Resource Assessment of a Floating Solar Photovoltaic (FSPV) System with Artificial Intelligence Applications in Lake Mainit, Philippines

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Abstract-The Floating Solar Photovoltaic (FSPV) system is an emerging solar PV installation, gaining traction primarily due to its distinct advantages over other forms of installations. FSPV mainly solves the problem when land area is scarce and the power plant capacity is on the megawatt (MW) scale. This paper investigates the resource potential of FSPV, specifically in Lake Mainit, Caraga Region, Philippines. This study implemented a descriptive research design to identify the resources needed to implement an FSPV system in the said lake. The Lake Mainit area can generate 762.96MWh per year. Accounting for the needs of the community, the resources needed to put up the FSPV should satisfy the 35,640Whr daily energy requirement of the community. Based on the analysis, the computed FSPV system size is 9.90kWp. The components required to implement an Artificial Intelligence (AI) integrated monitoring and data processing system for fault diagnosis and detection to help mitigate impact to the FSPV system with the undesirable weather conditions were also identified.

Keywords-floating solar photovoltaic system; renewable energy; artificial intelligence; machine learning

I. INTRODUCTION

Carbon dioxide (CO_2) emissions are a global environmental issue. CO_2 is one of the three Green House Gases (GHGs) that have increased in the atmosphere since pre-industrial times and is verified to be one of the leading causes of climate change [1-7]. Many developing countries, like Philippines, are highly vulnerable to climate change [8-9]. The signing of the Paris Agreement, in particular, paved the way for the countries' determined effort to reduce CO_2 and other GHGs by scaling up the use of Renewable Energy Sources (RESs) in order to mitigate the impact of climate change [10]. RESs are considered clean, produce minimal waste, and are considered sustainable [11]. RESs, like the solar photovoltaic (PV) systems, are regarded as a solution in mitigating CO_2 and other GHGs, thereby reducing global warming and slowing down the impact of climate change [12]. The global capacity for RESs significantly increased the last few years, with more than 260GW capacity added in 2020 alone despite the covid-19 pandemic. At the end of 2020, a total of 714GW of capacity were deployed by various countries through the use of solar PV systems as the third-highest RES installed after hydropower (1.211GW) and wind (733GW) [13]. There 5 five types of solar PV installations[14], as shown in Figure 1.

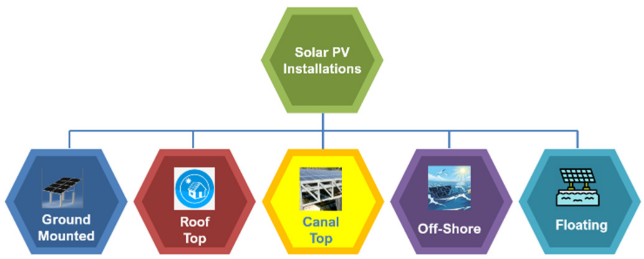

Fig. 1. Classification of solar installations.

The ground-mounted system is commonly adopted by large-scale or utility-scale installations and generally performs as a power plant [15]. This type of installation is generally in the Mega-Watt-peak (MWp) capacity scale. At the same time, rooftop installations are commonly used by households or commercial buildings with small to medium capacity scale. Households typically install one 1kWp systems and no more than 20kWp systems, depending on the energy requirements. Commercial buildings often exceed 100kW or more in capacity [16]. There are also installations wherein solar PV panels are typically mounted over a canal or irrigation system. The oceans are vastly available and attractive for solar PV installations, and there offshore installation is coming in. Offshore installations have a full view of the sun with no problems in shading that would affect the system's efficiency [16]. However, offshore installations are exposed to higher risks in terms of higher-level waves or even tidal waves [17].

