Single Phase PV Inverter Module

PEK-510

User Manual

GW INSTEK PART NO. 82EK-11000M01

ISO-9001 CERTIFIED MANUFACTURER

The information in this manual was correct at the time of printing. However, Good Will continues to improve products and reserves the right to change specifications, equipment, and maintenance procedures at any time without notice.

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Table of Contents

Introduction

As the figure 0.1 shown, PEK-510, the Single Phase PV Inverter Module, is based on both the first-stage structure of Boost Converter and the second-stage structure of Single Phase Inverter with fully digital control system. The purpose of it, as shown in the figure 0.2, is to provide a learning platform for power converter of specifically digital control, having users, via PSIM software, to understand the principle, analysis as well as design of power converter through simulating process. More than that, it helps convert, via SimCoder tool of PSIM, control circuit into digital control and proceed to simulation with the circuit of DSP, eventually burning the control program, through simulating verification, in the DSP chip. Also, it precisely verifies the accuracy of designed circuit and controller via control and communication of DSP.

Figure 0.1

Experiment module of Single Phase PV Inverter Module

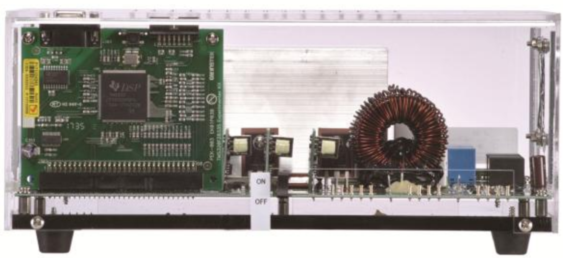
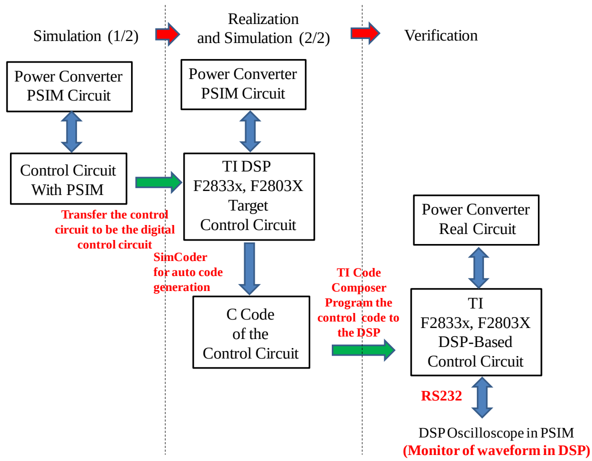


Figure 0.2

The process in details



Thre are 8 experiments can be fulfilled by PEK-510 as follows:

1. Boost Converter
2. Input Voltage Control of Boost Converter
3. MPPT Control of Boost Converter
4. Single Phase Boost Stand-alone Inverter
5. Single Phase Grid-connected Inverter
6. Single Phase PV Grid-connected Inverter
7. PQ Control of Single-phase PV Grid-connected Inverter
8. Single Phase Islanding Protection Inverter

In addition to PEK-510, it is required to utilize PEK-005A auxiliary power module as figure 0.3 shown and PEK-006 JTAG burning module as figure 0.4 shown for experiments. Also, PTS-5000 experiment platform as figure 0.5 shown is necessary for completing the experiments.

Figure 0.3

Auxiliary power module

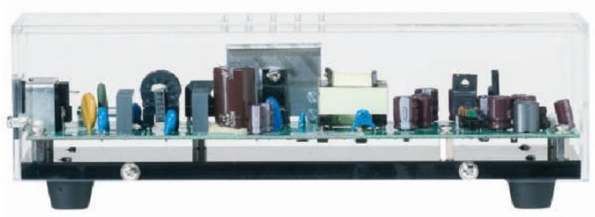


Figure 0.4

JTAG burning module

Figure 0.5

PTS-5000 experiment platform

The DSP I/O pin configuration of PEK-510 is shown as the figure 0.6. Refer to the appendix A for the circuit diagrams of PEK-510, which can be divided into power circuit, sensing circuit, drive circuit and protection circuit. The sensing circuit is further divided into 2 sections; one is for test point measurement, and the other one is for feedback DSP control, both of which have varied attenuation amplifications individually as the following table 0-1 and table 0-2 shown.

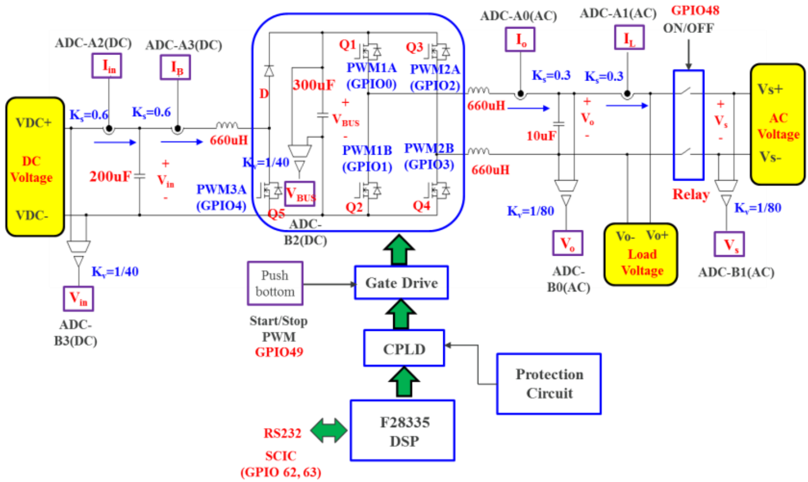


Figure 0.6
I/O configuration

Table 0.1 PEK-510 test point measurement ratio

	Sensing item	Sensing ratio
1	Boost Converter input voltage (Vin)	0.0249
2	DC link voltage (VBUS)	0.0249
3	Boost Converter input current (Iin)	0.8
4	Boost Converter inductor current (IB)	0.8
5	Inverter output current (Io)	0.8
6	Inverter load current (IL)	0.8
7	Inverter output voltage (Vo)	0.0124
8	Grid power voltage (Vs)	0.0124

Table 0.2 PEK-510 feedback ratio

	Sensing item	Sensing ratio
1	Boost Converter input voltage (Vin)	0.0249
2	DC link voltage (VBUS)	0.0249
3	Boost Converter input current (Iin)	0.6
4	Boost Converter inductor current (IB)	0.6
5	Inverter output current (Io)	0.2996
6	Inverter load current (IL)	0.2996
7	Inverter output voltage (Vo)	0.0124
8	Grid power voltage (Vs)	0.0124

The Description on Chapters

See the chapter arrangements as follows

Brief	Briefly describes the experimental method, experimental items and circuit setup. It also explains the contents of each chapter.
Experiment 1 Boost Converter	To get to know the principle and working mode of PWM switchable boost converter. Realize the measurements of voltage and current via PEK-510 module, and learn the TI F28335 DSP IC pins, PWM and A/D hardware setting. Also understand how to proceed to DSP internal signal control and measurement via RS-232.
Experiment 2 Input Voltage Control of Boost Converter	To get to know the small signal model derivation of boost converter, and learn the input voltage control, further proceeding to the code programming via SimCoder, after well mapping out the hardware.
Experiment 3 MPPT Control of Boost Converter	To get to know the characteristics of PV module and diversified MPPT method, and learn the SimCoder code programming of Perturb and Observe method. Also, to validate experiment result via the PEK-510 boost converter.
Experiment 4 Single Phase Boost Stand-alone Inverter	To get to know the way for modeling of single phase inverter, and learn the design of both voltage loop and current loop controllers, further proceeding to the code programming via SimCoder, after well mapping out the hardware.

Experiment 5 Single Phase Grid-Power Inverter	To get to know the fundamental with structure of single phase grid-power inverter, and learn not only the design method of phase-lock loop of single phase grid-power inverter, but the design of both voltage loop and current loop controllers as well, further proceeding to the code programming via SimCoder, after well mapping out the grid-power inverter.
Experiment 6 Single Phase PV Grid-Power Inverter	To get to know the fundamental with structure of PV grid-power inverter, and synthesize boost converter with single phase inverter to form the experiment of PV grid-power inverter, further proceeding to the code programming via SimCoder, after well planning.
Experiment 7 PQ Control of Single Phase PV Grid-Power Inverter	To get to know the verification capability of real power management and reactive power injection of smart inverter, and proceed to the code programming via SimCoder, after well mapping out the hardware.
Experiment 8 Single Phase Islanding Protection Inverter	To get to know the purpose of islanding protection and the verification method of islanding test, and proceed to the code programming via SimCoder, after well mapping out the hardware.

Experiment 1 – Boost Converter

Circuit Simulation

The circuit parameters of converter are as follows:

Input Voltage V_{in} = 50V

BUS Voltage V_{bus} = 80V

F_s = 40kHz， V_{tri} = $5V_{pp}$ (PWM)

L_b = 661.5uH， C_{BUS} = 300uF

K_s = 0.6 (DC current sensing factor)

K_v = 1/40 (DC voltage sensing factor)

The analogue circuit diagram based on the parameters above is as the following figure 1.1 shown:
PSIM File: PEK-510_Sim1_Boost_V11.1.5_V1.1

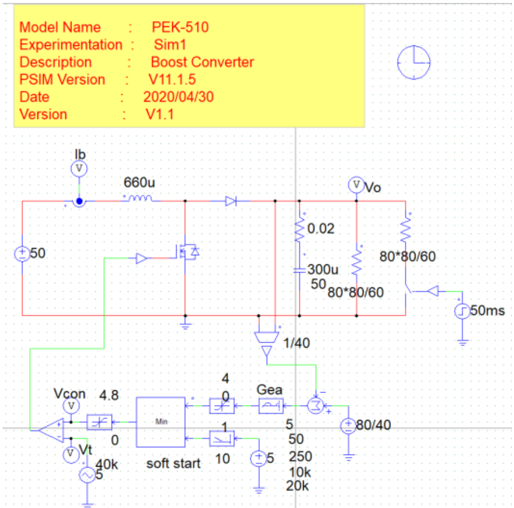


Figure 1.1 Experiment 1 PSIM analogue circuit diagram

The simulation result is shown within the figure 1.2 and 1.3:

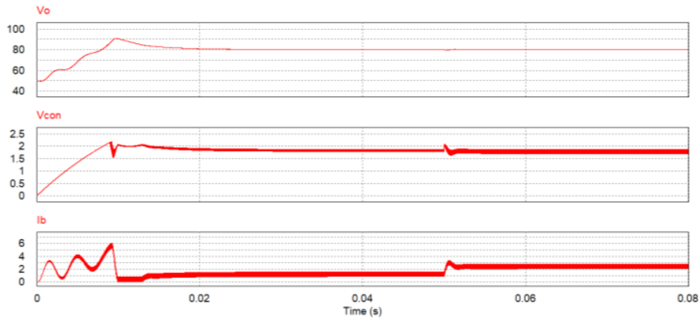


Figure 1.2 Experiment 1 analogue circuit simulation waveforms

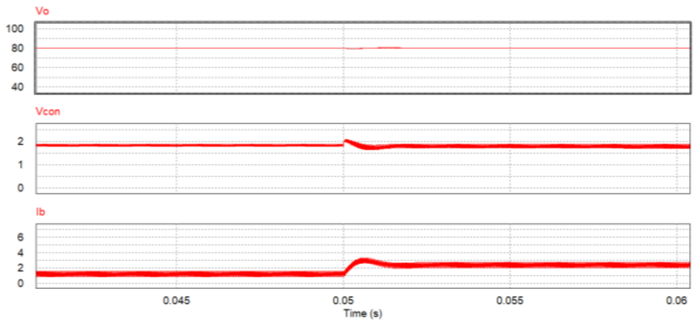


Figure 1.3 Experiment 1 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is shown as the figure 1.4:
PSIM File: PEK-510_Lab1_Boost_V11.1.5_V1.1

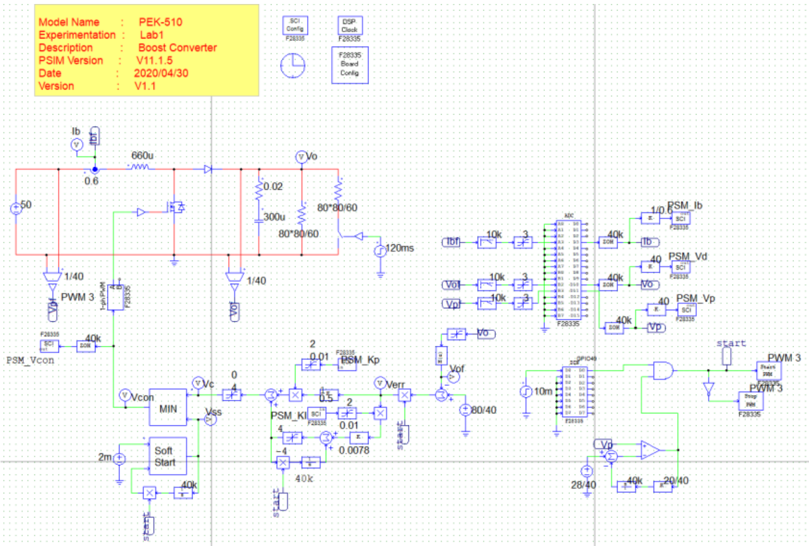


Figure 1.4 Experiment 1 PSIM digital circuit diagram

The simulation result is shown within the figure 1.5:

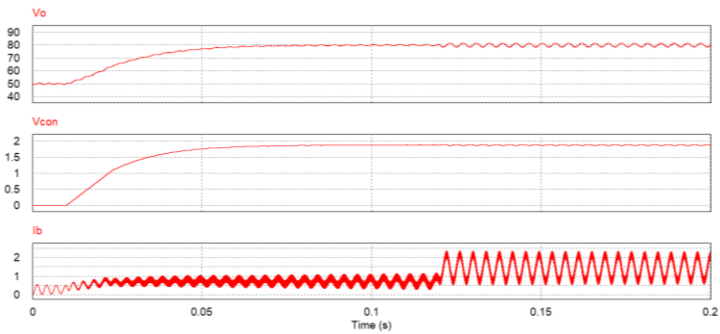


Figure 1.5 Experiment 1 digital circuit simulation waveforms

After confirming simulation, the corresponding C Code will be generated automatically via “Generate Code” of “Simulate”.

Experiment Devices

The required devices for experiment are as follows:

- PEK-510 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2, PEL-3031E)
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 1.6. Please follow it to complete wiring.

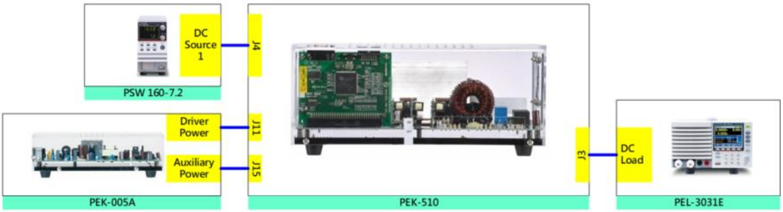
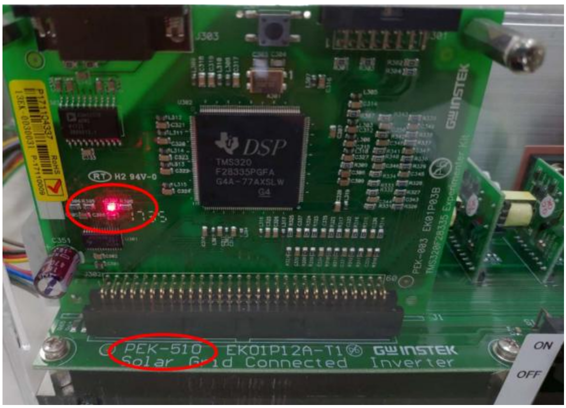


Figure 1.6 Experiment 1 wiring figure

2. After wiring, make sure the PEK-510 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 1.7 shown, which means the DSP power is steadily normal.

Figure 1.7 DSP normal status with light on

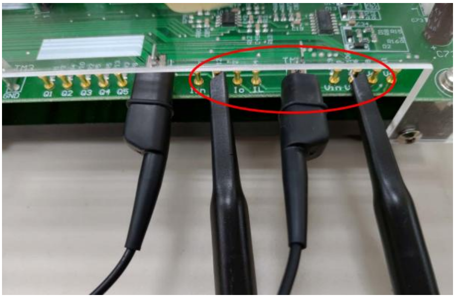


3. Refer to the appendix B for burning procedure.

4. Connect the test leads of oscilloscope to IB and VBUS, respectively, as the figure 1.8 shown.

Figure 1.8

Oscilloscope test leads wiring



5. As the figure 1.9 shown, set voltage as 50V and current as 3A, individually, for the power supply PSW160-7.2.

Figure 1.9

The settings of PSW

6. After powering on PEL-3031E, set CR Mode for Load mode with Low in Range. Further set 50Ω for Channel_A and 100Ω for Channel_B as the figure 1.10 shown.

Figure 1.10

The settings of PEL-3031E load

7. After setting up and turning on PSW power output, finally turn on the switch of PEK-510.

The purpose of experiment

This experiment, which is boost converter with load set in 100Ω and 50Ω respectively, discusses the possible influence on output voltage waveforms.

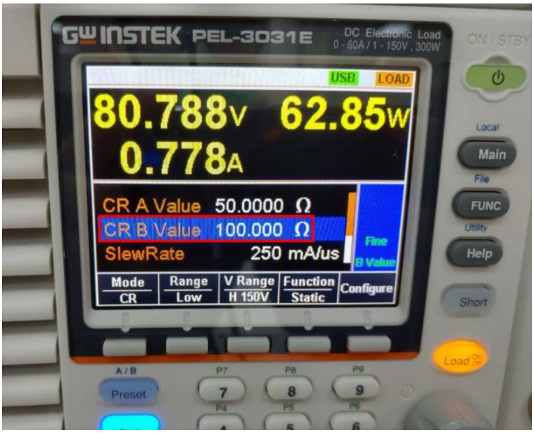
The experiment result

Electronic Load 100Ω

As the figure 1.11 shown, when load is set 100 Ω, the output voltage and output power will be 80V and 62.85W, respectively. The figure 1.12 displays that IB is 1.08A and VBus is 1.98V (79.52V in actual value).

Figure 1.11

Electronic load 100Ω setting



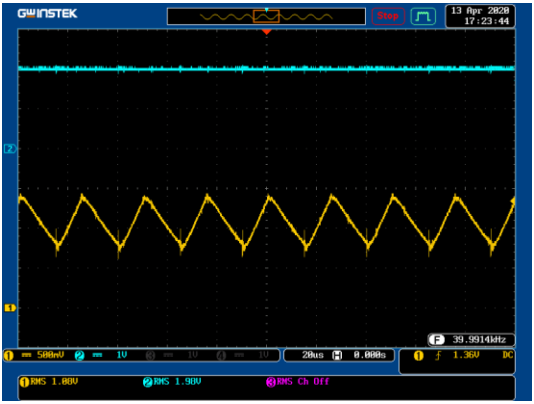


Figure 1.12

Load 100Ω measured waveform

Electronic Load 50Ω

As the figure 1.13 shown, when load is set 50 Ω, the output voltage of circuit power and output power will be 80V and 128W, respectively. The figure 1.14 displays that IB is 2.18A (2.725V in actual value) and VBus is 1.98V (79.52V in actual value).

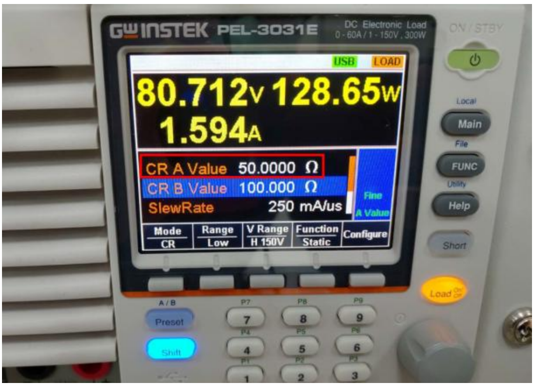
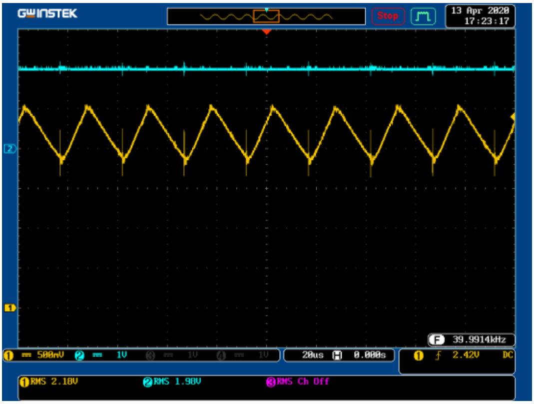


Figure 1.13

Electronic load 50Ω setting

Figure 1.14

Load 50Ω measured waveform



Per differed load operations, fill in the table 1.1 with the results in order. Refer to the table 0.1 for the sensing ratio.

Table 1.1 Output voltage current measured data in varied load settings.

	IB(Irms) (Measured value)	IB(Irms) (Actual value)	VBUS(Vrms) (Measured value)	VBUS(Vrms) (Actual value)
Load (100Ω)	1.08A	1.35A	1.98V	79.52V
Load (50Ω)	2.18A	2.73A	1.98V	79.52V

The Conclusion

Based on the table 1.1, in terms of boost converter, when load fluctuates, IB current changes in accord with load fluctuations from half to full load but the output voltage is remained in stability via feedback control.

Experiment 2 – Input Voltage Control of Boost Converter

Circuit Simulation

The converter specification is as follows:

Input Voltage V_{in} = 50V

BUS Voltage V_{bus} = 80V

F_s = 40kHz，V_{tri} = 5V_{pp} (PWM)

L_b = 661.5uH，C_{BUS} = 300uF

K_s = 0.6 (DC current sensing factor)

K_v = 1/40 (DC voltage sensing factor)

The analogue circuit diagram based on the parameters above is as the following figure 2.1 shown:
PSIM File: PEK-510_Sim2_Input_Control_Boost_V11.1.5_V1.1

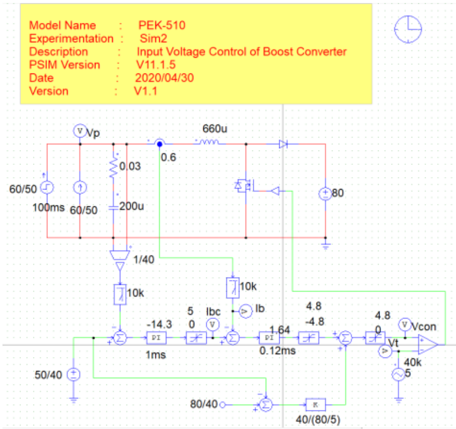


Figure 2.1 Experiment 2 PSIM analogue circuit diagram

The simulation result is shown within the figure 2.2 and 2.3:

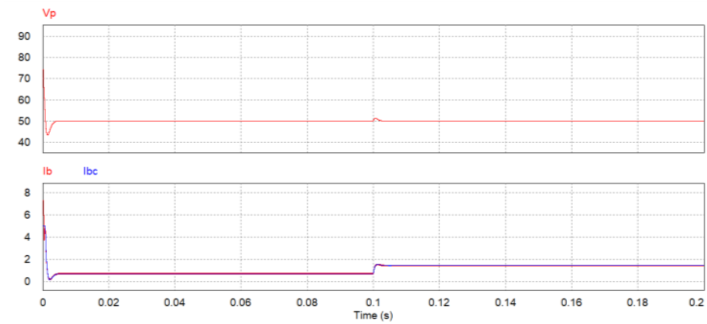


Figure 2.2 Experiment 2 analogue circuit simulation waveforms

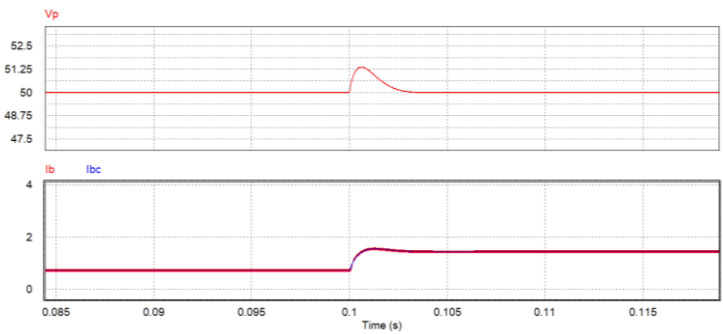


Figure 2.3 Experiment 2 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is shown as the figure 2.4:

PSIM File: PEK-510_Lab2_Input_Control_Boost_V11.1.5_V1.1

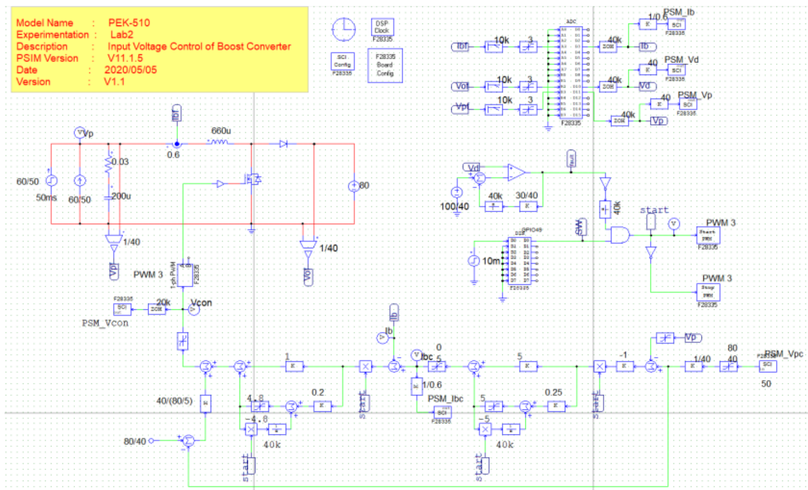


Figure 2.4 Experiment 2 PSIM digital circuit diagram

The simulation result is shown within the figure 2.5:

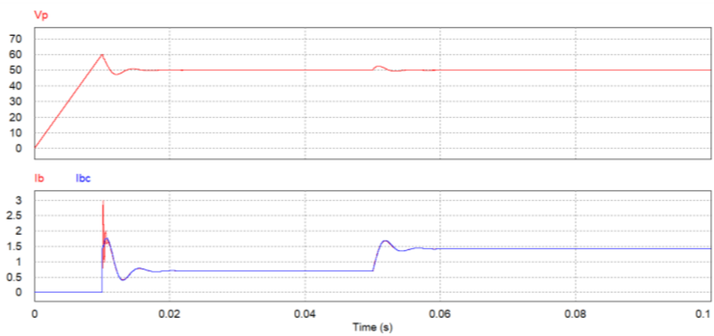


Figure 2.5 Experiment 2 digital circuit simulation waveforms

After confirming simulation, the corresponding C Code will be generated automatically via “Generate Code” of “Simulate”.

