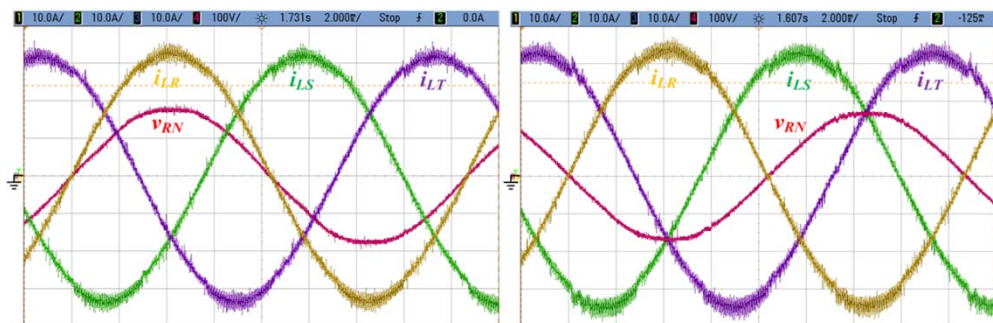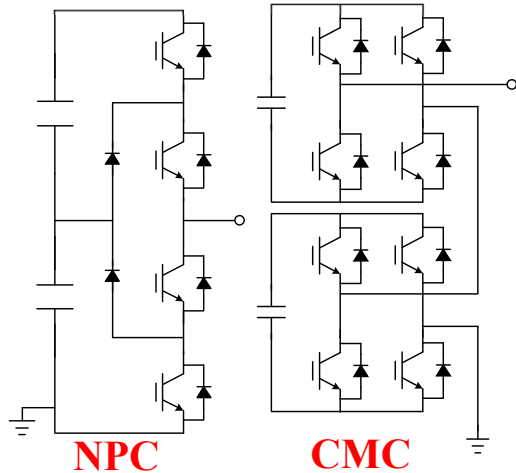## ➤ 三相四線穩態測試

市電併聯模式　　　　　整流模式
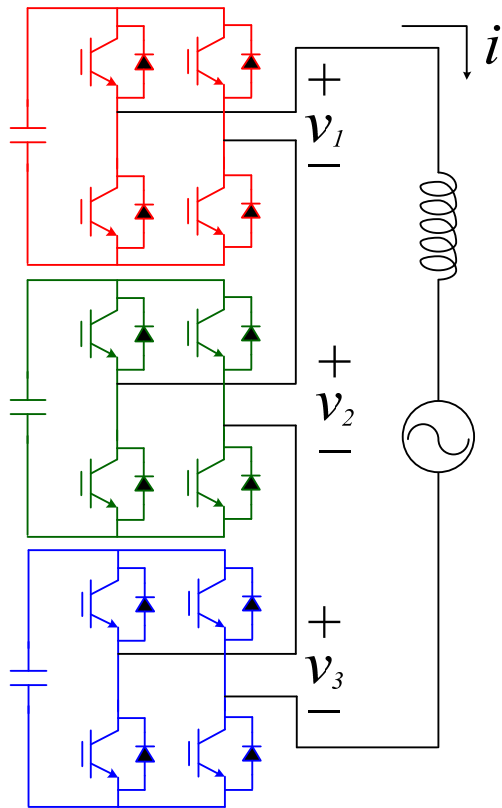
Case	Harmonic order	%	Measured Item	Without FCCC (GC Mode)	With FCCC (GC Mode)	Without FCCC (Rectification Mode)	With FCCC (Rectification Mode)
Case I	5 7 8	9.8 15.8 2.16	PF	0.96	0.98	0.96	0.98
			V$_{THD}$(%)	18.5	18.4	18.4	18.4
			I$_{THD}$(%)	18.8	3.2	18.7	2.8
Case II	3 5 7 11 15 17	4.9 1.6 2.7 1.4 2 1.1	PF	0.98	0.99	0.98	0.99
			V$_{THD}$(%)	6.4	6.4	6.4	6.4
			I$_{THD}$(%)	9.4	3.8	9.3	3.3
Case III	3	17.8	PF	0.96	0.98	0.96	0.98
			V$_{THD}$(%)	17.8	17.7	17.7	17.8
			I$_{THD}$(%)	17.7	2.1	17.8	2.0
Case IV	7 9 21 39	4.6 1 0.9 0.7	PF	0.97	0.98	0.97	0.98
			V$_{THD}$(%)	4.9	5.1	4.9	5.0
			I$_{THD}$(%)	5.1	2.5	5.1	2.6

第二期能源國家型科技計畫
National Energy Program-Phase II

(三)虛功補償器研製

NPC   CMC

	NPC converter	CMC converter
Voltage level	20	23
DC bus voltage	16.5 kV	850 V
Switches number	3*40	3*44
Capacitors	3*19	3*11

- **Neutral point clamped converter (NPC)**
  - Unbalanced blocking voltage of diodes
  - Implementation becomes complicated as voltage level increases
- **Cascaded multilevel converter (CMC)**
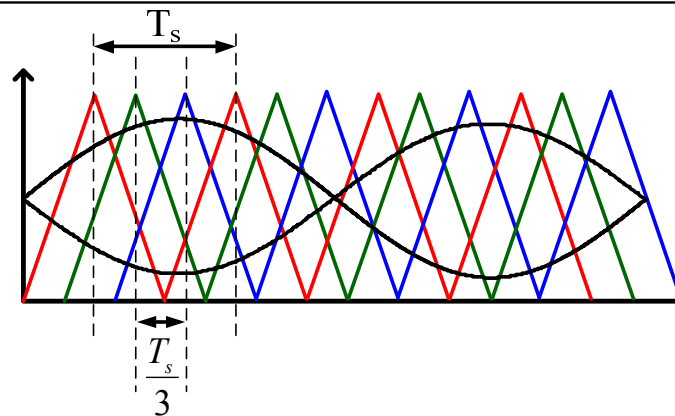 - Modular structure is suitable for high output voltage levels.

Behrouzian, Ehsan, et al. "An overview of multilevel converter topologies for grid connected applications." *Power Electronics and Applications (EPE), 2013 15th European Conference on*. IEEE, 2013.

第二期能源國家型科技計畫
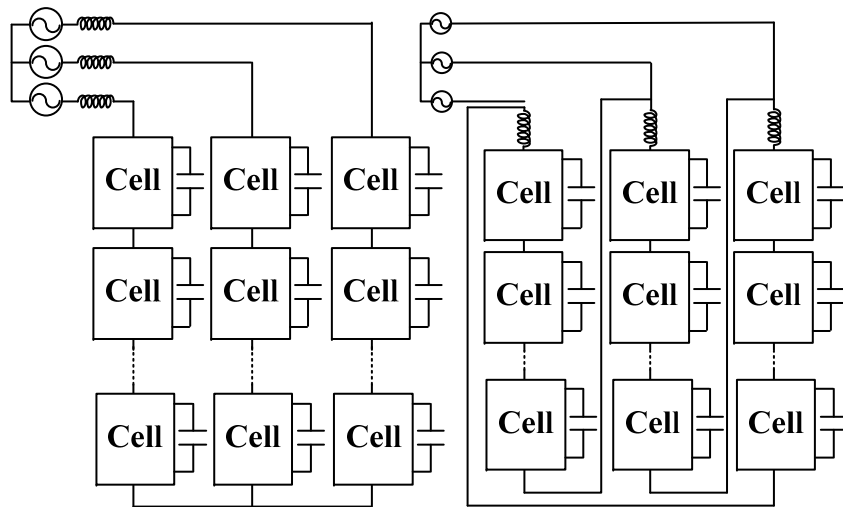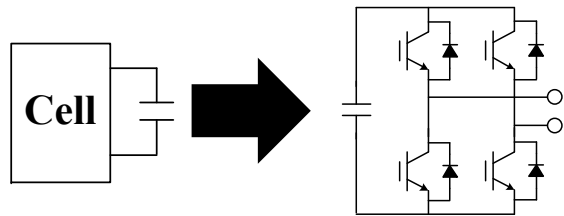National Energy Program-Phase II

Phase shift PWM (PSPWM)

- Low switching frequency
- Nice control performance

Switching frequency	$1/T_s$
Sampling frequency	N/T_s
Equivalent switching frequency of system	N/T_s

Liang, Yiqiao, and C. O. Nwankpa. "A new type of STATCOM based on cascading voltage-source inverters with phase-shifted unipolar SPWM." *Industry Applications, IEEE Transactions on* 35.5 (1999): 1118-1123.

