

# OCEAN CURRENT ENERGY CONVERSION SYSTEM IN WALLACEA REGION USING VARIABLE SPEED CONTROL APPROACH

**Aditya Sukma Nugraha, Estiko Rijanto**

Research Center for Electrical Power and Mechatronics, Indonesian Institute of Sciences  
Komplek LIPI, Jl. Cisitua No.21/154D,  
Bandung 40135, Indonesia  
adit003@lipi.go.id; estiko.rijanto@lipi.go.id

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## Abstrak

*Ocean Current Energy Conversion System (OCECS)* merupakan salah satu sumber energi ramah lingkungan yang menjanjikan di bumi ini. Data sirkulasi Thermohaline menunjukkan indikasi bahwa kawasan Wallacea memiliki potensi sumber energi arus laut. Tujuan makalah ini adalah untuk mengusulkan penelitian dan pengembangan OCECS yang akan dipasang di kawasan Wallacea. Pertama, pada makalah ini diulas empat macam sistem konversi energi dari lautan. Keunggulan dan kekurangan masing-masing sistem konversi dibandingkan. Kedua, diuraikan potensi OCECS di kawasan Wallacea. Ketiga, beberapa tipe turbin yang dapat digunakan untuk OCECS diulas dan kemudian dipilih tipe turbin yang cocok diaplikasikan di kawasan Wallacea. Keempat, diusulkan strategi pengendalian yang digunakan pada OCECS tersebut. Dari hasil kerja yang dilaporkan pada makalah ini dapat diambil kesimpulan bahwa adalah tepat memilih tipe turbin axial flow untuk OCECS yang akan dipasang di kawasan Wallacea, dan bahwa untuk memaksimalkan konversi energi tersebut maka dipilih pendekatan kendali kecepatan bervariasi bersama-sama dengan kendali mekanisme untuk menggerakkan turbin pada arah vertikal dan menggerakkan turbin pada arah yaw.

Kata kunci: arus laut, konversi energi, daerah Wallacea, kendali kecepatan bervariasi, sirkulasi Thermohaline.

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## Abstract

*Ocean Current Energy Conversion System (OCECS)* is a promising green energy resource in this globe. The Thermohaline circulation data indicates that the Wallacea region has the potential of ocean current energy resources. This paper is aimed to propose research and development of OCECSs to be implemented in the Wallacea region. Firstly, four types of green energy conversion systems extracted from ocean are reviewed. Their advantages and disadvantages are discussed. Secondly, the potential of OCECS in the Wallacea region is described. Third, many types of turbines used for OCECS are reviewed and the turbine type for OCECS is selected to be implemented in the Wallacea region. Fourth, control strategy is proposed. From the work reported in this paper it is concluded that it is appropriate to implement OCECSs using axial flow water turbines in the Wallacea region, and that to maximize energy conversion variable speed control approach is selected together with control of mechanism to move the turbine vertically as well as to rotate the turbine in yaw direction.

Keywords: ocean current, energy conversion, Wallacea region, variable speed control, Thermohaline circulation.

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## I. INTRODUCTION

Wallacea region is important because of at least three reasons: (1) it is historically recognized named after the publication of Wallace's paper in London, July 1<sup>st</sup>, 1858 entitled "On The Tendency of Varieties To Depart Indefinitely from The Original Type" [1]; (2) it is a unique region with its unique biodiversity and unique geographical characteristics [2]; (3) it is now categorized as being under developed eastern Indonesia from the point of view of national development.

At At the closing ceremony of the visit from Prof. Dr. Bruce Alberts, the U.S. special envoy for Science and Technology to Indonesia, the

Wallacea Young Scientists Forum was declared in Ternate on May 15<sup>th</sup>, 2010. Prior to this declaration, three commissions had been established in this forum. Those are: (1) life quality and food, (2) bio diversity, and (3) green energy and environment [3]. In the commission of green energy and environment some matters concerning green energy resources and environment protection were discussed. This paper is written as a follow up of the discussion in the commission of green energy and environment. Although there are many green energy potentials at the Wallacea region, this paper focus on energy resources from ocean.

Presently, there are four types of green energy based on renewable ocean's energy that are becoming promising for future use those are: tidal energy, wave energy, ocean thermal energy, and ocean current energy [4]. Tidal energy is intermittent source of energy because only provides power when the tide is actually moving in or out, yet it is totally predictable and produces electricity reliably. Offshore turbines and vertical-axis turbine are not too expensive to build and neither to maintain. Furthermore, their installations do not give large environmental impact. Tidal turbines provide a larger average power than either wind or wave devices for a given maximum capacity, and they also have higher duty cycle (50 %) than wave turbines (25 %). However, damming estuaries are very expensive to build, and change the environment so they produce negative impact on estuarine ecosystems. For this reason, it is difficult to find suitable sites for tidal barrages.