Experiment Devices

The required devices for experiment are as follows:

- PEK-510 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2 and PEL-3031E)
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 2.6. Please follow it to complete wiring.

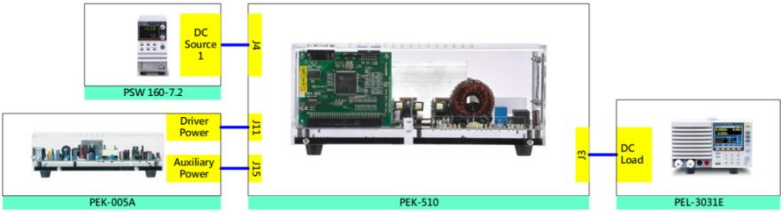
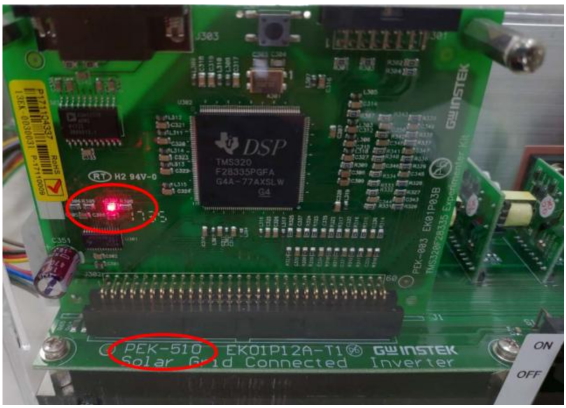


Figure 2.6 Experiment 2 wiring figure

2. After wiring, make sure the PEK-540 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 2.7 shown, which means the DSP power is steadily normal.

Figure 2.7

DSP normal status with light on



3. Refer to the appendix B for burning procedure.

4. Set voltage 60V and current 1.2A for PSW 160-7.2 as the figure 2.8 shown.

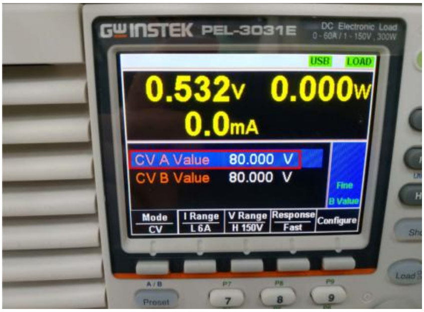
Figure 2.8

The settings of PSW

5. Set PEL-3031E as CV mode with 80V value as the figure 2.9 shown.

Figure 2.9

The settings of PEL-3031E



6. After setting up and turning on PSW power and PEL output, finally turn on the switch of PEK-510.

The purpose of experiment

The experiment of boost converter stabilizes input voltage within the set voltage value via closed-loop control. Due to output voltage without feedback control, it is required to set electronic load as CV mode in order to keep output voltage and further avoid damage from overly higher output voltage while booting.

The experiment result

(1) Set input voltage as 60V and current as 1.2A.

As the figure 2.10 shown, after powering on PEK-510, the voltage of power supply will be adjusted from the default 60V to 50V followed by entering the CC mode and outputting current based on the set current value. As the figure 2.11 shown, the electronic load output voltage is 80V and power is 56W.

Figure 2.10
PSW output display

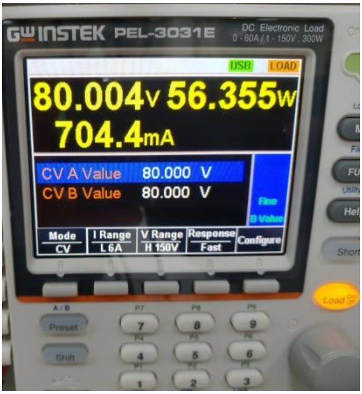


Figure 2.11

PEL load display

(2) Set input voltage as 60V and current as 2.4A.

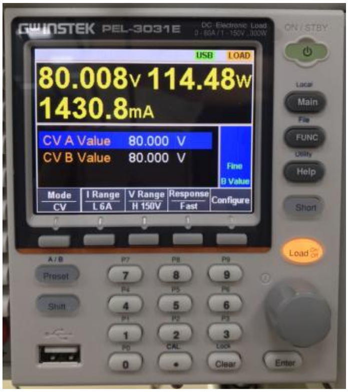
As the figure 2.12 shown, after powering on PEK-510, the voltage of power supply will be adjusted from the default 60V to 50V followed by entering the CC mode and outputting current based on the set current value. As the figure 2.13 shown, the electronic load output voltage is 80V and power is 114W.

Figure 2.12

PSW output display

Figure 2.13

PEK-510 load display



The Conclusion

It is able to observe that from the experiment of boost converter feedback system will maintain input voltage within the set voltage value.

Experiment 3 – MPPT Control of Boost Converter

Circuit Simulation

The circuit parameters of converter are as follows:

Input Voltage V_{in} = 50V

BUS Voltage V_{bus} = 80V

F_s = 40kHz，V_{tri} = 5V_{pp} (PWM)

L_b = 661.5uH，C_{BUS} = 300uF

K_s = 0.6 (DC current sensing factor)

K_v = 1/40 (DC voltage sensing factor)

The analogue circuit diagram based on the parameters above is as the following figure 3.1 shown:
PSIM File: PEK-510_Sim3_MPPT_Control_Boost_V11.1.5_V1.1

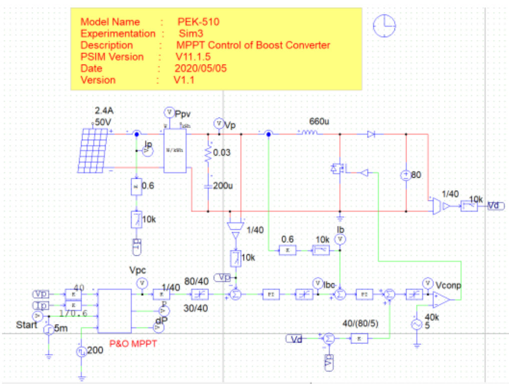


Figure 3.1 Experiment 3 PSIM analogue circuit diagram

The simulation result is shown within the figure 3.2:

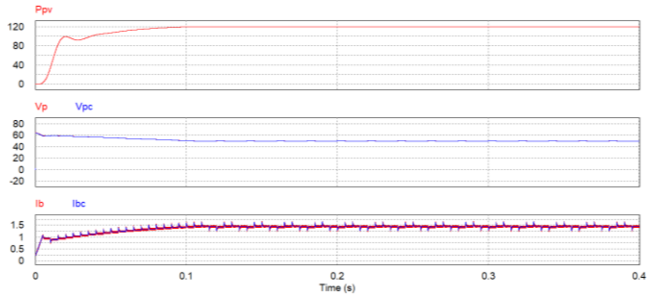


Figure 3.2 Experiment 3 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is shown as the figure 3.3:
PSIM File: PEK-510_Lab3_MPPT_Control_Boost_V11.1.5_V1.1

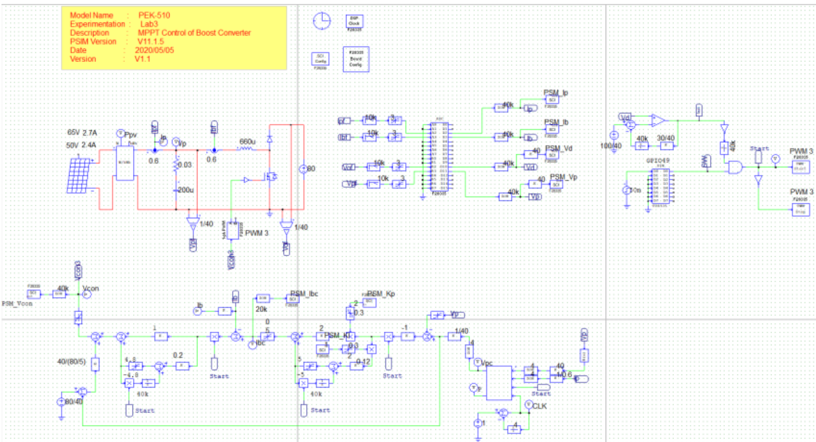


Figure 3.3 Experiment 3 PSIM digital circuit diagram

Because the circuit, which practically generates Code, has the MPPT adjusted frequency 4Hz and it is time-consuming for simulation based on this circuit file, we alternately provide another digital circuit, “PEK-510_Sim3-1_MPPT_Control_Boost_V11.1.5_V1.1”, of MPPT adjusted frequency 100Hz, based on which it requires relatively shorter period for simulation result. Refer to the figure 3.4 for the simulation result.

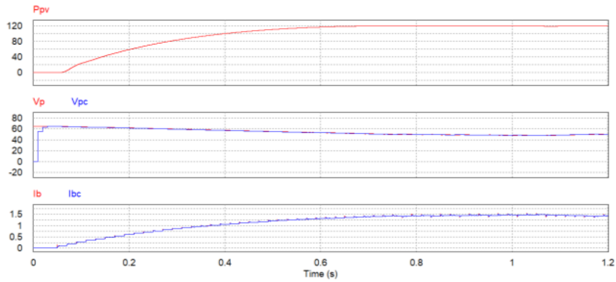


Figure 3.4 Experiment 3 digital circuit simulation waveforms

After confirming simulation, the corresponding C Code will be generated automatically via "Generate Code" of "Simulate".

Experiment Devices

The required devices for experiment are as follows:

- PEK-510 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2 and PEL-3031E)
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 3.5. Please follow it to complete wiring.

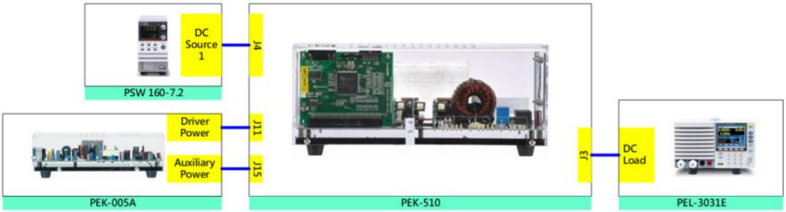
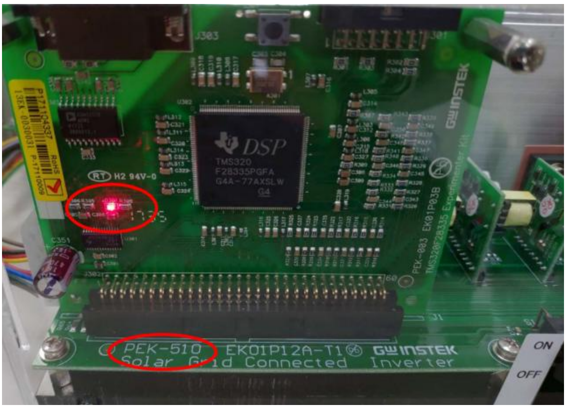


Figure 3.5 Experiment 3 wiring figure

2. After wiring, make sure the PEK-510 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 3.6 shown, which means the DSP power is steadily normal.

Figure 3.6

DSP normal status with light on



3. Refer to the appendix B for burning procedure.

4. Refer to the appendix D – SAS software operation manual for PV system setting process in simulation. As the figure 3.7 shown, the open circuit voltage of first curve is 65V, and the short circuit current is 2.7A with the MPP voltage 50V along with the MPP current 2.4A. As the figure 3.8 shown, the value of second curve is set 90% of the first curve. The open circuit voltage of the second curve, therefore, is 58.5V, and the short circuit current is 2.43A with the MPP voltage 45V along with the MPP current 2.16A.

Figure 3.7

The 1st curve setting value

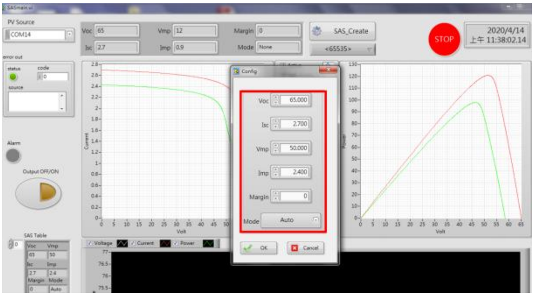
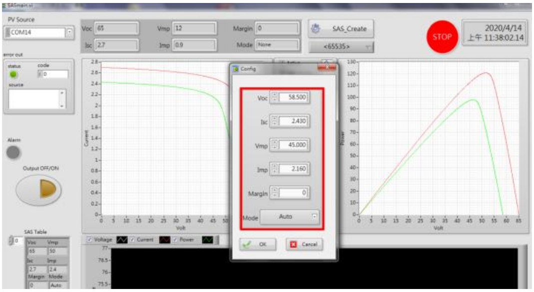


Figure 3.8

The 2nd curve setting value



5. As the figure 3.9 shown, DC load is set CV mode with voltage in 80V.

Figure 3.9

DC load setting

6. After setting, launch PSW output via SAS program and pull load of PEL followed by powering on PEK-510 for test.

The purpose of experiment

When simulating varied PV curves of PV panel, we retain, via MPPT control, the maximum power output to reach the highest utilization rate.

The experiment result

Simulate PV curves of PV panel via SAS program and retain the maximum power output, via MPPT control, in any given environments to reach the highest utilization rate. As the figure 3.10 and 3.11 shown, it is evident that the output power is approaching and retaining within the maximum power point gradually.

Figure 3.10

SAS exists in the initial startup of the 1st curve

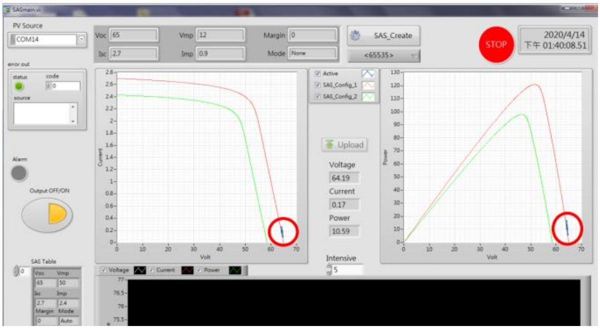
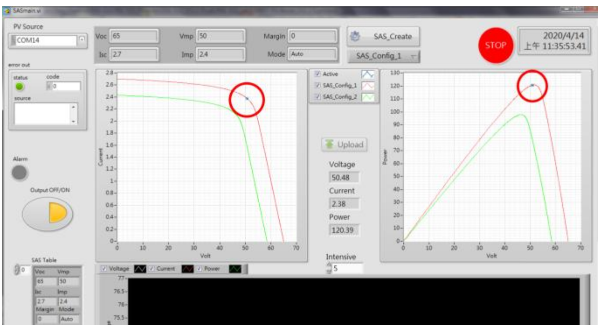


Figure 3.11

SAS exists in the maximum power point of the 1st curve



However, owning to the fact that PV curve of PV panel keeps changing in accord with external factors, we utilize the 2nd curve to verify that the maximum power output can be well maintained in any given environmental conditions to reach the highest utilization rate. As the figure 3.12 and 3.13 shown, it is evident that the output power is approaching and retaining within the maximum power point gradually.

Figure 3.12

SAS changes to the 2nd curve

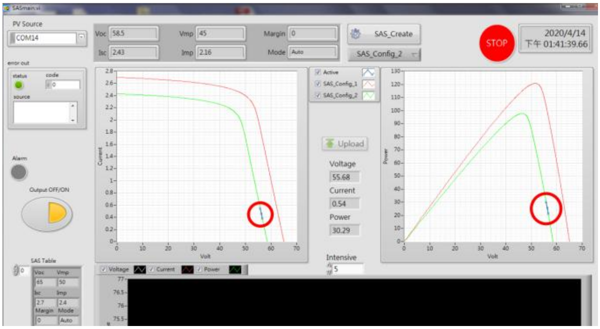
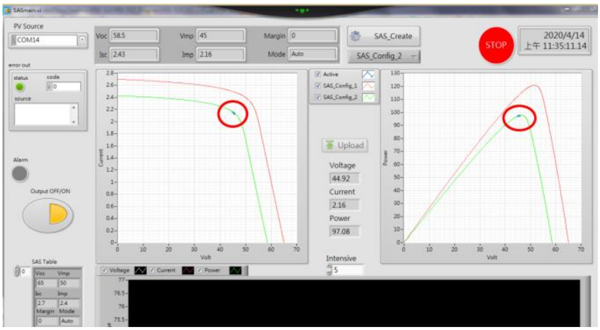


Figure 3.12

SAS exists in the maximum power point of the 2nd curve



The Conclusion

The experiment of boost converter simulates when PV panel occurs changes caused by intensifying light or environmental conditions, the PV curve changes accordingly. The MPPT controller, nevertheless, is able to locate the maximum power point of the latest curve.

Experiment 4 – Single Phase Boost Stand-alone Inverter

Circuit Simulation

The system specification is as follows:

DC Input Voltage V_b = 50V

DC bus Voltage V_d = 80V

F_s = 40kHz，V_{tri} = 5V_{pp} (Boost PWM)

F_s = 20kHz，V_{tri} = 10V_{pp} (Inverter PWM)

L_b = 661.5uH，C_{BUS} = 300uF

L = 661.5uH，C = 10uF

K_s = 0.3 (AC current sensing factor)

K_s = 0.6 (DC current sensing factor)

K_v = 1/80 (AC voltage sensing factor)

K_v = 1/40 (DC voltage sensing factor)

The analogue circuit diagram based on the parameters above is as the following figure 4.1 shown:
PSIM File: PEK-510_Sim4_1P_Boost_SA_Inv(50Hz)_V11.1.5_V1.1

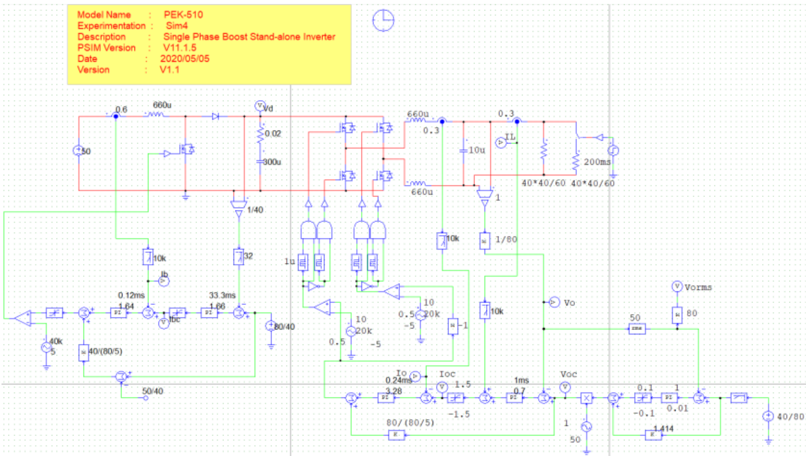


Figure 4.1 Experiment 4 PSIM analogue circuit diagram

The simulation result is shown within the figure 4.2:

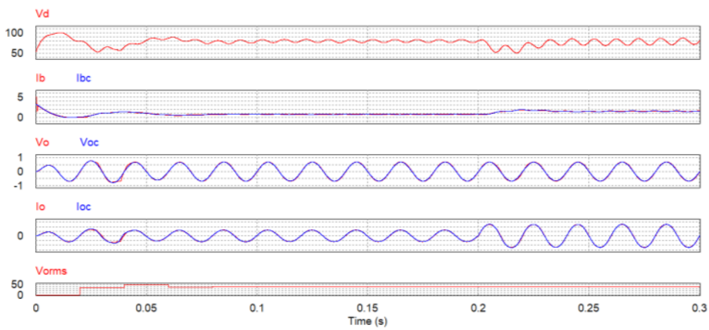


Figure 4.2 Experiment 4 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is shown as the figure 4.3:
PSIM File: PEK-510_Lab4_1P_Boost_SA_Inv(50Hz)_V11.1.5_V1.1

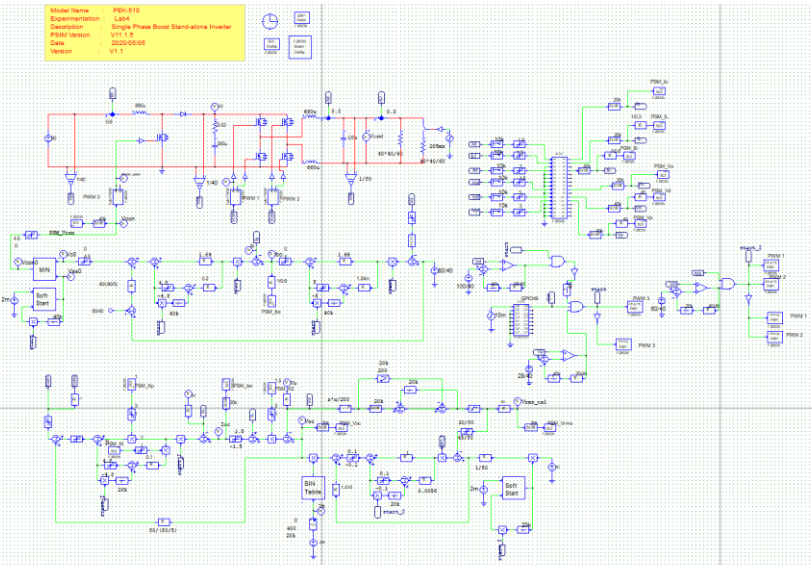


Figure 4.3 Experiment 4 PSIM digital circuit diagram

The simulation result is shown within the figure 4.4:

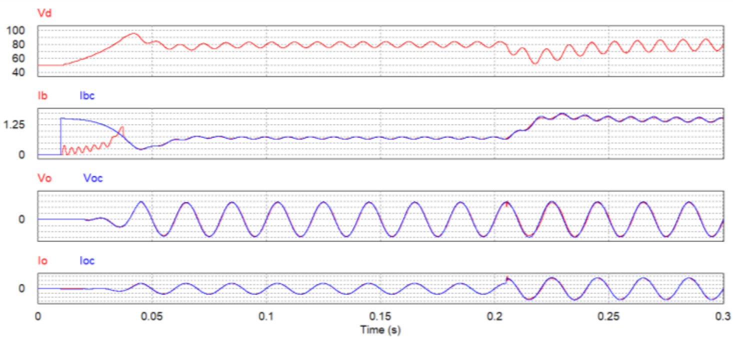


Figure 4.4 Experiment 4 digital circuit simulation waveforms

After confirming simulation, the corresponding C Code will be generated automatically via “Generate Code” of “Simulate”.

