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Simulation of Photovoltaic Water Pumping System in Sam Ratulangi University

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Abstract. Photovoltaic water pumps system can be a good option for renewable energy utilization and demonstration. The purpose of this study is to design and simulation a solar water pumping system in Sam Ratulangi University. This design can be a show case for promoting solar energy utilization as well as education for the students in Sam Ratulangi university of Indonesia. The methods used for this study are consists of literature review, design and simulation using HOMER (Hybrid Optimization of Multiple Energy Resources) software for the comparison between solar water pump and diesel power water pump is analyzed in term of net present cost, cost of energy (COE) and the emission to supply the water requirement in the laboratory. The result of simulation has been done in 2 scenarios of design about solar photovoltaic water pumping system in a laboratory scale as a case study. For scenario 1, the system has a daily load of 1.5 kWh/ day, 0.52 kW PV modules, 4 batteries 80 Ah and 1 kW inverter. For scenario 2, the system has a daily pump load of 2.5 kWh/day, 0.87 kW PV modules, 4 batteries 80 Ah and 1 kW inverter .The result indicates that the utilization of solar energy to power a PV water pumping done well and can be a showcase of case study about utilization of solar energy. For further studies about solar pump system application need to be implemented and tested for the performance of solar photovoltaic water pumping system.

1. Introduction

Photovoltaic water pump (PWP) system application can be a good option for renewable energy demonstration. It also give an example of green technology for further implementation. Besides that, the attraction of environment utilization of PWP system increase the beneficial of this technology application. The purpose of this research is to design and conduct techno-economic analysis for a solar pump that located in Sam Ratulangi university for demonstration site of solar energy utilization.

The PV water pump system is suitable for reducing Green House Gas that produced by diesel pump or electric grid that supply by fossil power plant. A PV system, or Solar Photovoltaic system, is a highly suitable solution for reducing the Greenhouse Gas (GHG) emissions that are produced by diesel pumps or electric grids supplied by fossil fuel power plants. By harnessing the power of sunlight, Solar PV systems generate electricity without relying on fossil fuels, thereby significantly mitigating the release of harmful GHG emissions into the atmosphere.

When compared to diesel pumps, PV systems offer numerous environmental benefits. Diesel pumps require the combustion of fossil fuels, which releases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N2O) emissions. These emissions contribute to global warming and air pollution, leading to adverse effects on human health and the environment. In contrast, Solar PV systems convert sunlight directly into electricity using photovoltaic cells, without any combustion process or associated emissions. Thus, using solar power instead of diesel pumps helps combat climate change by reducing the overall carbon footprint.

