SHANDONG UNIVERSITY

Global Synchronous Pulse Width Modulation

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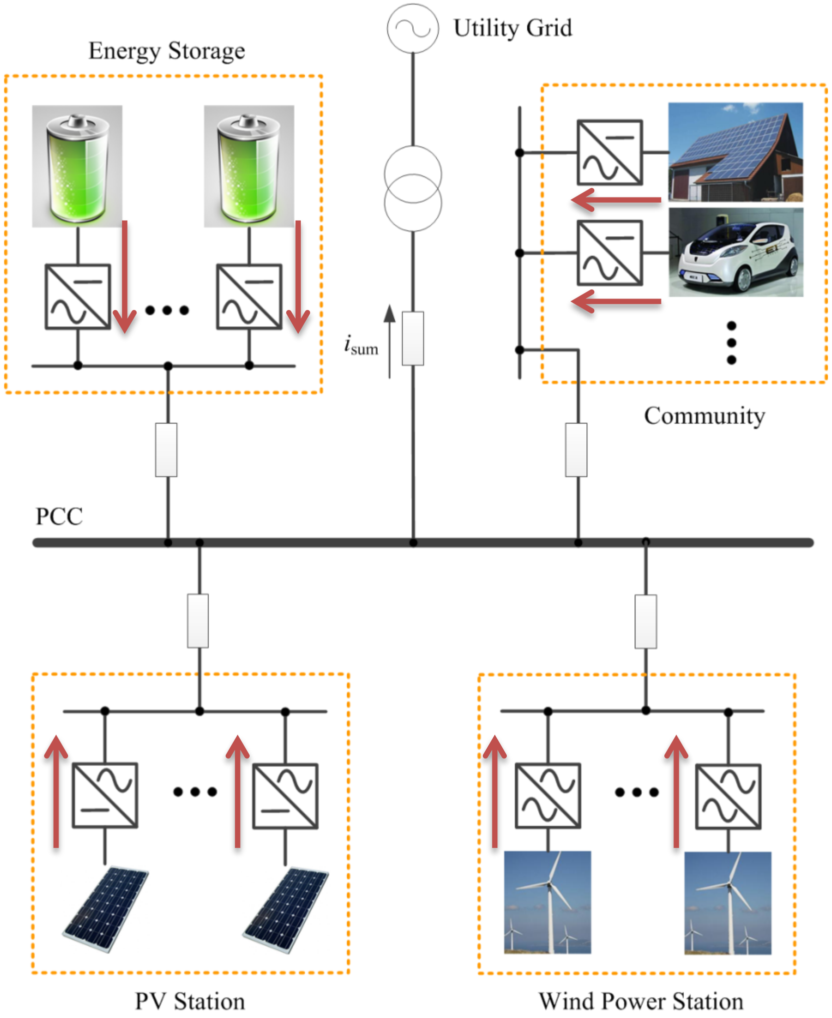
Outline

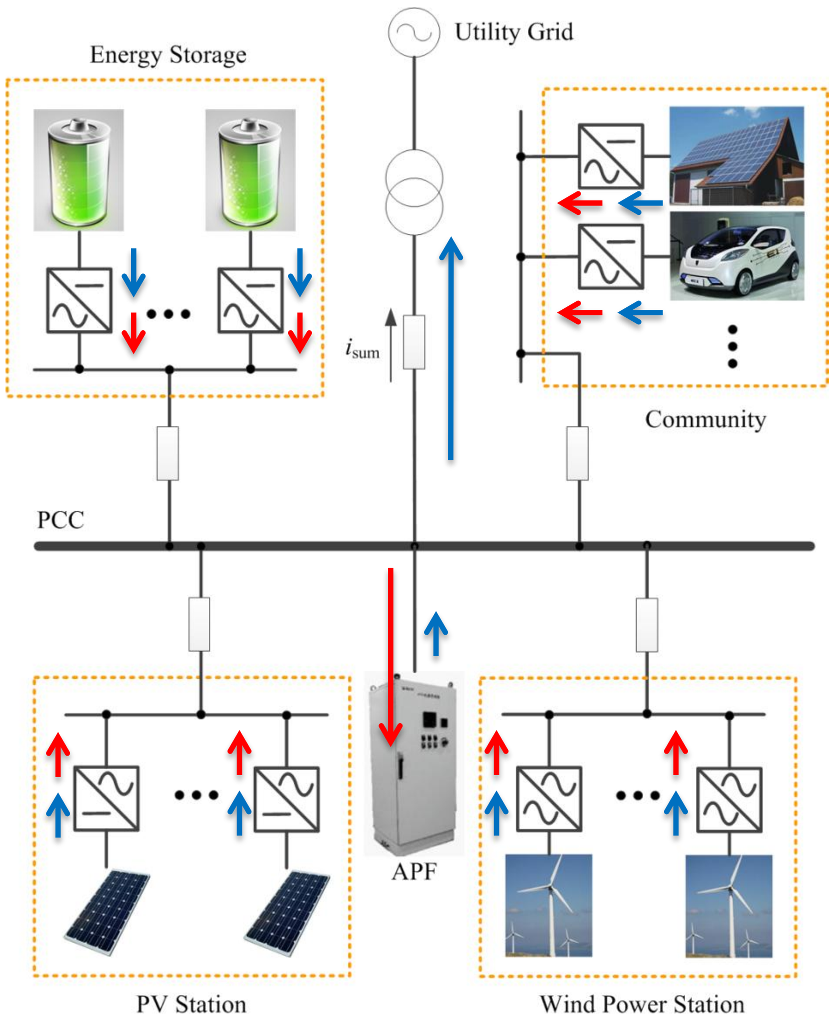
- Why need global synchronous PWM (GSPWM)?
- What is GSPWM?
- Principle and Realization of Global Synchronous PWM (GSPWM)
- Performance Evaluation
- Potential Application Areas


Why need global synchronous PWM



- The number of grid-tied converters has being increased dramatically.
- The injected current from grid-tied converter is not purely sinusoidal, which contains dc component, fundamental frequency component, low order harmonics and high order harmonics.
- The current harmonics will accumulate at PCC, worsen the voltage quality and induce the additional losses.

