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Simulation of Solar Energy Harvesting on a 25-Meter Electric Passenger Ferry

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***Abstract*— Urban water transportation plays a critical role in sustainable mobility but faces challenges related to fossil fuel dependency and environmental impact. In response, this study investigates the integration of solar photovoltaic (PV) systems on the 25-meter electric passenger ferry E.V. Calestia, which is designed to operate along the Pasig River in Manila.The objective is to assess the amount of solar energy harvesting as an auxiliary power source for the ferry's existing 1848 kWh battery system powered by dual 400 kW electric motors. A simulation model was developed using MATLAB/Simulink to evaluate solar power generation, based on 20 roof-mounted PV panels, solar irradiance data, and system efficiency parameters. The results indicate a peak instantaneous power output of approximately 3 kW during midday and a cumulative weekly energy generation of about 150 kWh under ideal conditions. These findings show that solar PV systems contribute a minor share to the overall battery capacity, offering limited support to operational sustainability while still aligning with efforts toward cleaner maritime transport in urban river settings.**

Keywords— passenger ferry, solar energy, power generation, electric vessel

I. INTRODUCTION

The maritime transportation sector has a significant impact on global energy consumption and carbon emissions, prompting urgent efforts to integrate renewable energy technologies into vessel designs [1], [2]. Urban water transport, such as river ferries, is an essential mode of transit in many metropolitan areas but traditionally depends on diesel-powered engines that contribute to environmental pollution and operational costs [3], [4]. As cities aim to reduce their carbon footprint, electrification of marine vessels coupled with renewable energy sources like solar photovoltaics (PV) is increasingly recognized as a viable solution [5].

Solar PV technology offers a clean, sustainable, and cost-effective means to supplement onboard energy systems, especially for passenger ferries that frequently dock and have predictable energy demands [6], [7]. Advances in panel efficiency and durability have expanded opportunities for maritime applications, where exposure to harsh marine conditions previously limited solar deployment [8], [9]. Furthermore, integrating solar power reduces reliance on shore-based electricity and fossil fuel generators, enhancing vessel autonomy and operational flexibility [10].

The design and integration of solar PV systems on vessels must consider several unique challenges, including limited deck space, shading effects, and the impact of vessel motion on panel performance [11]. Power electronics, such as DC-DC converters and battery management systems, are critical to optimizing energy harvesting and storage, ensuring stable and efficient power delivery to propulsion and auxiliary systems [12], [13]. Reliable system control strategies are essential to accommodate variable solar irradiance and fluctuating power loads in dynamic marine environments [14].

Electrification of passenger ferries presents a promising pathway to decarbonize urban waterways, reduce noise pollution, and improve air quality in densely populated areas [15], [16]. Solar augmentation supports electric propulsion by enabling trickle charging during docking, extending operational range and reducing downtime [5]. This approach aligns with global environmental goals and maritime regulations set by bodies such as the International Maritime Organization (IMO) [17].

Additionally, incorporating solar power into vessel design enhances system redundancy and energy security by diversifying power sources and reducing dependency on fossil fuels and grid electricity [18]. The integration of renewable energy fosters sustainable maritime transport systems that contribute to broader urban sustainability and climate resilience initiatives [19].

While the potential benefits of solar-assisted electric propulsion for ferries are well-documented, there remains a gap in detailed modeling and empirical validation of such systems under real-world irradiance conditions [20], [21]. Specifically, limited research addresses the performance of solar PV systems on small-scale passenger vessels, where space constraints and dynamic operational profiles significantly impact efficiency [22], [23].

This study presents a comprehensive simulation-based performance analysis of a solar PV-powered electric ferry, focusing on an E.V. Calestia river ferry. Unlike many previous studies that offer conceptual or large-scale naval applications, this research emphasizes small urban ferries and integrates actual irradiance data, and vessel-specific constraints. The novelty lies in the development of a MATLAB/Simulink-based simulation

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model that captures the interplay between solar generation based on irradiance variation [24].

In this study, a comprehensive simulation model was developed to analyze the solar PV system installed on the E.V. Calestia ferry. The system consists of 20 solar panels, each rated at 150 W, installed on the vessel's top deck. The model incorporates technical specifications of the solar panels, real-time solar irradiance data, and battery charging characteristics managed through DC-DC converters. The simulation results provide insights into daily and weekly power generation profiles, highlighting peak power outputs and cumulative energy yields under ideal and variable conditions.