2. Literature Reviews

There are many studies has been conduct to demonstrate the utilization of optimization techniques in designing photovoltaic (PV) systems for water pumping and various other applications using HOMER (Hybrid Optimization of Multiple Energy Resources) software (Salam et al., 2013)(Kazem et al., 2013)(Kazem et al., 2015)(Girma, 2013)(Mishra, and Singh, 2013). In (Salam et al., 2013), the authors designed a PV system to power the lighting load in a laboratory, while in (Kazem et al., 2013), the system was designed for a typical house load in Oman. The authors employed HOMER software to determine the optimal design for each system. They reported that the cost of energy generated by the PV system in the laboratory application was calculated to be 0.561 USD per kilowatt-hour (kWh). Similarly, for the typical house load, the authors claimed a cost of energy of 0.389 USD/kWh.
In (Kazem et al., 2015) presents the design and evaluation of a photovoltaic (PV) water pumping system in Sohar, Oman. The research focused on selecting the optimal components for the system, including PV modules, inverter, charger controller, and batteries specific to Oman. The daily energy load for the system was determined to be 2.22 kWh/day, with 0.84 kW of PV modules, 4 batteries (12V and 200 Ah), and a 0.8 kW inverter. The results of the study demonstrated that the PV system offered an attractive option with an optimum cost of energy at 0.309 USD per kilowatt-hour (kWh), as compared to the cost of energy from a diesel engine, which was reported to be 0.79 USD/kWh.
In (Girma, 2013), the authors conducted a study in Ethiopia where they designed and examined a hybrid PV/diesel generator system using HOMER software. The system was intended to supply a village with a daily energy consumption of 279 kWh. The optimized design indicated that 95% of the energy demand could be met by the PV system, while the remaining 5% would be generated by a diesel generator. The estimated cost of energy produced by the system was found to be 0.401 USD per kilowatt-hour (kWh). In (Mishra, and Singh, 2013) presents a proposal for the optimal design of a hybrid PV/biomass system, which was developed using HOMER software. The objective of the system was to provide energy to a village in India for two primary purposes: cooking and operating a water pumping system for irrigation. The authors aimed to determine the most efficient design configuration for the system in order to meet these energy demands effectively.
This study is the continuity techno economic analysis for the prototype that has been designed and developed (Bakelli et al., 2011). The prototype, as initially conceptualized and crafted by Bakelli and colleagues in 2011, serves as the nucleus of the ongoing research endeavors. This study aims to deepen our understanding of the prototype's technological nuances, providing an in-depth exploration of its operational efficiency, durability, and adaptability to real-world scenarios. By scrutinizing the technical aspects of the prototype, we seek to uncover valuable insights that can inform future iterations or applications in related contexts.
The previous study by author aims to showcase the utilization of solar energy to empower island communities, indicating successful utilization of solar energy for water pumping. The authors suggest further studies to explore and scale up solar pump system applications in terms of technical and economic considerations (Rumbayan et al., 2023). The review work covers various aspects such as renewable energy source water pumping systems, designing methods, control strategies, and field performance of photovoltaic water pumping systems, as reported in (Sontake et al., 2016). Additionally, a review on solar photovoltaic water pumping systems discusses the scope and limitations of photovoltaic solar water pumping systems, describing the components and functioning of PV solar pumping systems. It also includes a review of research works by previous researchers and emphasizes the popular and ideal use of solar energy exploitation in water pumping applications (Dhage et al., 2017).
Solar Pump system is a proven technology can be served for water requirements, irrigation and industrial application in both small and large size. The design of solar pump system depend on the requirement, solar availability and the budget. It is a challenge for the many researchers to design SPWP system based on the technical, economical and environmental analysis.

In essence, the design of a Solar Pump system represents a convergence of technology, economics, and environmental stewardship. The challenge lies in harmonizing these elements to create a system that not only meets the immediate water needs efficiently but also does so in a manner that is economically viable and environmentally responsible. Researchers engaged in the design of Solar Pump systems thus play a pivotal role in advancing sustainable water solutions, contributing to the ongoing global efforts to harness clean energy for essential applications.

3. Methods

The methods of simulation were used in this work consists of technical analysis and economic analysis based on HOMER software. HOMER is one the software application that used for analysing the feasibility of renewable energy system developed by National renewable Energy Laboratory (NREL). HOMER (Hybrid Optimization of Multiple Energy Resources) software navigates the complexities of building cost effective and reliable hybrid microgrid.

The data is used about solar radiation and clearness index for the location of Manado taken from NASA database in HOMER and presented in Figure 1.

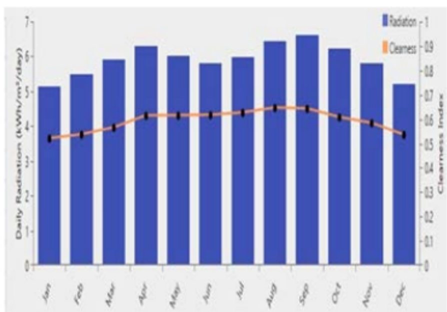

Figure 1 The solar radiation and clearness index data for the location in this study

As the solar radiation is high enough between 10:00AM and 3:00 PM it is considered the solar PV system is generating electricity in this period to supply the 350 liter water storage in a tank.

In this work, solar water pumping system has been designed for a toilet water supply in a laboratory that located at Faculty of Engineering, Sam Ratulangi University, Manado. The solar water pump system will be installed at laboratory for demonstration site. The proposed system in this study is comprised of several components, including a PV array with a limited number of modules, a charge controller, an inverter, batteries for energy storage, and additional components such as wires, protections, and module structures.

The solar water pump system is designed for 2 scenarios, i.e using 0.3 kW pump for scenario 1 and using 0.5 kW for scenario 2. The schematic diagram in HOMER model for the designed electric load to supply solar pump system is presented in Figure 2 and Figure 3 for scenario 1 and scenario 2 respectively.