Experiment Devices

The required devices for experiment are as follows:

- PEK-510 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2 and GPL-500)
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 4.5. Please follow it to complete wiring.

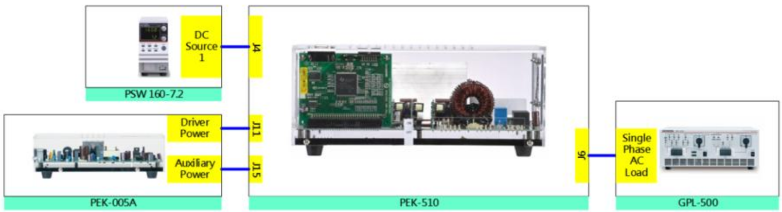
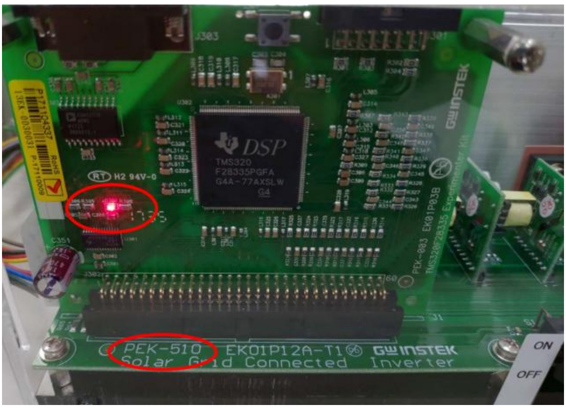


Figure 4.5 Experiment 4 wiring figure

2. After wiring, make sure the PEK-510 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 4.6 shown, which means the DSP power is steadily normal.

Figure 4.6 DSP normal status with light on

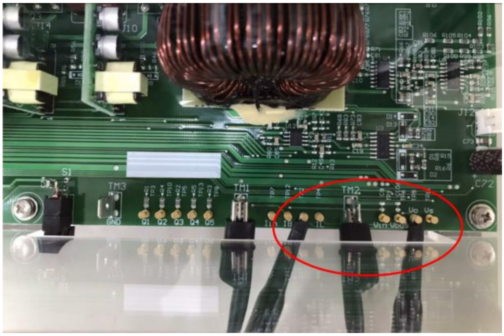


3. Refer to the appendix B for burning procedure.

4. Connect the test leads of oscilloscope to VO and IO, respectively, as the figure 4.7 shown.

Figure 4.7

Oscilloscope test leads wiring



5. Set voltage 50V and current 3A for PSW 160-7.2 as the figure 4.8 shown.

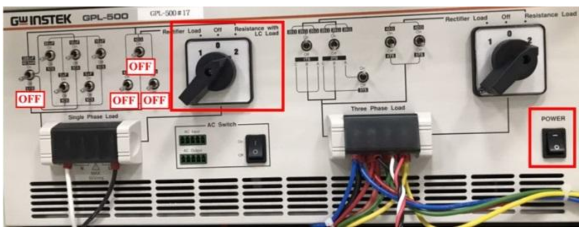
Figure 4.8

The settings of PSW

6. As the figure 4.9 shown, follow the steps below for GPL-500 operation. Power on GPL-500 → Rotate the Single Phase Lord knob to 2 (Resistance with LC Load) → Set 1SS, 2SS, 3SS and LCS as OFF, which indicates no-load mode.

Figure 4.9

The no-load setting of GPL-500



7. After setting up and turning on PSW, finally turn on the switch of PEK-510.

The purpose of experiment

The experiment of single phase inverter guarantees that output voltage, via closed-loop control, retains steady output in any given load fluctuation. Also it observes output current changes.

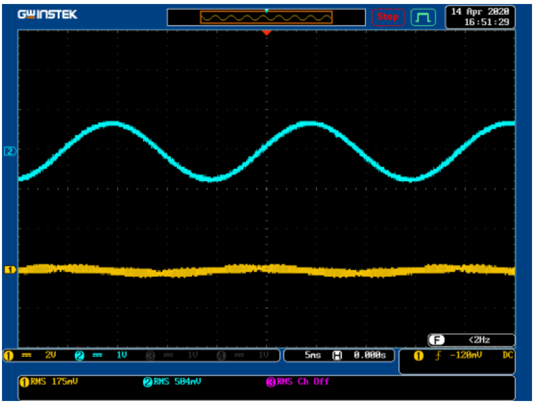
The experiment result

(3) No Load

The figure 4.10 shows that when GPL-500 is set as no-load mode, VO RMS voltage is 0.504V (40.65V in actual value), and IO RMS voltage is 0.175V (0.22A in actual value).

Figure 4.10

VO and IO measured waveforms under no-load mode



(4) Light Load (42 Ohm)

As the figure 4.12 shown, follow the steps below for GPL-500 operation. Set 1SS as ON, and 2SS, 3SS as OFF, which indicates light-load mode.

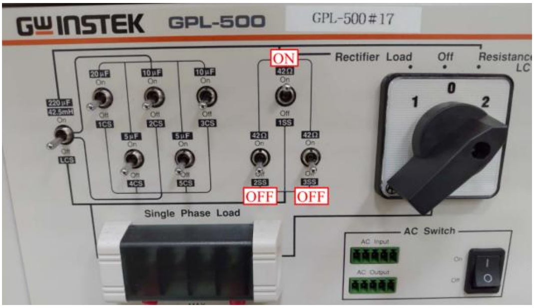


Figure 4.11

The light-load setting of GPL-500

The figure 4.12 shows that when GPL-500 is set as light-load mode, VO RMS voltage is 0.507V (40.89V in actual value), and IO RMS voltage is 0.772V (0.97A in actual value).

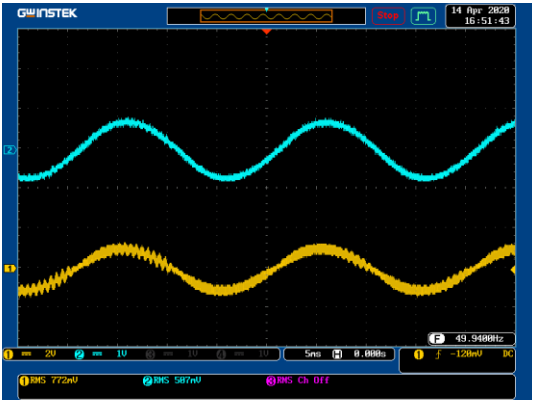


Figure 4.12

VO and IO measured waveforms under light-load mode

(5) Mid Load (21 Ohm)

As the figure 4.13 shown, follow the steps below for GPL-500 operation. Set 1SS and 2SS as ON, and 3SS as OFF, which indicates mid-load mode.

The figure 4.14 shows that when GPL-500 is set as mid-load mode, VO RMS voltage is 0.504V (40.65V in actual value), and IO RMS voltage is 1.51V (1.89A in actual value).

Figure 4.13

The mid-load setting of GPL-500

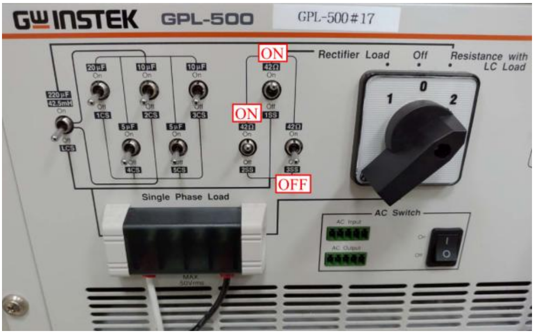
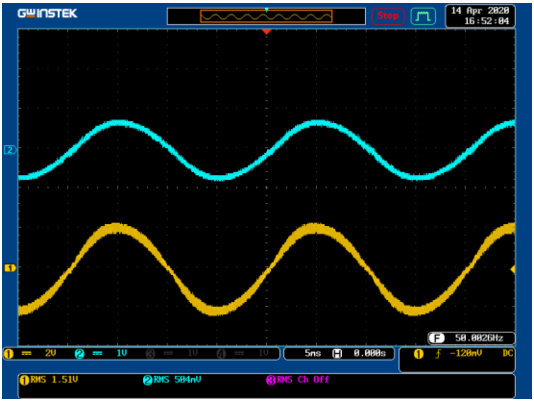


Figure 4.14

VO and IO measured waveforms under mid-load mode



(6) Full Load (14 Ohm)

As the figure 4.15 shown, follow the steps below for GPL-500 operation. Set 1SS, 2SS and 3SS as ON, which indicates full-load mode.

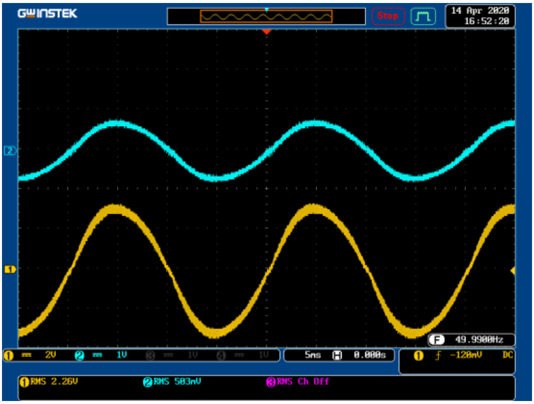
The figure 4.16 shows that when GPL-500 is set as full-load mode, VO RMS voltage is 0.503V (40.56V in actual value), and IO RMS value is 2.26A (2.83A in actual value).

Figure 4.15

The full-load setting of GPL-500

Figure 4.16

VO and IO measured waveforms under full-load mode



Per no-load, light-load, mid-load and full-load settings of GPL-500, fill in the table 4.1 with the measured values of VO and IO, respectively. Refer to the table 0.1 for the sensing ratio followed by filling in the actual values.

Table 4.1 voltage current measured data in varied load settings of GPL-500

	V_O(Vrms) (Measured Value)	V_O(Vrms) (Actual Value)	I_O(Irms) (Measured Value)	I_O(Irms) (Actual Value)
No Load	0.504V	40.65V	0.175A	0.22A
Light Load	0.507V	40.89V	0.772A	0.97A
Mid Load	0.504V	40.65V	1.51A	1.89A
Full Load	0.503V	40.56V	2.26A	2.83A

The Conclusion

This experiment is the single phase inverter. We can understand that, from the table 4.1, the output current increases gradually during the process from no load to full load, but the output voltage remains within 40V.

Experiment 5 – Single Phase Grid-connected Inverter

Circuit Simulation

The circuit parameters of system are as follows:

DC bus Voltage $V_d = 80V$

AC Source Voltage $V = 40\ V_{rms}$

$F_s = 20kHz$，$V_{tri} = 10V_{pp}$ (PWM)

$L = 661.5uH$，$C = 10uF$

$K_s = 0.3$ (AC current sensing factor)

$K_v = 1/80$ (AC voltage sensing factor)

$K_v = 1/40$ (DC voltage sensing factor)

The analogue circuit diagram based on the parameters above is as the following figure 5.1 shown:
PSIM File: PEK-510_Sim5_1P_GC_Inv(50Hz)_V11.1.5_V1.1

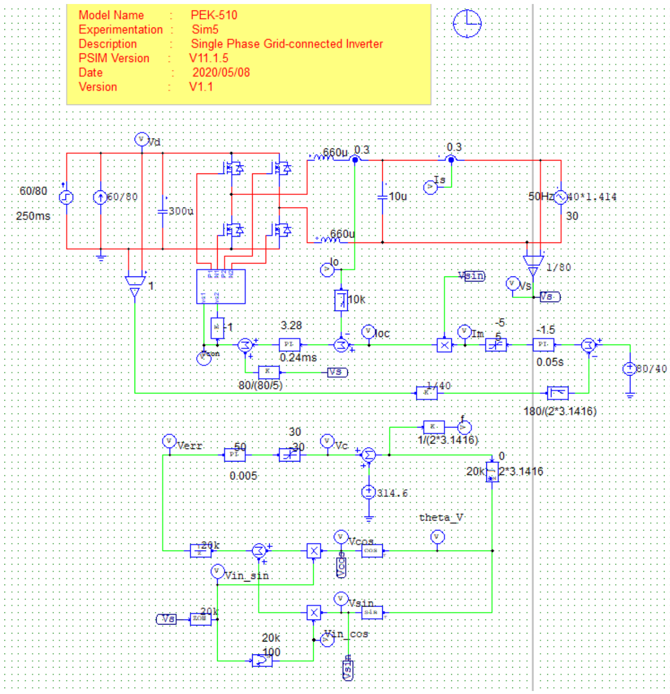


Figure 5.1 Experiment 5 PSIM analogue circuit diagram

The simulation result is shown within the figure 5.2:

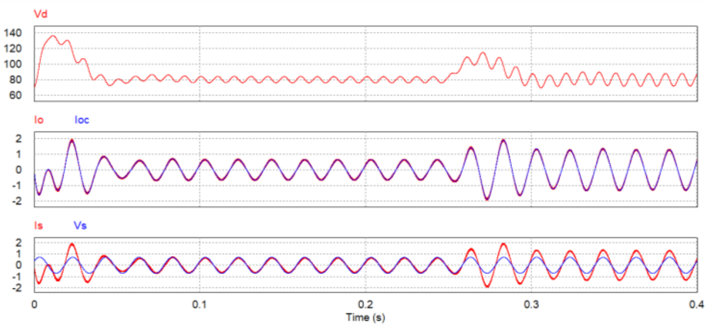


Figure 5.2 Experiment 5 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is shown as the figure 5.3:
PSIM File: PEK-510_Lab5_1P_GC_Inv(50Hz)_V11.1.5_V1.1

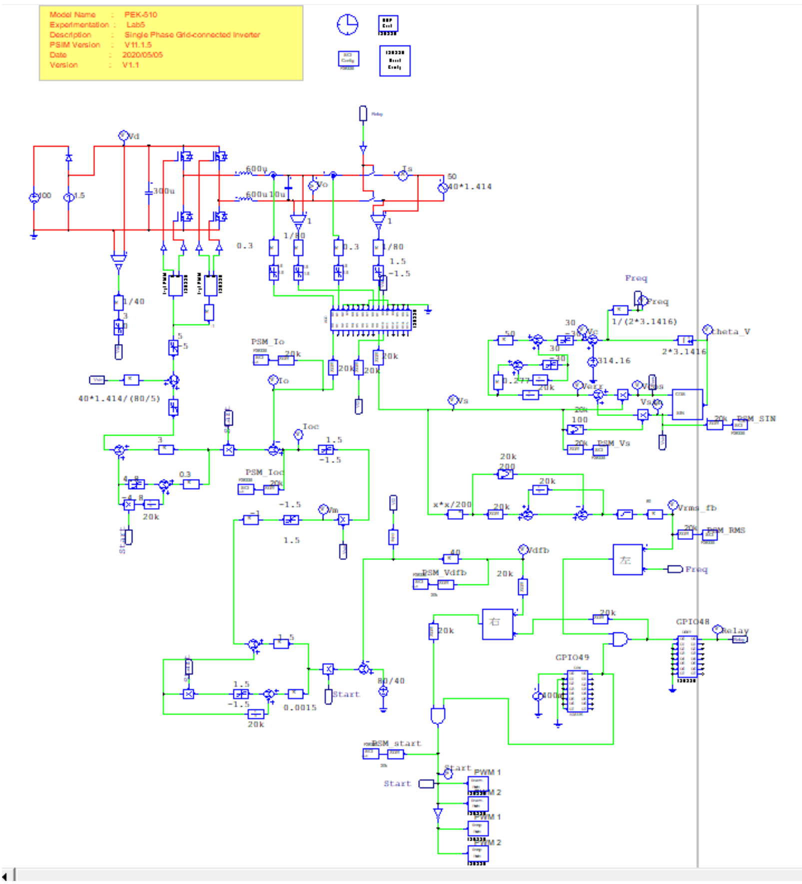


Figure 5.3 Experiment 5 PSIM digital circuit diagram

The simulation result is shown within the figure 5.4:

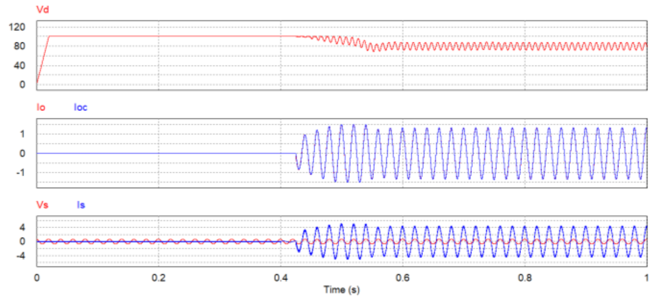


Figure 5.4 Experiment 5 digital circuit simulation waveforms

After confirming simulation, the corresponding C Code will be generated automatically via “Generate Code” of “Simulate”.

Experiment Devices

The required devices for experiment are as follows:

- PEK-510 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2, APS-300 and GPL-500)
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 5.5. Please follow it to complete wiring.

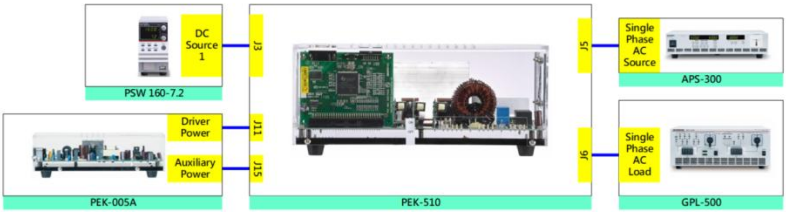
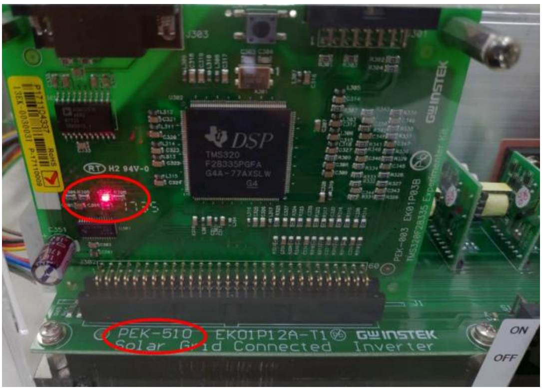


Figure 5.5 Experiment 5 wiring figure

2. After wiring, make sure the PEK-510 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 5.6 shown, which means the DSP power is steadily normal.

Figure 5.6

DSP normal status with light on

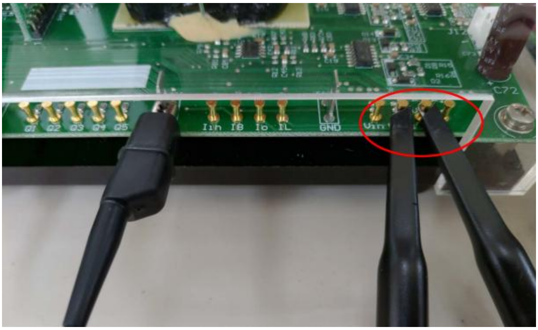


3. Refer to the appendix B for burning procedure.

4. Connect the test leads of oscilloscope to VBUS and Vo, respectively, as the figure 5.7 shown.

Figure 5.7

Oscilloscope test leads wiring



5. Set voltage 100V and current 1.2A for PSW 160-7.2 as the figure 5.8 shown.

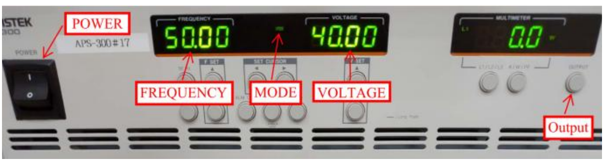
Figure 5.8

The settings of PSW

6. As the figure 5.9 shown, follow the steps below for APS-500 operation. Power on APS-500 → Set APS-300 frequency as 50Hz → Set operation mode as 1P2W → Set voltage as 40V.

Figure 5.9

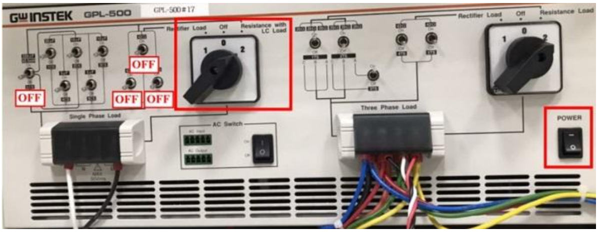
The setting of APS-300



7. As the figure 5.10 shown, follow the steps below for GPL-500 operation. Power on GPL-500 → Rotate the Single Phase Lord knob to 2 (Resistance with LC Load) → Set 1SS, 2SS and 3SS as OFF, and LCS as OFF, which indicates no-load mode.

Figure 5.10

The no-load setting of GPL-500



8. After setting up, turn on PSW output via SAS programm and enable APS-300 output followed by turning on the switch of PEK-510.

The purpose of experiment

The experiment of grid-connected inverter system discusses the power differences between inverter and grid power under varied load power requirements.

The experiment result

(7) No Load

The figure 5.11 shows that VOA RMS voltage is 0.499V (40.24V in actual value), and IO RMS value is 1.77V (2.21V in actual value). As the figure 5.12 shown, the output power provided by PSW is 97W. When it is no-load, the full power is absorbed via APS-300 due to the fact that the power generated by inverter feedbacks to grid power, the power shown on APS will be -87.6W in which "-" indicates absorbed power.

Figure 5.11

VO, IO measured waveforms of inverter

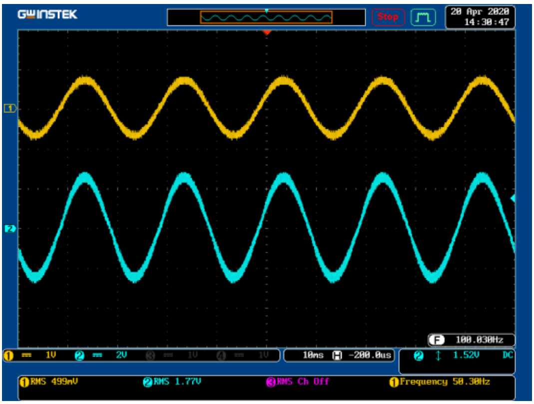


Figure 5.12

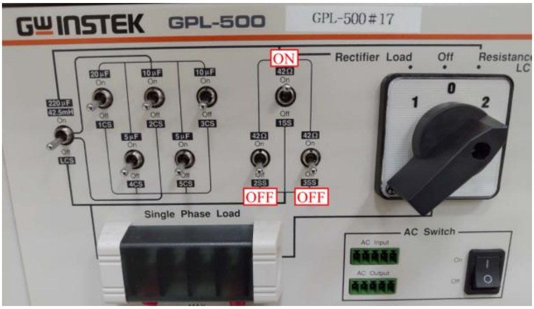
The power state of PSW and APS-300 when no load

(8) Light Load (42 Ohm)

As the figure 5.13 shown, follow the steps below for GPL-500 operation. Set 1SS as ON, and 2SS, 3SS as OFF, which indicates light-load mode.

Figure 5.13

The light-load setting of GPL-500



As the figure 5.14 shown, under the light-load mode, PSW output power is 97W and load consumes partial power followed by feedforward the redundant power to grid power. Therefore, it is clear that APS power is -50.4W.

Figure 5.14

The power state of PSW and APS-300 when light load

(9) Mid Load (21 Ohm)

As the figure 5.15 shown, follow the steps below for GPL-500 operation. Set 1SS and 2SS as ON, and 3SS as OFF, which indicates mid-load mode.

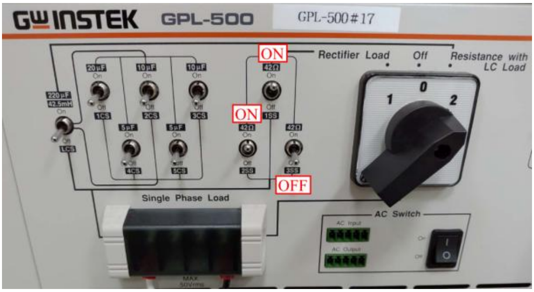


Figure 5.15

The mid-load setting of GPL-500

As the figure 5.16 shown, under the mid-load mode, PSW output power is 97W and load consumes more power followed by feedforward less power to grid power. Therefore, it is clear that APS power is -14.0W.

Figure 5.16

The power state of PSW and APS-300 when mid load

(10) Full Load (14 Ohm)

As the figure 5.17 shown, follow the steps below for GPL-500 operation. Set 1SS, 2SS and 3SS as ON, which indicates full-load mode.

