# Clean Power Grid with Tidal Power Generations

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***Abstract***: *In order to develop independent island microgrid, a tidal power generation will be used to supply an electric power as a renewable energy besides photovoltaic power generation for remote islands of Indonesia. Since fuel cell generation system launched for residential application in Japan, has a significant and future use as backup power supply replacing a diesel engine, it will also use in this analysis as backup power supply from renewable energy resources. Although the hydrogen fuel can obtain from natural gas, due to this island proposed as a pilot project of eco-green microgrid concept, the hydrogen will be produced by separating water of electrolysis. Through the MATLAB/Simulink 2016b, this system was modeled and analyzed in order to get the optimum rating capacity of renewable energy for increasing the hydrogen production from water electrolysis. As a result, a solid oxide fuel cell (SOFC) perform as well as diesel engine as backup power supply from renewable energy of photovoltaic and tidal power generation for one-hundred residence houses in Ternate islands. By considering to the economic efficiency, the installation of photovoltaic increased to become 600kW in order to obtain the hydrogen fuel for* $3.01x10^{-7}$*[kg/day].*

***Keywords:*** *tidal power, fuel cell, hydrogen, microgrid.*

## 1. Introduction

A reliable electric power supply for all of islands, is one of the main problems in archipelago country. As we knows, a development of reliable electric supply in remote islands are more economically difficult than in urban areas, due to low population density. Mostly in remote islands today still using diesel engine to meet electric demand load. Moreover, when introducing renewable energy sources such as wind and solar power in remote islands in the last decades, still using backup power supply from diesel engine generator. However, a fuel supply of diesel engine is another obstacle for rural islands and make it costly, also inefficient when peak demand load come. Therefore, many other researchers in the world, looking for another potential eco-friendly backup power system like fuel cell generation to replace diesel engine as backup power supply for independent island microgrid application [1].

This work considers to the Ternate island of Indonesia as a tropical region, which an electricity supplied by diesel engine, as the pioneer of an independent island fuel cell microgrid. The SOFC is suitable used in this study due to high efficiency characteristics [2]. Because of the location is in the tropical region means doesn't need a demand for heat system. In addition for economic efficiency, the electric power get supplies from Maluku as a big neighbor island trough the submarine cable. The topology of this island has a potential renewable energy of tidal power generation that is yet to optimize whereas the investigation of wind speed on these islands based on weather database indicates a low speed of wind. So that the photovoltaic and tidal power as a renewable energy which installed in this island.In order to reach fully green energy concept, the hydrogen fuel will be produced by water electrolysis as follows [3] that stored in hydrogen storage tank and supplied to another island through the submarine pipeline. The performance of water electrolysis analyzed depending on the output power from renewable energy. By using a numerical simulation, a model of the proposed system was established, for future use of independent island microgrid. Eventually, it can assists the researchers or governments to solve the problem of electricity in remote islands of tropical region. Finally, the analysis of maximum renewable energy rate was clarified in order to get the optimum hydrogen production by water electrolysis in order to consider to the minimum unit price of electric power system in remote islands.

TABLE I: Data of the Ternate island

| Parameter | Ternate |
|---|---|
| Area | 1118 $km^2$ |
| Population | 185,705 (2010) |
| Average tidal velocity | 2.2 m/s/month |
| Average global solar radiation | 793.2 $kJ/m^2/year$ |

# 2. Outline Proposed Microgrid Concept

## 2.1. Characteristics island

Ternate islands is located in the active volcano island with the capital city name of Ternate city which was originally formed as a result of trade and political relations between the Sultanate of Ternate and the *Verenigdee Oostindische Compagnie* (VOC). Ternate also is one of the remote island in Indonesia close to the Maluku islands and Pacific Ocean. So that the electric power get supply from main island of Maluku by submarine pipeline cable. Through the Table 1 about Ternate islands, the introduction of eco-green independent microgrid concept is hard to establish due to low population density. Therefore, a development microgrid concept was proposed for long term and will be used to supply electric power for neighbor island of Ternate at once.

