reducing the activation of expensive power plants and encouraging renewable sources.
- *Emission reduction:* minimization of carbon emissions through careful load management.
- *Network resilience:* dynamic response to changes in supply and demand, decreasing the risk of outages.
- *Economic benefits:* better energy rates (consumers).
- *Active participation:* transforming consumers into "prosumers."
- *Technological innovation*: stimulating the development of advanced technologies.

The DR, in its complexity, requires an interdisciplinary approach, combining expertise from engineers, economists, and social scientists. In short, DR is essential to address today's energy challenges, combining sustainability and innovation in an interconnected world. Its implementation, however, requires multifunctional teams to explore and integrate technical and behavioral challenges.

B. *Techniques*

The so-called Demand Side Management (DMS) wants to introduce different paradigms to optimize the real-time power balance between power generation and consumption. Such a smart management has been discussed since several years [3]-[6]. As in [4], the actions of DMS are usually subdivided in three families (Fig. 1). On one hand, the Demand Response activities (i.e. peak clipping, valley filling, load shifting, flexible load shaping), on the other the strategic load growth and the energy efficiency. For what concerns the All Electric Ships, a strategic reduction of the load burden greatly enhances the ship functioning, while both limiting fuel consumption and increasing the overall system sustainability. Although in Demand Side Management, the desired load reduction is a consequence of an improvement in energy efficiency [4], this paper is conversely aimed at introducing the UX as effective measure the decrease the onboard load demand. Albeit the UX is conceived in other contexts, in authors opinion it can be a crucial tool especially when pursuing a load reduction on large ships.

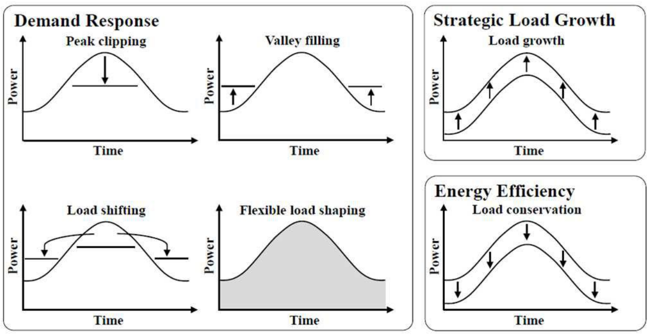

Fig. 1 Categorization of Demand Side Management [4].

III. User Experience as a Tool for Demand-Response

In the following, a new concept to enhance the demand response action is proposed as effective in reducing the load. To introduce the UX as tool to improve the DR, it is necessary to pint the attention on the Importance of User-Centered Design (User Experience, UX) in the field of electrical engineering.

A. *Theory*

In the UX domain, the focus has historically been on physical components, circuits and system architectures. However, with the gradual spread of digital technologies and the emergence of user-focused platforms, the growing importance of User Experience (UX) is highlighted. The genesis of UX can be traced long before the digital age. As early as the 1950s, with the appearance of the first computers, there was a growing interest in optimizing human-machine interaction. But it was with the digital revolution and the emergence of interactive design in the 1990s that UX consolidated its position as a distinct discipline. Donald Norman [9]: an emblematic figure in this field, coined the term "User Experience" during his time at Apple in 1990, emphasizing the need to create products that met users' real needs and expectations.

The UX is understood as the totality of an individual's emotions, perceptions, and responses in interacting with a particular system, product, or service. It transcends mere functionality or aesthetics, representing a compendium of the user's interactions and emotional responses. A prime example, often cited in the UX literature, is the design of a chair. Although its primary function is to provide a place to sit, the design can modulate the user's perception of comfort, aesthetics, and efficiency.

For electrical power systems professionals, it is essential to recognize that a carefully designed UX is not a mere ornament but a pivotal element that can modulate the effectiveness and adoption of a technology solution. To illustrate, an electronic device, regardless of its practical utility, may not gain popularity if users perceive its interface as hostile or non-intuitive. In summary, while electrical engineering focuses on the operational dynamics of a system, UX dives into the "why" and "how that system is perceived" during the interaction. The fusion of these two areas can culminate in holistic solutions that are easy to implement and ultimately more competitive in today's technology landscape. In the following the benefits of incorporating UX [7]-[9] into engineering contexts:

- *Optimization of Operations:* by reducing errors and simplifying interactions, UX can enhance user productivity.
- *Facilitation of Adoption:* well-structured interface can promote faster acceptance and diffusion of emerging technologies.
- *Increased User Trust:* a well-crafted UX can boost user confidence and stimulate user curiosity toward more advanced and/or desired functionality.
- *Decreased Costs:* a carefully designed UX can reduce related costs by limiting errors and support needs.
- *Stimulus to Innovation:* by focusing on user needs and preferences, new innovative directions that may not emerge from a strictly technical perspective can be identified.

