VSG User Manual

Shenzhen Sinexcel Electric Co.

Sinexcel

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directory (on computer hard drive)

1. VSG Introduction

1.1 What is VSG?

VSG (Virtual Synchronous Machine) control, is a T-type three-level based control method for VSG-constructed grid-type inverters. In this control method, LCL type filter is used and double closed loop control of voltage and current is implemented.

VSG control is an inverter control method applied in power systems. Its core idea is to use the inverter to simulate the behaviour of the synchronous machine in order to achieve balance and stability in the power system. In VSG control, the output of the inverter is kept at the same frequency as the synchronous machine (generator) in the power system and active and reactive power is supplied to support the stable operation of the power system.

Midpoint potential balance control is an important part of VSG control. Since the inverter adopts a T-type three-level structure, its output voltage has a midpoint potential. In midpoint potential balance control, the control strategy of the inverter is optimised to keep the midpoint potential at a stable level, thus reducing the harmonic content of the inverter output voltage and improving the power quality of the system.

Dual closed-loop control of voltage and current is another important part of VSG control. By double closed-loop control of the output voltage and current of the inverter, precise control of the output voltage and current of the inverter can be achieved. In the dual closed-loop control of voltage and current, advanced control algorithms, such as PID controller, are used to achieve fast response and stable control of the inverter output voltage and current.

1.2 Why do you need VSG for energy storage?

Because of the inertia support and primary FM function, we use VSG technology, on top of which secondary FM can be added to realise a variety of energy storage application strategies.VSG is able to simulate the synchronous generator governor and excitation control characteristics, and realise primary FM and voltage regulation functions, centralised and distributed secondary control functions. In addition, based on appropriate pre-synchronised control algorithms, the VSG can achieve seamless switching functions, adapting to the flexible conversion between grid-connected and islanded operation modes.

To summarise, VSG is suitable for the following application scenarios:

- Seamless switching with the oil engine and the power grid (the power grid requires the addition of a synchronisation device and carries a certain risk of overloading)
- Together with oil and photovoltaic systems, they form a microgrid to carry the load

(weak network support)

- Quick support for changing shock loads (EMS dispatch is too slow)
- Multiple PCS off-grid parallel application and support secondary power scheduling function
- Seamless transition between PCS on-grid and off-grid modes.

2. How to use VSG?

2.1 Introduction to PCS Operational Status

PCS has four operating states - PQ mode (On-Grid), VF mode (Off-Grid), grid-connected VSG mode (On-Grid Drooping), and off-grid VSG mode (Off-Grid Drooping) See 2-1 for details.

PQ (On-Grid)	Mostly for grid-connected use, following the waveform of the VF source in the system
VF (Off-Grid)	Off-grid, establishing a systematic source of VF
VSG (On-Grid Drooping)	Transitional use only when switching between VSG and PQ modes
VSG (Off-Grid Drooping)	The VSG operates in this mode for a long time, depending on the system frequency response power

Figure 2-1 Four PCS operating states

2.2 VSG Parameter Profile

The VSG has a total of four control parameters that can be adjusted

are the KAVR primary regulation coefficient, KAFR primary regulation coefficient, Kd system damping coefficient and H time constant.

Address	Register Name	Register Name
53600	Grid interconnection mode	Off-grid mode: 0 - on-grid, 1 - off-grid
53616	VSG primary voltage regulation	VSG primary regulation factor Kavr

	factor	
53617	VSG primary frequency regulation factor	VSG primary FM factor kAFR
53618	VSG damping factor	VSG damping factor kD
53619	VSG time constant	VSG time constant H

KAVR - primary voltage regulation coefficient, the parameter setting range is 0.025~0.3, if it is set to 0.1, then it means that if you put 100% inductive reactive loads (motors and so on) into the system, the overall voltage will drop by 10%. For example, at this time, the system AC voltage is 400V, the model is 500kW, at this time, put 50kW reactive load, then the voltage will drop 1% to 396V, if put 250kW reactive load, then the voltage will drop 5% to 380V.

KAFR - primary frequency modulation coefficient, the parameter setting range is 0.005~0.1, if set to 0.03, it means that after the system puts in 100% of the discharged active power (with resistive loads), the overall frequency decreases by 3%, and falls to 48.5Hz. for example, at this time, the system frequency is 50Hz, and the machine type is For example, if the system frequency is 50Hz and the model is 500kW, and 250kW active load is put into the system, the frequency will drop by 1.5%, that is 49.25Hz.

$$U_{out} = U_N - k_{AVR}\frac{U_N*(Q_{out}-Q_{set})}{Q_N} \quad (1)$$

$$f_{out} = f_N - \mathrm{k}_{\mathrm{AVR}}\frac{f_{\mathrm{N}}*(\mathrm{P}_{\mathrm{set}}-\mathrm{P}_{\mathrm{out}})}{\mathrm{P}_{\mathrm{N}}} \quad (2)$$

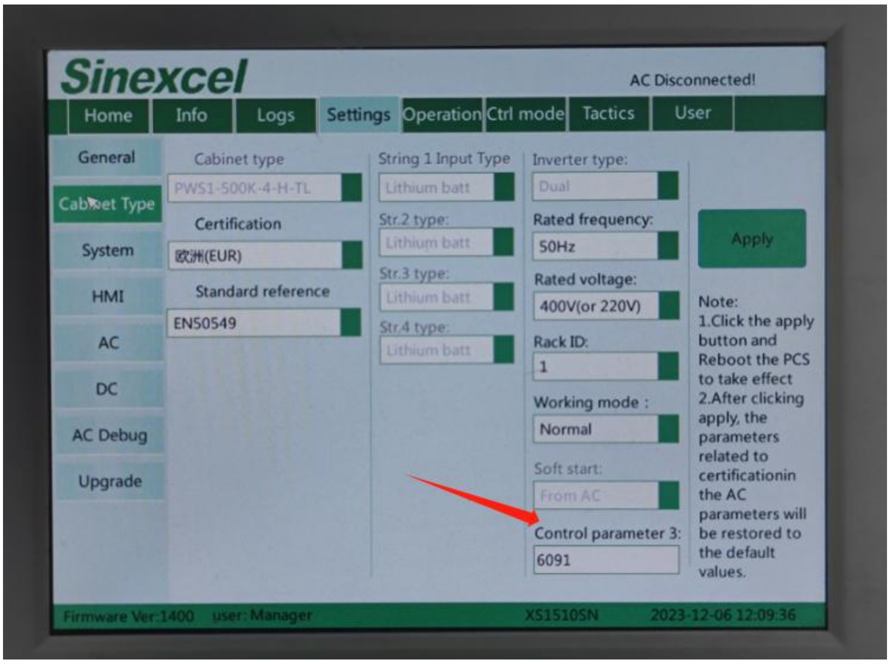
Note: U_{out} is the output voltage; UN is the standard voltage, default is 400V/480V; Q_{out} is the reactive power required by the load; Q_{set} is the reactive power generated by the inverter according to the setting; f_{out} is the output frequency; f_N is the standard frequency, default is 50/60Hz; P_{out} is the active power required by the load; P_{set} is the active power generated by the inverter according to the setting.

Kd and H - are used to adjust for different operating conditions, either transient or steady state. It is not recommended to change these parameters on your own, but to do so under the guidance of a Sinexcel engineer, otherwise the default values will suffice.

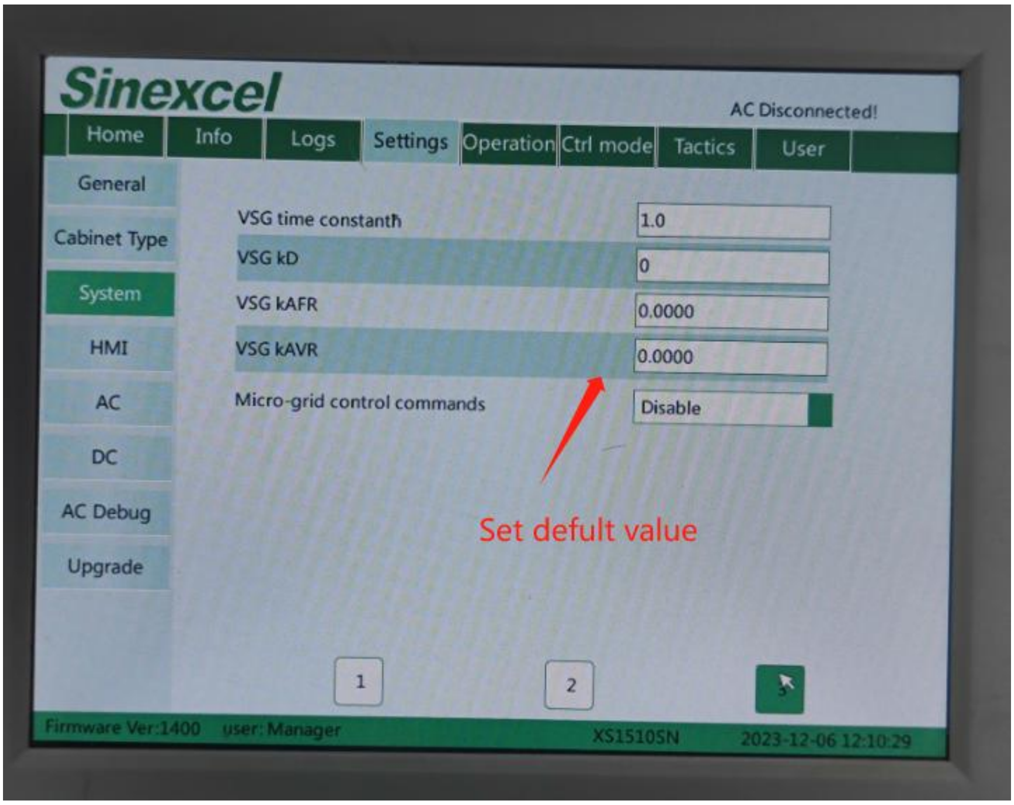
2.3 How do I switch on VSG?