第二期能源國家型科技計畫
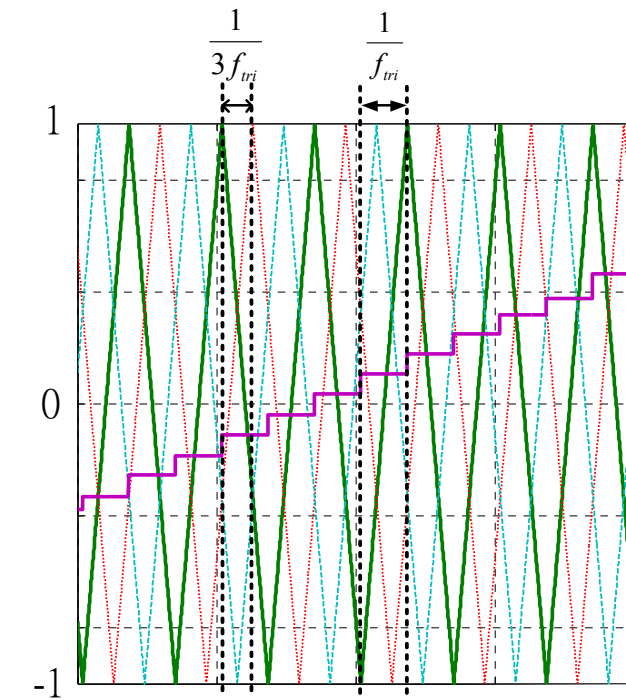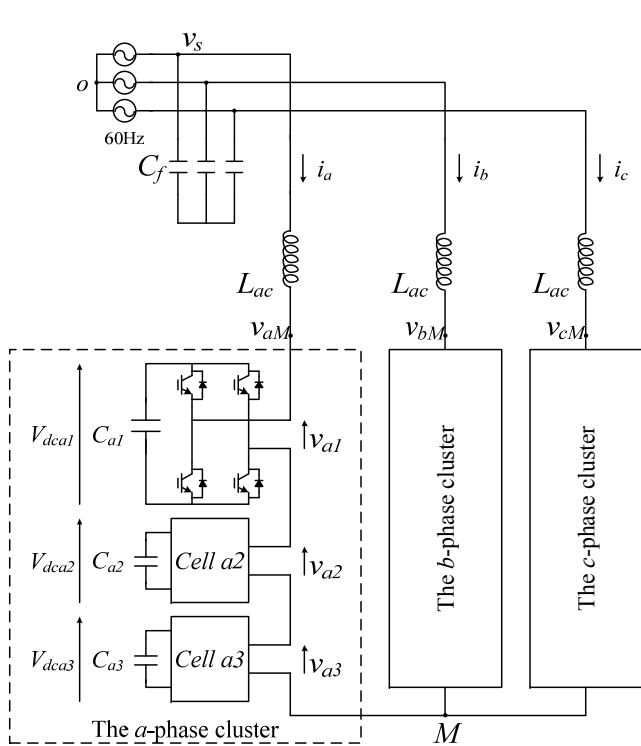National Energy Program-Phase II

- **Single-Star Bridge Cell**
  - Positive sequence current compensation (STATCOMs)
  - No circulating current
  - Zero sequence voltage injection

- **Single-Delta Bridge Cell**
  - Negative sequence current compensation (flicker comp.)
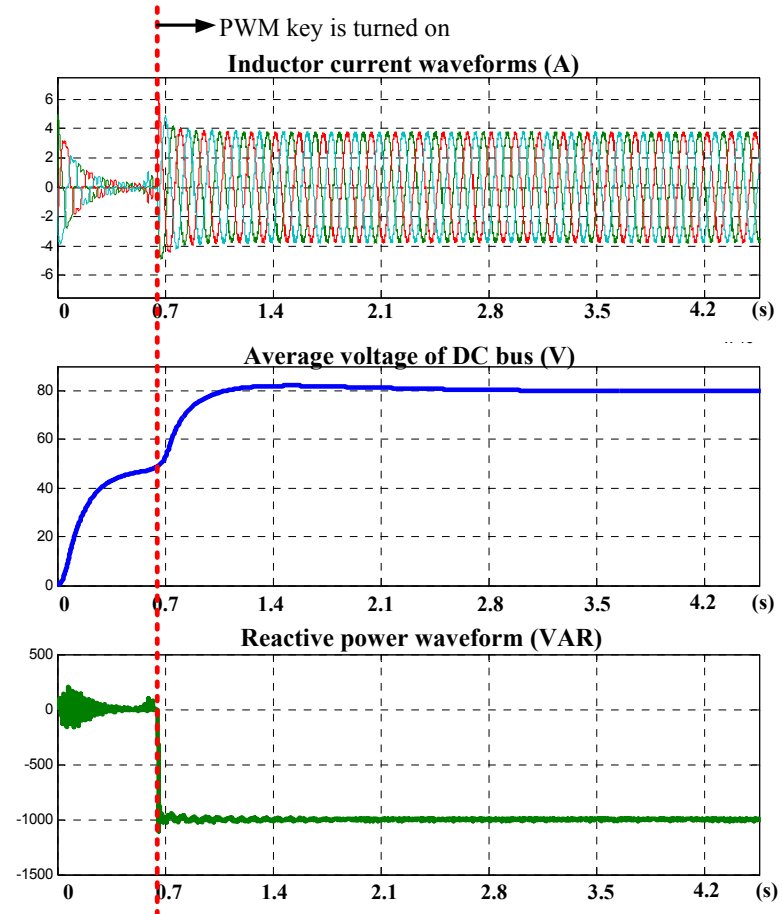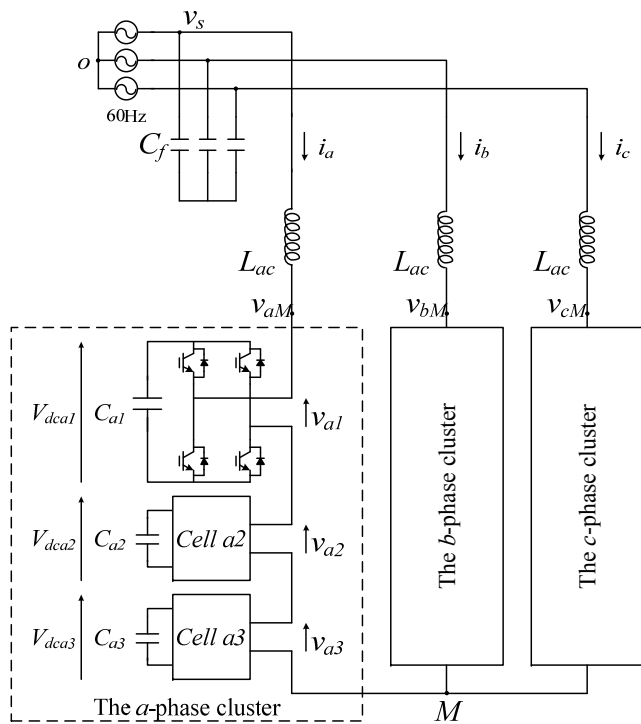 - One degree of freedom of circulating current

Akagi, Hirofumi. "Classification, terminology, and application of the modular multilevel cascade converter (MMCC)." *Power Electronics, IEEE Transactions on* 26.11 (2011): 3119-3130.

