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Modified Buck-Boost DC-DC Converter with Hyeteresis Band on Ocean Wave Emulator

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Abstract

Currently, the utilization of ocean wave technology is still in the prototype stage. Erratic ocean waves affect the power generated. The results of ocean wave energy in the mechanical array cannot be utilized due to erratic waves, causing unstable power output and damage to electronic equipment. The solution to this problem is to modify the DC-DC buck-boost converter circuit using the Hyeteresis band method so that the generated power remains constant and as energy to be stored in the storage system. The result of this research is that the performance of the DC generator in generating voltage is strongly influenced by speed. At low speeds, the voltage produced by the generator is still too low to charge the battery or in other words cannot be in a perfect charging position. Conversely, at maximum Speed, the generator produces a voltage that reaches a level sufficient for battery charging. Therefore, controlling and adjusting the speed of the generator is very important in maximizing the efficiency of charging the battery using a buck-boost converter.

Keywords: Hysteresis Band, DC-DC Converter, Buck-Boost Converter

Abstrak

Saat ini pemanfaatan teknologi gelombang laut masih dalam tahap prototipe. Gelombang laut yang tidak menentu mempengaruhi daya yang dihasilkan. Hasil energi gelombang laut pada mechanical array tidak dapat dimanfaatkan karena gelombang yang tidak menentu sehingga menyebabkan keluaran daya yang tidak stabil dan kerusakan pada peralatan elektronik. Solusi dari permasalahan ini adalah memodifikasi rangkaian konverter DC-DC buck-boost dengan menggunakan metode Hyeteresis band agar daya yang dihasilkan tetap konstan dan sebagai energi untuk disimpan pada sistem penyimpanan. Hasil dari penelitian ini adalah kinerja generator DC dalam menghasilkan tegangan sangat dipengaruhi oleh Kecepatan. Pada kecepatan rendah, tegangan yang dihasilkan generator masih terlalu rendah untuk mengisi baterai atau dengan kata lain tidak dapat berada pada posisi pengisian yang sempurna. Sebaliknya, pada Kecepatan maksimum, generator menghasilkan tegangan yang mencapai tingkat yang cukup untuk pengisian baterai. Oleh karena itu, mengontrol dan menyesuaikan kecepatan generator sangat penting dalam memaksimalkan efisiensi pengisian baterai dengan menggunakan konverter buck-boost.

Kata-kata kunci*: Hysteresis Band, DC-DC Converter, Buck-Boost Converter*

1. Introduction

Indonesia has the potential for sea wave energy, with the second-largest coastline having a density of up to 20 kW / m^2. Currently, the use of sea wave technology is still at the prototype stage, with several weaknesses, such as erratic sea waves, tides, and ocean currents that can affect the power generated in sea wave energy [1]. Currently, the use of sea wave technology is still at the prototype stage, with some weaknesses such as sea waves every year that change resulting in not maximum energy utilization [2]. The energy conversion of ocean waves will produce full power if you know the characteristics of the ocean waves. By using ocean wave energy, there are advantages, namely (i) the energy can be utilized at any time, (ii) it will never run out, (iii) no waste is produced, (iv) changes in mechanical energy are found in the ocean waves themselves, (v) the intensity of kinetic energy is more significant than other renewable energy (vi) sea waves can be predicted [3]. Based on data on significant wave heights and wave periods data on NASA satellites, the area of operation on the sea waves south of Cilacap is an average of 2 meters. The problem that often occurs in sea wave power plants is that when there is a high sea wave, the energy conversion provides a cut-off to produce average power. When the sea wave occurs very high, the energy conversion must be stopped so that there is no damage to the system.