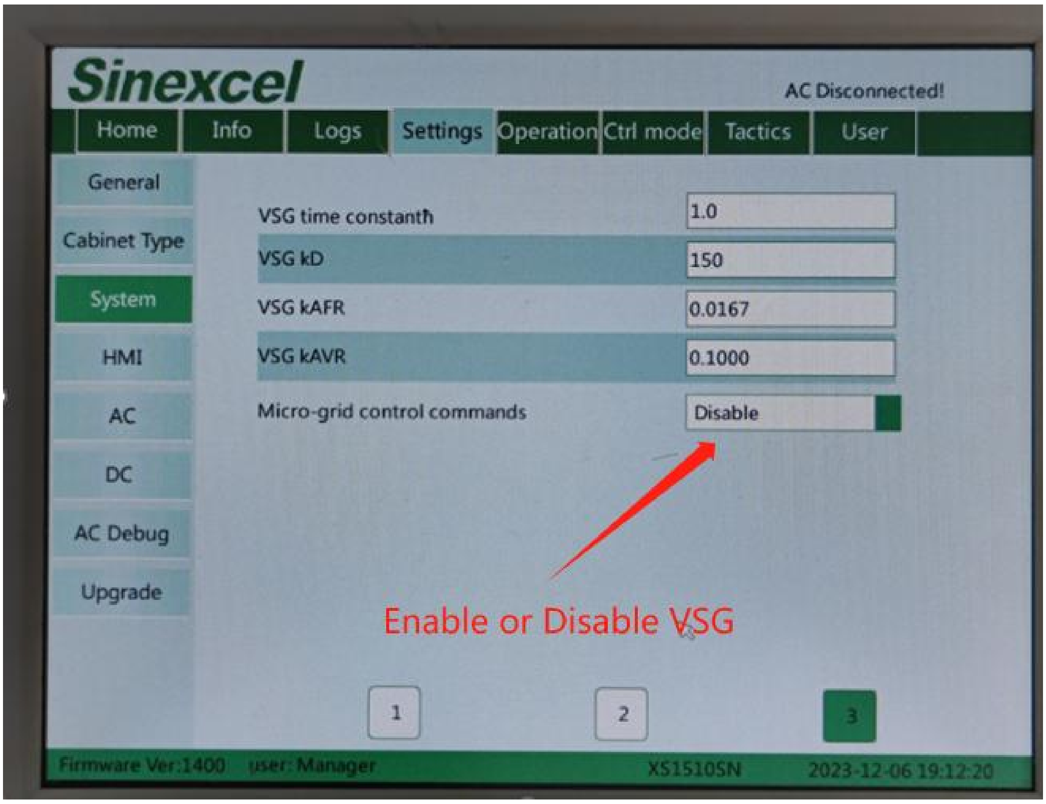
2.3.1 Monitor screen manual enable

VSG function needs to enter 6091 in the control parameter 3 of the model setup interface will open the VSG setup menu in the third page of the system setup, and at the same time the address of the registers will become accessible (not enable VSG), and then turn on or off the VSG function in the fourth item of the VSG interface.



Then you can see the VSG parameter setting interface on the third page of the HMI system setting interface of PCS, and you need to enter the default values for the first time.

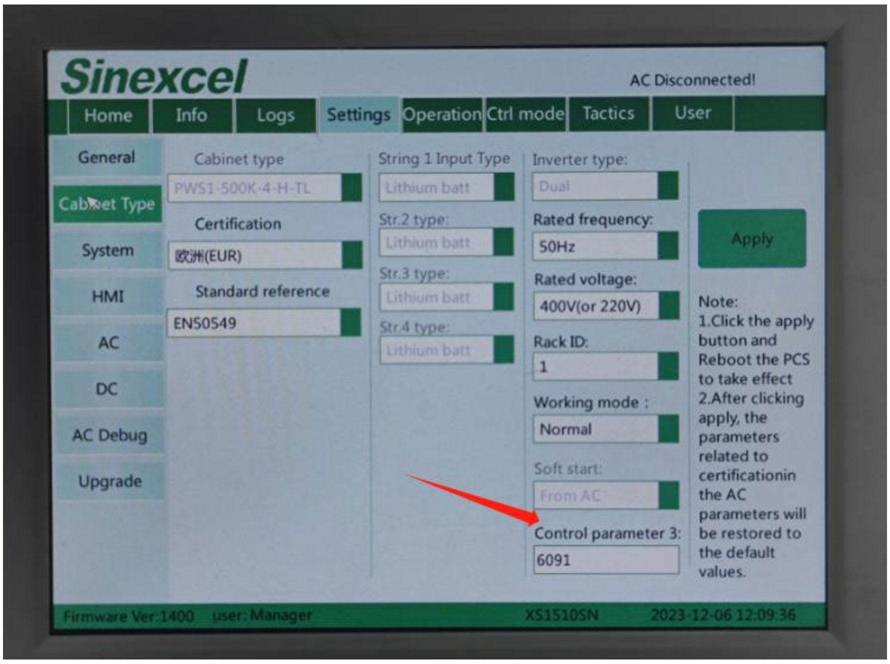




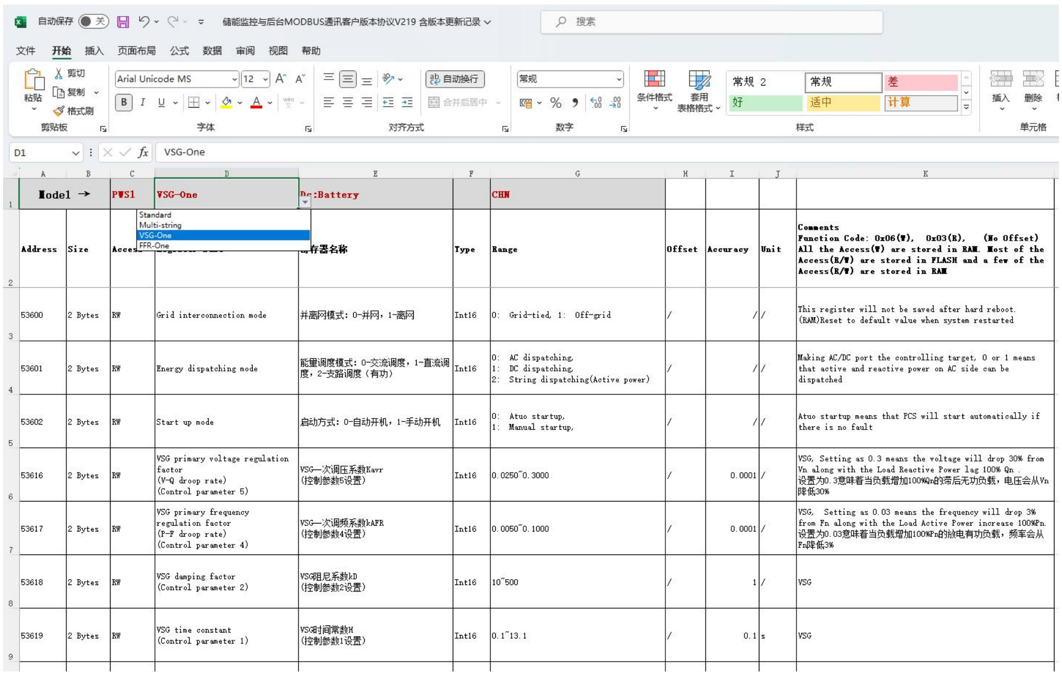
The first setup requires entering default values of H=1 kD=300 KAFR=0.03 KAVR=0.1 respectively

2.3.2 Modbus protocol EMS enable

First of all make sure that control parameter 3 is activated on the PCS monitor 6091.



Modbus protocol requires switching to the VSG-one interface to view the VSG control registers.