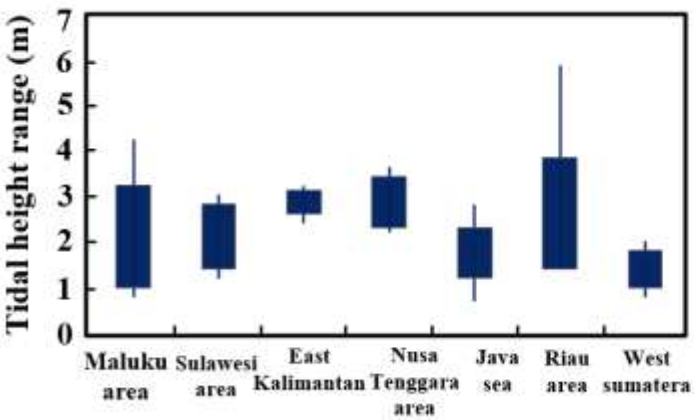


Fig. 1 Estimation tidal height range in Indonesia island [4]


Fig. 2 Maps of Ternate island

As refer to the potential tidal power energy investigation in all small island analysis [3-6], as shown in Fig. 1 (Maluku area), makes the tidal power generation was decided to installed in Ternate island as a renewable energy besides photovoltaic power generation. As we can see from this map above, the topography of Ternate can install many types of tidal power, such as tidal fences type that can apply between Ternate and neighbor island (Tidore) so that the economic potential can also be increased, or tidal stream turbine type at the north sides of that island. Although tidal fences type promises many opportunities, however in the first phase of development, also consider to the high potential tidal wave and cost investement, tidal fences unable to install in these islands. Therefore, tidal stream types was decided as the best type of tidal turbine in Ternate island.

## 2.2. System Configuration

Figure 3 shows a system configuration in Ternate island that examined by using MATLAB/Simulink 2016b. Based on the government program about development renewable energy for independent remote-island microgrid, makes the proposed system of this study is concerning to optimize the potential renewable energy in every rural islands of Indonesia. Therefore, a tidal power generation that was generated by using Darius water turbine with 35% efficiency as follows [8] are suitable installed in north side of Ternate islands. That’s turbine has the rotating advantageous does not depending on the direction of tide flow, so that the turbine can response the changes from ebb to flood tides. Another renewable energy of photovoltaic (PV), which has the maximum rated capacity 5kW/module, will also installed by considering to the potential average global solar radiation as shown in Table 1 above. An uncontrolled system of renewable energy will be affecting power fluctuation due to unstable weather condition. Hence, a 3MW solid oxide fuel cell (SOFC) installed as backup power supply with fuel rate controller, battery as an auxiliary devices for assisting SOFC overcoming power fluctuation which installed inside the SOFC stack system, and power conditioning converts from direct current (DC) output voltage to become alternating current (AC) output voltage. Besides supplying an electric demand load, this renewable energy will also be planned to supply water electrolysis for producing the hydrogen fuel of SOFC as backup power system.