In previous studies, it has applied a sea wave energy system using a mechanical array. It is currently in the technical service stage of patent filing with NO Patent Application S00202211668, which produces output power from two buoys arranged in collections. This invention is only limited to generating energy from sea waves, not yet the stage of distributing the energy of sea waves to the coast. To utilize the potential of sea wave energy, especially in the Cilacap Regency, a system is needed for energy distribution from energy storage, transmission, and distribution to the utilization of electrical power. New renewable energy systems are different from conventional energy, where the storage system is the main component for distributing electrical energy.

Some studies have applied electrical energy systems from ocean waves, such as research [4] using hydraulic systems for ocean wave power generation. Research [5] the development of hybrid power generation systems in the form of sea-photovoltaic currents and batteries, using these battery systems for the absence of power vacuums from both sources. A further application for ocean waves to storage systems is research on battery storage systems obtained from renewable energy to make charging faster in electric cars [6]–[8]. While several studies have explored energy storage systems with lithium and supercapacitors, some considerations need to be made, such as heat and battery use efficiency [9], [10].

Research [11] compares the three types of batteries commonly on the market, namely lead acid, lithium Ion, and Nickel Metal hydride, using systems (CC) and (CV) as a determination for the length of charging time. The results of the three types of batteries that can charge to full are the fastest with the type of lithium-ion battery for 2.6 hours. Lithium-ion is also chosen for several mobile applications because its efficiency is currently higher than that of other types of batteries. In addition, storage systems with fast charging are widely applied to electric cars [12], [13]. The use of applications in electric vehicles is the same as the use of the electricity grid for energy consumption for household needs. This study explains the storage system with fast charging [13] by paying attention to electrochemical conditions and developing electrodes and cathodes in lithium ions. In addition, for fast charging, it can also be used in the charging system with its electronic circuit on the DC-DC Converter device [14] Development of a DC-DC Converter with a boost converter is commonly used so that the power generated increases or by another name maximum power point tracking (MPPT) [15]. Fast charging requires CC and CV together where CC battery capacity is below 60% while CV is used for above 40%. A study [16] used hysteresis by utilizing current surges to get a fast response and a PI controller to produce a constant response at a steady state.

From the literature review above, the problem is that the results of ocean wave energy in mechanical arrays cannot be utilized because of erratic waves. The higher the lock, the greater the power generated, and vice versa. If this problem is not resolved, it can cause unstable power output and cause damage to electronic equipment. The solution to this problem is to use a DC-DC buck-boost Converter system when erratic waves can maintain a work of constant voltage and current to enter the storage system. The latest of this research is in the storage system using lithium-ion fast charging mode by modifying the DC-DC buck-boost converter, which utilizes the Hysteresis Band method so that the CC SOC is 60% fulfilled and maintains the CV voltage when the SOC is above 60% or the range of 60-100%.

2. Method

The problem in this study is overcoming the incoming current surge against the resulting wave. This problem must be solved; it will have an unstable power output and cause damage to electronic equipment. With this problem, it aims to use a DC-DC buck-boost converter system to enter the storage system when erratic waves can maintain production in the form of constant voltage and current. The research block diagram can be seen in **Figure 1**.

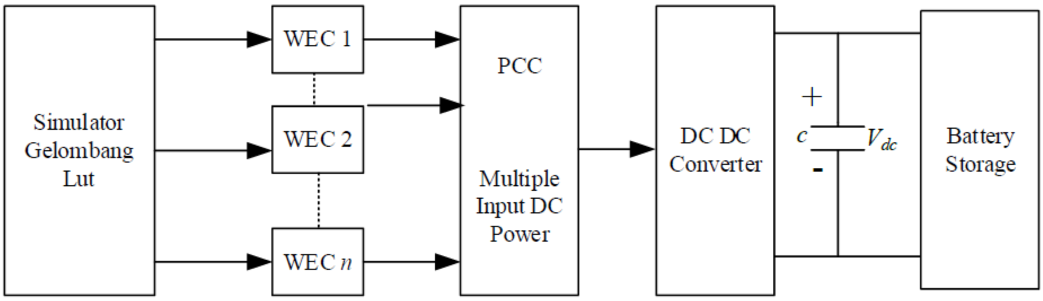


Figure 1. Ocean Wave Lyric Generating System Block Diagram

2.1 Modified DC-DC Converter

DC-DC Converter Modification After knowing several stages of energy generation, the next step in power electronics devices is to convert ocean wave energy into electrical energy. At this stage, the electric generator uses a DC generator with DC voltage output. The production of the wave simulator is the average output DC voltage (V_{dc}), which can be expressed as follows: $\boldsymbol{V_{dc}}$.

