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DESIGN AND PERFORMANCE EVALUATION OF ANALYTIC-TUNING PID ON BOOST CONVERTER FOR 200 WP PHOTOVOLTAIC

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Abstract

Nowadays, renewable energy showed enormous growth. In contrast to other renewable energy, solar energy has turned out to be the most decent source because of its unique advantages such as zero carbon emission, noiseless, inexhaustible, safe, and efficient. However, this photovoltaic scheme has several weaknesses like this energy is very dependent on weather conditions which causes unstable output energy produced. Therefore, DC to DC Converter combined with PID control can be used to produce a stable output voltage. In addition, this control can increase the output voltage response generated by the DC to DC Boost Converter. This research presents the analysis of Analytic-Tuning PID on Boost Converter simulation and implements the system for 200 WP photovoltaic. Simulations have been performed using MATLAB Simulink and validated with hardware implementation. The simulation results show that the Analytic-Tuning PID has a better output response than the Analytic PID depicted on the maximum overshoot voltage by 3.317 Volt (95%) and steady state error by 0.2087% (50%). This research will provide a better method to maximize the output response of the Boost Converter.

Keywords: Analytic and tuning, Boost converter, Photovoltaic, PID.

1. Introduction

Energy is very important for humans to fulfil all existing activities. Energy is useful for fulfilling daily life, health, communication, social activities and well beings. Renewable energy schemes provide a green economic that will provide a low carbon, resource efficient, socially inclusive, and sustainable energy rather than conventional fossil fuels. The renewable energy source such as photovoltaic (PV) and wind are rated at an increased level due to environmental conditions and improvement in technology, also receiving tremendous demand since it is pollution free from any poisonous by-products that can pollute the environment [1-4]. One of the promising renewable energy sources is solar photovoltaic. Photovoltaic can convert solar energy into electrical energy. Photovoltaic (PV) solar power generation systems are widely used in grid connected and off grid applications. Even photovoltaic can produce environmentally friendly and sustainable energy, but photovoltaics requires some supporting equipment for power quality management such as harmonic suppression, reactive power compensation and power outage avoidance [5, 6].

DC to DC Converter is a power electronic circuit that provides energy transfer between input energy such as renewable energy to output energy such as storage energy. This DC to DC circuit can transform variable or constant DC voltage to a different variable or constant DC voltage level, usually used to stabilize the output voltage.

The DC to DC Converter used power semiconductor switches like IGBT or Mosfet components that function as duty cycle settings at the gate foot of the Mosfet based on the desired voltage. Several parameters must be considered when designing a DC to DC Converter such as the number of circuit components, galvanic isolation, power rating, energy conversion efficiency, current conversion ratio and voltage conversion ratio [7, 8]. The DC to DC Converter application as a power converter has been widely used in several industrial applications such as photovoltaic conversion, hybrid storage batteries, electric vehicles and fuel cell automotive applications [9, 10].

There are several types of DC to DC Converters which are divided based on their function, namely DC to DC Buck Converter, Boost Converter and Buck-Boost Converter [11-13]. The Boost converter is a step up converter that converts the output voltage to be greater than the input voltage by changing duty ratio D [14].

One of the most important things in a DC to DC Boost Converter is the duty cycle control. Recently, many control methods for boost converters have been developed, such as fuzzy logic controller [15-17], artificial neural network [18, 19], perturb and observe [20, 21] and PID [22]. Some of these methods have their respective advantages and disadvantages. The method that is often used is PID control due to its relatively easy calculation and implementation. However, there are limitations from previous research on the parameters of the output response Maximum overshoot voltage which is quite high [23-25]. This parameter will be able to cause damage to the components and system.

The objective of this research is to provide the analysis of PID Analytic-Tuning Method based on DC to DC Boost Converter. The difference between this PID Analytic method and PID Analytic-Tuning method by tuning for one control parameter (Integral). This method will increase several parameters of the output response of the Boost Converter, especially on Maximum overshoot voltage and steady state error. This will increase the performance of the Boost Converter to work at a better working voltage.

2. Photovoltaic Design

Converting solar energy using photovoltaic, to produce electrical energy is one of the most promising markets in the field of renewable energy [26]. Photovoltaic design in this research is calculated based on the power that will be used for the load. This system uses a battery as a store of electrical energy from photovoltaic. The batteries used in this research amounted to 2 units with a specification of 12 Volt 32 Ah which were installed in series to get a battery with a specification of 24 Volt 32 Ah. After determining the battery capacity, the required voltage and charging current can be determined.