Wave energy depends on the waves to produce power, so it needs to be extracted in a suitable site where waves are consistently can produce a great deal of energy. Shore based wave turbines requires massive concrete constructions on coastlines which may destroy visual landscape. Meanwhile, offshore wind and wave power farms are unpredictable and unreliable energy sources that are subject to extreme weather conditions.

Ocean thermal energy conversion (OTEC) has many different applications such as water desalination, and it is able to produce both heat and electricity. It has low thermal efficiency because the temperature difference is small (10 to 25°C), so that energy extraction is difficult and expensive. It requires extremely high initial investment and huge civil construction.

Ocean current energy is particularly promising as it is available on frequent, regular, predictable schedule. There is little danger to marine life due to the slow rotation speed.

The objective of this paper is to report preliminary results and to propose research and development of OCECS (Ocean Current Energy Conversion System) to be implemented in the Wallacea region.

## II. METHODOLOGY

In order to achieve the above objective, in this paper the following procedure has been carried out:

- a. Literature survey concerning ocean current potential in Wallacea region.
- b. Literature survey concerning ocean current energy conversion system.

### A. Potential in Wallacea Region

Wallacea is a biogeographical designation for a group of Indonesian islands separated by deep water straits from the Asian and Australian continental shelves. Wallacea is islands within red area shown in Figure 1. The islands of Wallacea lie between Sundaland (the Malay Peninsula, Sumatra, Borneo, Java, and Bali) to the west, and Near Oceania including Australia and New Guinea to the south and east. Provinces and major islands in Wallacea are: Sulawesi (6 provinces), North Maluku (including Halmahera), Maluku (excluding Aru Islands), West Nusa Tenggara (Lombok, Sumbawa), East Nusa Tenggara (including Komodo, Flores, Sumba, West Timor), and East Timor (independent) [5].

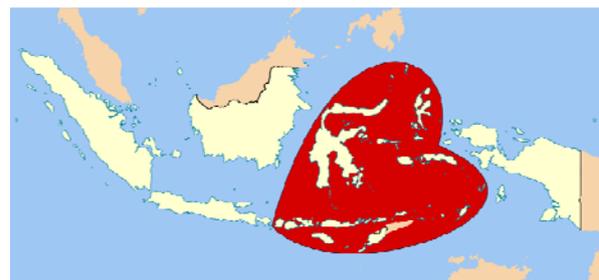


Figure 1. Wallacea region

Wallacea region is a significant location for doing research on biodiversity and geology. Biodiversity conservation in this region becomes an important issue [2].

However, many places in the Wallacea region still have problems of energy (electricity) availability. For example, the electricity utility company which is responsible for the provinces of Maluku and North Maluku covers area of 85728 km<sup>2</sup> with the area of terrestrial is only 8.573 km<sup>2</sup> or 10%. Diesel electrical power plants have been the only sources of electricity [6]. In the Ambon electric utility system there exist diesel electrical power plants with the installed capacity of 55072 kW, but they can only produce electricity of 17900 kW resulting in electricity deficit of 17100 kW at night and 9100 kW in the day. Most of these diesel electrical power plants are in not good condition [7]. At the Seram island 19 villages have not been receiving electricity in the day for 3 years, electricity is only available at night [8].

The balance between development activities to achieve MDG (milenium development goal) and the natural resources conservation becomes challenging. In this context, providing electricity based on green renewable energy is welcomed.

Figure 2 shows global ocean current called Thermohaline Circulation [9], [10]. The ocean current phenomenon is due to radiation of the sun, Coriolis effect because of the rotation of the planet, and density gradient of the sea water. The radiation of the sun and the Coriolis effect yields wind current which moves the surface water of the seas (it is the water between 0 and 400 m of depth) causing ocean surface current denoted by red line. On the other hand, the cold water from the poles tends to go deeply (the water of the depth more than 400 m) to the equator while the warm water from the equator tends to go to the poles by the surface.