This research contributes valuable case-study data and modeling approaches that support the ongoing transition to sustainable urban water transportation. By demonstrating the benefits of solar PV integration on a river passenger ferry, this study offers practical insights for maritime operators, policymakers, and engineers aiming to reduce emissions and adopt renewable energy in similar contexts worldwide. Future work may explore optimization of system sizing, integration with other renewable sources, and real-time energy management to further enhance system performance and sustainability.

This study is divided into several sections, beginning with an introduction in section 1, then a methodology presentation in section 2, a summary of the design and stability analysis results in section 3, and conclusions in section 4 as the study's final section.

II. METHOD

This study focuses on evaluating the integration of a solar photovoltaic system aboard the passenger ferry E.V. Calestia, which designed for operates along the Pasig River in Manila. The vessel's specifications, including a catamaran hull for stability and dual 400 kW electric motors powered by a large battery bank (1848 kWh), set the foundation for assessing renewable energy supplementation. Twenty solar panels, each rated at 150 W, were designed to be installed on the ferry's top deck, contributing a total nominal power output of 3000 W. The technical characteristics of these panels—including voltage, current, power tolerance, and physical dimensions—were carefully considered to optimize performance without compromising vessel stability. The electrical system schematic routes the solar-generated DC power through DC-DC converters to efficiently charge the onboard battery bank, maintaining system stability and protecting battery health. A Simulink simulation model was developed to estimate the solar power output by inputting parameters such as panel area, number of panels, panel efficiency (approximately 15%), and time-varying solar irradiance. This model calculates instantaneous power generation and integrates it to determine cumulative energy production over daily and weekly cycles. Solar irradiance data were approximated to simulate real-world variations, enabling the study to assess energy yield under typical operating conditions. The simulation outputs include peak power values and total energy generated, which provide insights into the feasibility and performance of the solar system as an auxiliary power source for the ferry.

III. RESULTS AND DISCUSSION

The Pasig River is well-known because the expansion of Manila and the Pasig River's banks have made it a center of development and historical events. This river is one of the most significant bodies of water in Manila and one of the country's most important river systems. The Pasig River flows approximately 25 kilometers in a north-westerly direction and is crossed by 19 bridges. The river is 50 meters wide at its narrowest point. Its typical depth is 4–5 meters, although at the landings, the depth is closer to 2.2 meters.

E.V. Calestia is a ship with specifications designed to accommodate 100 passengers and adapted to the navigational conditions of the Pasig River in Manila, Philippines. The vessel features a catamaran hull, which provides excellent stability ideal for riverine transport. This ship has a service speed of 15 knots and a maximum speed of 19 knots, powered by a pair of 400 kW electric motors equipped with cooling systems and an AC electrical system supplied by 1848 kWh batteries. Photovoltaic solar panels supplement the energy system through trickle charging at key docking points such as Guadalupe and Lawton to maintain battery capacity.

Table 1 details the principal dimensions of E.V. Calestia, showing that the vessel has an overall length (LOA) of 25.00 meters, a length between perpendiculars (LPP) of 23.80 meters, and a waterline length (LWL) also of 25.00 meters. The ship's depth measures 2.15 meters, breadth 7.80 meters, and draught 1.30 meters. The light weight tonnage (LWT) is 59.18 tons, with a dead weight tonnage (DWT) of 19.77 tons, and the vessel operates at a density of 1.00 ton per cubic meter.

TABLE 1.
PRINCIPAL DIMENSION OF E.V. CALESTIA

Designation	Sym.	Unit	Value
Length Overall	LOA	meters	25.00
Length /between Perpendicular	LPP	meters	23.80
Length of Waterline	LWL	meters	25.00
Depth	D	meters	2.15
Breadth	B	meters	7.80
Draught	T	meters	1.30
Light Weight Tonnage	LWT	ton	59.18
Dead Weight Tonnage	DWT	ton	19.77
Speed	Vs	m/s	15.00
Density	ρ	ton/m3	1.00

