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Effect of Using PID Control in Switched Inductor Boost Converter

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Abstract: Among the different kinds of boost converters is the switched inductor boost converter. But the Switched Inductor Boost Converter still has drawbacks, like output voltage results that still overshoot, a lengthy time to attain a steady state, and output voltage that fluctuates in response to input voltage changes. This shortcoming can be addressed in this investigation by using a PID controller. The PID parameter is obtained using the Direct Synthesis method, which includes Kp, Ki, and Kd. The state space averaging method is employed for the converter modeling. By applying the PID controller to the Switched Inductor Boost Converter while simulation is carried out using MATLAB-Simulink, the output voltage's transient response is improved where PID control can eliminate overshoot on output voltage response and speed up settling time by 1.35 times and also improves system's resistance to variations in input voltage and load value, allowing it to sustain the output voltage and lower momentary voltage change up to 68.3045% and speeds up recovery time up to 2.5287 times faster when input voltage changes occurs and lower overshoot value up to 39.2809% and speeds up recovery time up to 2.708 times faster when load changes occurs.

Keywords: boost converter, direct synthesis, PID controller, switched inductor boost converter.

1. Introduction

Over the past few years, as the utilization of renewable energy sources has grown, so have also increased the demands on DC power supply loads. Using a DC-DC converter is anticipated to assist with the wide range of load requirements using a DC power source. Nowadays, DC-DC converter has largely applied on electronic devices, such as fuel cell system and solar cell system, battery storage, light-emitting diodes products, car's electronic devices, and portable devices [6].

A boost converter is frequently used to increase DC voltage by storing energy in an inductor while it is in the ON state and transferring it to the load when it is in the OFF state [10]. A boost converter is one of the tools that may be utilized as a solution for solar cell systems and other renewable energy systems. Solar cell system have variable generated voltage value, It resulted in the output voltage of the solar cell system being dependent on the weather at the moment. It reaches its highest efficiency during hot weather and when there are less clouds in the sky. However, the output voltage of solar cell system will in minimum condition when there were cloudy weather occurred. This is a problem when solar cell system used for charge the battery because stable voltage is needed for battery charging. Because of that, boost converter can be used to stabilize the solar cell system's output voltage so solar cell system can be use for battery charging. Boost converter have a lot of model and composition which every of them have their own advantage and disadvantage

One sort of boost converter with a single switch is the switched inductor boost converter. It is a single switch converter that was developed from the conventional boost converter by substituting the conventional inductor for a switched inductor cell—which is made up of two identical inductors L_1, L_2, and passive switching network D_1, D_2, D_3 [14].

But, Switched Inductor Boost Converter still have some downside. Switched Inductor Boost Converter circuit has output voltage with high overshoot value, long settling time and output voltage will change along with the change of input voltage. That downside make Switched Inductor Boost Converter circuit need a controller, so they have reduced overshoot value, reduced settling time and constant output voltage even when the input voltage value have change. Controller that used in this study is PID controller.

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PID controller have many applied in converter because of PID controller was knows as its simplicity and effectiveness at compromise the error resulting from difference between the set point and feedback voltage in power converters design [4]. Compered to other controller such as P, PI, and PD, PID controller have advantages like most optimum controller, have a quick response, didn't producing oscillation and having high stability, where P controller used to reduce error steady state, but P controller producing oscillation and also amplify noise. PI controller used to eliminate P controller error steady state , but didn't have ability to predict future error from a system, also can't lower the rise time and can't eliminate oscillation. PD controller used to increase the system stability, but D controller also amplify noise directly [11]. Because of that, PID controller was chosen to applied at Switched Inductor Boost Converter circuit in this study

At Switched Inductor Boost Converter study before [1], only focused on steady state condition, the shown phase only without overshoot. But after further study, the output from Switched Inductor Boost Converter circuit from last study has a high overshoot value, long settling time and output voltage will change along with the change of input voltage. In this study, an assessment will conducted on the use of PID controller in Switched Inductor Boost Converter circuit which expected to reduce overshoot value, reduce settling time and stabilize Switched Inductor Boost Converter output voltage also makes Switched Inductor Boost Converter resist from disturbance at input voltage change and load change.

2. Methods

2.1 Switched Inductor Boost Converter

Switched Inductor Boost Converter is a DC-DC converter which work as boost converter, that is a DC-DC converter with higher output voltage than input voltage. This single switch converter was derived from the traditional boost converter by replacing the regular inductor by the switched inductor cell, comprised of a pair of identical inductors L_1, L_2, and passive switching network D_1, D_2, D_3 [14].

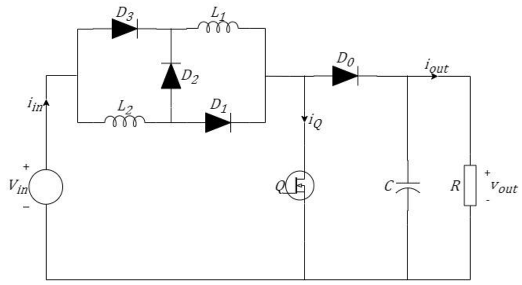

Figure. 1 Switched Inductor Boost Converter circuit

According to Fig. 1, Switched Inductor Boost Converter consists of 1 switch, 4 diodes, 2 inductors, 1 capacitor and 1 load. There are 2 operation modes for Switched Inductor Boost Converter, that is mode 1 at closed switch condition (on) and mode 2 at open switch condition (off).

