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A Comparisson of Synchronous And Nonsynchronous Boost Converter

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Abstract. Modern electronic systems require resources with high efficiency. The efficiency of direct current to dicrect current converters as a power source can be increased by replacing a diode with MOSFET. The use of MOSFET is expected to reduce power loss as the internal resistance of MOSFET is lower than a diode. To implement the propossed idea, a boost type direct current chopper and TL494 as PWM generator circuit were applied in this work. MOSFET is used in synchronization mode to replace diode at conventional topology of chopper.. The proposed circuit and conventional topology were made and their performance were observed. The efficiency of both circuit were compared and analyzed. The result of the experiments showed that the efficiency of converter within MOSFET at synchronization mode is proportional with the increment of duty cycle, while at conventional topology the efficiency remain stable at any duty cycle. Synchronous boost converter is more efficient than nonsynchronous boost converter at duty cycle over than 40%.

1. Introduction

Modern electronic systems require resources with high efficiency [1]. The efficiency of DC to DC converter as power source of electronic equipment can be increased by replacing diode with MOSFET [2]. DC to DC converter within MOSFET synchronization mode called synchronous DC to DC converter. Both of MOSFET on synchronous converter must have similar frequency and does not work simultaneously. MOSFET is expected to reduce power loss at DC to DC converter because MOSFET has low internal resistance ($R_{ds(on)}$) during conduction mode [3]. The experiment will calculate and compare conduction loss at TL494 synchronous and nonsynchronous boost converter then analyze the efficiency [4, 5].

2. Method

2.1. Nonsynchronous Boost Converter

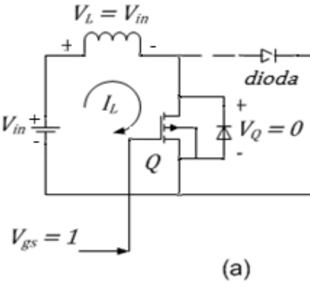


Figure 1a. Nonsynchronous boost converter schematic equivalent circuit when Q active but diode inactive.

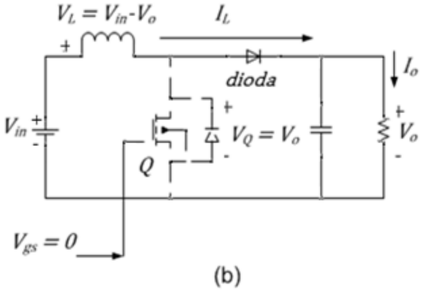


Figure 1b. Nonsynchronous boost converter schematicequivalent circuitwhen Q inactive but diode active.

The MOSFET (*Q*) is active when the nonsynchronous converter run at *D* duration. The source only supplies the inductor (*L*), so the inductor voltage (V_L) equals the input voltage (V_{in}) as shown in Figure 1a. The inductor current (I_L) linearly ramps up $\left(dI_L/dt\right)$ at *D* duration and increasing the energy in inductor *L* (Figure 2). The $\left(dI_L/dt\right)$ shifting current may call asΔI_L.

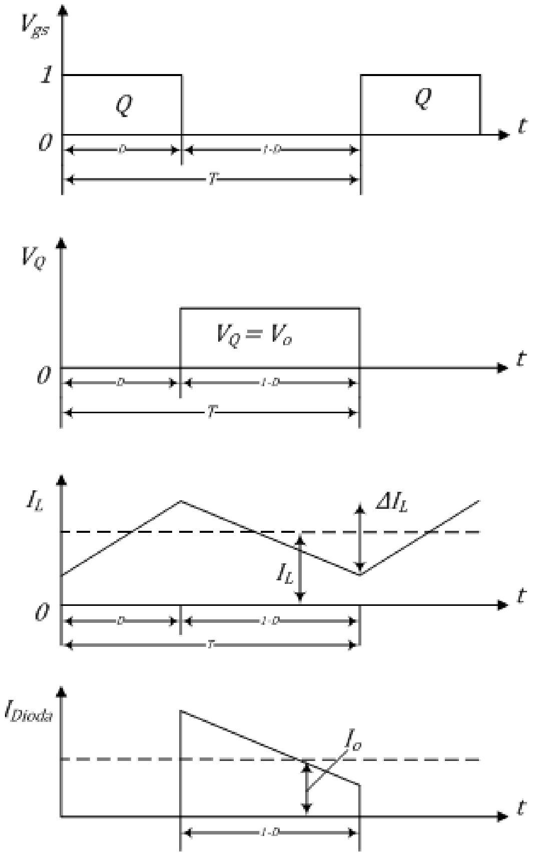


Figure 2. Ideal waveform of nonsynchronous boost converter.