Why need global synchronous PWM

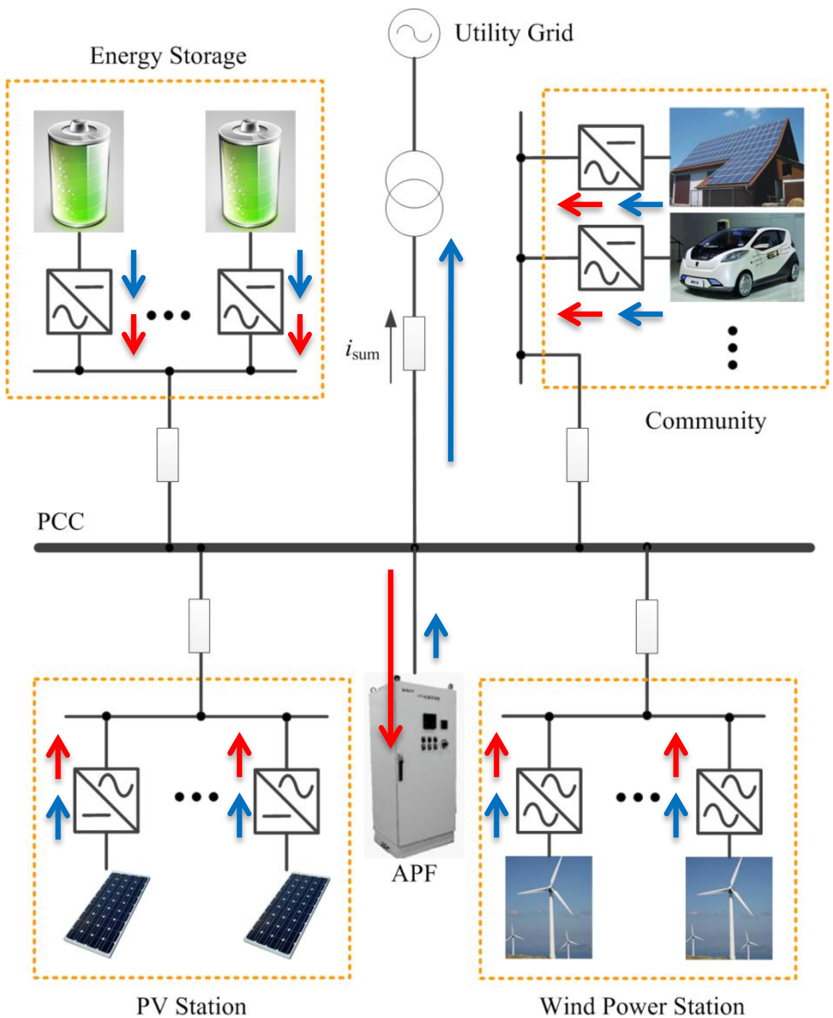


- The passive and active power filters can only eliminate the low order current harmonics in theory.
- High frequency harmonics will bring serious problems:
  - Increased power dissipation because the high frequency harmonics will cause serious skin effect.
  - Increased copper loss of transformer because of the skin effect.
  - Increased iron core loss of transformer.

Low frequency hamonics

High frequency hamonics

Why need global synchronous PWM

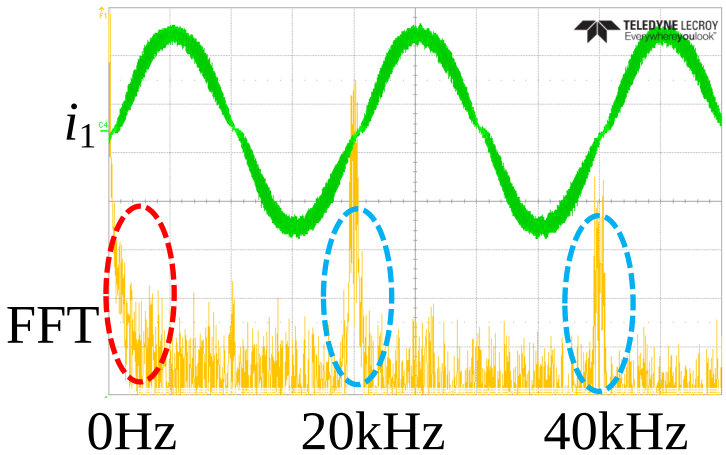


- Increased flux leakage of transformer and it will cause serious EMI.
- Part of high frequency harmonics will be injected into the utility grid.
- Reduce the voltage quality of whole grid.
- Influence the communication channel, such as PLC.
- Influence the normal operation of equipments connected to PCC directly.

→ Low frequency hamonics

→ High frequency hamonics

Why need global synchronous PWM

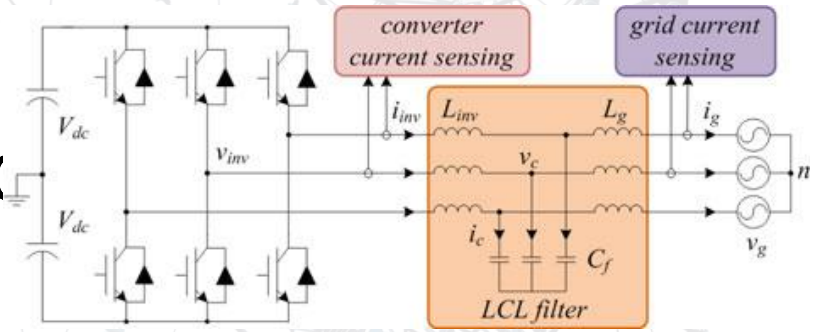


- There is no solution for attenuating the high frequency current harmonics.
- Any grid-tied pulse-width switched converter will produce the high frequency current harmonics.

The highly penetrated power electronics converters in grid will produce the severe power quality issue, which cannot be solved by now.

What is global synchronous PWM

- Current methods to re frequency harmonics
  - High order filters (e.g.



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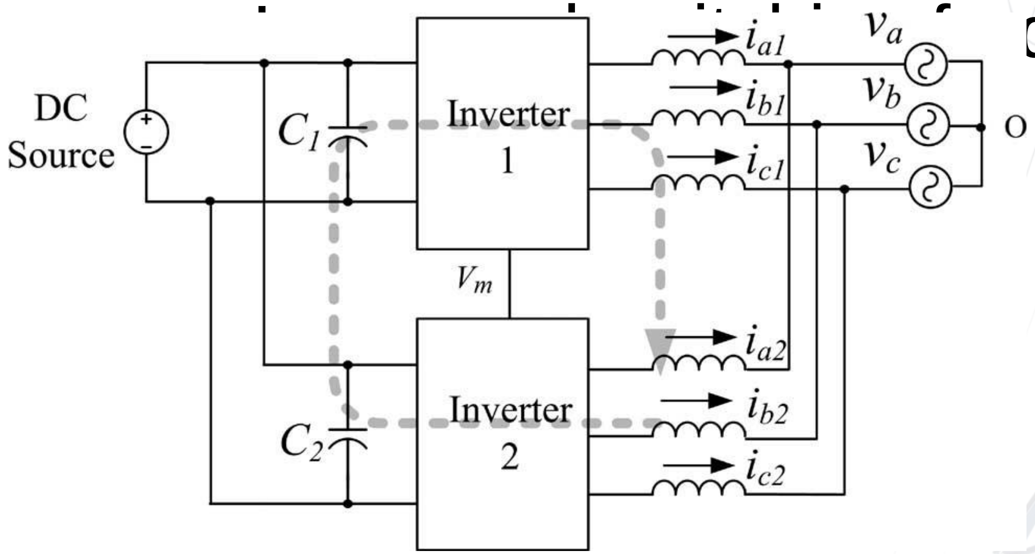
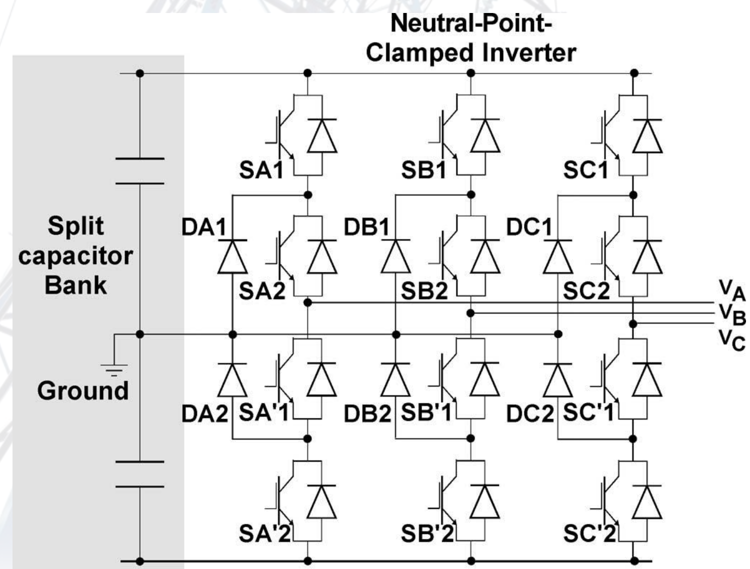




