Energy Management of Shore Power and Pier-Based Charging Infrastructure Development for Marine Vessels

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Abstract

The electrification of vehicles and marine vessels is on the rise. The charging infrastructure, also known as electric vehicle service equipment (EVSE), requires energy management to be sustainable. Since the charging infrastructure of these vehicles depends on the existing electric power grid, the energy management techniques used in the industrial sector can be modified and applied to maintain a healthy energy consumption profile of ports and be sustainable. First, all energy consumers in a port must be identified and categorized using energy auditing tools. Energy analysis tools reveal machines and operations that place unnecessary demand on the grid and consumption trends, plus energy conservation measures that help renewable energy integration and greenhouse gas (GHG) reduction. The electrification of the transportation sector will increase the electrical demand (kW). New geospatial data and EPA data are helpful in developing better energy conservation opportunities for a given port location. The paper shows how the above techniques can provide greener energy solutions to US ports.

Introduction

The composition of shore power installations has been changing over the past twenty years, mainly due to the efforts of the Environmental Protection Agency (EPA) to reduce emissions caused by fossil fuels. In recent years, several ports in the USA have adopted strategic plans to reduce emissions by installing electric outlets for hoteling vessels, starting from cruise lines and moving to cargo vessels [1]. It is estimated about 25% of cruise ships' emissions in Puget Sound can be eliminated with shore power. However, the pier and the vessel must have shore power technologies to benefit from this initiative. The load can be somewhat predictable due to the predetermined arrival and departure times of cruses and cargo vessels. The electrical energy for the shore power comes from regional electric utilities. The growing electric vehicle (EV) market will place an additional burden on the utility grid. Furthermore, electric car owners boarding cruise ships will demand charging power for their vehicles from ports while traveling.

This paper presents energy management techniques that can be taught in marine engineering technology courses to assess existing energy consumption of shore power and to curtail EV charging demands for sustainable operation of pier buildings. An electric utility supplying energy to a pier expects the peak demand of the port, and the power factor falls within the agreed levels. The paper also uses other federal data sources to generate cost-effective and greener solutions.

Energy Management

Energy management and energy efficiency improvements have reduced industrial sector energy intensity significantly since the 1970s. Global agencies repeatedly emphasize the need to apply energy management and energy efficiency to reduce the current global climate crisis. As shown in Figure 1, some key elements need attention to generate a positive impact on greenhouse gas (GHG) emissions. The process begins with conducting an energy assessment so that the consumption patterns and wastes become transparent. A process known as MAT is handy. MAT process consists of measurement, analysis, and taking-action. Time-stamped data collected through modern data collection tools are beneficial in providing valuable information after the analysis stage. With more granular data, higher dynamic energy consumption profiles are possible. Consumer behavior patterns influence the shape of electric power demand placed on the grid by EV owners. The energy consumption of marine vessels depends on the maneuvering patterns of the vessel in the port. The energy management goal is to provide the needed electrical power for the port without jeopardizing the reliability and stability of the electric power grid. Initially, no-cost initiatives must be considered for quick energy savings. Then, low-cost initiatives with short-term returns on investment must be considered. Local and national level policies may help to raise necessary funds or identify cost-share options to cover initial costs.

The installation of EVSEs and shore power pier equipment alone will not suffice to achieve the sustainable goals of a port or a dock. A robust energy management program and a continuous improvement plan must be in place to ensure the project's economic viability and technical sustainability.

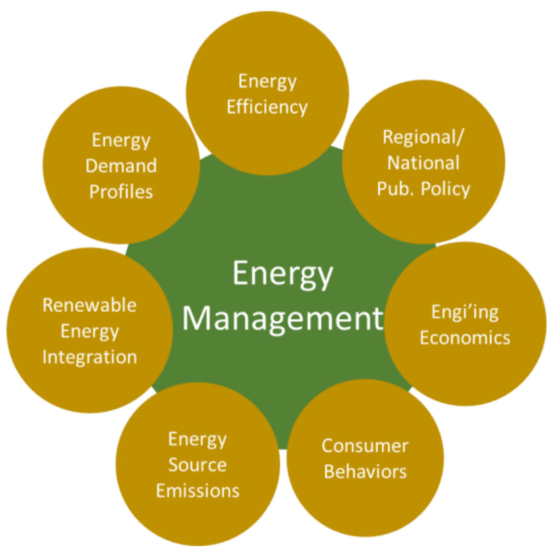

Fig. 1. Key component of energy management.

Energy Visibility

The energy management process begins with identifying energy consumers at a location, permanent and intermittent. What are the primary energy consumers in a port? It is tough to obtain publicly available energy consumption data from ports in the US territory for research purposes. Table 1 shows key energy consumers from the major ports in South America. The study shows the energy source of major equipment without indicating their individual power or energy consumption. This lack of granularity prevents usable predictions [2]. In addition to pier-based equipment, ports utilize an array of diesel-powered vessels for maneuvering and localized movements. These short-distance ships are good candidates for fully battery-powered or hybrid electric powertrains, resulting in zero-emission during use.

