

Application Note

汽车系统中的直流母线电容器预充电设计



Daniel Gao, Forest Fu

摘要

在混合动力电动汽车和电动汽车 (HEV/EV) 中，对直流母线电容器进行预充电至关重要。传统的预充电电路包含昂贵的机电继电器 (EMR) 和大量的大功率电阻器，这与高功率密度和更低的物料清单 (BOM) 成本的要求相矛盾。本应用手册介绍了几种替代性的预充电设计，包括隔离开关驱动器、有源预充电控制器、高压 (HV) 降压转换器和隔离式 DC/DC 转换器，以及各自的控制方法。这些设计在功率密度、元件成本和功能安全参数方面具有明显的相对优势。

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1 简介

在 HEV/EV 系统中，高压负载不直接由 HV 电池中存储的能量供电。直流母线电容器位于 HV 电池和 HV 负载之间，用作缓冲级。直流母线电容器有两个主要功能：去耦 HV 电池和 HV 负载之间的寄生电感效应，以及为高频电流提供低阻抗路径。直流母线电容的范围通常为几百微法拉至几千微法拉。

但是，当 HV 负载处于非活动状态时，直流母线电容器上不存在电压。如图 1-1 所示，主接触器正极 (MCP) 和主接触器负极 (MCN) 保持断开，在两个终端上都断开 HV 电池与 HV 负载的连接，同时直流母线电容器保持放电状态。当 MCP 和 MCN 闭合时，这会导致直流母线电容器直接短路，从而产生极高的电流。如果不适当限制此浪涌电流，电缆、连接器和保险丝可能会损坏。

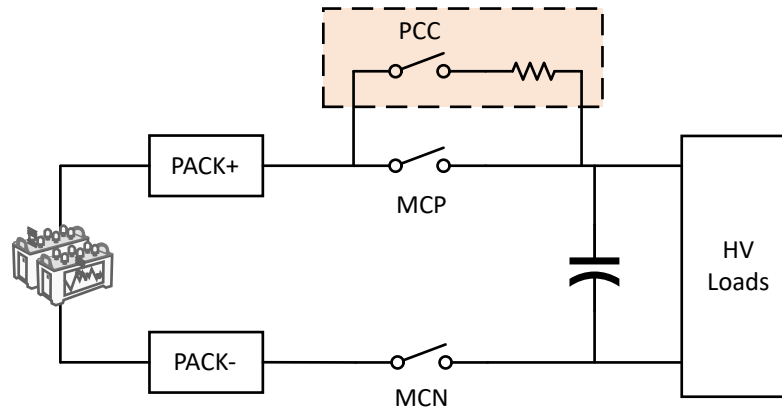


图 1-1. HEV/EV 系统中的直流母线电容器

因此，HV 系统需要预充电电路来限制浪涌电流。传统的预充电电路包含预充电接触器 (PCC) 和电流限制电阻器。在预充电阶段，PCC 和 MCN 闭合，将直流母线电容器充电至与 HV 电池相近的电压。电路中的电流限制电阻器可限制此阶段的浪涌电流。在预充电阶段之后，PCC 断开且 MCP 闭合，从而允许 HV 电池为负载供电。电流限制电阻器被绕过，以降低电路阻抗。传统的预充电电路通常包含昂贵的 EMR 和大量大功率电阻器，这与对高功率密度和更低 BOM 成本的要求相矛盾。

2 直流母线电容器预充电的系统挑战

直流母线电容器的电容会根据牵引逆变器的输出功率而变化，范围从几百微法拉到几千微法拉。直流母线电容器的预充电持续时间不得超过 400ms。对直流母线电容器进行预充电所采用的传统方法利用了机电继电器。第一章介绍了这种方法的工作原理，以下章节将详细介绍参数设计方法。如图 2-1 所示，当预充电接触器闭合时，等效电路构成标准 RC 串联配置。

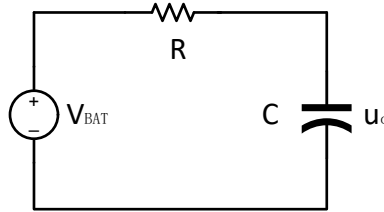


图 2-1. 预充电电路的等效电路

直流母线电容器上的电压表示为：

$$u_C = V_{BAT} \left(1 - e^{-\frac{t}{\tau}} \right), \tau = RC \quad (1)$$

假设 HV 电池为 800V、直流母线电容为 1000uF、预充电时间要求为 150ms。根据预充电时间要求选择电阻：

$$t = 3\tau \leq 150\text{ms} \quad (2)$$

$$R \leq \frac{t/3}{C} = 50\Omega \quad (3)$$

选择预充电电阻器的平均功率：

$$P_{AVG} = \frac{E}{t} = \frac{1}{2} C (0.95 V_{BAT})^2 / t = 1925\text{W} \quad (4)$$