Q is inactive. When the nonsynchronous boost converter run at *1-D* duration. I_L flows through the diode as shown in Figure 1b. The inductively stored energy transferred to the output stage. I_L linearly ramps down $\left(-dI_L/_{dt}\right)$ at *1-D* duration. The $\left(-dI_L/_{dt}\right)$ shifting current may call as $-\Delta I_L$ (Figure 2).
In a boost converter, I_L equals the input current (I_{in}). The average of I_L can be calculated from the output current (I_{out}) by equating the input and the output power [4]:

$$V_{in} \times I_{in} = V_{out} \times I_{out} \tag{1}$$

Equation 1 replaced by Equation 2:

$$I_{in} = \frac{V_{out}}{V_{in}} \times I_{out} = \frac{I_{out}}{(1-D)} \tag{2}$$

2.2. Synchronous Boost Converter

The low-side MOSFET (*Q1*) is active when synchronous boost converter run at *D* duration. The source only supplies the inductor (*L*). The inductor voltage (V_L) equals the input voltage (V_{in}) as shown in Figure 3a. The inductor current (I_L) linearly ramps up,and increasing the energy in *L* (Figure 4). Then the synchronous boost converter run at dead time (D_t) duration, in this case *Q1* is inactive. I_L flows through the high-side MOSFET body diode (*D2*), because in this period the high-side MOSFET (*Q2*) is inactive. The inductively stored energy transferred to the output stage through *D2* (Figure 3b).

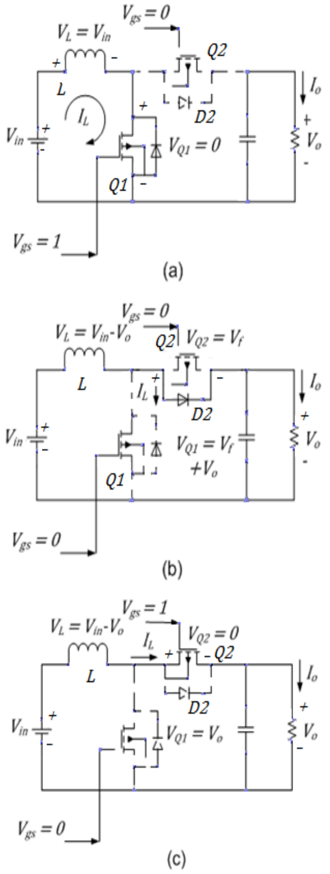


Figure 3. Synchronous boost converter schematic
(a) Q1 is active and Q2 is inactive
(b) Q1 is inactive and D2 is active
(c) Q1 is inactive and Q2 is active