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A. Floating Solar Photovoltaic (FSPV) Systems

The floating type of installation is a newer concept gaining traction and is considered an emerging technology in renewable energy [14, 18-21]. FSPV is a solar application, in which PV panels are designed and installed to float on water bodies [18]. FSPV systems are commonly deployed in hydroelectric reservoirs [19, 21] and irrigation dams [22, 23], including abandoned depleted mines [24-26]. In FSPV, solar panels are usually mounted upon a pontoon-based floating structure to keep its location fixed, and the floating system is anchored and moored [27]. The use of FSPV protects productive lands and prevents the conversion of agricultural land to solar farms [20, 28]. Unlike the ground-mounted system, the FSPV currently has no commercial deployments but is primarily used in demonstrator projects deployed in various countries [29], including Philippines [30]. The research and development activities of FSPVs gained interest during the last decade due to benefits other from providing clean energy. FSPV has several advantages over the traditional land-based solar PV systems. Among these benefits are [19, 21, 39, 32, 33]: economic viability due to reduced real-estate costs, the cooling effect of water which improves the energy yield on the FSPV system, the shading provided by the FSPV panels on the water reduces the rate of evaporation and improves water quality by lowering algae growth, and the lesser accumulation of dust on the panel arrays as the surrounding environment of water surfaces contains less dust than land.

B. Artificial Intelligence (AI) Applications in Renewable Energy Systems

Several studies have been conducted on AI in RESs and specifically in solar PVs [34-36]. Authors in [36] presented two of the most innovative AI algorithms for cost-effectiveness, software appropriateness, accuracy, and viability of instantaneous applications. It was established from the research that the application of AI and IoT for Fault Detection and Diagnosis (FDD), using cost-effective hardware and chips, is technically and economically viable in solar PV plants situated in far-flung areas faced with maintenance accessibility issues. AI applications and IoT implementations use data loggers and monitoring systems to collect data and implement fault detection algorithms to check the PV plant performance. These methods are often used for PV systems with a few kW to hundreds of MWs [37]. However, a large dataset is being used (measured currents, voltages, solar irradiance, infrared or electro-luminance images) in order to identify and diagnose faults [37].

In this paper, the authors intend to identify the resources needed to implement these data loggers to monitor and automate system operation of an FSPV system. The FSPV system is potentially exposed to environmental events such as typhoons, water level raises, and flooding. With the application of AI algorithms and monitoring systems, the problems are minimized.

II. BRIEF BACKGROUND OF THE PHILIPPINE LAKES

The Philippines is home to over a hundred freshwater lakes of various sizes, from a few hundred to a thousand hectares. The lakes in the country have a total area of more than 200 thousand hectares. These lakes are known to be of particular use to the nearby communities due to their economic contributions, specifically in fishing activities [38]. Table I shows the top 5 lakes in terms of area. The Lakes Lanao, Taal, and Laguna de Bay, the latter in particular, are the most popular lakes due to, among others, their domestic and aquaculture uses. These lakes have the potential for FSPV implementation.

TABLE I. FIVE BIGGEST LAKES IN THE PHILIPPINES

Name of the lake	Location	Area (ha)
Laguna de Bay	Cavite, Laguna, Rizal &Quezon	93,000
Lanao	Lanao del Sur	34,000
Taal	Batangas	23,420
Mainit	Agusan del Norte, Surigao del Norte	17,340
Naujan	Oriental Mindoro	8,125

A. Status of FSPV in Philippines and Objectives of this Study

In Philippines, FSPVs are very much unexplored. There are very limited investigations or research and development activities related to the FSPVs in the country, especially from Higher Education Institutions (HEIs). There are no reports, documents or journal articles that can be found in highly regarded journals or in conference proceedings related to the FSPV development in the country, when prior searches were conducted. There are no existing reports on FSPV systems made known to the proponents from other HEIs. This paper explored the FSPV potential from an academic point of view. This paper provides pioneer and preliminary information regarding the consideration of FSPV placement in the local lakes. The main objective of this paper is to explore and determine the resources needed to implement an FSPV system integrated with AI applications to automate its operation. The specific objectives of this study were to determine and identify the potential of FSPV system implementation in Lake Mainit in the Caraga Region, Philippines. This study investigated the needs of a specific community in terms of adopting the FSPV system. The data collected from the community served as a baseline for consideration of the resources needed for the establishment of the FSPV system. This study explored and investigated the solar PV potential in the target location with the attainment of solar irradiance and solar power output that served as input data to determine the resources required for the FSPV System. The components (i.e. IoT devices, microcontrollers, etc.) that will act as devices to implement the AI application aspect of the operations of the FSPV were determined.