The charging voltage (Vch) of the battery should be set at a value of 2.3 Volt - 2.4 Volt per cell. If each 12 Volt battery has 6 cells, then the battery should be charged with the following voltage:

$$Vch = 2.4 \times \text{battery cell} \tag{1}$$

$$= 2.4 \times 12 = 28.8 \text{ Volt}$$

The charging current of the battery should be set around 0.1 to 0.3 (10% - 30%) of the battery capacity. If a 32 Ah battery is used, the charging current is around 3.2 A - 9 A. In this research using 6 amperes charging current of with details:

$$Ich = \% \, x \, Ah \tag{2}$$

$$\% = \frac{Ich}{Ah} \, x \, 100\%$$

$$= \frac{6}{32} \, x \, 100\% = 18.75\%$$

Based on the above calculations, the value of the charging voltage is 28.8 V, and the charging current is 6 A. These two parameters are used in designing the photovoltaic power supply requirements.

Battery charging time (*t*)

$$t = \frac{Ah}{Ich} \tag{3}$$

$$= \frac{32}{6} = 5.4 \text{ hour}$$

Total output energy (*Wout*)

$$Wout = Vch \, x \, Ich \, x \, t \tag{4}$$

$$= 28.8 \, x \, 6 \, x \, 5.3 = 915.84 \text{ Wh}$$

The input energy required to supply the output energy must be greater than the output energy as much as 1000 Wh. Photovoltaic is assumed to be able to produce maximum power during the day for 4-5 hours per day, so the photovoltaic peak power required for this research is:

$$Win = P(peak) x \, h \tag{5}$$

$$P(peak) = \frac{Win}{h}$$

$$= \frac{1000}{532} = 200 \text{ Wp}$$

According to the calculations, this research uses a solar panel of 200 Wp which is installed in parallel to maximize the current output. The specification for photovoltaic 200 WP is depicted in Table 1.

Table 1. 200 WP photovoltaic specifications.

No.	Specification	Unit
1	Maximum Power (Pmax)	200 W
2	Short Circuit Current (Isc)	12.12 A
3	Voltage at Point of Maximum Power (Vmpp)	18 V
4	Current at Point of Maximum power (Impp)	11.12 A
5	Open Circuit Voltage (Voc)	22 V

3. Boost Converter Design

A DC to DC Boost Converter consists of Mosfet or BJT as the power switches to control the Pulse Width Modulation (PWM), inductor, diode, output filter capacitance as low pass filter and resistive load are depicted on Fig. 1. The output voltage for this DC to DC converter is always bigger than the output voltage. This Converter runs in two modes called ON-Mode and OFF-Mode. On-Mode running when the switch is on, represents a short circuit ideally the diode will be in a reverse biased state which cannot transmit its energy to the load. The electric current enters through the inductor and continues into the Mosfet. Therefore, electrical energy when On-mode is stored in the inductor Off-Mode running when the switch is off, the energy stored in the inductor is released and eventually dissipated in the load resistance, and this helps to keep the current flowing in the same direction through the load and also increases the output voltage as the inductor now also acts as a source in conjunction with the input source. The DC to DC boost converter in this system is used to increase the output voltage and stabilize the output voltage to 28.8V as battery charging.

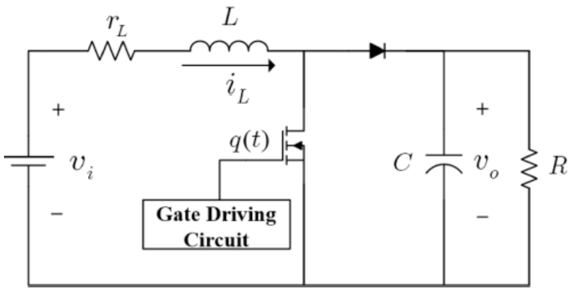

Fig. 1. Boost converter circuit [27].

