A New Resonant Gate Drive Circuit Utilizing Leakage Inductance of Transformer

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1. Introduction

2. Proposed Resonant Gate Drive Circuit

3. Analysis and Design Guideline

4. Experimental Results

5. Conclusions
1. Introduction

- Increasing demand for higher switching frequency:
  - Compact package
  - Fast loop response
- Gate charge loss occupies more share of total loss at high frequency application
- Drawbacks of conventional gate driver
  - Driving energy total lost
  - Overheat of driver
  - Longer turn-off transition
  - Higher switching loss
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2. Proposed Resonant Gate Drive Circuit

Proposed Resonant Gate Drive Circuit
Operating Principle (Half Cycle)

Before t1:
1. Q1 and Q4 on
2. Q2, Q3, Q5 and Q6 off
3. M1 on, M2 off
Operating Principle
(Half Cycle)

\[ t_1 \sim t_2: \]
1. At \( t_1 \), Q1 turned off and Q5, Q6 turned on
2. Resonant current discharged Cg of M1
3. M1 is turned off
4. Q2 is turned on at ZVS
Operating Principle (Half Cycle)

\( t_2 \sim t_3: \)

1. Q4 is turned off at \( t_2 \)
2. Resonant current charges \( C_g \) of M2
3. M2 is turned on
Operating Principle (Half Cycle)

1. At $t_3$, resonant current reaches zero
2. Q5, Q6 turned off at ZCS
3. Q3 is turned on to charge the deficit voltage from Vcc
Summary of Proposed circuit

- Utilizing leakage inductance of transformer
- Pulse controlled resonance is utilized to minimize the conduction loss
- Low voltage-second applied to transformer, minimizing driving transformer size
- Fast transition, minimizing duty cycle limitation
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3. Analysis and Design Guideline

Loss distribution:

\[ P_{gr} = P_{rms} + P_{drive} + P_{core} \]  \hspace{1cm} (2)

1. Conduction loss – main contributor
2. Driving loss – small share
   - selecting small gate charge driving mosfets (Q1 to Q6)
   - Driving fets realize ZVS or ZCS, switching loss neglected
3. Core loss – neglected
   - Low voltage-second applied, minimizing core loss
Conduction Loss Analysis

Conduction loss calculation:

\[ I_L(t) = I_{PK} e^{-\alpha t} \sin(\omega_d t) \quad (3) \]

\[ V_c(t) = V_{cc} \cdot (1 - K e^{-\alpha t} \cos(\omega_d t)) \quad (4) \]

Where

\[ \alpha = \frac{R_{tot}}{2L_{LK}} \quad \omega_d = \sqrt{\omega_o^2 - \alpha^2} \]

\[ K = \frac{1}{\sqrt{1 - \xi^2}} \quad \xi = \frac{R_{tot}}{2} \cdot \sqrt{\frac{C_g}{L_{LK}}} \]

\[ I_{PK} = \frac{V_{cc}}{\sqrt{\frac{L_{LK}}{C_g} - \left( \frac{R_{tot}}{2} \right)^2}} \]

\[ P_{rms} = \int i_L(t)^2 \cdot R_{tot} \cdot dt \quad (6) \]
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Fig 8. Logic control block for resonant gate driver
Circuit Parameters and Results

• Circuit Parameters:
  \[ V_{cc} = 5V; \quad f_s = 500KHz; \quad L_{lk} = 100nH; \]
  2 FDS6680 paralleled;

• Results:
  – 69% energy transfer Efficiency
    \[ \left( \frac{V_{peak}^2}{V_{cc}^2} \right) \]
  – 52% actual loss saving
Result Waveforms

Fig 11. Key experiment waveform

Fig 12. Detail gate voltage waveform
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5. Conclusions

- A new resonant gate drive circuit was introduced
- The circuit driving a pair of MOSFETs
- Partial of gate driving energy is recovered
- Leakage inductance of transformer is utilized
- Pulse controlled resonance reduces the conduction loss
5. Conclusions

- Low voltage-second applied, minimizing transformer size
- Fast transition, relaxing duty cycle limitation