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Design and Implementation of a Solar Panel–Based Backup Energy Supply System for an Egg Incubator in Jatijejer Village, Mojokerto

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ABSTRACT

Power supply reliability is a critical factor in the hatchery industry, as egg incubator machines require continuous and stable electrical energy to maintain optimal temperature and humidity conditions throughout the incubation period. In many rural areas, including Jatijejer Village, Mojokerto, East Java, Indonesia, frequent power outages from the main electricity grid often disrupt incubator operation, causing temperature fluctuations that can reduce hatchability rates and negatively affect poultry productivity. These conditions highlight the need for a reliable backup energy solution to ensure uninterrupted incubation processes. To address this challenge, this study implements a small-scale solar photovoltaic (PV) system as a backup power supply for a semi-automatic egg incubator installed in Desa Jatijejer, Mojokerto. The proposed backup energy system consists of a 20 Wp solar panel, a 10 A solar charge controller, and a 12 V 12 Ah battery as the primary energy storage unit. With an available energy capacity of approximately 144 Wh, the battery is capable of supplying power to a low-consumption egg incubator during temporary grid outages. This capability is particularly important during critical stages of embryonic development, where stable temperature conditions are essential to ensure successful hatching. The PV–battery configuration is designed to function as an emergency backup system rather than a long-term replacement for the main grid, thereby maintaining incubation continuity during short-duration electrical disturbances. In addition to technical implementation, this study evaluates partner perceptions through a satisfaction survey involving 20 respondents from the local poultry farming community. The survey results indicate a high level of satisfaction with the implemented system, reflected by an overall mean score of 4.37 out of 5. The suitability of the technology achieved a mean score of 4.30, while system performance obtained a mean score of 4.35. Ease of operation and maintenance recorded a mean score of 4.25, suggesting good usability with potential for minor improvement. The highest satisfaction scores were observed for service team responsiveness and overall satisfaction, both reaching 4.45, while training clarity achieved a mean score of 4.40. Overall, the findings confirm that the solar PV backup system enhances incubator reliability and supports sustainable poultry production in rural areas with unstable electricity supply.

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INTRODUCTION

In the poultry industry, the incubation process plays a critical role in determining the productivity and viability of chick production. Egg incubators are designed to provide stable temperature and humidity conditions that mimic natural brooding environments, which are essential for successful embryonic development and hatch rates. However, in many rural and peri-

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urban areas such as Jatijejer Village, Mojokerto (Figure 1), the reliability of the main electrical grid (PLN) remains inconsistent, leading to frequent power outages that interrupt incubator operations and jeopardize hatchability outcomes. Interruptions in power supply can cause temperature fluctuations that result in abnormal embryonic development or chick mortality, thereby reducing productivity and increasing economic losses for smallholder poultry farmers.

Figure 1. Location of Chicken Coop Owner Partners in Jatijejer Village, Mojokerto

The conventional incubator systems in Indonesia and similar developing contexts are primarily powered by grid electricity, which exposes them to vulnerabilities when power interruptions occur. These systems often lack backup energy solutions, resulting in substantial risk during critical incubation periods. To address this issue, alternative energy solutions such as PV systems have been proposed and studied for application in energy-constrained environments (Widagdo et al., 2023). Solar PV systems convert solar radiation into electrical energy through photovoltaic modules, offering a reliable off-grid energy source that can supply power independent of grid availability (Widagdo et al., 2024). Research has demonstrated the feasibility of using solar energy as an alternative power source for egg incubators, showing that PV systems can provide consistent output and mitigate dependence on conventional electricity grids in rural settings where access to reliable grid power is limited or intermittent (Ramadhan & Hermawan, 2024). Several studies have investigated the integration of solar PV technology into egg incubation systems. For example, analysis of small-scale solar cell-powered incubators indicates that converting incubator energy sources from grid to PV can reduce operational risks and support continuous incubation processes (Ridwan et al., 2023). Additionally, hybrid energy solutions combining solar and grid power have been tested to optimize reliability and reduce dependence on grid, particularly in areas with unstable grid supply (Nuban et al., 2024). These studies underscore the potential of solar PV and hybrid energy configurations to provide sustainable, low-carbon, and autonomous power solutions appropriate for rural hatchery applications.