III. METHODOLOGY

This paper employed a descriptive research design. A desktop study was accomplished to identify the prior available information relevant to this particular investigation (Figure 2). Data collection for the potential resources needed consisted of field visits with officials and dialogue with the community representatives, and initial assessments of the prospective area.

A literature review of the relevant studies was conducted. The use of available maps and information from relevant websites was performed to identify the potential location of the study site and the geographic characteristics of the area. This part of the methodology was carried out to determine the latest available data on PV power potential, global horizontal radiation, and direct normal radiation. Analysis was performed to determine the potential system sizing and the needed components, based on the possible resources available for the FSPV system and the requirements for an AI-integrated system.

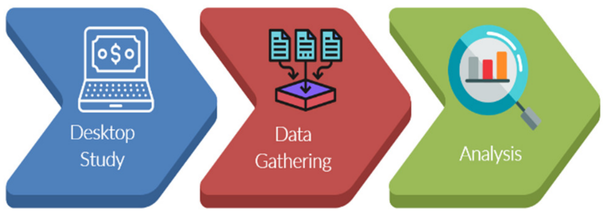

Fig. 2. The methodology of this study consists of a desktop study, data gathering, and analysis.

IV. ASSESSMENT RESULTS AND DISCUSSION

A. Site Identification and Field Assessment

Pre-assessment was conducted to determine the most viable lake for the conduct of the study based on location, potential, and viability. The lead author of this study is a professor at Caraga State University, Butuan City in the Philippines. The most viable lake which the lead author is closest to is Lake Mainit in the northeast of Mindanao. Lake Mainit is the 4th largest lake and is considered the deepest in the country [38]. It is home to several communities with their livelihoods depended on fishing activities. It is bounded by the municipalities of Jabonga and Kitcharao in Agusan del Norte and the municipalities of Mainit and Alegria in Surigao del Norte. The target location for the FSPV is in the control of Barangay San Roque, Jabonga, Agusan del Norte (with coordinates: 9.3754141,125.5549301). The authors surveyed the area for potential locations of the proposed implementation site. With prior cooperation with the Local Government Unit (LGU) in Jabonga, Agusan del Norte on other projects, the authors were referred to the fishing village with concerns about the high cost of battery charging. The authors met with the representatives of the fishers and some officials of San Roque in Jabonga, where the village is located along Lake Mainit. Consultations for the proposed project were carried out to correctly identify problems with the local community and have a shared understanding and acceptability. This is a part of the design thinking methodology wherein end-users are considered when innovations and technologies are developed to ensure that the solutions provide impact to the project users.

As per field inspection and consultations, 110 fishers with their family members in Barangay San Roque in Jabonga, Agusan del Norte, Philippines live below the poverty line and rely on their overnight fish catch at Lake Mainit. The fishers in this area use basic lighting systems consisting of 12V-100Ah batteries and 12V led bulbs that absorb a significant chunk of their annual income. The fishers had to charge their batteries during daytime to use them on their nighttime work. According to them, this would incur further costs at Php50 a day (USD1.00) to charge the batteries using the electrical power from the electricity grid, spending about 1/6 to 1/4 of their daily income depending on the previous night's harvest. This would translate to Php1,500.00 (USD30.00) per month, maybe enough to buy one sack of rice for a family of five for their one-month consumption.