What is global synchronous PWM

- The methods for reducing the high frequency harmonics of individual inverter will unavoidably increase the system cost and complexity.
- The high frequency harmonics are still randomly accumulated in the grid.

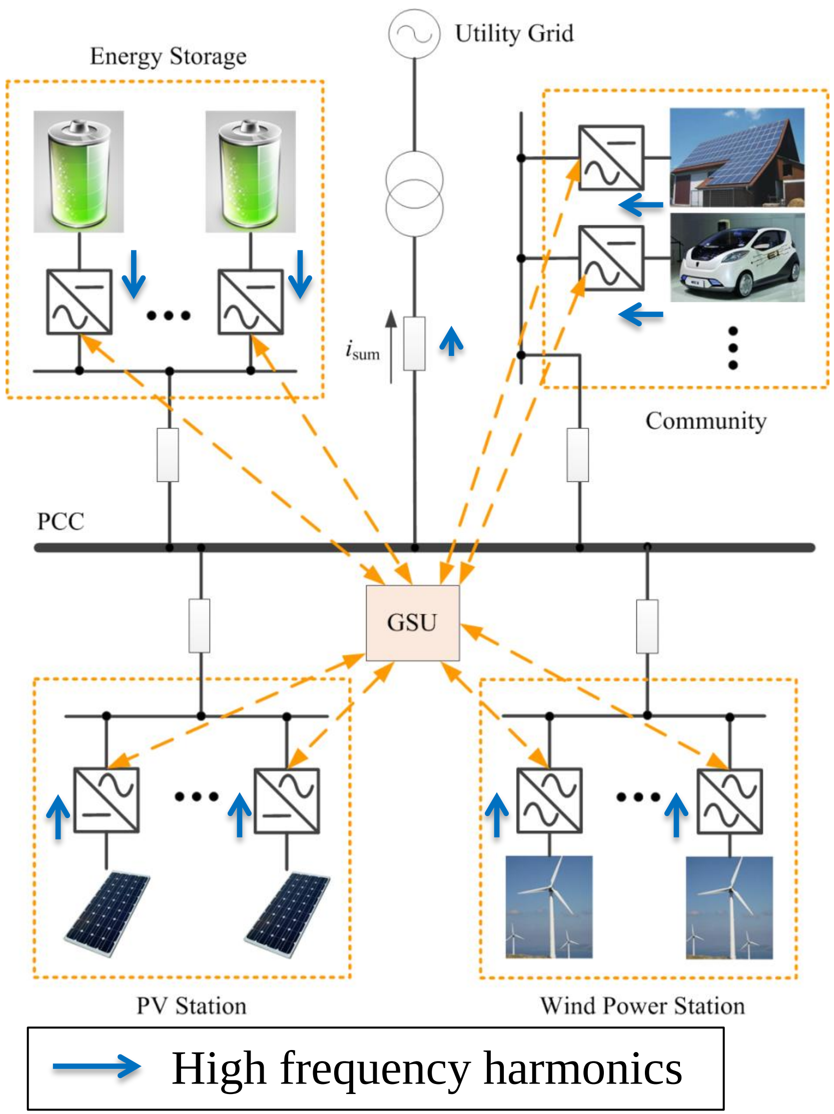
Global Synchronous Pulse Width Modulation

Is there a practical method to reduce the accumulated high frequency harmonics among the distributed converters?

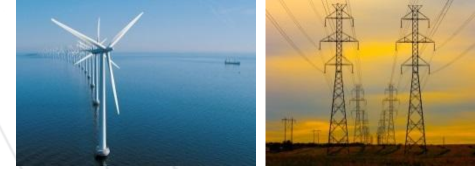
What is global synchronous PWM


- Previously, there is no method to synchronize the PWM sequences of multiple independent converters.
  - Traditionally, the cost, speed, reliability of communication system cannot afford such high level requirements for synchronizing the PWM sequences.
  - The resonant frequency of digital controller indeed will vary depending on the working condition.