Moreover, the use of thermostatic control systems such as digital thermostats in solar-powered incubators can improve precision in maintaining target incubation temperatures. Maintaining optimum temperature is essential for adjusting heat input and ensuring favorable embryo development. Experimental solar-powered designs with integrated thermal storage have shown that maintaining incubation temperatures within desired ranges is possible using solar energy as a primary source, particularly in areas with sufficient solar irradiance, thus improving hatchability outcomes while reducing dependence on fossil or grid energy sources (Saputra et al., 2023). Despite the demonstrated potential of PV energy, challenges remain in adapting these technologies for small-scale and semi-automatic incubators. Energy availability, storage capacity, climatic variability, and system cost are critical factors that influence the viability of solar backup systems (Widagdo et al., 2025). However, effective solar PV integration can serve as an alternative energy solution, reducing operational cost, increasing energy autonomy, and enhancing the sustainability of poultry operations in regions like Jatijejer Village where grid instability persists. Transitioning to renewable energy not only improves reliability but also aligns

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with broader sustainable development goals by leveraging abundant solar resources in Indonesia's tropical climate to support rural electrification and agricultural productivity.

METHODS

This activity was conducted in Jatijejer Village as the primary location for data collection and the implementation of all stages of the research. The selected site represents a rural area with relevant characteristics for evaluating the performance of a small-scale solar energy backup system for an egg incubator. The research was carried out over a period of two months, from December 2025 to January 2026, allowing sufficient time for system installation, operational testing, data monitoring, and performance evaluation under actual field conditions.

Design of a Semi-Automatic Thermostat-Based Egg Incubator

Egg incubation is a critical process in poultry production that requires stable temperature conditions to ensure optimal embryo development and high hatchability rates. In small-scale hatchery systems, particularly in rural areas, semi-automatic egg incubators are commonly used due to their simple design and affordable cost. However, maintaining consistent temperature remains a major challenge, as fluctuations can negatively affect the hatching process. Therefore, the integration of a thermostat-based control system is essential to automatically regulate heat within the incubator, improve temperature stability, and enhance the reliability and efficiency of the egg incubation process.

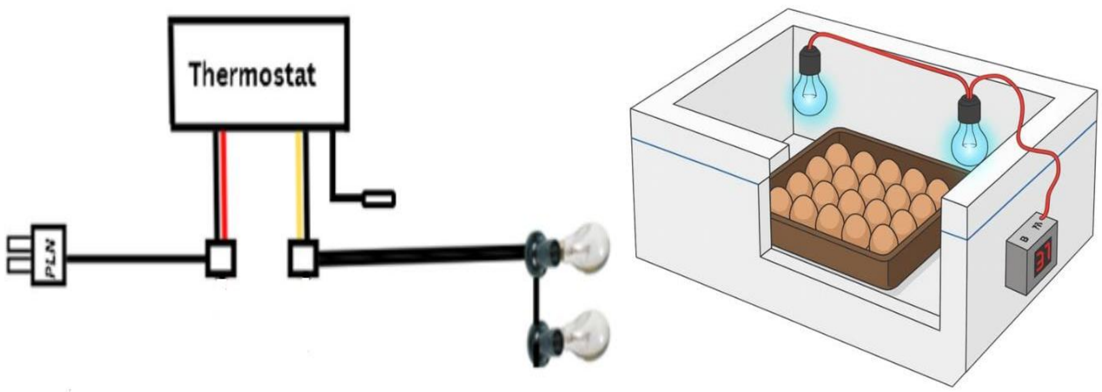

Figure 2. Design of a Semi-Automatic Thermostat-Based Egg Incubator

Figure 2 illustrates the design and working principle of a semi-automatic egg incubator equipped with a thermostat-based temperature control system. This incubator is designed to maintain optimal environmental conditions required for egg hatching by regulating temperature automatically while still allowing simple manual operation where necessary.