选择预充电电阻器和继电器的峰值电流：

$$I_{PEAK} = \frac{V_{BAT}}{R} = 16\text{A} \quad (5)$$

根据计算，针对预设参数，必须选择电阻器和 16A 继电器。在实际电路设计实现中，必须考虑参数降额，这导致需要在该预充电电路中使用成本高昂的继电器和大功率电阻器。

随着 HEV/EV 系统对降低成本和优化体积的需求不断增长，出现了几种替代设计来替代传统的预充电电路。我们将在后续章节分析和比较这些设计。

3.2 有源预充电控制器

TPSI31P1-Q1 是一款具有 17V 隔离式栅极驱动器和偏置电源的有源预充电控制器。它与外部电源开关、功率电感器和二极管相结合，可构成一种有源预充电设计。与 TPSI3050-Q1 相比，TPSI31P1-Q1 包含两个专为预充电应用设计的附加功能。

- 在磁滞运行模式下持续监测和控制电感器电流，以对直流母线电容器的大电容进行线性充电。
- 此设计集成了一个通信反向通道，可将状态信息从次级侧传输到初级侧以指示次级侧的电源状态。

图 3-2 展示了此应用的方框图。TPSI31P1-Q1 通过来自微控制器的 EN 输入接收控制信号。外部功率电感器 (L1) 连同功率二极管 (D1) 和功率 FET (M1) 一起构成降压转换器。M2 表示用于实现反向阻断功能的可选 MOSFET。分流电阻器有助于通过测量 IS+ 引脚上的电压以监测 L1 中的电流。

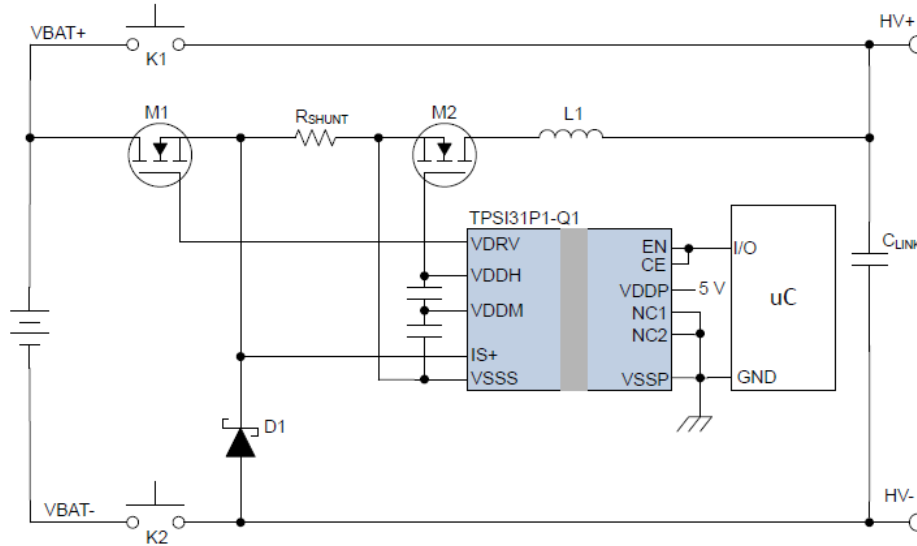


图 3-2. 应用中的 TPSI31P1-Q1 方框图

主要运行特性在于降压转换器配置。当 IS+ 降低至低于 VREF- 时，VDRV 被置为高电平以激活 M1，启动降压转换器的储能周期。当 IS+ 超过 VREF+ 时，VDRV 被置为低电平以停用 M1，开始降压转换器的电力传输周期。此过程在整个预充电周期中持续进行，以调节充电电流。

假设 HV 电池为 800V、直流母线电容为 1000uF、预充电时间要求为 150ms。平均充电电流的计算公式如下：

$$I_{AVG} \geq \frac{C \times V_{BAT}}{t} = 5.33A \quad (6)$$

可以计算出设置电感器电流所需的分流电阻：

$$R_{SNS} \leq \frac{V_{REF+} + V_{REF-}}{2 \times I_{AVG}} = 130m\Omega \quad (7)$$

最大电感器电流为：

$$I_{PEAK} = \frac{V_{REF+}}{R_{SNS}} = 9.46A \quad (8)$$

最小电感器电流为：

$$I_{MIN} = \frac{V_{REF-}}{R_{SNS}} = 1.23A \quad (9)$$

当母线电容两端的电压达到中点值时，达到最大开关频率，中点值可由 TPSI31P1 的最小电力传输能力、FET 的总栅极电荷和栅源电压确定。假设 $P = 55\text{mW}$ 、 $V_{gs}=15\text{V}$ 、 $Q_g = 14\text{nC}$ ，则最大开关频率为：

$$f_{\text{MAX}} = \frac{P}{V_{gs} \times Q_g} = 261.9\text{kHz} \quad (10)$$

基于最大开关频率，可计算出最小电感：

$$L_{\text{MIN}} \geq \frac{V_{\text{BAT}}}{4 \times f_{\text{MAX}} \times (I_{\text{PEAK}} - I_{\text{MIN}})} = 92.8\mu\text{H} \quad (11)$$

