Optimization of Gate Resistance for Motor Driver Design

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Abstract. Owing to the rapid increase in the use of small- and medium-sized motors at various industries, the reliability of the electronic control systems is emerging as an issue. Accordingly, research on a method that guarantees reliable motion of motors by selecting appropriate gate resistance of the driver part and that contributes as a solution to the thermal issue and EMC (Electromagnetic Compatibility) in terms of design was conducted. Among methods that increase the reliability of motor drivers, one involving the calculation of an optimal gate resistance value is the most efficient in cost aspects without hardware and the application of a complex motor control algorithm. Therefore, this study proposed the process of finding optimal gate resistance of the driver circuit. An approach was made to find a safe operation area about switching, which has considered only partially, and a practical experiment was carried out through the evaluation board to prove the proposed method. As a result, although the estimated range and experimental results had slight deviation, we proved that it could be used as a method to find the optimal resistance value.

1. Introduction
Today, the electronic systems of industries have to be designed with goal of reducing expenses while maintaining high reliability. It is very contradiction. In particular, with respect to design considering the reliability of motor controllers, including EMC and hardware composition, many research studies on software composition (algorithm) are in progress[1][2][3][4]. Except software reliability, in hardware reliability, there is a trade-off with the cost. Therefore, this issue should be approached from the aspect of efficiency. It is necessary to find a method that guarantees the stable function of hardware without adding any further hardware components. Although there can be various methods and discussion, in this paper, we have described a method to select an appropriate gate resistance value to optimize the switching properties of a motor driver. This makes it possible to derive a cost-effective benefit of controlling EMC properties and simultaneously guaranteeing reliable operation of the motor[5].

2. Optimization Method of Gate Resistance
The basic structure of bridge circuits can be interpreted in the context of a correlation between the gate driver that input he on/off signals such as PWM to the gate of the switching device and the power device that switches the high voltage or the high current.

2.1. Minimum resistance value for protection of device in the worst case
In general, a small quantity of current is applied to obtain the Miller capacitance as well as the threshold voltage required to turn on the switching device. As the current is momentary, the switching time($t_{SW}$) depends on its quantity. In general, the maximum output for this transient current is specified in the data sheet of the gate drive IC. First, the minimum resistance for device protection in the worst case can be expressed as follows:

$$R_{protect} = \frac{\Delta V}{I_{sioh}}$$  \hspace{1cm} (1)

$R_{protect}$ is the resistance value to avoid the physical damage of the gate drive IC, which is the minimum reference value for all subsequent considerations.

2.2. Resistance value for rapid turn-on

The calculation of the resistance value to facilitate rapid switching when turned on switching device can be examined from two perspectives. Switching when considered from the device viewpoint takes into account the gate input current and the output characteristics of the switching device. The gate input current can be replaced with the gate driver output current. The $R_G$ calculation approach that considers each element is as follows[6]:

$$I_{AV} = \frac{Q_{gd} + Q_{gs}}{t_{SW}}$$  \hspace{1cm} (2)

$$\frac{dV_{DS(\text{falling})}}{dt} = \frac{I_{AV}}{C_{rxx}}$$  \hspace{1cm} (3)

$$R_{G(\text{min})} = \frac{V_{CC} - V_{\text{miller}}}{I_{AV}} = \frac{V_{CC} - V_{\text{miller}}}{C_{rxx} \cdot \frac{dV_{DS(\text{falling})}}{dt}}$$  \hspace{1cm} (4)

On the basis of equation (2) and (3), we can derive the following:

$$\left(\frac{Q_{gd} + Q_{gs}}{C_{rxx}}\right) \cdot \frac{1}{t_{SW}} = \frac{dV_{DS(\text{falling})}}{dt}$$  \hspace{1cm} (5)

In general, as there are many cases where the gate driver lacks the current driving ability, $I_{source}$ is the first input in place of $I_{AV}$ for the sake of calculation. Then, the maximum values of $t_{SW}$ and right term of equation (5) are calculated. However, as right term of equation (5) is a parameter that is already specified in the physical specifications of the switching device, certain selection work is required. If right term of equation (5) in the data sheet has a lower value, $I_{AV}$ and $t_{SW}$ are calculated on the basis of this value and these values can be regarded as the maximum $I_{AV}$ value and the maximum $t_{SW}$ value that can be obtained from a combination of the gate driver IC and the switching device.

2.3. Resistance value for deterministic turn-off

When the switch is opened, the inrush current flows through $C_{rxx}$(Miller capacitance) because of the rapid voltage change[7]. The current path is shown in Figure 1. Further, the gate resistance should be selected by considering the prevention of a phenomenon in which the switch is closed when a voltage higher than the gate threshold voltage is applied because of the current that flows when the switch is opened[6].