On the left side of the figure, a schematic diagram shows the electrical control system centered on a thermostat unit. The thermostat functions as the main control component, responsible for monitoring the internal temperature of the incubator. It is connected to a power source and to heating elements, represented by incandescent lamps (Yasir et al., 2023). When the internal temperature drops below the predefined setpoint, the thermostat closes the electrical circuit, allowing current to flow and activating the heating lamps. Conversely, when the temperature reaches or exceeds the desired value, the thermostat opens the circuit, disconnecting the power supply to the lamps and preventing overheating. This on–off control mechanism ensures temperature stability during the incubation process (Hambakodu et al., 2024).

The right side of the figure presents a three-dimensional visualization of the incubator chamber. Inside the insulated enclosure, eggs are placed on a tray positioned below the heating lamps. The lamps serve as heat sources that evenly distribute thermal energy throughout the incubation space. A thermostat sensor is installed inside the chamber to accurately detect the internal temperature near the eggs, ensuring reliable feedback for temperature regulation.

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Ventilation openings are also shown, which help maintain air circulation and support uniform heat distribution within the incubator. This semi-automatic incubator design offers a balance between simplicity and functionality. While the temperature control is handled automatically by the thermostat, other operations, such as egg turning, may still be performed manually. The system is particularly suitable for small-scale or rural hatchery applications, where reliable temperature control is essential but fully automated systems may be costly or impractical.

Design of a 20 Wp PV System with 12 Ah Battery Capacity as an Alternative Energy

The increasing demand for reliable and sustainable energy solutions has encouraged the use of small-scale solar power systems in agricultural applications. This project focuses on the design of a 20 Wp solar system equipped with a 12 Ah battery as an alternative energy source for a semi-automatic egg incubator. By integrating solar energy with a thermostat, the proposed design aims to ensure stable temperature regulation, improve energy efficiency, and provide a practical solution for areas with limited access to conventional electricity.

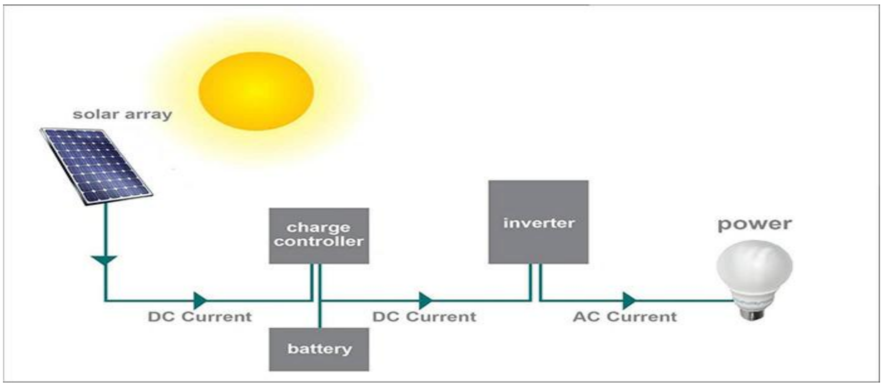

Figure 3. Mini Solar Power Plants Design for Thermostat Power Supply

Figure 3 illustrates the design of a mini solar power plant that functions as a power supply for a thermostat-based temperature regulation system. The solar array captures sunlight and converts it into direct current (DC) electrical energy, which is then managed by a charge controller to regulate voltage and protect the battery during the charging process. The battery serves as an energy storage unit, ensuring the availability of power when solar energy is insufficient or unavailable. Furthermore, the stored DC energy can be supplied directly to DC loads or converted into alternating current (AC) using an inverter, depending on the requirements of the system (Saputera et al., 2020). This configuration ensures a stable and continuous power supply for the thermostat and heating elements, thereby maintaining consistent temperature control in the semi-automatic egg incubator system.