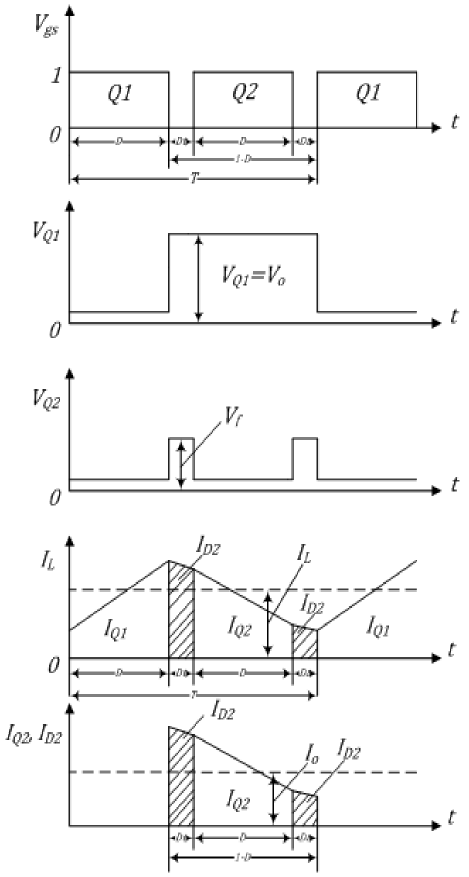


Figure 4 Ideal waveform of synchronous boost converter

The synchronous boost converter runs at the second D duration, in this condition $Q2$ is active and $Q1$ is inactive (Figure 3c). I_L flows through $Q2$. The inductively stored energy transferred to the output stage, so I_L linearly ramps down decreasing the energy in L (Figure 4).

3. Result

The power dissipation at MOSFET conduction process is major loss in DC converter system [5]. The power dissipation at MOSFET conduction process comes about drain to source resistance at MOSFET saturation mode. In this case the output current is directly proportional to the power dissipation. Basically,$I^2R_{ds(on)}$ at synchronous mode is smaller than IV_{fD} at nonsynchronous. This point ensues the low of MOSFET$R_{ds(on)}$.

Efficiency at the general system can be represented by Equation 3:

$$\eta = \frac{P_{out}}{P_{in}} \tag{3}$$

$P_{in}$is the input power, which consist of the output power (P_{out}), the power rectifier losses (P_{Rec}) and the power loss exclude the rectifier loss (P_{loss}) [5-7]:

$$P_{in} = P_{out} + P_{loss} + P_{Rec} \tag{4}$$

P_{loss}can be ignore, so Equation 4 replaced by Equation 5 [5-7]:

$$\eta = \frac{P_{out}}{P_{out} + P_{Rec}} \tag{5}$$

P_{Rec} at the nonsynchronous boost converter or P_{RecD} is accumulated losses from the diode and MOSFET when both of them conduct. P_{RecD} can be calculated by Equation 6 [5]:

$$P_{RecD} = P_{conQ} + P_{swQ} + P_{conD} + P_{gateQ} + P_{rrecQ,D} \tag{6}$$

At the low frequency DC converter whose lower than 300kHz, P_{gateQ} dan$P_{rrecQ,D}$ can be eliminated [5]. Equation 5 is replaced by Equation 7 [5-7]:

$$\eta = \frac{P_{out}}{P_{out} + P_{conQ} + P_{swQ} + P_{conD}} \tag{7}$$

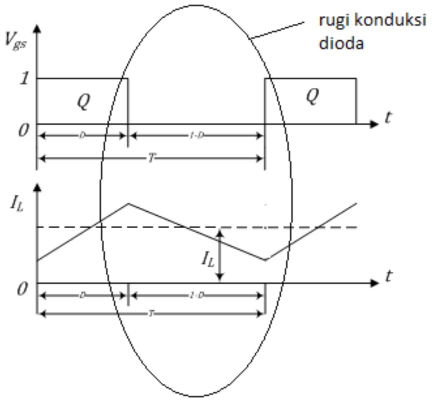


Figure 5 Ideal diode power dissipation area of nonsynchronous boost converter

P_{conQ} is power dissipation at Q while$Q$ is active. Q is active when DC converter is working at D duration, so P_{conQ} can be calculated by I_L, D, and $R_{ds(on)Q}$ parameters [2]:

$$P_{conQ} = R_{ds(on)Q} \times \frac{I_o}{(1-D)} \times D \tag{8}$$

where:

P_{conQ} = Q power dissipation
$R_{ds(on)Q}$ = Q drain to source resistance
I_o = output current
D = duty cycle

P_{conD} is power dissipation at the diode while Q is inactive. Q is inactive when DC converter is working at $1-D$duration, as shown at Figure 5. P_{conD} can be calculated by I_L, $1-D$, and the diode forward voltage drop (V_{fD}) parameters [2]:

$$P_{conD} = V_{fd} \times I_o \tag{9}$$

P_{Rec}at the synchronous boost converteror P_{RecSM} is accumulated losses from all loss at $Q1$dan$Q2$, soP_{RecSM} can be calculated by Equation 10 [5]:

$$P_{\mathrm{Re}\,cSM} = P_{conQ1} + P_{swQ1} + P_{conQ2} + P_{conD2} + P_{gateQ1,Q2} + \mathrm{Pr}_{recQ1,D2} \tag{10}$$