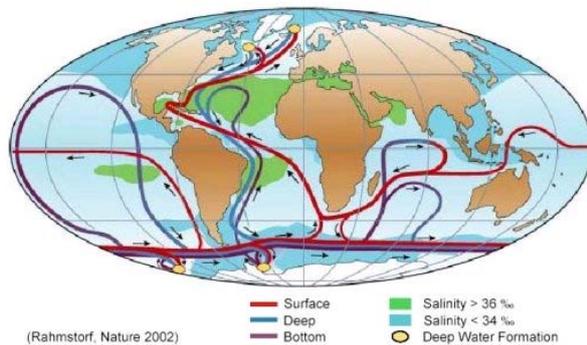


Figure 2. Thermohaline circulation [9], [10].

From the Thermohaline circulation shown in figure 2, it is clear that the Wallacea region is passed by the ocean surface current which is denoted by red line. The ocean surface current flows from the Pacific ocean into the Hindia ocean crossing the Wallacea region. This becomes a preliminary indication of the potential for building electrical power plants based on ocean current. Research on measurement of ocean current in the Wallacea region is necessary to be conducted in order to obtain detail ocean current energy potential mapping.

With the above Thermohaline circulation as the first basis, research on design of electrical power plants using ocean current energy in the Wallacea region is valuable. In the context of national capacity building, it is preferable to conduct research and development of such power plants using as much as national capabilities in cooperation with scientists and engineers from advanced countries.

## B. Ocean Current Energy Conversion

An ocean current electrical power plant is to convert the kinetic energy of the ocean currents to electricity. The amount of the ocean water moves the rotor, and in turn it rotates a generator to produce the electricity. The principle of the ocean current energy conversion system (OCECS) is the same as the wind energy

conversion system (WECS). The Betz principle can be used to derive the power extracted by the turbine as follows [11].

$$P = C_p \left( \frac{1}{2} \rho A v^3 \right) \quad (1)$$

The value of power coefficient  $C_p$  depends on turbine blade construction, its aerodynamics parameter and ocean water current speed and direction.

An OCECS should be designed in order to fulfill the following objectives: maximizing efficiency, being well fixed to the seabed, easy maintenance and operation, environmentally benign, and minimizing costs.

Many researchers, engineers, and companies have been conducting research and development of many types of prototypes to fulfill the above objectives. In this paper they are classified into 3 classes as follows: (1) axial flow water turbine (AFWT), (2) cross flow water turbine (CFWT), and (3) reciprocating wing turbine (RWT).

Ocean Current Turbines (MTC) Ltd based in UK, with financial support from the DTI (Department of Trade and Industry) United Kingdom, the German government, the European community and other partners, has successfully developed a axial flow water turbine (AFWT) prototype having 2 blades named Seaflow shown in figure 3. It has maximum power capacity of 300 kW, and has been successfully implemented in 2003 in Lynmouth, UK. Further development is undertaken to enlarge its power capacity [12].



Figure 3. Seaflow prototype of MTC [12].

Hammerfest Strom, a subsidiary of the Norwegian oil and gas company Statoil Hydro, has developed an axial flow water turbine (AFWT) with 3 blades which can produce maximum power of 300 kW shown in figure 4. This prototype has been installed in the north of Norway, near Kvalsund [4], [13].

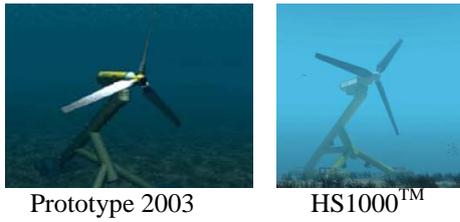


Figure 4. Hammerfest Strom prototypes [4].

Initiated in 2002, Verdant Power’s Roosevelt Island Tidal Energy (RITE) Project is being operated in New York City’s East River. In three phases, the RITE Project conducted testing, demonstrating and delivering commercial electricity from Verdant Power’s *Free Flow Kinetic Hydropower System* (tidal). Phase 1 (2002 – 2006): prototype testing, phase 2 (2006 – 2008): demonstration, phase 3 (2009 – 2012): MW-Scale build-out [14]. Verdant Power would build out the RITE Project in the east channel of the East River to a 1 MW, 30-turbines (Gen5), and commercially deliver the energy generated by the field to local customers. Figures 5 and 6 show Verdant Power turbines.



Figure 5. The turbines are transported to the RITE project site (Sep.2008) [14].

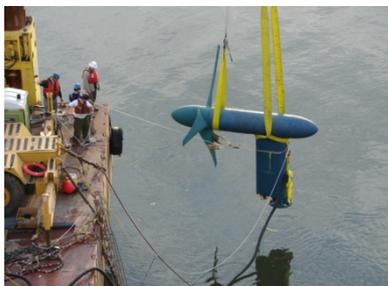


Figure 6. The turbine is being installed in East River (Sep.2008) [14].