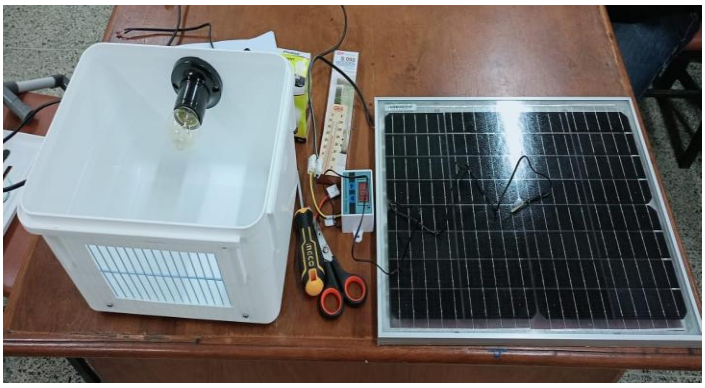

Figure 4. Thermostat-based 10-Egg Capacity Incubator with Photovoltaic Power Supply

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Figure 4 shows the implementation of a thermostat-based egg incubator with a capacity of 10 eggs powered by a photovoltaic energy system. The incubator unit is equipped with a heating lamp and a thermostat to maintain the required temperature for the egg hatching process. The compact design demonstrates the practical integration of thermal control components within a small-scale incubation chamber. In addition, the photovoltaic power supply, consisting of a solar panel, charge controller, and supporting electrical components, provides an alternative and sustainable energy source for the incubator. This configuration allows the system to operate independently of the conventional power grid, ensuring reliable temperature regulation and continuous operation, particularly in areas with limited access to electricity.

RESULT AND DISCUSSION

This section introduces the results obtained from the implementation and testing of the semi-automatic egg incubator integrated with a small-scale solar photovoltaic backup system. The analysis focuses on evaluating the performance of the thermostat-based temperature control, the reliability of the PV–battery energy supply during grid outages, and the overall effectiveness of the system in maintaining stable incubation conditions under real operating scenarios. The discussion further examines the relationship between energy generation, storage capacity, and incubator load requirements. Particular attention is given to battery charging behavior, nighttime backup performance, and the limitations imposed by the 20 Wp solar panel and 12 V 12 Ah battery configuration. Through this analysis, the feasibility and practical applicability of the proposed system as a low-cost and reliable solution for small-scale hatchery operations in rural areas are assessed.

Thermostat Testing in the Room Temperature Stabilization Process

As part of the experimental methodology, a calibration procedure was carried out using a reference mercury thermometer to ensure the accuracy and reliability of the temperature control system. The calibration setup was designed to systematically compare the temperature readings obtained from the thermostat sensor with those measured by the mercury thermometer under controlled conditions. This procedure is critical for minimizing measurement uncertainty and for validating that the thermostat provides accurate and consistent temperature feedback for subsequent experimental analysis. Furthermore, the calibration results were used to identify and quantify any systematic deviations between the thermostat sensor and the reference thermometer. Where necessary, appropriate calibration adjustments were applied to align the sensor readings with the reference values. This step ensures that the temperature control system operates within acceptable accuracy limits during experimental operation.

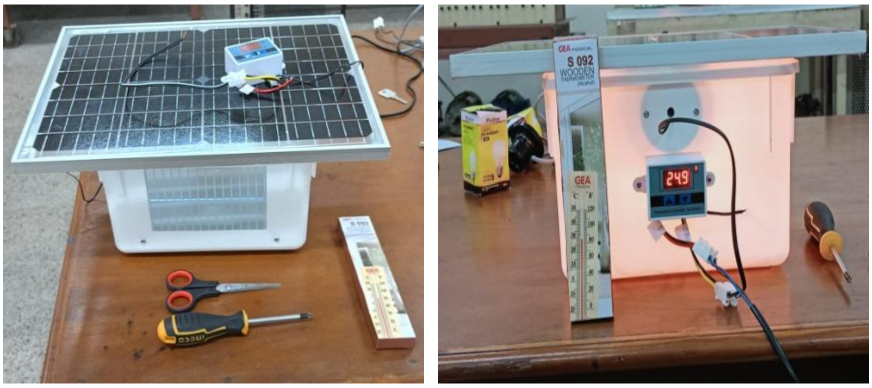

Figure 5. Thermostat Calibration Results with a Mercury Thermometer

Figure 5 illustrates the experimental setup and the results of the thermostat calibration process using a mercury thermometer as the reference instrument. The thermostat was exposed to varying temperature conditions, and its displayed readings were directly compared with the corresponding values indicated by the mercury thermometer. The observed results show a close

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agreement between the two measurements, indicating that the thermostat operates within an acceptable error range. This confirms that the calibrated thermostat is suitable for accurate temperature monitoring in the experimental system.