$$V_{dc} = \frac{6}{2\pi} \int_{\pi/3}^{2\pi/3} Vm,_{L-L} \sin\theta \, d\theta$$

Or

$$V_{dc} = \frac{3Vm_{L-L}}{\pi} = 0.955Vm_{L-L}$$

Where is Vm_{L-L} the voltage line to line? The rectifier circuit above has ripples; therefore, capacitor filters are used. Capacitors are selected based on the voltage received and how much ripple is allowed. If only 2% ripple is allowed, then the value of the capacitor that must be installed is Vm_{L-L}

$$V_{ripple} = Vm - V_L$$

$$= \sqrt{2}V_{L-L} - \sqrt{2}V_{L-L}e^{-\frac{t}{RC}}$$

$$= \sqrt{2}V_{L-L}\left(1 - e^{-\frac{t}{RC}}\right) \quad , karena\ t \ll RC$$

$$= \sqrt{2}V_{L-L}\left(1 - \left(1 - \frac{t}{RC}\right)\right)$$

$$= \sqrt{2}V_{L-L}(t/RC)$$

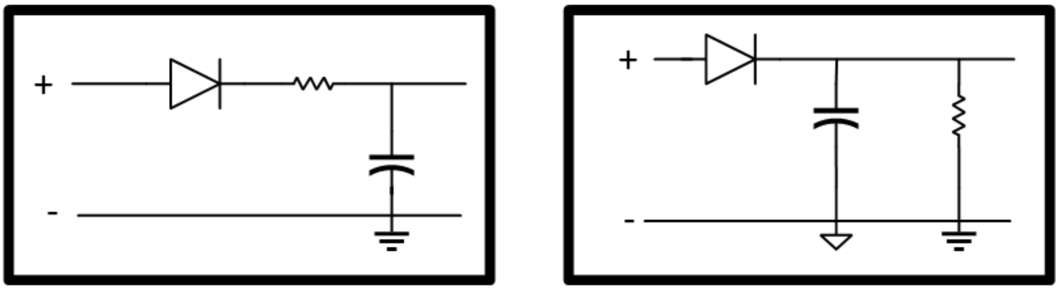
$$Discharge\ kapasitor\ 3\ fasa \frac{1}{6fRC}$$

$$= \sqrt{2}V_{L-L} \times \frac{1}{6fRC}$$

$$V_{ripple} = \sqrt{2}V_{L-L} \times \frac{1}{6fRC}$$

$$atau, 2\% \times V_{ripple} = \sqrt{2}V_{L-L} \times \frac{1}{6fRC}$$

It is then adjusted to the capacitors on the market. Then, the rectifier's current detector and output voltage will be executed for the buck-boost converter. The function of the current and voltage detector for control will be used in the microcontroller circuit to provide pulses to the buck-boost converter circuit. **Figure 2** is a circuit of current and voltage detectors.



(a) (b)

Figure 2. Circuit (a) Current Detector (b) Voltage Detector

The buck-boost converter is a DC to DC voltage conversion from low voltage, producing a greater voltage and vice versa. The buck-boost converter circuit consists of transistors given a duty cycle as a switch to make a larger or smaller voltage according to the desired setpoint. When the microcontroller generates the duty cycle, the transistor is ON, the inductor will rise line, and the first diode will be OFF. When the transistor is OFF, the previously stored energy will flow to the diode and enter the load. The microcontroller determines the duty cycle we will use. Figure 6. It is a series of boost converters. Microcontrollers are used with a frequency of 8 MHz, so that PWM is determined to be:

$$f_{PWM} = \frac{f_{clk}}{N \times 256}$$

Buck boost converter range is presented in **Figure 3**.