Many other researchers have been doing research and development concerning AFWTs [15], [16], [17].

Some types of CFWT have been researched and developed. Some researchers have conducted research on optimization of cross flow turbines and comparison between different types of cross

flow turbines [18], [19], [20]. Jeronimo Zanette et.al. have proposed a new CFWT named Harvest 2007 and proved that it has better performance than Darriusu 1925, Gorlov 1997, and Harvest 2004. Figure 7 shows turbine types of Darrius (a), Gorlov (b), and Harvest 2004 (c), and Figure 8 shows turbine type of Harvest 2007. Brian Kirke and Leo Lazauskas proved that variable pitch Darrius water turbines have some advantages compared to fixed pitch Darrius turbines and helical blades.

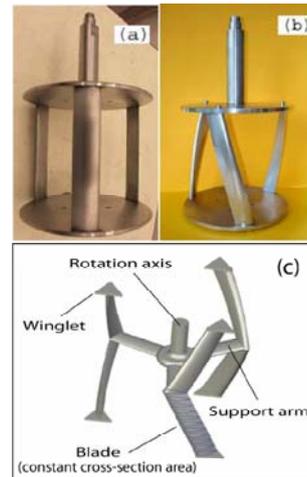


Figure 7. Turbine types of (a) Darrius, (b) Gorlov, and (c) Harvest 2004 [18].

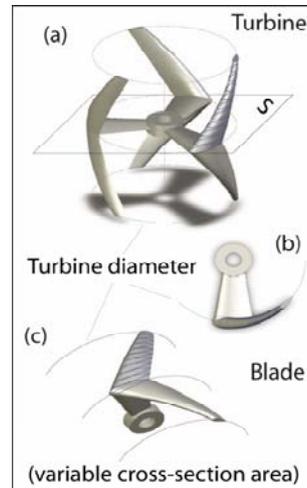
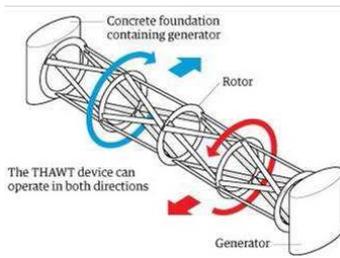


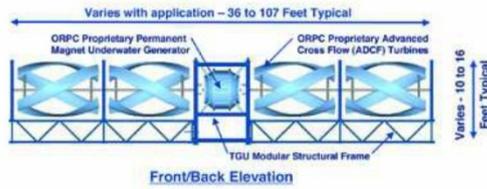
Figure 8. Harvest 2007 turbine geometry [18].

Other types of horizontal axis CFWT have also been researched and developed as shown in Figure 9 [21], [22]. These types of CFWTs are smaller and allow chaining multiple rotors together.

A reciprocating wing turbine has been developed by Engineering Business Ltd, United Kingdom as shown in figure 10. This prototype was dimensioned to produce a net power of 150 kW and has been implemented in 2002 in Yell Sound, at the large of Shetland Island [23].



(a). Solon by Atlantis Resources Corporation.



(b). OCGen by Ocean Renewable Power Company.

Figure 9. Horizontal axis CFWCT [21].



Figure 10. Reciprocating wing turbine prototype [23].

Under the context of green energy resource which should be environmentally friendly, all the design objectives of being well fixed to the seabed, maximizing efficiency, and easiness of maintenance and operation can be wrapped up in a single objective that is minimizing electricity unit cost (electricity selling price) Rp/kWh. To estimate electricity selling price, the following price model which is based on conventional engineering economics can be adopted [24].

$$r_{f\_ref} C_t = \left\{ L'_{ref} - LF \left( \frac{L_{fom}}{8760CF} + L_{vom} \right) - PPT_{ref} \right\} 8760 P_{eR} CF \quad (2)$$

The electricity selling price  $L'_{ref}$  in Rp/kWh is based on the power purchase agreement (PPA). The levelized factor  $LF$  depends on macro economics indicators and is assumed to be uncontrollable, the levelized maintenance and operation cost ( $L_{fom}$ ,  $L_{vom}$ ) is assumed to be constant. The maximum (nominal) power capacity  $P_{eR}$ , capacity factor  $CF$ , and investment cost per kW maximum capacity  $C_t$  depends on

the optimization design. Power plant operator profit including profit tax  $PPT_{ref}$  can be controlled. The fixed cost ratio  $r_f$  is composed by fixed cost components including interest rate, depreciation, income tax, property tax, and insurance.