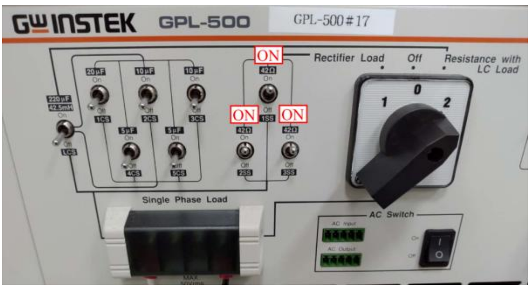


Figure 5.17

The full-load setting of GPL-500

As the figure 5.18 shown, under the full-load mode, PSW output power is 97W and the power provided by inverter is insufficient to afford to load consuming. The grid power will instead compensate the insufficient portion for keeping power balance. Therefore, it is clear that APS power is 22.3W.

Figure 5.18

The power state of PSW and APS-300 when full load

After the experiment, power off PEK-510 followed by turning off PSW, APS-300 and GPL-500.

Fill in the table 5.1 with the power of PSW and APS-300 under no load, light load, mid load and full load, individually.

Table 5.1 Power states of PSW and APS-300 in varied load settings.

Load Power	PSW Output Power	APS Output Power	(Considering component loss)
No Load (0W)	97W	-87.6W	97 + (-87.6) ≑ 0
Light Load (38W)	97W	-50.40W	97 +(-50.4) ≑ 38
Mid Load (76W)	97W	-14.0W	97 +(-14.0) ≑ 76
Full Load (112W)	97W	22.3W	97 + 22.3 ≑ 112

The Conclusion

This experiment is the grid-connected inverter system in which when the power provided by inverter is greater than the requirement of load, the power will be feedforward back to grid power. In contrast, when the power provided by inverter is insufficient to afford to load consuming, the grid power will instead compensate the insufficient portion required by load for keeping power balance.

Experiment 6 – Single Phase PV Grid-connected Inverter

Circuit Simulation

The circuit parameters of system are as follows:

DC Input Voltage V_b = 50V

DC bus Voltage V_d = 80V

AC Source Voltage V = 40V_{rms}

F_s = 40kHz，V_{tri} = 5V_{pp} (Boost PWM)

F_s = 20kHz，V_{tri} = 10V_{pp} (Inverter PWM)

L_b = 661.5uH，C_{BUS} = 300uF

L = 661.5uH，C = 10uF

K_s = 0.3 (AC current sensing factor)

K_s = 0.6 (DC current sensing factor)

K_v = 1/80 (AC voltage sensing factor)

K_v = 1/40 (DC voltage sensing factor)

The analogue circuit diagram based on the parameters above is as the following figure 6.1 shown:
PSIM File: PEK-510_Sim6_1P_PV_GC_Inv(50Hz)_V11.1.5_V1.1

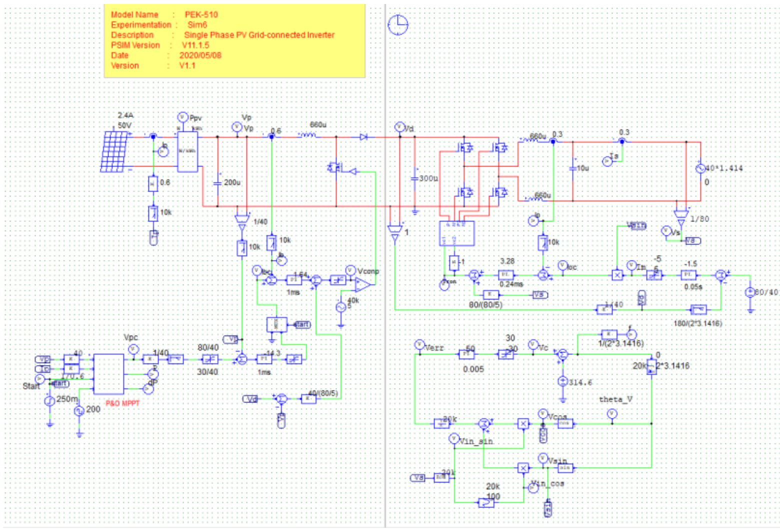


Figure 6.1 Experiment 6 PSIM analogue circuit diagram

The simulation result is shown within the figure 6.2:

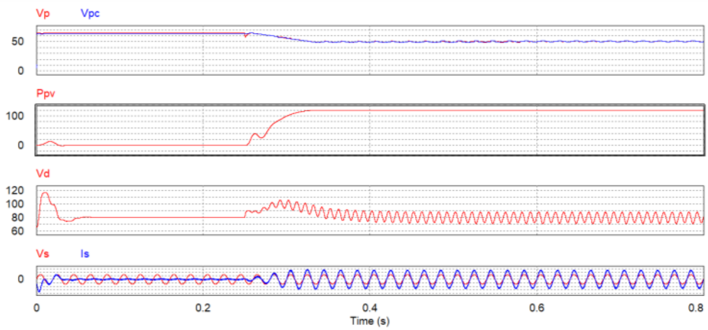


Figure 6.2 Experiment 6 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is as the following figure 6.3 shown:
PSIM File: PEK-510_Lab6_1P_PV_GC_Inv(50Hz)_V11.1.5_V1.1

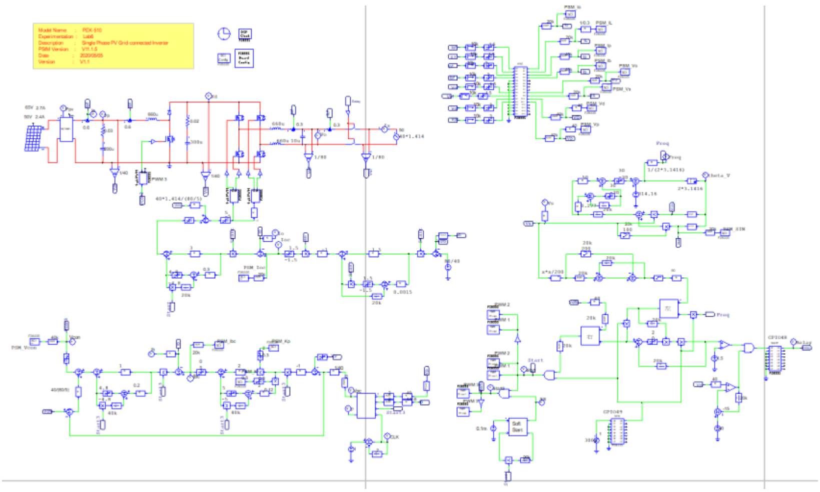


Figure 6.3 Experiment 6 PSIM digital circuit diagram

Due to the actually generated Code circuit with MPPT adjusted frequency of 2Hz, it is time-consuming for simulation which is based on this file. Hence, we provide another digital circuit, ”PEK-510_Sim6D_1P_PV_GC_Inv(50Hz)_V11.1.5_V1.1”, of MPPT adjusted frequency of 100Hz for simulation, which generates simulation result in a shorter period of time. Refer to the figure 6.4 for simulation result.

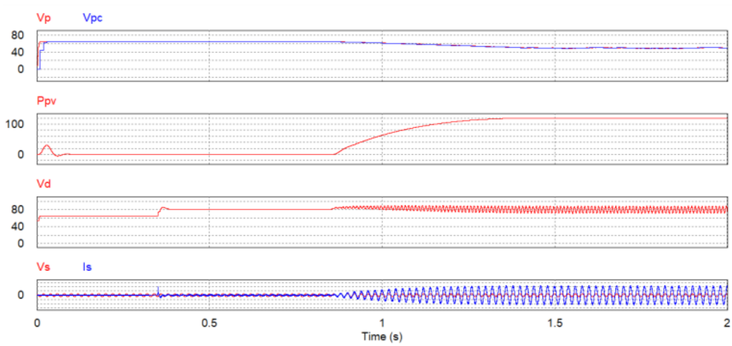


Figure 6.4 Experiment 6 digital circuit simulation waveforms

After confirming simulation, the corresponding C Code will be generated automatically via “Generate Code” of “Simulate”.

Experiment Devices

The required devices for experiment are as follows:

- PEK-510 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2, APS-300 and GPL-500)
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 6.5. Please follow it to complete wiring.

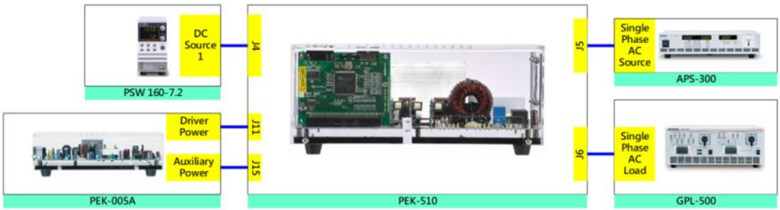
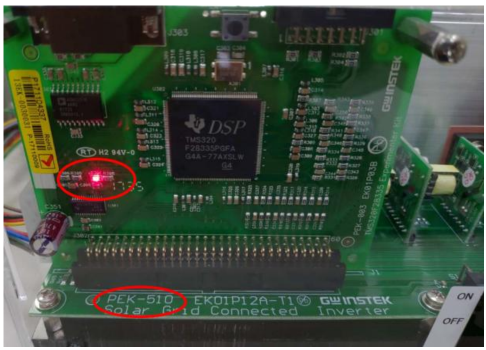


Figure 6.5 Experiment 6 wiring figure

2. After wiring, make sure the PEK-510 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 6.6 shown, which means the DSP power is steadily normal.

Figure 6.6

DSP normal status with light on



3. Refer to the appendix B for burning procedure.
4. Refer to the appendix D – SAS software operation manual for PV system setting process in simulation. As the figure 6.7 shown, the open circuit voltage of first curve is 65V, and the short circuit current is 2.7A with the MPP voltage 50V along with the MPP current 2.4A. As the figure 6.8 shown, the value of second curve is set 90% of the first curve. The open circuit voltage of the second curve, therefore, is 58.5V, and the short circuit current is 2.43A with the MPP voltage 45V along with the MPP current 2.16A.

Figure 6.7

The 1st curve setting value

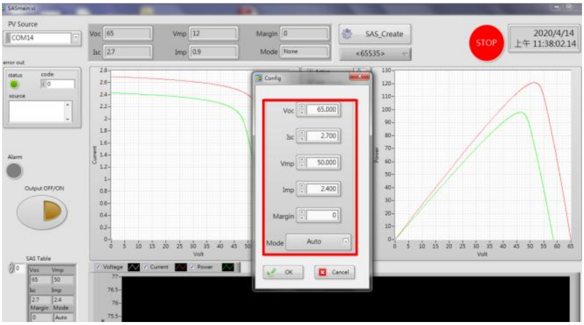
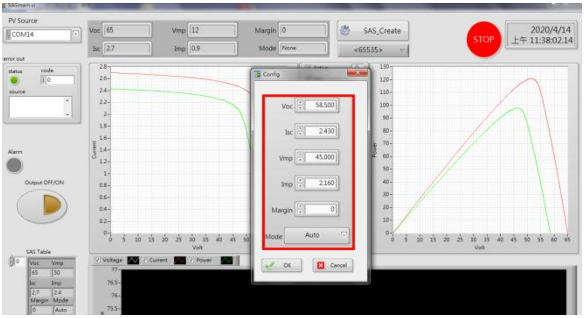


Figure 6.8

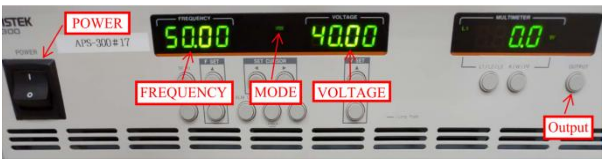
The 2nd curve setting value



5. As the figure 6.9 shown, follow the steps below for APS-300 operation. Power on APS-300 → Set APS-300 frequency as 50Hz → Set operation mode as 1P2W → Set voltage as 40V.

Figure 6.9

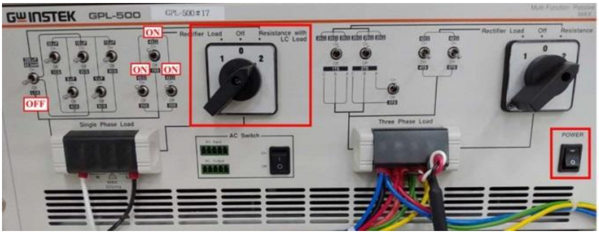
The settings of APS-300



6. As the figure 6.10 shown, follow the steps below for GPL-500 operation. Power on GPL-500 → Rotate the Single Phase Lord knob to 2 (Resistance with LC Load) → Set 1SS, 2SS and 3SS as ON, and LCS as OFF, which indicates full-load mode.

Figure 6.10

The full-load setting of GPL-500



7. After setting, launch PSW output via SAS program followed by enabling APS-300 output and finally turn on the switch of PEK-510.

The purpose of experiment

We observe, via the MPPT control, if the output power of PV curve can reach the highest utilization rate.

The experiment result

As the figure 6.11 and 6.12 shown, it has seen that, from the SAS program, the first curve output power will rise gradually from the initial startup to the maximum power point eventually.

Figure 6.11

SAS exists in the initial startup of the 1st curve

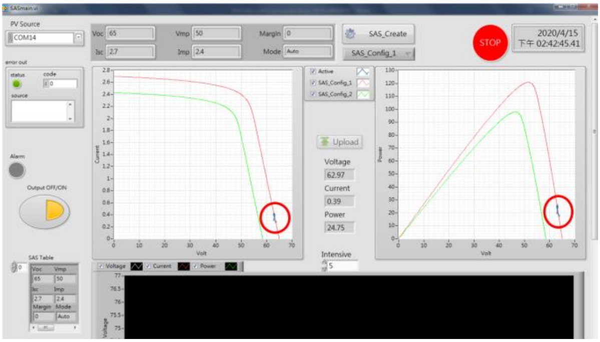
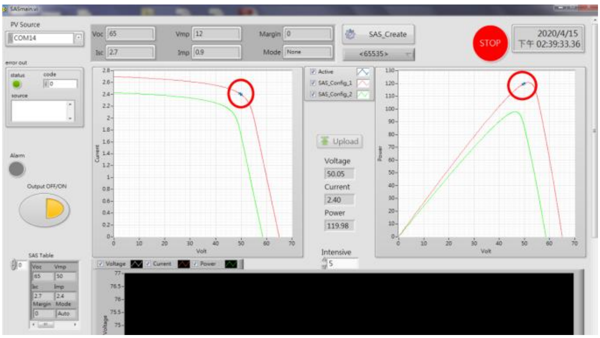


Figure 6.12

SAS exists in the maximum power point of the 1st curve



As the figure 6.13, 6.14 shown, it is evident from the power supply that output power is rising gradually from the SAS initial state to the maximum power point eventually.

Figure 6.13

Power supply exists in the initial startup of the 1st curve

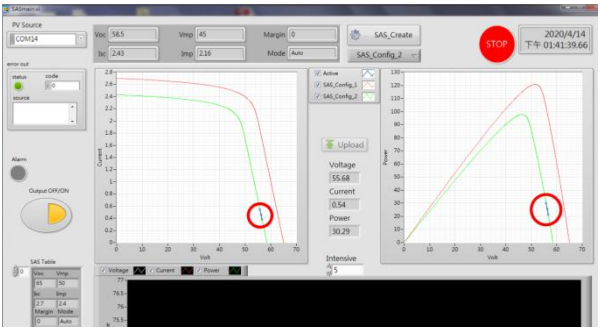
Figure 6.14

Power supply exists in the maximum power point of the 1st curve

As the figure 6.15 and 6.16 shown, the 2nd curve is generated due to the I-V and P-V curves, both of which are influenced by external factors. Although the output power drops off abruptly, it keeps rising gradually to the maximum power point eventually.

Figure 6.15

The state of switch to the 2nd curve



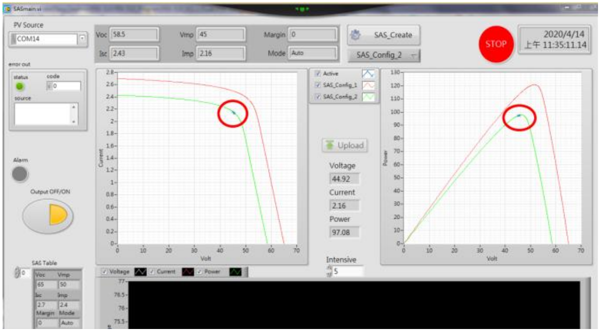


Figure 6.16

SAA exists in the maximum power point of the 2nd curve

As the figure 6.17 and 6.18 shown, it is evident from the power supply that although the power drops off abruptly when switch to the 2nd curve, it keeps rising gradually to the maximum power point eventually.

Figure 6.17

The abrupt switch state of the 2nd curve of power supply

Figure 6.18

Power supply exists in the maximum power point of the 2nd curve

The Conclusion

The experiment circuit with the first-stage structure of boost converter and the second-stage structure of single phase inverter will change PV curve, due to the intensifying lights and external impacts on PV power panel, in order to reach the full utilization rate. Via the MPPT function, boost circuit is able to maintain the highest power output for PV power panel. Even though PV curve will be influenced by external environment, the highest utilization rate can be met still. The single phase, on the other hand, connecting with power grid in parallel, passes the power on to load and grid power.

Experiment 7 – PQ Control of Single-phase PV Grid-connected Inverter

Circuit Simulation

The circuit parameters of system are as follows:

DC Input Voltage V_b = 50V

DC bus Voltage V_d = 80V

AC Source Voltage V = $40V_{rms}$

F_s = 40kHz，V_{tri} = $5V_{pp}$ (Boost PWM)

F_s = 20kHz，V_{tri} = $10V_{pp}$ (Inverter PWM)

L_b = 661.5uH，C_{BUS} = 300uF

L = 661.5uH，C = 10uF

K_s = 0.3 (AC current sensing factor)

K_s = 0.6 (DC current sensing factor)

K_v = 1/80 (AC voltage sensing factor)

K_v = 1/40 (DC voltage sensing factor)

The analogue circuit diagram based on the parameters above is as the following figure 7.1 shown:
PSIM File: PEK-510_Sim7_1P_PV_GC_Inv_PQ(50Hz)_V11.1.5_V1.1

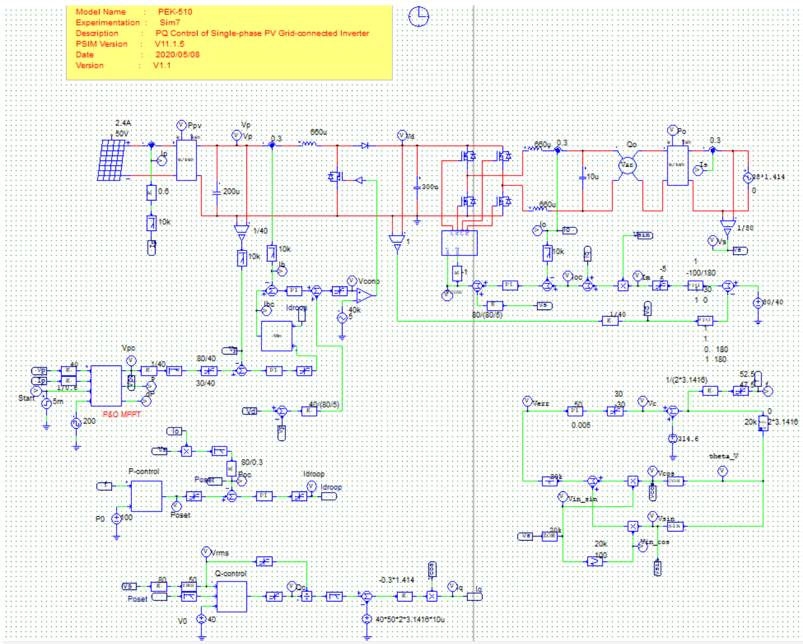


Figure 7.1 Experiment 7 PSIM analogue circuit diagram

The simulation result is shown within the figure 7.2:

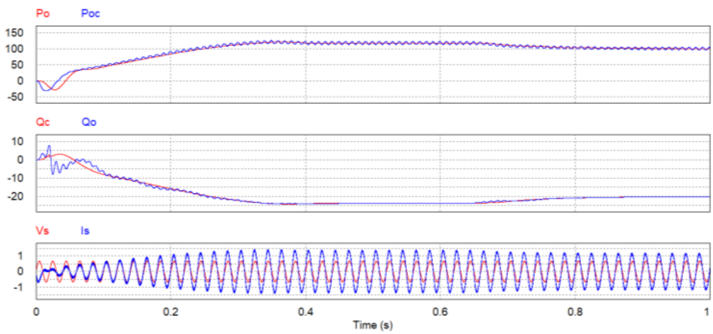


Figure 7.2 Experiment 7 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is shown as the figure 7.3:
PSIM File: PEK-510_Lab7_1P_PV_GC_Inv_PQ(50Hz)_V11.1.5_V1.1

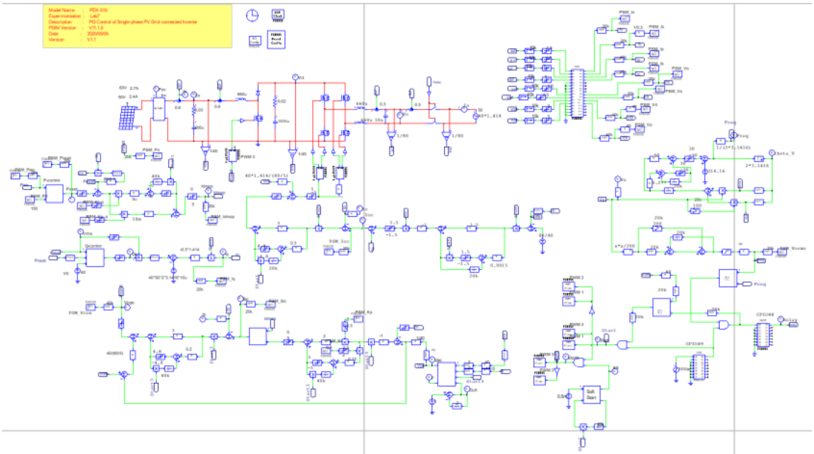


Figure 7.3 Experiment 7 PSIM digital circuit diagram

Because the generated Code circuit with MPPT adjusted frequency 2Hz consumes much longer time for simulation, we instead provide the other digital circuit, “PEK-510_Sim7D_1P_PV_GC_Inv_PQ(50Hz)_V11.1.5_V1.1”, which is set 110 in PSM_PO value with adjusted MPPT frequency 100Hz for simulation that consumes less time for practical result. Refer to the figure 7.5 & 7.6 for the simulation result.

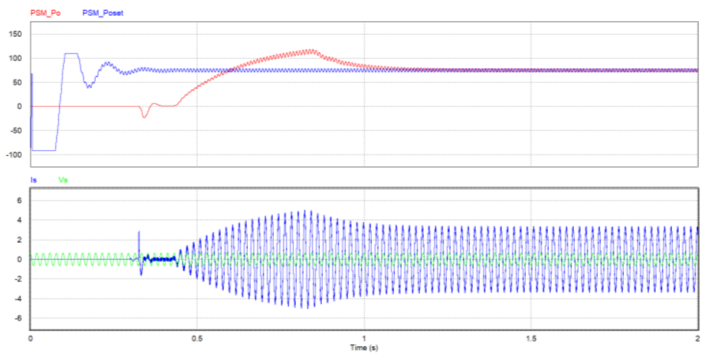


Figure 7.4 Experiment 7 digital circuit simulation waveforms

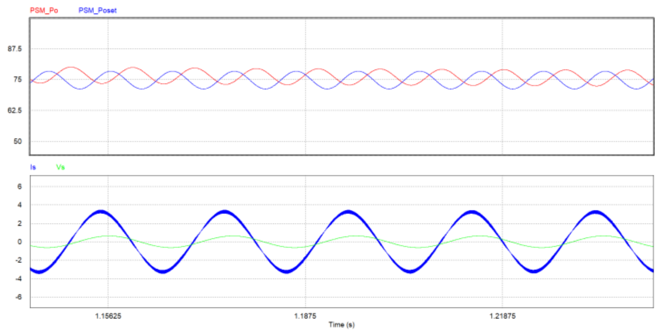


Figure 7.5 Experiment 7 digital circuit simulation waveforms

After confirming simulation, the corresponding C Code will be generated automatically via “Generate Code” of “Simulate”.

Experiment Devices

The required devices for experiment are as follows:

- PEK-510 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2, APS-300 and GPL-500)
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 7.6. Please follow it to complete wiring.