The relationship of input voltage (Vo) and duty cycle (D) to produce the higher output voltage using DC to DC Boost Converter are observed. The output value (Vs) depends on the duty cycle. This system uses a battery charging voltage of 28.8 Volt, and photovoltaic 200 WP has a minimum working voltage of 12 Volt. Therefore the value of the duty cycle in this circuit is:

$$Vo = \frac{Vs\ (min)}{1-D} \quad (6)$$

$$D = 1 - \frac{Vs\ (min)}{Vo}$$

$$= 1 - \frac{12}{28.8} = 0.583$$

There are 2 important components in the DC to DC Boost Converter circuit, namely the inductor and capacitor. These two components can be calculated by determining the voltage and current ripples. In this study, the current ripple (ΔIL) is 20% and the output voltage ripple (ΔVo) is 0.5%. This DC to DC Boost Converter uses a 40 kHz switching frequency. Therefore the value of inductor and capacitor in this circuit are:

$$L = \frac{1}{f}[\,Vo - Vs(min)]\,\frac{Vs(min)}{Vo}\,\frac{1}{\Delta IL} \quad (7)$$

$$= \frac{1}{40000}(28.8 - 12)\,\frac{12}{28.8}\,\frac{1}{2.874} = 60.89\ \text{uH}$$

$$C = \frac{Vo\ x\ D}{\Delta Vo\ x\ R\ x\ f} \quad (8)$$

$$= \frac{28.8\ x\ 0.583}{0.144\ x\ 4.8\ x\ 40000} = 607.29\ \text{uF}$$

After calculating several components in the DC to DC Boost Converter circuit. After that, an open loop simulation was carried out to determine the output voltage response of the circuit. The observed output voltage responses are time peak (Tp), maximum overshoot (Mp), time settling (Ts), time rise (Ts), and steady state error (ess). Figure 2 is the simulation of open loop Boost Converter circuit whose output voltage is compared to the setting point value

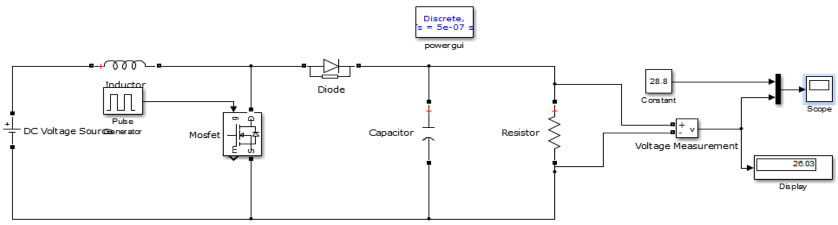

Fig. 2. Open loop boost converter simulation.

In Fig. 3, there are 2 output waves, namely the desired reference voltage is black with the resulting output voltage being red and it can be seen that the output voltage from the boost converter is still not good, as shown by the parameter values, namely Tp = 0.00155s, Mp=7.2V, Ts = 0.0124s , Tr = 0.00095s and ess = 9.7%. Based on the simulation, the output voltage still does not match the reference voltage from the calculation.

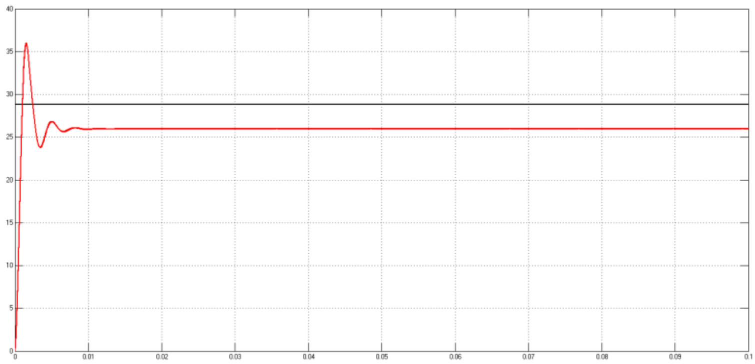

Fig. 3. Open loop boost converter simulation output response.

After the design and simulation process is done, the next step is to make the hardware. Hardware is made based on the calculation value of the Inductor (L) and Capacitor (C) which can be seen in Fig. 4. After that, the Boost Converter test was carried out to determine the working performance of the converter in an open loop mode. To test the Boost converter, an ARM STM32F4 microcontroller is needed to provide duty cycle pulses to the Mosfet. Duty cycle is set above and below the calculated Duty Cycle (65% to 37%). The data taken is in the form of input and output voltage and current data. This will get efficiency data from the Boost Converter which can be seen in Table 2. Based on the test data, this boost converter has succeeded in increasing the output voltage which has an average efficiency of 79%. Based on Fig. 5, this boost converter has been able to increase the output voltage, but the results are still different from the calculated output voltage (28.8 Volts).