因此，可以选择 $100\mu\text{H}$ 的电感值。 C_{DIV1} 和 C_{DIV2} 电容器取决于 VDDH 压降要求。例如， C_{DIV1} 和 C_{DIV2} 串联组合形成的总电容必须使得 VDDH 电源轨出现 0.5V 的压降：

$$C_{\text{DIV1}} \parallel C_{\text{DIV2}} \geq \frac{Q_G}{\Delta V} = 28\text{nF} \quad (12)$$

为了进一步降低压降，可以选择电容 $C_{\text{DIV1}} = 330\text{nF}$ 、 $C_{\text{DIV2}} = 1\mu\text{F}$ 。

TPSI31P1-Q1 包含一个运用了这些公式的计算器，会生成预期的充电波形。如需了解更多详情，请参阅 [TPSI31P1-CALC](#)。

3.3 分立式高压降压设计

分立式 HV 降压设计提供了另一种对直流母线电容器进行预充电的选项。此方案在功率级设计方面与 TPSI31P1-Q1 有相似之处，但控制方法有很大差异。

图 3-3 所示为一种分立式 HV 降压设计的方框图。OBC/DCDC/逆变器的微控制器单元 (MCU) 从电池管理系统 (BMS) 获取 HV 电池电压信息，配置 HV 降压转换器的输出电压，然后闭合 RELAY2 并启动直流母线电容器预充电。完成后，向 BMS 发送 READY 信号以闭合 RELAY1。

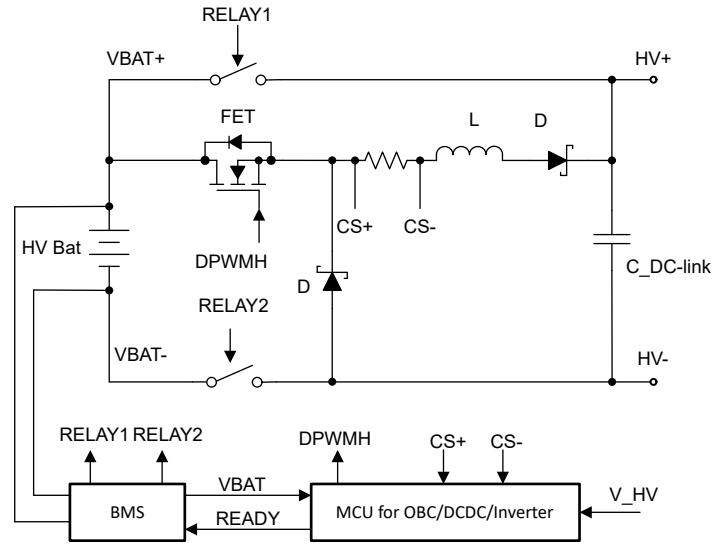


图 3-3. 分立式 HV 降压设计 1 的方框图

图 3-4 展示了用于对直流母线电容器进行预充电的替代分立式 HV 降压设计。OBC/DCDC/逆变器的 MCU 从 BMS 接收 HV 电池电压数据，确立 HV 降压转换器的输出电压参数，然后激活 RELAY1 并启动直流母线电容器的预充电过程。完成后，向 BMS 发送一个 READY 信号以激活 RELAY2。在此配置中，控制器和 FET 以 VBAT- 为基准，只需要低侧驱动器即可激活 FET，而 HV 降压设计 1 需要隔离式驱动器来激活 FET。

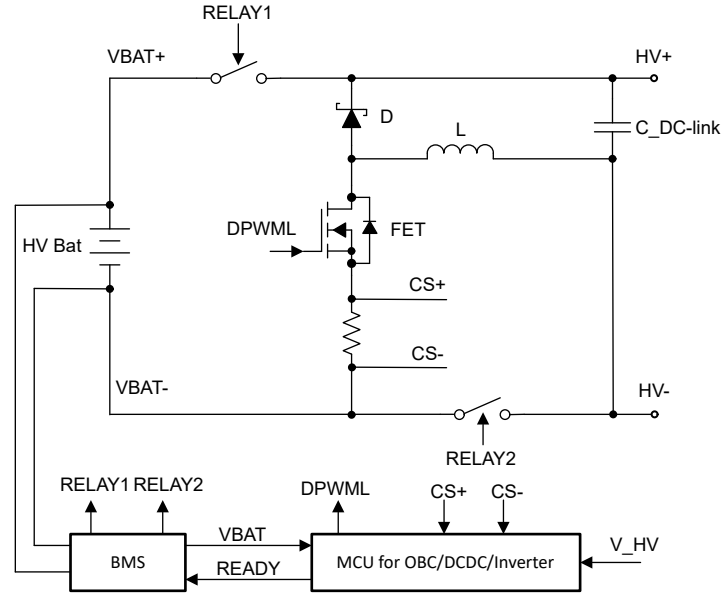


图 3-4. 分立式 HV 降压设计 2 的方框图

例如，假设直流总线电压为 400V、直流母线电容为 600 μF，而且预充电时间要求小于 200ms，则可以计算出平均电流：

$$I = \frac{C \times U}{t} = \frac{600\mu\text{F} \times 400\text{V}}{200\text{ms}} = 1.2\text{A} \quad (13)$$