第二期能源國家型科技計畫
National Energy Program-Phase II

$$\begin{cases} P = \dfrac{3}{2}\left(v_\alpha i_\alpha + v_\beta i_\beta\right) \\[2mm] Q = \dfrac{3}{2}\left(v_\alpha i_\beta - v_\beta i_\alpha\right) \end{cases}$$

$\Rightarrow$

$$P = \dfrac{3}{2}\left(V_q^p I_q^p + V_d^p I_d^p\right)$$
$$Q = \dfrac{3}{2}\left(V_q^p I_d^p - V_d^p I_q^p\right)$$

$\Rightarrow$

I_q^{p*} **is for overall voltage control**

$$I_d^{p*} = \dfrac{1}{V_q^p}\left(\dfrac{2}{3}Q + V_d^p I_q^p\right)$$

Kim, Hyosung, and Hirofumi Akagi. "The instantaneous power theory on the rotating pqr reference frames." *Power Electronics and Drive Systems, 1999. PEDS'99. Proceedings of the IEEE 1999 International Conference on*. Vol. 1. IEEE, 1999.

第二期能源國家型科技計畫
National Energy Program-Phase II
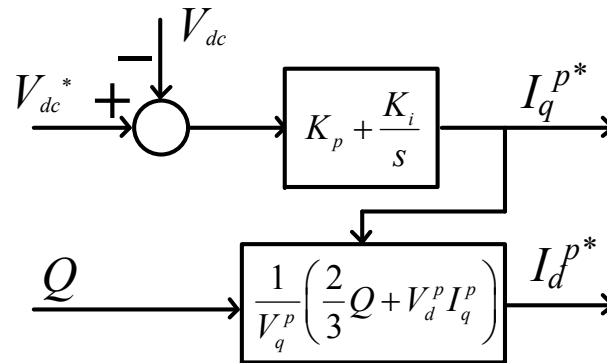
Modulation index and carrier waveform

PWM carrier frequency	f_{tri}	2 kHz
Equivalent PWM switching frequency	f_{sw}	12 kHz
Dead time	t_{dead}	1 μsec
Reactive power command	Q^*	1 kVA
DC bus voltage command	V_{dc}^*	80 V

PWM key is turned on

Inductor current waveforms (A)

Average voltage of DC bus (V)

Reactive power waveform (VAR)

第二期能源國家型科技計畫
National Energy Program-Phase II

DSP 控制模組

回授訊號角位

交流電壓回授　　直流電　交流電
　　　　　　　　壓回授　流回授

DC bus voltages

Grid voltages

Grid currents

MMC converter
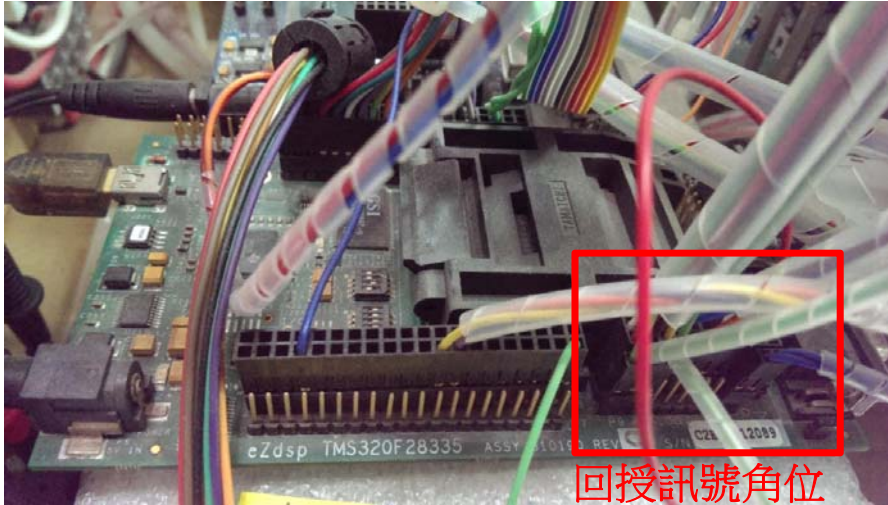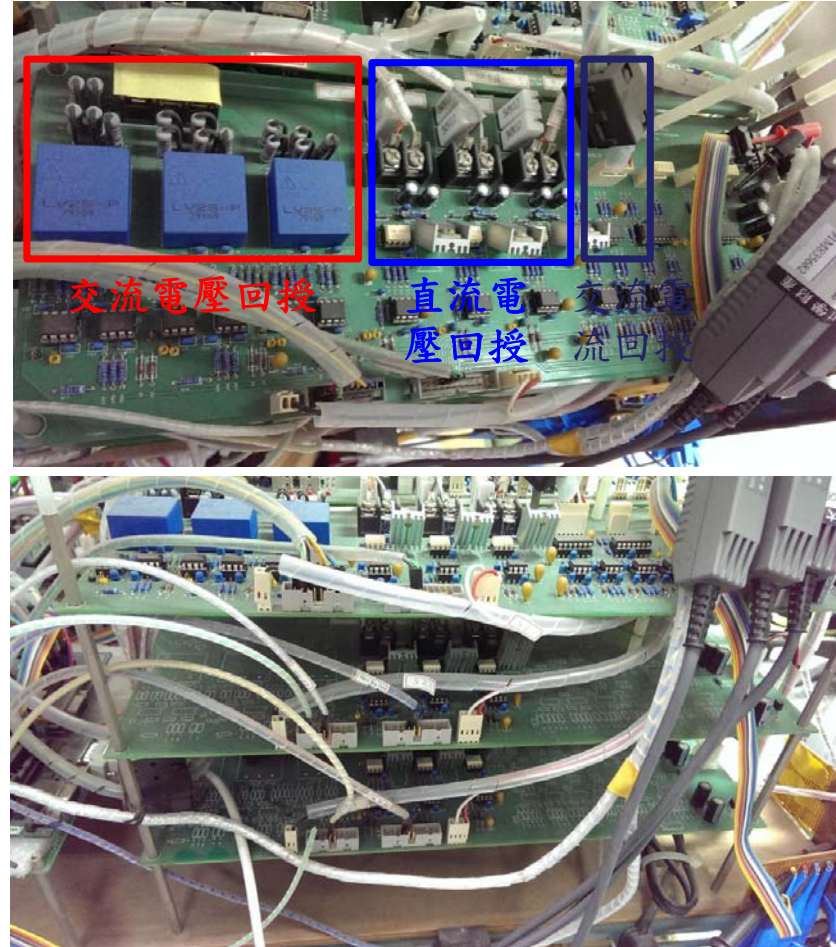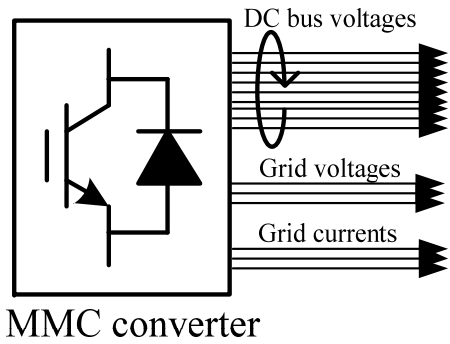
(四)充放電器研製