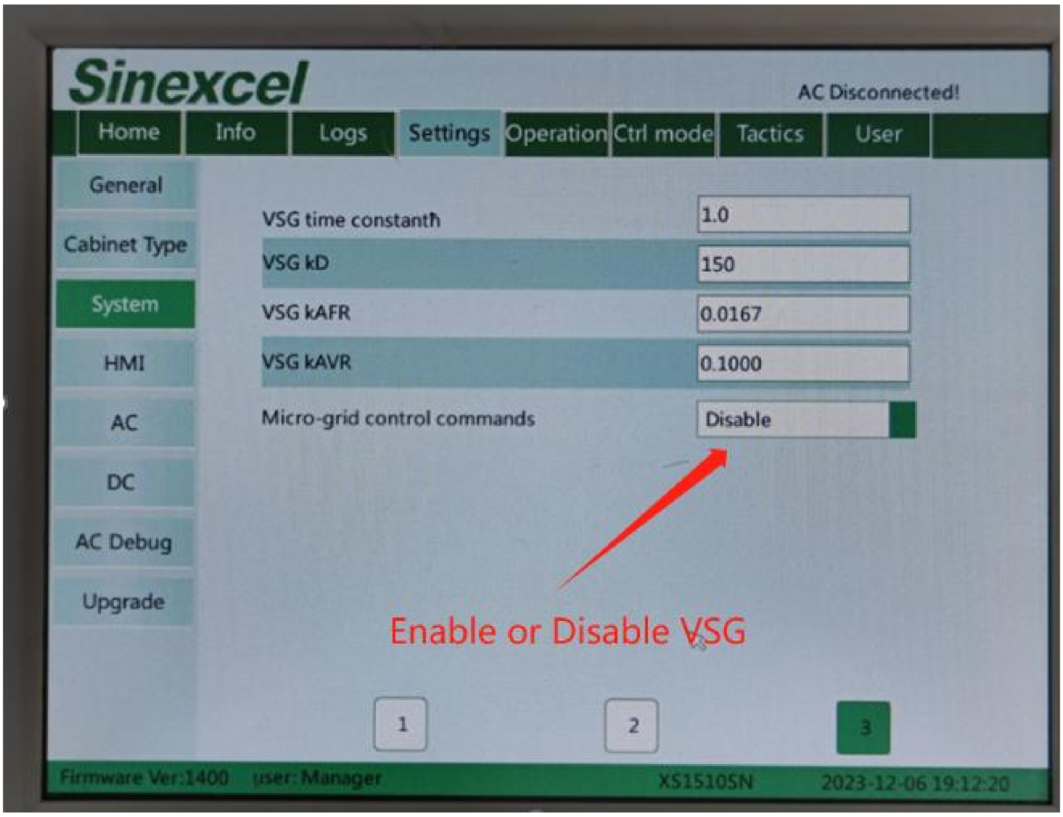


Model →		PWS1	VSG-One	Dc:Battery		CHN				
Address	Size	Acces		存器名称	Type	Range	Offset	Accuracy	Unit	Comments Function Code: 0x06(W), 0x03(R), (No Offset) All the Access(W) are stored in RAM. Most of the Access(R/W) are stored in FLASH and a few of the Access(R/W) are stored in RAM
53600	2 Bytes	RW	Grid interconnection mode	并离网模式：0-并网，1-离网	Int16	0: Grid-tied, 1: Off-grid	/	/	/	This register will not be saved after hard reboot.(RAM)Reset to default value when system restarted
53601	2 Bytes	RW	Energy dispatching mode	能量调度模式：0-交流调度，1-直流调度，2-支路调度（有功）	Int16	0: AC dispatching, 1: DC dispatching, 2: String dispatching(Active power)	/	/	/	Making AC/DC port the controlling target, 0 or 1 means that active and reactive power on AC side can be dispatched
53602	2 Bytes	RW	Start up mode	启动方式：0-自动开机，1-手动开机	Int16	0: Atuo startup, 1: Manual startup,	/	/	/	Atuo startup means that PCS will start automatically if there is no fault
53616	2 Bytes	RW	VSG primary voltage regulation factor (V-Q droop rate) (Control parameter 5)	VSG一次调压系数Kavr (控制参数5设置)	Int16	0.0250~0.3000	/	0.0001	/	VSG, Setting as 0.3 means the voltage will drop 30% from Vn along with the Load Reactive Power lag 100% Qn . 设置为0.3意味着当负载增加100%Qn的滞后无功负载，电压会从Vn降低30%
53617	2 Bytes	RW	VSG primary frequency regulation factor (P-F droop rate) (Control parameter 4)	VSG一次调频系数kAFR (控制参数4设置)	Int16	0.0050~0.1000	/	0.0001	/	VSG, Setting as 0.03 means the frequency will drop 3% from Fn along with the Load Active Power increase 100%Pn. 设置为0.03意味着当负载增加100%Pn的放电有功负载，频率会从Fn降低3%
53618	2 Bytes	RW	VSG damping factor (Control parameter 2)	VSG阻尼系数kD (控制参数2设置)	Int16	10~500	/	1	/	VSG
53619	2 Bytes	RW	VSG time constant (Control parameter 1)	VSG时间常数H (控制参数1设置)	Int16	0.1~13.1	/	0.1	s	VSG

Switching VSG protocol in Modbus list

The control command for VSG enable can then be found in register 53640, corresponding to the last setting on the monitor screen. bit0 of 53640 is set to 0 for Disable and 1 for Enable.

53640	2 Bytes	RW	Micro-grid control commands	微网控制命令	Uint16	bit0-VSG enable: 0-No，1-enable; bit1-Quasi-synch: 0-No，1-synch; bit2~bit15- reserved;	/		1	/	VSG, bit0 for VSG enable



2.3.3 Analysis of VSG operation status

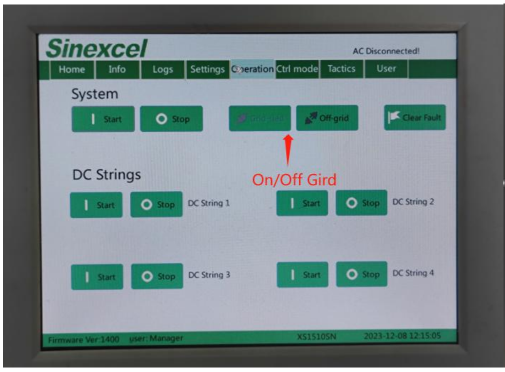
PQ (On-Grid)	On-Grid+ VSG Disable(53600→0 + 53640→0)
VF (Off-Grid)	Off-Grid+ VSG Disable(53600→1 + 53640→0)
VSG (On-Grid Drooping)	On-Grid+ VSG Enable(53600→0 + 53640→1)
VSG (Off-Grid Drooping)	Off-Grid+ VSG Enable(53600→1 + 53640→1)

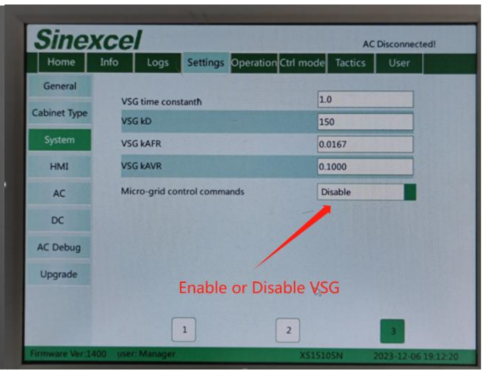
Explanation of the four operation modes of VSG

Example: On-Grid+ VSG Disable(53600→0 + 53640→0)

PCS grid-connected mode enabled + VSG function disabled = register 53600 in EMS set to 0 + register 53640 set to 0

- Monitor screen and off-grid and VSG enable position





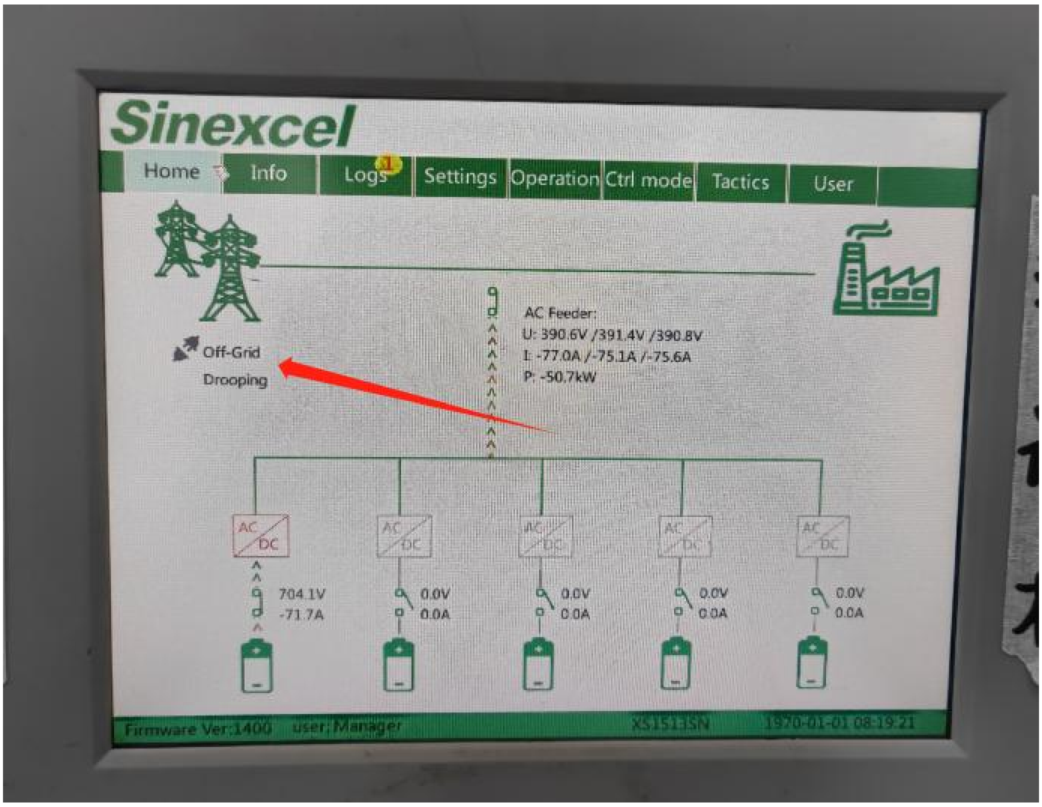
- Protocol Parallel Off-Grid and VSG Enable Registers

53640 bit0 Set to 0 to disable VSG 1 to enable VSG

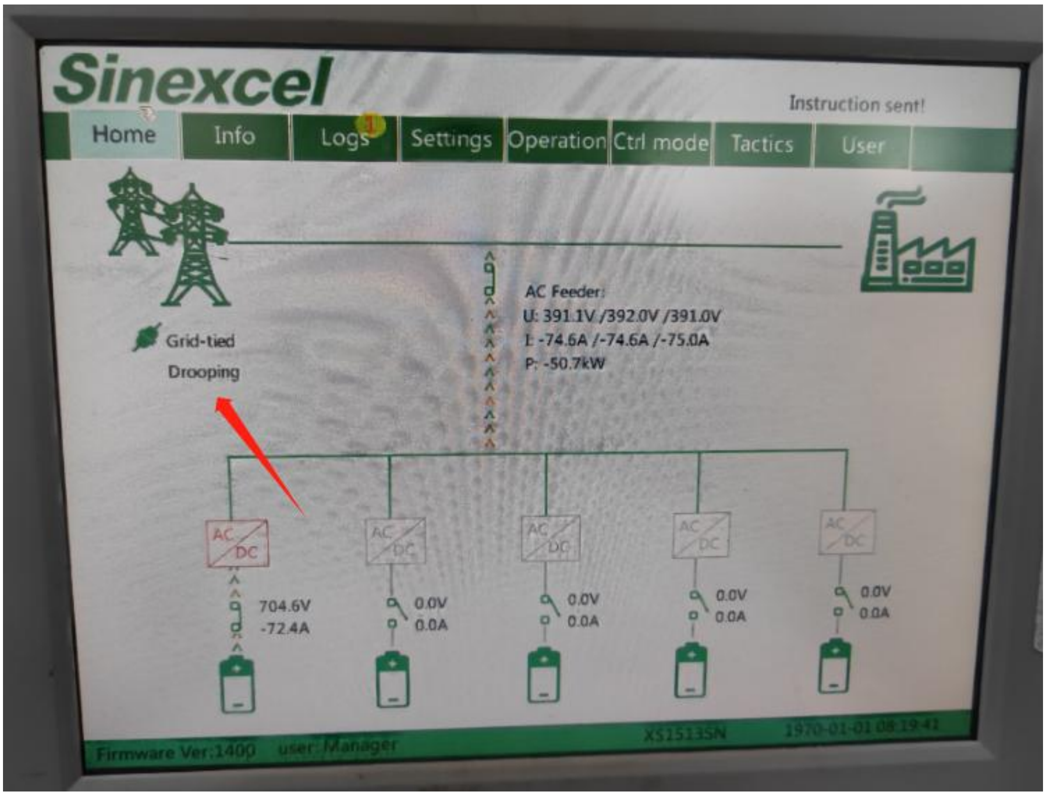
53600	2 Bytes	RW	Grid interconnection mode	并离网模式：0-并网，1-离网	Int16	0: Grid-tied, 1: Off-grid
53640	2 Bytes	RW	Micro-grid control commands	微网控制命令	Uint16	bit0-VSG enable: 0-No，1-enable; bit1-Quasi-synch: 0-No，1-synch; bit2~bit15- reserved;