From the above electricity selling price model, it is obvious that scientists and engineers are responsible to optimize the design which minimizes investment cost  $C_t$  while satisfying the given technical specifications. To cope with this problem the selection of the best site in the Wallacea region is crucial as well as the optimization of the design of the OCECS. Such a task needs inter discipline approach including oceanography, mechanical engineering, electrical engineering, electronics engineering, material engineering, civil engineering, and other related fields.

### III. RESULT AND ANALYSIS

Considering the track record of research and development activities related to wind electrical power plants at the Research Center for Electrical Power and Mechatronics, Indonesian Institute of Sciences (LIPI), as the first step this paper proposes research and development of 3 blade AFWT to be implemented in the Wallacea region. Such AFWTs have similar power characteristics as WECS whose efficiency curves are shown in figure 11 [25].

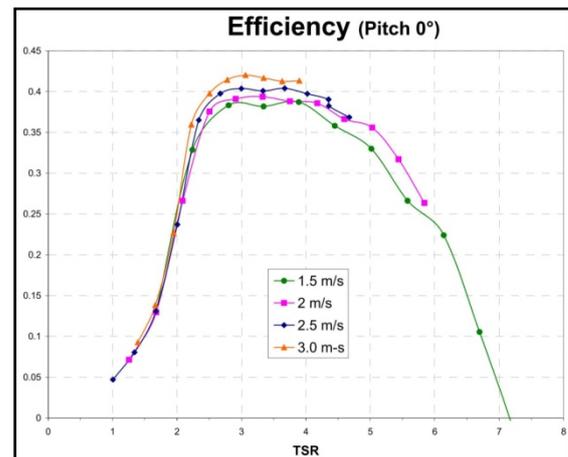


Figure 11. Efficiency vs TSR [25].

From Figure 11 it can be noted that there exists maximum efficiency for any water current velocity at certain tip speed ratio (TSR).

Figure 12 shows effect of yaw angle on the power coefficient in axial flow ocean current turbine having 3 blades [26]. When yaw angle is controlled to be larger the power coefficient becomes smaller for a given TSR.

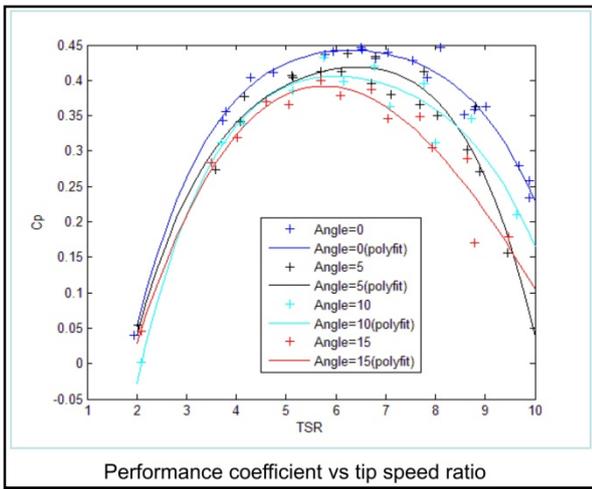


Figure 12. Effect of yaw to power coefficient [26].

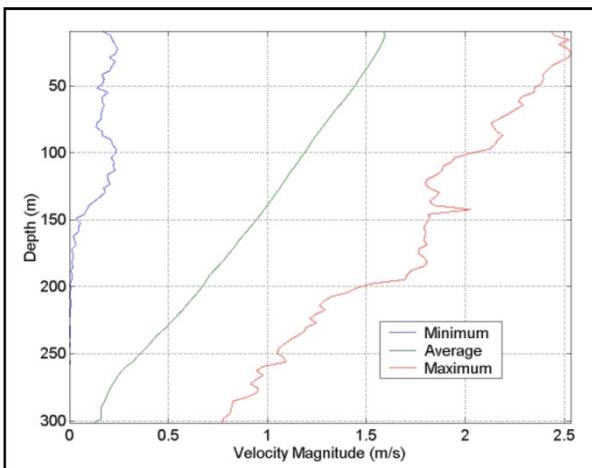


Figure 13. Ocean current speed at Florida, USA [17].