Switched inductor boost converter circuit with closed switch condition shown as Fig. 2.

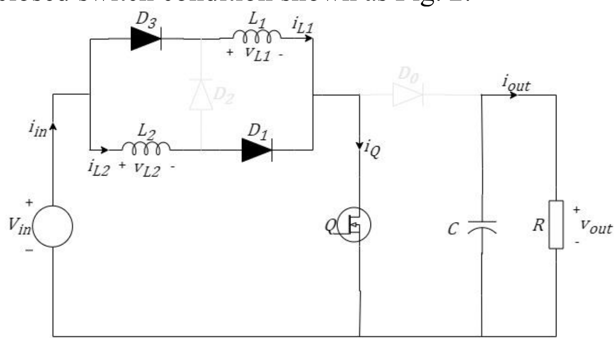

Figure. 2 Switched inductor boost converter circuit with closed switch condition

According to Figure 2 when switch on at interval $0 < t < DT$, when switch on diode (D_1, D_3) active and (D_0, D_2) in off condition. Inductor L_1 and L_2 receive an energy from voltage source in parallel form. Stored energy from capasitor C was released to load. Using KVL (Kirchoff Voltage Law) and KCL (Kirchoff Current Law) methods [9], so:

$$\Sigma V = 0 \tag{1}$$
$$\Sigma i = 0 \tag{2}$$

Then we get equation like [1]:

$$V_{L1} - V_{in} = 0 \tag{3}$$
$$V_{L1} = V_{in} \tag{4}$$

Because L_1 and L_2 parallel, so:

$$V_{L_1} = V_{L_2} = V_{in} \tag{5}$$

Then,

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$$V_L = V_{in} \tag{6}$$
$$L\frac{di_L(t)}{dt} = V_{in} \tag{7}$$
$$\frac{di_L(t)}{dt} = \frac{V_{in}}{L} \tag{8}$$
$$i_c = -i_{out} \tag{9}$$
$$C\frac{dv_{out}(t)}{dt} = -\frac{v_{out}}{R} \tag{10}$$
$$\frac{dv_{out}(t)}{dt} = -\frac{v_{out}}{CR} \tag{11}$$

According to Eq. (8) and Eq. (11), matrix was created like:

$$\begin{bmatrix} \frac{di_L(t)}{dt} \\ \frac{dv_{out}(t)}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{CR} \end{bmatrix} \begin{bmatrix} i_L \\ v_{out} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} [V_{in}] \tag{12}$$

Switched Inductor Boost Converter circuit with open switch condition shown as Fig. 3.

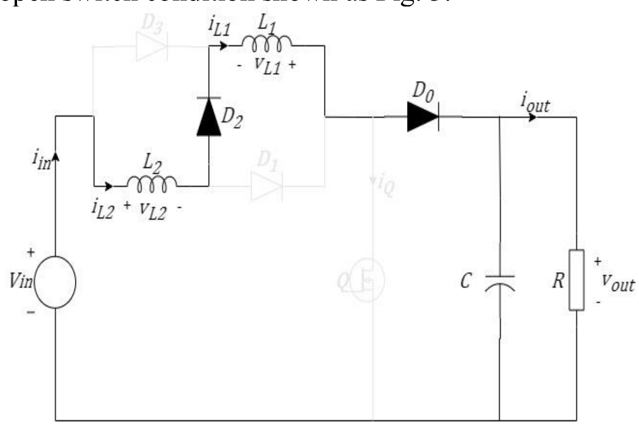

Figure. 3 Switched inductor boost converter circuit with open switch condition.

Switch off at interval $DT < t < T$, when switch off diode (D_0, D_2) active, and diode (D_1, D_3) in off condition. When switch off condition, capacitor C in charge condition gaining from inductor L_1 and L_2 which in discharge on series condition. Using KVL (Kirchoff Voltage Low) and KCL (Kirchoff Current Law) methods, then [1]:

$$V_{L1} + V_{L2} + V_{out} = V_{in} \tag{13}$$
$$V_{L1} + V_{L2} = V_{in} - V_{out} \tag{14}$$

If $L_1 = L_2 = L$ then $V_{L1} = V_{L2} = V_L$, so:

$$V_L = \frac{1}{2}(V_{in} - V_{out}) \tag{15}$$
$$L\frac{di_L(t)}{dt} = \frac{1}{2}(V_{in} - V_{out}) \tag{16}$$
$$\frac{di_L(t)}{dt} = \frac{1}{2L}(V_{in} - V_{out}) \tag{17}$$
$$i_c = i_L - i_{out} \tag{18}$$
$$C\frac{dv_{out}(t)}{dt} = i_L - \frac{V_{out}}{R} \tag{19}$$
$$\frac{dv_{out}(t)}{dt} = \frac{i_L}{C} - \frac{V_{out}}{CR} \tag{20}$$