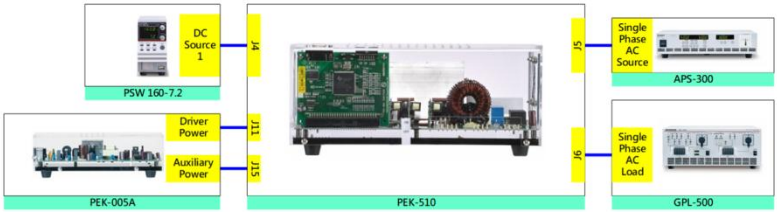
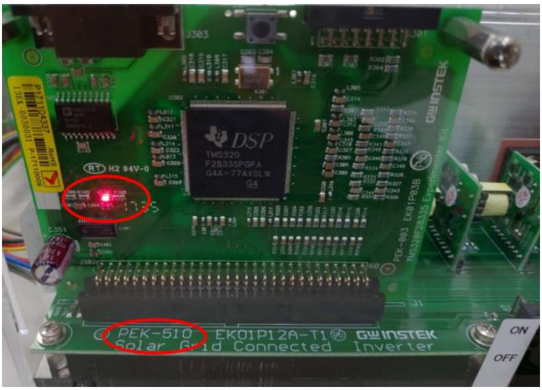


Figure 7.6 Experiment 7 wiring figure

2. After wiring, make sure the PEK-510 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 7.7 shown, which means the DSP power is steadily normal.

Figure 7.7

DSP normal status with light on

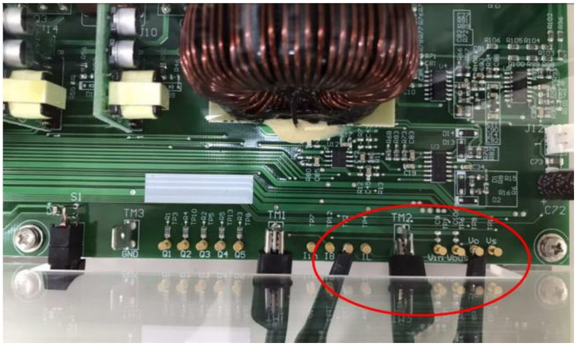


3. Refer to the appendix B for burning procedure.

4. Connect the test leads of oscilloscope to VO and IO, respectively, as the figure 7.8 shown.

Figure 7.8

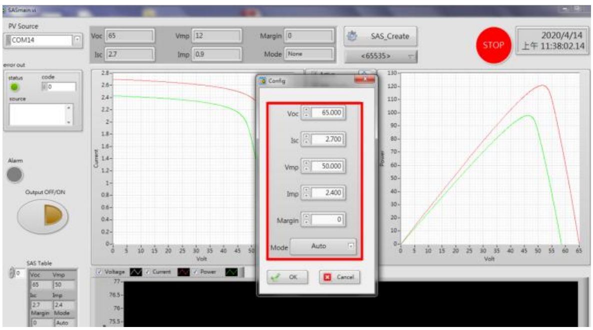
Oscilloscope test leads wiring



5. Refer to the appendix D – SAS software operation manual for the setting process of simulation PV panel. As the figure 7.9 shown, the open circuit voltage of the 1st curve is 65V, and the short circuit current is 2.7A, and the maximum power point voltage is 50V, and the maximum power point current is 2.4A. As the figure 7.10 shown, value of the 2nd curve is set at 90% of that of the 1st curve, and therefore the 2nd curve open circuit is of values as follows: 58.5V in open circuit voltage, 2.43A in short circuit current, 45V in maximum power voltage and 2.16A in maximum power current.

Figure 7.9

Set value of the 1st curve



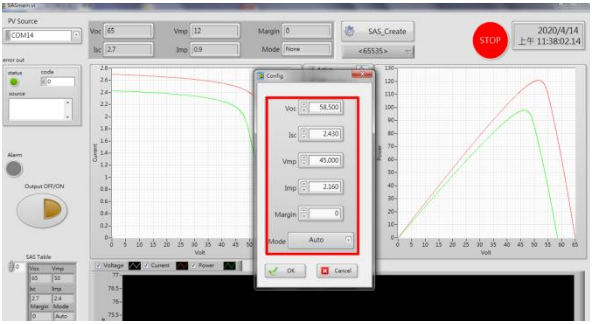


Figure 7.10

Set value of the 2nd curve

6. The operation process of APS-300 is shown as the figure 7.11. Power on APS-300 → Set 50Hz for APS-300 frequency → Set operation mode as 1P2W → Set output voltage as 40V.

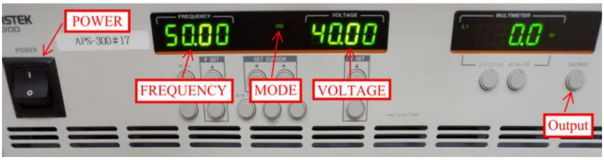


Figure 7.11

APS-300 settings

7. As the figure 7.12 shown, follow the steps below for GPL-500 operation. Power on GPL-500 → Rotate the Single Phase Lord knob to 2 (Resistance with LC Load) → Set 1TS, 2TS and 3TS as ON, and LCS as OFF, which indicates full-load mode.

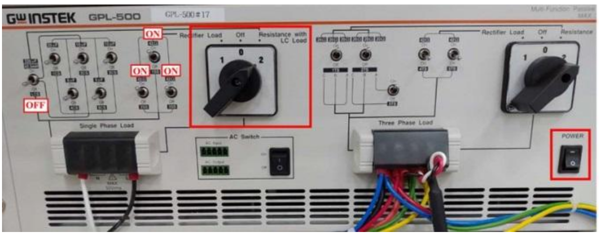


Figure 7.12

GPL-500 full-load setting

8. Proceed to connection steps in accordance with the appendix C – RS232 Connection.

9. After setting, launch PSW output via SAS program followed by enabling APS-300 output and finally turn on the switch of PEK-510

The purpose of experiment

This experiment is for Smart Inverter application. When either voltage or frequency fluctuation occurs in grid power, the inverter, in accord with present situation, adjusts power output (real power or reactive power) via PQ controller of system.

The experiment result

(11) Real Power Control (P-ω)

As the figure 7.13 shown, the system output power limitation, PSM_Poset, is 150W, and similarly the default power set value, PSM_P0, is 150W. When system reaches the maximum power point of the 1st curve, the inverter output power, PSM_Po, is 100W approximately. Because it is way difficult to change PSM_Poset in order to lower down PSM_Po output via the droop control which adjusts ω,the set value of PSM_P0 is adjusted to 110 accordingly in an effort to make PSM_Poset close to PSM_Po. As the figure 7.14 shown, the ω is adjusted to proceed to the droop control.

Figure 7.13

PSM_PO is set 150

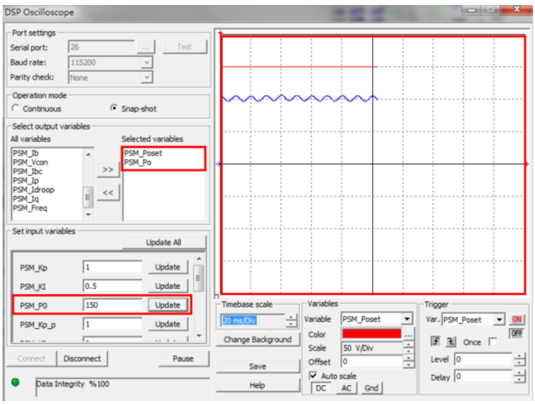
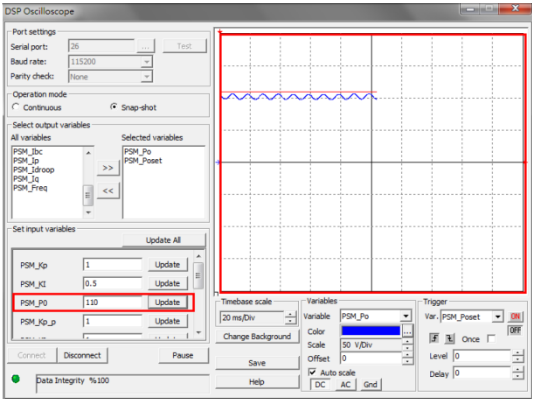


Figure 7.14

PSM_PO is set 110



As the figure 7.15 and 7.16 shown, it is evident that, from the SAS program, the 1st curve will rise gradually from the initial startup to the maximum power point eventually.

Figure 7.15

SAS exists in the initial startup of the 1st curve

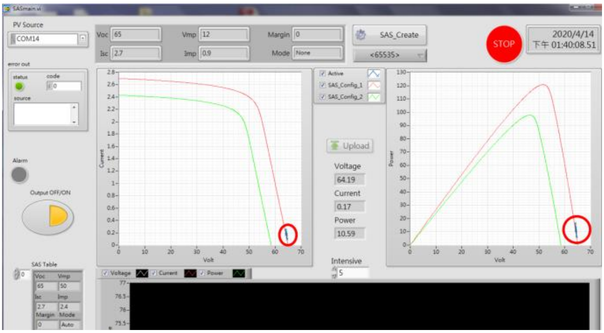
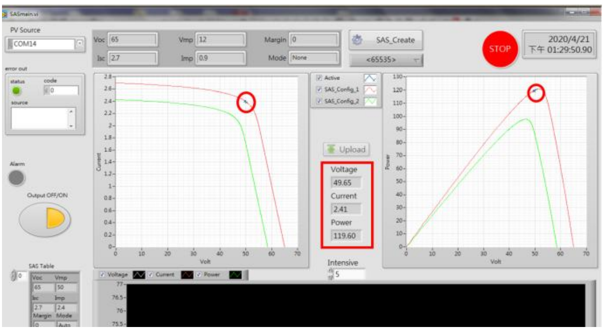


Figure 7.16

SAS exists in the maximum power point of the 1st curve



As the figure 7.17 shown, adjust frequency of APS-300 to 51Hz. As the figure 7.18 shown, PSM_Poset descends due to ω rising, and PSM_Po reduces accordingly. As the figure 7.19 shown, when system no longer outputs based on the maximum power, the PV curve must deviate from the maximum power point in order to maintain balance.

Figure 7.17

APS-300 set in 51Hz

Figure 7.18

PSM_Poset and PSM_Po change due to wrising

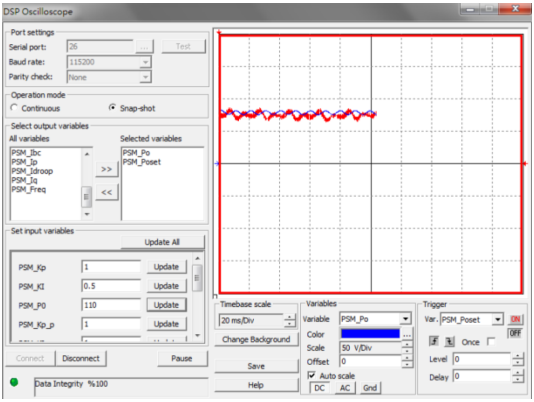
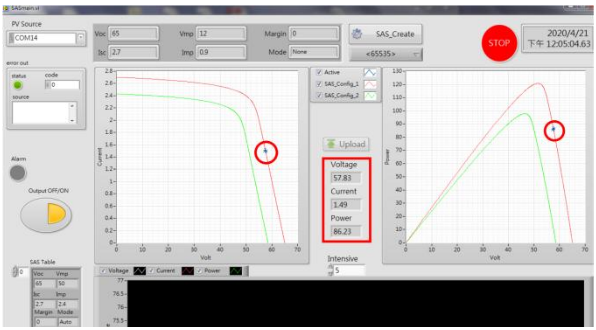


Figure 7.19

SAS deviates from the maximum power point



As the figure 7.20 and 7.21 shown, it is evident that when APS-300 frequency is adjusted from 50Hz to 51Hz, the inverter output current lowers down from 2.07A (2.588A in actual value) to 1.53A (1.913A in actual value), which indicates output power decreases accordingly.

Figure 7.20

The inverter output voltage current waveforms when APS-300 frequency is 50Hz

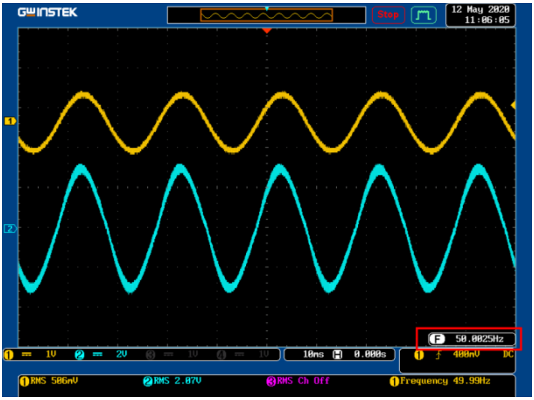
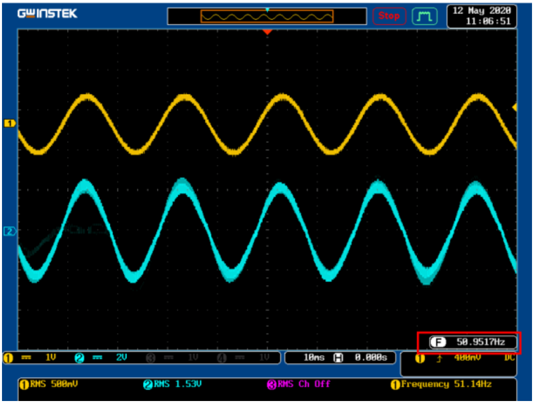


Figure 7.21

The inverter output voltage current waveforms when APS-300 frequency is 51Hz



As the figure 7.22 shown, the PV curve changes from the 1st one to the 2nd one and the output power drops down transiently when APS-300 frequency is 51Hz. As the figure 7.23 shown, even though output power drops down transiently, it will rise gradually to the power point in the proximity of the 1st curve.

Figure 7.22

SAS exists in the transience of switch to the 2nd curve

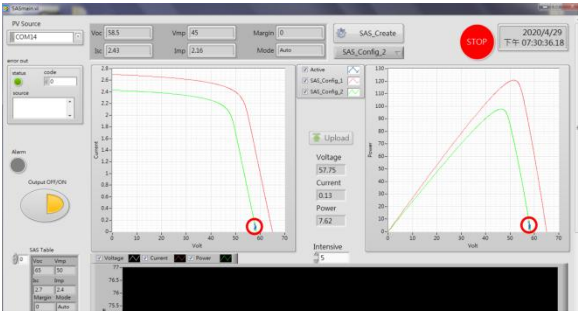
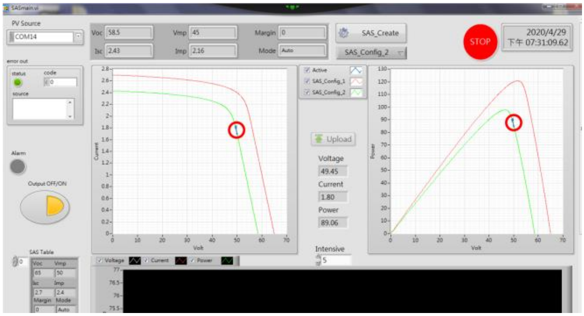


Figure 7.23

SAS exists in the power output of the 2nd curve (not the maximum power point)



(12) Reactive Power Control (Q-V)

As the figure 7.24 shown, when APS-300 output voltage is 40V, no reactive power is output from inverter. As the figure 7.25 shown, it is seeable that PSM_Vs has no phase difference with PSM_Is from DSP oscilloscope. As the figure 7.26 shown, it is available to observe from the actual circuit.

Figure 7.24

APS-300 voltage is set 40V

Figure 7.25

DSP oscilloscope voltage and current waveforms when grid power voltage is 40V

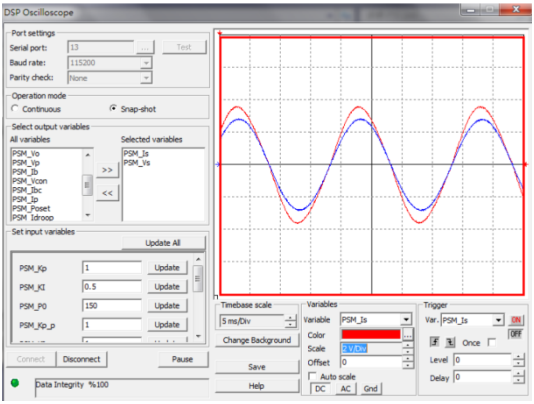
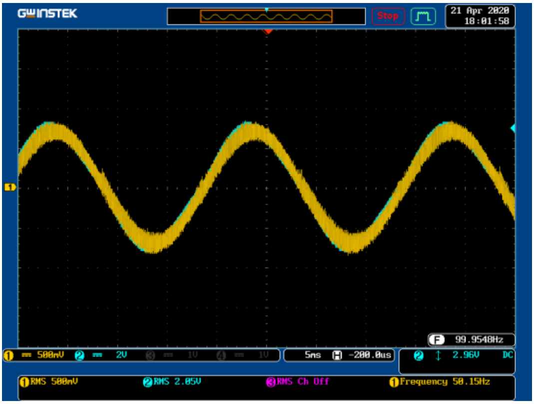


Figure 7.26

Oscilloscope voltage and current waveforms when grid power voltage is 40V



As the figure 7.27 shown, when APS-300 output voltage is adjusted to 36V, reactive power is generated by inverter. As the figure 7.28 shown, it is seeable that PSM_Vs has phase difference with PSM_Is and PSM_Is is getting ahead of PSM_Vs. As the figure 7.29 shown, it is available to observe from the actual circuit.

Figure 7.27

APS-300 voltage is set 36V

Figure 7.28

DSP oscilloscope voltage and current waveforms when grid power voltage is 36V

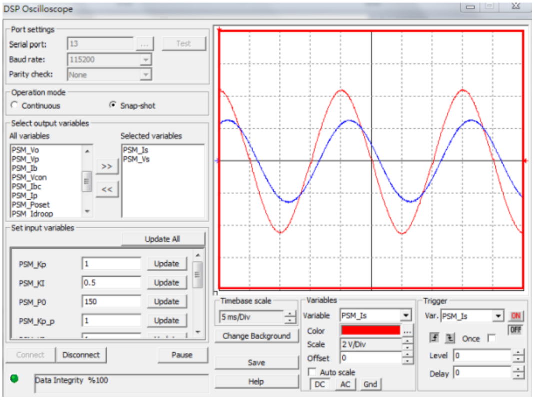
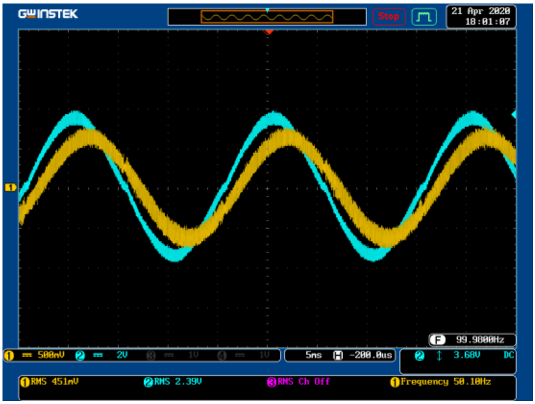


Figure 7.29

Oscilloscope voltage and current waveforms when grid power voltage is 36V



As the figure 7.30 shown, when APS-300 output voltage is adjusted to 44V, reactive power is generated by inverter. As the figure 7.31 shown, it is seeable that PSM_Vs has phase difference with PSM_Is and PSM_Is is behind PSM_Vs. As the figure 7.32 shown, it is available to observe from the actual circuit.

Figure 7.30

APS-300 voltage is set 44V

Figure 7.31

DSP oscilloscope voltage and current waveforms when grid power voltage is 44V

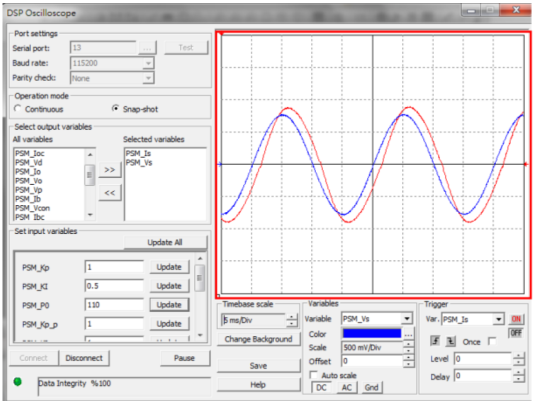
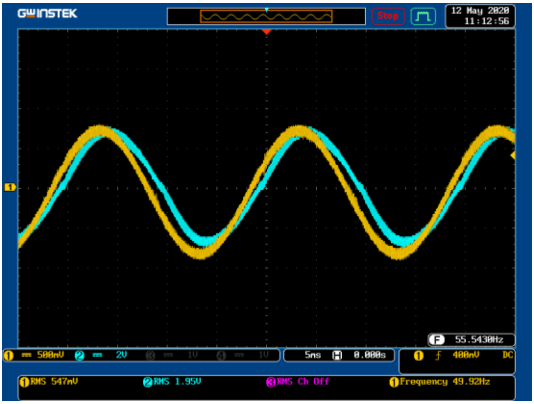


Figure 7.32

Oscilloscope voltage and current waveforms when grid power voltage is 44V



The Conclusion

From the experiment it is evident that when grid power frequency is rising, inverter lowers down the output power scale in accordance with the scale of frequency fluctuation. When, however, grid power voltage fluctuates, inverter adjusts the scale of output reactive power in accordance with the scale of voltage fluctuation.

Experiment 8 – Single Phase Islanding Protection Inverter

Circuit Simulation

The circuit parameters of system are as follows:

DC bus Voltage V_d = 80V

AC Source Voltage V = $40V_{rms}$

F_s = 20kHz，V_{tri} = $10V_{pp}$ (PWM)

L = 661.5uH，C = 10uF

K_s = 0.3 (AC current sensing factor)

K_v = 1/80 (AC voltage sensing factor)

K_v = 1/40 (DC voltage sensing factor)

The analogue circuit diagram based on the parameters above is as the following figure 8.1 shown:
PSIM File: PEK-510_Sim8_1P_Islanding_Prot_Inv(50Hz)_V11.1.5_V1.1

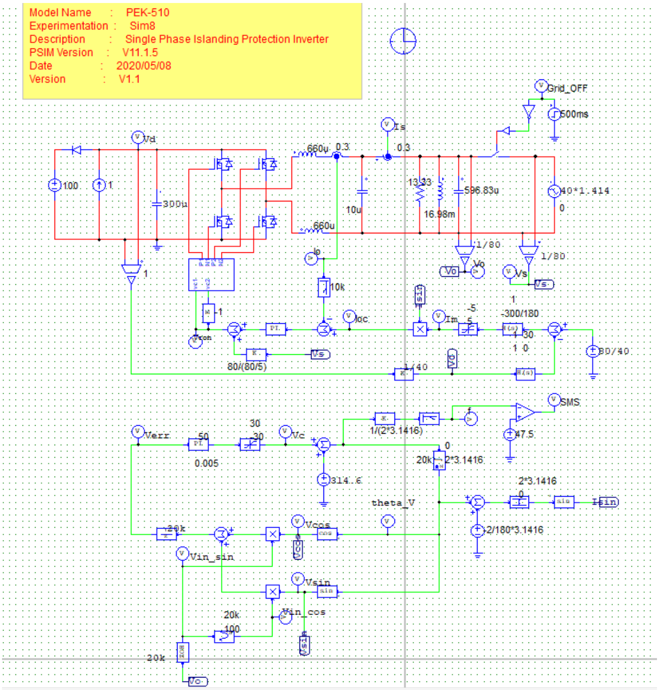


Figure 8.1 Experiment 8 PSIM analogue circuit diagram

The simulation result is shown within the figure 8.2:

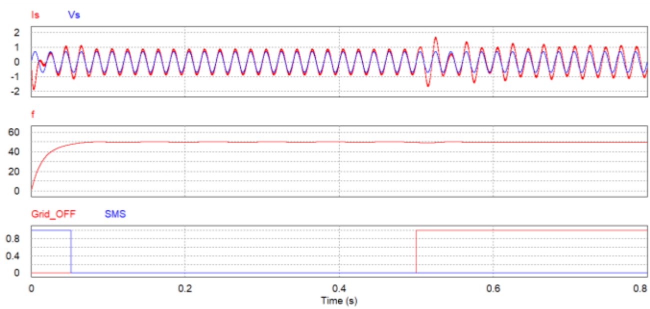


Figure 8.2 Experiment 8 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is as the following figure 8.3 shown:
PSIM File: PEK-510_Lab8_1P_Islanding_Prot_Inv(50Hz)_V11.1.5_V1.1

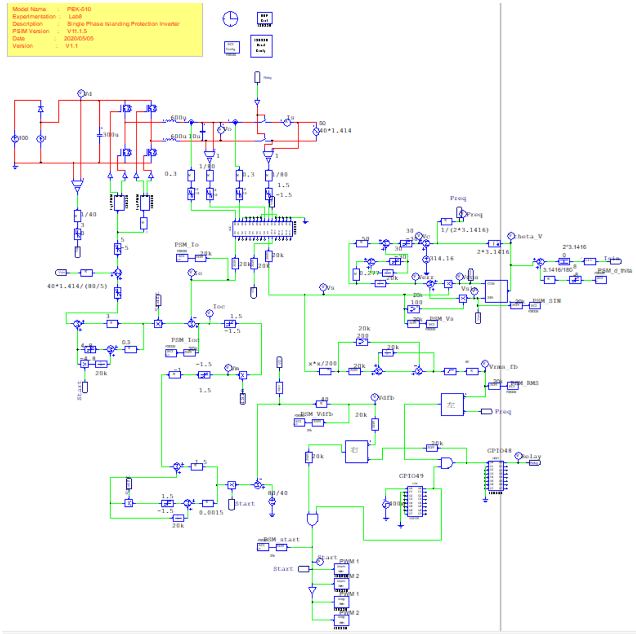


Figure 8.3 Experiment 8 PSIM digital circuit diagram

The simulation result is shown within the figure 8.4:

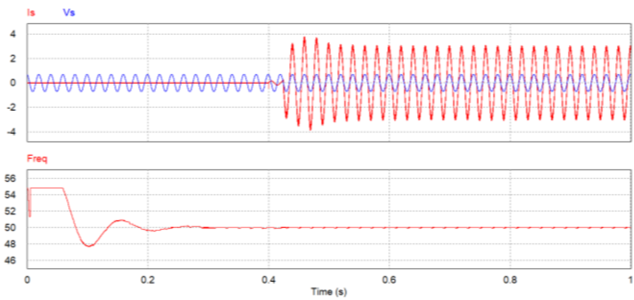


Figure 8.4 Experiment 8 digital circuit simulation waveforms

After confirming simulation, the corresponding C Code will be generated automatically via “Generate Code” of “Simulate”.