Equation 10 replaced by Equation 11 [5]:

$$\eta = \frac{P_{out}}{P_{out} + P_{conQ1} + P_{swQ1} + P_{conQ2} + P_{conD2}} \tag{11}$$

$P_{conQ1}$is$Q1$loss while $Q1$is active. $Q1$is active when the DC converter is working at D duration. P_{conQ1}can be calculated byI_L, D and $R_{ds(on)Q1}$ parameters [2]:

$$P_{conQ1} = R_{ds(on)Q1} \times \frac{I_o}{(1-D)} \times D \tag{12}$$

where:

P_{conQ1} = Q1 power dissipation
$R_{ds(on)Q1}$ = Q1 drain to source resistance
I_o = output current
D = duty cycle

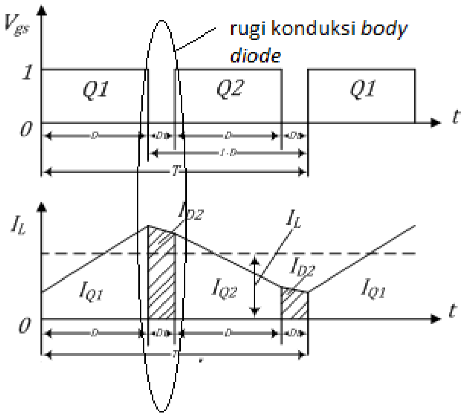


Figure 6 Ideal body diode power dissipation area of synchronous boost converter

$P_{conD2}$is$D2$power dissipation while $Q1$and $Q2$ is inactive. In this case the DC converter is working at D_t duration (Figure 6). The inductively stored current flows through diode, soP_{conD2}can be calculated by I_L, D_t and the forward voltage drop $D2$ (V_{fD2}) parameters [2,5]:

$$P_{conD2} = 2 \times D_t \times V_{fD2} \times \frac{I_o}{(1-D)} \tag{13}$$

P_{conQ2} is Q2 power dissipation while Q1 is inactive and Q2 is active. In this case, the DC converter is working at D duration (Figure 7). P_{conQ2}can be calculated byI_L, D, and$R_{ds(on)Q2}$ parameters [2]:

$$P_{conQ2} = R_{ds(on)Q2} \times \frac{I_o}{(1-D)} \times D \tag{14}$$

where:
P_{conQ2} = Q2 power dissipation
$R_{ds(on)Q2}$ = Q2 drain to source resistance
I_o = output current
D = duty cycle

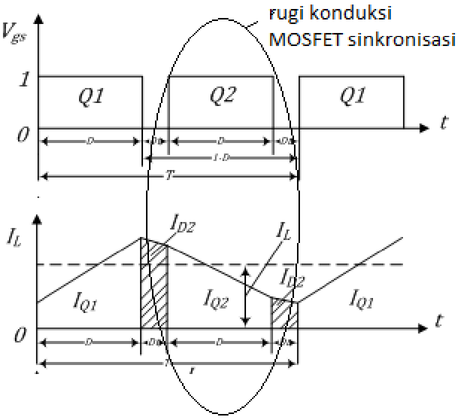
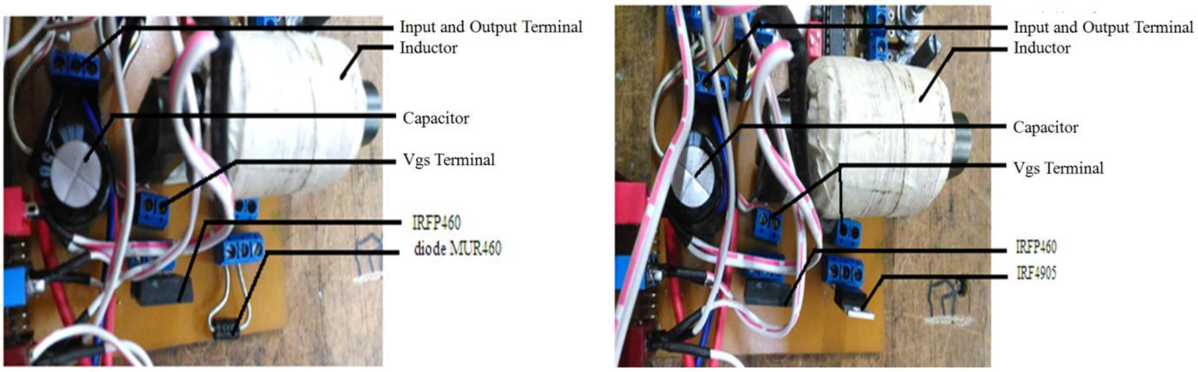