Fig. 4. Boost converter hardware.

Table 2. Open loop boost converter hardware testing.

No	Duty cycle	Vs (Volt)	Is (A)	Vo(p) (Volt)	Vo(t) (Volt)	Io (A)	η (%)	%error (%)
1	65%	10	12.9	21.8	28.5	4.28	72.4	23.59
2	62%	11	12	21.9	28.9	4.42	73.3	24.34
3	58%	12	11.3	22.4	28.5	4.51	74.5	21.6
4	55%	13	11	23.5	28.8	4.74	77.8	18.65

5	51%	14	10.3	23.9	28.5	4.78	79.2	16.35
6	48%	15	9.9	24.4	28.8	4.9	80.5	15.41
7	44%	16	9.4	24.8	28.5	4.98	82.1	13.2
8	41%	17	9	25.1	28.8	5.03	82.5	12.88
9	37%	18	8.5	25.3	28.7	5.06	83.6	11.95

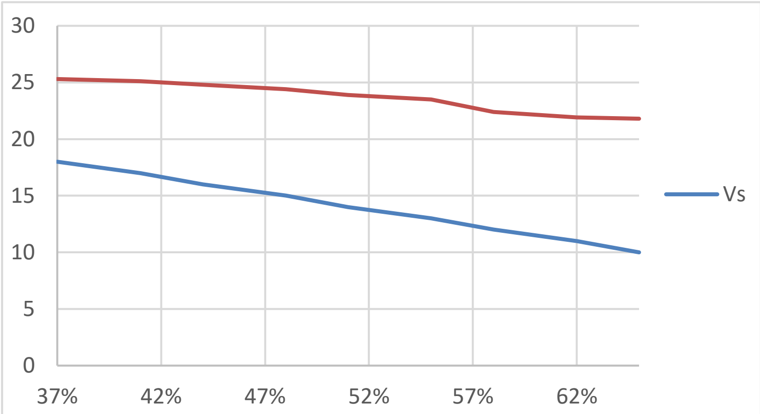

Fig. 5. Boost converter output response (without PID).

4. Analytic Tuning PID Design

The existence of a controller in a control system has a major contribution to the behavior of the system. One of the tasks of the controller component is to reduce the error signal, namely the difference between the setting signal and the actual signal. This is because the purpose of the control system is to get the actual (desired) signal always the same as the setting signal. The faster the reaction of the system follows the actual signal and the smaller the error that occurs, the better the performance of the applied control system. If the difference between the setting value and the output value is relatively large, a good controller should be able to observe this difference to immediately produce an output signal.

Based on the results of the Open Loop simulation of the Boost Converter output wave, the resulting output voltage is not following the reference voltage and there is a high overshoot voltage. This shows that the output voltage response is not good. Therefore, this system is equipped with the PID Algorithm which aims to produce a fixed output voltage according to the reference voltage. In addition, this PID algorithm will stabilize the voltage with a variable input voltage. The way the PID algorithm works is by comparing the output voltage with the reference voltage set for the duty cycle setting which can be seen in Fig. 6. PID tuning analysis is done by calculating the analytical method to get the value of Kp, Ki and Kd. After getting the value of these three components, then a simulation is carried out to determine the output response generated from this PID control. After that, tuning the values of Kp, Ki and Kd is done to get a better voltage output (small overshoot and fast settling time). The use of the PID analytic tuning method increases the output voltage response quality of the Boost Converter.