目標：
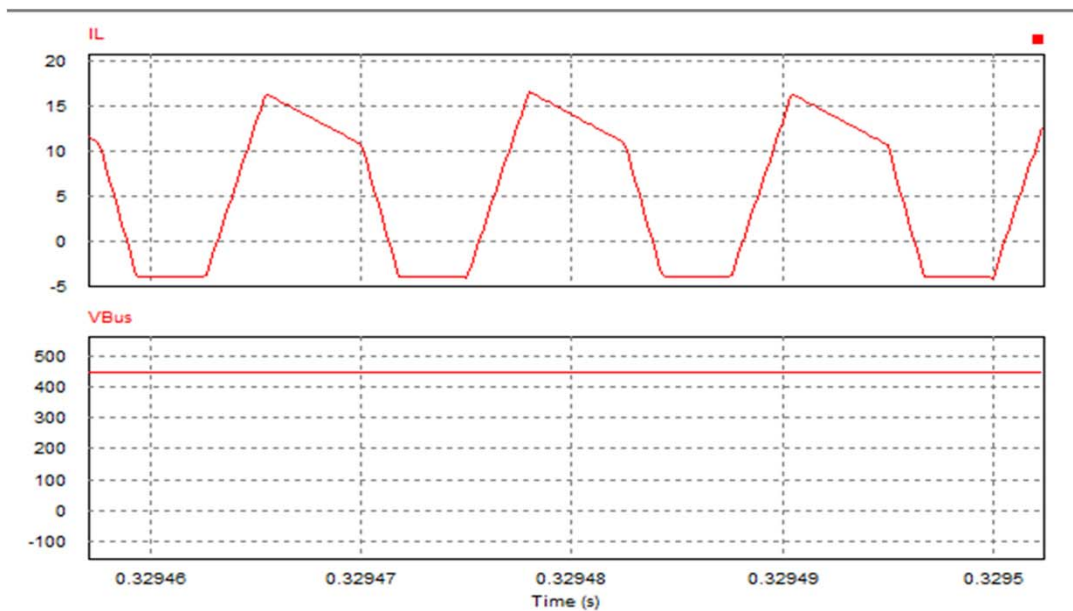
電池側 :380 V

電網側 :420 V

輸出功率: (單組5 kW，總瓦數並聯4組20 kW)

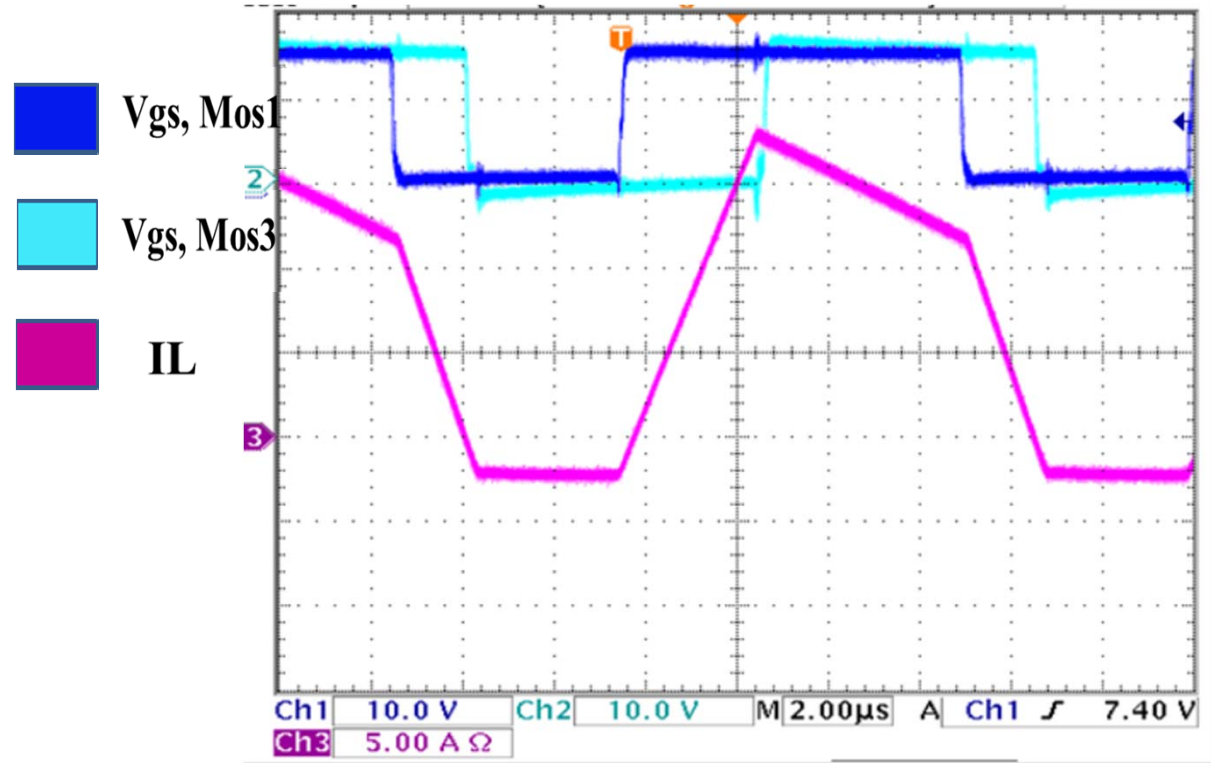非隔離型雙向半橋轉換器

電路架構模擬

NEP 第二期能源國家型科技計畫
National Energy Program-Phase II
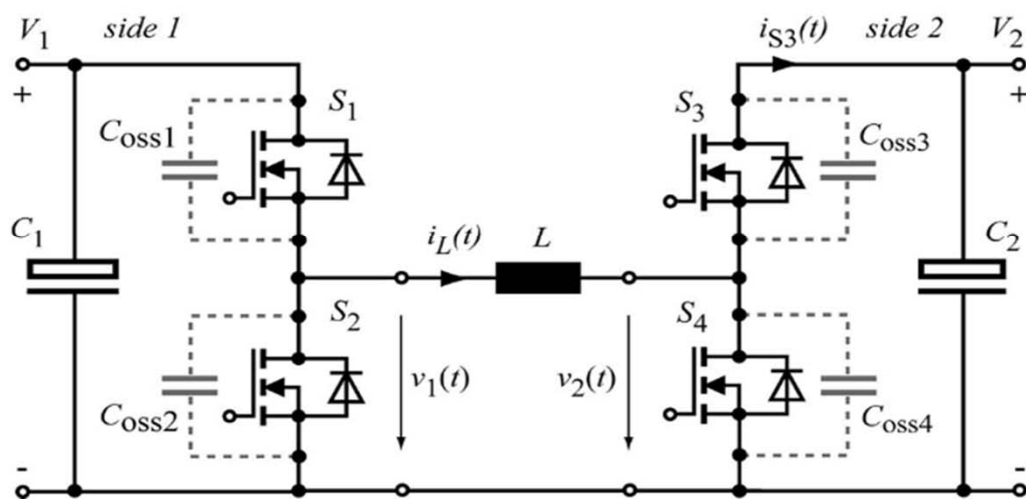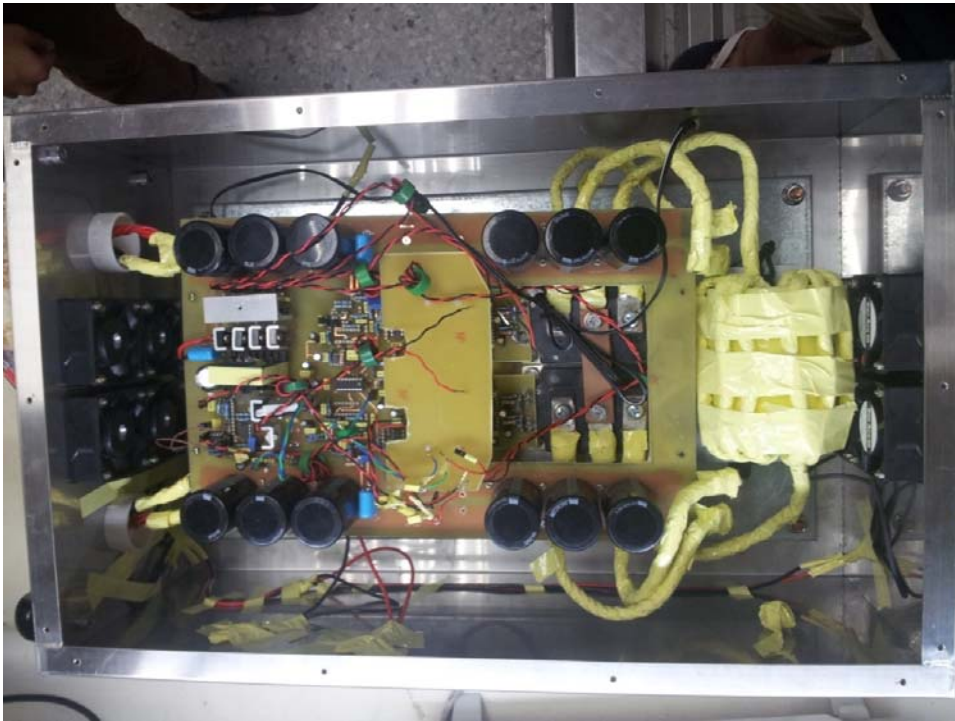
單組5kW電路實體