- Successful Enablement Prompt

Off-grid VSG enabled successfully



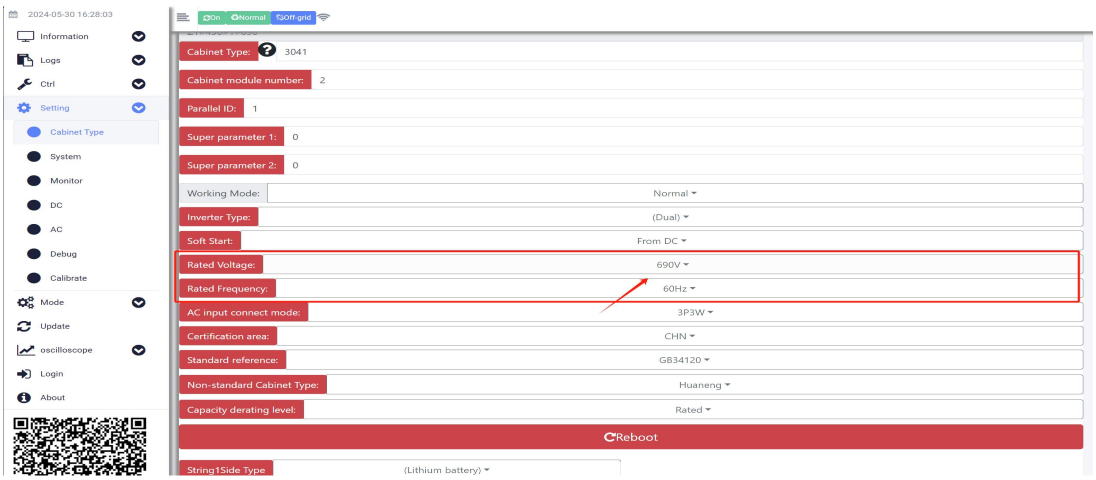
Grid-connected VSG enabled successfully



2.4 How do I switch on VSG for PWS1-1725kTL-H

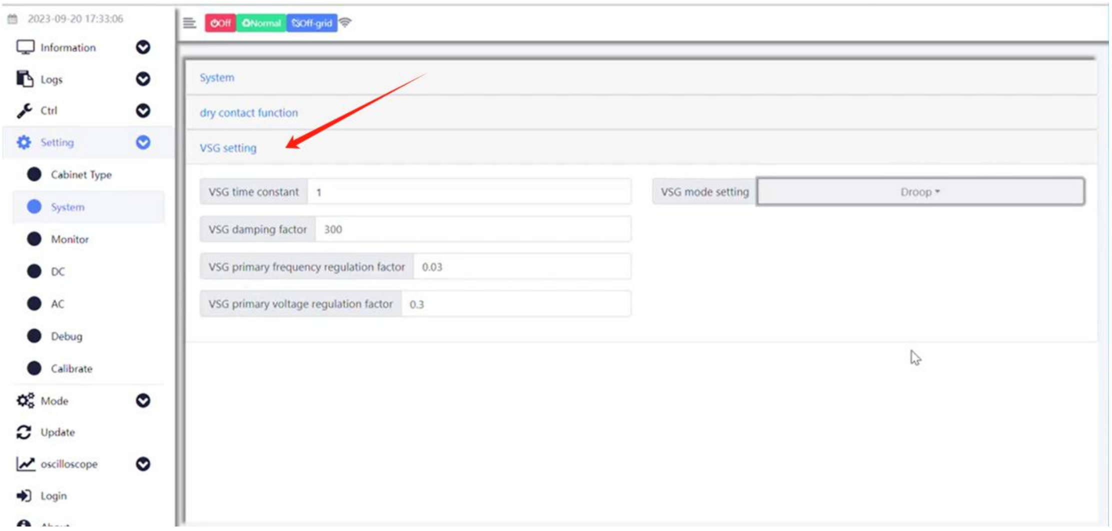
2.4.1Pre-power-on setting check

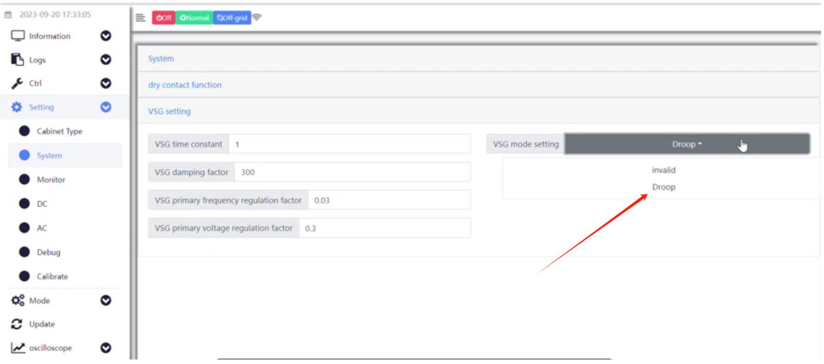
1. Check whether the voltage and frequency are set correctly in the model settings before use, you need to ensure that the voltage and frequency settings of each device are consistent, otherwise the AC side will report over-voltage and over-frequency faults.



2.4.2Monitor screen manual enable

Open the monitoring background web page, enter the system settings and select VSG Settings.





The first setup requires entering default values of H=1 kD=300 KAFR=0.03 KAVR=0.1 respectively.

Click on VSG Function Setting, select VSG Mode Setting as ‘Droop’, VSG function will be turned on.

Please read whether the 1236 register is 1 through modbus, if yes, then the VSG function enable successfully.

1236	1	R/W	uint16	VSG mode setting	VSG模式设置	0- invalid, 1- droop, 2~10- reserved, default: 0	0- 无效, 1- 下垂, 2~10- 预留, 默认值: 0

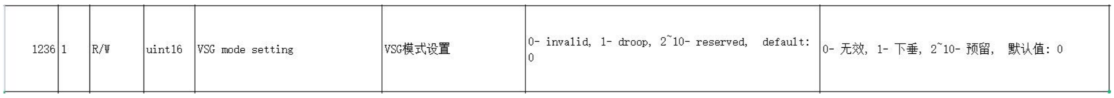
2.4.3 Modbus protocol EMS enable

The Modbus protocol needs to select the VSG first to view the VSG control registers.

Model →		PWS1-125K-One	Dc:Battery	/////	EUR	Model demonstration example:	
					VSG /////		
Address	Size	Access	Type	Register Name	寄存器名称	范围 & 默认值 & 单位 EMS可以频繁下设(RAM)寄存器，EMS下设非(RAM)寄存器应该间隔>5s	Comments EMS could send commands of RAM Registers very frequent, EMS should send commands of NO RAM Registers after 5s since sending command of NO RAM Registers last time
1220	1	R/W	uint16	BMS limit current and power mode	BMS限流限功率模式	0- Current limit, 1- Power limit, 2- Current & Power limit, 3- Prohibited limit, default: 0	0- 限流, 1- 限功率, 2- 限流限功率, 3- 禁止限值, default: 0
1236	1	R/W	uint16	VSG mode setting	VSG模式设置	0- invalid, 1- droop, 2~10- reserved, default: 0	0- 无效, 1- 下垂, 2~10- 预留, 默认值: 0
1237	1	R/W	uint16	VSG time constant	VSG时间常数H	0.1~13.1, Unit: 0.1s, default: 1.0	0.1~13.1, 单位: 0.1s, 默认值: 1.0
1238	1	R/W	uint16	VSG damping factor	VSG阻尼系数kD	10~500, Unit: 1, default: 300	10~500, 单位: 1, 默认值: 300
				VSG primary frequency regulation		[illegible]	0.0050~0.1000, 单位: 0.0001, 默认值: 0.0300	Set to 0.03, indicating 100% Pnom change in active

Chose VSG protocol in Modbus list

Then the control command for VSG enable can be found in register 1236, it corresponds to the VSG mode setting on the monitoring web page.Then you can find the VSG enable control command in register 1236, it corresponds to the VSG mode setting on the monitoring web page. 1236 bit0 set to 0 to disable VSG and 1 for Enable.



1236	1	R/W	uint16	VSG mode setting	VSG模式设置	0- invalid, 1- droop, 2~10- reserved, default: 0	0- 无效, 1- 下垂, 2~10- 预留, 默认值: 0

2.4.4 Analysis of VSG operation status

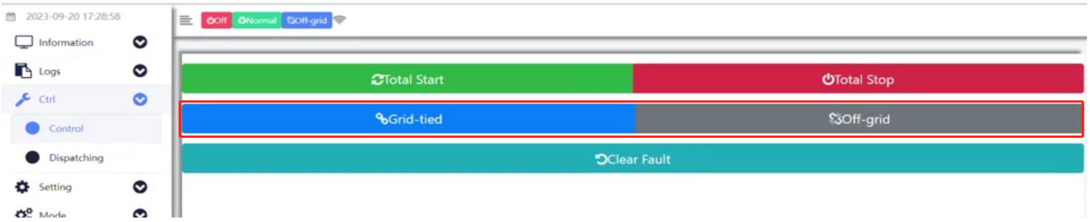
PQ (On-Grid)	On-Grid+ VSG Disable(1006→0 + 1236→0)
VF (Off-Grid)	Off-Grid+ VSG Disable(1006→1 + 1236→0)
VSG (On-Grid Drooping)	On-Grid+ VSG Enable(1006→0 + 1236→1)
VSG (Off-Grid Drooping)	Off-Grid+ VSG Enable(1006→1 + 1236→1)