When conducting an energy audit in US ports, the data related to the above equipment must be collected, especially the equipment, vehicles, and vessels that have the potential to be electrified in the future.

Table 1. The energy-consuming equipment and their energy sources of 16 South American ports.

	Diesel	Gasoline	Natural Gas	Electricity
Ship-to-shore cranes	●			●
Mobile cranes	●			●
Rail-mounted gantry cranes	●			●
Rubber-tyred gantry cranes	●			●
Reach stackers	●			●
Straddle carriers	●			●
Tractor-trailer units and truck	●		●	●
Generators	●		●	
Buildings				●
Lightings				●
Refer containers				●
Other port vehicles	●	●	●	●

A non-energy factor that contributes to CHG emission at ports and docks is dwell time. During the dwell times, auxiliary engines powered by diesel fuel have to run. Shore power is able to provide electrical energy, shutting down the GHG emitters. EPA's annual report to Congress [4] provides data in Figure 2, showing the monthly average container vessels' dwell times at the top 25 U.S. ports. This graph brings policymakers' attention to examine what causes long delays in our ports. On the other hand, the graph shows shore power opportunities if other useful data related to vessels can be discovered.

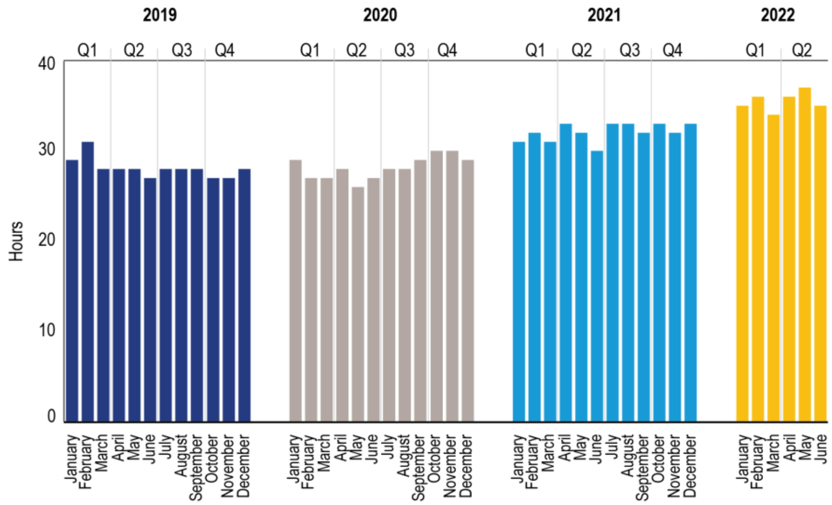

Fig.2. Monthly average dwell time at the top 25 US ports.

For example, the energy consumption due to a dwell time period can be calculated using the following equation:

*Monthly energy due to dwell time (kWh) = auxiliary power of the vessel (kW) * dwell hours per month (1)*

The dwell time meant that the vessels needed to run auxiliary power and continue to emit CHG while at the port, which may be very close to a metropolis. The following sections show how to determine auxiliary power for various vessel types.

Energy Source Emissions

The annual global shipping industry's CO_2 emission is 300 million tons, equivalent to emissions from 67 million gasoline-powered cars [5]. For energy management purposes, localized emissions, all the way down to a specific vessel level, may be necessary. The EPA's Shore Power EMS calculator [6] provides data for energy assessment, such as emissions due to a particular vessel. EPA estimates emissions based on each electric utility's fossil fuel profile. For example, if one of the goals of a shore power project is to reduce emissions, one must have an inventory of dwelling hours per call and auxiliary power capacity of the vessels visiting the port annually. Energy assessments must be based on an annual basis to include seasonal variations.

Energy & Sustainability Conservation Opportunities (ESCMs)

The following example shows how tools produced for one purpose may help other energy conservation measures. We can expand the data produced by the EPA calculator to identify energy and sustainability opportunities at ports. In this example, the energy consumption of two vessels is calculated, as shown in the first two sections of Table 1. The objective is to determine the total energy consumption in kWh due to a vessel's annual dwell time in a port.

The first section of the table summarizes the data inputs to the calculator. The calculator uses the following equation to determine the emissions. The calculation takes the type of fuel, engine capacity, grid loss, and dwell time into consideration.

The second part shows the equivalent kWh in electrical units and emission reduction if the vessel is powered by the electric grid of the local electric utility, in this case, FRCC in Florida.

$$Emissions = Vessel\ Fuel\ Emission\ Factor \times Aux.\ Engine\ Hotel\ Load \times Number \times Average\ Hotel\ Hours \quad (2)$$

The CO_2 emission reduction is very significant, with 72 MT reduction by the chemical tanker and 40 MT reduction by the container ship. Shore power helps to reduce CO_2 emissions by 43 percent in both vessels while dwelling, in addition to a 95 percent reduction of NOX and 82 percent reduction of SO_2. In a marine environment, NIOX and SO_2 reductions definitely benefit life forms

Using the EPA calculator as the base, we can generate other helpful information to make financial decisions. The annual cost saving is the basis for performing an economic analysis of energy-saving opportunities. In some cases, a simple payback period is sufficient. In other investments, net present value, internal rate of return, equivalent uniform annual cost, and lifecycle costing are necessary. The third section converts energy data into cost estimations using the Florida FRCC service providers. In the FRCC region, the industrial electric unit rate is about 9.2 cents per kWh (kilowatt hours.) Based on the number of calls and the dwelling times, the tanker pays $22,800 annually, and the container ship pays $12,300 annually.