Mini Solar Power Plant Testing Related to Operation and Security

Following the calibration of all measurement instruments, the inverter system was subjected to a series of experimental tests to evaluate its output power performance as well as its capability to supply energy for battery charging. These experiments were conducted under controlled laboratory conditions to ensure the reliability of the measurements, while systematically observing the operational behavior of the inverter, the stability of its output characteristics, and its interaction with the battery charging subsystem. In addition, the experimental investigation was designed to examine the operational reliability of the inverter during sustained operation under varying load conditions. Several key performance indicators, including output power efficiency, voltage regulation, and battery charging response, were measured and analyzed in detail.

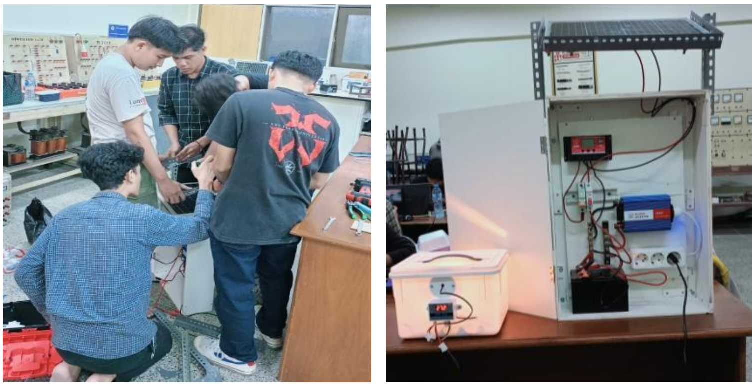

Figure 6. Testing Inverter Output Power and Energy Absorption for Battery Charging

Figure 6 presents the experimental setup and testing process used to analyze the inverter output power and the energy absorbed by the battery during charging. The inverter output was monitored while supplying power to the charging circuit, and key electrical parameters such as voltage, current, and power were recorded. The results demonstrate that the inverter is capable of delivering sufficient power for effective battery charging, with stable operation observed throughout the testing period. These findings confirm the suitability of the inverter system for energy conversion and storage applications.

Trial, Testing, and Handover of Tools to Community Service Partners

Figure 7. Egg Incubator Testing and Handover of Equipment to Partners

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To ensure the functionality and reliability of the developed egg incubator, a series of testing procedures were conducted under real operating conditions. These tests aimed to evaluate the incubator's ability to maintain stable temperature and support the hatching process effectively. Following successful testing, the equipment was formally handed over to the project partners as part of the technology implementation and community engagement activities.

As illustrated in Figure 7, the egg incubator testing process demonstrated that the system operated as intended, with eggs placed inside the incubator under controlled conditions. In addition, the handover session symbolized the transfer of knowledge and technology to the partners, accompanied by a brief explanation regarding operation and maintenance. This activity is expected to enhance the partners' capacity in poultry farming and contribute to sustainable local economic development.

Table 1. Partner Satisfaction Statistics Toward the Community Service Team (n = 20)

No.	Evaluation Aspect	Very Satisfied (5)	Satisfied (4)	Fair (3)	Dissatisfied (2)	Mean Score
1	Suitability of the technology provided	9	8	3	0	4.30
2	Performance of the egg incubator machine	10	7	3	0	4.35
3	Ease of operation and maintenance	8	9	3	0	4.25
4	Responsiveness of the service team	11	7	2	0	4.45
5	Clarity of training and guidance	10	8	2	0	4.40
6	Overall satisfaction	11	7	2	0	4.45
	Average					4.37

Based on the satisfaction survey involving 20 partner respondents (Table 1), the overall evaluation of the community service team in developing the egg incubator machine indicates a high level of satisfaction, with an average mean score of 4.37 out of 5. The suitability of the technology provided obtained a mean score of 4.30, showing that most partners perceived the egg incubator machine as appropriate for their needs and local conditions. This suggests that the technology transfer process was well-aligned with the partners' operational capabilities.