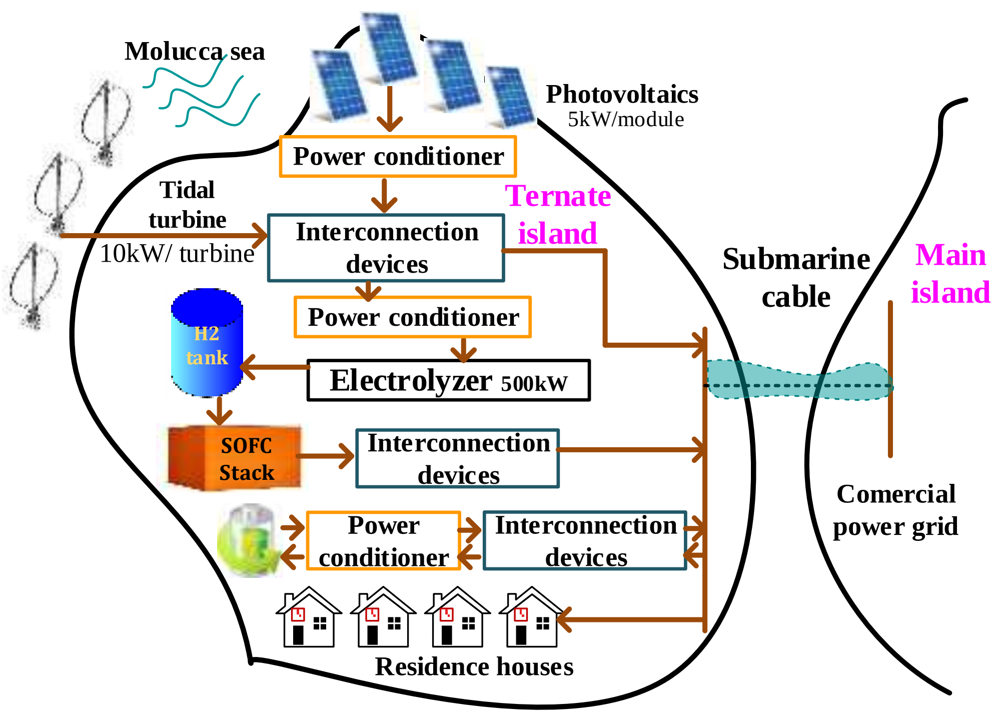


Fig. 3 System configuration.

Even though the hydrogen fuel of SOFC can be supplied from natural gas, however as a pilot project of eco green island microgrid concept, the hydrogen fuel will be produced by separating water in electrolysis with maximum rated capacity for 500kW. While, for hydrogen storage pressure and temperature was set in constant value. By refer to the previous study about power quality of independent fuel cell microgrid with renewable energy, revealed that the installed capacity of renewable energy is highly affecting the frequency fluctuation and the best installing combination between photovoltaic and tidal power is around 15-25% at maximum rated capacity of the system. So that, the installed capacity for each tidal and photovoltaic generation decided 300kW and 600kW respectively. Due to this study is the phase step of developing eco-green island microgrid concept, a total capacity of the equipment just planning to supply for one hundred residence houses, so that a comercial power supply from main island through the submarine cable is still used.

## 3. Analysis Method

### 3.1. Modelling of the system

#### a. Tidal power generation

Tidal power is a form of hydropower that converts the energy of tides into electricity through the tidal turbine, drive train, and permanent magnet synchronous generator (PMSG) as shown in Fig.4. Although tidal energy supply is renewable and plentiful, it is not easy to convert tidal energy into useful electrical power. Therefore, for easily estimate the potential energy of tidal movement in Maluku area as shown in Fig. 1, can be

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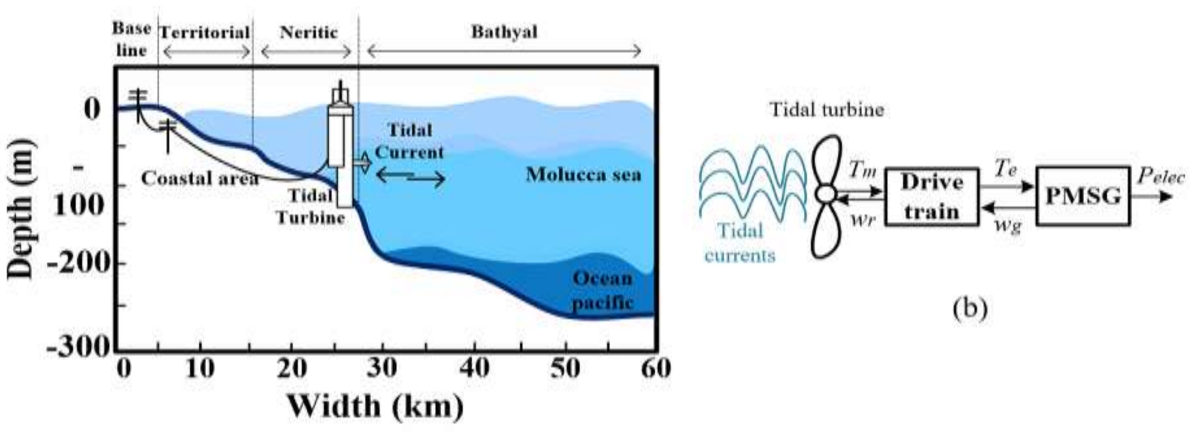
estimated approximately by the formula of [6] below, where $g$ is gravity acceleration ($m^2/s$), $h$ is tidal range or head (m), $m_s$ is mass of seawater, and $w'$ is a basin surface area ($Km^2$).

