Permanent Magnet Synchronous Generator Wind Inverter Module

PEK-520

User Manual

GW INSTEK PART NO. 82EK-11000M01

ISO-9001 CERTIFIED MANUFACTURER

GW INSTEK

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.

Good Will Instrument Co., Ltd.
No. 7-1, Jhongsing Rd., Tucheng Dist., New Taipei City 236, Taiwan (R.O.C.).

Table of Contents

Introduction

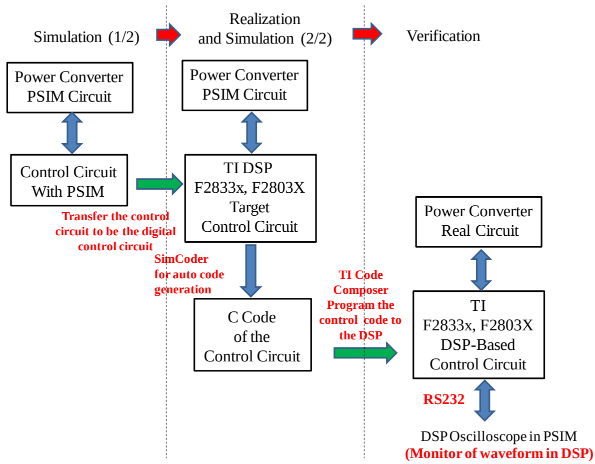
As the figure 0.1 shown, PEK-520, the Permanent Magnet Synchronous Generator Wind Inverter Module, consists of three parts: PEK-520_1, the PMSM Driver, PEK-520_2, the PMSG Driver and Grid-connecter Inverter, and the Permanent Magnet Synchronous Motor Module, which is a fully digital-control system. The purpose of this, 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 program 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

Permanent magnet synchronous generator wind inverter module

Figure 0.2

The process in details



Thre are 8 experiments can be fulfilled by PEK-520 as follows:

1. Three Phase Stand-alone Inverter
2. Three Phase Grid-connected Inverter
3. Speed and Torque Control of PMSM
4. Speed Control of PMSG
5. Wind Turbine Generator (WTG) Emulation
6. Maximum Power Point Tracking of WTG
7. Grid-connected PMSG Wind Power Generation System)
8. Low Voltage Ride Through (LVRT) of PMSG WTG System)

In addition to PEK-520, 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

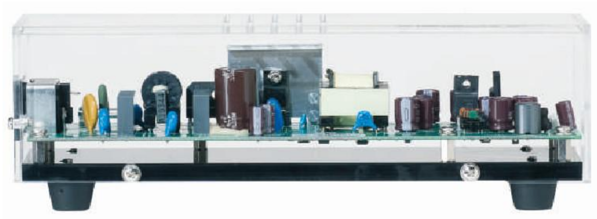


Figure 0.4

JTAG burning module

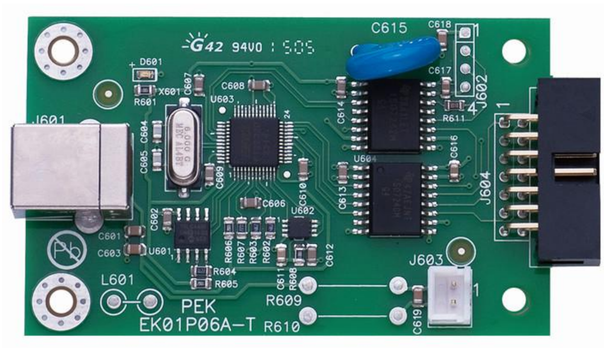


Figure 0.5

PTS-5000 experiment platform

The DSP I/O pin configuration of PEK-520 is shown as the figures 0.6 and 0.7. Refer to the appendix A for the circuit diagrams of PEK-520, 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 to table 0-4 shown.