B. Solar Photovoltaic Power Potential, Global Horizontal Radiation, and Direct Normal Radiation

The sun is the most abundant source of energy available on earth. The sun's power output is known as solar radiation, or as emission. A common term in solar power is irradiation, and it is defined as the radiation delivered to a given surface area at any given time. Solar irradiance is the measurement of the sun's radiation and is expressed in W/m^2. The Philippines is well-positioned to maximize its potential in solar energy due to its geography. The solar radiation for the country was pegged at 161.7W/m^2 on average per day in 2013 based on the duration of the sunlight as provided by the report of the National Renewable Energy Laboratory and the country's Department of Energy in 2013. Recently, Solargis released and updated, on October 2019, a massive collection of solar resource maps for over 140 countries to assist the solar industry in further development and implementation of solar-related projects. The countries with available maps include the Philippines [39]. The data collected by Solargis are much more recent, covering dates from 2007 to 2018. Solargis methodology uses data inputs from geostationary satellites and meteorological models to develop the maps. Based on these recent data, the year-round average global horizontal irradiance in Lake Mainit of Jabonga, Agusan del Norte is at 4.4kWhr/m^2. The solar PV power potential is at 3.6kWhr/kWp. These figures will be used in estimating the size of the FSPV system and the resource potential of the lake to produce solar energy. If the entire Lake Mainit is covered with solar PV systems, the potential energy that can be generated from the available area will reach 762.96MWh. For practical purposes, the authors intend to identify the specific resources based on the capacity of the FSPV system and primarily on the energy consumption requirements of the fishing village.

C. Resource Analysis for the FSPV System and Battery Storage based on the Potential Resources

Every fisher in Barangay San Roque uses one 100Ah battery and three 9W-12V DC LED bulbs to last overnight. For the 110 fishers, the total battery storage requirement is 2200Ah and 330 pieces of 9 W-12 V DC LED bulbs. These figures are significant in determining the minimum size of the battery storage and charging capacity and the FSPV system. Each day, the FSPV system needs to respond to the requirement of 27W multiplied by 110 fishers as the required capacity. The batteries are assumed to be used for 12h (from sundown to sunrise). With this figure, the resources needed to put up the FSPV should satisfy the 35,640Whr daily energy requirement. Using the solar PV power potential data at 3.6kWhr/kWp, we can solve the system size, which is 35,640Whr divided by 3.6kWhr/kWp. This would give us an FSPV system size of 9.90kWp. Theoretically, the 12V-100Ah battery can last 44.44h or around 3 days of use. The requirement to charge the battery based on the consumption of a 27W bulb in 12h (6 PM-

6 AM) is 324Wh per day. The total capacity needed from 324Wh times the number of fishers gives us a 35,640Wh energy requirement to be supplied by the FSPV system each day. In battery storage, the capacity requirement is 35,640Wh divided by 12V which gives 2,970Ah or an equivalent of 29.7(~30) units of 100Ah batteries. In order to address the community's needs, the FSPV system size should be at 9.90kWp and 30 units of 100Ah batteries. The 9.90kWp system can be rounded off to 10kWp and can be divided into two arrays of 5kWp. This 10kWp FSPV system requires two power inverters rated at 5,000W. For solar panels, there are various sizes in the market available, from 160Wp to 670Wp. Twenty 500Wp solar panels are the expected rating for the 10kWp system.

D. Resource Identification

The FSPV system with AI applications requires the essential components to implement a solar PV power plant. Figure 3 shows the block diagram for the FSPV system comprising of: (1) the floating solar plant, (2) the combiner box, (3) a power inverter, (4) the data acquisition and wireless transmission unit, (5) battery bank or storage, and (6) the data receiving monitoring and supervision unit. The critical components for the AI applications include the sensors that shall be applied to acquire the data coming from the floating PV plant. In Figure 4 we see the block diagram concerning the sensed data to be processed and analyzed using machine learning to identify faults and diagnose electrical problems in the system. The components needed comprise current, voltage, wind speed, air temperature, relative humidity, and wave sensors. For this specific implementation of a 10kWp FSPV system broken down into 2 PV arrays at 5kWp each, there will be 2 sensors for the current and voltage to monitor the arrays.