$$E_{tidal} = w' m_s g_a I \int_0^H h \frac{dH}{T} = \frac{\frac{1}{2}\left(103\times10^3\right)H^2\left(w\times10^6\right)}{60\cdot60\cdot62} = 225wH \tag{1}$$

Based on the sea zone area, that is territorial zone, neritic zone, and bathyal zone, the tidal turbine can generate an electricity when installed in the range >100 meter of base line. After understanding the topography location of Ternate islands that shown in Fig. 2 above, the maximum depth of Molucca Sea is more than 2000 meter in year of 2001 [4]. Therefore, in the first step development of tidal power generation, it can be installed around 200m between neritic zone and bathyal zone as shown in Fig. 4(a) below to keep safe the underwater ecosystem. While to generate an electricity, the turbine, that shown in Fig. 4(b), converts the kinetic energy of tidal current into mechanical energy, $T_m$, controlled by the drive train with generator angular speed, $w_g$, to produce electrical torque, $T_e$, then a rotor angular speed, $w_r$, is used to control the speed ratio of turbine [5].




(a)

(b)

Fig. 4 Tidal current energy system

Whereas in Fig. 5 shows the tidal velocity from May 15 – June 15, 2017 that measured in the north sides of Ternate islands. The using of bidirectional tidal turbine that can respond the changes tidal current from ebb tides to flood tides, obtain the electric output power by generator continuously as shown in Fig. 6 as follow to the Eq. (2) with turbine efficiency was set about 35% refer to the [7], the speed of tidal wave $R_{TP,t}$ for 1 s to an area A is set to $V_{TP,t}$ then for kinetic energy $P_{TP}$ is defined by following equation below,

$$P_{TP} = 0.5 \cdot R_{TP,t} \cdot V_{TP,t}^2 \quad \text{which} \quad R_{TP,t} = \rho_{TP} \cdot A \cdot V_{TP,t} \tag{2}$$

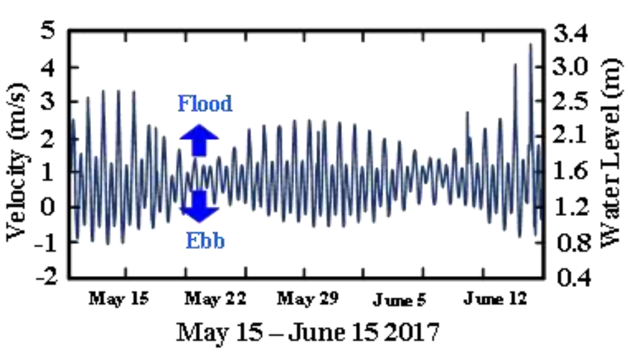



Fig. 5 Tidal current speed profile for 30 days [13]

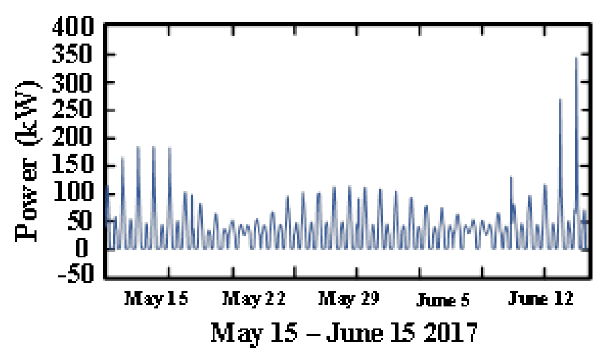



Fig. 6 Tidal power for 30 days

### b. SOFC

A basic concept of thermodynamic analysis of energy conversion processes is important when modelling electrochemical processes of fuel cells.Generally the classification of fuel cell can be seen by the type of electrolyte they use, and the choice of electrolyte dictates the range of their operating temperature and the degree of fuel processing required.Solid Oxide Fuel Cells (SOFCs) are high-temperature (600-1000°C) direct energy conversion devices, which transport the chemical energy of a fuel to electrical energy with approximately efficiencies as high as 70% up to 90% in combined heat & power (CHP) generation. There are many auxiliary devices working behind the scene in order to operate smoothly and efficiently. These devices that take part in managing the parameters at a desired value. Fig. 3 shows a block diagram of SOFC simulation developed in MATLAB/Simulink 2016b. Thats model based on its electrochemical and thermodynamic characteristics to predict the fuel cell dynamic response [2].