放電模式下，功率開關訊號與電感電流實測波形

放電模式下，最高效率可達**97%以上**、滿載效率**95.5%以上**、平均效率**96%以上**

Vin(V)	Iout(A)	Vout(V)	Pout(kW)	Eff(%)
380	0.997	450.8	0.449	83.18
	1.992	450.4	0.882	91,9
	3.015	449.9	1.356	96.99
	4	449.5	1.8	97.53
	5	449.1	2.209	96.98
	6.015	449	2.7	96.8
	7.1	449	3.18	96.4
	8.1	448.8	3.63	96.2
	9.4	448.8	4.2	96.1
	10.2	448.7	4.57	95.8
	11.3	448.6	5.062	95.5

(五)大功率轉換器模擬

> ➤ 雙向三相全橋換流器
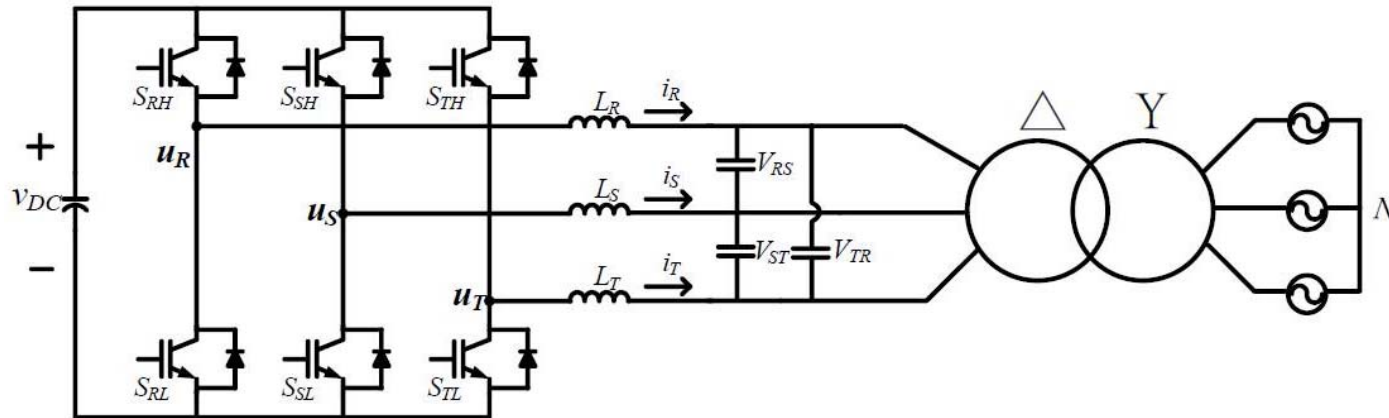
電路架構

$$\begin{bmatrix} u_{RS} \\ u_{ST} \end{bmatrix} = \begin{bmatrix} L_R & -L_S \\ L_T & L_S + L_T \end{bmatrix} \begin{bmatrix} \dfrac{di_R}{dt} \\ \dfrac{di_S}{dt} \end{bmatrix} + \begin{bmatrix} v_{RS} \\ v_{ST} \end{bmatrix}$$

動態狀態空間模型

電氣規格

輸入電壓	700 V
輸出電壓	220 V_{rms}
輸出功率	30 kVA
頻率	60 Hz

第二期能源國家型科技計畫
National Energy Program-Phase II

電感與電流變化建表

Current I(A)	電感(H)
3.738988	1977.03
7.477975	1937.09
11.21696	1917.12
14.95595	1897.15
18.69494	1877.18
22.43393	1777.33
26.17291	1697.45
29.9119	1637.54
33.65089	1557.66

Current I(A)	電感(H)
37.38988	1477.78
44.86785	1298.05
56.08481	1198.2
65.43228	1098.35
74.77975	878.68
80.38823	798.8
96.09198	698.95
106.5611	599.1
112.1696	499.25

電感與電流使用CFTOOL尋找近似曲線
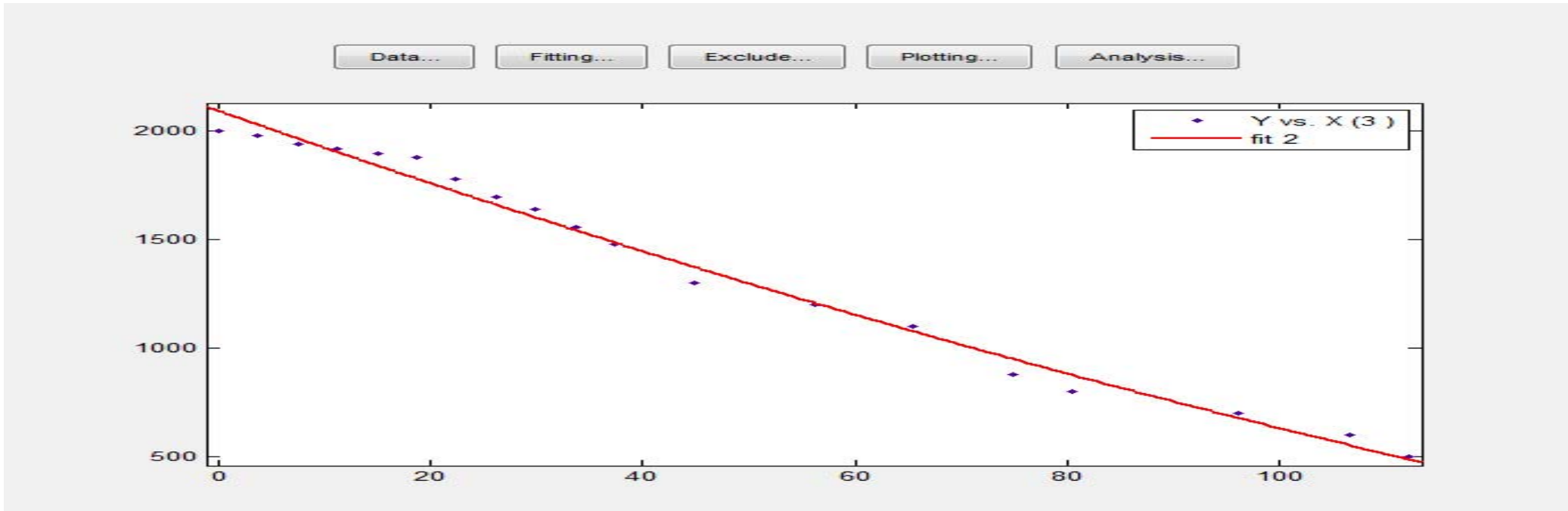
近似方程式：$L(I) = 0.02584I^2 - 17.2I + 2092$