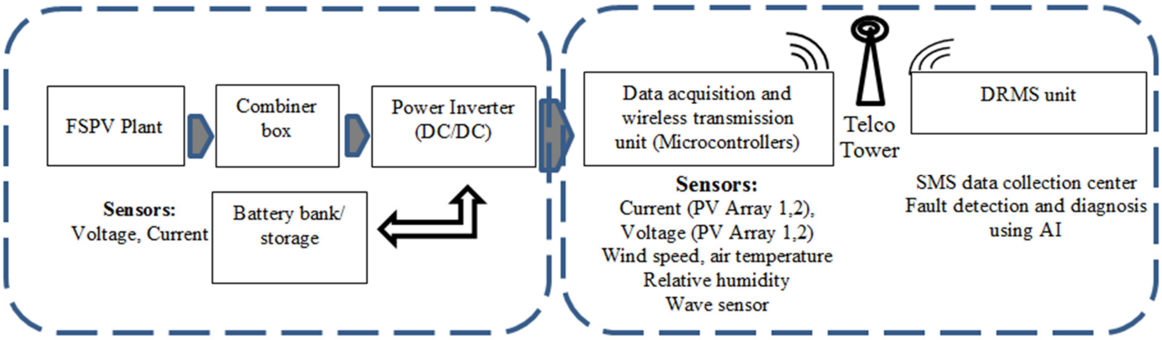

Fig. 3. The block diagram for the FSPV system with AI application.

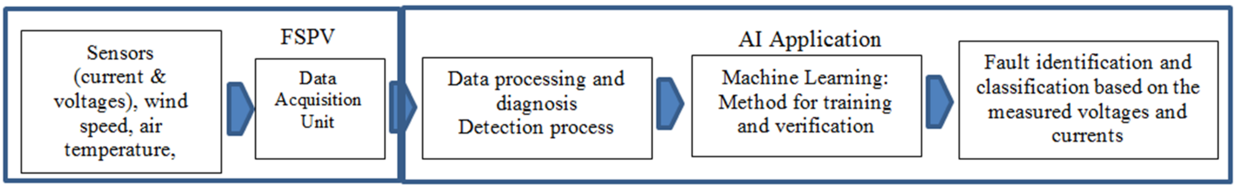

Fig. 4. Block diagram for the AI applications using machine learning on the diagnosis and fault detection of the FSPV system.

The use of microcontrollers and wireless devices enables the system to collect data coming from the sensors and be transmitted via SMS using the current telecommunication infrastructure. The data from the PV plant and battery storage shall be collected from the Data Receiving, Monitoring, and Supervision (DRMS) unit at a remote location, specifically in the site where the researchers are based. The AI techniques are implemented at the DRMS unit to monitor, detect and diagnose any faults in the FSPV system and implement the actions necessary to prevent harm when the conditions at the FSPV site are undesirable (i.e. strong wind conditions leading to undesired wave levels). The AI components monitor the current and voltage outputs of the two PV arrays including data such as wind speed, wave level, and temperature. Various devices are available to carry out these functions. Most data processing and diagnosis detection tools can be carried out by high-powered computing machinery available currently in the research laboratory or in the university's R&D center called High Performing Computing (HPC) Center.

V. SUMMARY AND CONCLUSIONS

The motivation behind this paper was to primarily investigate and assess the resources available for energy conversion in Lake Mainit, Caraga Region, Philippines. Assessment was carried out to determine if it is viable to implement an FSPV system based on the needs and requirements around the lake. While traditionally FSPV systems are installed in dams to complement hydroelectric power generation and for power generation for the electric grid, for this particular case, a community of fishermen was explored as recipients for the FSPV system output. Based on the findings, the Lake Mainit area has a year-round average global horizontal irradiance of 4.4kWhr/m^2 and a solar PV power potential of 3.6kWh/kWp. If the entire Lake Mainit is covered with solar PVs, the potential energy that can be generated will reach 762.96MWh per year. For the fishers' daily requirements, the resources needed to put up the FSPV should satisfy the 35,640Whr daily energy requirement. The FSPV system size was computed at 9.90kWp. This is the minimum FSPV system size required to provide for the community's needs.

The resources needed to implement an AI-ready FSPV system were also briefly highlighted. The implementation of AI using Machine Learning tools to automate the diagnostics and fault detection in the system mitigates or prevents misfortunes when the FSPV system is deployed. The system requires various environmental sensors that cover data gathering on wind speed, wave level, temperature, humidity, voltage, and currents. These form a part of the bigger data acquisition unit installed at the system's location. The data processing and machine learning techniques will be executed at the university's R&D laboratory.

Based on this resource assessment and identification of the resources needed to put up the FSPV system, there is an excellent motivation to pursue the implementation of the FSPV system to address the identified needs of community. The solar resource potential in Lake Mainit is massive. This study provided a preliminary basis for future renewable energy system implementation, in the form of FSPV, specifically in Lake Mainit, Philippines.

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