What is global synchronous PWM

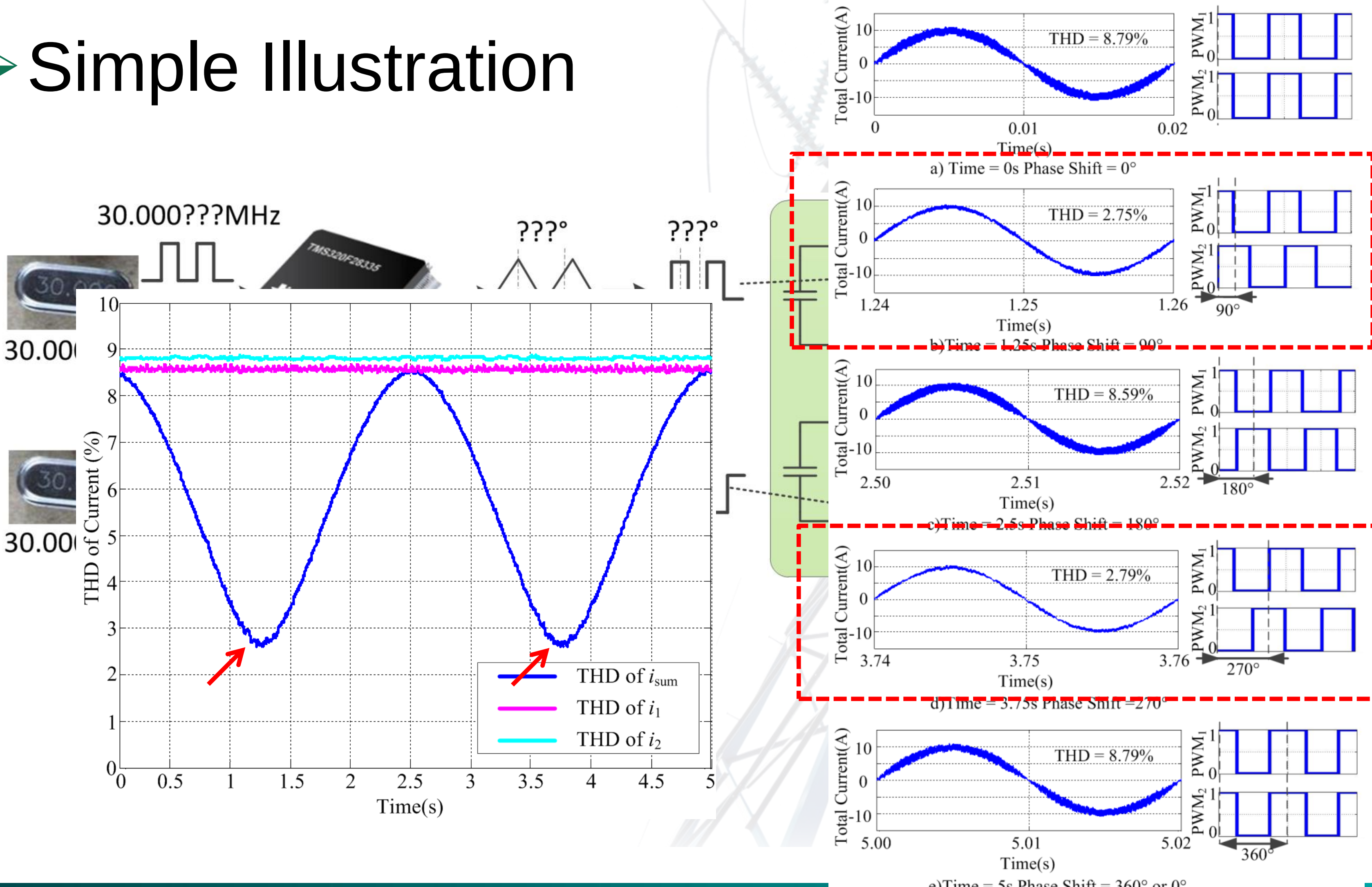


- GSPWM can be employed among the distributed converters to minimize the accumulated high frequency harmonics.
  - Only need simple communication channels;
  - Does not influence the normal operation of converters;
  - Global synchronous unit (GSU) is assumed to calculate the optimal phase-shift angle and synchronous frequency.



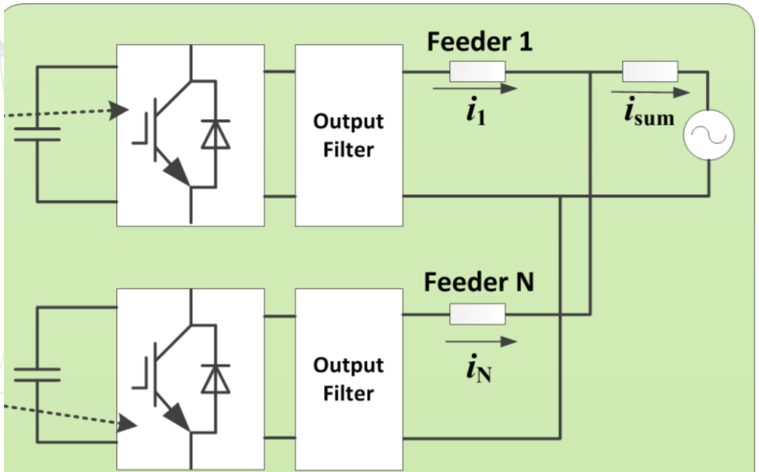
Principle and Realization of GSPWM

➢ Simple Illustration



Principle and Realization of GSPWM

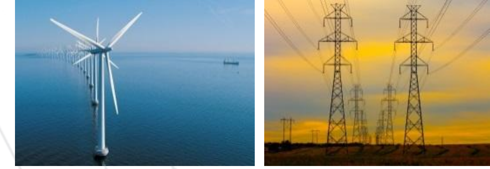
- Practical Challenges
  - Unequal dc-link voltage
  - Unequal switching frequency
  - Unequal filter impedance and line impedance



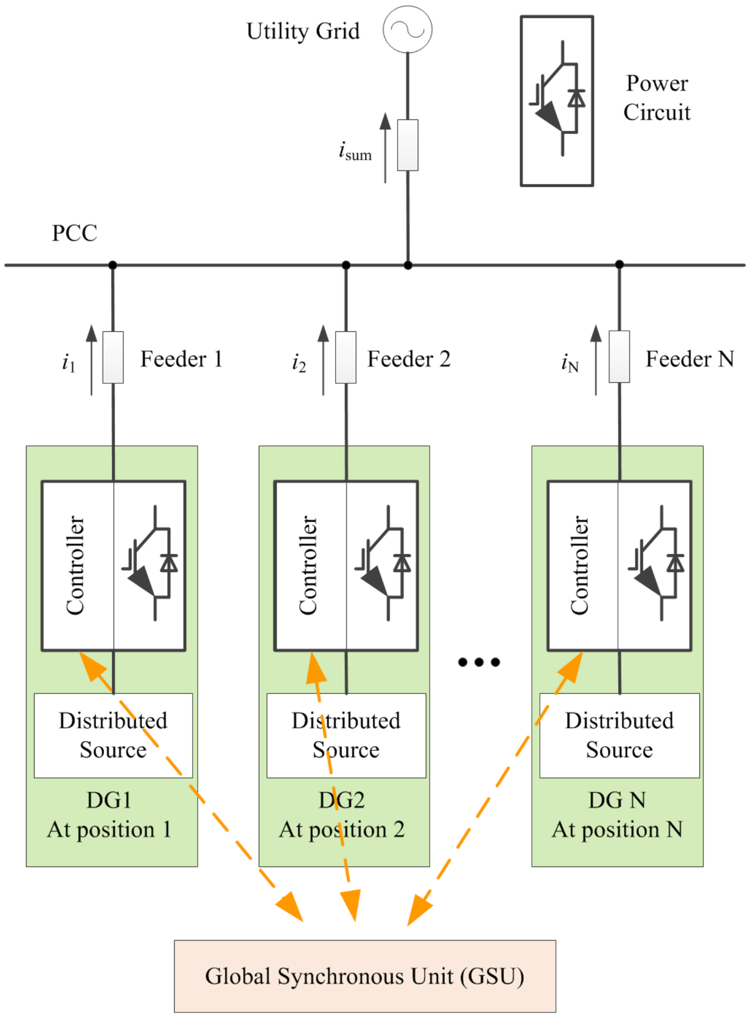
Two parallel-connected inverters

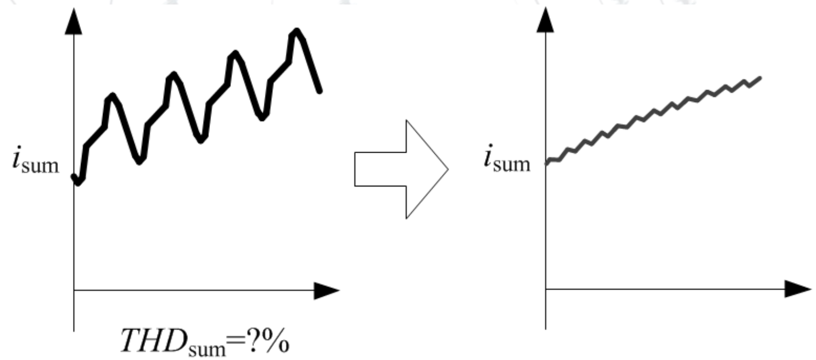
The current ripples of distributed inverters are different.