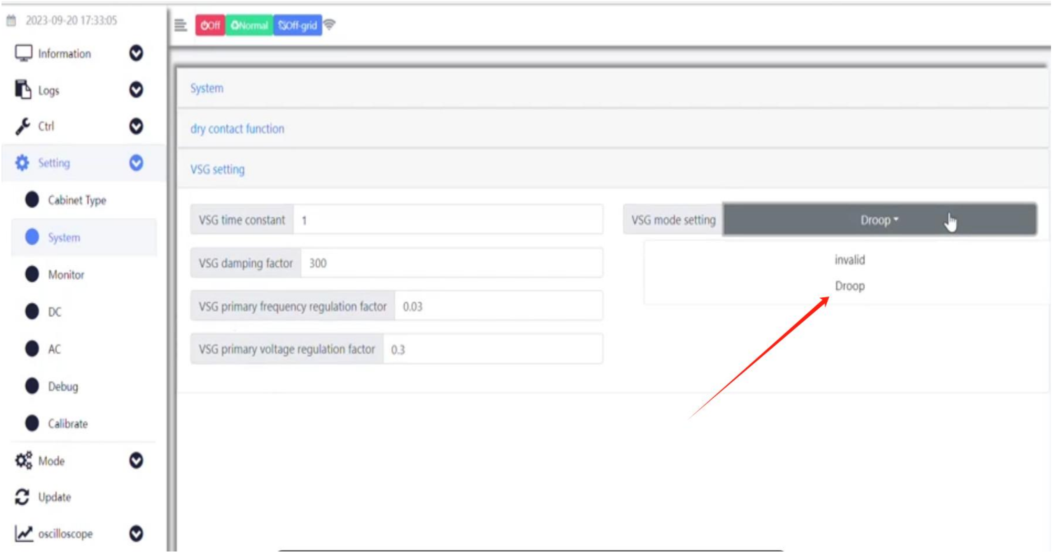
Explanation of the four operation modes of VSG

Example: Off-Grid+ VSG enable(1006→1 + 1236→1)

PCS off-grid enable+VSG enable=Register 1006 set to 1 in EMS+ Register 1236 set to 1 in EMS

- Monitor screen on/off-grid and VSG enable position





- Register for on/off grid and VSG enable

Register 1006 bit0 set to 0 for on-grid mode and 1for off-grid mode.

1006	1	W	uint16	Grid interconnection mode	并离网模式	0- Grid-tied, 1- Off-grid	0- 并网, 1- 离网

Register 1236 bit0 set to 0to disable VSG and 1 for enable.

2.5 VSG Policy Control

2.5.1 How to use to achieve seamless switching from PQ to VF mode?（Medium power product）

PQ (On-Grid)	On-Grid+ VSG Disable(53600→0 + 53640→0)
VF (Off-Grid)	Off-Grid+ VSG Disable(53600→1 + 53640→0)
VSG (On-Grid Drooping)	On-Grid+ VSG Enable(53600→0 + 53640→1)
VSG (Off-Grid Drooping)	Off-Grid+ VSG Enable(53600→1 + 53640→1)

Explanation of the four operation modes of VSG

As mentioned in the previous section, PCS has 4 modes of operation, and we have reordered this list to the following order.

1	PQ (On-Grid)	On-Grid+ VSG Disable(53600→0 + 53640→0)
2	VSG (On-Grid Drooping)	On-Grid+ VSG Enable(53600→0 + 53640→1)
3	VSG (Off-Grid Drooping)	Off-Grid+ VSG Enable(53600→1 + 53640→1)
4	VF (Off-Grid)	Off-Grid+ VSG Disable(53600→1 + 53640→0)

The order is 1-2-3-4, and they can be switched seamlessly from one to the other. For example, to switch from PQ (state 1) to VF (state 4), we only need to go through the following steps:
Step 1 Manual: set VSG status enable EMS: 53640 register to 1
Step 2 Manual: switch PCS to off-grid state EMS: 53600 register set to 1
Step 3 Manual: Disable VSG status EMS: 53640 register is set to 0.
Seamless switching from PQ to VF can be accomplished.

2.5.2 How to use to achieve seamless switching from PQ to VF mode?（1725k）

1	PQ（On-Grid）	On-Grid+ VSG Disable(1006→0 + 1236→0)
2	VSG（On-Grid Drooping）	On-Grid+ VSG Enable(1006→0 + 1236→1)
3	VSG（Off-Grid Drooping）	Off-Grid+ VSG Enable(1006→1 + 1236→1)
4	VF（Off-Grid）	Off-Grid+ VSG Disable(1006→1 + 1236→0)

Explanation of the four operation modes of VSG

As mentioned in the previous section, PCS has 4 modes of operation, and we have reordered this list to the following order.

1	PQ（On-Grid）	On-Grid+ VSG Disable(1006→0 + 1236→0)

2	VSG（On-Grid Drooping）	On-Grid+ VSG Enable(1006→0 + 1236→1)
3	VSG（Off-Grid Drooping）	Off-Grid+ VSG Enable(1006→1 + 1236→1)
4	VF（Off-Grid）	Off-Grid+ VSG Disable(1006→1 + 1236→0)

The order is 1-2-3-4, and they can be switched seamlessly from one to the other. For example, to switch from PQ (state 1) to VF (state 4), we only need to go through the following steps:
Step 1 Manual: set VSG status enable EMS: 1236 register to 1
Step 2 Manual: switch PCS to off-grid state EMS: 1006 register set to 1
Step 3 Manual: Disable VSG status EMS: 1236 register is set to 0.
Seamless switching from PQ to VF can be accomplished.

2.5.3 Description of power control in VSG mode

Single PCS power control

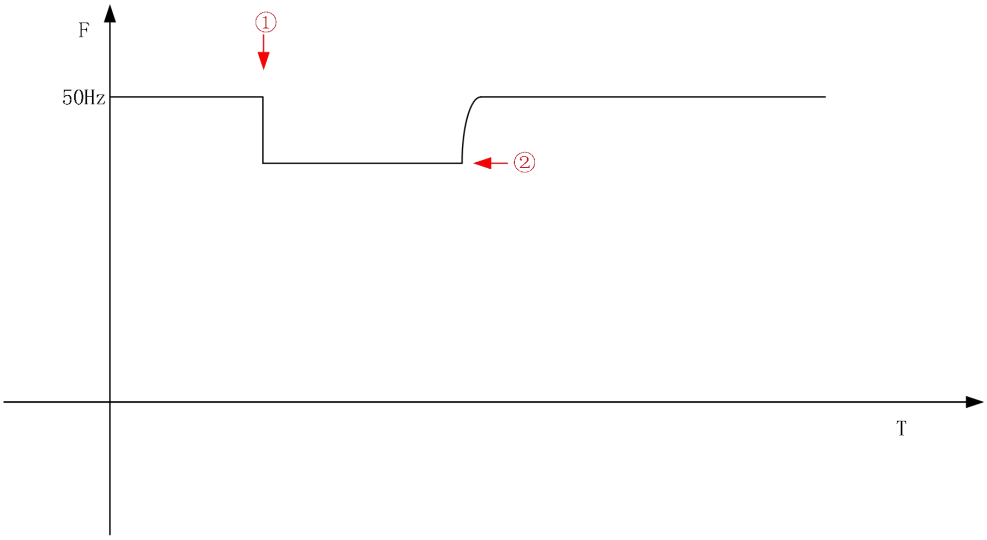
In VSG mode, the EMS is free to set the active and reactive power to control the output of the PCS, the specific registers are

53622 and 53623, active power settings and reactive power settings. The monitoring screen can be operated directly in the AC parameters in the settings. A positive number is charging and a negative number is discharging.

In particular, if the grid/oiler is online, the system frequency and voltage will not be affected regardless of how much active and reactive power is set, due to the presence of primary FM.

However, in the case of off-grid individual loads, the following conditions need to be met to ensure system stability

All active and reactive loads are consumed



Note ① : Load surge, a frequency control, PCS automatically support the load active balance at the cost of frequency according to a certain proportion of KAFR.

PCS actual power = load

PCS set power = 0kW

System frequency = drop according to KAFR

②: EMS will set the load power to PCS for secondary frequency regulation according to the load change, at this time the frequency returns to the normal base 50Hz.

PCS actual power = load

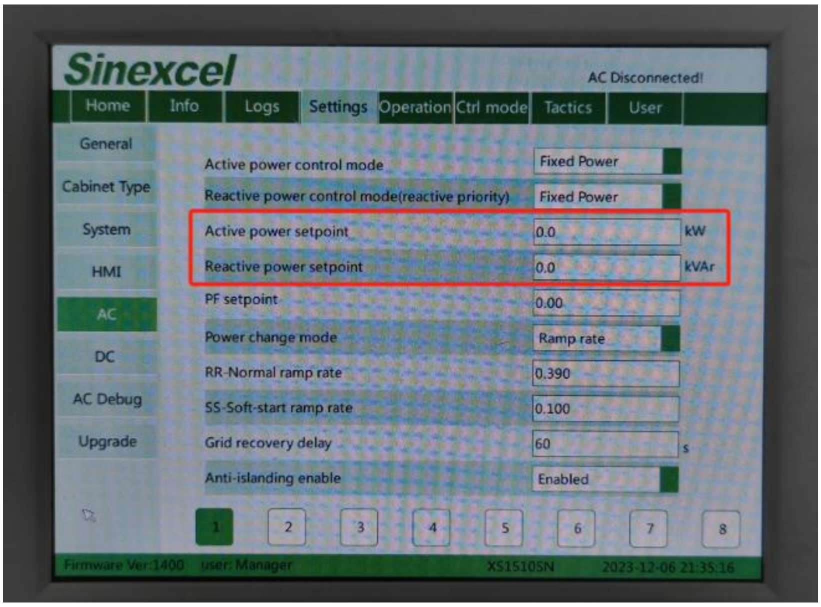
PCS set power = load

System frequency = 50Hz

As the load increases, the PCS will automatically take the load, at this time as the KAFR and KAVR settings, if the model is 500kW, the system load has 250kW, KAFR is set to 0.03, then after the grid/tanker is offline, if it does not take the initiative to set the active power, then the system frequency will drop to 49.25Hz. So at this time, we need to set the active power of 250kW to the PCS, which is the same as the load, so the system frequency will be pulled back to 50Hz. So at this time, EMS needs to set the same active power of 250kW to PCS as the load to bring the system frequency back to 50Hz, then when PCS is off-grid in VSG mode, EMS needs to collect the load power, do load tracking, and set the power to PCS in real time (the setting frequency is determined according to the frequency of the load change; the faster the load change rate is, the shorter the interval between the setting is, 0.5S is recommended), so as to make the system frequency and voltage maintain at a stable benchmark. stable benchmark.