According to Eq. (17) and Eq. (20), matrix was created like:

$$\begin{bmatrix} \frac{di_L(t)}{dt} \\ \frac{dv_{out}(t)}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{2L} \\ \frac{1}{C} & -\frac{1}{CR} \end{bmatrix} \begin{bmatrix} i_L \\ v_{out} \end{bmatrix} + \begin{bmatrix} \frac{1}{2L} \\ 0 \end{bmatrix} [V_{in}] \tag{21}$$

2.2 State Space Averaging (SSA)

Mathematical modeling is crucial for analyzing and controlling switched-inductor boost converters. Various modeling techniques have been employed, including circuit modeling, transfer function modeling, and state-space modeling [12]. The state-space averaging method is commonly used for controller design. Nonlinear phenomena, such as bifurcations and chaos, can occur in these converters, necessitating careful parameter selection [7]. Averaged modeling and linear complementarity systems have been utilized to model coupled inductor boost converters in discontinuous conduction mode [2]. Fractional calculus has also been applied to develop fractional mathematical models and state-averaged models for boost converters in continuous conduction mode [13]. These modeling approaches enable the analysis of converter characteristics, stability, and dynamic behavior, facilitating the design of suitable controllers. The matrix of Switched Inductor Boost Converter in closed switch and open switch condition using KVL and KCL was obtained before.

After equation from switch on and off condition was obtained, using SSA method, inductor current change and capacitor voltage change will be get with Eq. (22) and Eq. (23) [3].

$$\dot{x} = AX + BU \tag{22}$$
$$y = CX \tag{23}$$

With:

$$\dot{X} = \begin{bmatrix} \frac{di_L(t)}{dt} \\ \frac{dv_{out}(t)}{dt} \end{bmatrix} \tag{24}$$
$$A = D \cdot A_{ON} + (1-D)A_{OFF} \tag{25}$$
$$B = D \cdot B_{ON} + (1-D)B_{OFF} \tag{26}$$

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After matrix A and B values was obtained, by adding Eq. (12) and Eq. (21) to Eq. (22) and Eq. (23), we will get state space model in matrix form which shown in Eq. (27) and Eq. (28).

$$\begin{bmatrix}\frac{di_L(t)}{dt}\\ \frac{dv_{out}(t)}{dt}\end{bmatrix} = \begin{bmatrix}0 & -\frac{(1-D)}{2L}\\ \frac{(1-D)}{C} & -\frac{1}{CR}\end{bmatrix}\cdot\begin{bmatrix}i_L\\ v_{out}\end{bmatrix} + \begin{bmatrix}\frac{(1+D)}{2L}\\ 0\end{bmatrix}\cdot[V_{in}] \quad (27)$$

$$V_o = [0 \quad 1]\begin{bmatrix}i_L\\ v_C\end{bmatrix} \quad (28)$$

2.3 PID control

PID controller is feedback mechanism that used in closed loop control system. The resulting output based at measured error from combined 3 controller that is proportional controller (K_p), integral controller (K_i) and derrivatif controller (K_d) [5]. All three controller can be used together or individually depending on the desired response. By using all three controller together, we can get better control capabilities compared to the use of controllers individually. By using PID controller, it is expected to get lower overshoot value, faster settling time, and smaller error steady state value [8].

3. Results and Discussion

In this section, simulation was carried out to obtain the response of Switched Inductor Boost Converter output voltage. First simulation was done using open loop system to obtain the parameter to design PID control. Close loop system simulation was done after PID control parameter was obtained. Different input voltage and output voltage then applied to compare the output voltage response from open loop and close loop system of Switched Inductor Boost Converter.

3.1 Switched Inductor Boost Converter without controller simulation

The first simulation was performed to obtain the PID control parameter values. Simulation was carried out with the Switched Inductor Boost Converter Parameters that are shown in Table 1.

Table 1. Switched Inductor Boost Converter Parameters

No	Specification	Value
1	Input voltage	8 V
2	Desired output	36 V
3	Duty cycle	0.6364
4	Load resistance	10 Ω
5	Inductance	0.1 mH
6	Capacitor	100 µF
7	Switching frequency	46.5 kHz

MATLAB-Simulink is used for doing simulation. The simulation block model used to simulate the Switched Inductor Boost Converter circuit with an open loop system in the MATLAB-Simulink using parameters from Table 1 is shown in Fig. 4.