Table 2 presents the technical specifications of the solar panels used in the system, where each panel has a maximum power output (Pmax) of 150 W and the system's maximum voltage rating is 1000 VDC. The voltage at maximum power (Vmp) is 18.6 V, while the current at maximum power (Imp) reaches 8.06 A. The panels have an open-circuit voltage (Voc) of 22.4 V and a short-circuit current (Isc) of 8.53 A, with a power tolerance range of 0 to 5 W. Classified as Class A, each panel measures 148 × 65.5 × 3 cm and weighs 12 kg. The system comprises 20 such panels, producing a total power output of 3000 W. Additionally, the series fuse rating is set at a maximum of 15 A, indicating that the system is designed for medium to high power applications with adequate efficiency and safety measures.

TABLE 2.
SOLAR PANEL DETERMINATION

Designation	Sym.	Unit	Value
Maximum Power	Pmax	W	150
Power Tolerance Range	–	W	0 – 5
Open Circuit Voltage	Voc	V	22.4
Voltage at Maximum Power	Vmp	V	18.6
Short Circuit Current	Isc	A	8.53
Current at Maximum Power	Imp	A	8.06
Maximum System Voltage	–	Vdc	1000
Series Fuse Rating	–	A	15
Application Class	–	–	Class A
Dimensions (L × W × H)	–	cm	148 × 65.5 × 3
Weight	–	kg	12
Quantity of Panels	–	unit	20
Total Power	–	W	3000

Table 2 presents the typical efficiencies of various types of solar panels, showing that monocrystalline panels have the highest efficiency, ranging from 17% to 23%, followed by polycrystalline panels with efficiencies between 13% and 17%. Thin-film (amorphous) solar panels exhibit lower efficiencies of around 10% to 12%, while flexible panels such as CIGS (Copper Indium Gallium Selenide) demonstrate efficiencies ranging from 10% to 15%. These efficiency variations are influenced by the material properties and manufacturing technologies of each panel type, which determine how effectively the panels convert sunlight into electricity [25].

TABLE 2.
SOLAR PANEL EFFICIENCY

Type of Solar Panel	Typical Efficiency
Monocrystalline	17% – 23%
Polycrystalline	13% – 17%
Thin-film (amorphous)	10% – 12%
Pico / Flexible (CIGS)	10% – 15%

A total of 20 solar panels, each rated at 150 W, are planned to be installed on the top deck of the passenger ferry to supplement its power system. This installation aims to harness solar energy efficiently by maximizing the available surface area on the vessel's deck without compromising stability or operational safety. The panels will be arranged strategically to capture optimal sunlight throughout the day, contributing to the ferry's auxiliary power needs and supporting its battery system. By integrating these 20 solar units, the ferry enhances its sustainability and reduces reliance on conventional energy sources, promoting cleaner and greener maritime transportation along its route. Figure 1 shows the design of 20 units installed on the top deck of a passenger ferry.

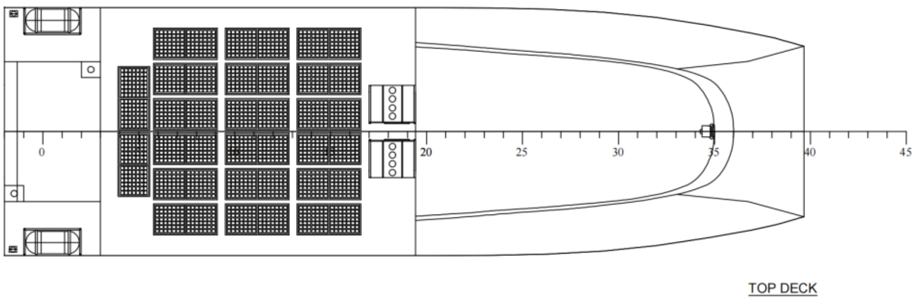

Figure 1. Design of 20 Units Installed on the Top Deck of a Passenger Ferry

The schematic of the solar power electrical system begins with the solar panels, which capture sunlight and convert it into direct current (DC) electricity. This generated DC power is then fed into a DC-DC converter, a critical component that regulates the voltage and current to match the charging requirements of the battery system. The converter ensures efficient power transfer by stepping up or stepping down the voltage as needed, protecting the battery from overcharging or voltage fluctuations. After regulation, the controlled DC power is used to charge the battery bank, which stores the energy for later use in powering the vessel's electrical loads. This setup optimizes energy harvesting from the solar panels while maintaining battery health and system stability.