Figure 0.6

I/O configuration of PEK-520_1

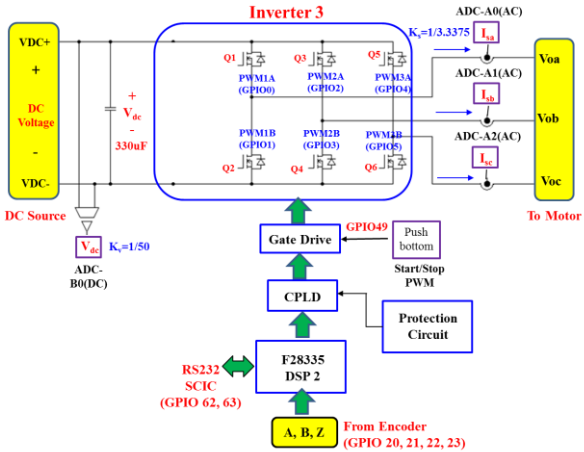


Figure 0.7

I/O configuration of PEK-520_2

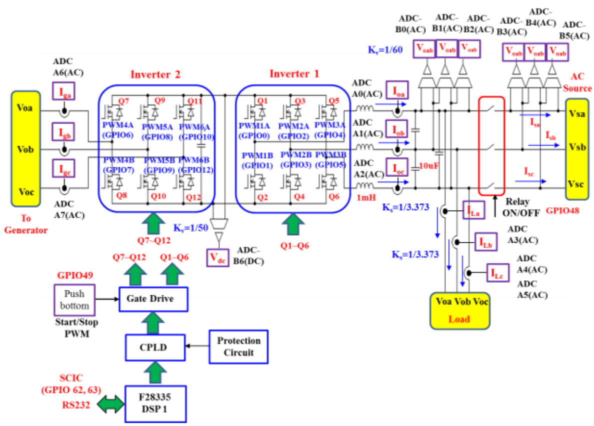


Table 0.1 PEK-520_1 test point measurement ratio

	Sensing item	Sensing ratio
1	DC input voltage (VDC)	0.0154
2	Wind turbine generator inverter output AB arm line voltage (VO-AB)	0.0150
3	Wind turbine generator inverter output BC arm line voltage (VO-BC)	0.0150
4	Wind turbine generator inverter output CA arm line voltage (VO-CA)	0.0150
5	Wind turbine generator inverter A phase output current (IO-A)	0.4768
6	Wind turbine generator inverter B phase output current (IO-B)	0.4768
7	Wind turbine generator inverter C phase output current (IO-C)	0.4768

Table 0.2 PEK-520_2 test point measurement ratio

	Sensing item	Sensing ratio
1	Generator inverter A phase output current (IG-A)	0.4768
2	Generator inverter B phase output current (IG-B)	0.4768
3	Generator inverter C phase output current (IG-C)	0.4768
4	DC link voltage (VBUS)	0.0154
5	Grid-connected inverter A phase output current (IO-A)	0.4768
6	Grid-connected inverter B phase output current (IO-B)	0.4768
7	Grid-connected inverter C phase output current (IO-C)	0.4768
8	Grid-connected inverter A phase load current (IL-A)	0.4768
9	Grid-connected inverter B phase load current (IL-B)	0.4768
10	Grid-connected inverter C phase load	0.4768

	current (IL-C)	
11	Grid-connected inverter output AB arm line voltage (VO-AB)	0.0287
12	Grid-connected inverter output BC arm line voltage (VO-BC)	0.0287
13	Grid-connected inverter output CA arm line voltage (VO-CA)	0.0287
14	Power grid AB arm line voltage (VS-AB)	0.0287
15	Power grid BC arm line voltage (VS-BC)	0.0287
16	Power grid CA arm line voltage (VS-CA)	0.0287

Table 0.3 PEK-520_1 DSP feedback ratio

	Sensing item	Sensing ratio
1	DC input voltage (VDC)	0.0202
2	Wind turbine generator inverter output AB arm line voltage (VO-AB)	0.0124
3	Wind turbine generator inverter output BC arm line voltage (VO-BC)	0.0124
4	Wind turbine generator inverter output CA arm line voltage (VO-CA)	0.0124
5	Wind turbine generator inverter A phase output current (IO-A)	0.2996
6	Wind turbine generator inverter B phase output current (IO-B)	0.2996
7	Wind turbine generator inverter C phase output current (IO-C)	0.2996