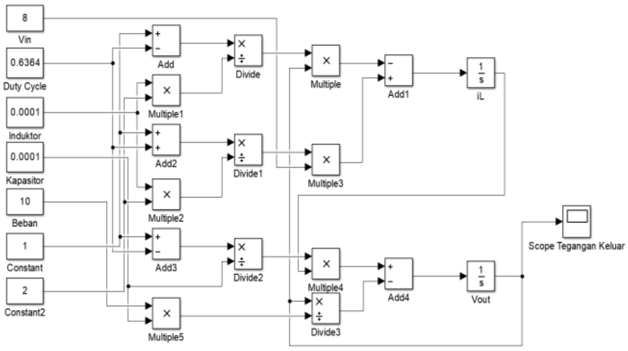

Figure. 4 Block model of Switched Inductor Boost Converter circuit with an open loop system

In Fig. 4, the simulation of Switched Inductor Boost Converter in open loop condition is performed to see the results from the converter if operated without controller. Things that need to be observed in this simulation are the overshoot value, the time needed to reach a steady state (settling time) and produced output voltage. After the simulation was done running, the results obtained is shown in Fig. 5.

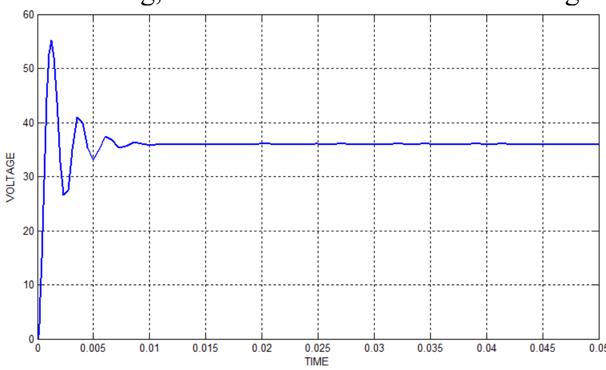

Figure. 5 Switched Inductor Boost Converter circuit with an open loop system output voltage response

Fig. 5 shown the output voltage response of Switched Inductor Boost Converter without controller with an input voltage of 8 volts and duty cycle 0.6364, the output voltage of Switched Inductor Boost Converter at steady state condition (V_{oss}) is 36 volts

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as desired with a peak voltage (V_p) of 55.26 volts at 0.001275 seconds and using criteria (± 5%) has a settling time of 0.00669 seconds. Maximum overshoot ($\%M_p$) value be calculated using V_{oss} and V_p value, so:

$$M_p = \frac{V_P - V_{OSS}}{V_{OSS}} = \frac{(55{,}26)-(36)}{(36)} = 0.535 \quad (29)$$

The output voltage graph that is shown in Figure 4 has the characteristics of a second order system. Thus to design the PID controller will be carried out using a second order system. Second order system is shown as Eq. (30) [15]:

$$\frac{Y(s)}{U(s)} = \frac{K}{\frac{1}{\omega_n{}^2}S^2 + \frac{2\xi}{\omega_n}S + 1} \quad (30)$$

While K is system amplifier, ω_n is natural frequency, and ξ is damping ratio. To create a 2nd order system model, the information from Figure 4 is used. The calculation of system amplifier value (K) is shown in the Eq. (31):

$$K = \frac{Voss}{U} \quad (31)$$

by steady state output voltage ($Voss$) is 36 V and duty cycle (U) is 0.6364, so obtained K value is 56.5682.

To find parameters value of ξ and ω_n, information from peak time (t_p) and maximum overshoot ($\%M_p$) is used for:

$$M_p = e^{-\left(\pi\xi / \sqrt{1-\xi^2}\right)} \quad (32)$$

By adding the M_p value that has been obtained to Eq. (32), then damping ratio (ξ) is obtained at 0.1954. After damping ratio obtained, then natural frequency (ω_n) can be obtained using Eq. (33).

$$t_p = \frac{\pi}{\omega_n\sqrt{(1-\xi^2)}} \quad (33)$$

By adding the peak time (t_p) = 0.001275 that obtained from Fig. 4, obtained ω_n value is 2511.1315 rad/s. So we get the mathematic model as:

$$\frac{Y(s)}{U(s)} = \frac{56.5682}{0.0000001584\, s^2 + 0.0001576\, s + 1} \quad (34)$$

From Fig. 5, the obtained t_s value (±5%) is 0.005273 s, so :

$$t_s(\pm 5\%) = 3\tau^* \rightarrow 0.005273 = 3\tau^* \rightarrow \tau^* = 0.001758 \quad (35)$$

To get the PID parameter value, the direct synthesis method is used. The direct synthesis method is one method for determining PID parameters based on a mathematical model of the system to fit the reference model [15]. The equation used to get these parameters can be obtained by analyzing the close loop system scheme as in Fig. 6 [15].