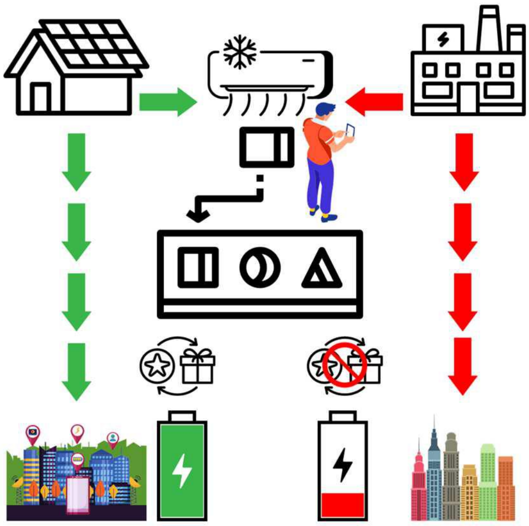

Fig. 2 UX optimized control interface on prosumer DS mode.

B. UX Interaction Design and Influence on DR

In the specific context of Demand Response (DR), both UX and interaction design play a crucial role. Considering that DR is a strategy aimed at modulating or altering user behavior to maximize energy efficiency, its effectiveness is closely linked to the quality of user interaction with technology platforms. Here are some examples [7]-[9]:

- *Consumption Analysis:* a well-designed dashboard can give users an in-depth view of their energy consumption habits, facilitating more informed decisions.
- *Instant Feedback:* the ability to receive real-time feedback can guide the user toward more sustainable energy choices.
- *Adaptability:* the ability to customize settings can enhance the effectiveness of DR, allowing users to calibrate the system according to their own needs.
- *Intuitive Interface:* careful design facilitates the user in dealing with complex processes, minimizing perceived complexity and making interaction more fluid [7].
- *Educational Elements and Gamification:* educational tools and playful techniques can incentivize greater user participation, encouraging responsible energy behaviors.
- *Informed Decision:* synergy with other systems can provide a more comprehensive overview, facilitating holistically informed decisions [9].

The efficiency of DR systems can benefit significantly from well-curated UX and interaction design. This synergy enhances operational efficiency and can positively influence the acceptance and deployment of such solutions. An example of the interaction between UX and DR is offered in Fig. 2. This figure shows the optimized control interface with UX processes and immediate feedback with rewards for electricity consumption improvement of a prosumer's cooling plant under DS mode.

C. Energy management in industry

To give an example about UX potentiality, this theory is supposed to be applied in in industrial facilities. Industry, with its high energy consumption, is a key field for applying UX concepts. Energy efficiency in this field has not only economic but also ecological effects. With the emergence of Industry 4.0, digitization represents a unique chance to integrate UX to perfect energy management.

- *Monitoring and Analysis:* the ability to monitor consumption in real-time is the first step toward effective energy management. Well-structured UX interfaces can make this data easily accessible and interpretable, making it easier to detect areas of inefficiency [7], [9].
- *Forecasting and Refinement:* using sophisticated algorithms makes it possible to anticipate consumption peaks and adjust production. An effective UX can make these forecasts easily accessible and interpretable, facilitating information-based decisions.
- *Interaction and Education:* resistance to change is a major challenge in adopting new technologies. A clear UX can ease the transition by providing real-time education and immediate feedback.
- *Integration with Other Systems:* modern factories are intricate ecosystems. An effective UX can facilitate the integration of various systems, providing a comprehensive view of operations [8].

IV. Application of UX concepts to All Electric Ships

In this Section, the concepts of UX are introduced on All Electric Ships [10]-[11] to provide a new methodology for intelligent load management. After a short introduction on AESs, the UX is proposed for the onboard load reduction.

A. All Electric Ships and drivers towards load management

Ship design aims at maximizing the amount of payload, while minimizing the acquisition and operating costs. While this ensures the best gain for the owner, it is not the only goal to be considered. Sustainability has been increasing its priority in ship design, requiring the introduction of new technologies to meet the progressively limiting regulations. These so-called "key enabling technologies" allow a "quantum jump" in the design and operation of ships, making it possible to reach new goals that seemed unreachable until then. A fitting example was the cruise ships electrification, which happened in the XX century (around 1990) thanks to the availability of new large power electric motors and drives. The latter were not developed from scratch, but came from different industrial applications (railways, petroleum & chemical plants, steel industry, rolling mills, etc.), where the development of power electronics led to significant advantages. Thus, ship designers used such existing technologies, modifying them for the specific maritime application, to enable a complete redesign of the onboard power system (from generation, through distribution, down to the users), leading to the birth of the All Electric Ships (AESs). In the latter, internal combustion engines are only used as prime movers for electrical generators, and electrical power is distributed to all the loads, which include not only auxiliaries and hotel load, but also propulsion. This is achieved [10]-[11] by installing onboard a set of power stations, a dedicated power distribution system, and electrically powered users, giving birth to the so-called Integrated Power System (IPS). The result is an improvement in fuel efficiency and customer satisfaction, and a reduction in operative costs for cruise ships, at the same time paving the way for introducing new innovative electrical technologies aimed at improving the ships' sustainability (e.g., battery energy storage systems and/or fuel cell onboard integration). In particular, the latter is a critical topic nowadays, due to the increasing attention towards energy efficiency, pollutant emissions, and sustainability of maritime transport as a whole.