平均电流约为 1.2A，平均功率为 480W。假设开关频率为 200kHz，则输出电压为 380V。可以计算出降压电感器的电感：

$$L = \frac{V_{\text{out}} \times \text{toff}}{\Delta I} = \frac{380\text{V} \times (1 - 380\text{V}/400\text{V})}{0.4 \times 1.2\text{A} \times 200\text{kHz}} = 197\mu\text{H} \quad (14)$$

图 3-5 显示了基于前述这些计算的 SIMetrix 仿真电路，图 3-6 显示了仿真结果。流经电感器的最大浪涌电流为 4A。对于交叉部分面积 (Ae) 为 154mm² 的 PQ32 磁芯,可以计算出匝数比：

$$N = \frac{L \times \Delta I}{A_e \times \Delta B} = \frac{197\mu\text{H} \times 4\text{A}}{154\text{mm}^2 \times 0.3\text{T}} = 17 \quad (15)$$

考虑到浪涌电流的裕度，匝数比可确定为 20。必须注意的是，降压电感器的额定值必须适用于高压应用。可以为降压电感器选择较低的电感值，前提是验证确认电感器具有足够的饱和电流容量。

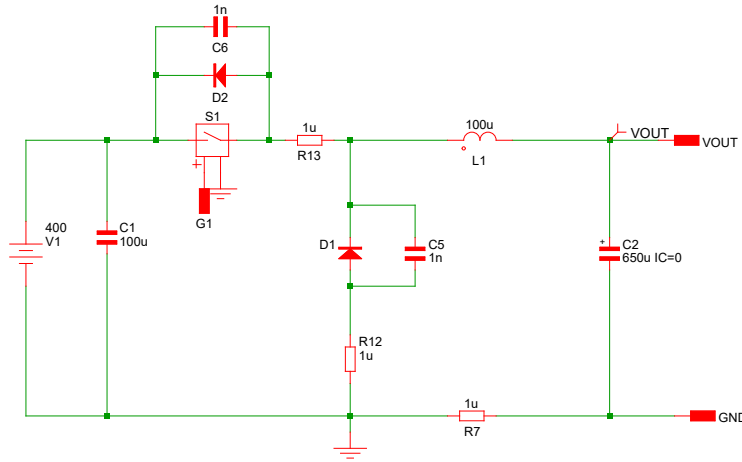


图 3-5. HV 降压设计的 SIMetrix 仿真电路

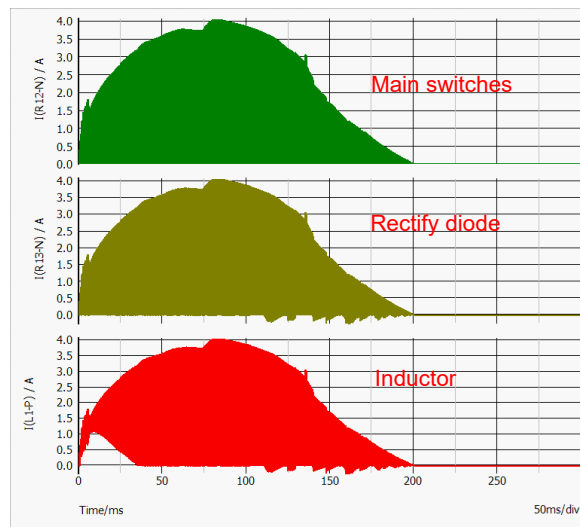


图 3-6. HV 降压设计的 SIMetrix 仿真结果

表 3-1 列举了分立式 HV 降压设计中使用的主要元件。OBC/DCDC/逆变器中的现有 MCU 可以改变用途。隔离式驱动器有助于激活高侧 FET。在图 3-3 和图 3-4 中所示的方框图中，分流元件也可实现为霍尔传感器。

表 3-1. TI Components

	器件型号	规格
MCU	F29H859TU-Q1	C2000 系列
控制器	UCC28740-Q1	1.HV 降压控制器 2.偏置电源，将 400V/800V 转换为 12V/24V
隔离式驱动器	UCC21351-Q1	基础型隔离
隔离式驱动器	UCC21551-Q1	增强型隔离
隔离式驱动器	UCC5350L-Q1	增强型隔离
霍尔传感器	TMCS1133-Q1	替代 CT
LLC 转换器	UCC25800-Q1	偏置电源，将 12V 转换为 12V/24V

3.4 独立隔离式 DCDC 升压设计

在 HV-LV DCDC 转换器缺乏双向功能的系统中，独立隔离式 DCDC 升压设计是一种可行的替代方案。这种方案还有助于利用 LV 电池对直流母线电容器进行预充电。根据平均功率要求，通常优先选择推挽式拓扑。

图 3-7 显示了一种独立隔离式 DCDC 设计的方框图。OBC/DCDC/逆变器的 MCU 从 BMS 接收 HV 电池电压信息，配置隔离式 DCDC 转换器的输出电压，并启动直流母线电容器的预充电过程。完成后，向 BMS 发送一个 READY 信号以激活 RELAY1 和 RELAY2。