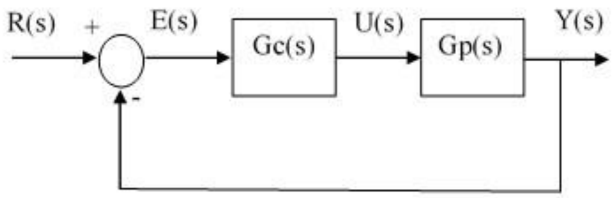

Figure. 6 Close loop with PID controller diagram block

Transfer function from Fig. 6 diagram block is shown as Eq. (36):

$$\frac{Y(s)}{R(s)} = \frac{Gc(s)\cdot Gp(s)}{1+Gc(s)\cdot Gp(s)} \quad (36)$$

Transfer function from PID controller is shown as Eq. (37)

$$G_c(s) = \frac{K_d s^2 + K_p s + K_i}{s} \quad (37)$$

Switched Inductor Boost Converter as a plant is a 2nd order system plant. So, transfer function of 2nd order system plant equation can be shown as Eq. (38)

$$G_p(s) = \frac{Y(s)}{U(s)} = \frac{K}{\frac{1}{\omega_n{}^2}S^2 + \frac{2\xi}{\omega_n}S + 1} \quad (38)$$

Because the desired output response result has a steady state error value of 0 and has no overshoot, a first-order system is used. By adding Eq. (37) and Eq. (38) to Eq. (36), the first-order equation is obtained as in Eq. (39):

$$\frac{Y(s)}{R(s)} = \frac{\frac{Kp\,K}{\tau_i s}}{1+\frac{Kp\,K}{\tau_i s}} = \frac{1}{\frac{\tau_i}{Kp\,K}s+1} = \frac{K^*}{\tau^* s+1} \quad (39)$$

Through Eq. (39), then PID controller parameters can be obtained using Eq. (40), Eq. (41) and Eq. (42)

$$K_p = \frac{\tau_i}{K\,\tau^*} \quad (40)$$

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$$\tau_i = \frac{2\xi}{\omega n}, K_i = \frac{K_p}{\tau_i} \quad (41)$$

$$\tau_d = \frac{1}{\tau_i \omega n^2}, K_d = Kp \ x \ \tau_d \quad (42)$$

By adding the results from Eq. (31), (32) and (35) to Eq. (40), (41) and (42), Parameters of PID controller are obtained as K_p= 0.001565, K_i = 10.0575 and K_d= 1.595 x 10^{-6}.

3.2 Switched Inductor Boost Converter with PID controller simulation

According to SSA models from converter at equation (27) and (28). The circuit parameters that will be used in the simulation are given in Table 1. After K_p, K_i and K_d values is obtained, The next step is to simulate Switched Inductor Boost Converter circuit in closed loop condition with PID controller on MATLAB-Simulink. These simulation are carried out to obtain the output voltage response from Switched Inductor Boost Converter with a closed loop system using PID control. The circuit used for simulation in MATLAB-Simulink can be seen in Fig. 7.

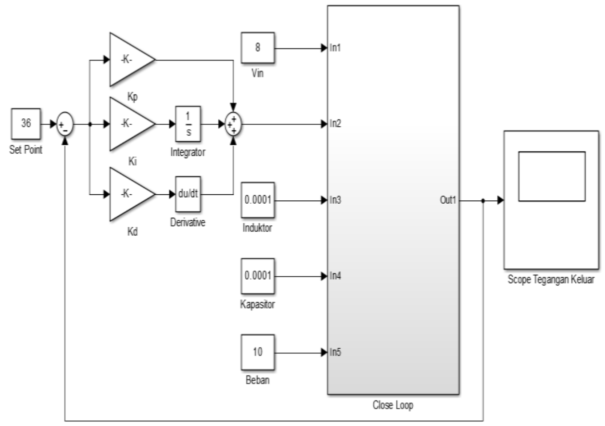

Figure. 7 Block model of Switched Inductor Boost Converter circuit with a close loop system using PID control

After the simulation was done running, the output voltage response from Switched Inductor Boost Converter with a closed loop system using PID control is shown in Fig. 8.

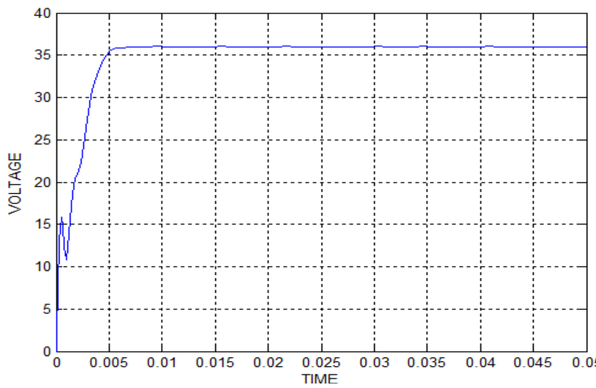

Figure. 8 Switched Inductor Boost Converter circuit with a close loop system using PID control output voltage response

In Fig. 8 shows the response of the output voltage from Switched Inductor Boost Converter with PID control with 8 volts input voltage. The PID controller is able to eliminate overshoots to 0.00% or 100% lower than open loop system and speed up settling time to 0.00494 s or 1.35 times faster at the output voltage.

To find out the resistance of Switched Inductor Boost Converter with PID control from disturbance, both open loop and close loop systems are performed with added disturbance to the input voltage and load values so that it can be analyzed how the system performance in maintaining the desired output voltage.

3.3 Switched Inductor Boost Converter with variable input voltage simulation

The first simulation is done by giving a variable input voltage value, the purpose of this simulation is to see the ability of PID control on Switched Inductor Boost Converter in overcoming changes in input voltage values. The input voltage value change is written in Table 2.