Table 0.4 PEK-520_2 DSP feedback ratio

	Sensing item	Sensing ratio
1	Generator inverter A phase output current (IG-A)	0.2996
2	Generator inverter B phase output current (IG-B)	0.2996
3	Generator inverter C phase output current (IG-C)	0.2996
4	DC link voltage (VBUS)	0.0202
5	Grid-connected inverter A phase output	0.2996

	current (IO-A)	
6	Grid-connected inverter B phase output current (IO-B)	0.2996
7	Grid-connected inverter C phase output current (IO-C)	0.2996
8	Grid-connected inverter A phase load current (IL-A)	0.2996
9	Grid-connected inverter B phase load current (IL-B)	0.2996
10	Grid-connected inverter C phase load current (IL-C)	0.2996
11	Grid-connected inverter output AB arm line voltage (VO-AB)	0.0169
12	Grid-connected inverter output BC arm line voltage (VO-BC)	0.0169
13	Grid-connected inverter output CA arm line voltage (VO-CA)	0.0169
14	Power grid AB arm line voltage (VS-AB)	0.0169
15	Power grid BC arm line voltage (VS-BC)	0.0169
16	Power grid CA arm line voltage (VS-CA)	0.0169

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 Three Phase Stand-alone Inverter	To get to know the principle of three phase SPWM and SVPWM. Realize the measurements of voltage and current via PEK-520-2 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 Three Phase Grid-connected Inverter	To get to know the fundamental with structure of three phase grid-connected inverter, and learn not only the design method of phase-lock loop for three phase grid-connected 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-connected inverter.
Experiment 3 Speed and Torque Control of PMSM	To get to know the fundamental of PMSG, encoder, calculation of speed, vector control theory as well as controller design for current and speed. To learn the way to establish circuit in simulation and proceed to the code programming via SimCoder, after well mapping out the DSP digital control circuit.

Experiment 4 Speed Control of PMSG	To get to know the fundamental of PMSG, vector control theory as well as controller design for current and speed. To learn the way to establish circuit in simulation and proceed to the code programming via SimCoder, after well mapping out the DSP digital control circuit.
Experiment 5 Wind Turbine Generator (WTG) Emulation	To get to know the fundamental of WTG and establish WTG model, further learning the way to simulate fundamental of WTG via motor and not only setting up the circuit in simulation of WTG simulation system, but proceeding to simulation as well. Finally, to map out the WTG simulation system via DSP digital control circuit.
Experiment 6 Maximum Power Point Tracking of WTG	WTG generates differed power curves in accordance with different wind speeds. In order to better take advantage of wind power, work point, in accord with wind speeds, is supposed to be altered for keeping it at the highest level of power curve, which is known as Maximum Power Point Tracking (MPPT). This experiment locates MPP curve, based on the attributes of wind turbine, and further design MPPT controller on the basis of MPP curve, fulfilling it through DSP digital control circuit.
Experiment 7 Grid-connected PMSG Wind Power Generation System	Integrate MPPT generator actuator, grid-connected inverter with wind turbine simulator to establish circuit in simulation of integrated system and to proceed to full system verification in simulation.

Experiment 8 Low Voltage Ride Through (LVRT) of PMSG WTG System	To learn the requirements of both frequency operation and reactive power by grid-connected power to WTG and to understand the requirement of adaptation by WTG to grid-connected voltage. To learn the Low Voltage Ride Through (LVRT) method of PMSG WTG and establish DSP digital control programming of LVRT and to verify LVRT function via experiment.