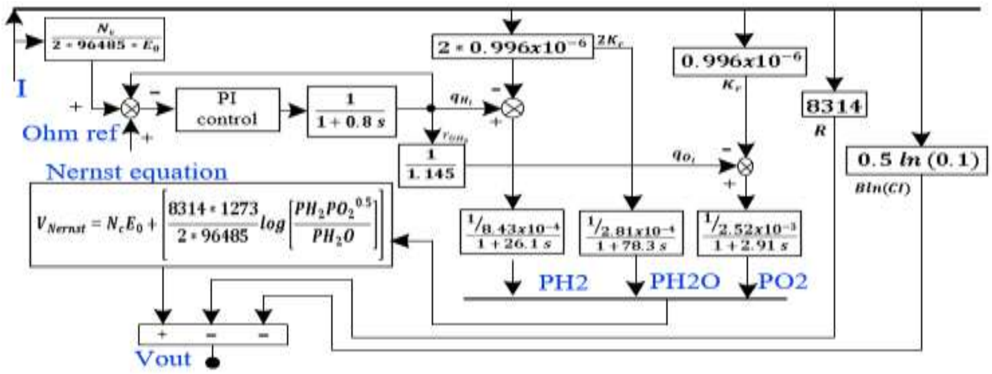



Fig. 7 Schematic diagram of a SOFC

### c. Photovoltaic

In this paper, the PV model introduced by Markvard (2000) is the simple and validated model by many other researchers. Through this model, the output power of PV panel, $P_{PV}$, can be obtained at each hour by using the solar radiation data multiple with ambient temperature, $R_{PV}$, and instantaneous efficiency of the PV module, $\eta_{PV}$, with total installation area of PV, $N_{PV}$, which can be expressed below as follows [2]:

$$P_{pv} = \eta_{pv} \cdot R_{pv,t} \cdot N_{pv} \tag{3}$$

### d. Electrolysis

Actually, the basic theory and reactions for electrolysis is similar to those for fuel cells consider a reverse process that produces hydrogen and oxygen from water. The opposite of electrochemical reaction occurring in a fuel cell, an electrolysis in [8] converts the dc electrical energy into chemical energy stored in hydrogen that given in Eq.(4) with the parameter $\eta F$ is faraday efficiency $\eta F = 96.5 e^{(0.09/i - 75.5/i^2)}$, $S_{stc}$ is the electrolysis stack calculation [9], $i$ is input current, $t$ is the time-period (second).

$$H_{2,prod} = \eta F \frac{S_{stc} \cdot 8314 \cdot (65 + 273) \cdot i \cdot t}{96485 \cdot 10^5 \cdot 2} \tag{4}$$

### e. Battery system

The open circuit battery voltage which depends on the battery current, state of charge (SOC) and hysteresis phenomenon of the battery with the temperature ignored as follows [14]. The value of battery voltage in the discharge mode ($I > 0$) and charge mode ($I < 0$) is given by;

$$V_{b,dis} = V_0 - K \frac{Q}{Q - Q_{act}} I^* - K \frac{Q}{Q - Q_{act}} Q_{act} + A_{cd} \exp(-BQ_{act}) \tag{5}$$

$$V_{b,cha} = V_0 - K \frac{Q}{0.1Q + Q_{act}} I^* - K \frac{Q}{Q - Q_{act}} Q_{act} + A_{cd} \exp(-BQ_{act}) \tag{6}$$

### 3.2. Hydrogen Consumption Estimation

The hydrogen fuel consumption $S_{fuel,t}$, calculates refer to the [2] which depending on output power of SOFC, $P_{FC}$, and efficiency, $\eta_{fc.}$ Can be writtem by this equation below;

$$S_{fuel,t} = \frac{P_{fc,t}}{\eta_{fc,t}} \tag{7}$$

### 3.3. Energy Balance Equation

Energy balance equation of electric demand load expressed by Eq. (8). The left side of equation containing total power supply from SOFC, photovoltaics, tidal, battery and flywheel for electric demand load and water electrolysis equation.