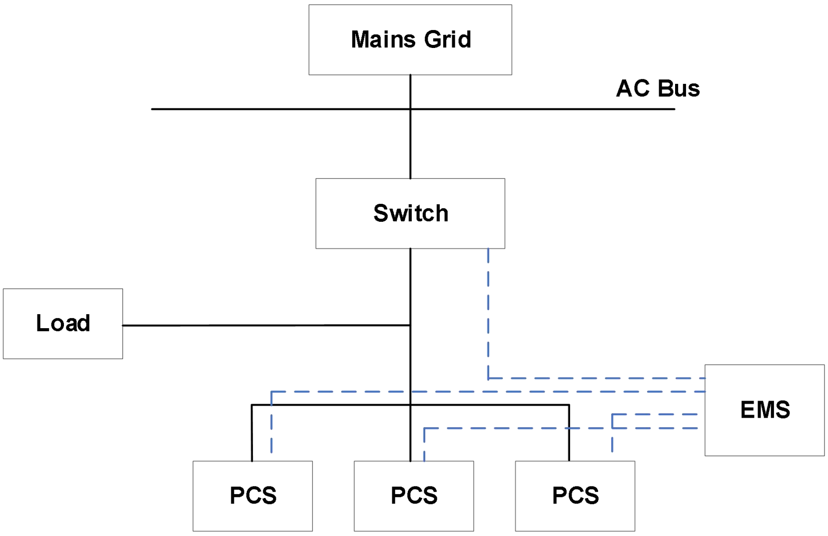
53622	2 Bytes	RW	Active power setpoint	有功功率设置	Int16	－770.0~770.0. +: charge, power from grid to battery. －: discharge, power from battery to grid	/	0.1	kW	Available in AC dispatching mode(53601). (RAM)Reset to default value when system restarted
53623	2 Bytes	RW	Reactive power setpoint	无功功率设置（正感性无功，负容性无功）	Int16	－770.0~770.0 +: lagging, －: leading	/	0.1	kvar	Available in AC dispatching mode(53601) and Fixed reactive power control mode(53620). (RAM)Reset to default value when system restarted

Register points in Modbus list



Active-reactive settings on HMI

Parallel power control of multiple PCS



Multiple PCS parallel communication topology

When multiple PCSs are paralleled, free power distribution is guaranteed in both off-grid and grid-connected modes, but the following conditions need to be met

All active and reactive loads are consumed

When grid/oiler is online

Since there is a grid present, the PCS is free to distribute active and reactive power and do active and reactive compensation.

When the grid/oiler is offline

Sum of PCS power output = sum of loads not consumed

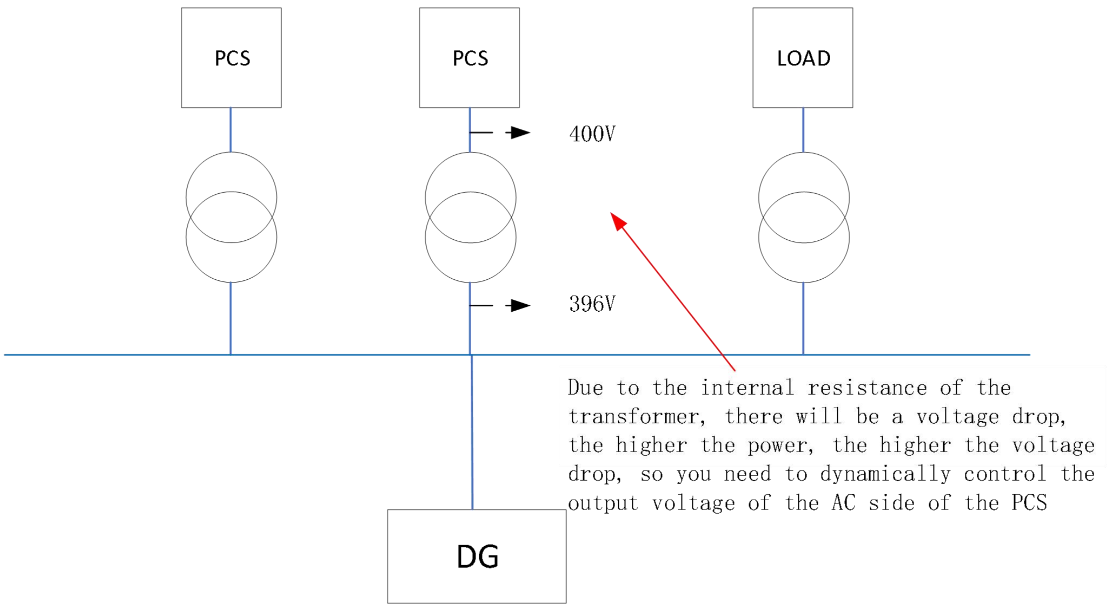
Example: Total active load 1500kW, 3 PCS in the system, PV output 600kW.

At this time, the remaining active load is 900kW, you can use an equalised distribution of 300kW of active power from each of the 3 PCSs. It is also possible to distribute the power unevenly, but to ensure that the total active power output of the three PCSs is equal to 900kW, for example, PCS No. 1 outputs 500kW, PCS No. 2 outputs 400kW, and PCS No. 3 outputs 0kW.

2.5.4 Reactive power management in VSG mode

Closed loop reactive power control

If the AC output voltages of the various voltage sources in the system are not equal and also the transformer produces a voltage drop, this can lead to reactive power involvement in the system, which affects the overall system efficiency and load carrying capacity, so closed loop reactive power control is required to reduce the reactive power.

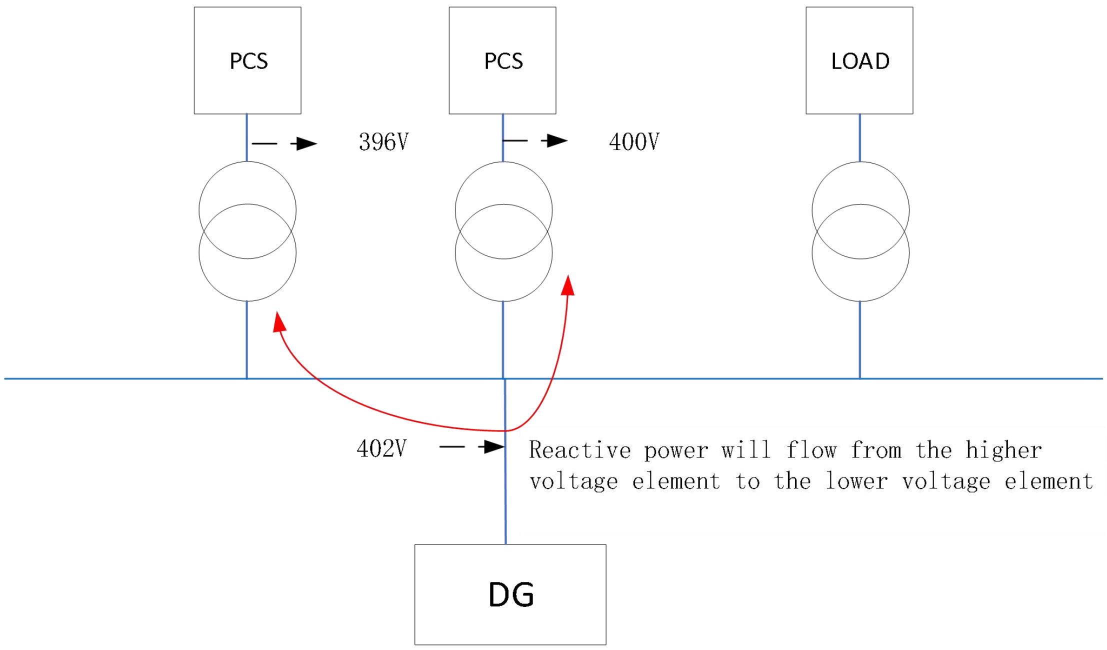


Principle analysis: If the voltage reference of all electrical components on the AC bus is uneven, then the reactive power will surge to the components with lower voltage.

53645	2 Bytes	RW	AC voltage compensation	交流电压补偿	Int16	- 0. 150~0. 150		/	0. 001	ratio * Vnom	Available in Offgrid or VSG. (RAM)Reset to default value when system restarted

This register can be used to adjust the off-grid AC output voltage of the PCS to compensate the output voltage of the PCS and reduce the reactive power of the system. If the reference is 400V and this register is set to 0.001, then the PCS off-grid output is 400.4V.

Example: EMS detects that PCS2 is accepting reactive power, then it means that the voltage of this PCS is low, then it is necessary to raise the voltage output of this PCS.



The outputs of the two PCSs should be calibrated to the same reference, otherwise there will be reactive power inter-feeding problems.

3.VSG Performance Analysis

3.1 Feasibility analysis of long-term stable operation of VSG

At the beginning of VSG mode, the power fluctuation in steady state is generated by three main reasons, and it is concluded that as long as the system frequency is stable enough and the EMS sampling speed and control accuracy are good enough, the PCS can ensure the long-term stable operation in VSG mode. the fluctuation value of the PCS itself is within 2%, which is in line with the EU standard.

1 **Fluctuations in the system frequency itself lead to fluctuations in the power of the PCS.**

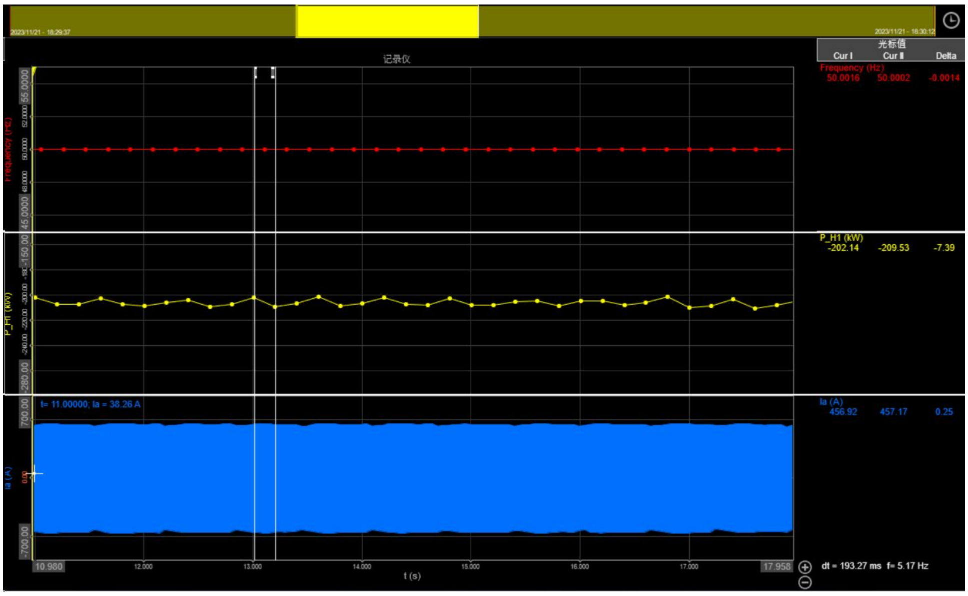
The fluctuation of this item is negligible because the system frequency is basically stable since it is cooperating with the grid.