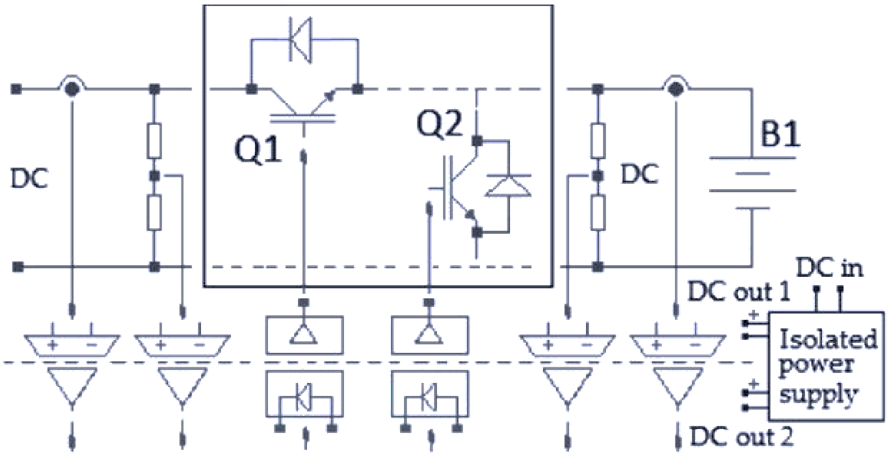


Figure 3. Buck Boost Converter Range

Figure 3 is a series of buck-boost converters that will be implemented using the STM32 microcontroller. The input of this system is the result of conversion from kinetic energy to electrical energy produced by DC generators. The information is in the form of DC voltage, which can increase or decrease the voltage depending on the buck/boost mode with the duty cycle calculation. Inductors affect determining the current to be used for fast charging. The maximum current is generated by selecting the fast-charging mode in the hysteresis method. Some ways and equations to produce this research can be seen in **Table 1**.

Table 1. Operation Mode of DC-DC Converter

Mode Parameter	Buck	Boost	Buck Boost
Input (V_{dc})	0 – 9	9 – 15	15 – 21
Output (V_{dc})	14,5	14,5	14,5
Duty Cycle	$D = \frac{V_{out}}{V_{in}}$	$D = 1 - \frac{V_{in(min)}}{V_{out}}$	
Inductor	$L = \frac{V_{out}(1 - D)}{F_{s\omega} \times \Delta I_L}$	$L = \frac{V_{IN(min)} \times D_{boost}}{F_{sw} \times \Delta I_L}$	
Maximum Output Current	$I = I_L - \frac{\Delta I_L}{2}$	$I = \left(I_{L(min)} \frac{\Delta I_L}{2}\right) \times (1 - D)$	
Maximum Switching Current	$I_{sw} = \frac{\Delta I_{max}}{2} + I_{out}$	$I_{sw} = \frac{\Delta I_{max}}{2} + \frac{I_{out}}{1 - D_{boost}}$	
V_{out}	$V = D_{buck} - V_{in}$	$V = D_{boost} \times V_{out\ Boost}$	

2.2 Hysteresis Band

Current control with a hysteresis band helps limit the minimum and maximum current according to the maximum output current. The use of the hysteresis band comes from the ratio of the reference current with the inductor current that has been controlled and entered the transistor to produce pulses that are then sent to the DC-DC converter switch. The use of the Hysteresis Band can be seen in **Figure 4**.