- Technical Problems
  - How to calculate the optimal phase shifts when the number of inverters is large and their parameters are different?
  - How to keep the optimal phase shifts unchanged during operation?



Principle and Realization of GSPWM





- ➢ Solution of Problem 1:
- ✓ Receive parameters of inverters;
- ✓ Calculate optimal interleaved switching angles;
- ✓ Sends optimal interleaved switching angles to inverters;

- ➢ Solution of Problem 2:
- ✓ Calculate the synchronous frequency
- ✓ Send the synchronization signals.

Global Synchronous Unit (GSU) is proposed to solve these two problems.

Principle and Realization of GSPWM

➢ Solution of Problem 1

The mathematical model is:

$$\min \; I_{\text{hsum}} = f(\varphi_{\text{PWM1}} \ldots\ldots \varphi_{\text{PWMN}})$$

$$\text{s.t.} \qquad 0^\circ \le \varphi_{\text{PWMM}} \le 360^\circ \;, \; M=1,\ldots,N$$

$$I_{\text{hsum}} = \sqrt{\begin{array}{l}\sum_{f=0}^{\infty}\left(\sum_{M=1}^{N} I_{\text{hMf}} \cos\left(\varphi_{hMf} + \theta_{hMf}\right)\right)^2 \\ + \sum_{f=0}^{\infty}\left(\sum_{M=1}^{N} I_{\text{hMf}} sin\left(\varphi_{\text{hMf}} + \theta_{hMf}\right)\right)^2\end{array}} = f\left(\varphi_{PWM1}, \ldots, \varphi_{PWMN}\right)$$

This is a large-scale nonlinear optimization problem. Evolutionary computation is necessary. And Particle Swarm Optimization (PSO) is employed.

Principle and Realization of GSPWM

➤ Solution of Problem 2

The mathematical model is:

$$\max\ I_{\mathrm{hsum}} = f(\varphi_{\mathrm{PWM1}} \ldots\ldots \varphi_{\mathrm{PWMN}})$$

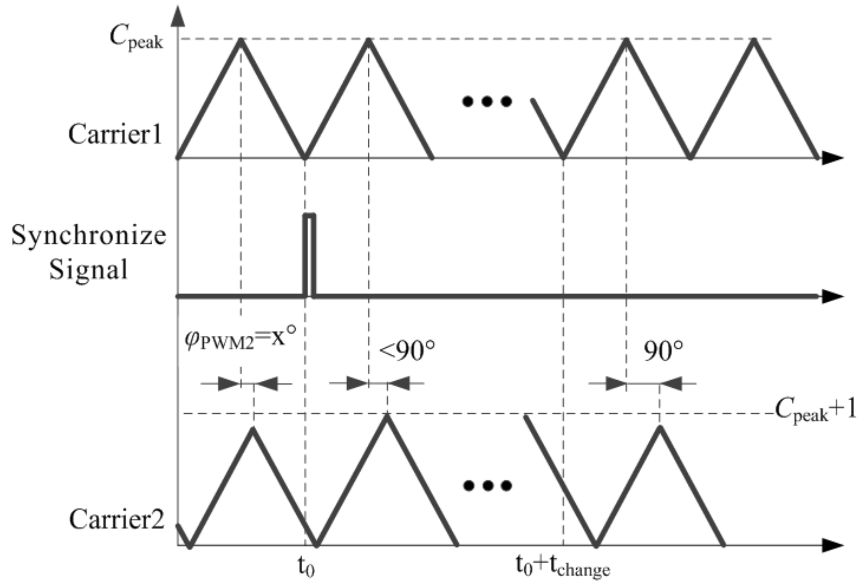
$$\text{s.t.}\quad \varphi_{\mathrm{PWMMbest}} - \Delta\varphi_{\mathrm{Mmax}} \leq \varphi_{\mathrm{PWMM}} \leq \varphi_{\mathrm{PWMMbest}} + \Delta\varphi_{\mathrm{Mmax}},\ \mathrm{M}=1,\ldots,\mathrm{N}$$

$$I_{\mathrm{hsum}} = \sqrt{\begin{matrix}\sum_{f=0}^{\infty}\left(\sum_{M=1}^{N} I_{\mathrm{hMf}}\cos\left(\varphi_{hMf}+\theta_{hMf}\right)\right)^2 \\ +\sum_{f=0}^{\infty}\left(\sum_{M=1}^{N} I_{\mathrm{hMf}} sin\left(\varphi_{\mathrm{hMf}}+\theta_{hMf}\right)\right)^2\end{matrix}} = f(\varphi_{PWM1},\ldots,\varphi_{PWMN})$$

The synchronous frequency can be determined according to the allowed communication speed.

Principle and Realization of GSPWM

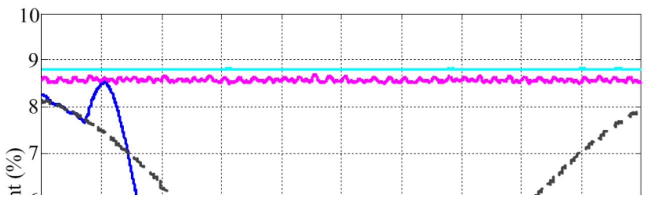
➢ Gradually Changing of Phase-Shift Carrier



The phase shift of carrier will change suddenly when controller receives the synchronization signal at t_0. The sudden change of carrier may cause the serious output distortion.

Principle and Realization of GSPWM

➢ Principle Summary



✓ GSU calculates the optimal phase shift angles and synchronization

GSPWM does not change the normal operation of distributed inverters.

