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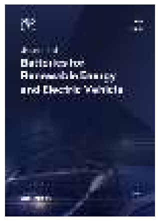

The Potency of Seawater Battery with NiHCF + C Cathode Paired to Wind Turbine for Generating Clean Electricity in Rural Area

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A B S T R A C T

Electricity supply becomes the main issue in every country, because most of them are not distributed well. Electricity deficit potentially threatens the society and hampers the economic growth due to lack of power capacity. At the same time, many areas have untapped renewable sources that possibly fulfill the electricity demand. In fact, renewable energy (RE) is more environmentally friendly compared to fossil fuels power plant. However, the RE intermittency remains a problem. The most promising solution comes from RE storage, one of them are seawater battery. Besides it does not depend on heavy metal extraction, in which claimed safer, seawater also has a maximum power density and more effective voltage efficiency. The utility of seawater battery possibly will be used as RE storage on wind turbines system in rural area so-called 3T. In this study, seawater battery applies NiHCF cathode. NiHCF intercalation of sodium is synthesized using a gellatic method. NiHCF is smoothed and blended with polyvinylidene fluoride and black carbon at 3.5 milliliters 1-metil-2-pyrrolidone. The NiHCF cathode has an advantage of a voltage discharge with a 60-86% range. Compared with RO battery, seawater battery has nearly twice as much efficiency as RO battery. It is also known in previous research that NiHCF cathode has a capacity at 75 kW. The seawater battery is composed in a three-part battery pack, namely C1, C2, and C3. The separator that is used between C1 and C2 is AEM, while between C2 and C3 is NASICON. Electricity flows from wind turbines that generates electricity and streams to the battery pack, then distributes to the user.

INTRODUCTION

Energy demand always increases following the population growth. However, it is not accompanied with amount of electricity supply. Particularly in Indonesia, electricity supply has not been depleted yet. Although it has experienced power supply shortage in some areas, it is predicted that energy deficit will occur while the power capacity cannot meet the raised of electricity consumption. According to Electricity Supply Business Plan or so called *Rencana Usaha Penyediaan Tenaga Listrik* (RUPTL) PLN year of 2021, stated that by 2030, new renewable energy in rural areas will not be built and will only depend on diesel power plant or PLTD [1].

It is highly volatile to see resources opportunities that can be used to harness renewable energy resources. At the same time, it will comply with electricity needs in the rural areas without any electricity grids.

Merauke becomes the strategic example for 3T (Frontier, Outermost and Least Developed) area, in which has a potential resource for utilizing renewable energy sources. As depicted in Fig. 1, the wind at Merauke region reached 9 m/s with wind energy average is about 200 W/m^2 in a year [2].

Given that Merauke region's electricity supply is limited, its territory has a potential to establish renewable energy technology through Bayu power generation or *Pembangkit Listrik Tenaga Bayu* (PLTB). The PLTB could be a solution to meet electricity needs. Theoretically, PLTB uses wind turbines to catch up kinetic energy from wind, rotate the generator and generate electricity [3].

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Those powerplant categorized as green renewable energy, because the total of carbon emission produced by wind power are 118.8 kg/MWh, much less compared to fossil fuel with 31 million kg/MWh [4]. Hence, the implementation of PLTB in Merauke is critical to utilize wind renewable sources to solve limited electricity issue.

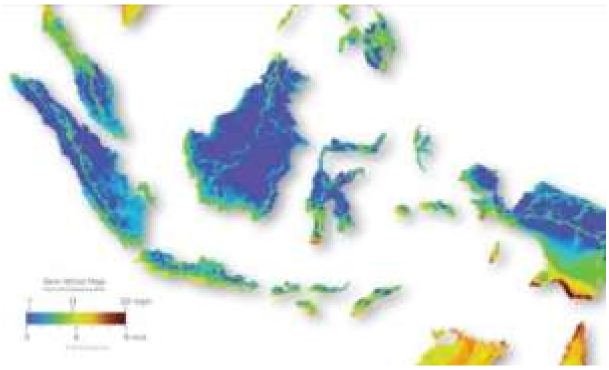

Fig. 1. Wind speed in Indonesia at 80 m height [4]

Furthermore, PLTB will be more efficient while it is paired by energy storage technology. The use of seawater battery pack as a storage system becomes a promising choice compared to lead acid battery. The use of H_2SO_4 material in lead acid battery has a danger potential from its liquid corrosive that can cause skin or even eyes irritation or other harm [5].

Seawater battery does not need heavy metal extraction or toxic material and can be recycled at the end of its cycle. Seawater battery has a maximum power density about 75 kW/m^3 and voltage efficiency at 86%. Seawater battery technology can be optimizied through NiHCF + C cathode that possibly increases its effectiveness as energy storage. NiHCF + C cathode has a larger capacitance and redox reaction. The faster relative reactions so called intercalation/ deintercalation of sodium) increases higher currents on NiHCF cathode. Moreover, energy efficiency that caused by NiHCF is 86%, higher than carbon cathode in 61% [6].