Figure 13 shows ocean current speed measured offshore Ft. Lauderdale Florida over a period of nearly 2 years. Velocity measurements were made at 15 minute intervals. It shows that the mean current speed near the surface is nearly 1.7 m/s,

and can exceed 1 m/s even at the depth of up to 150 m. On average, the Florida current decreases monotonically with depth to a weak 0.19 m/s near the ocean bottom at 320 m, in the outer edge of the Miami Terrace. The current speed ranges between 1 and 2 m/s 85 % of the time, in the top 100 meters. At 50 and 100 m depth, the flow exceeded 2 m/s only 3.3 and 0.06 % of the time, respectively. The predominate direction of the Florida current offshore Ft. Lauderdale ranges between 15° and 16.5°. Directional consistency is dependent on velocity, and in the absence of velocity, or during periods of low velocity, the flow direction becomes confused [17].

Based on the above preliminary information, the axial flow water turbines having 3 blades which are proposed to be installed at Wallacea region will be controlled according to the following control strategy:

- (1) to maximize energy conversion this paper proposes the use of variable speed control approach. In such approach the turbine rotation speed is controlled so that TSR gives its maximum power coefficient. The turbine rotation speed is controlled by manipulating electrical torque in the generator,
- (2) no pitch controlled is necessary,
- (3) the vertical position of the turbine is controlled for 2 purposes: adjusting the maximum power which can be extracted by the turbine, and maintenance,
- (4) yaw controlled is provided to optimize the operation of the turbine

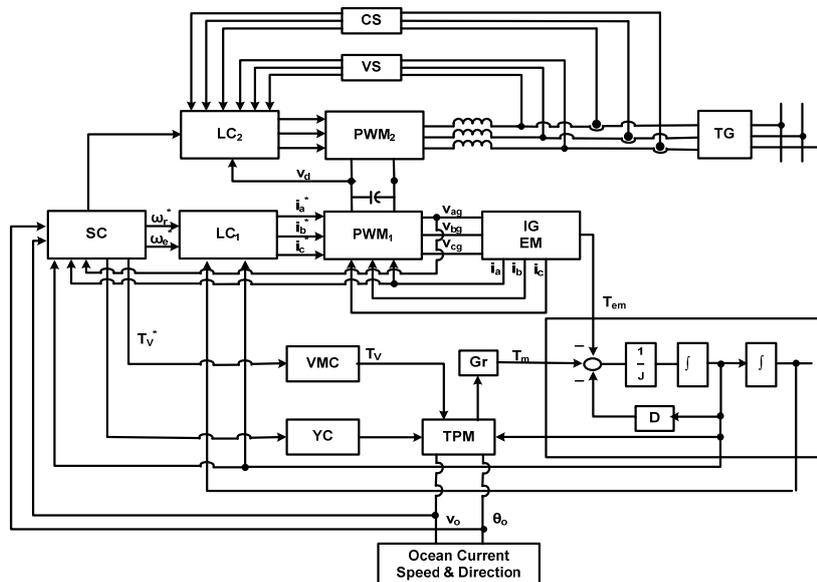


Figure 14. The proposed control system for OCECS in the Wallacea region.

The variable speed control approach described by Estiko Rijanto et. all. which is devoted for Wind Energy Conversion Systems can be adopted for this purpose [27], [28]. Further elaborations must be carried out to design an optimum mechanism for controlling vertical position and yaw angle.

Figure 14 illustrates the control system proposed in this paper. Basically the control system is composed of two parts coupled by a DC link capacitor. The lower part denotes the controller for generator side while the upper part denotes the controller for grid connection.

#### IV. CONCLUSION

The following conclusion can be obtained:

- (1) OCECS (Ocean Current Energy Conversion System) has promising future as green energy resources,
- (2) The Wallacea region possesses ocean current energy potential according to the Thermohaline circulation,
- (3) Many types of ocean current turbines can be classified into 3 classes those are: (a) axial flow water turbine (AFWT), (b) cross flow water turbine (CFWT), and (c) reciprocating wing turbine (RWT). As the first step, this paper proposes the use of AFWT having 3 blades to be implemented in the Wallacea region,
- (4) The AFWT will be controlled using variable speed control approach together with vertical position control as well as yaw angle control.

As the follow up of the work reported in this paper, an inter discipline R&D team will be established consisting researchers and engineers from disciplines of oceanography, mechanical engineering, electrical electronic engineering, control system, civil engineering, and other related fields to discuss and formulate an action plan including: ocean current potential mapping in the Wallacea region, design of an optimum OCECS dedicated for the region, building the OCECS, implementation the OCECS, and monitoring as well as evaluation. Financial support is inevitable to make this plan go to reality. In order to accelerate the plan, international cooperation is welcomed.

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