$$P_{pv,t} + P_{Tp,t} + P_{fc,t} \pm P_{bt,t} = P_{dl,t} + P_{We,t} + P_{loss,t} \tag{8}$$

## 4. Analysis Result

### 4.1. Electricity production

Figure 7, shows the analysis output power from photovoltaic, SOFC, and tidal power generator that analyzed from May 15 to June 15, 2017. Although tidal power generation is one of the renewable energies which has a good predictable output power, due to the rotation of solar, lunar, and earth gravitation. Hence, to get to know the fluctuation responses of tidal power, the analysis should be done at least for one week or one month [6-8]. The electric power from tidal turbines was obtained through the Eq. (2) with input data of velocity tides that shown in Fig. 5, and the electricity production from photovoltaics was obtained from the amount of global solar radiation, which has the maximum rated capacity for 600kW. Though the capacity of photovoltaic decided maximum for 600kW, actually the installation capacity of PV was decided by refer to the previous study [10] as shown in Fig. 9. Then analyzed to increase the quantity of hydrogen fuel production by water electrolysis which depending on the output power from renewable energy sources.

Even though in the first phase of this study, a supplying demand load was limited for one hundred residence houses only in that island, around 1MW. However, the operational of microgrid planned for a long term and will use to meet an electric demand load for another neighbor islands indeed. Thus, the installation of SOFC was decided for 3MW and 300kW for maximum rated capacity of tidal turbine generator. The graphs shows the SOFC plays as a backup power supply following the energy balance in Eq.(8), when occurring the power fluctuation accompanied by small capacity of Li-ion battery, in microgrid system both come from renewable energy and demand load.

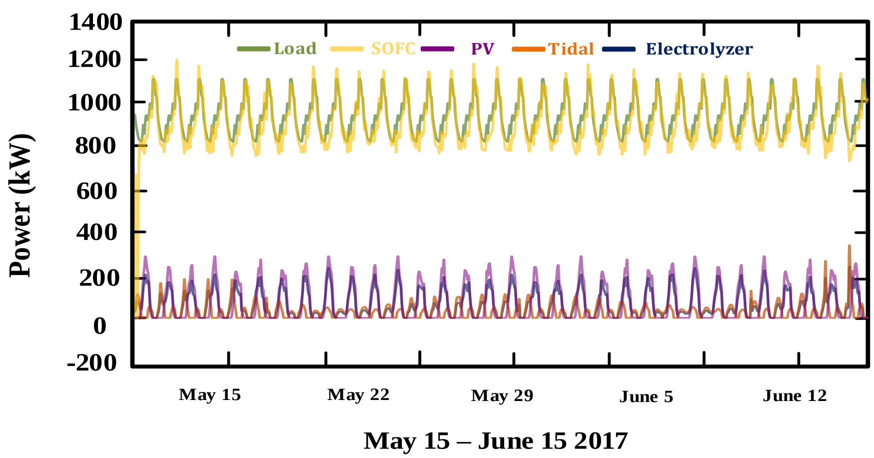



Fig. 8 Electric demand supply for 30 days

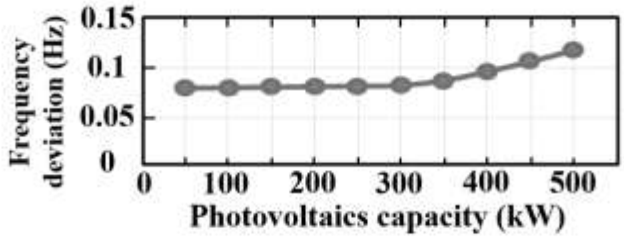



Fig. 9 Frequency deviation with different capacity [10]