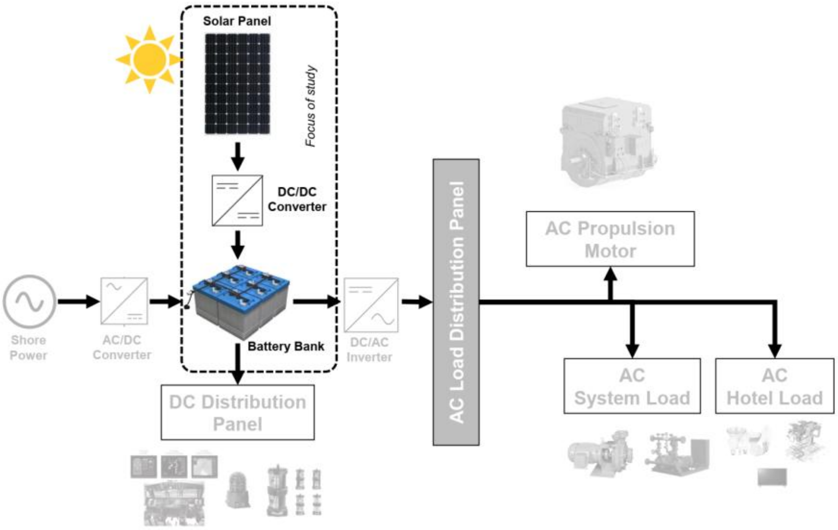

Figure 2. Solar Panel Power System Schematic of the Electric Passenger Ferry

Equation (1) is used to calculate the power output (P) of a solar panel system based on the solar irradiance intensity (G), the efficiency of the solar panels (η), and the total surface area of the panels (A) [26], [27]. In this context, the power generated is directly influenced by the amount of solar energy received per unit area of the panel surface (expressed in W/m²), the panels' ability to convert that solar energy into electrical power, and the total area available to capture sunlight. This equation forms the fundamental basis for analyzing the performance of photovoltaic systems and allows for an initial estimation of the potential energy that can be produced from a solar panel installation.

$$P = G \times \eta \times A \quad (1)$$

Where:
P = Power output (Watts)
G = Solar irradiance (W/m²)
η = Efficiency of the solar panel
A = Total surface area of solar panels (m²)

Figure 3 shows a typical 24-hour irradiance profile at the Pasig River in May 2025. Based on hourly solar radiation, the Pasig River area in Manila exhibits a characteristic diurnal pattern with radiation intensity starting at 29 W/m² at 6:00 AM, rapidly increasing to 909 W/m² by 11:00 AM. Peak solar intensity (exceeding 900 W/m²) is maintained between 10:00 AM to 1:00 PM, making this window ideal for photovoltaic energy generation. After 2:00 PM, radiation levels show a steady decline, dropping to 736 W/m² (2:00 PM), 639 W/m² (3:00 PM), and eventually to just 5 W/m² by 6:00 PM. This daily profile demonstrates excellent solar potential during midday hours, though energy systems would need to account for the sharp drop in afternoon irradiation.