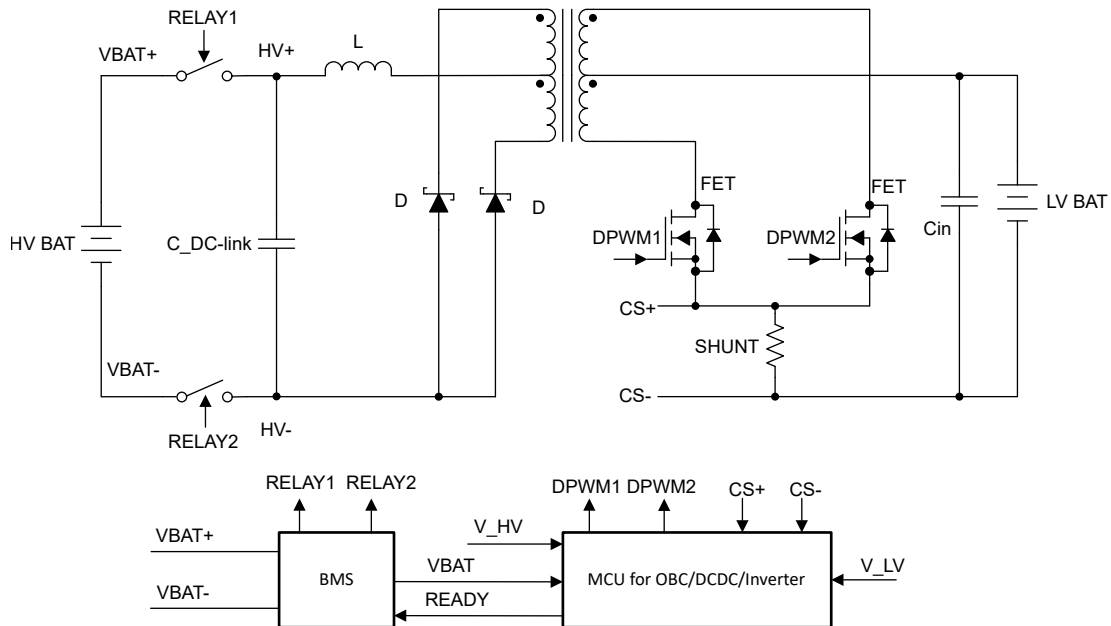


图 3-7. 独立 DCDC 设计的方框图

以 400V 直流总线电压和 600 μ F 直流母线电容器为例，当 LV 电池电压范围为 9V 至 16V 时，可以确定变压器匝数比为 1:50。根据方程式 1，平均电流为 1.2A。将 ΔI_L 设置为 0.3I_{out}，将开关频率设置为 100kHz：

$$D = \frac{N_{ps} \times (V_{out} + V_d)}{V_{in}} = \frac{400v + 1v}{50 \times 12V} = 0.668 \quad (16)$$

$$L_{out} = \frac{(V_{out} + V_d) \times (1 - D)/2}{\Delta I \times f_{sw}} = \frac{(400v + 1v) \times (1 - 0.668)/2}{0.3 \times 1.2A \times 200kHz} = 924\mu H \quad (17)$$

计算出的电感为 924 μ H；不过，在仿真中，考虑到电感器的浪涌电流和绕组匝数，使用了 500 μ H。图 3-8 显示了基于这些计算的 SIMetrix 仿真电路，图 3-9 显示了仿真结果。