Fully electrically supplied ships, i.e. ships where all the energy required for their operation is provided by the land power grid and stored onboard in batteries, are nowadays a possible solution for short routes, thanks to the advancements in battery technologies. The range of such "Full" electric ships is expected to improve over time, due to the technical advancements in electrical technologies, leading to a significant reduction in the maritime sector pollutant emissions. Also, land supplied electrical energy is usually more sustainable than the one produced onboard, due to the actual energy mix of the land power grid (which will become more and more renewables based). However, investments in suitable recharge infrastructure in ports is needed, as well as improvements in battery technologies and onboard energy production means (not based on internal combustion engines). Moreover, energy production and storage technologies are only a part of the overall equation, which includes also the energy utilization (i.e., the loads management). The latter may provide significant improvements to the overall ship sustainability that can be useful not only for the full electric ships, but for all the AESs, motivating a research effort in such a direction.

B. *UX for load reduction*

The UX increases the interaction between system design and users. UX has become fundamental in regulating and administrating electrical load. Effective adoption of UX concepts can:

a) *Improve usage*: a well-designed UX can guide users toward more thoughtful consumption of electrical appliances, reducing the load at peak consumption times. This feature is particularly pertinent in industrial environments, where machine operating hours can coincide with times of low demand, resulting in energy savings [7].
b) *Continuous Feedback*: providing users with constant feedback on their consumption promotes the adoption of greener behaviors. This information, conveyed through graphs, alerts, or suggestions, increases user awareness of their consumption patterns.
c) *Automation and Customization*: well-defined interfaces allow users to program devices to operate at times of low demand, distributing the load in a balanced manner. This method is particularly suitable in home environments, where smart thermostats can be set to maximize efficiency.

V. Optimization of Shipboard Electric Loads

Ships are complex and highly specialized ecosystems. Electrical load management aboard these vessels is essential to ensure the operation of vital systems and operational comfort and efficiency. Adopting UX concepts in electrical load management aboard ships offers several relevant benefits, for instance the Clear Interfaces for Personnel. Modern ships have advanced electrical systems requiring continuous monitoring and intervention.

A. *Actions*

A carefully designed UX interface can provide shipboard personnel with a clear view of the status of the electrical system, allowing timely intervention in case of anomalies. Some possible actions are expressed in the following:

- *Active Load Management:* by adopting advanced UX dashboards, it is possible to anticipate and manage peaks in electrical consumption, distributing load optimally among various on-board systems and devices with reduced operating costs.
- *Integration with other systems:* a well-designed UX can facilitate electrical system integration with other onboard systems. This holistic integration can provide a complete view of on-board operations, improving safety and efficiency.
- *Reducing Electricity Load with Dashboard UX for Guests Aboard Ship:* the use of dashboards based on UX principles for guests aboard ships greatly affects the management and reduction of electrical load.
- *Personal Environmental Control*: guests, through a clear interface, can manage temperature and lighting, minimizing waste. However, they may not always make optimal energy-saving choices.
- *Real-Time Consumption Feedback*: the dashboard informs guests about their consumption, prompting them to limit device use at peak times. But, some may overlook or find this data invasive [8].
- *UX-based incentives:* competitions or games incentivize efficient behaviors but may not appeal to everyone and require management resources.

In summary, shipboard UX dashboards have a high potential for reducing electrical load. Success depends on intuitive design, timely feedback, and appropriate incentives.