Experiment Devices

The required devices for experiment are as follows:

- PEK-510 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2, APS-300 and GPL-500)
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 6.5. Please follow it to complete wiring.

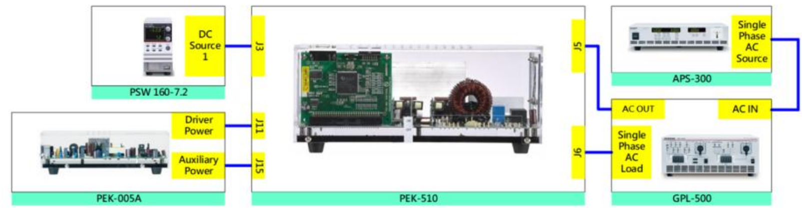
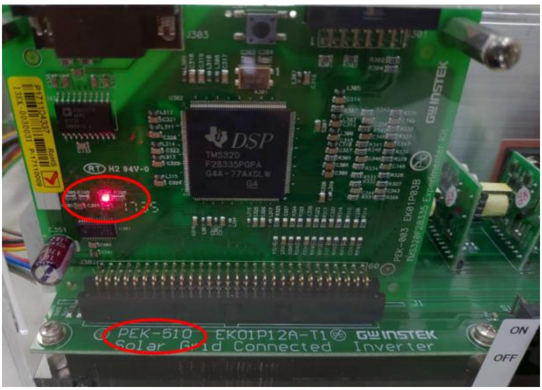


Figure 8.5 Experiment 8 wiring figure

2. After wiring, make sure the PEK-510 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 8.6 shown, which means the DSP power is steadily normal.

Figure 8.6

DSP normal status with light on

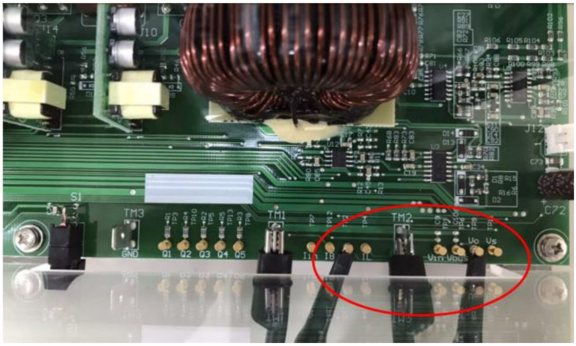


3. Refer to the appendix B for burning procedure and appendix C for RS232 connection.

4. Connect the test leads of oscilloscope to VO and IO, respectively, as the figure 1.8 shown.

Figure 8.7

Oscilloscope test leads wiring



5. Set voltage 100V and current 1.5A for PSW 160-7.2 as the figure 8.8 shown.

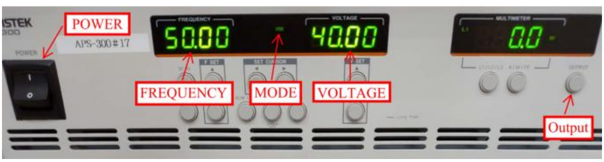
Figure 8.8

The settings of PSW

6. The operation process of APS-300 is shown as the figure 8.9. Power on APS-300 → Set 50Hz for APS-300 frequency → Set operation mode as 1P2W → Set output voltage as 40V.

Figure 8.9

APS-300 Settings

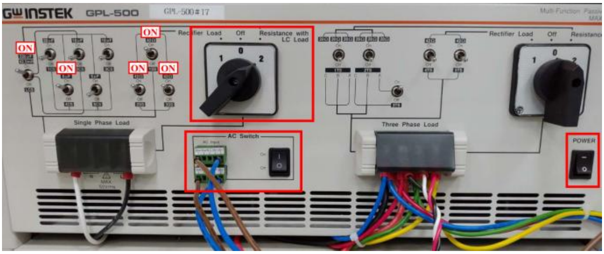


7. As the figure 8.10 shown, follow the steps below for GPL-500 operation. Power on GPL-500 → Rotate the Single Phase Lord knob to 2 (Resistance with LC Load) → Set 1SS, 2SS and 3SS as ON → Set LCS as ON → Set 4CS (capacitor 5uF) as ON

(capacitor setting per experiment requirement), which indicates RLC load mode → Turn ON AC Switch. As the figure 8.5 and 8.10 shown, connect APS-300 to AC Input followed by connecting single phase test leads from AC Output to PEK-510.

Figure 8.10

GPL-500 single phase RLC load setting



8. After setting up, turn on PSW and APS-300 output followed by powering on PEK-510 for test.

The purpose of experiment

This experiment simulates that when inverter and grid power are under operation in parallel, power outage occurs due to grid power breakdown. Because the inverter is under islanding effect and thus not able to escape, the Active Frequency Deviation detection (AFD) is employed to help inverter escape immediately.

The experiment result

(13) Non-built Islanding Effect

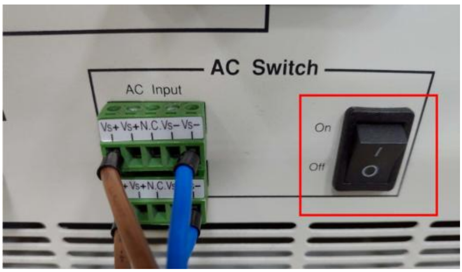
As the figure 8.11 shown, when PEK-510 is powered on, it is seeable that PSW provided power is 120W and APS-300 provided power is single phase 8.4W. As the figure 8.12 shown, when AC Switch is cut off (grid power input interrupt), the inverter will escape due to sensing grid power being cut off.

Figure 8.11

PSW and APS-300 power (PSW in 1.5A)

Figure 8.12

APS-300 cut off



(14) Built Islanding Effect

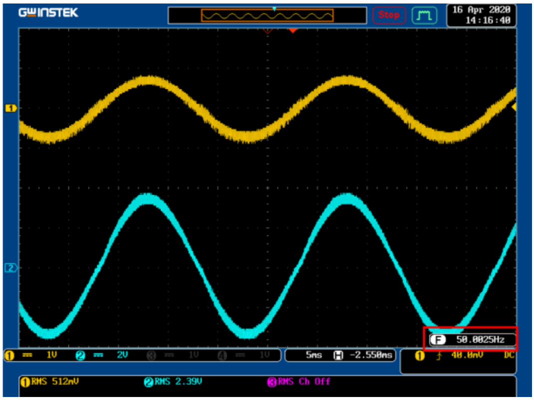
In order to build islanding effect, adjust APS-300 output power down to zero via adjusting PSW output power. As the figure 8.13 shown, APS-300 output power turns out zero when adjusting PSW output current to 1.6A and PSW output power to 130W. Under the aforementioned condition, when cutting off GPL-500 AC Switch, PEK-510 remains operation, which indicates the so-said islanding effect where inverter keeps operation still because it is not able to detect the cut-off grid power. As the figure 8.14 shown, it is evident that via VO the resonant frequency generated by system is 50Hz.

Figure 8.13

PSW & APS-300 power (PSW in 1.6A)

Figure 8.14

Output voltage frequency under islanding effect



When APS-300 output power is zero and AC Switch is cut off, PEK-510 escapes still, which indicates that the resonant frequency generated by system is not within the set range (it is set 48~52Hz for frequency in this experiment). Hence, it is required to turn off PEK-510 first followed by powering both PSW and APS-300 off. And then adjust the capacitors in parallel of GPL-500 subtly (1CS ~ 5CS). When completing fine-tuning for the capacitors in parallel, please repeat the previous steps in order until PEK-510 stops escaping. As the figure 8.15 shown, the capacitors in parallel adopted by this experiment are 4CS (5uF).

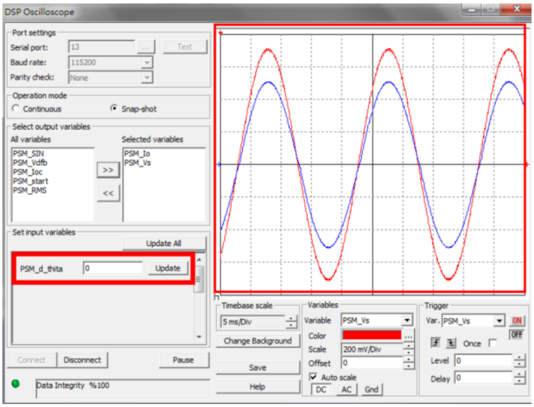
Figure 8.15

Capacitors in parallel setting

As the figure 8.16 shown, after islanding effect occurs, the deviation angle can be changed via adjusting command value PSM_d_thita (zero by default) from PSIM DSP oscilloscope.

Figure 8.16

Deviation angle (thita)



A. Deviation angle is 1

As the figure 8.17 shown, output voltage frequency is 50.48Hz.

B. Deviation angle is 4

As the figure 8.18 shown, output voltage frequency is 51.42Hz.

C. Deviation angle is 5

When output voltage frequency is greater than 52Hz, PEK-510 escapes then.

D. Deviation angle is -1

As the figure 8.19 shown, output voltage frequency is 49.91Hz.

E. Deviation angle is -6

As the figure 8.20 shown, output voltage frequency is 48.33Hz.

F. Deviation angle is -7

When output voltage frequency is greater than 48Hz, PEK-510 escapes then.

Figure 8.17

Deviation angle is 1

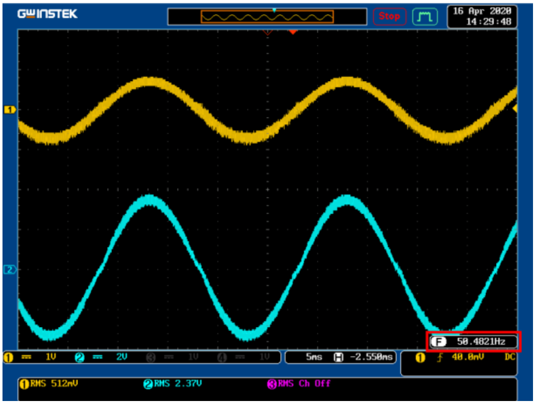


Figure 8.18

Deviation angle is 4

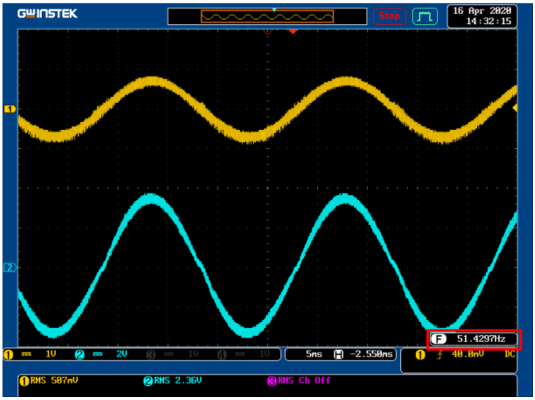


Figure 8.19

Deviation angle is -1

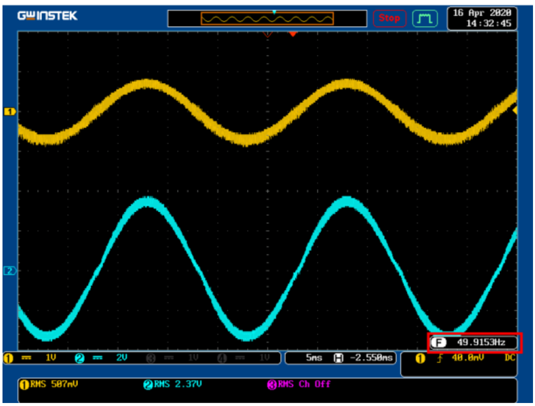
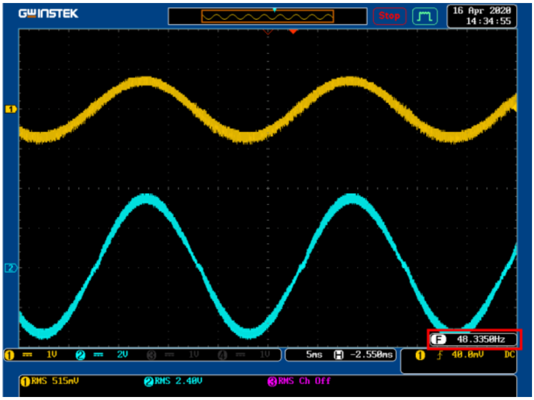


Figure 8.20

Deviation angle is -6



Fill in the table 8.1 with the varied deviation angles and the corresponding voltage frequencies.

Table 8.1 Deviation angles and output voltage frequencies

Deviation Angle	Output Voltage Frequency (Hz)
0	50.00Hz
1	50.48Hz
2	50.80Hz
3	51.11Hz
4	51.42Hz
-1	49.91Hz
-2	49.56Hz
-3	49.23Hz
-4	48.91Hz
-5	48.66Hz
-6	48.33Hz

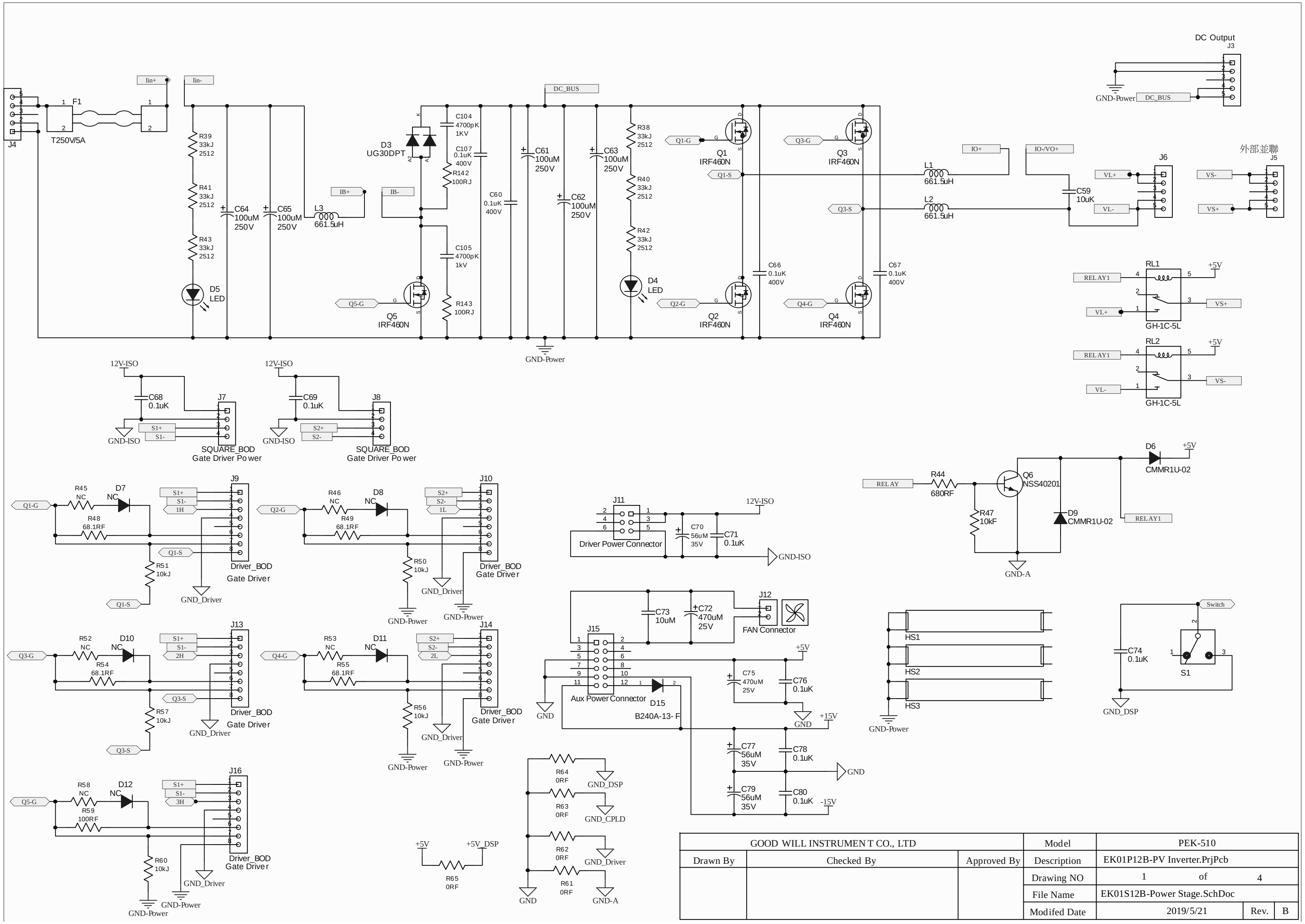
From the table 8.1, output voltage frequency increases gradually until PEK-510 escapes (output voltage frequency greater than 52Hz) in accord with the positive value increase of deviation angle. By contrast, output voltage frequency decreases gradually until PEK-510 escapes (output voltage frequency less than 48Hz) in accord with the negative value increase of deviation angle.

The Conclusion

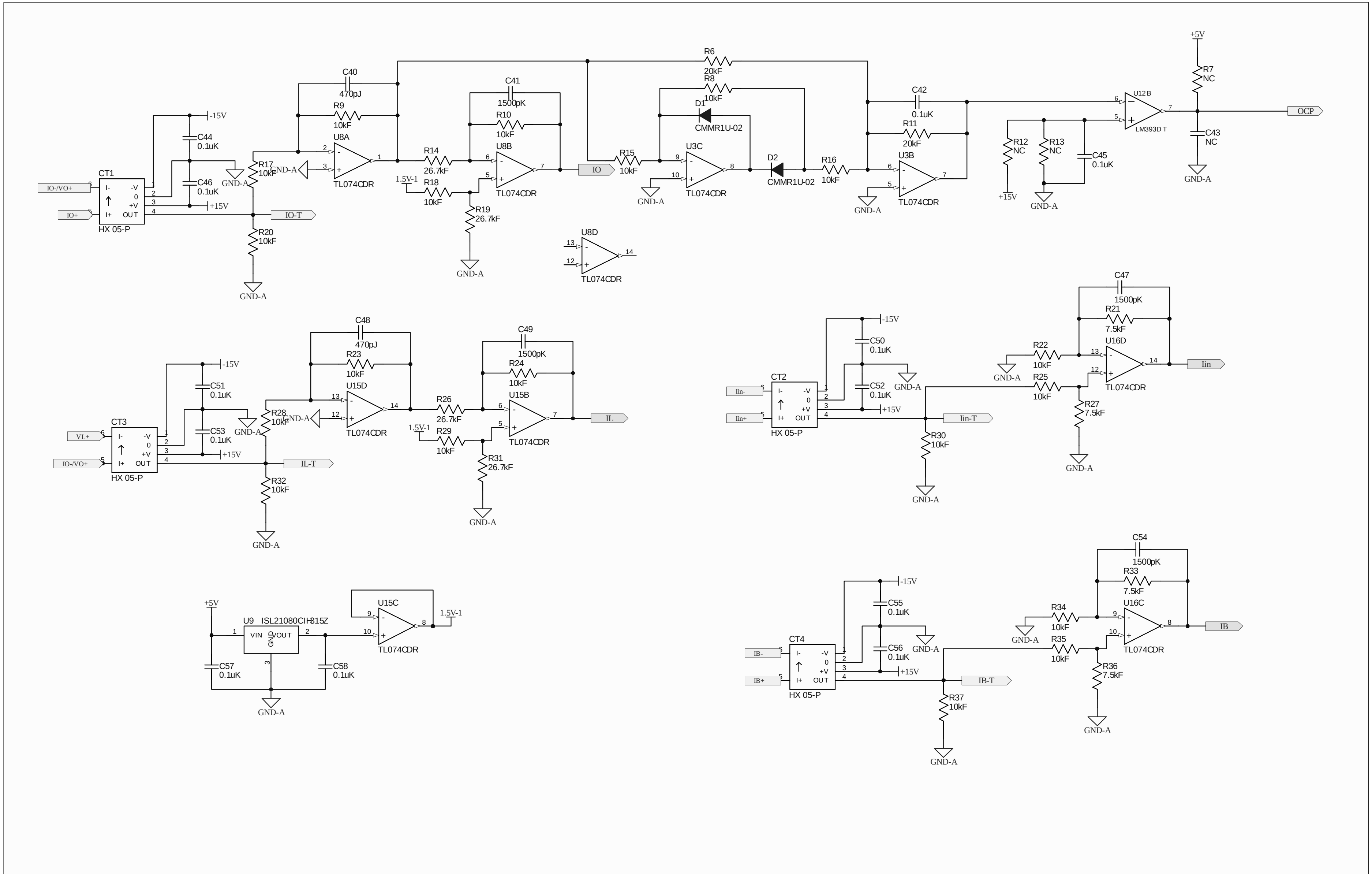
From the experiment, we can clearly realize that while system is under islanding effect, Active Frequency Deviation detection (AFD) is able to, via deviation angle adjustment, make frequency out of the range set by system in order to meet the exact function of islanding protection.