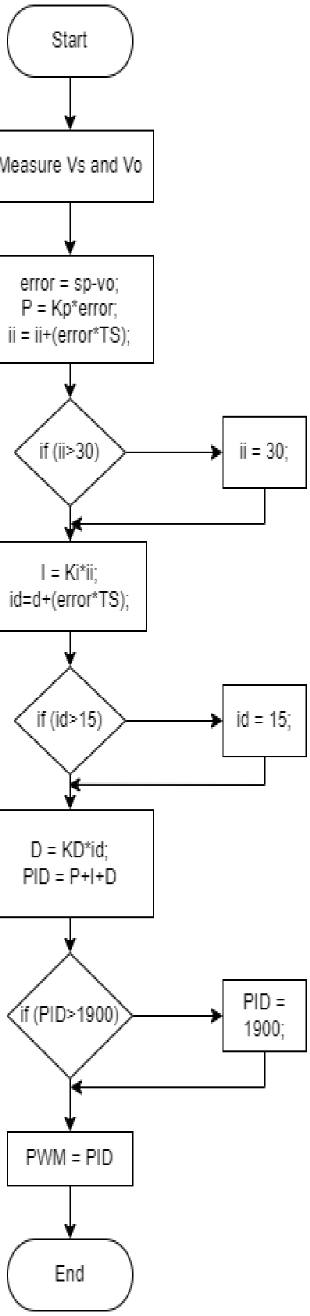

Fig. 6. PID flowchart system.

$$\omega_d = \frac{\pi}{t_p} \tag{9}$$

$$= \frac{3.14}{0.00155} = 2025.8 \text{ rad/s}$$

$$\tau = \frac{t_s}{4} \tag{10}$$

$= \frac{0.0124}{4} = 0.0031\ s$

$\alpha = \frac{1}{\tau}$ (11)

$= \frac{1}{0.0031} = 322.58\ s^{-1}$

$K = \frac{Y_{ss}}{X_{ss}}$ (12)

$= \frac{26.04}{28.8} = 0.904$

$\xi^2 = \frac{\alpha^2}{\left(\alpha^2+\omega_d{}^2\right)}$ (13)

$= \frac{322.58^{\ 2}}{(322.58^2+2025.8^2)} = 0.157$

$\omega_n = \frac{\alpha}{\xi}$ (14)

$= \frac{322.58}{0.157} = 2054.64$

$\tau_i = \frac{2\xi}{\omega_n}$ (15)

$= \frac{2\times0.157}{2054.64} = 0.0001528$

Analytic PID

$\tau = \frac{t_s}{4}$ (16)

$= \frac{0.002}{4} = 0.0005$

$K = \frac{Y_{ss}}{X_{ss}} = \frac{28.8}{28.8} = 1$

$k_p = \frac{\tau_i}{\tau\ K}$ (17)

$= \frac{0.0001528}{0.0005\ x\ 1} = 0.3056$

$k_i = \frac{k_p}{\tau_i}$ (18)

$= \frac{0.3056}{0.0001528} = 2000$

$k_d = k_p\ x\ \tau_d$ (19)

$= 0.3056\ x\ 0.00155 = 0.000474$

Equations (9)-(19) are used to find the Kp, Ki, and Ki parameters from the Boost Converter output response using the Analytical method. Figure 7 is a block diagram of the entire system consisting of input, PID control, system plan, feedback, and output. The whole block diagram is a series of PID controls and Boost Converters that have been calculated mathematically to be simulated. The simulation in the block diagram of the whole system is a closed loop Boost Converter simulation which has been controlled to stabilize the output voltage of the system.

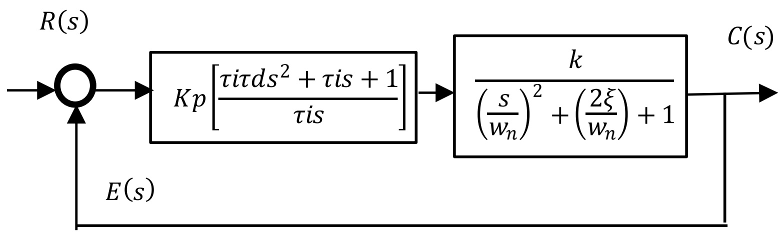

Fig. 7. PID algorithm system.

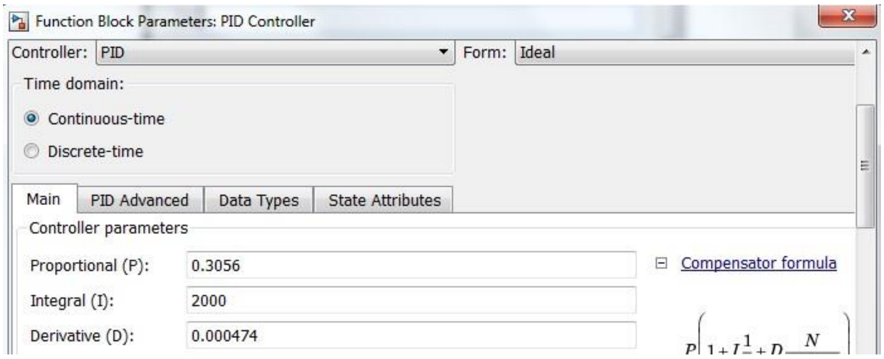

Fig. 8. PID control parameter using analytic method.