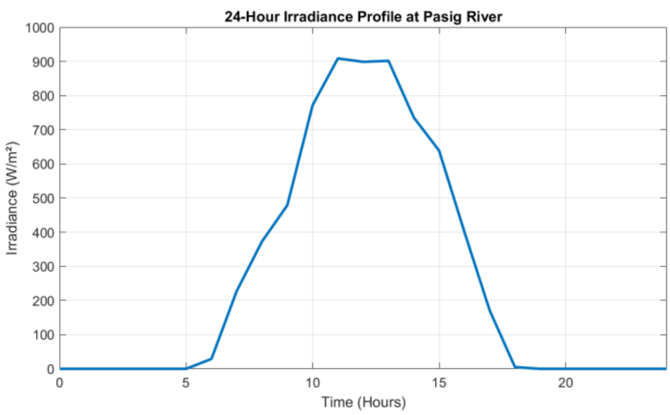

Figure 3. Typical 24-hour irradiance profile at the Pasig River in May 2025

Figure 4 shows a Simulink simulation model designed to calculate the power and energy output of a solar panel system based on technical parameters and solar irradiance conditions. The main inputs include the surface area of a single panel (1.48 × 0.655 m²), the total number of panels (20 units), and the panel efficiency (0.15 or 15%). Solar irradiance (G), in W/m², is provided as a time-varying input signal. These values are multiplied to compute the instantaneous power output (PowerGenerated), which is then integrated using a function block to determine the total energy output (TotalEnergyOutput). A control logic is also implemented to ensure that no power is generated when irradiance is zero (i.e., no sunlight), allowing the model to accurately simulate real-world performance of the solar energy system under various lighting conditions.

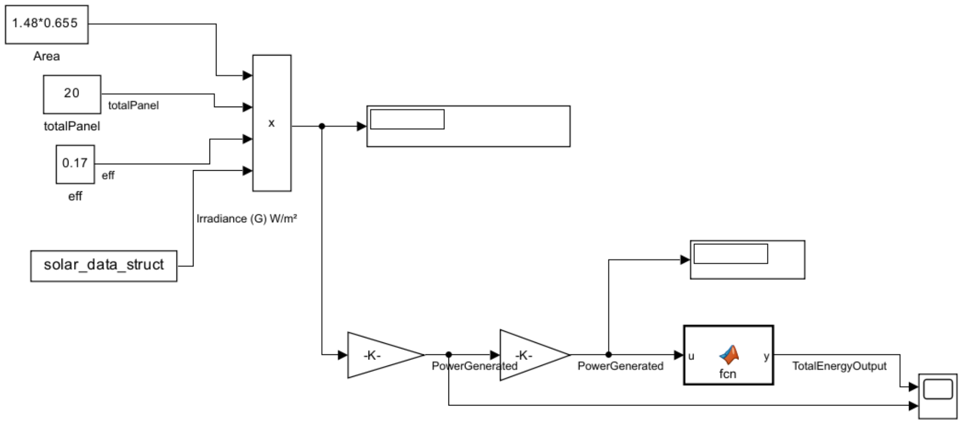

Figure 4. Estimated Daily Power Generation under Ideal Conditions (kWh)

The Figure 5 illustrates the power output (PowerGenerated) of the solar panel system over time, displaying a periodic pattern that corresponds to the daily solar irradiance cycle. The maximum power output reaches approximately 3 kW, which occurs during peak solar irradiance conditions. This peak indicates the system's optimal performance when solar radiation is at its highest and the panels operate near their rated capacity. The recurring rise and fall in power generation suggest a day-night cycle, where energy production increases during daylight hours and drops to zero at night due to the absence of sunlight. This confirms that the system is effectively capturing and converting solar energy in response to varying irradiance throughout the simulation period.

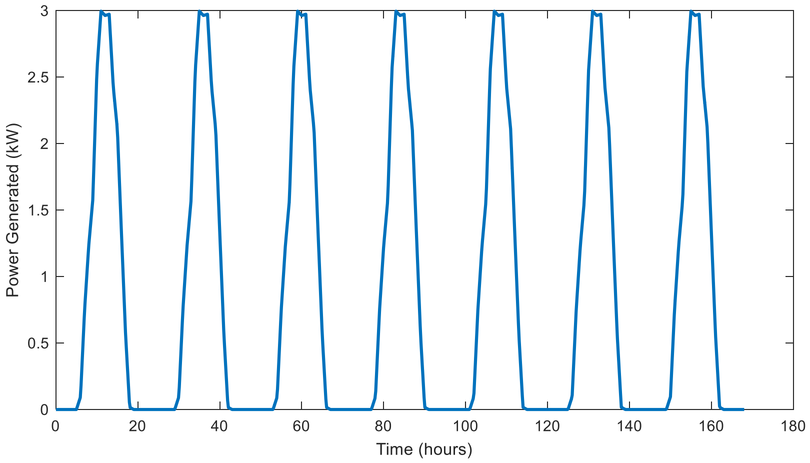

Figure 5. Estimated Daily Power Generation under Ideal Conditions (kWh)

Figure 6 shows the cumulative weekly total energy output of the solar panel system over a one-week simulation period. The step-like increase in the curve reflects daily energy generation cycles, where energy is produced during daylight hours and remains constant at night. Each step corresponds to the accumulation of energy produced throughout the day, with no generation occurring during periods of darkness. By the end of the simulation, the total energy generated reaches approximately 150 kWh, indicating the system's performance under the given solar irradiance conditions. This result confirms the system's ability to consistently generate renewable energy, contributing to an average daily energy yield of around 21.4 kWh.