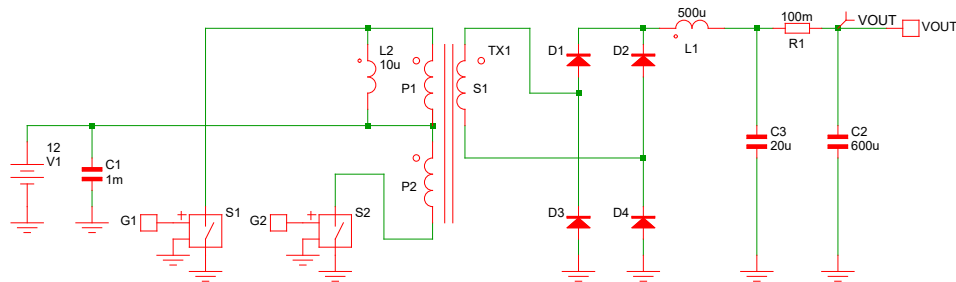


图 3-8. 独立 DCDC 设计的 SIMetrix 仿真电路

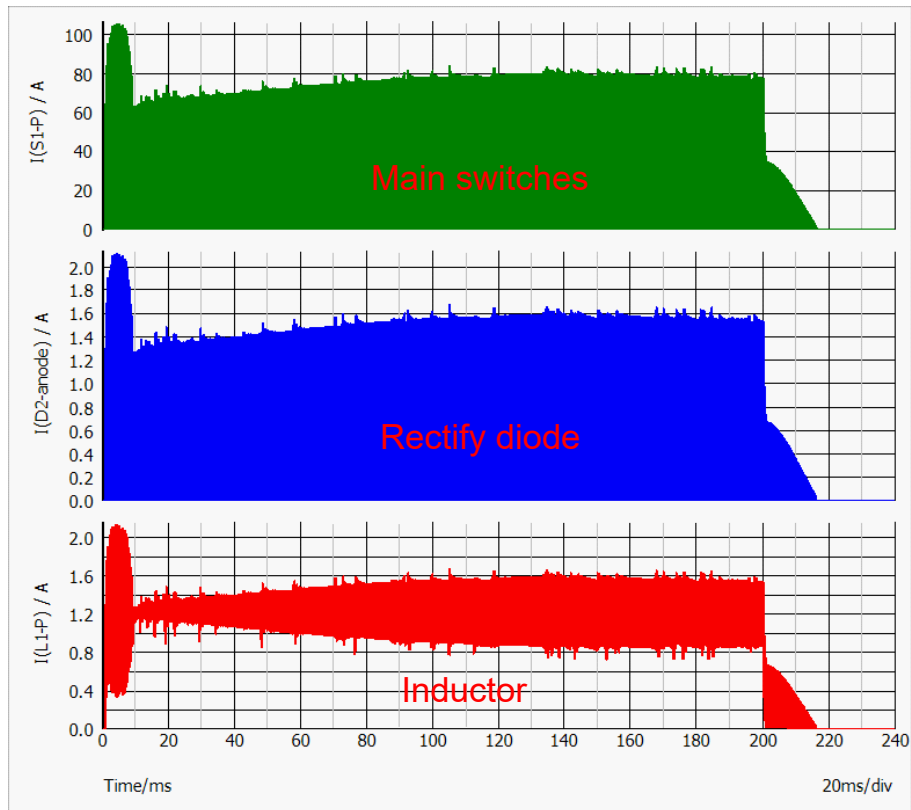


图 3-9. 独立 DCDC 设计的 SIMetrix 仿真结果

表 3-2 列举了独立 DCDC 设计中使用的主要元件。OBC/DCDC/逆变器的现有 MCU 可改用于生成 PWM 信号并实现闭环控制。如果 MCU 带宽受到限制，LM25037-Q1 可用于提供控制功能，ISOM8110-Q1 可用于提供隔离式反馈。

表 3-2. TI Components

	器件型号	规格
MCU	F29H859TU-Q1	C2000 系列
低侧驱动器	UCC27524A-Q1	双通道
低侧驱动器	UCC27518A-Q1	单通道
推挽式控制器	LM25037-Q1	
光学仿真器	ISOM8110-Q1	光耦合器

3.5 集成式预充电设计

汽车制造商可以利用现有的车辆 ECU (例如电池管理系统 (BMS)、HV-LV DC/DC 转换器)，通过复杂的软件算法来协调预充电序列，而无需开发专门的硬件。通过在车辆的现有电子架构中嵌入预充电功能，制造商可以实现更高效的系统设计，同时为高压动力总成元件提供强大的保护。

3.5.1 双向高压转低压 (HV-LV) DCDC

在 HEV/EV 系统中，HV-LV DCDC 转换器与 HV 电池连接，将 HV 电池的电能转换后供给 LV 电池并为 LV 负载供电。双向功能可用于对直流母线电容器进行预充电，如图 3-10 所示。

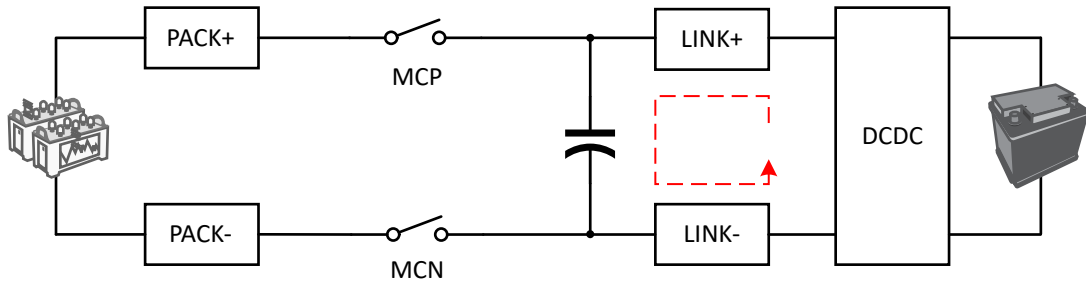


图 3-10. 具有 HV-LV DCDC 的预充电电路

假设 HV-LV DCDC 拓扑使用相移全桥 (PSFB) 配置，图 3-11 展示了反向控制运行的方框图。此过程可分为能量存储周期和电力传输周期。

- 能量存储周期：
 - 在次级侧，Q5、Q6、Q7、Q8 导通。次级侧作为升压转换器运行，用于为输出电感器充电。
 - 在初级侧，Q2 和 Q4 导通。初级侧处于续流级，用于传导漏电感上的电流。
- 电力传输周期：
 - 图 3-11 中的红线是电流路径的示例。
 - Q1、Q4、Q5、Q8 导通，以将能量从 LV 电池和输出电感器传输到 HV 电池。