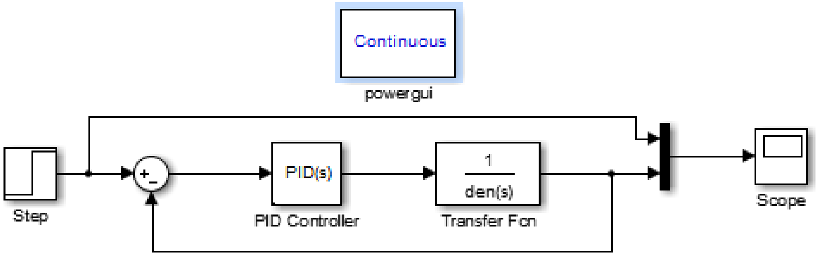

Fig. 9. Closed loop boost converter PID Analytic simulation.

Figure 8 shows the Proportional (P), Integral (I) and Derivative (D) on Matlab Simulink Simulation. Figure 9 is a simulation of the Boost Converter system which has been equipped with PID Control. Based on Fig. 10, there are 2 wave images, namely the output waveform with the PID control in red line colour (Analytic method) and the reference voltage in blue line colour. After being equipped with PID control, the output of the Boost Converter shows some changes with the following parameters Tp = 0.00067s, Mp=3.3V, Ts = 0.057s, Tr = 0.000384s and ess = 0.4167%. It can be seen that the output response produced is quite good, but a tuning method must be carried out to produce a better output to produce a faster settling time and not too large an overshoot.

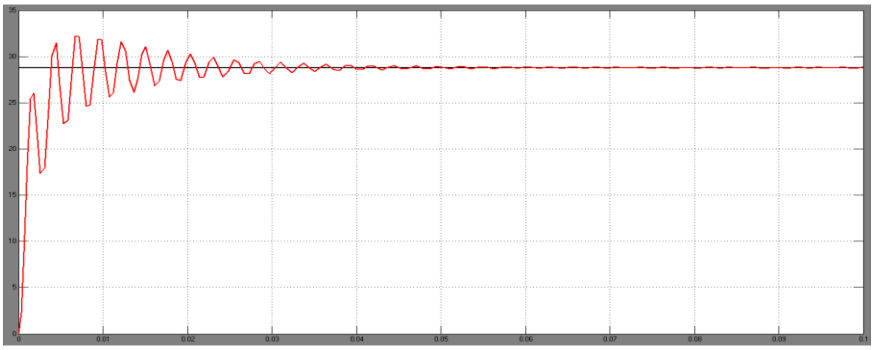

Fig. 10. Output response of closed loop boost converter PID analytic simulation.

Parameter tuning is done by changing the Proportional (P), Integral (I) and Derivative (D) values to changes in the output voltage wave image of the system. After tuning the parameters several times, the values obtained are P = 0.3056, I = 1200, and D = 0.000474 which are shown in Fig. 11. In this study, the focus is only on changing one of the parameters, namely the Integral. The purpose of Integrative parameter tuning is to minimize overshot and reduce the steady state error value. Based on Fig. 12, there are 2 wave images, namely the blue reference voltage and the output voltage with PID (Analytic-Tuning Method) control, the results of the output voltage response are Tp = 0.0122s, Mp = 0.163V, Ts = 0.0329s, Tr = 0.012s and ess = 0.208%. This indicates an improvement in the response with a decrease in the maximum overshoot voltage and a smaller steady state error value.