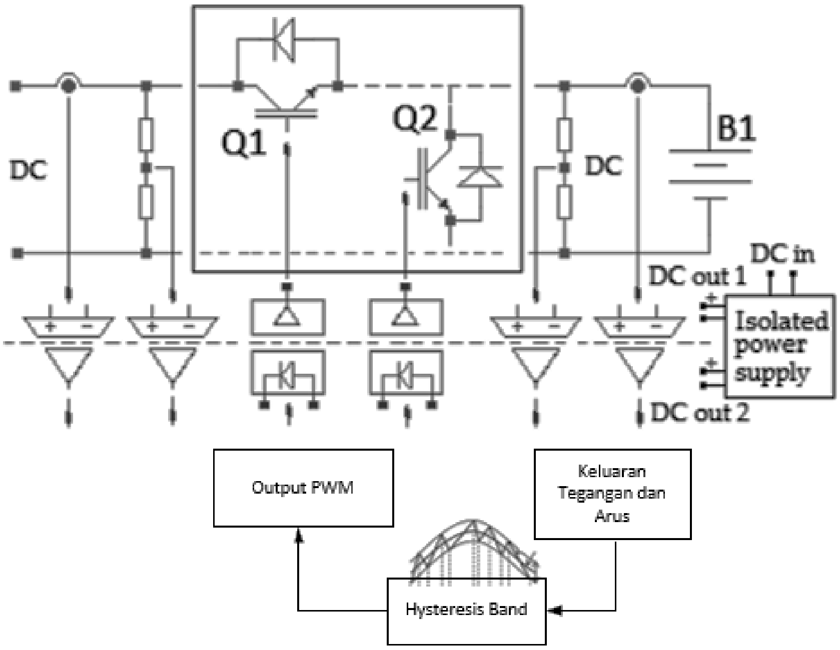


Figure 4. Buck Boost Converter with Hysteresis Band

3. Results and Discussion

In this study, the data compilation stage is the first step of this research series. This research is a continuation of previous research that focused on generating energy from ocean waves using an array system, where the ocean waves do not have such large amplitude. Therefore, in this study, researchers decided to use emulators that can replace ocean wave systems to generate energy. This emulator generates DC resources corresponding to DC generators' use. The emulator is used to be able to adjust the rotation of the DC generator so that it produces a small or large amplitude. Therefore, energy conversion is needed to increase the DC voltage to be more significant.

The focus of this research was on converting DC energy to higher DC, and to achieve this, researchers decided to modify the buck-boost converter. This modification considers the situation of ocean waves that may have a small or large amplitude. In the case of low-amplitude ocean waves, a buck converter will be used to lower the voltage, while in high-amplitude ocean waves, a converter boost will be used to increase the voltage. Thus, this converter allows voltage adjustments according to the conditions of the ocean wave at that time to maximize energy generation from fluctuating ocean wave resources. The data obtained can be seen **Figure 5**..

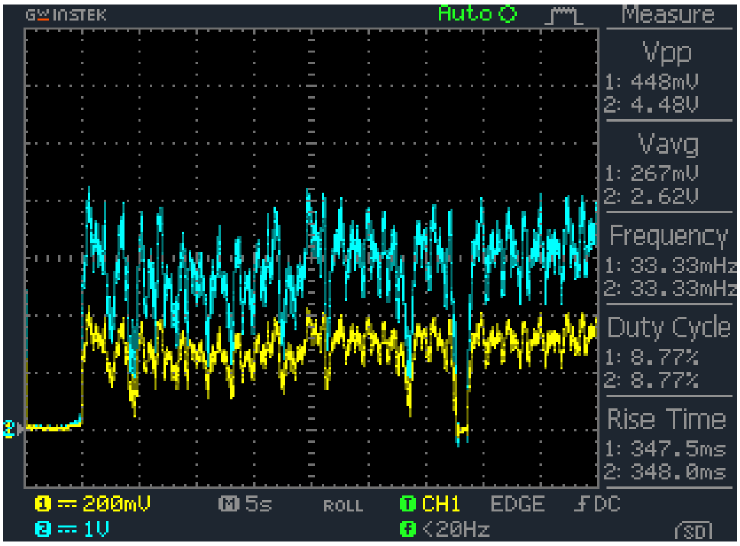


Figure 5. Comparison of Generation and Conversion of Electrical Energy at Low Speed

From the oscilloscope image above, it can be seen that the voltage output of the generator is shown in yellow, while the voltage in the buck-boost converter circuit is shown in magenta. The figure compares the Speed of DC generators as generators and the process of converting electrical energy at low rates.