The performance of the egg incubator machine achieved a mean score of 4.35, reflecting that the majority of respondents were very satisfied with the machine's functionality and effectiveness in supporting hatching activities. This indicates that the technical design and implementation met practical performance expectations. In terms of ease of operation and maintenance, a mean score of 4.25 was recorded. Although still categorized as high satisfaction, this aspect received a slightly lower score compared to others, implying that minor improvements in user interface or maintenance procedures could further enhance usability. The highest satisfaction levels were observed in the responsiveness of the service team and overall satisfaction, both achieving a mean score of 4.45. This highlights the strong commitment of the community service team in providing assistance, responding to partner needs, and ensuring smooth implementation throughout the program.

Furthermore, the clarity of training and guidance yielded a mean score of 4.40, indicating that the training sessions and technical explanations were delivered clearly and effectively, enabling partners to operate the egg incubator machine independently. Overall, the statistical results demonstrate that the community service program was successfully implemented and well received by partners. The high satisfaction scores across all evaluated aspects confirm the positive impact of the egg incubator machine development and the effectiveness of the service team's engagement with the community.

Based on Figure 8, a significant improvement is observed in both evaluated aspects, namely knowledge and practical skills, after the community service program was conducted. For

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the knowledge aspect, the average pretest score was 60%, indicating a moderate level of understanding prior to the intervention. After the program implementation, the posttest score increased to 85%, showing a substantial improvement in partners' comprehension of egg incubator technology and its working principles. Similarly, the practical skills aspect showed an increase from 62% in the pretest to 88% in the posttest.

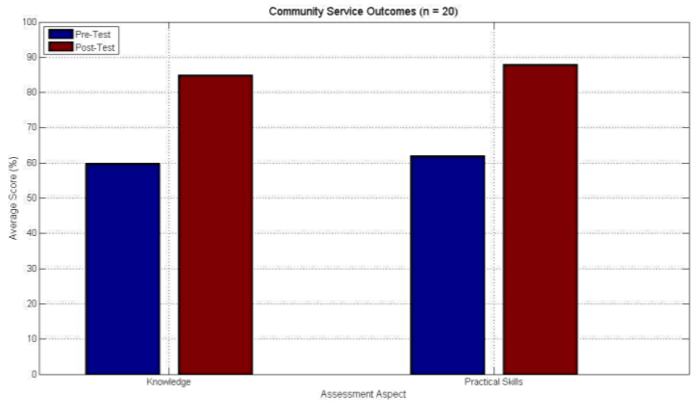

Figure 8. Community Service Outcomes Based on Pretest and Posttest Results

This result demonstrates that hands-on training and direct assistance effectively enhanced the partners' ability to operate and maintain the egg incubator machine. Overall, the increase in both knowledge and practical skills confirms that the community service activities had a positive and significant impact on partner capacity building. The results indicate that the combination of technology provision, training, and mentoring was successful in improving both theoretical understanding and practical competence of the partners.

CONCLUSION

This project demonstrates that the integration of a semi-automatic thermostat-based egg incubator with a small-scale PV backup system is technically feasible and effective for application in rural poultry farming environments with unstable electricity. The experimental results confirm that the thermostat control system is capable of maintaining incubation temperatures within acceptable limits, while the 20 Wp solar panel combined with a 12 Ah battery provides sufficient backup energy to support continuous incubator operation during power outages. The calibration and system testing results further indicate that the proposed design offers reliable performance, and practical suitability for small-scale hatchery operations.

In addition to technical performance, the community service outcomes indicate a positive impact on partner capacity building and technology acceptance. The pretest–posttest analysis shows significant improvements in both knowledge and practical skills, while the satisfaction survey reveals a high level of partner satisfaction across all evaluated aspects. These findings suggest that the combination of appropriate technology design, renewable energy integration, and effective training contributes not only to improved operational reliability but also to sustainable technology adoption at the community level. Overall, the proposed system presents a low-cost, environmentally friendly, and scalable solution that can enhance poultry productivity, reduce dependence on unreliable grid electricity, and support sustainable rural development in regions with similar energy constraints.

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