Table 2. Variants Input Voltage Changes

No	Time (s)	V_{in} (volt)
1	0	8
2	0.02	14
3	0.04	16
4	0.06	10
5	0.08	12

From Table 2, input voltage changes scheme curve that used for simulation in MATLAB-Simulink can seen from Fig. 9.

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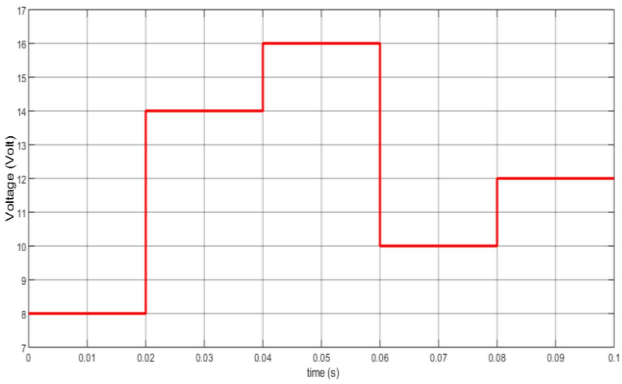

Figure. 9 Input voltage scheme curve

The circuit used for the simulation of Switched Inductor Boost Converter systems with input voltage changes in MATLAB-Simulink can be seen in Fig. 10.

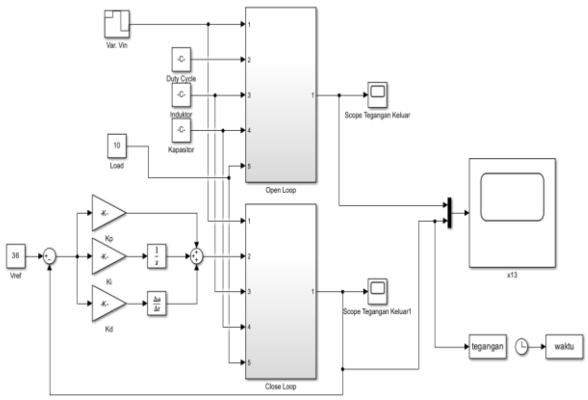

Figure. 10 Block model of Switched Inductor Boost Converter circuit with input voltage changes

After the simulation was done running, the response of the output voltage Switched Inductor Boost Converter with input voltages changes is shown by Fig. 11.

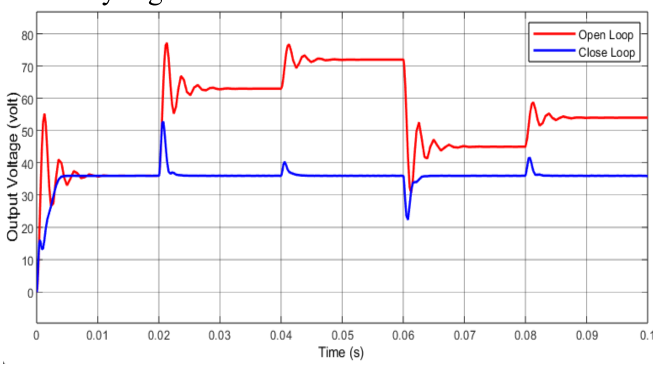

Figure. 11 Switched Inductor Boost Converter circuit output voltage response with input voltage changes.

From Fig. 11, we can obtain detailed information that can be seen in Table 3.

Table 3. Switched Inductor Boost Converter Output Voltage with several variants input voltages

No	Time (s)	Parameters	Open Loop	Close Loop
1	0.02	$\|\Delta V\|$ (volt)	41.1823	16.8118
		t_{rec} (s)	0.003924	0.001552
		V_{oss} (volt)	45	36
2	0.04	$\|\Delta V\|$ (volt)	13.7149	4.347
		t_{rec} (s)	0.001507	0.001121
		V_{oss} (volt)	54	36
3	0.06	$\|\Delta V\|$ (volt)	41.3801	13.6332
		t_{rec} (s)	0.004125	0.002236
		V_{oss} (volt)	63	36
4	0.08	$\|\Delta V\|$ (volt)	13.7657	5.5411
		t_{rec} (s)	0.001617	0.001239
		V_{oss} (volt)	72	36

From Table 3 it can be seen that as the input voltage changes, the Switched Inductor Boost Converter with PID control has better output voltage response than without PID control with Switched Inductor Boost Converter. Through Table 3, when the input voltage changes to 14 volts at t = 0.02, the Switched Inductor Boost Converter without PID control experiences a momentary voltage change of 41.1823 volts, has a recovery time of t_{rec} = 0.003924 s and experiences a change in output voltage to 63 volts, while the Switched Inductor Boost Converter with PID control experiences a momentary voltage change of 16.8118 volts, has a recovery time of t_{rec} = 0.001552 s and maintains the output voltage at 36 volts, this makes the Switched Inductor Boost Converter with PID control have a smaller momentary voltage change of 59.1771%, a faster recovery time of 2.5287 times and provides the desired output voltage value when compared to the Switched Inductor Boost Converter without PID control. When the input voltage changes to 16 volts t = 0.04, the Switched Inductor Boost Converter without PID control experiences a momentary voltage change of 13.7149 volts, has a recovery time of t_{rec} = 0.001507 s and experiences a change in output voltage to 72 volts, while the Switched Inductor Boost Converter with PID control experiences a momentary voltage change of 4.347 volts, has a recovery time of t_{rec} = 0.001121 s and maintains the output voltage at 36 volts, this makes the Switched Inductor Boost Converter with PID control have a smaller momentary voltage change of 68.3045%, a faster recovery time of 1.3435 times and provides the desired output voltage value when