2 **Power fluctuations under the EMS lead to fluctuations in the power of the PCS**

In the case of off-grid individual load, EMS needs to accurately sample the load power and then set it to the PCS, at this time, the active power set by EMS in the steady state will have an impact on the output power of the PCS. Therefore, it is recommended that when EMS calculates the load power, if the load power fluctuates within a certain range (e.g., a 500kW load can set a 5kW fluctuation dead zone), it will not change the power set by EMS, and once the load fluctuates more than 5kW, then it will change the power set by EMS to PCS.

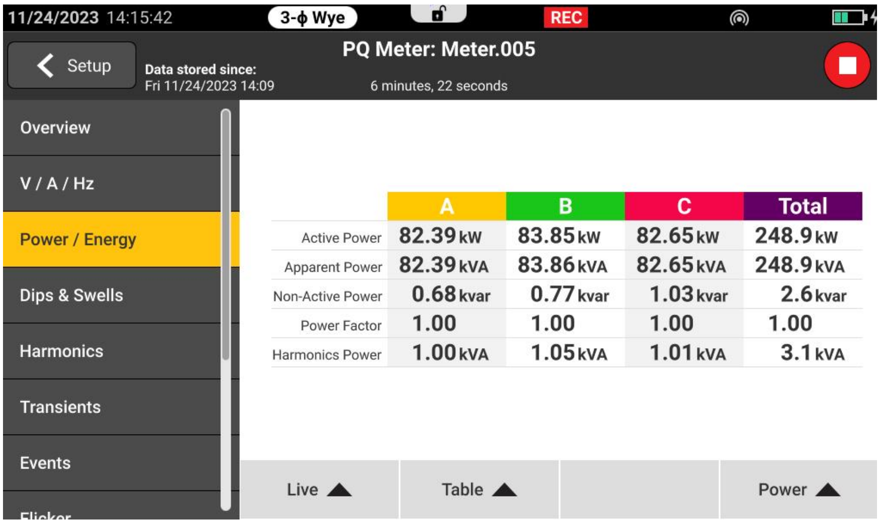
3 **Fluctuations in the control accuracy of the PCS itself**

The steady state power fluctuation value of PCS in the EU standard is required to be within 2%. In the laboratory, has been verified PCS steady state fluctuations for the full load of 250kW, fluctuations of about 7kW, within 1.75% of the fluctuations.

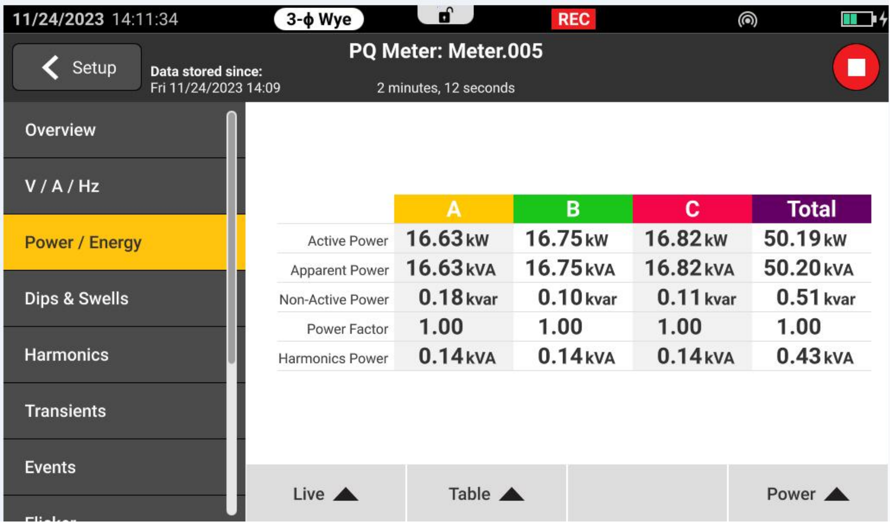


Laboratory tested steady state fluctuations of 1.75 per cent

Tested in actual project operation, using a three-phase AC meter with the oil machine with full load test steady state fluctuation of 1.2 per cent



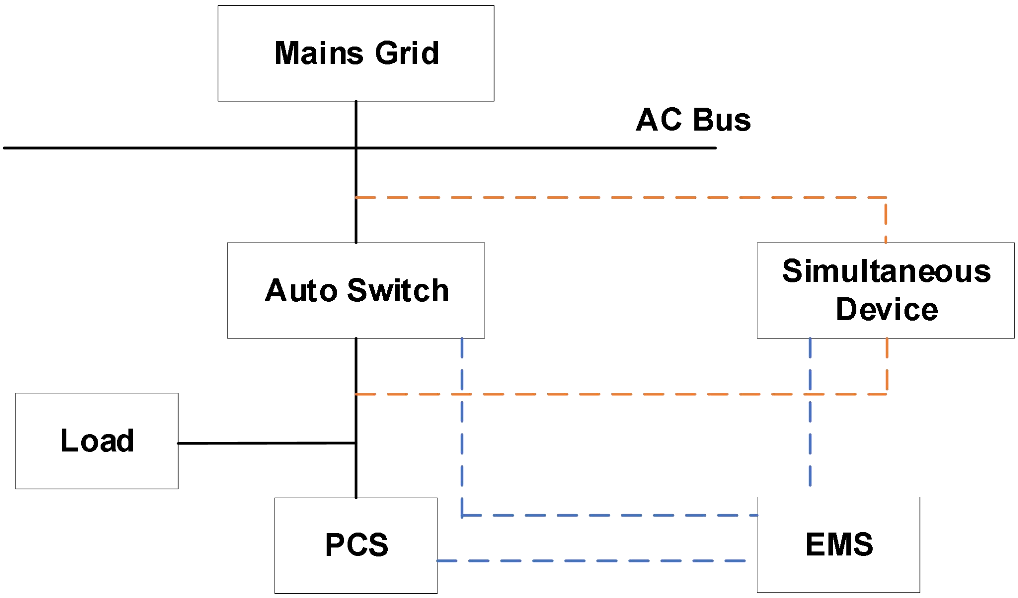
Fluctuation of 1.2 per cent at 250 kW with load



	A	B	C	Total
Active Power	16.63 kW	16.75 kW	16.82 kW	50.19 kW
Apparent Power	16.63 kVA	16.75 kVA	16.82 kVA	50.20 kVA
Non-Active Power	0.18 kvar	0.10 kvar	0.11 kvar	0.51 kvar
Power Factor	1.00	1.00	1.00	1.00
Harmonics Power	0.14 kVA	0.14 kVA	0.14 kVA	0.43 kVA

Fluctuation of 0.8 per cent at 50 kW with load

3.2 Experimental results of seamless on-grid and off-grid switching with the grid



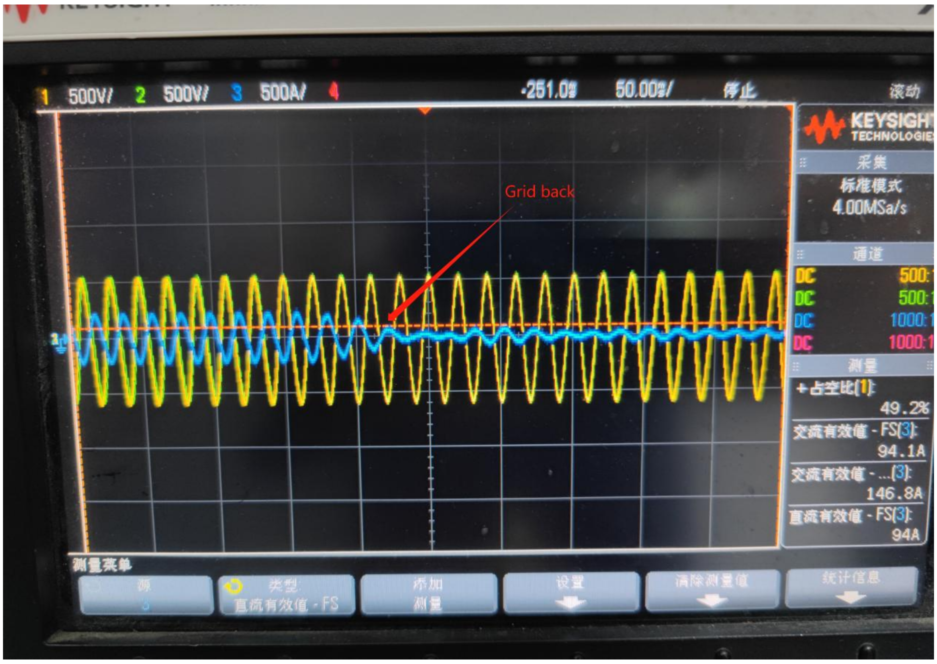
- Grid-connected to off-grid

The experimental environment is basically the same as the application logic, firstly, the grid is online, PCS off-grid VSG enable under Off-Grid Drooping ,cut off the waveform of the grid.

