# Application and cost–benefit analysis of solar hybrid power installation on merchant marine vessels

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## ARTICLE INFO

## ABSTRACT

Photovoltaic systems are renewable energy sources with various applications and their implementations in energy production and saving are verified. Installing those systems onto merchant marine vessels could prove to be an efficient way of minimizing fuel costs and simultaneously protecting the environment by reducing significant carbon dioxide emissions. This paper examines the feasibility of installing solar panels onto vessels and also calculated the payback period from the adopted investment with respect to fuel oil savings. Thus, the two important parameters incorporated in the parametric analysis are the solar radiation density and the fuel cost. In order to calculate the energy production of the solar installation systems, the globe is divided in six different zones, according to solar radiation density (Stackhouse and Whitlock, 2008). For one square meter of the considered solar panels the peak output power is taken equal to 130 W (Kagaraki, 2001). The payback period of the investment depends greatly on the fuel prices. For a reasonable fuel price annual increase at about 10–15% the estimated payback period varies from 16 to 27 years. The more the fuel oil increases, the methodology reveals that the payback period converges to a minimum of 10 years. When using any storage media such as hydrogen, the methodology shows that the payback period increases and this depends on the proportion of the energy stored and from the storage media itself.

## 1. Introduction

Nowadays the pollution caused by the marine industry is calculated to be double to what initially was assumed. The annual carbon dioxide emissions from tanker vessels and bulk carriers equal the emissions from the whole USA. Marine industry has major responsibilities for the Greenhouse effect and measures against profuse pollution should be taken (Papalambopoulos Michail and Glykas Alexandros, 2008).

The presented paper is based on the concept of hybrid power systems. The term hybrid power system (Hybrid Power Systems, 2008) is used to describe any power system with more than one type of generator (usually a conventional generator powered by a diesel or gas engine) and a renewable energy source such as a photovoltaic (PV), wind, or hydroelectric power system. There are thousands of those systems in use today. They range in size from a few tens of watts to tens of kilowatts. The smaller systems are mostly on remote residences where homeowners add a few PV modules to their existing Genset to reduce the noise and inconvenience of having the generator running all the time.

Should there be multiple generators, a smart controller is required. The ultimate smart controller is a human; however many hybrids are installed in remote locations which rely on electronic controllers. Based on parameters, such as the load demand, generator status, and battery state of charge, the controllers should act to keep power flowing to the load as well as to protect the equipment. Performing this with efficiency is not an easy task due to the fact that most hybrid controllers are custom designed.

Except from the generators and the alternative energy sources, hybrid power systems also consist of an inverter (often called a power conditioning unit or PCU), which is necessary to drive AC loads from a battery or a photovoltaic array. A battery charger/rectifier is required if batteries are to be charged from an engine generator or the alternative energy source and finally there is the balance of systems (BOS).

## 2. Installation of photovoltaic systems on vessels

The main idea is to examine whether an implementation of solar energy on motor vessels would be cost–benefit and would actually assist in reducing fuel oil consumption along with the emissions of $CO_2$.
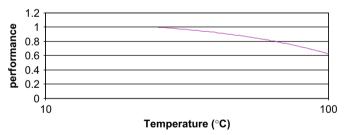
Installation of photovoltaic systems on merchant marine vessels is innovative not only conceptwise but also because the PV systems have to be adopted within the abnormal and non-continues geometric area of the vessel. Within this paper the cost–benefit analysis is examined and results are extracted with reference to the applicability and viability of PV systems. The parameters incorporated in the analysis are the solar radiation density (SRD) and the fuel cost increase (FCI) during the last decades. Data for SRD have been extracted from statistical data (Stackhouse and Whitlock, 2008). All financial and commercial values used for items such as PV systems, Inverters, Fuel oil, etc. are reflecting current market prices (June 2008).

## 3. Average PV performance, heating and dirtiness performance fraction

The performance of the P/V panels fluctuates between 10% and 22% (22% is mostly found in laboratory applications). The P/V panels, based on polycrystalline silicon, in commercial usage can perform around 13–15% (Kagaraki, 2001). In this project the performance considered is 13% (the lower possible).

The heating performance coefficient (Kagaraki, 2001) is an index that shows the connection between temperature and P/V performance. The higher the temperature on the P/V panels, the lower the performance of the system. In room temperature the heating performance fraction equals 1 and for every 1 °C temperature increase, it is reduced by 0.005. Graph 1 shows this correlation. In the presented analysis the heating performance fraction was taken to be equal to 0.9 with the assumption that the maximum developed temperature on the panel surface would not exceed 70 °C at the sea environment.

The dirtiness performance coefficient (Kagaraki, 2001) shows the connection between the performance of the P/V panel and the

dirtiness of its upper surface. The dirtier the surface is, the lower the performance is. The dirtiness performance fraction was taken to be equal to 0.93 since it is assumed that the developed system will operate at the sea, which is considered to be a clean environment.

## 4. Solar radiation density

The solar radiation density depends on the geographical latitude and the season. The most determinant factor is the geographical latitude. The closer to the equator, the higher the solar radiation density (Stackhouse and Whitlock, 2008). With respect to the effect of seasons, it was found that during the summer, solar density reaches higher rates compared to the winter.

For merchant marine vessels there is no constant reference point since they always operate within different zones worldwide. Calculation of the solar radiation density referring to vessel operation is a complicated analysis, contrary to inland implementation where such information is easy to obtain from statistical data.

All the same, for solar installations on merchant vessels operating worldwide, the statistical data required include a wide range of areas. Such data were collected from NASA's statistical tables (Stackhouse and Whitlock, 2008), where there was a detailed record on a daily basis for the solar radiation density, for every latitude and longitude and from year 1983 to 2005. From all those records an average was calculated for different latitudes.

The globe was divided into 6 zones. Each zone has a range of 30° in latitude. The zones were divided amongst the latitude instead of the longitude since the variation of the solar radiation density depends on the latitude.

Hence the three developed zones are the following:

- zone 1 (0–29° north),
- zone 2 (30–59° north) and
- zone 3 (60–89° north).

Similarly for the south hemisphere there is

- zone 1 (1–29° south),
- zone −2 (30–59° south) and finally
- zone −3 (60–90° south).

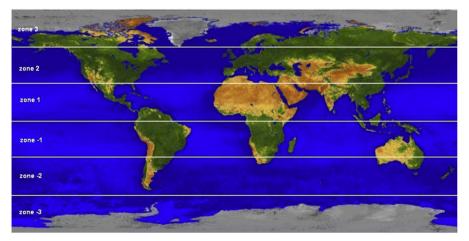Fig. 1 presents the division of the globe in all those zones.

**Graph 1.** Correlation between the performance of P/V panel and the temperature which evolves on it. The temperature axis is on logarithmic scale.

**Fig. 1.** Different zones according to different latitudes.