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compared to the Switched Inductor Boost Converter without PID control. When the input voltage changes to 10 volts t = 0.06, the Switched Inductor Boost Converter without PID control experiences a momentary voltage change of 41.3801 volts, has a recovery time of t_{rec} = 0.004125 s and experiences a change in output voltage to 45 volts, while the Switched Inductor Boost Converter with PID control experiences a momentary voltage change of 13.6332 volts, has a recovery time of t_{rec} = 0.002236 s and maintains the output voltage at 36 volts, this makes the Switched Inductor Boost Converter with PID control have a smaller momentary voltage change of 67.0537%, a faster recovery time of 1.8447 times and provides the desired output voltage value when compared to the Switched Inductor Boost Converter without PID control. When the input voltage changes to 12 volts t = 0.08, the Switched Inductor Boost Converter without PID control experiences a momentary voltage change of 13.7657 volts, has a recovery time of t_{rec} = 0.001617 s and experiences a change in output voltage to 54 volts, while the Switched Inductor Boost Converter with PID control experiences a momentary voltage change of 5.5411 volts, has a recovery time of t_{rec} = 0.001239 s and maintains the output voltage at 36 volts, this makes the Switched Inductor Boost Converter with PID control have a smaller momentary voltage change of 59.7471%, a faster recovery time of 1.3048 times and provides the desired output voltage value when compared to the Switched Inductor Boost Converter without PID control.Through the data mentioned, PID control is able to overcome the shortcomings of the Switched Inductor Boost Converter in dealing with changes in input voltage values.

3.4 Switched Inductor Boost Converter with variable load simulation

The Next simulation is done by giving a variable load value, the purpose of this simulation is to see the ability of PID control on Switched Inductor Boost Converter in overcoming changes in load values. The load value change is written in Table 4.

Table 4. Variants Load Changes

No	Time (s)	*R* (Ω)
1	0	10
2	0.02	25
3	0.04	20
4	0.06	30
5	0.08	15

From Table 4, load value changes scheme curve that used for simulation in MATLAB-Simulink can seen from Fig. 12.

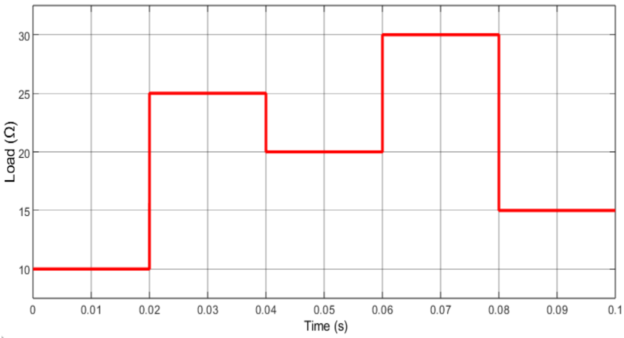

Figure. 12 Load changes scheme curve

The circuit used for the simulation of Switched Inductor Boost Converter systems with load value changes in MATLAB-Simulink can be seen in Fig. 13.

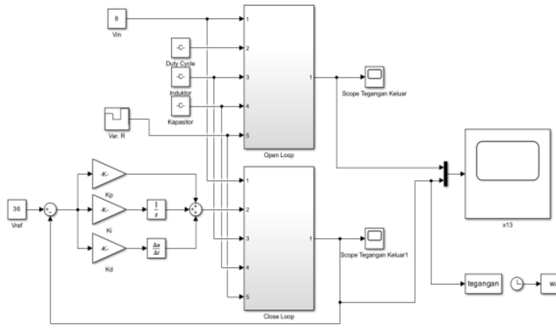

Figure. 13 Block model of Switched Inductor Boost Converter circuit with input voltage changes

After the simulation was done running, the response of the output voltage Switched Inductor Boost Converter with load value changes is shown by Fig. 14

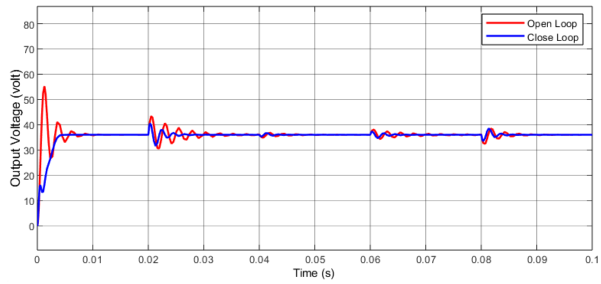

Figure. 14 Switched Inductor Boost Converter circuit output voltage response with input voltage changes

From Fig. 14, we can obtain detailed information that can be seen in Table 5.

