AN6018

Application note

How to implement a peak current control avoiding minimum-on-time limit

Introduction

This application note is applicable specifically to the following devices:

- Brushed DC motor drivers: L6207, L6207Q, L6227, L6227, L6227Q, STSPIN240, STSPIN250, STSPIN840, STSPIN948, STSPIN958
- Stepper motor drivers: L6208, L6208Q, L6228, L6228Q

One of the most common methods to control the current into an inductive load, as a motor or a relay, is to implement a peak current control: the current is increased until a target threshold and is then reduced applying a decay strategy. In some cases this method could fail to keep the current under control, in particular, when the minimum-on-time limit is reached.

This document explains how the peak current control circuits are impacted by minimum-on-time and the strategies to avoid this issue.

1 Current control in inductive loads using fixed-off-time

Inductive loads are normally driven through a switching circuitry, as shown in Figure 1 (unipolar driving) and Figure 2 (bipolar driving).

Figure 1. Half-bridge driving an inductive load (unipolar)

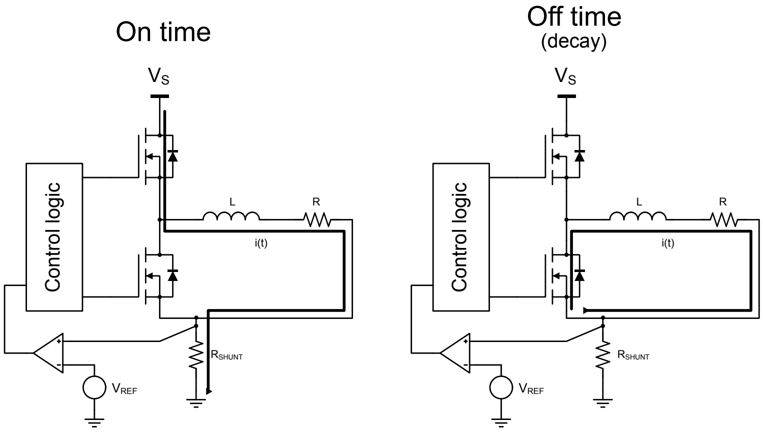
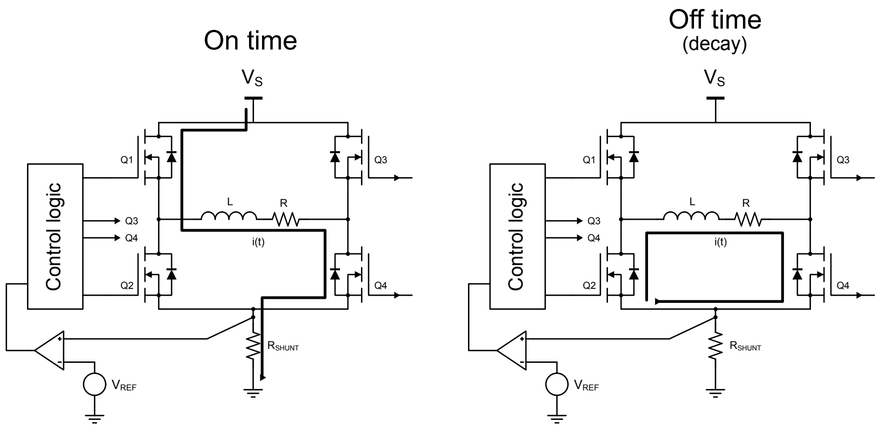