The average voltage from the generator output is 267 mV, while the average electrical energy conversion voltage reaches 2.62 V; in addition, the generator output has the highest voltage of about 448 mV, while the buck-boost converter circuit voltage reaches approximately 4.5 volts. It is important to note that voltage fluctuations in generators that rise and fall also impact voltage fluctuations in the buck-boost converter. However, this low Speed is limited because it cannot be used for battery charging. Comparison of generation and conversion of electrical energy at changing speeds can be seen **Figure 6**.

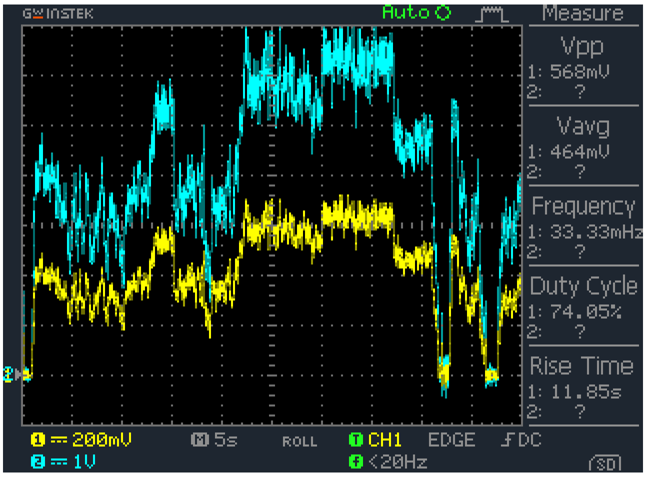


Figure 6. Comparison of Generation and Conversion of Electrical Energy at Changing Speeds

In the picture above the oscilloscope, it can be seen that the output voltage of the generator is shown in yellow, while the voltage in the buck-boost converter circuit is shown in magenta. The figure compares the Speed of a DC generator with the conversion of electrical energy at changing rates.

The highest voltage observed is about 300 mV at the output of the generator, while the voltage of the buck-boost converter circuit reaches about 6 volts. It is important to note that voltage fluctuations in the generator rising and falling also affect changes in the buck-boost converter. However, this varying low Speed cannot be used for battery charging. Maximum speed DC motor presented in **Figure 7**.

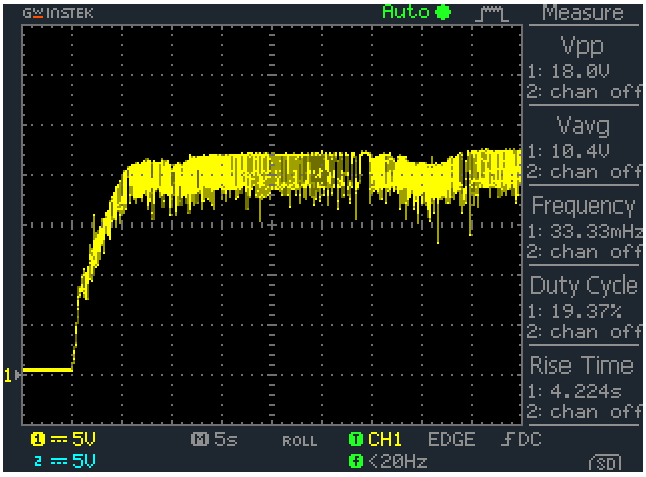


Figure 7. Maximum Speed DC Motor

The picture above shows that the DC generator operates at maximum Speed, producing an output voltage of 22 Volts. This offers the peak performance of the generator in making power at the highest conditions. Constant speed is presented in **Figure 8**.