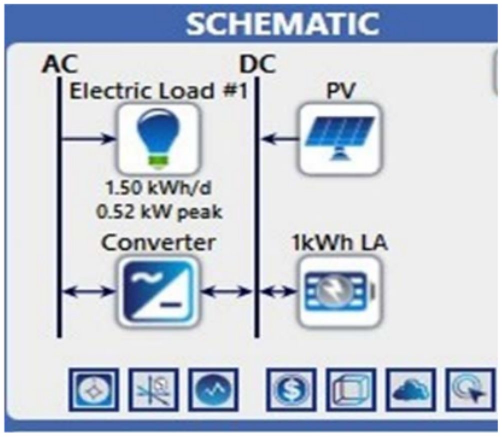

Figure 2 The schematic of PV system for supplying the 0.3 kW solar water pump in this work (scenario 1)

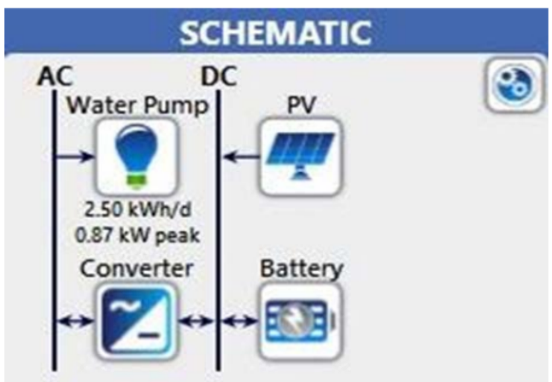

Figure 3. The schematic of PV system for supplying the 0.5 kW of solar water pump in this work (scenario 2)

Figures 2 and 3 illustrate the intricately designed schematic of a cutting-edge photovoltaic power water pump system meticulously crafted to fulfil the imperative role of supplying water to the designated demonstration site. This innovative system seamlessly integrates advanced photovoltaic technology to harness solar energy, presenting an eco-friendly and sustainable solution for the efficient and reliable provision of water resources at the demonstration site in Faculty of Engineering, Sam Ratulangi University.

At the heart of this innovation lies the seamless integration of advanced photovoltaic technology, a testament to its commitment to harnessing solar energy. The incorporation of cutting-edge photovoltaic elements underscores the system's commitment to sustainability, offering an eco-friendly alternative for meeting the water requirements of the demonstration site. This integration not only reduces the system's environmental impact but also positions it as a forward-thinking and responsible solution in the realm of water resource management.

This holistic approach emphasizes the convergence of technology and environmental consciousness, creating a symbiotic relationship between the innovative use of solar power and the imperative need for a reliable and efficient water supply. As a result, the system emerges as a beacon of sustainable engineering, providing not only a glimpse into the future of water management but also serving as a tangible example of how advancements in technology can be harnessed for the betterment of both humanity and the environment.

4. Results

The feasibility of the proposed solar water pumping system was designed and analyzed using HOMER. After simulating the system model in HOMER, the result shows that the greatest optimal result is achieved when the system is composed of 0.546 kW PV array, 4 batteries, and 0.8kW inverter. The economic analysis of the proposed model system find the total NPC is Rp. 16,800,000 (1,120 USD) and the cost of energy as 3,400 Rp/kWh equals 0.23 USD/kWh. The result is acceptable compare to other results were 0.561 USD/kWh (Salam et al., 2013), 0.389 USD/kWh (Kazem et al., 2013), 0.309 USD/kWh (Kazem et al., 2015), 0.401 USD/ kWh (Bakelli et al., 2011), 0.21-0.304 USD/kWh (Al-Badi et al., 2011) and 0.327-0.361 (Al-Badi et al., 2012). The result of techno economical study is presented in Table 1.

Table 1. The result of techno economical study between scenario 1 and scenario 2

	Scenario 1	Scenario 2
Cost of energy (Rp/kWh)	3400	2370
Net Present Cost (Rp)	16,800,000	27,000,000

To compare the PV system results with the diesel generator to choose the best and costless system, This comparative study analysis shows that a size of 0.3 kW and 0.5 kW generator has been estimated with capital, operating, and total net cost being Rp 3,000,000 (equal to 300 USD), 200 (USD/yr), and 8,185 USD, respectively. The cost of Energy (CoE) is found to be Rp. 3212 per kWh (0.21 USD/kWh), which is considered to be high as compared with CoE of the proposed PV system. The schematic of 0.3 kW and 0.5 kW diesel generator plant for powering the water pump as shown in Figure 4 and Figure 5 respectively.