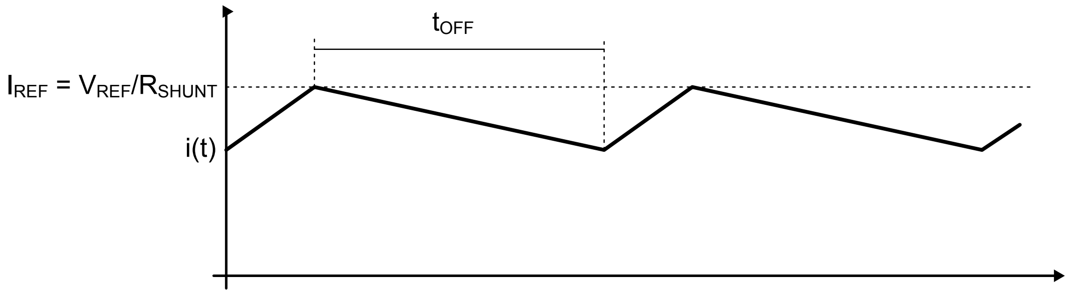
Figure 2. Full-bridge driving an inductive load (bipolar)



The current is increased applying the supply voltage V_S to the load, and flowing through the shunt resistor it is converted into a voltage. Comparing the drop on the shunt resistor with a reference value, the reaching of the target peak current is detected, and the bridge applies 0 V to the load.

During this phase, named slow decay, the current decreases due to the drop on the resistive component of the load. The system is kept in this condition for a predefined period of time (t_{OFF}) and then the charging condition is restored.

Figure 3. **Peak current control with fixed-off-time**



The current is described by Eq. (1) during charging and Eq. (2) during slow decay:

$$i(t) = \frac{V_S}{R} + \left(i(0) - \frac{V_S}{R}\right) \cdot e^{-t \cdot R/L} \quad (1)$$

$$i(t) = i(0) \cdot e^{-t \cdot R/L} \quad (2)$$

The control loop reaches a stable condition when the following condition is satisfied:

$$\Delta I_{ON} = \Delta I_{OFF} = I_{ref} \cdot \left(1 - e^{-t_{OFF}\frac{R}{L}}\right) \quad (3)$$

2 Minimum-on-time and minimum current limit

One of the key requirements for the implementation of the peak current control is the possibility to sense the current into the load to be compared with the target reference.

Using a current sensing strategy based on shunt resistor (see Figure 1 and Figure 2), the current feedback is only available during the charging phase, consequently, it is not possible to check the current level without increasing its value:

$$\Delta I_{ON,min} = \left(\frac{V_S}{R} - i(0)\right) \times \left(1 - e^{-t_{ON,min} \cdot R/L}\right) \quad (4)$$

Where $t_{ON,min}$ is the minimum-on-time, that is, the minimum time required by the system to provide reliable current feedback after a commutation.

Minimum-on-time is defined by:

- Switching timings of the power stage
- Injected noise generated by the commutation (for example, recovery current of recirculation diodes)
- Settling time of the current sensing circuitry
- Propagation delay of the comparator

The main consequence of this is a minimum current limit to the current controller imposed by Eq. (3) when $\Delta I_{ON} = \Delta I_{ON,min}$.

To simplify the calculation of this minimum value, it is better to convert the minimum-on-time in a minimum duty-cycle:

$$DC_{min} = \frac{t_{ON,min}}{t_{ON,min} + t_{OFF}} \quad (5)$$

In this way the resulting average current comes directly from Eq. (6):

$$I_{min} = \frac{DC_{min} \times V_S}{R} \quad (6)$$

3 Guidelines

The best way to avoid minimum-on-time issues is to properly dimension the current limiter considering application voltage and load characteristics.

Controlling low currents on low resistive loads with high supply voltage implies the need for very small duty cycles and consequently a higher risk of reaching the minimum-on-time limit.

As a rule of thumb, the target duty cycle should be greater than 5%:

$$DC = \frac{R \cdot I_{ref}}{V_S} > 5\% \quad (7)$$

Another critical aspect is the fixed-off-time duration: the shorter the off-time, the higher the minimum duty cycle limit of the control circuit. For example, a fixed-off-time of about 10 times the minimum-on-time imposes a minimum duty cycle of 9%.

For this reason, loads with low inductive values and then requiring high control frequency (short off-time), are also sensitive to minimum-on-time. In this case, the best solution is to select a device with a very short minimum-on-time and try to limit the supply voltage.

Revision history

Table 1. Document revision history

Date	Version	Changes
13-Nov-2023	1	Initial release.

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