\(I_{source} = \frac{Q_{gd} + Q_{gs}}{C_{rxx}} \cdot \frac{1}{t_{SW}} = \frac{dV_{DS(\text{falling})}}{dt}\)
Figure 1. Current path when low-side is off and high-side is on

By summarizing the above contents in the form of a formula, we obtain the following:

$$R_{G(max)} \leq \frac{V_{TH}}{C_{rxs} \cdot \frac{dV_{DS(ymn)}}{dt}}$$

(6)

Here, $R_{G(max)}$ becomes the maximum resistance value for switching the safe operation area (SOA), among the considered values.

Figure 2. $R_{G(max)}$ calculation flow

Through the considerations in switching procedure of turn-on and turn-off, the flow chart of Figure 2 was derived. This calculation flow simply determines $R_{G(max)}$ by entering parameters of driver IC and switching device.

3. Experimental Results

The experiment was conducted using TI DRV8301-LS31-KIT and controlled by the input of a BLDCM Hall Sensor. A system in which the control is stopped in the case of a hardware error, which is also recognized as a fault in the controlling motor such as arm short through TMS570LS31 supporting ISO26262, was set up.
Furthermore, the current driving capability of DRV8301 is available in three options, and the experiment was conducted after setting up hardware with which rapid switching was possible by setting the largest capability[8]. As the selection of the gate resistor procedure according to the flow chart of Figure 2, first,

\[
\left( \frac{dV_{DS}}{dt} \right)_{max} = \frac{I_{source}}{C_{rss}} = \frac{1.7 \cdot 10^{12}}{600} \approx 2.833 \text{ V/ns}
\]

The MOSFET of DRV8301-LS31-KIT is SUM110N06-3m9H, whose \( t_{f\max} \) is 14 ns @ 30 V, and after adjusting units, \( t_{f\max} \) is about 2.143 V/ns[8][9]. The maximum output voltage slope of the switching device is more gradual, and the combined properties of the gate driver and the MOSFET can be regarded as considerably better than that of the MOSFET. \( R_G \) can be found by calculating the current by using the value of 2.143 V/ns.

\[
I_{mod} = C_{rss} \cdot \left( \frac{dV_{DS}}{dt} \right) = 600 \cdot 10^{-12} \cdot 2.143 \cdot 10^9 \approx 1.286
\]

\[
R_G = \frac{V_{oc(max)} - V_{miller}}{I_{source}} = \frac{11.5 - 6.3}{1.286} \approx 4.044
\]

Another method that can be considered for obtaining the minimum gate resistance is the calculation of the resistance value required for protecting the gate driver in the worst case.

\[
R_{protect} = \frac{\Delta V_G}{I_{sink}} = \frac{11.5}{23} = 0.5
\]

\[
R_{G(max)} \leq \frac{V_{TH(min)}}{C_{rss} \cdot \frac{V_{DS(rising)}}{dt}} = \frac{3.4}{600 \cdot 10^{-12} \cdot 187.5 \cdot 10^9} \approx 30.222
\]

Here, we conclude that \( R_G \) should have a value in the range 5 to 30.222 Ω.

Figure 4 shows the result of the measuring waveforms in accordance with the resistance values obtained through an experiment. The waveform seems to change stably with an increase in the resistance value; however, at values higher than 17 Ω, frequent switching errors cause the controller to sense faults.
As Figure 4 shows, it may be recommended to select a gate resistance from the SOA range of 7.6 to 16.2, and it would be better to select smaller value within the range because devices are being studied to enable high-speed switching performance these days[10]. The experimental results show that 8 to 9 ohms is the optimal setting value because it is advantageous for the gate resistance value to be lowered in order to maintain on-state of the MOSFET[11].

4. Discussions and Future Work

Thus far, we have discussed the calculation of the gate resistance value required for improving the reliability of the motor driver part, and in safety-required electronic control system, every device has to be selected carefully. In particular, the electronic components controlling a motor can enter into the failure state easily because of switching and a rush current. Further, the failure state can fatally decrease the reliability of the entire system. It is anticipated that a more appropriate gate resistance can be calculated through the proposed method. The theoretical calculations based on the parameters of the devices available through the datasheet may not exactly match the practical experiments. The reason is that in addition to the two dominant devices, the characteristics of PCB patterns and the source or ground characteristics and conditions are very different in many cases. However, trying to estimate SOA through the proposed method is a meaningful approach and the results of the experiment are proving it. Further, the findings of this study are expected to contribute to EMC solution and heat property improvement[12]. Further, the findings of this study are expected to contribute to EMC solution and heat property improvement. I expect that other significant methods can be found, analyzing the correlation between the amount of EMI variation and switching loss due to changes in resistance values.

5. References

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