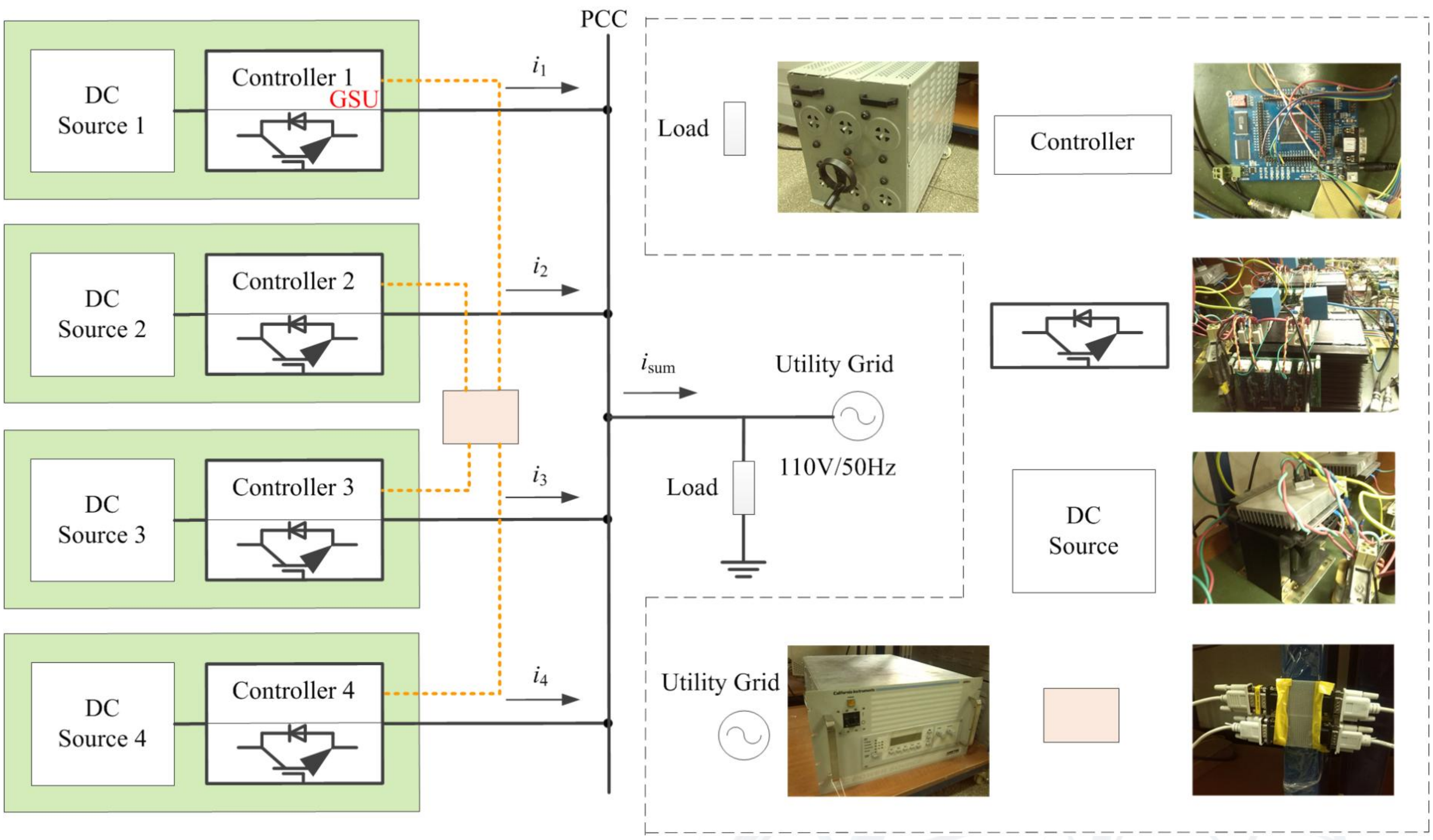
GSPWM does not need additional high speed communication system.

Shift Phase Mode

Normal Mode

Performance Evaluation

Experimental Prototype

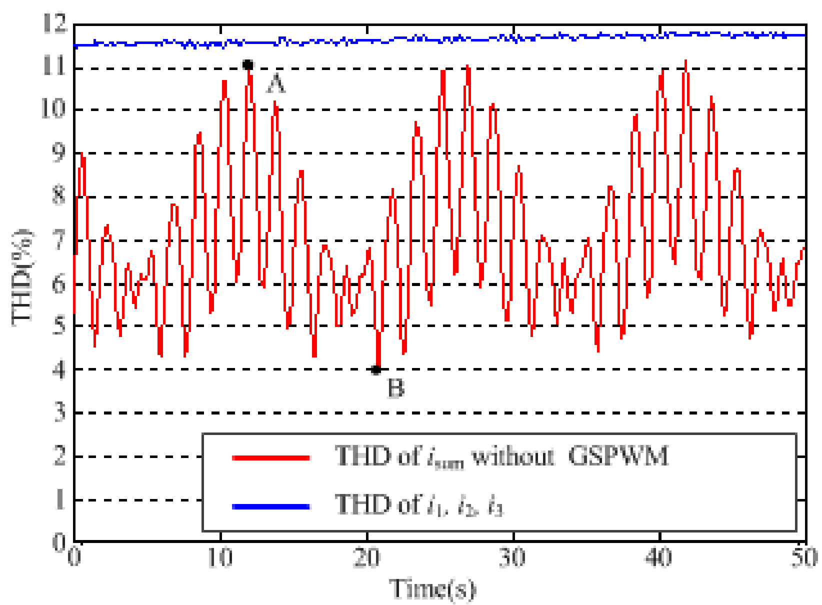


Performance Evaluation

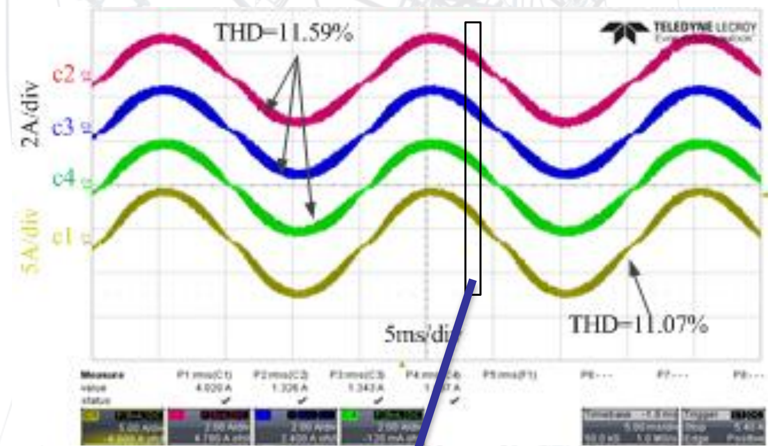
Three inverters with the same operation parameters are used to verify the theory.