The purpose of this study is to design energy storage system-seawater based that safer and more affordable with better efficiency compared to previous generation. This system is used to store the electricity that generated by wind turbine in 3T region which has a high wind speed. The novelty of seawater cathode is discussed through NiHCF + C compound that potentially enhance battery charging and discharging capability. Additionally, this paper also includes an example of energy storage application on wind turbine system in the 3T area that potentially supply its electricity demands.

METHODOLOGY

NiHCF Cathode

According to Son M. *et al.* (2022), NiHCF intercalation of sodium is synthesized using a cohesive method. Mortar and pestle is used for powder making. NiHCF powder is dissolved along with polyvinylidene flouride and black carbon in 3.5 millilitres-1-metil-2-pyrolidone on a hot plate. NiHCF powder is stirred using vortex-genie 2. A carbon layer has been coated with NiHCF substrate through dorp-casting methods. Then, NiHCF cathode is dried using vacuum ovens together with a silica gel and it is stored in a desiccator siliga gel-based at room temperature [6].

Battery Module Compartment

Based on Son M. *et al.* (2022), battery module consists of three compartments: C1 as cathode compartment, C2 as desalination compartment and C3 as anode compartment. The C1 compartment is filled with 200 ml [200 ml of NaCl 0.6 M], which is chosen to replicate seawater, based on the assumption that the module is operated under seawater conditions.

NiHCF + C cathode then is submerged in C1 with titanium mesh collector. In C2, consists 1.2 M NaCl (3 ml) water. Anion exchange membrane is placed against C1. The other side of the C2 faces C3 (seawater battery coin cell) with a rubber ring to prevent leakage.

For C3, the sodium superior conductor membrane positioned toward C2. As anode, 200 ml electrolytes are mixed to fill C3. Seawater battery coin cells are assembled in glove boxes where argon gas is filled [6].

Wind Turbine as Power Plant

Wind power (including land and ocean winds) occurs as a result of the difference surface temperature between two earth surfaces. In its development, wind energy is converted into mechanical energy then transformed into electrical energy. One type of turbine that can maximize wind energy is a horizontal wind turbine with three blades. This is because horizontal-axis wind turbine with three blades gains power during swivel times and mills capable of moving vertically toward the wind. Wind turbines that is used for the power plant has an output at 87.5 kW. The power plant is projected to produce 2,100 kWh for supplying up to 200 households in Merauke [4].

Electricity Flow from Upstream to Downstream

The electricity system that is applied to the scheme starts with the wind turbines power plant installation. It is installed following the amount of electricity needs. Then, it is combined with battery module to deal with intermittency. Finally, electricity current from the battery pack is switched using a DC transformer to AC and distributed to the users.

RESULTS AND DISCUSSION

Data Comparison

The capacity of NiHCF cathode is measured using CVS at the 0.5 mV/s scanning level. It is 50% higher than carbon electrodes. The higher NiHCF capacity and sharper Current Voltage (CV) show oxidation and iron reduction (Fe (III) ↔ Fe (II)) as well as the intercalation of sodium in the NiHCF structure [7-8].

In NiHCF, nickel plays an important role. Nickel dissipation causes failure of the grid structure to induce a structural failure of iron and at the same time reduces capacity retention. However, increased voltage steps for measuring capacitance are used in the study (three electrodes citation settings), while constant stream operations are used in the literature (galvanostatic load release Settings) [8].

When the voltage at 4.5 V is applied to each cathode in seawater battery system, a higher specific capacity is observed from NiHCF cathode compared to carbon cathode. It is caused by greater capacitance and rapid regenerative reactions on NiHCF cathode. In 24-hour test, NiHCF cathode reached 35.28 mAh battery capacity. It is 26% bigger than carbon-based cathode at 27.99 mAh. NiHCF cathode allows for higher application (>1 m) in the same voltage window (~ 4.5 V) because of sodium intercalation and deintercalation (Na_1 + xNi [Fe $(CN)_6$] = NaNi [Fe$(CN)_6$] + xNa^+ + xe^-). Therefore, bigger current is required to cut-off the desalination time.

Furthermore, NiHCF also has been tested for electricity charging at 3,516 mWh in one hour and discharging at 3,015 mWh with the same cycle. Compared to carbon cathode, charging capacity is 4,040 mWh with less energy in discharge capacity at 2,473 mWh. Thus, NiHCF cathode shows a significant increase in energy efficiency (85.7 ± 3.2%) compared to carbon cathode (61.3 ± 2.6%). The seawater battery system has some unique properties where direct desalination can be higher than seawater (>0.6 M NaCl) [9-10]. CDI and BDI applications are often limited to the desalination of briny water (3 V), theoretically higher than DB (120 bar).