Figure 7 Ideal MOSFET *Q2* power dissipation area of synchronous boost converter

The main block for experimental circuits for nonsynchronous and synchronous boost converters are shown in Figure 8.



(a) (b)

Figure 8 (a) nonsynchronous and (b)synchronous boost converter

The conduction loss comparison result of the synchronous and nonsynchronous boost convereter showed at Table 1:

Table1 Conduction loss comparison result of the synchronous and nonsynchronous boost converter.

Duty cycle (%)	Synchronous boost converter (W)	Nonsynchronous boost converter (W)
6,8	1,411719	0,531607
10	1,44159	0,50175
15	1,479826	0,575158
20	1,312618	0,595362
25	1,271958	0,63057
30	1,134797	0,658106
35	0,957773	0,704584
40	0,856632	0,804452
43,5	0,729494	0,943483

Table 1 present the result of the synchronous and nonsynchronous boost converter power dissipation comparison. The power dissipation of nonsynchronous boost converter increases proportionally with duty cycle. The power dissipation of synchronous boost converter is inversely proportional with duty cycle.

The output characteristic of TL494 PWM generator at push pull mode where deadtime grown at small duty cycle and dead time alight at high duty cycle will affect to conduction loss of the synchronous boost converter.

When the duty cycle is enlarged, the output current flowing through the body diode goes up. The power dissipation at body diode will be rise. The efficiency of synchronous and nonsynchronous boost converter can be calculated with Equation 11 and 7, as shown at Figure 9:

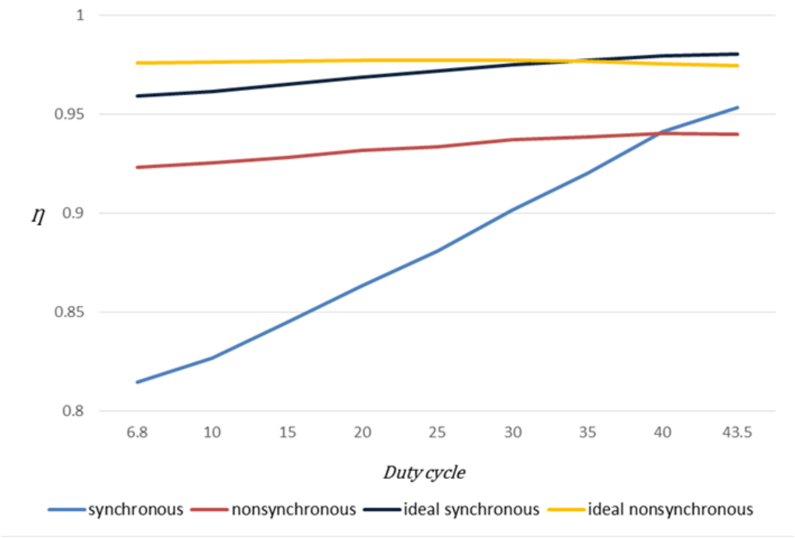


Figure 9 Efficiency comparison of synchronous and nonsynchronous boost converter

4. Conclusion

At the TL494 synchronous boost converter, the efficiency linearly ramps up when duty cycle increase. The efficiency is steady on various duty cycles. The efficiency of synchronous boost converter is greater than nonsynchronous when duty cycle is more than 40%. Minimizing duty cycle has made dead time increases, so conduction loss of body diode at the synchronous converter topology is less. Selected appropriate component at synchronous converter topology can maximize the efficiency.

5. References

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