市電併聯模式之三相電感電流波形

➤ 多階轉換器

200 V, 50 Hz
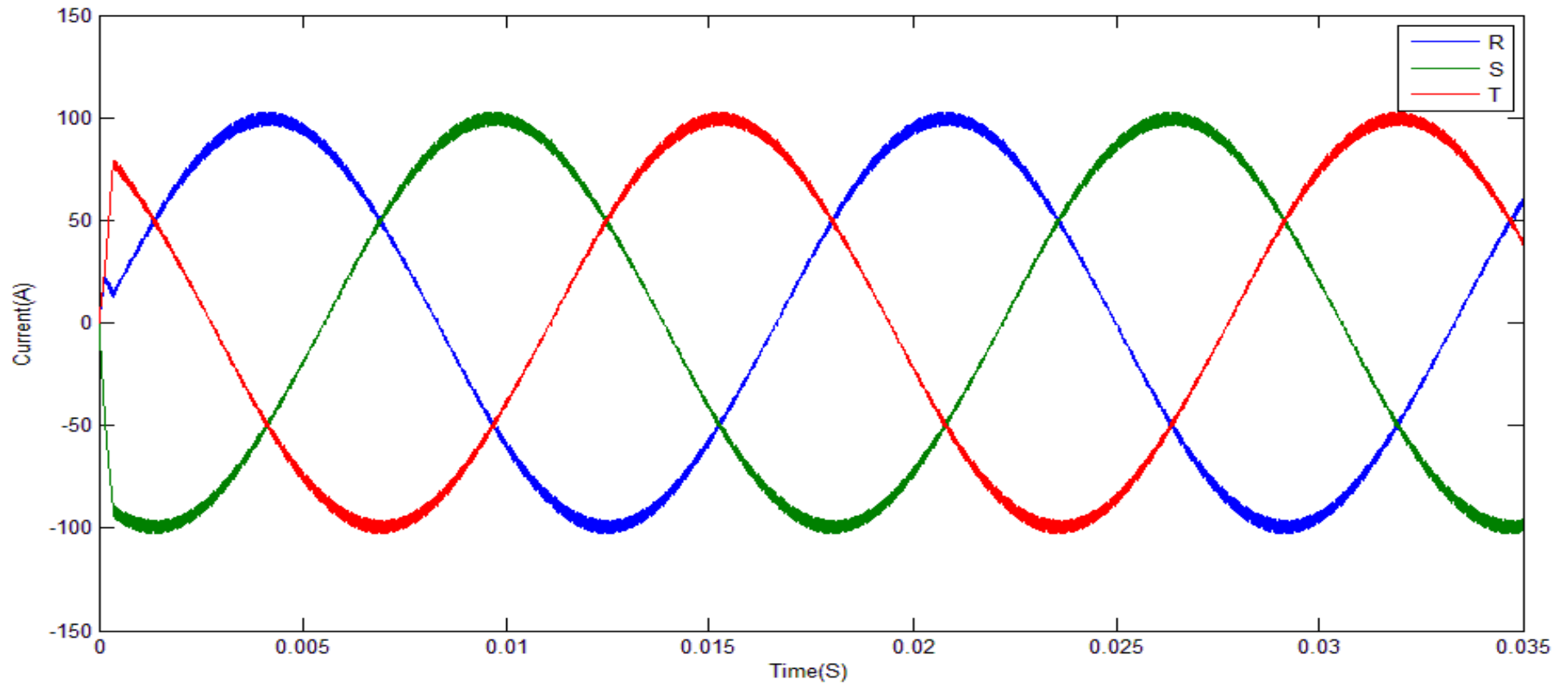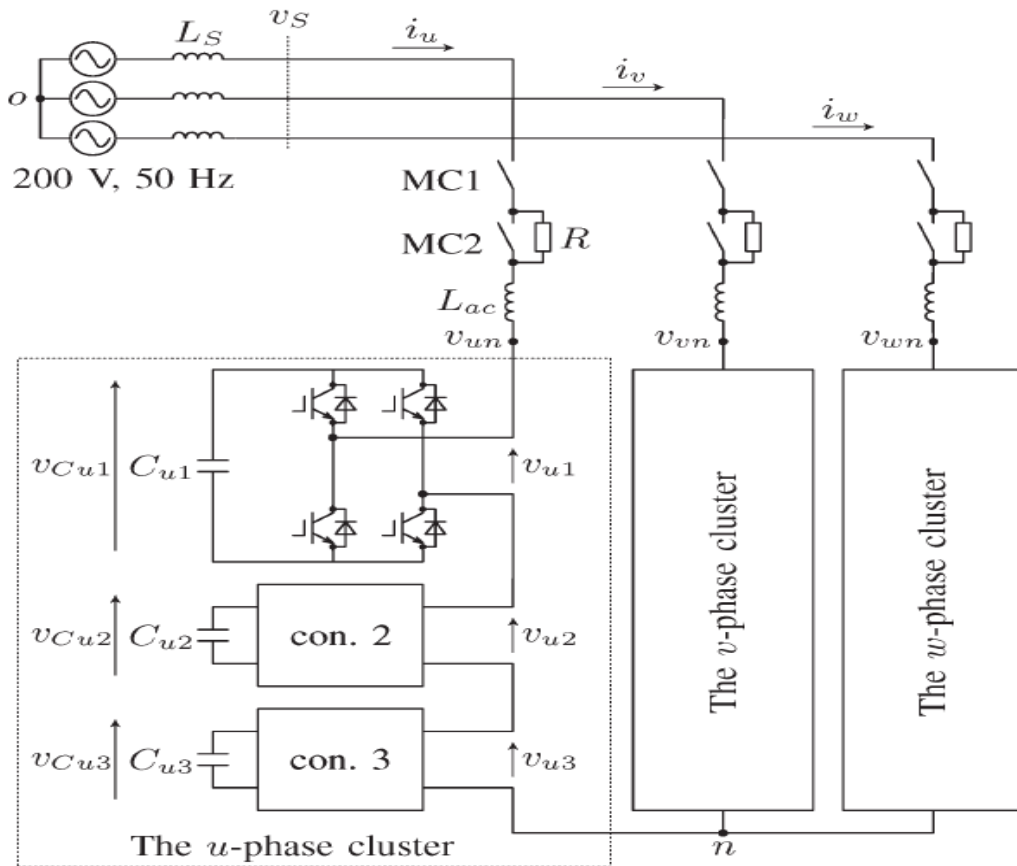
電路參數:

Rated reactive power	Q	10 kVA
Nominal line-to-line rms voltage	V_S	200 V
Background system inductance	L_S	48 μH (0.4%)
AC inductor	L_{ac}	1.2 mH (10%)
Starting resistor	R	10 Ω
DC capacitor voltage reference	v_C^*	60 $\sim$ 70 V
DC capacitor capacitance	C	16,400 μF
Unit capacitance constant	H	36 ms at 70 V
Carrier frequency for PWM		1 kHz
Low-pass-filter time constant	T	11 ms
Dead time in each converter		2 μs