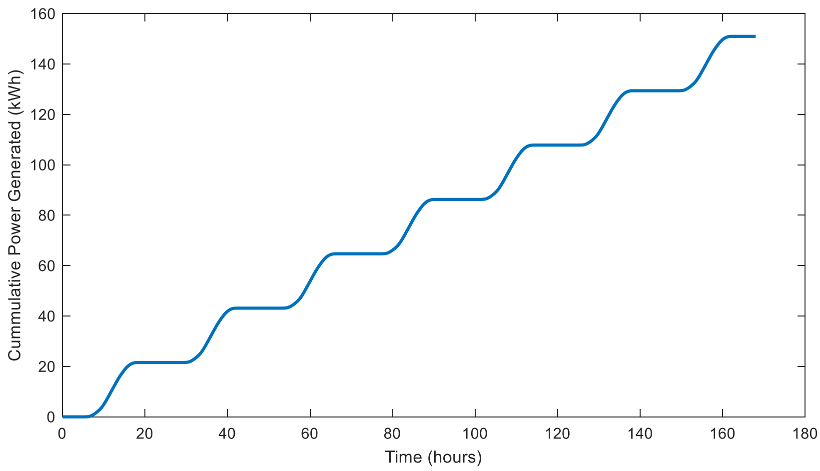

Figure 6. Cumulative Weekly Solar Power Generation (kWh)

The results of this study highlight the potential and limitations of integrating solar photovoltaic (PV) systems on a 25-meter electric passenger ferry operating in an urban river environment. The simulation indicates that while the solar PV array contributes a relatively small fraction of the ferry's total battery capacity, approximately 150 kWh of cumulative energy over a week from 20 panels rated at 150 W each—the integration nevertheless represents a meaningful step toward enhancing the vessel's energy autonomy and environmental sustainability. This contribution, although modest, helps reduce dependence on shore-based electricity, supporting cleaner maritime transport. A key novelty of this research lies in its detailed system modeling that incorporates actual solar irradiance data specific to the Pasig River area, coupled with vessel-specific technical constraints such as panel placement, efficiency. Unlike many previous studies that focus on theoretical or large-scale applications, this study applies a realistic scenario for a small urban ferry with space limitations, providing practical insights into operational performance and energy yield. The MATLAB/Simulink simulation framework developed here offers a replicable methodology for evaluating solar energy harvesting under dynamic environmental conditions, including diurnal irradiance variation, thus bridging the gap between conceptual design and real-world implementation. Furthermore, this approach lays the groundwork for future optimizations in system sizing, power electronics management, and hybridization with other renewable sources, which could amplify the sustainability benefits of electric ferries. By quantitatively assessing the energy output and operational impact, this study contributes valuable data to the growing field of sustainable maritime transportation, underscoring the feasibility and challenges of adopting solar energy in urban waterway applications.

IV. Conclusion

This study aimed to evaluate the potential of solar energy harvesting as an auxiliary power source for the electric passenger ferry E.V. Calestia, which operates along the Pasig River in Manila. Using a simulation model developed in MATLAB/Simulink, we assessed the energy output from 20 roof-mounted photovoltaic panels under typical solar irradiance conditions. The simulation results indicate that the system can generate a peak power output of approximately 3 kW during midday, with a cumulative energy production of around 150 kWh per week under ideal conditions. While the harvested energy represents a small fraction of the ferry's total battery capacity (1848 kWh), it contributes meaningfully to auxiliary charging, especially during docked periods. The findings demonstrate that although solar PV systems alone cannot replace primary propulsion energy sources, they can effectively supplement onboard systems, enhance energy resilience, and reduce reliance on shore-based charging infrastructure. This supports broader efforts toward greener and more sustainable maritime transportation in urban river environments. Future studies may focus on optimizing panel configurations, integrating hybrid renewable sources, and improving real-time energy management for enhanced operational efficiency.

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