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Table 5. Open Loop System Output Voltage with several variants input voltages

No	Time (s)	Parameters	Open Loop	Close Loop
1	0.02	M_p (%)	20.4736	12.4314
		t_{rec} (s)	0.006928	0.002558
2	0.04	M_p (%)	3.0861	2.1575
		t_{rec} (s)	0.000735	0.000367
3	0.06	M_p (%)	5.6731	3.6533
		t_{rec} (s)	0.000749	0.000337
4	0.08	M_p (%)	6.9783	6.8211
		t_{rec} (s)	0.002108	0.001662

From Table 5 it can be seen that as the load value changes, the Switched Inductor Boost Converter with PID control has better output voltage response than without PID control Through Table 5, when the load value changes to 25 Ω at t=0.02, the Switched Inductor Boost Converter without PID control has an overshoot of 20.4736% and has a recovery time of t_{rec} = 0.006928 s, while the Switched Inductor Boost Converter with PID control has an overshoot of 12.4314% and has a recovery time of t_{rec} = 0.002558 s, this makes the Switched Inductor Boost Converter with PID control have a smaller overshoot of 39.2809 %, a faster recovery time of 2.708 times when compared to the Switched Inductor Boost Converter without PID control. When the load value changes to 20 Ω at t=0.04, the Switched Inductor Boost Converter without PID control has an overshoot of 3.0861 % and has a recovery time of t_{rec} = 0.000735 s, while the Switched Inductor Boost Converter with PID control has an overshoot of 2.1575% and has a recovery time of t_{rec} = 0.000367 s, this makes the Switched Inductor Boost Converter with PID control have a smaller overshoot of 30.09%, a faster recovery time of 2 times when compared to the Switched Inductor Boost Converter without PID control. When the load value changes to 30 Ω at t=0.06, the Switched Inductor Boost Converter without PID control has an overshoot of 5.6731% and has a recovery time of t_{rec} = 0.000749 s, while the Switched Inductor Boost Converter with PID control has an overshoot of 3.6533% and has a recovery time of t_{rec} = 0.000337 s, this makes the Switched Inductor Boost Converter with PID control have a smaller overshoot of 35.602%, a faster recovery time of 2.2245 times when compared to the Switched Inductor Boost Converter without PID control. When the load value changes to 15 Ω at t=0.08, the Switched Inductor Boost Converter without PID control has an overshoot of 6.9783 % and has a recovery time of t_{rec} = 0.002108 s, while the Switched Inductor Boost Converter with PID control has an overshoot of 6.8211 % and has a recovery time of t_{rec} = 0.001662 s, this makes the Switched Inductor Boost Converter with PID control have a smaller overshoot of 2.253 %, a faster recovery time of 1.2685 times when compared to the Switched Inductor Boost Converter without PID control. Through the data mentioned, Switched Inductor Boost Converter with PID control has better performance in dealing with changes in load value than Switched Inductor Boost Converter without PID control.

4. Conclusion

Based on the results of previous simulations that carried out using MATLAB-Simulink, the PID control system designed using the direct synthesis method for the Switched Inductor Boost Converter circuit produces parameters parameter K_p = 0.001565, K_i = 10.0575, K_d = 1.595 × 10^{-6}. After PID control is applied to the Switched Inductor Boost Converter circuit, the output voltage response becomes better. PID control can eliminate overshoot where the Switched Inductor Boost Converter without PID control has an overshoot of 0.535% and accelerates the settling time by 1.35 times faster which in Switched Inductor Boost Converter with PID has settling time of 0.00494 s where the circuit without PID control has a settling time of 0.00669 s.

When simulating both open loop and close loop conditions of the Switched Inductor Boost Converter circuit is done by providing a variable input voltage value, PID control in the closed loop circuit also provides better performance than the open loop circuit. PID control in the closed loop circuit can maintain the output voltage value constant at 36 V according to the desired output voltage while the open loop circuit has an output voltage value that changes when there is a change in input voltage. The momentary voltage change after a change in input voltage occurs is 59.1771 - 68.3045% lower than the open loop circuit. The recovery time required by the closed loop circuit is 1.3048 - 2.5287 times faster than the open loop circuit.

When simulating both open loop and close loop conditions of the Switched Inductor Boost Converter circuit is done by providing a variable load value, the PID control on the closed loop circuit also provides better performance than the open loop circuit. The PID control on the closed loop circuit has a voltage

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overshoot value when there is a load change lower by 2.253 – 39.2809% compared to the open loop circuit. The recovery time required by the closed loop circuit is 1.2685 – 2.708 times faster than the open loop circuit.

This research is expected to be a reference for further research by creating a real model of the Switched Inductor Boost Converter circuit with PID control so can be applied in the real world. This research can also be a reference for designing other controls other than PID control on the Switched Inductor Boost Converter so that its performance can then be analyzed and developed even more.

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