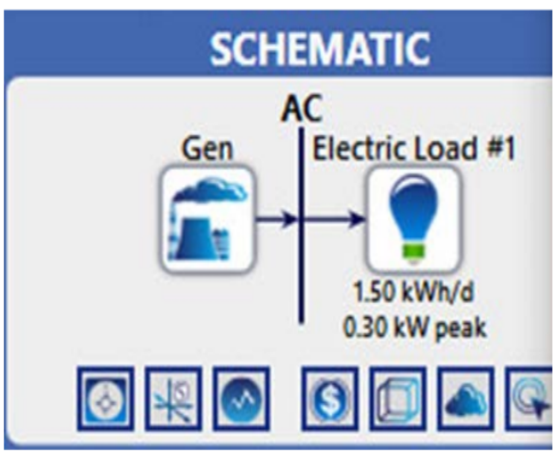

Figure 4. The schematic of 0.3 kW diesel plant for supplying water pump pump 0.3 kW

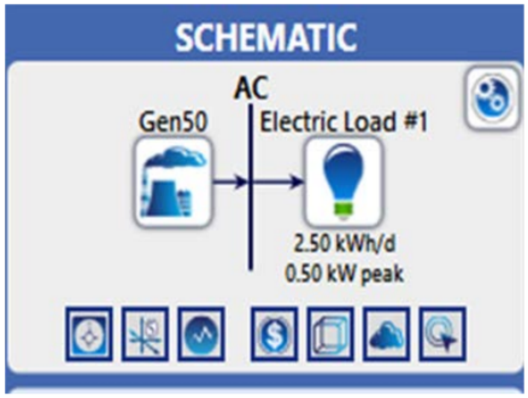

Figure 5. The schematic of 0.5 kW diesel plant for supplying water pump

The amount of greenhouse gas emission produced by the diesel generator for 0.3 kW and 0.5 kW is presented in Table 2.

Table 2. The amount of greenhouse gas emission produced by the diesel generator for 0.3 kW and 0.5 kW

Pollutant	Emission (kg/year)	Emission (kg/year)
Carbon dioxide	426	810
Carbon monoxide	2.69	5.05
Unburned hydrocarbons	0.117	0.223
Particulate matter	0.0163	0.03
Sulfur dioxide	1.04	1.98
Nitrogen oxides	2.52	4.75

5. Conclusion

The technical and economic analysis of solar water pump is found feasible to implement. In this study water pumping system for a laboratory in Sam Ratulangi university has been designed. For scenario 1, the system has a daily load of 1.5 kWh/ day, 0.52 kW PV modules, 4 batteries 80 Ah and 1 kW inverter. For scenario 2, the system has a daily pump load of 2.5 kWh/day, 0.87 kW PV modules, 4 batteries 80 Ah and 1 kW inverter.

The economic analysis in term of Cost of energy (COE) and Net Present Cost (NPC) have been calculated for scenario 1 and scenario 2. The COE is Rp 3400 per kWh for scenario 1, while Rp 2370 per kWh for scenario 2. For the NPC is Rp. 16,800,000 for scenario 1 while Rp 27,000,000 for scenario 2.

The environment analysis shows that substituting diesel power pump system by solar power pump will reduce the greenhouse gas (GHG) emission 425 kg/year of CO2, 2.69 kg/year of CO, 0.117 kg/year of HC, 0.0163 kg/year of particulate matter, 1.04 kg/year of SO2, and 2.52 kg/year of NOx.

Solar PV systems provide a sustainable and environmentally friendly alternative to diesel pumps and fossil fuel-based electric grids. By harnessing the power of the sun, these systems enable the production of clean, renewable electricity, effectively reducing GHG emission associated with the combustion of fossil fuels. Implementing Solar PV systems on a wider scale can play a crucial role in mitigating climate change and transitioning towards a more sustainable and low-carbon future.

In essence, this research encapsulates more than just a design and simulation; it encapsulates the thoughtful planning and strategic placement of PV panels within the Faculty of Engineering at Sam Ratulangi University. It serves as a visual testament to the university's commitment to sustainable energy practices and offers insights into the optimized utilization of solar resources within the educational institution's infrastructure.

Further research and practical implementation are necessary to explore innovative approaches, optimize system performance, and expand the adoption of solar water pumps in small-scale settings. The continuity of research is integral for bridging the gap between theoretical conceptualization and practical implementation. This study represents a forward-looking exploration, building upon established foundations to contribute to the evolution of the prototype's trajectory. It provides valuable insights that can inform future developments, applications, and decisions within the realm of technological innovation and economic viability.

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