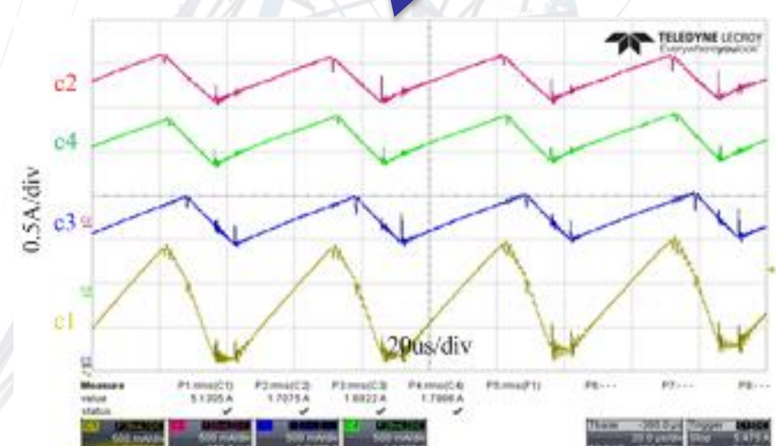
f_c=10kHz, f_0=50Hz, V_d=200V, L=3.5mH.

GSPWM is not employed.



Waveforms of i_1(C2), i_2(C3), i_3(C4), i_{sum}(C1) at point A:





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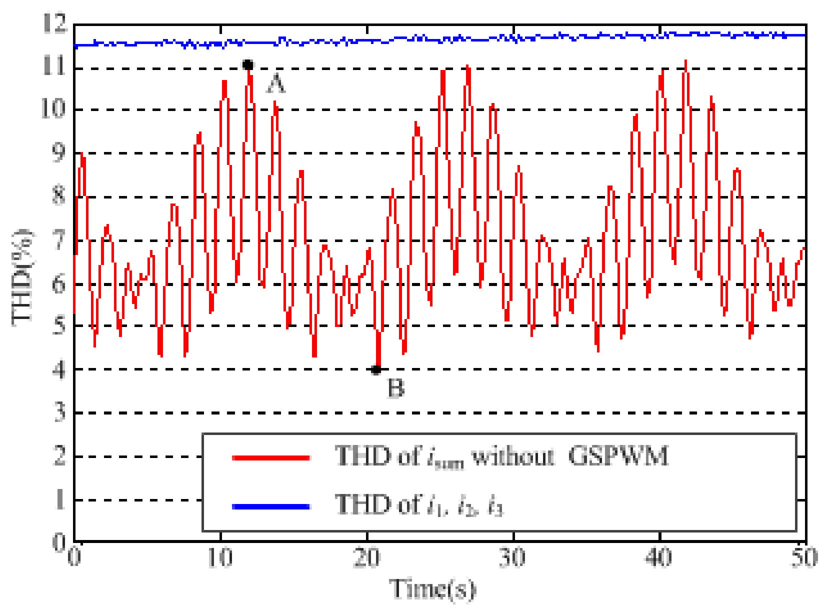
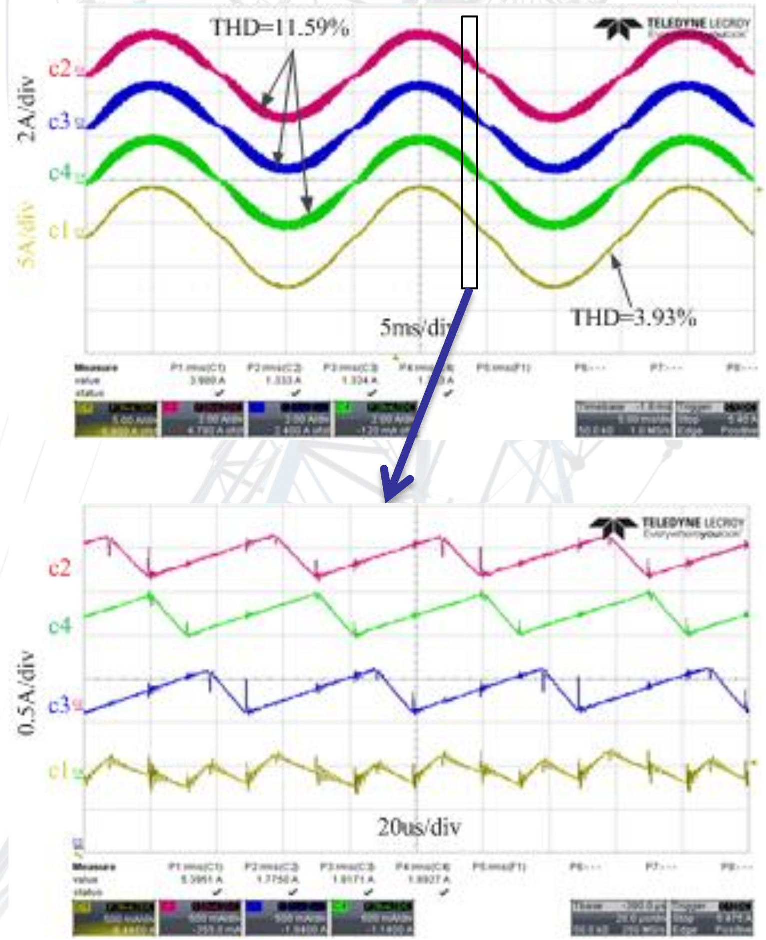


Waveforms of i_1(C2), i_2(C3), i_3(C4), i_{sum}(C1) at point B:



Performance Evaluation

Three inverters with the same operation parameters are used to verify the theory.