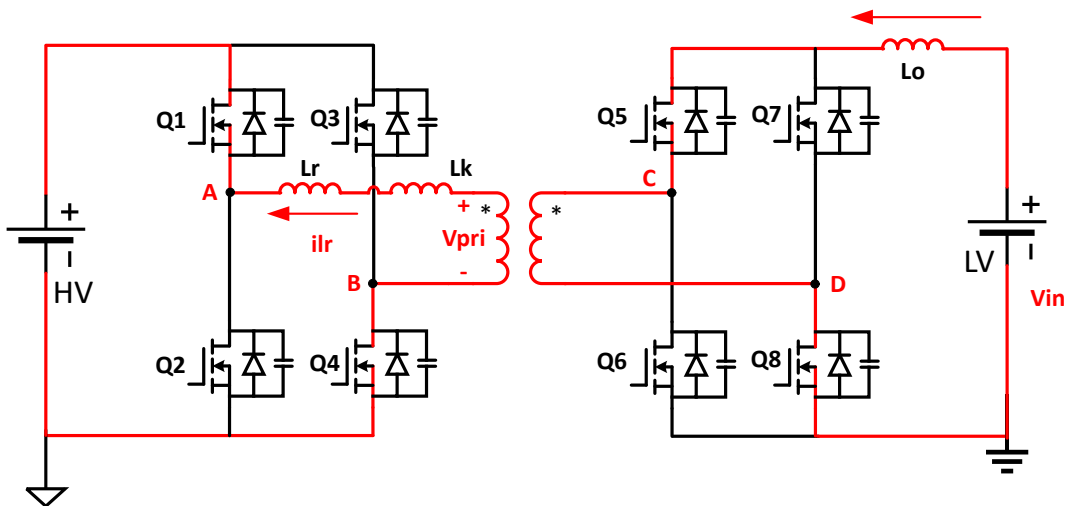


图 3-11. PSFB 反向控制的方框图

此设计的一个主要问题是次级侧电源开关上因电流失配而出现电压尖峰。PMP41078 代表了一种能够以反向模式运行的 3.5kW 400V 至 14V HV-LV DCDC 参考设计。如需了解更多详情，请参阅 PMP41078。

3.5.2 电池加热器

图 3-12 展示了一种集成式设计的方框图，该设计用于从正极方向对直流母线电容器进行预充电。最初，KL1 闭合，Q7 和 Q3 激活以为电感器 L1 充电。随后，Q7 停用，导致电感器电流流经 Q3、HV_BAT、KL1、C_DC_link 和 Q4。此过程将 C_DC_link 预充电至电池电压。此后，Q1 和 Q2 激活，以在 HV_BAT 和 C_DC_link 之间建立并联连接。

需要加热电池时，Q1 和 Q2 停用，同时 Q3 和 Q7 激活以为 L1 充电。接下来，Q7 停用且 Q4 激活，导致直流母线电容器上的电压超过 HV_BAT。在 L1 中的电流反转方向后，直流母线电容器放电至 HV_BAT。随后，Q4 停用且 Q7 激活，导致 HV_BAT 上的电压超过直流母线电容器的电压。在 L1 中发生另一次电流反转后，下一个周期开始。该控制方法有助于在 HV_BAT 和直流母线电容器之间发生能量振荡，从而加热 HV_BAT。

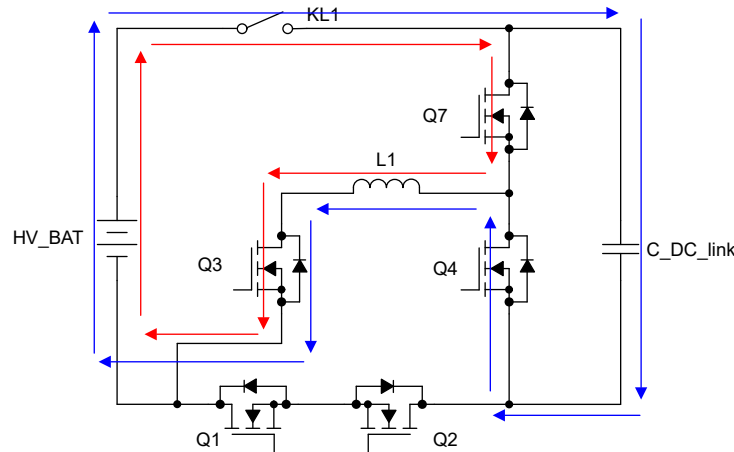


图 3-12. 集成式预充电设计 1 的方框图

图 3-13 展示了一种集成式设计的方框图，该设计用于从负极方向对直流母线电容器进行预充电。最初，KL1 激活，Q5 和 Q8 激活以为电感器 L1 充电。随后，Q8 停用，导致电感器电流流经 Q6、C_DC_link、KL1、HV_BAT 和 Q5。此过程将 C_DC_link 预充电至电池电压。此后，Q1 和 Q2 激活，以在 HV_BAT 和 C_DC_link 之间建立并联连接。