B. *Gamification*

This is the key to good UX aboard ship. Gamification, essentially, applies game dynamics to nongaming contexts. Originally used in marketing, it has expanded to sectors such as education, health and energy management due to digitization. This strategy harnesses people's intrinsic motivation to achieve goals and overcome challenges, being effective in encouraging behaviors such as energy conservation. Imagine its application on the shipboard through dashboards with optimized UX focusing on these dynamics:

- *Energy Points:* guests earn "Energy Points" whenever they adopt energy-efficient behaviors. As rewards, by accumulating a certain amount of "Energy Points," guests could get discounts at stores or restaurants on board or access to exclusive events.
- *Daily Challenges:* the dashboard offers daily challenges such as "Natural Light Hour," encouraging guests to limit the use of certain devices for a period of time. As rewards, by completing these challenges, guests could receive digital badges visible on their dashboard, which could then be converted into physical rewards or onboard experiences.
- *Rankings:* guests can see how they compare with others regarding energy efficiency through a ranking. As rewards, guests at the top of the leaderboard at the

end of each cruise may receive special rewards, such as a cabin upgrade or a free spa package.

- *Goals and Milestones:* guests can set personal goals on the dashboard, such as "Reduce energy consumption by 10% compared to the previous day". As rewards, each goal achieved could unlock exclusive benefits, such as access to restricted areas of the ship or unique experiences.

By integrating gamification elements into UX dashboards, ships can incentivize guests to become active partners in managing and reducing electrical load. Adopting user-centered design principles can revolutionize how electrical systems are designed and used. The convergence of electrical engineering and UX represents a promising area, with potential innovations that can transform our relationship with electrical technology. Adopting UX principles in electrical cargo management aboard ships represents a breakthrough in the maritime industry. Despite the technical and operational challenges, the potential benefits in terms of efficiency and user safety are enormous and are expected to grow over time.

C. Implications for the design

The adoption of user experience (UX) in shipboard electrical load management through the demand response model, brings with it several implications for design. These implications can be divided into several categories, and lack of attention to these focal points could compromise the design:

1. *User Interface and Intuitive Design:* the user interface should be designed to be intuitive and easy to use, minimizing the need for training [8].
2. *Immediate feedback: u*sers should receive immediate feedback on their actions, allowing them to understand the impact of their decisions in real-time [8].
3. *Incentives and Motivation.* Offering tangible incentives, such as discounts or prizes, can motivate users to participate in demand response actively.
4. *Technology& Integration-interoperability:* ensuring that various systems and devices on board the ship can communicate with each other effectively is critical to effective cargo management [9].

In summary, while adopting UX in shipboard electrical load management offers many opportunities, it is essential to consider the implications for design to ensure effective and safe implementation. Combining intuitive design, motivational incentives, and advanced technology can produce optimal energy efficiency results.

D. Potential Savings on Cruise Ships

Considering the total installed power of a typical cruise ship, which is approximately 80 MW, it is distributed across various onboard services such as propulsion, thrusters, lighting, heating/cooling systems, and onboard electronics. Suppose we postulate that a portion of this power directly correlates with passenger activities (e.g., usage of electronic devices, cabin lighting, etc.). In that case, around 5-20 MW can be attributed to passengers. It is estimated that such a cruise ship accommodates around 3,000 passengers. This translates to an average unitary power consumption in the range of 1.66-6.66 kW per passenger. Assuming an effective UX implementation could lead to a 20% reduction in power request, this would result in a savings of 0.33-1.33 kW for each passenger. It is hypothesized that, through gamification strategies, tactile feedback, and incentives, up to 50% of the passengers can be actively engaged. This would mean the active participation of approximately 1,500 passengers. If these 1,500 passengers were to reduce their power demand by 0.33-1.33 kW, the cumulative savings would be in the range of about 0.5-2.0 MW. In summary, engaging 1,500 passengers (representing 50% of the total) through effective UX strategies can even achieve a potential energy savings of 2 MW on a large cruise ship. This serves as a testament to the profound impact of UX when implemented on a large scale.

VI. Conclusions

In an era of rapid advances in electrical engineering, where the search for sustainable and innovative solutions is imperative, user experience (UX) emerges as an essential but often underestimated component in optimal electrical load management. This study investigated the interaction between UX and load management, focusing particularly on the marine domain. It highlighted how effective UX can enhance energy efficiency and stimulate active and informed user engagement. Electrical engineering, for a long time, has emphasized purely technical solutions, overshadowing the crucial importance of the human element. However, as this work makes clear, real load optimization does not depend solely on sophisticated technologies or algorithms but also on the ability to integrate and sensitize users, making them active players in the system. However, some aspects could be further considered for an even more complete understanding.

Analysis of data collected from user behavior could offer valuable insights on how to optimize UX further and, consequently, electric load management but call attention to end-user privacy. For what regards cultural and social aspects, the perception and adoption of UX might vary according to the culture and background of users. Understanding these differences could be critical to designing a user experience that is universally accepted and effective.

Therefore, recognizing UX not as a mere adjunct but as an essential component in load management is a decisive challenge. Only by valuing the interaction between the individual and technology and recognizing the centrality of UX can we aspire to new frontiers of efficiency and progress in All Electric Ships context.

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