Compared to NiHCF cathode, carbon cathode stores the same amount of energy (~75 kWh/m^3 at 2 mA) but significantly consume more energy for desalination (~ 29 kWh/m^3 at 2 mA).

The current system of seawater battery is estimated to have a cost of USD 1.02/m^3 (lower than 0.6 – 1.2 USD/m^3 for RO battery) to desalination seawater in which has 96% of efficiency [6]. Referring to Son M. *et al.* (2022), attained energy efficiency is (~ 86%) is already competitive.

Seawater Battery Pack for Wind Turbine Power Plant

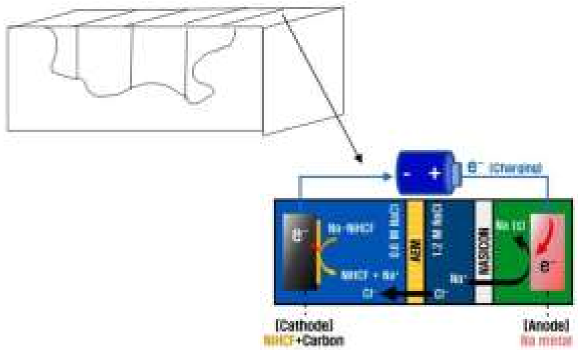

Fig. 2. Compartment Seawater Battery Pack [6].

Considering the result of previous studies, it is concluded that seawater battery NiHCF + C cathode based has a promising efficiency of 86% with cheaper cost about 50% contrasted to RO battery. In battery pack system, there will be an adjustment with more compartments: C1 for the cathodes, C2 for desalination, and C3 for anodes.

Oxygen evolutionary reaction (OER; 4OH compounds O_2 + 2H_2O + 4e^- E0 = - 0,77 vs. SHE) and sodium suspension (4Na + + 4e^- → 4Na E0 = - 2.71 V vs. SHE) occurred in cathode and anode, respectively[6]. Thus, the overall cell voltage during charging is 3.48 V (vs. Na/Na+). During discharing, the reduction of oxygen (ORR) followed the reaction: O_2 + 2H_2O + 2e^- →HO^- + OH^-, E0= 0.21 V vs. DIA; O_2 + 2H_2O + 4e− → 4OH^- E0 = 0.77 V vs. SHE. Also, chlorine (CER) reaction can possibly happen in compartment.

Electricity Flow

The Merauke electricity power distribution scheme would require a one unit of wind turbines with a capacity of ~ 87.5 kW, with an average wind speed of 9 m/s. One unit of wind turbines with three blades able to charge 28 battery packs of seawater battery within one day.

There are 200 households in Merauke that require electricity. For fulfilling electricity demand, wind turbines need a one-day operation that is supported by 24 battery packs.

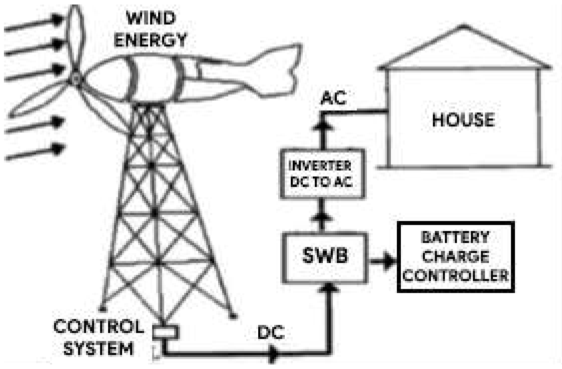

Fig. 3. Electricity Flow from Upstream to Downstream [11]

After the electricity is stored in seawater battery, the current is transformed from DC to AC using a high scale inverter before distributed to user. The aim for those strategy is to maximize the electricity power, because DC has less transportation power and create significant energy storage.

CONCLUSION

Seawater battery with NiHCF + C cathode based has higher efficiency and cheaper cost compared to lead acid battery. Also, it is safer and does not require extraction of heavy metal. Furthermore, seawater battery with NiHCF cathode is more compatible and easier to use in various areas. Hence, seawater battery becomes a suitable candidate for utilizing in rural areas or 3T. With the battery capability amounts 87.5 kW, it is enough to be attached in wind turbines power plant system in 3T area to generate electricity from renewable sources, particularly from wind speed.

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AUTHOR CONTRIBUTION

Fadhillah Raka Pratama, Alfi Gymnastiar Pratama and Beta Maisaroh equally contributed as the main contributors of this paper. All authors read and approved the final version of the paper.

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