Appendix A – PEK-510 Circuit Diagram

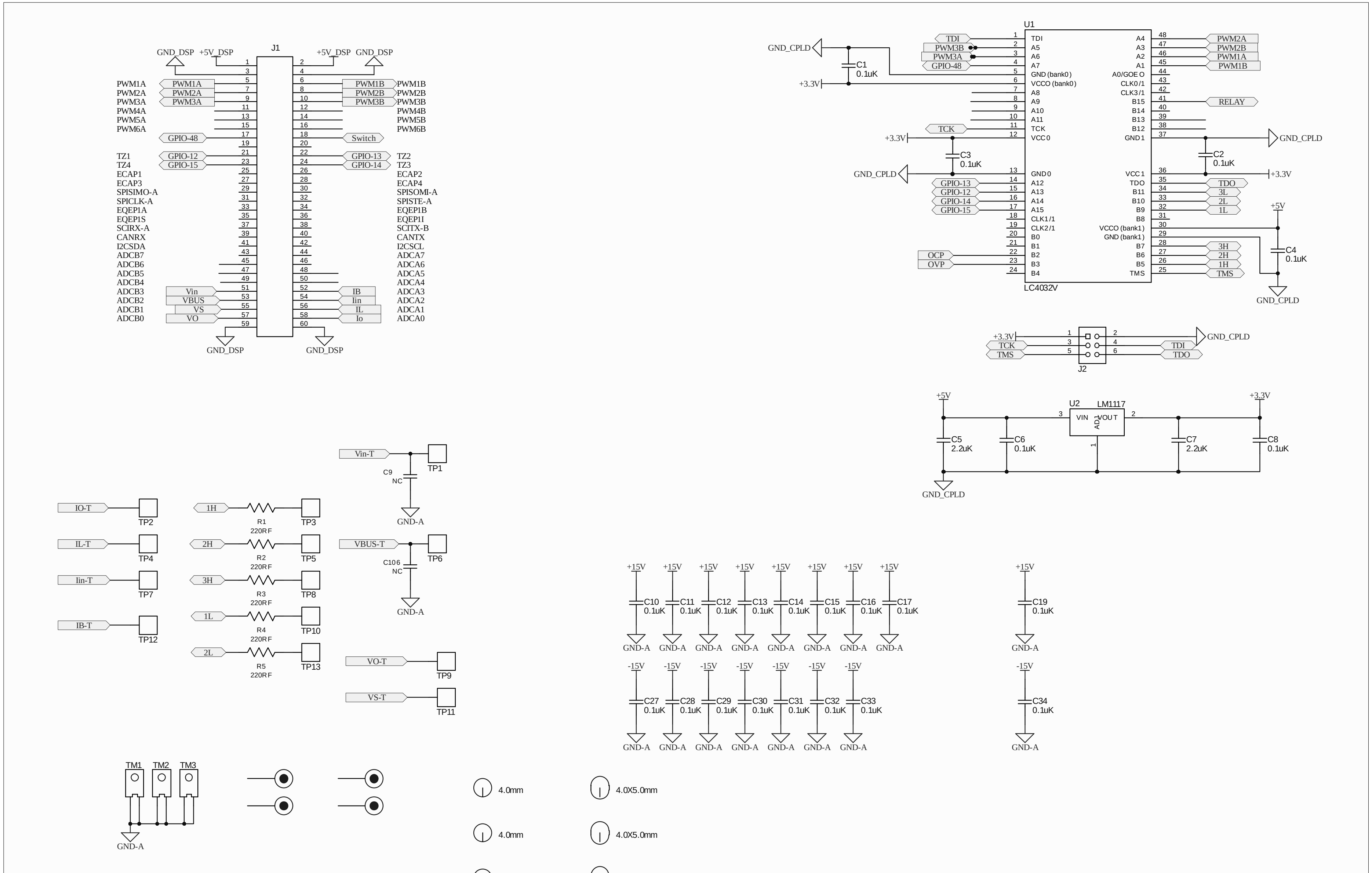
Single Phase PV Inverter



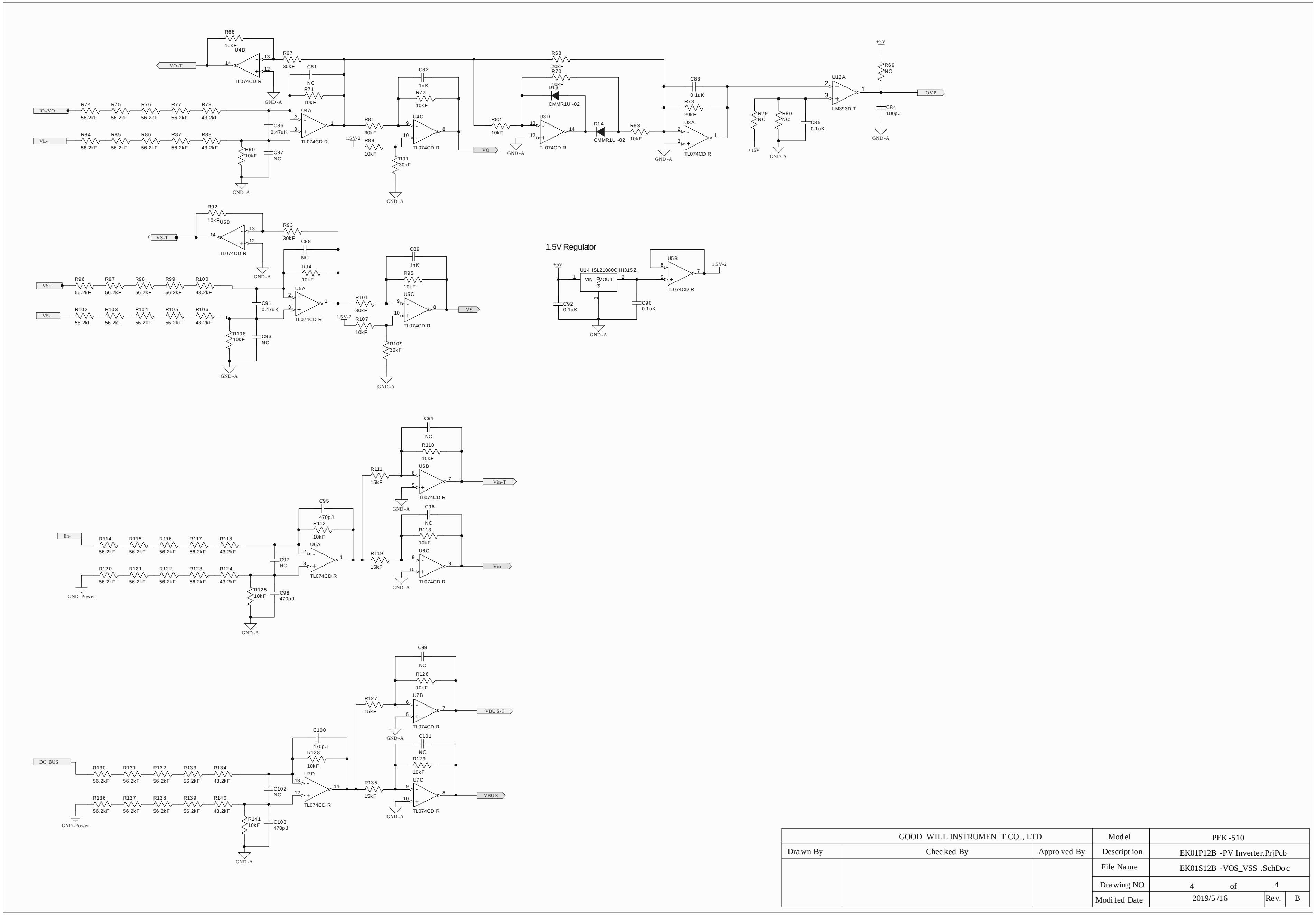
Appendix A – PEK-510 Circuit Diagram



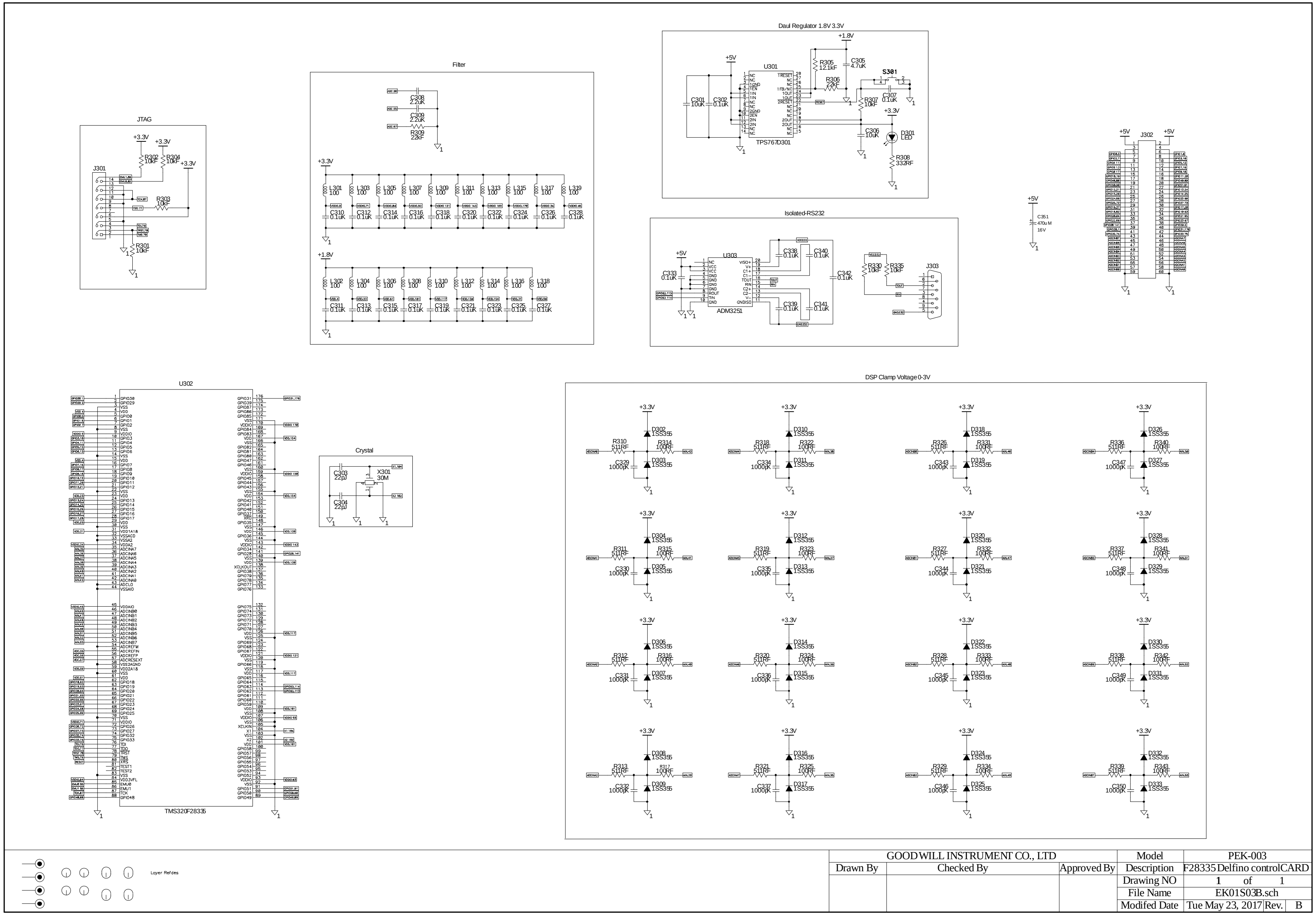
GOOD WILL INSTRUMENT CO., LTD			Model	PEK-510		
Drawn By	Checked By	Approved By	Description	EK01P12B-PV Inverter.PrjPcb		
			Drawing NO	2 of 4		
			File Name	EK01S12B-IOS.SchDoc		
			Modifed Date	2019/5/16	Rev.	B



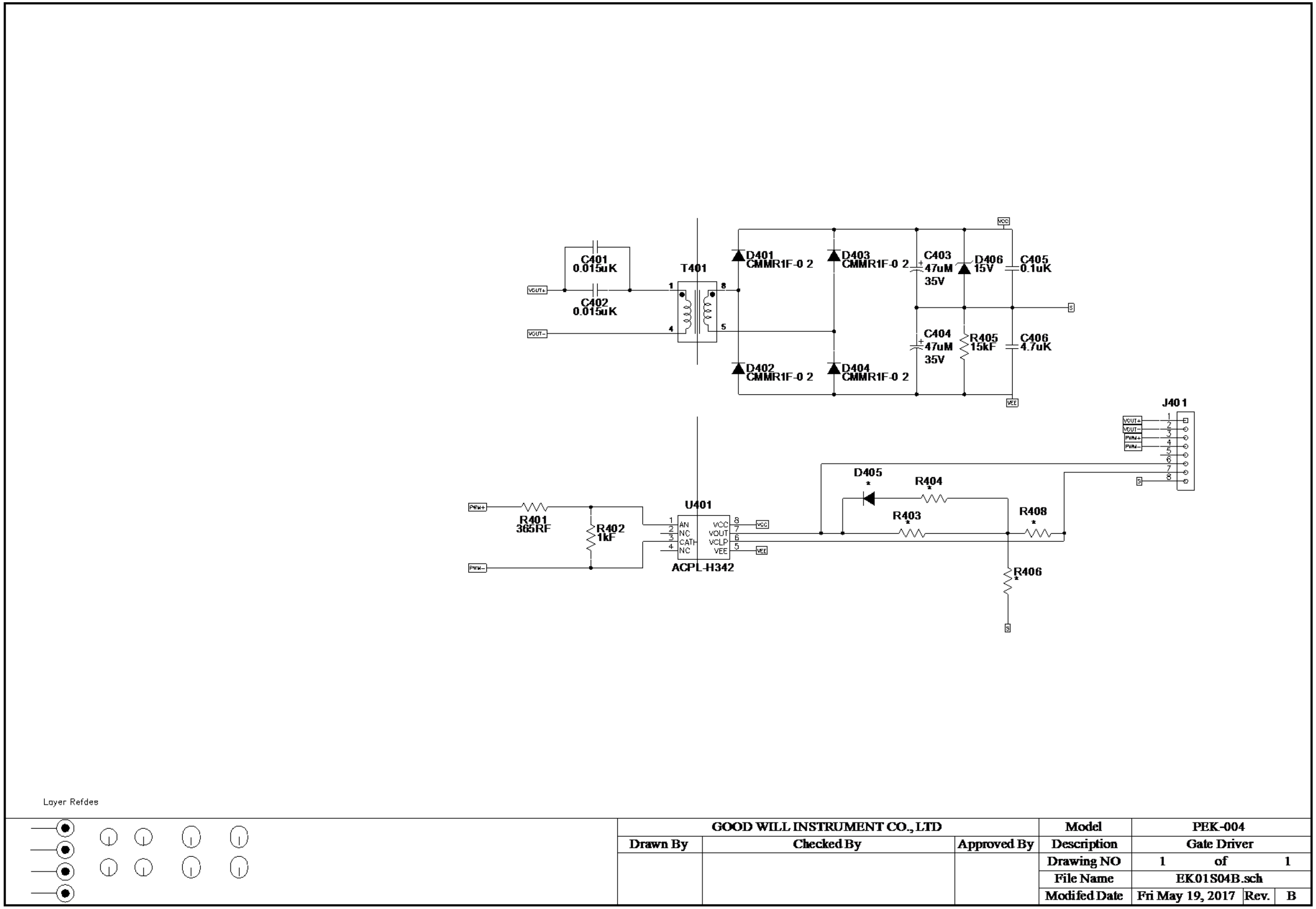
GOOD WILL INSTRUMENT CO., LTD			Model	PEK-510	
Drawn By	Checked By	Approved By	Description	EK01P12B-PV Inverter.PrjPcb	
			Drawing NO	3 of 4	
			File Name	EK01S12B-Interface.SchDoc	
			Modifed Date	2019/5/21	Rev. B


1.5V Regulator
U14 ISL21080C IH315Z
VIN VOUT
GND
VO-T
IO-/VO+
VL-
VO
VS-T
VS+
VS-
VS
Iin-
Vin-T
Vin
DC_BUS
VBUS-T
VBUS
OVP
GND-A
GND-Power
+5V
+15V
1.5V-2
TL074CD R
LM393D T
CMMR1U -02
GOOD WILL INSTRUMENT CO., LTD
Model
PEK-510
Drawn By
Checked By
Approved By
Description
EK01P12B -PV Inverter.PrjPcb
File Name
EK01S12B -VOS_VSS .SchDoc
Drawing NO
4 of 4
Modified Date
2019/5/16
Rev.
B

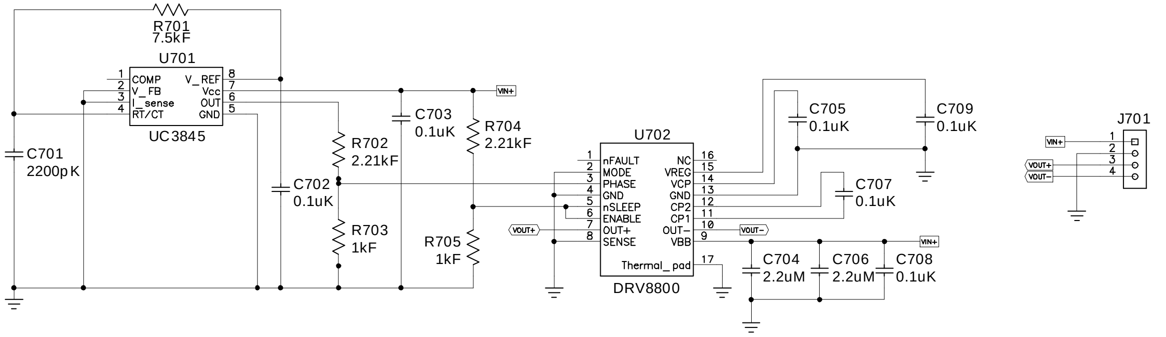
F28335 Delfino control CARD



Gate Driver


C401
0.015uK
C402
0.015uK
T401
VOUT+
VOUT-
D401
CMMR1F-0 2
D402
CMMR1F-0 2
D403
CMMR1F-0 2
D404
CMMR1F-0 2
C403
47uM
35V
C404
47uM
35V
D406
15V
C405
0.1uK
R405
15kF
C406
4.7uK
VCC
VEE
S
J401
PWM+
PWM-
D405
R404
R403
R408
R406
U401
AN
NC
CATH
NC
VCC
VOUT
VCLP
VEE
ACPL-H342
R401
365RF
R402
1kF
Layer Refdes
GOOD WILL INSTRUMENT CO., LTD
Drawn By
Checked By
Approved By
Model
PEK-004
Description
Gate Driver
Drawing NO
1 of 1
File Name
EK01S04B.sch
Modifed Date
Fri May 19, 2017
Rev.
B

Gate Driver Power



Layer Refdes

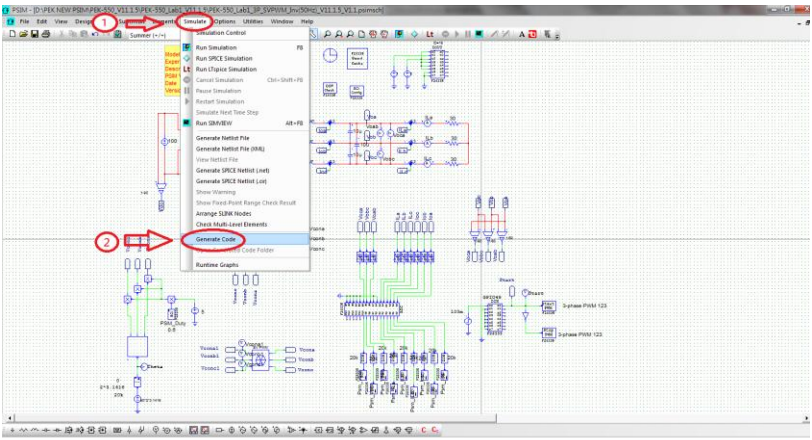
GOOD WILL INSTRUMENT CO., LTD			Model	PEK-100	
Drawn By	Checked By	Approved By	Description	Gate Driver Power	
			Drawing NO	1 of 1	
			File Name	EK01S07A.sch	
			Modifed Date	Mon Mar 09, 2015	Rev. A

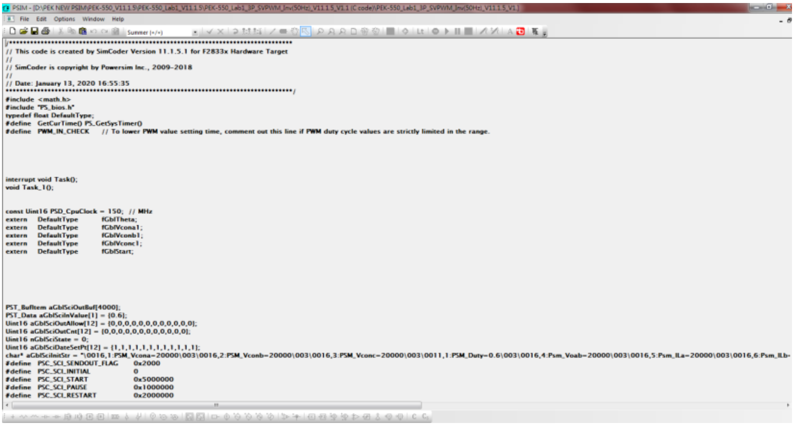
Appendix B – C Code Burning Procedure

This appendix takes “PEK-550_Lab1_3P_SVPWM _Inv(50Hz)_V11.1.5_V1.1” as an example for the instruction. See the detailed steps below.

Operating steps

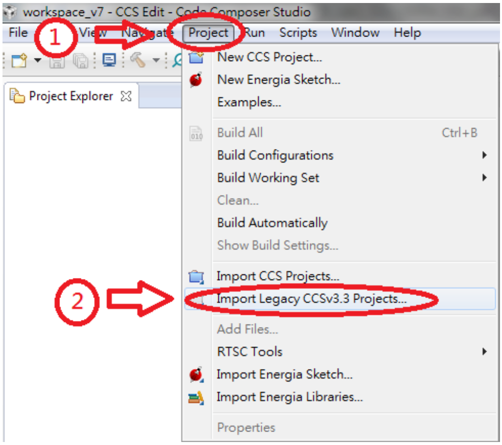
1. Open the digital circuit file “PEK-550_Lab1_3P_SVPWM_Inv(50Hz)_V11.1.5_V1.1” within the PSIM program followed by clicking “Generate Code” from “Simulate” tab. The PSIM will generate C Code automatically as shown below.



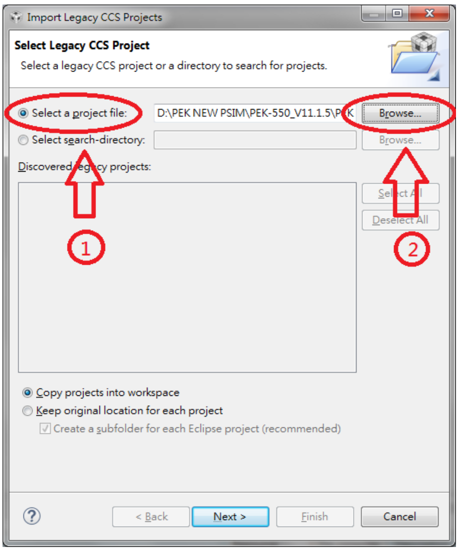


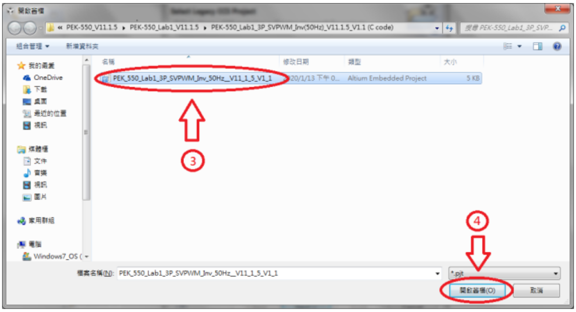
2. A folder of identical name with the PSIM circuit file in which the required files for burning and C Code are well saved will be generated in the location of PSIM circuit file by system.

3. Open CCS and select "Project" tab followed by clicking "Import Legacy CCSv3.3 Projects" as the figure below.

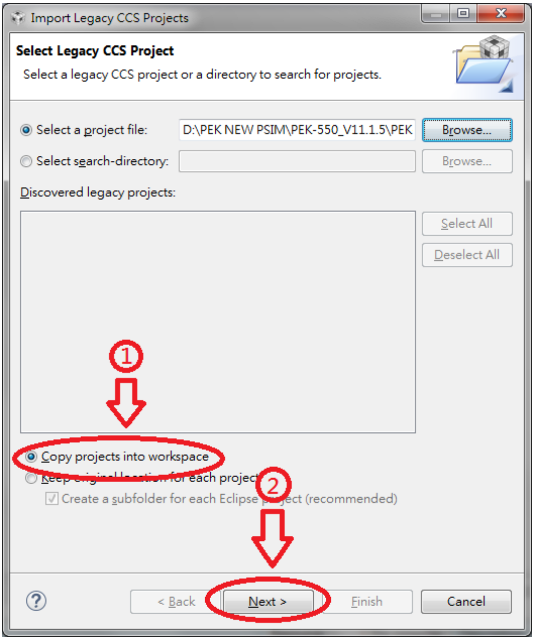


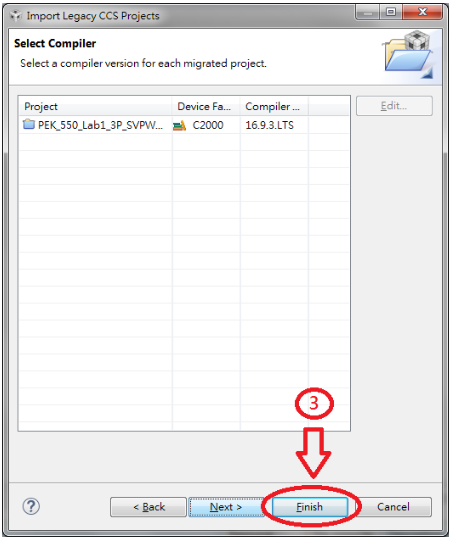
4. Go to "Select a project file" and click "Browser" followed by searching the folder where C Code is located and selecting the file with name extension ".pjt" as the following figure shown.