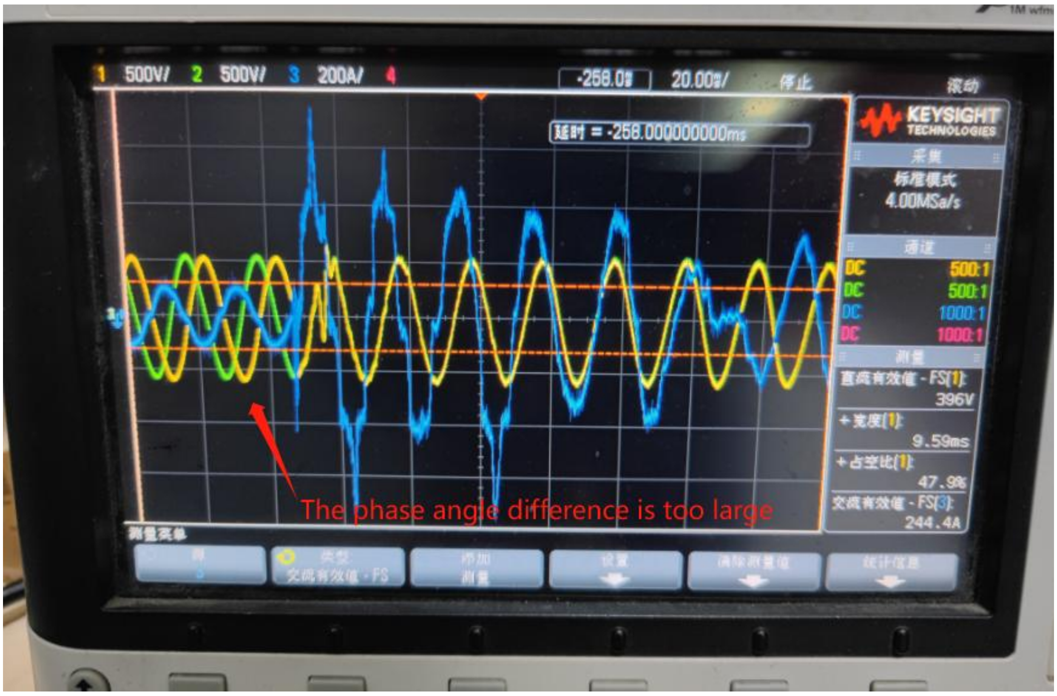
In the figure, the yellow one is the PCS voltage waveform, the green one is the grid side voltage waveform, and the blue one is the PCS side current. At this time, the experimental conditions for the grid and PCS together with a full load, PCS active power is set to 0, so before cutting off the grid PCS side current is 0. When the grid is cut off, the PCS seamlessly bear the load, the blue curve that is the PCS output current. As the PCS and grid cut off, so the frequency gap, you can see the yellow and green waveforms slowly have a phase angle difference.

- Off-grid to on-grid

Then it is the off-grid to grid-connected experiment, you can see that in the off-grid state, the PCS carries the load alone, the active power is set to 0, and the system frequency is slightly lower than the reference frequency, at the red arrow, the grid cuts back, the PCS output current will steeply drop to 0 due to the active power is set to 0, the grid assumes the full load, and the theory is consistent with the experimental results.



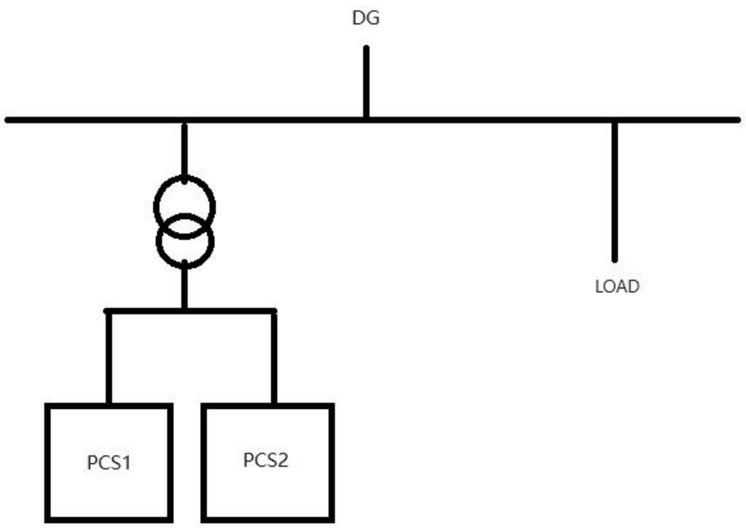
A comparative experiment shows that if a switch is not closed when the phase angle difference is small, the current will become large, but since the PCS has its own overload capacity, switching is guaranteed when the switch is closed within a phase angle difference of 10° .



At this time the inrush current is relatively high but the PCS still completes a seamless switchover.

3.3 Power Control Accuracy Test

Test condition description: two PWS1-500KTL-EX single-branch DC side is separated, AC measurement is connected in parallel with a 1MVA transformer and 300kW rated power oil machine is connected in parallel with a pure resistive load. Primary frequency modulation coefficient = 0.05



Data analysis showed that the oiler frequency fluctuations were minimal, with 95% of the steady state time frequency fluctuating around 0.03 Hz above and below 50 Hz.

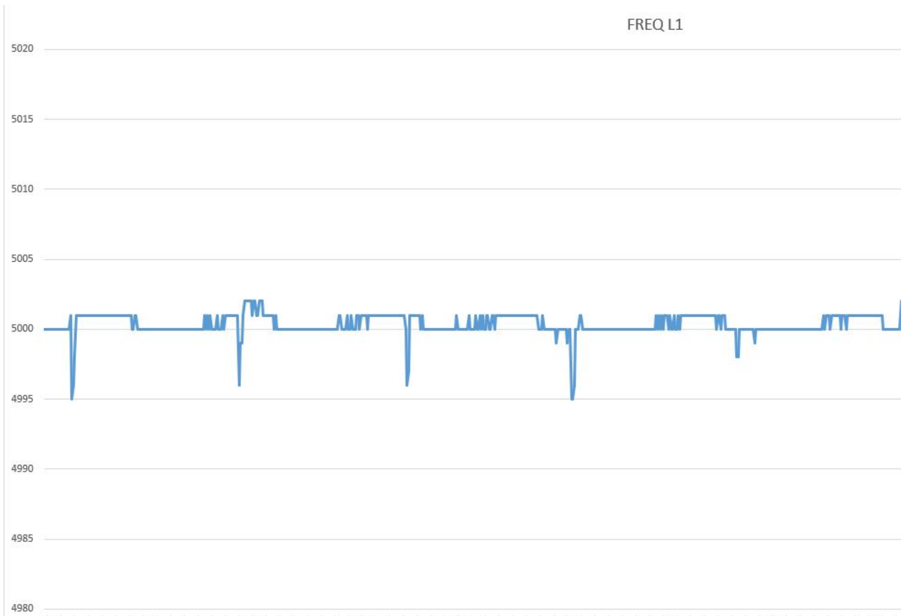
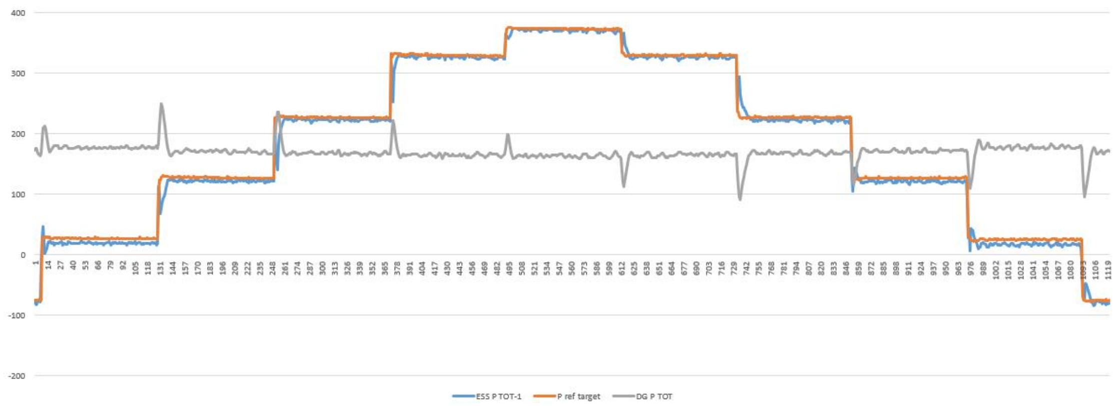


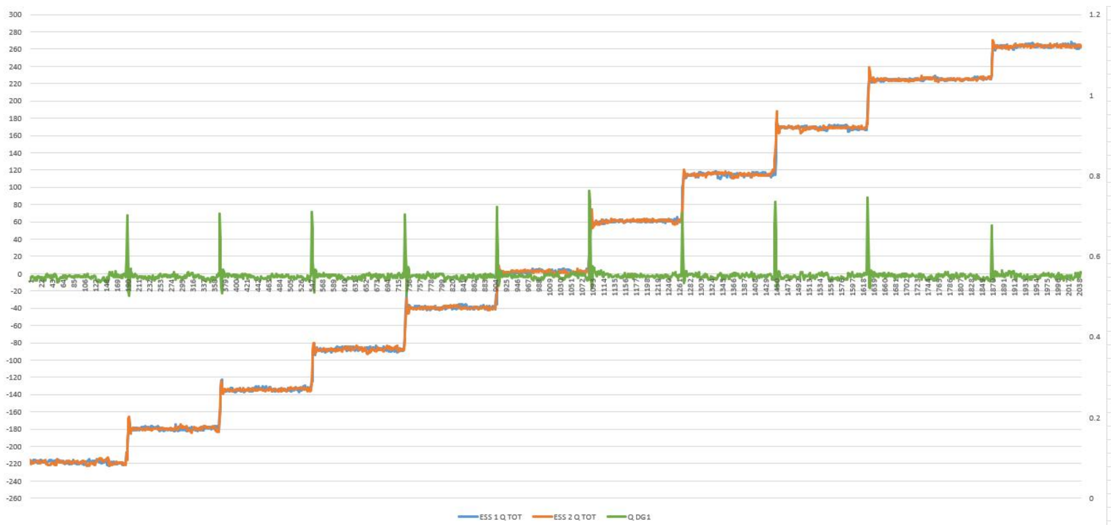
Figure Tanker frequency fluctuations



Discharge test 0kW-380kW Desired power in orange Actual active power in blue

PCS in the steady state state will almost not be due to frequency fluctuations produce a frequency modulation leads to active down the existence of error, and can also be faster into the steady state, does not affect the transient response.

And the desired power of the oiler is also very stable, and the oiler and PCS share the load when the load changes.



Blue for PCS1 reactive power Orange for PCS2 reactive power Green for oil machine reactive power

There will be almost no reactive power inter-feeding in the parallel state of the two PCSs, while keeping the reactive power of the oil machine close to 0 kW in the steady state.

REVISED RECORD

Document version	*revision date*	*Description of changes*	*person in charge*	*audits*
1.0	31st January 2024	Create the document	Ember	Morgan
1.1	Letter dated 24 May 2024 from the Minister for Foreign Affairs of the United Kingdom of Great Britain and Northern Ireland	Improve the introduction, add the description of control logic, add precision control test	Ember	