多階轉換器電容電壓追蹤波形

Capacitor Current

Capacitor Voltage

第二期能源國家型科技計畫
National Energy Program-Phase II
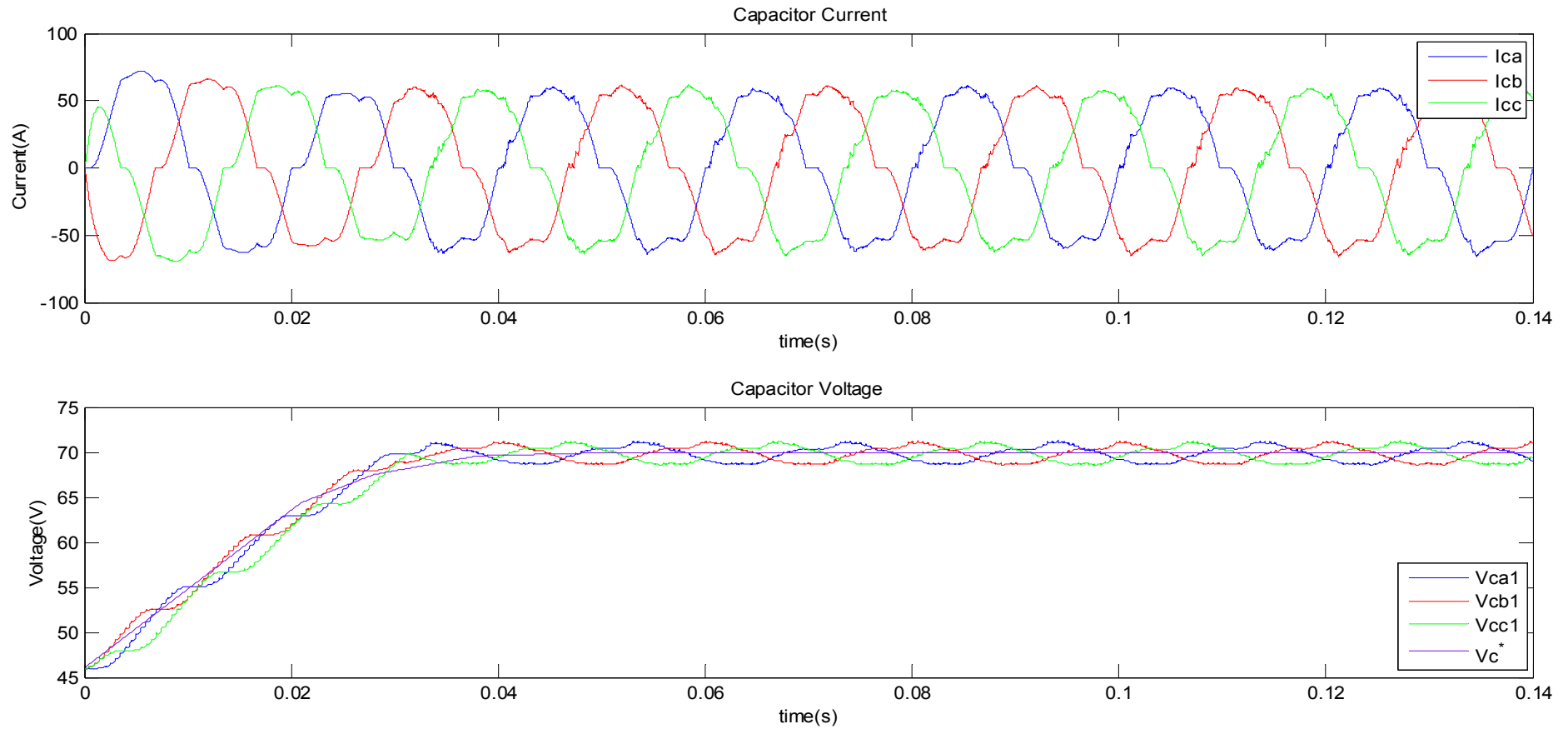
➤ 20kW充/放電器
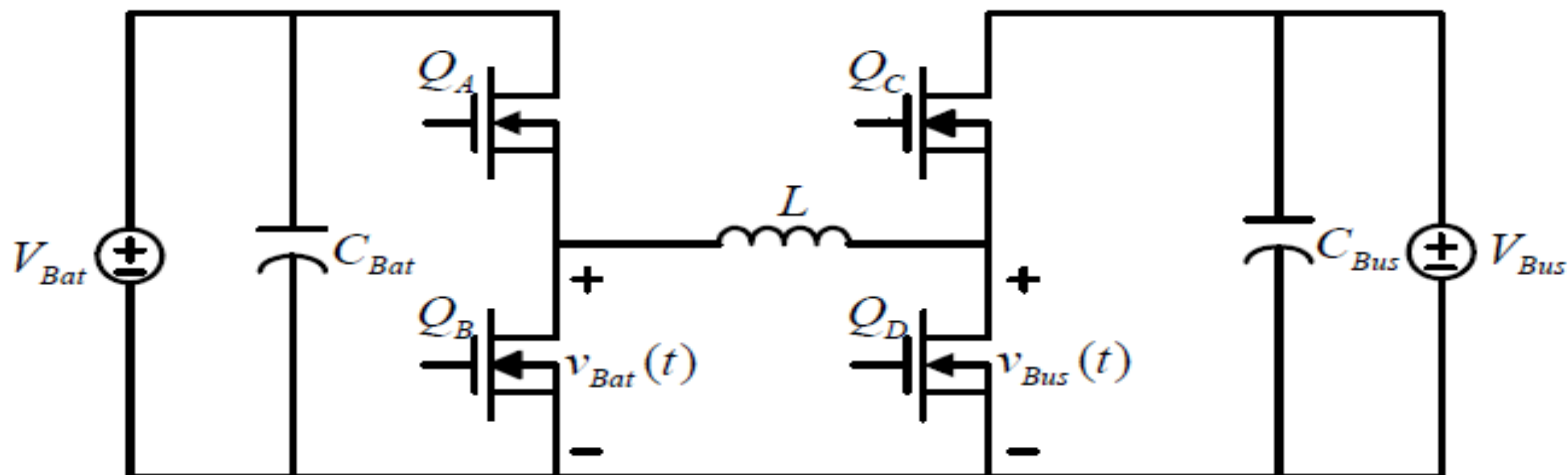
電池電壓 V_{Bat}	350~400V
匯流排電壓 V_{Bus}	450V
輸出功率 P_o	5kW
開關工作頻率 f_s	80kHz