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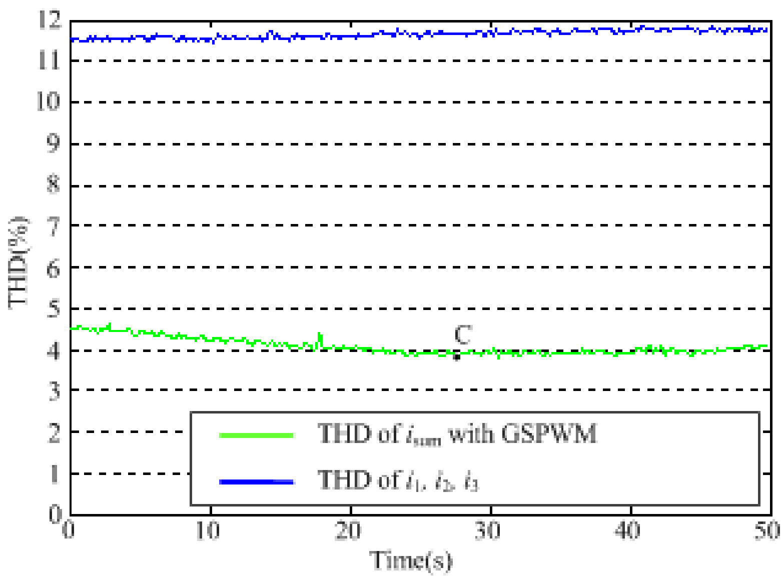
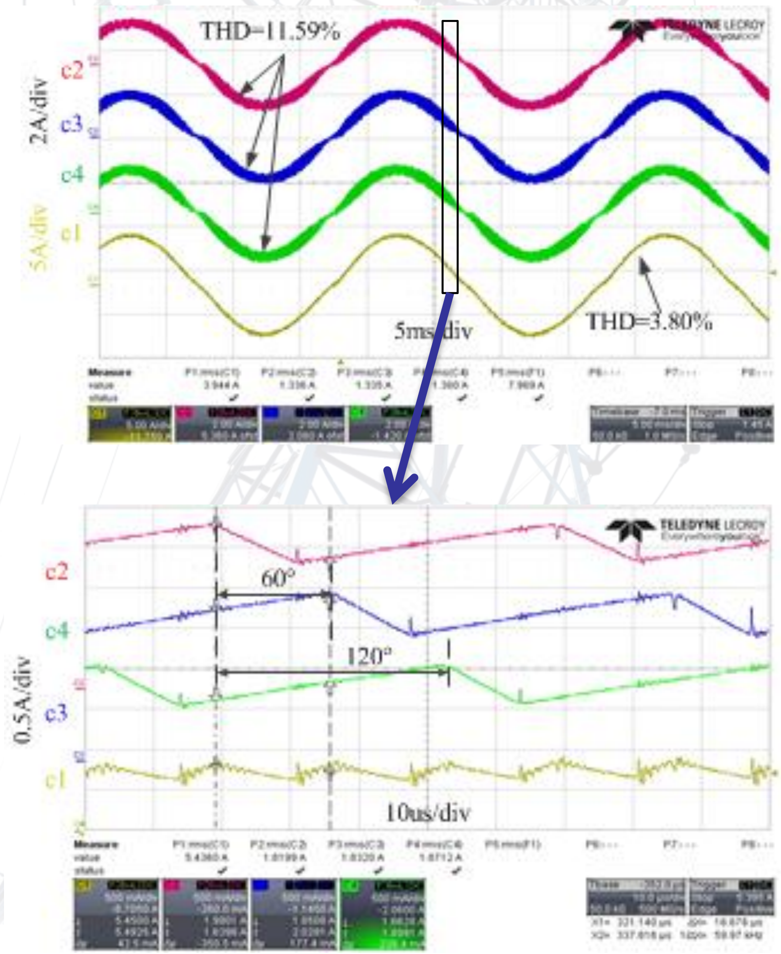
GSPWM is employed.

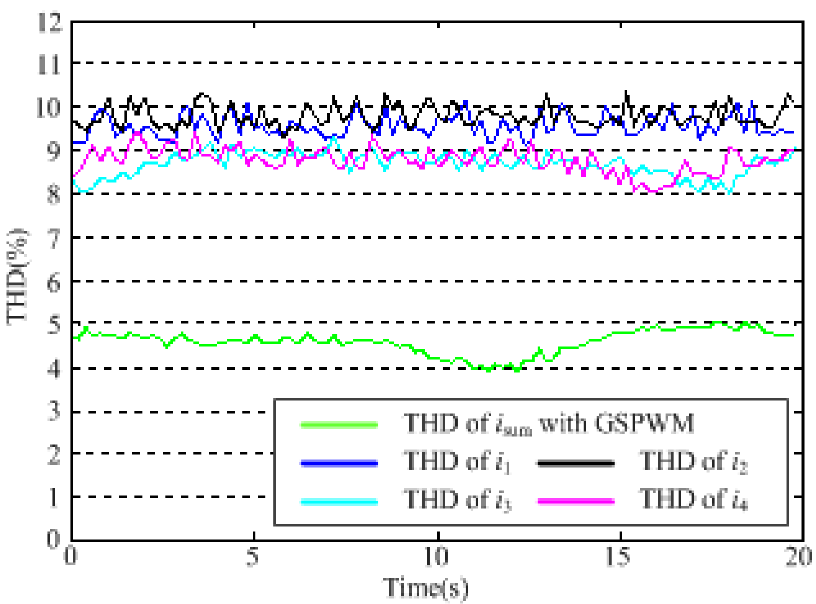


Waveforms of i_1(C2), i_2(C3), i_3(C4), i_{sum}(C1) at point C:

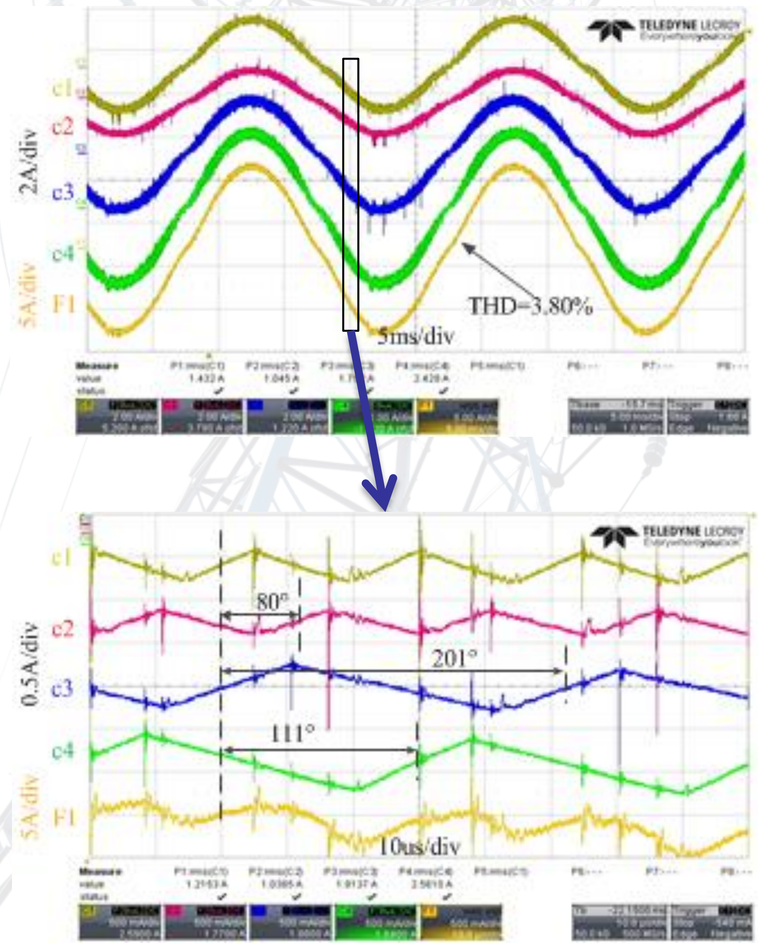


Performance Evaluation


M	V_{dcM} /V	L_M /mH	f_{cM} /kHz	P_M /W	Optimal Phase Shift
1	210	3.4	20	160	0°
2	210	4.4	20	110	80°
3	190	4.4	10	220	201°
4	190	3.4	10	275	111°



Waveforms of i_1(C1), i_2(C2), i_3(C3), i_4(C4), i_{sum}(F1) :



Potential Application Areas

- ✓ Reduce the output filter to achieve the more cost-effective solution
- ✓ Reduce the switching frequency to increase the operational efficiency

- Large-scale PV station with multiple same inverters assumed
- AC power electronics microgrid
- DC microgrid

Thank you
for your attention!