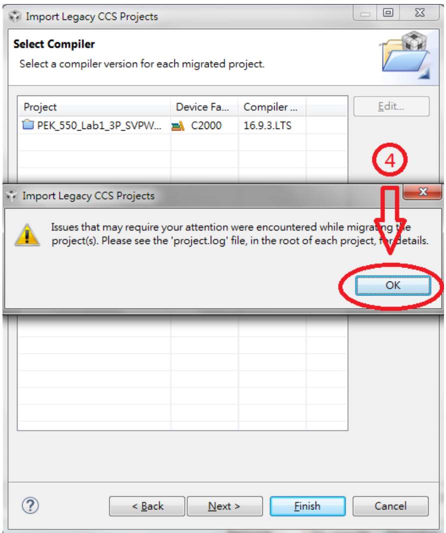




5. Select " Copy projects into workspace “ followed by clicking “Next” and then “Finish” to import C Code into CCS program. See the figure below.




Import Legacy CCS Projects
Select Compiler
Select a compiler version for each migrated project.
Project
Device Fa...
Compiler ...
PEK_550_Lab1_3P_SVPW...
C2000
16.9.3.LTS
Edit...
3
< Back
Next >
Finish
Cancel


Import Legacy CCS Projects
Select Compiler
Select a compiler version for each migrated project.
Project
Device Fa...
Compiler ...
PEK_550_Lab1_3P_SVPW...
C2000
16.9.3.LTS
Edit...
4
Import Legacy CCS Projects
Issues that may require your attention were encountered while migrating the project(s). Please see the 'project.log' file, in the root of each project, for details.
OK
< Back
Next >
Finish
Cancel

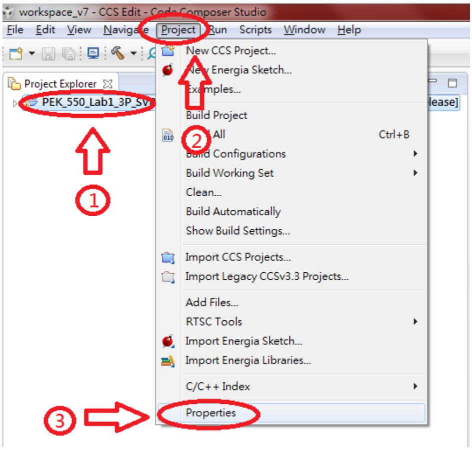
6. Select C Code file and choose "Properties" from "Project" tab. The setting steps are as follows.

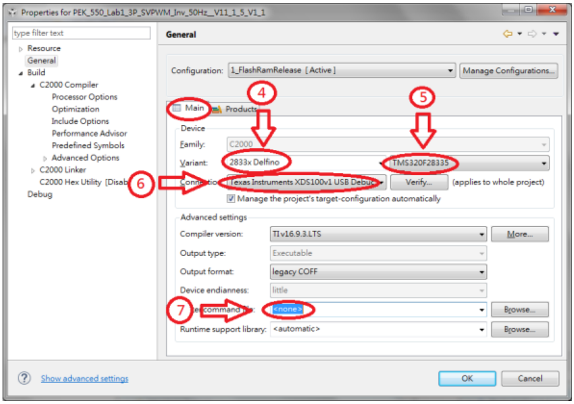
   1) Select "TMS320F28335" of "2833X Delfino" from Variant under Main tab.

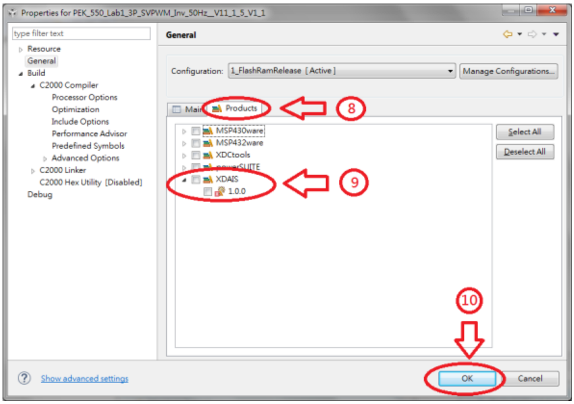
   2) Select "Texas Instruments XDS100v1 USB Debug Probe" from Connection under Main tab.

   3) Select "none" from Linker command file under Main tab.

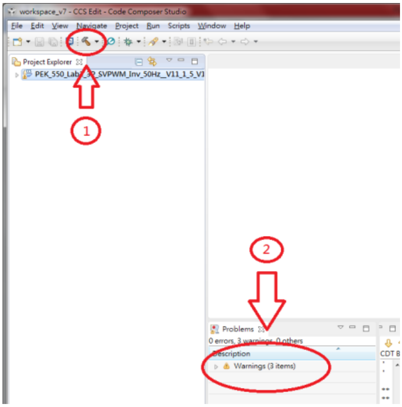
   4) Deselect "XDAIS" under Project tab. (Ignore this step if your CCS version doesn't provide this option.



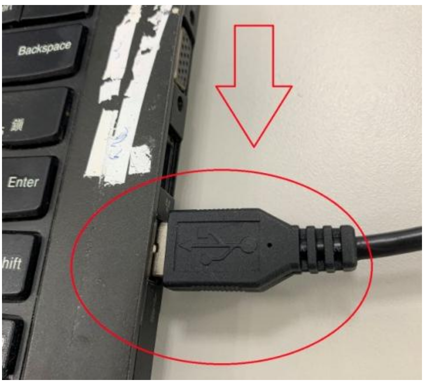


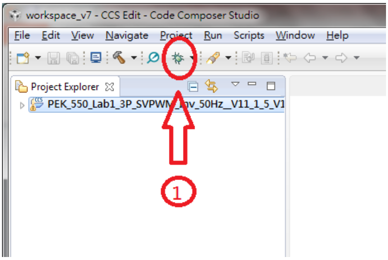


7. After the setting, click "Build" for compilation. If no errors occur after compiling, the program is eligible for burning. Simply ignore the warnings, which have no impact on burning process.

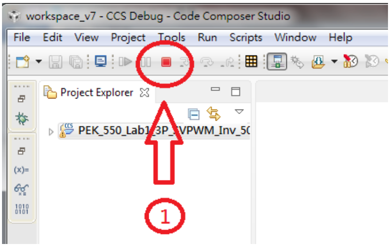


8. Connect PEK-006 to PC and PEK module respectively followed by clicking “Debug” to proceed to burning process.

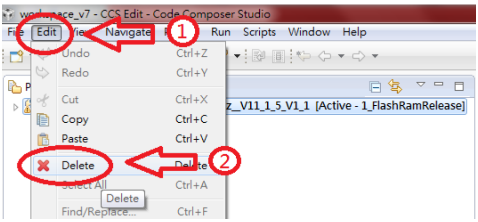


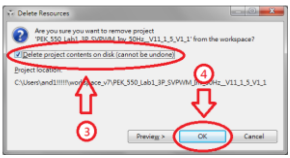


9. After the burning process, click "Terminate" and remove "PEK-006"to finish the entire procedure.



10. If it needs to delete file, select C Code file followed by selecting "Delete" under "Edit" tab and checking "Delete project contents on disk". Finally, click "OK" to complete the action.



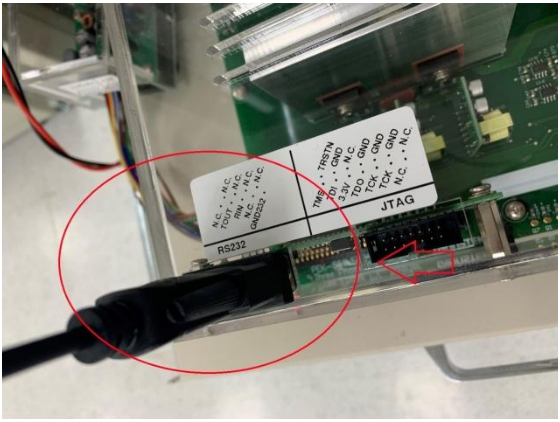


Appendix C – RS232 Connection

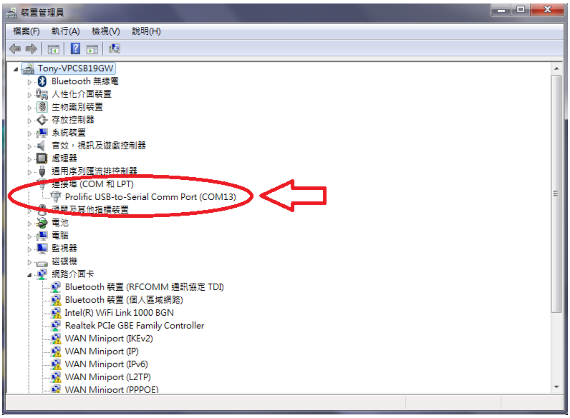
Operating steps

1. Connect PEK-005A to PEK module and make sure DSP is working normally.

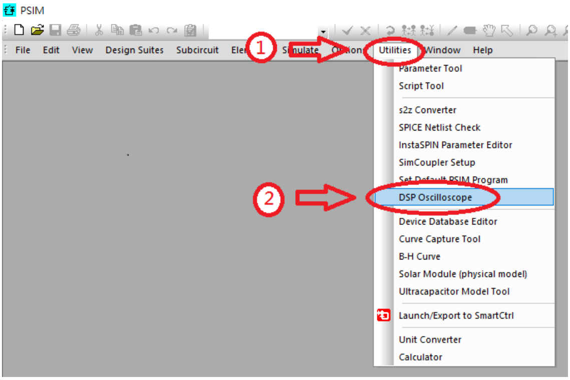
2. Connect one end of RS232 cable to PC, and the other end to the RS232 connector of PEK module.



3. Open Device Manger from PC and identify the COM port number being utilized by RS232 cable.



4. Open PSIM program and select "DSP Oscilloscope" under "Utilities" tab.

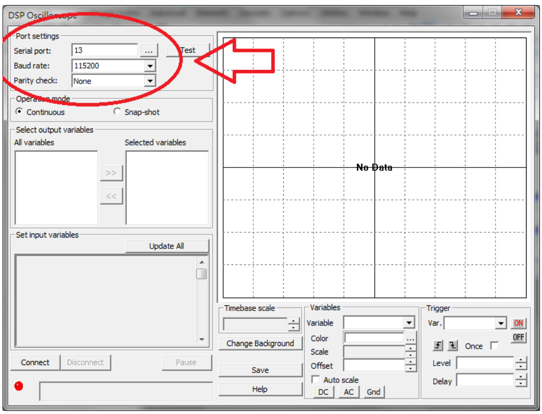


5. The Port settings are as follows.

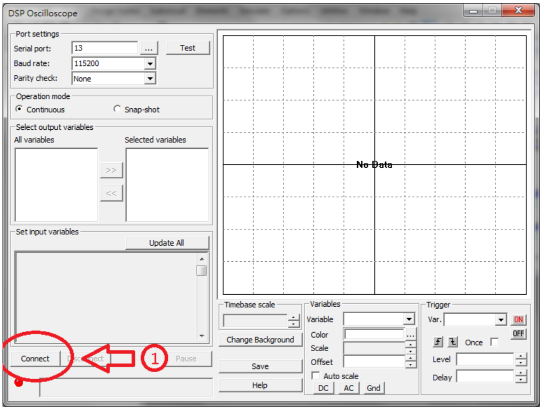
   1) Select the COM port being used by RS232.

   2) Set 115200 for Baud rate.

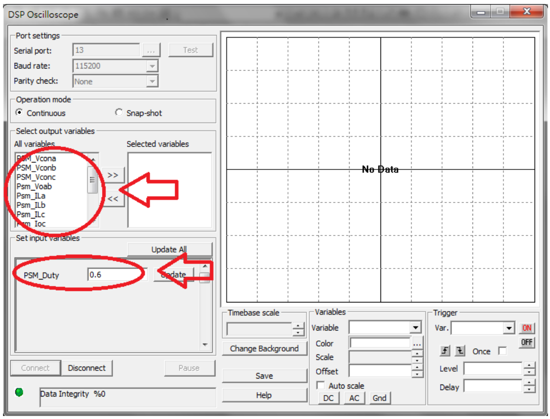
   3) Set None for Parity check.



6. After the settings, click "Connect" to proceed to RS232 connection.



7. Both the output and input variables schemed within PSIM circuit can be clearly observed when connection is properly established.



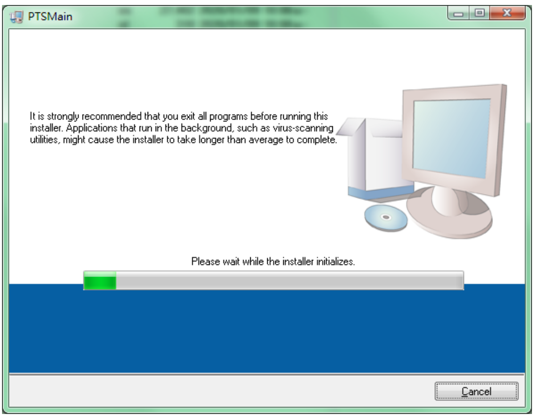
Appendix D – SAS Operation Procedure

We thoroughly introduce the PTS software covering SAS signal tracking, BAT simulation and real-time signal measurement subsystem. Through the system auto-detection function, each device can be well applied to the corresponding functions.

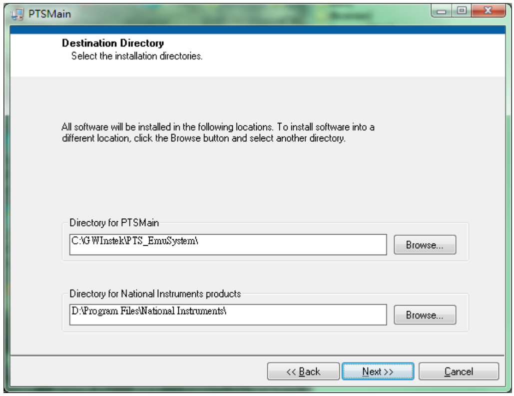
Installation and Startup

Operating steps

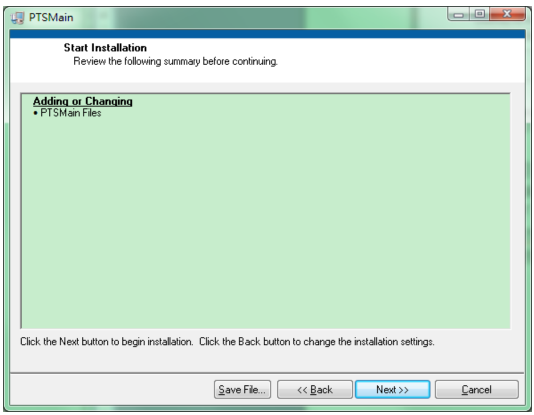
1. Install the complete PTS software: download the PTS5 installer and decompress it to the location c:\PTS installer followed by entering the Volume and executing the Setup.exe as follows.



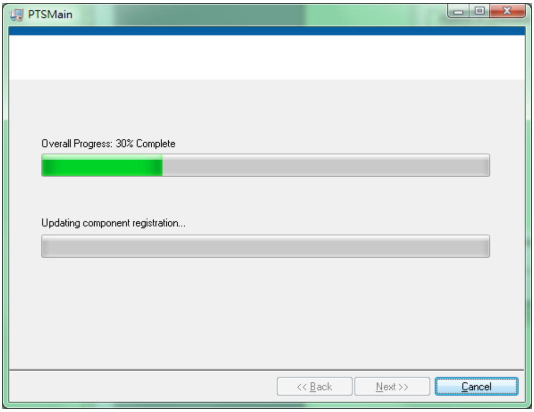
2. The system will search if the required component has been installed. If the required component is not installed yet or the installed one is with old version, the required component will be in the waiting list for installation. In contrast, if the installed one is with higher version than the required one, the installation process will be skipped.



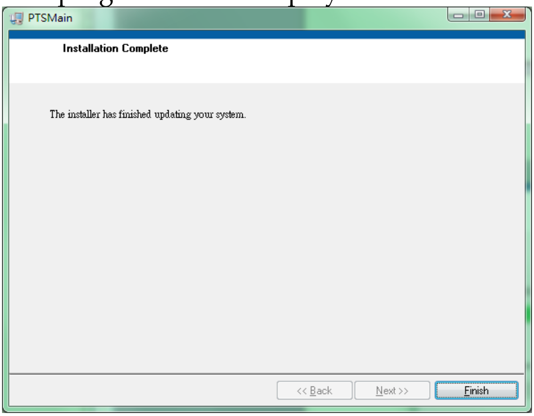
Use the default location and press the "Next" to finish installation. Then, the installed software and the software waiting to be installed including the required executing component will be listed.



3. Press “Next” to proceed to the following installation.

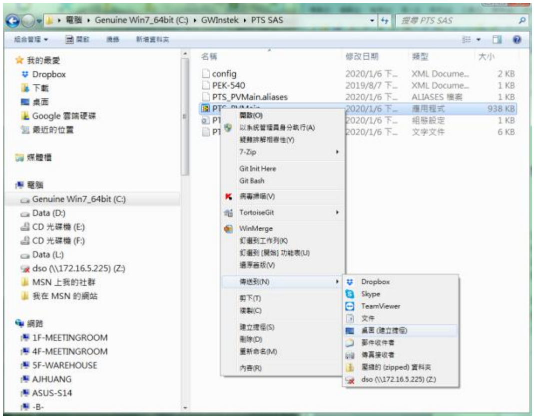


The overall installation progress along with each item progress will be displayed.



4. Download the PTS SAS package software and decompress it to the previous location for installation. A new directory will be added under the location c:\gwinstek\.

5. Switch to the directory and it is available to create a shortcut on the desktop for convenient execution. See the following screenshot shown.



Right click on the PTS_PVMain file followed by selecting “Sent to” -> “Desktop (create shortcut)” to create a shortcut, which allows you to promptly execute the software from the desktop directly with ease.

6. Locate the shortcut from desktop and execute it promptly when necessary later.

Uninstall

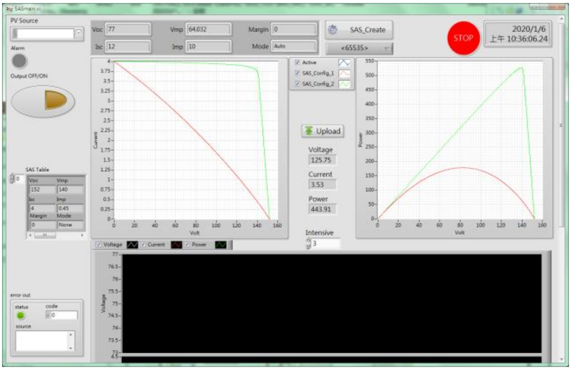
7. In the Control Panel, click the “Programs and Features” item followed by locating the PTSMain one for uninstall.

Interface Introduction

1. Program Running Interface

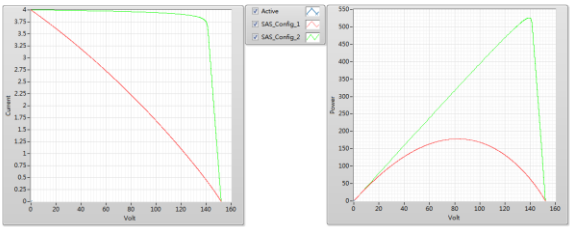
Diagram 1

System Running Interface



The PV trajectory curve of the configured system

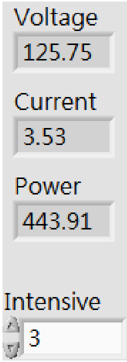
Diagram 2



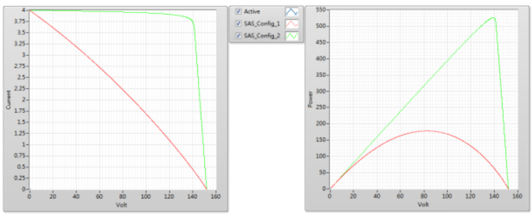
V1 display in left and PV display in right. Active indicates the one after startup. The real IV measurements, via Intensive setting, allow user to check the relevant trajectories.

2. Real-time readings monitor

Diagram 3



Both Voltage and Current are indicated in the left side of the IV curve chart from the diagram 2, whereas both Voltage and Power are indicated in the right side of the PV curve chart from the figure 2. Intensive indicates the remaining data points on screen, which tracks the real IVP fluctuating trajectory.

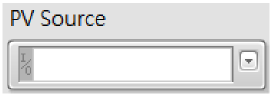


Operation

3. Device connection setup

Diagram 4

Device selection

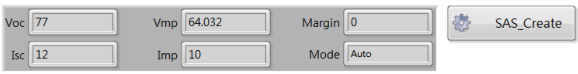


Establish system connection, via the drop-down menu, to designate the applicable device.

4. Establish PV reference curve

Diagram 5

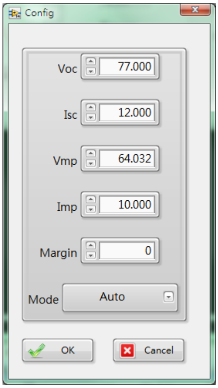
Trajectory parameters of previous setup



SAS_Create: Establish a new curve as the following screenshot shown:

Diagram 6

SAS trajectory parameter setting

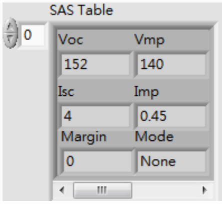


When a new curve is established, the relevant curve will be displayed in the VI and PV charts. And it is available to add parameters for the curve into the SAS table.

- Voc: Open circuit voltage
- Isc: Short circuit current
- Vmp: Max power point voltage
- Imp: Max power point current
- Margin: Output will not be updated within the ample area (%)
- Mode: Select Auto mode when utilizing
- OK: Confirm parameter setting and import into SAS Table
- Cancel: Discard the modification setting

Diagram 7

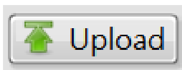
Trajectory parameter table



- SAS Table: The curve ready to be written into device. Right click to open the operational functions: Import Table, Export Table
- Import Table: Load the previously established curve and parameter in the auto-saving file.
- Export Table: Export the current curve and parameter. Point the cursor to the SAS Table, through the delete button, to delete the current setting (trajectory curve).

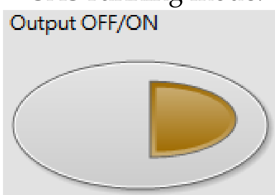
Upload / Load PV trajectory curve parameter

Diagram 8



Write the set trajectory curve parameter from the SAS Table into the device and wait for execution. In the meantime, PSW enters the SAS running mode.

Diagram 9



Start / Stop PSW output

In the SAS mode, PSW output reacts in accord with the selected curve. In the normal mode, PSW acts as a standard function.

5. Select Trajectory Parameter

Diagram 10

Refer to trajectory parameter selection

6. Stop and End

Diagram 11

Once the upload action is executed, the device enters the SAS mode and all the Output ON/OFF control determine if PSW proceeds to tracking operation.

If PSW requires to returning back to the normal operation mode, it must select stop software and restart it.

Appendix Description

A: PSW Tracking Mode

After SAS software startup, PSW will, by uploading trajectory curve software, initiate tracking mode. User then is able to switch freely among the established trajectory software. In order to exit from the tracking mode, press the “STOP” to make the device return back to the default operation mode.

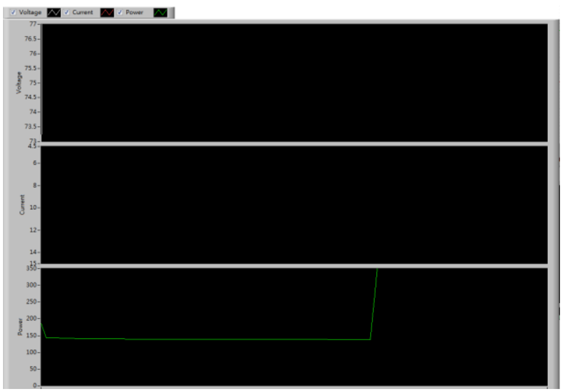
B: Normal Mode

System is under the normal operation mode after startup. PSW enters the tracking mode after successfully uploading the PV trajectory curve.

C: IVP Real-Time Record Curve

In the tacking mode, apart from IV and PV trajectories, the both trajectory record charts are also provided, individually.

Diagtam 12



8.