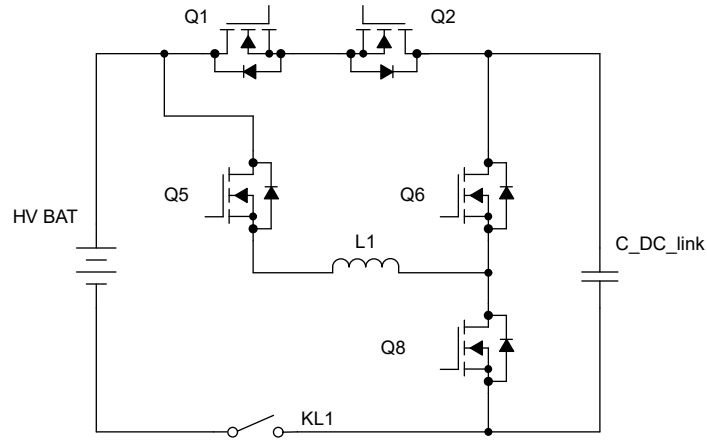


图 3-13. 集成式预充电设计 2 的方框图

该集成式设计代表了一种系统级方案。为了实现直流母线电容器预充电和 HV_BAT 加热，微控制器不可或缺。此外，还需要各种隔离式或非隔离式驱动器。对于背对背 FET Q1/Q2，可以替换双向 GaN LMG3660-Q1。表 3-3 列举了此集成式设计中使用的主要 TI 元件，包括微控制器、驱动器和传感器。

表 3-3. TI Components

	器件型号	规格
MCU	F29H859TU-Q1	C2000 系列
低侧驱动器	UCC27524A-Q1	双通道
低侧驱动器	UCC27518A-Q1	单通道
隔离式驱动器	UCC21351-Q1	基础型隔离
隔离式驱动器	UCC21551-Q1	增强型隔离
隔离式驱动器	UCC5350L-Q1	增强型隔离
霍尔传感器	TMCS1133-Q1	替代 CT
双向 GaN	LMG3660-Q1	

4 总结

本应用手册分析了对直流母线电容器进行预充电的七种不同设计。传统设计以大功率电阻器为特征，具有最低的功率密度，而双向 HV-LV DCDC 在这方面表现最佳。在物料清单 (BOM) 成本方面，传统设计的成本最高。表 4-1 列出了每种设计在各种参数 (包括 BOM 成本，功率密度和功率损耗) 上的全面比较。

表 4-1. 预充电设计

设计	原始	隔离开关驱动器	有源预充电控制器	分立式 HV 降压	独立隔离式 DCDC	双向 HV-LV DCDC	集成式预充电
Bom 成本	高	高	中	中	高	低	中
功率密度	低	低	中	中	中	高	高
功率损耗	高	高	低	低	低	低	低

5 术语

HEV/EV - 混合动力电动汽车和电动汽车

HV - 高压

PCC - 预充电接触器

EMR - 机电继电器

MCP - 主接触器正极

MCN - 主接触器负极

SSR - 固态继电器

6 参考资料

- 德州仪器 (TI), [为何高压系统需要预充电电路](#), 应用简报。
- 德州仪器 (TI), [TIDA-050080: 具有过流保护功能的高压无源预充电参考设计](#), 参考设计。
- 德州仪器 (TI), [TPSI31P1-Q1 具有 17V 隔离式栅极驱动器和偏置电源的汽车级有源预充电控制器](#), 数据表。
- 德州仪器 (TI), [TPSI31P1-CALC](#), 计算工具。
- 德州仪器 (TI), [LM25037-Q1 具有交替输出的双模 PWM 控制器数据表](#), 数据表。
- 德州仪器 (TI), [PMP41078](#) 产品页面。

7 修订历史记录

Changes from Revision * (October 2025) to Revision A (April 2026)	Page
• 更新了隔离器的器件型号并且添加了超链接.....	9

STANDARD TERMS FOR EVALUATION MODULES

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User shall operate the Evaluation Kit within TI's recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI's recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI's instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:

EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGRADATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 Regulatory Notices:

3.1 United States

3.1.1 Notice applicable to EVMs not FCC-Approved:

FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

3.2 Canada

3.2.1 For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

3.3 Japan

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lstds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。

<https://www.ti.com/ja-jp/legal/notice-for-evaluation-kits-delivered-in-japan.html>

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If User uses EVMs in Japan, not certified to Technical Regulations of Radio Law of Japan, User is required to follow the instructions set forth by Radio Law of Japan, which includes, but is not limited to, the instructions below with respect to EVMs (which for the avoidance of doubt are stated strictly for convenience and should be verified by User):

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive):*

This is a class A product intended for use in environments other than domestic environments that are connected to a low-voltage power-supply network that supplies buildings used for domestic purposes. In a domestic environment this product may cause radio interference in which case the user may be required to take adequate measures.

-
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 - 4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.
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