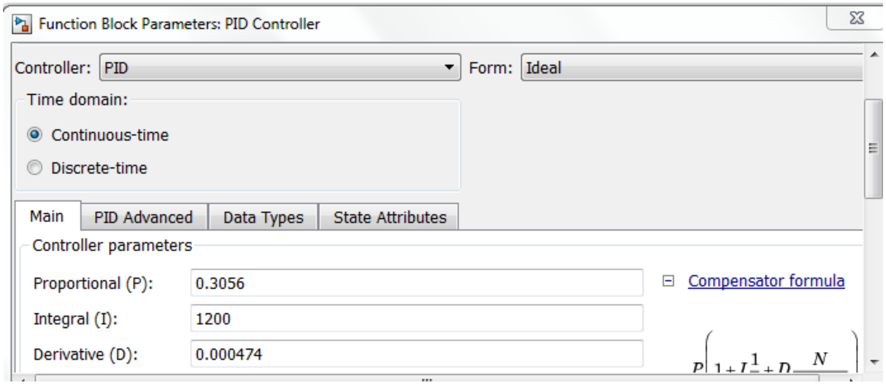

Fig. 11. PID parameter analytic-tuning simulation.

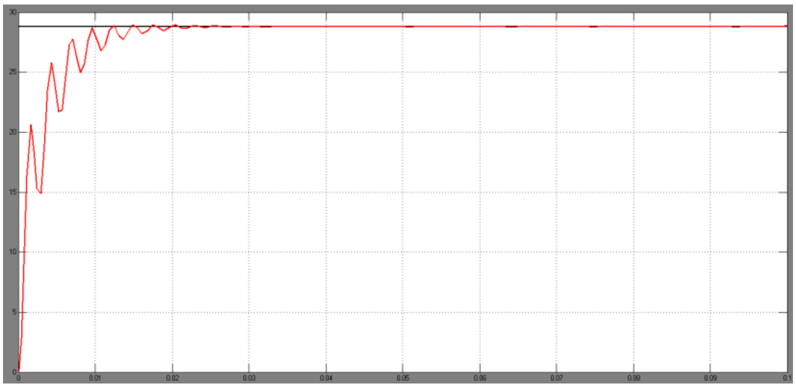

Fig. 12. Output response of closed loop boost converter PID analytic-tuning simulation.

5. Implemented System

This system consists of the use of 200 WP photovoltaic as a source of electrical energy by converting solar energy, a boost converter to produce an output voltage greater than the input voltage, PID control to stabilize the output voltage by changing the input voltage value from the solar panel, and a battery (24 Volt 32 Ah) as electrical energy storage are depicted on Fig. 13. These four subsystems are tested as one system that is connected.

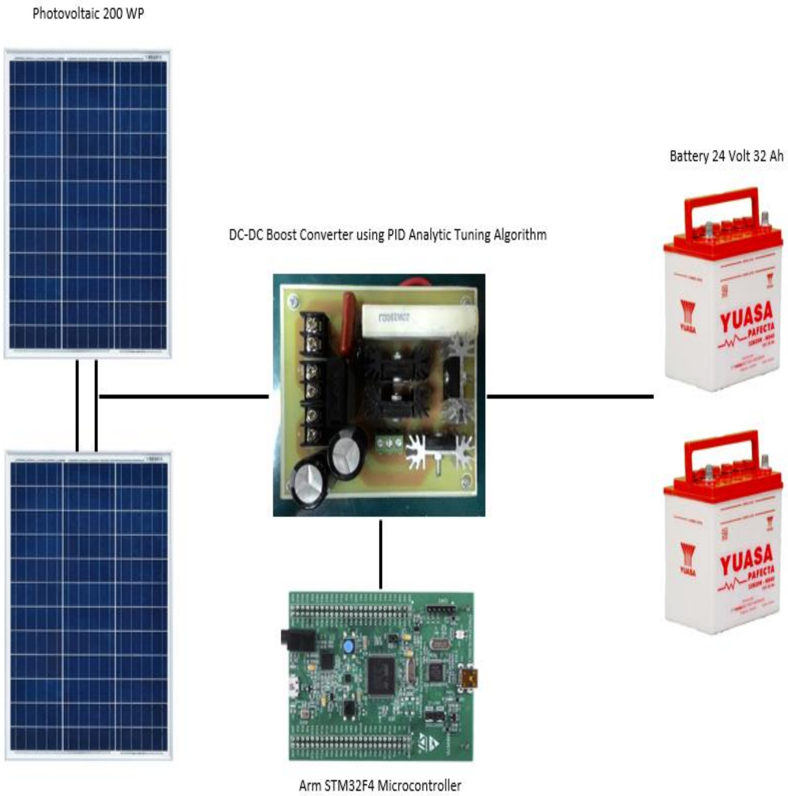

Fig. 13. Block diagram system.