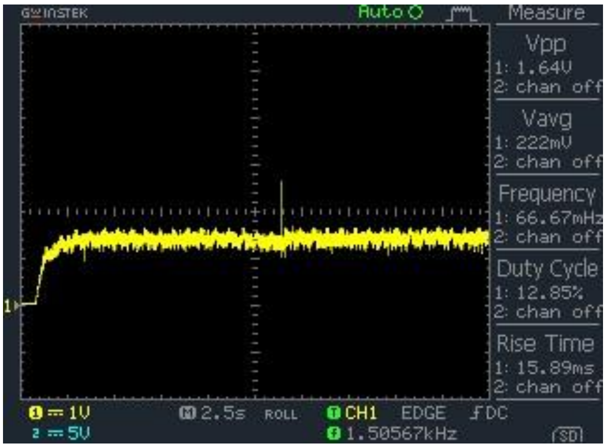


Figure 8. Constant Speed

The oscilloscope image above shows that the generator operates at a constant speed with a stable output voltage of 1.64 Volts. This voltage will be used in the process of converting electrical energy. Constant speed with electrical energy conversion output can be seen in **Figure 9.**

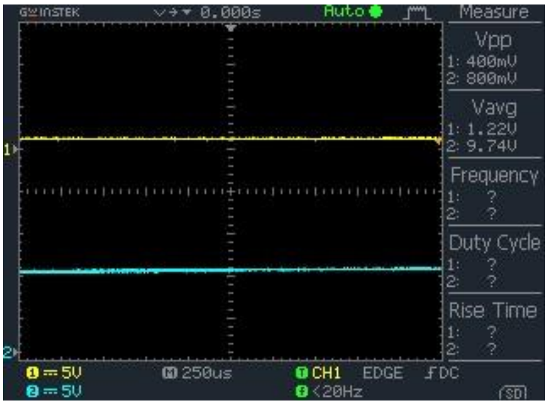


Figure 9. Constant Speed with Electrical Energy Conversion Output

The picture above shows that the generator operates at low Speed, producing an output voltage of about 600 mV, while the voltage on the buck-boost converter reaches about 11 Volts. However, even though the converter voltage is relatively high, this condition does not allow for battery charging because the voltage produced is still too low. Minimum speed to be able to charge the battery is presented on **Figure 10**.

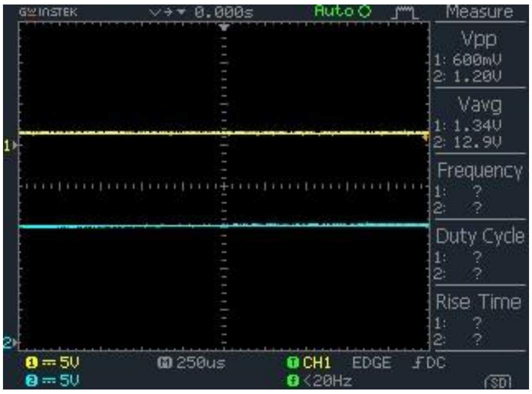


Figure 10. Minimum Speed to be Able to Charge the Battery

In the figure above, the oscilloscope shows that the voltage generated has reached the minimal level required to charge the battery. The generator's output voltage reaches 1.34 Volts, while the output voltage of the buck-boost converter reaches 12.9 Volts, which means that it has been possible to charge the battery effectively.

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4. Conclusion

Their operating Speed dramatically influences the performance of DC generators in generating voltage. Speedow rates: the voltage produced by the generator is still too low to charge the battery, while at maximum Speed, Speedvoltage reaches a level sufficient for charging the battery. Therefore, control and adjustment of generator speed are vital in maximizing battery charging efficiency using a buck-boost converter

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