### 4.2. Hydrogen Production

The hydrogen production through water electrolysis may had been analyzed by supplying from multiple renewable energy sources like analysis result from [11] which analyzed through the surplus power from installed capacity of renewable resources for each prefecture in Japan in order to get an economic efficiency of hydrogen fuel. While in the analysis result of [12] was obtained the hydrogen fuel estimation production through the potential area of renewable energy resources analysis in Algeria. Therefore, even if the hydrogen fuel was analyzed by renewable energy sources, however due to this study is the first phase of development renewable energy in that area, means there is no renewable energy sources like photovoltaic, hydropower, and tidal power generation installed in Ternate islands. Moreover, there are many factors, like catalyst membrane, to increase the hydrogen production, nevertheless it can be analyzed through the increasing value of REs installation capacity. When increasing the installation capacity of tidal turbine, the cost of investment will increase automatically. Then following to the previous study [10] about correlation between installation area of photovoltaic and frequency deviation as shown in Fig. 9, the installation capacity of PV around 500kW, didn't affecting the frequency deviation more than ±0.3Hz as a frequency deviation requirement in that's area. Inconsequence, the installation capacity of PV was increased from 300kW to become 600kW.

At the same time, besides supplying an electric demand load, a 40% power supply from photovoltaic and tidal power will use to supply water electrolysis as follows the Eq. (4), in order to get a sustainable hydrogen fuel production. Perhaps in the next phase of development, the hydrogen production can analyze through the optimization installing capacity of renewable energy sources to meet the hydrogen fuel of SOFC as backup power supply around 0.372 up to 0.363[kg/day] in the analysis of 600kW and 300kW photovoltaic installation capacity respectively. As a result, based description graph on the Fig. 10, shows the amount of hydrogen production and hydrogen consumption by SOFC as follows Eq. (7) for a month. From this graph can be seen that 40% power supply from REs obtained insufficiently to the hydrogen fuel demand of SOFC, around $0.987\text{x}10^{-7}$[kg/day] and $3.01\text{x}10^{-7}$[kg/day] for 300kW and 600kW photovoltaic installation capacity respectively.

## 5. Conclusion

The study on clean power grid with tidal power generation for independent island microgrid was analysed based investigation first on the potential renewable energy in Ternate islands, besides photovoltaic power generation. In order to reach a pilot project of the real eco-green island microgrid concept, SOFC and water electrolysis will use as a backup power supply and hydrogen fuel production respectively. A simulation software of MATLAB/Simulink 2016b was used to analyse in this system with actual load profile and weather data for a month. Through the above result is becoming clear that SOFC worked as well as diesel engine to overcome power fluctuation accompanied by battery as an auxiliary device. The hydrogen fuel production through water electrolysis with 40% input power of REs, could be obtained around $0.987\text{x}10^{-7}$ [kg/day] by installing 300kW photovoltaic, while $3.01\text{x}10^{-7}$ [kg/day] can be reached by installing 600kW photovoltaic in the system. Moreover, this research needs to investigate a detail of cost system facilities for investment.

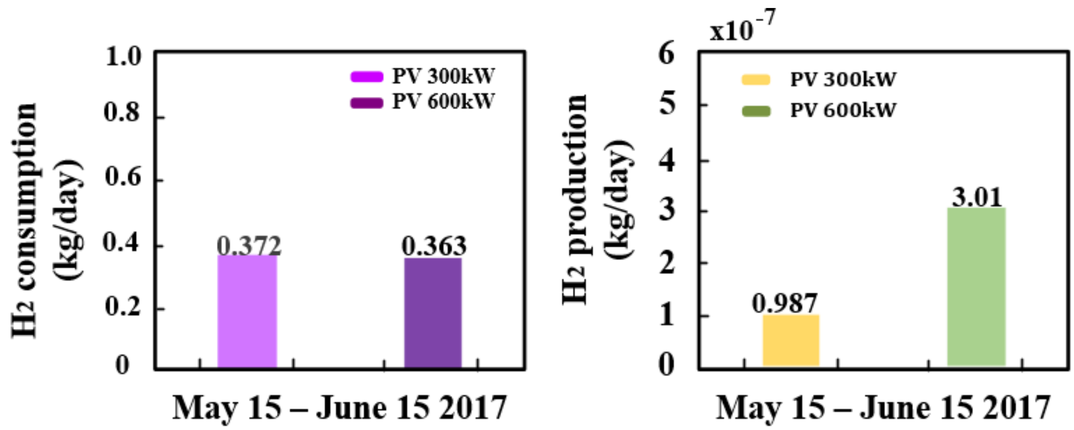



Fig. 10 Hydrogen consumption and production

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