In this closed loop boost converter test, the aim is to test the boost converter for battery charging with a solar panel source that has a variable voltage and uses PID control to make the boost converter output voltage constant. The ARM STM32F4 microcontroller functions to regulate all the work of the control, namely for reading the voltage and current sensors, for PID control, and giving the ignition angle of the Mosfet which is controlled by the PID control. Table 3 shows a closed loop boost converter test with a photovoltaic input (200 WP) which has a variable input voltage for battery charging (24 Volt 32 Ah). The closed loop boost converter test is carried out from morning to noon to determine the resulting charging current. The data shows that the output voltage generated from the PID control has approached the value of the setting point, which is 28.8 Volt. Figure 14 is the result of the input and output voltage response by recording data with serial communication in real time. The PID control response seen is the settling time, the time it takes for the voltage to reach steady (constant) 28.8 Volt, which is about 50 seconds.

Table 3. Closed loop boost converter hardware testing.

No.	Time	Duty	Vs (Volt)	Is (A)	Vo(p) (Volt)	Io (A)	η (%)
1	10:30	30	11.01	11	28.56	2.4	56.5
2	10:40	26	9.8	11	28.93	2.07	55.5
3	10:50	23	9	11.4	28.98	1.83	51.6
4	11:00	21	8.15	11.5	28.88	1.62	49.9

5	11:10	21	8.14	11.5	28.99	1.56	48.3
6	11:20	20	8.03	11.5	28.98	1.51	47.3
7	11:30	19	7.58	11.8	28.86	1.44	46.4
8	11:40	18	7.5	12	28.88	1.42	45.6
9	11:50	19	7.6	11.9	28.94	1.4	44.7
10	12:00	20	7.85	11.5	29.08	1.39	44.7
11	12:10	19	7.8	11.5	28.91	1.37	43.9
12	12:20	19	7.6	11.8	28.93	1.36	43.8
13	12:30	19	7.73	11.6	28.92	1.33	42.8
14	12:40	19	7.75	11.6	28.89	1.31	42.0
15	12:50	19	7.67	11.4	28.94	1.29	42.6
16	13:00	18	7.3	11.3	28.84	1.27	44.4

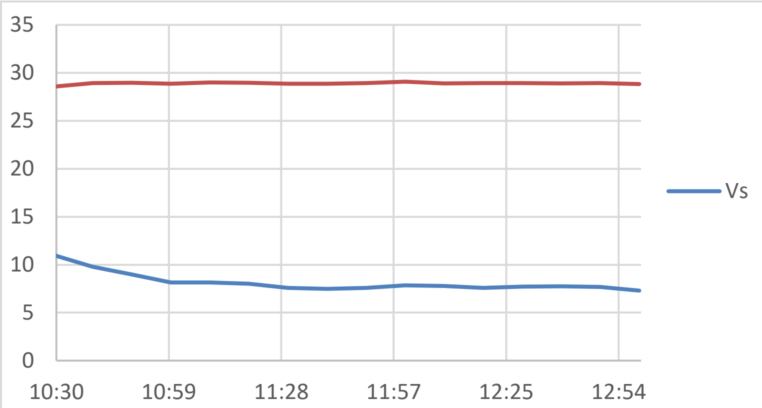

Fig. 14. Real time boost converter output response.

6. Conclusions

The PID control on Boost Converter for 200 WP Photovoltaic with Analytic-Tuning Method is designed, implemented, and tested to obtain the stabilized output voltage for charging the battery. The performance of the control system is analysed using the PID simulation model of the Boost Converter and then validated on hardware. By using this PID control with Analytic Tuning Method on Integrative parameters, it can make the system less overshoot voltage and less steady state error. Based on the simulation data between the analytic method and the Analytic-Tuning, there is a decrease in Maximum Overshoot Voltage by 3.317 Volt (95%) and steady state error by 0.2087% (50%). PID Control can stabilize the output voltage based on the output voltage setting point.

Nomenclatures

Ich	Charging current
t	Time
t_p	Time peak
t_s	Time settling
Vch	Charging voltage
Win	Input energy
Wout	Output energy

Abbreviations

D	Duty Cycle
DC	Direct Current
PID	Proportional Integrative Derivative
PV	Photovoltaic
PWM	Pulse Width Modulation
WP	Watt peak

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