電力級加控制級模組(PLECS)
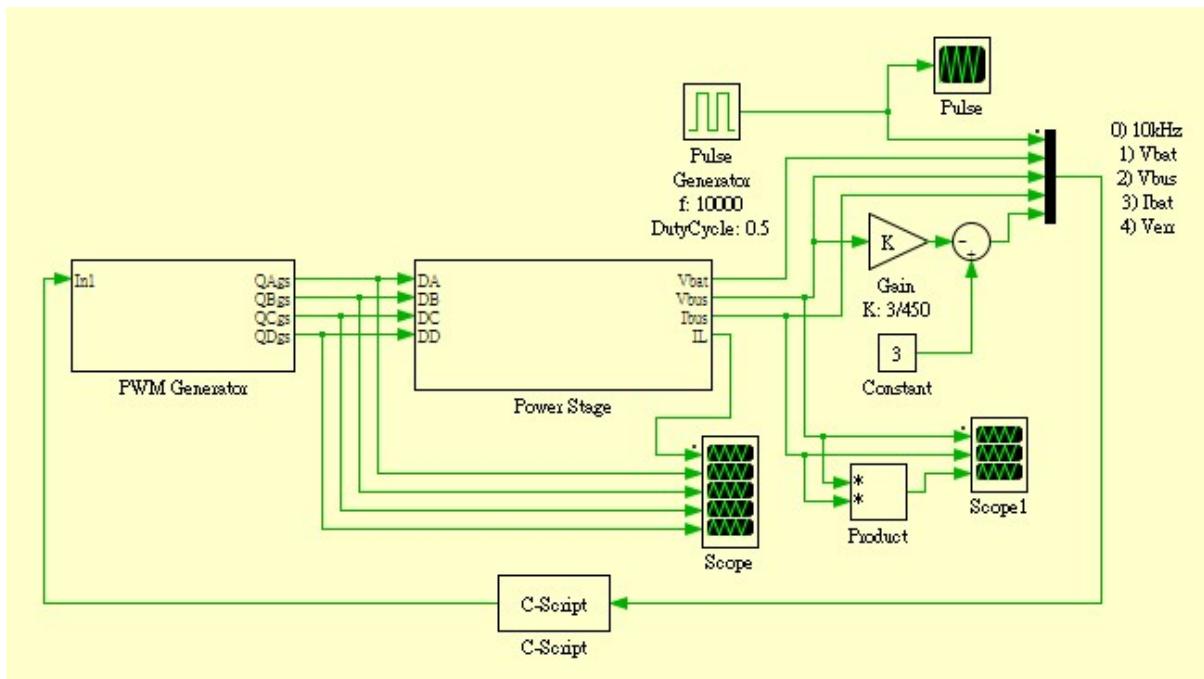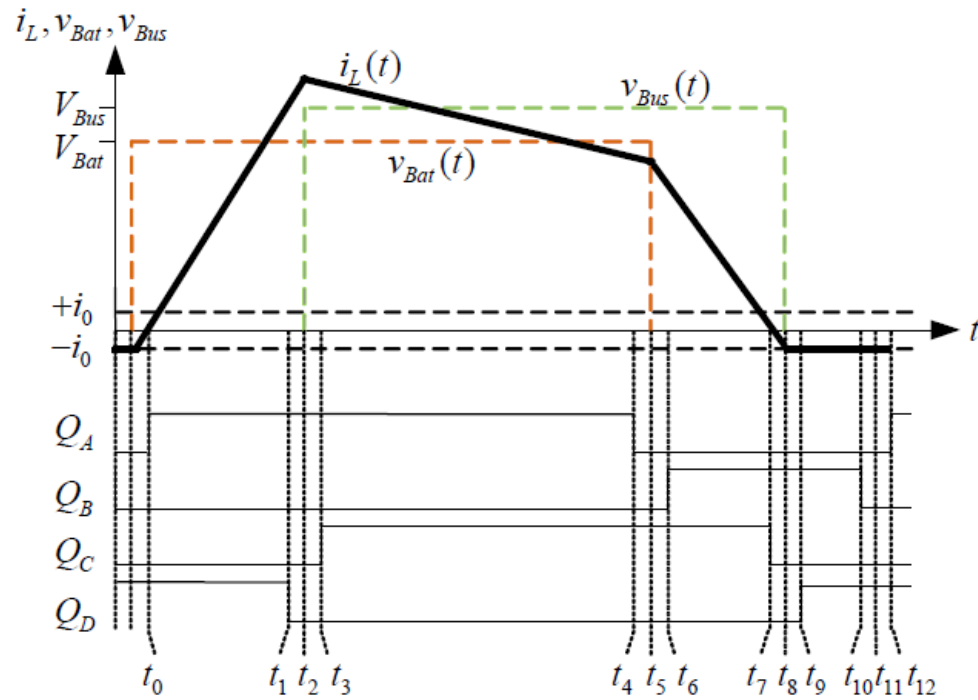
放電模式電感電流及開關波形

放電模式2.5kW模擬條件：

電池電壓V_{Bat}	380 V
匯流排電壓V_{Bus}	450 V
輸出功率P_o	2.5 kW
開關工作頻率f_s	80 kHz
電感L	47 μH
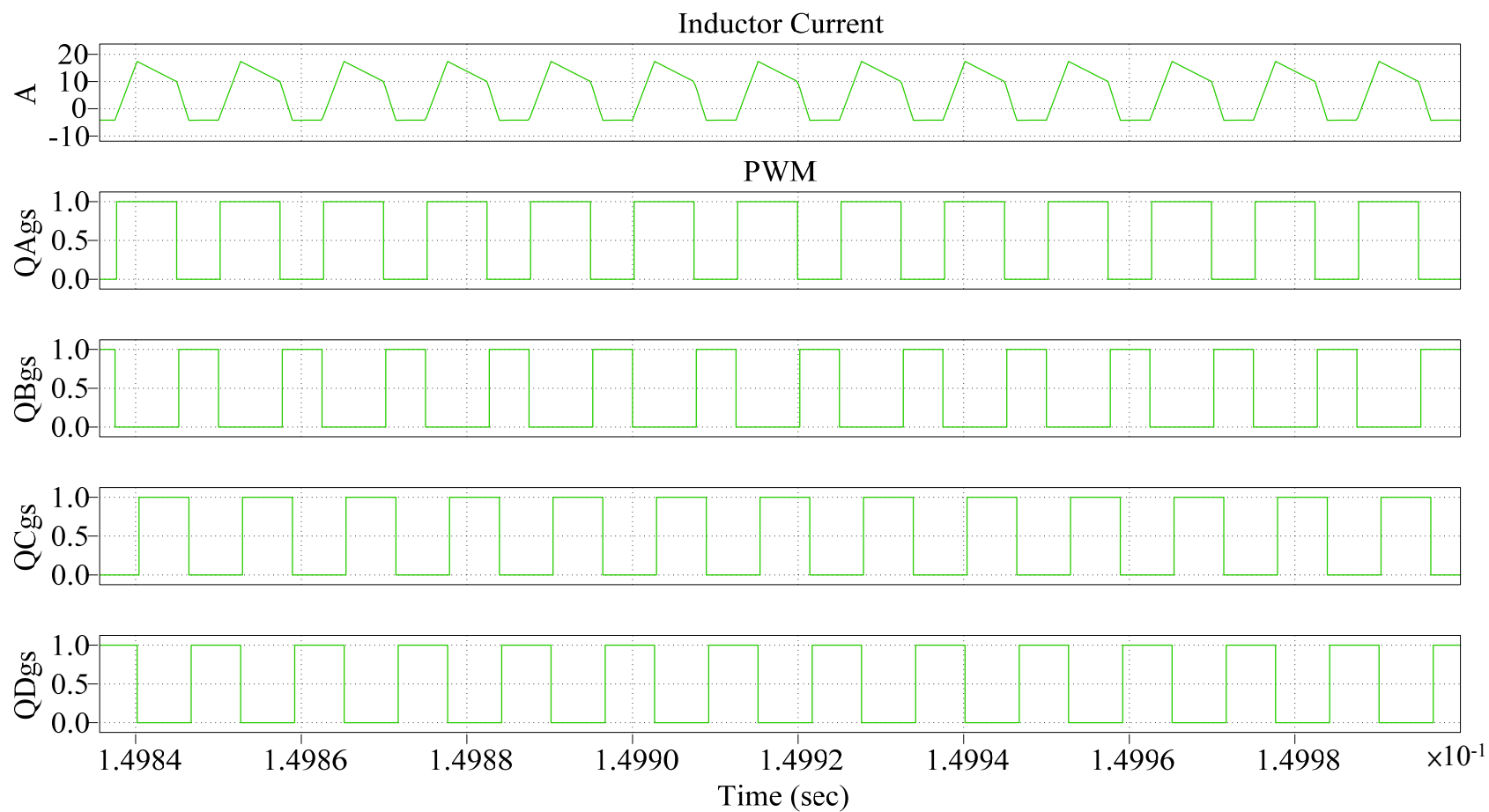
電感電流與PWM波形圖

充電模式電感電流及開關波形

充電模式2.5kW模擬條件：

電池電壓V_{Bat}	380 V
匯流排電壓V_{Bus}	450 V
輸出功率P_o	2.5 kW
開關工作頻率f_s	80 kHz
電感L	47 μH

電感電流與PWM波形圖