The last section summarizes the potential of PV to reduce the CHG further. Once the amount of supplemental annual solar energy potion is determined for a given application, one can determine the required solar PV equipment. Even though detailed analysis is needed before installation begins, a preliminary assessment is enough for energy management. Open-source and vendor-specific solar PV calculators are available. PV Watts by the National Renewable Energy Lab (NREL) is a good starting calculator. PV Watts allows the user to orient the panels closer to the service equipment. As ports spread over a vast space, installing PV panels closer to the service or charging point increases system efficiency. A calculator from Sunwatts.com provides the results in the last part of Table 2.

Table 2. Discovering ESCMs from EPA Shore Power calculator.

Input		
Category	Chemical Tanker Small	1000 TEU Container Ship
Port Region	FRCC	FRCC
Auxiliary Engine Hoteling Load (kW)	490	340
Fuel/Engine Tier*	III	III
Vessel's Dwell Time per Call [7]	40	30
Number of Annual Vessel Calls	12	12
Output of Shore Power Calculator		
Annual Energy Consumption (kWh)	235200	130560
Gross grid loss %	5.3	5.3
Emission Impact CO2 MT	-72	-40
Emission Impact CO2 MT %	-43	-43
Emission Impact NOX MT %	-95	-95
Emission Impact SO2 MT %	-83	-82
Energy Management Calculations from Shore Power Data		
FRCC $/kWh charge [8]	9.24	9.24
Billed annual consumption	247665.6	137479.68
Billed cost ($/kwh x billed consumption)	22884.30144	12703.12243
Renewable Energy Integration & Savings		
Solar array size (kW) to provide 100% annual consumption [9]	15.4	8.27
Unit cost [9]	20000	12100
Installation labor cost (15% of the total system cost)	2000	1210
Total PV Cost	22000	13310
Simple payback (Initial total cost / annual savings) in years	0.961357726	1.04777389
Emission about	0	0

Results from EPA Show Power Calculator

Cost calculations for energy economics

Opportunities for renewable energy integration

We can apply a similar analysis to other pier-based equipment shown in Figure 2. The listed electrically operated systems need to be analyzed to record peak currents and efficiency of the electric drive systems. Industrial and commercial customers have to pay demand charges in addition to the consumption charges. Peak time additional unit costs are significant. Thus, all electrically driven devices need energy assessment studies to increase energy efficiency and change the load profile to benefit electric utilities while satisfying local needs.

Renewable Energy Potential for Ports

Wind and photovoltaic (PV) power are good choices for ports and docks. Let's look at our two cases to determine what further benefits are possible. The annual energy consumption of the tanker can be met with a 15-kW PV unit and an 8-kW unit would be able to meet the enemy consumption of the container ship [9] if they are installed in Florida. Based on the current market values and by allocation 15% of the total system cost for labor and installation costs, the initial costs are calculated. The simple payback period calculation shows the payback time is around one year. This is an extremely favorable investment. Additionally, a PV system will reduce the emissions to almost nothing.

The Impact of EVs on Shore Power Systems

As port employees and cruise ship passenger bring their EVs to the port, naturally the demand for EV charging will rise. On a given day about 15,000 passengers embark and disembark cruise ships from Port Canaveral port in Florida [10]. About 5000 passenger cars are parked on a given day. Soon, the port needs to add public EV charging stations in addition to charging stations for pier equipment and recreational electric boats. A DC fast charger (DCFC) demands 22kW of peak power. Even with 10 DCFC, the peak power reaches to 220kW. Unmanaged 100 DCFCs may demand 2200 kW or 2.2 MW of peak power. The situation is similar to having DC fast chargers for electric boats

Energy management of EV charging infrastructures takes place in three levels: static load management, dynamic load management, and artificial intelligence-based load management. These methods can be modified to meet the needs of Shore Power systems as well. To apply them effectively, energy managers need more granular data from ports and docks.

Conclusions

In a time when shore power is gaining traction in US ports, it is vital to apply energy management techniques during the development stage of the charging infrastructure to reap the best emission reductions and other environmental benefits to the marine ecosystem. The methods described in the paper can be applied to every piece of energy-consuming equipment and vessel on the pier and in water. Developing an inventory of ESCMs for the entire port is a good place to start. Continuous improvement plans with metrics, maintenance programs, and system upgrade plans must be in place for sustainability. Port authorities should promote research studies to develop much-needed data for energy management initiatives by partnering with area universities. It is time to introduce a port energy management course, highlighting greener solutions with CHG-reducing potentials.

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Biographies

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