Experiment 1 – Three Phase SVPWM Inverter

Circuit Simulation

The circuit parameters of inverter	DC bus Voltage V_{bus} = 100V F_s = 20kHz, V_{tri} = 10V_{pp} C_{Bus} = 300uF, L = 1.02uH, C = 10uF K_s = 0.3 (AC current sensing factor) K_v = 1/60 (AC voltage sensing factor) K_v = 1/50 (DC voltage sensing factor)

The analogue circuit diagram based on the parameters above is as the following figure 1.1 shown:
PSIM File: PEK-520_2_Sim1_3P_SA_Inv(50Hz)_V11.1.5_V1.1

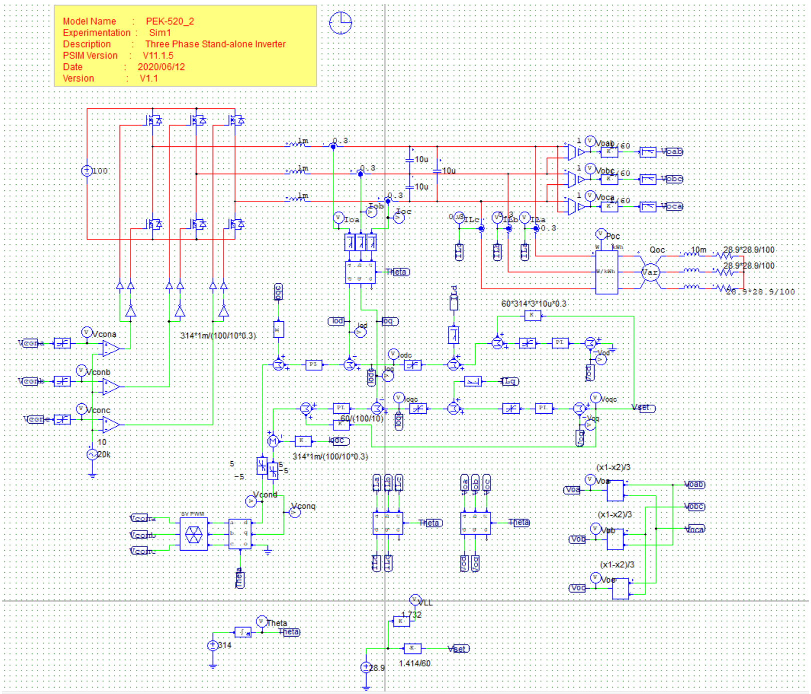


Figure 1.1 Experiment 1 PSIM analogue circuit diagram

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

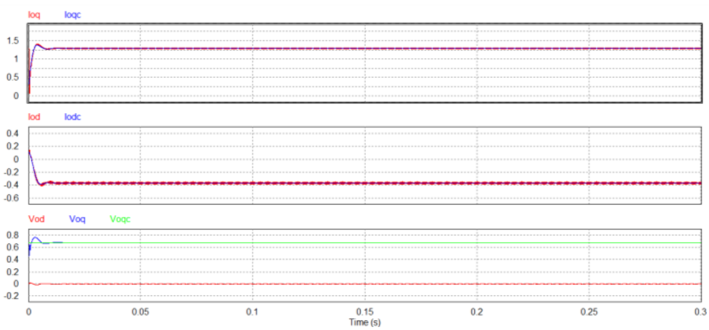


Figure 1.2 Experiment 1 analogue circuit simulation waveforms

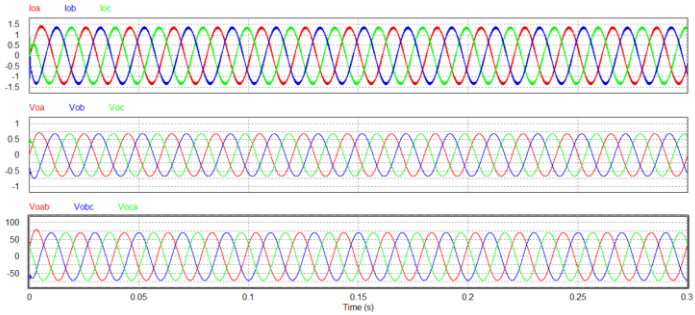


Figure 1.3 Experiment 1 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is shown as the figure 1.4:

PSIM File: PEK-520_2_Lab1_3P_SA_Inv(50Hz)_V11.1.5_V1.1

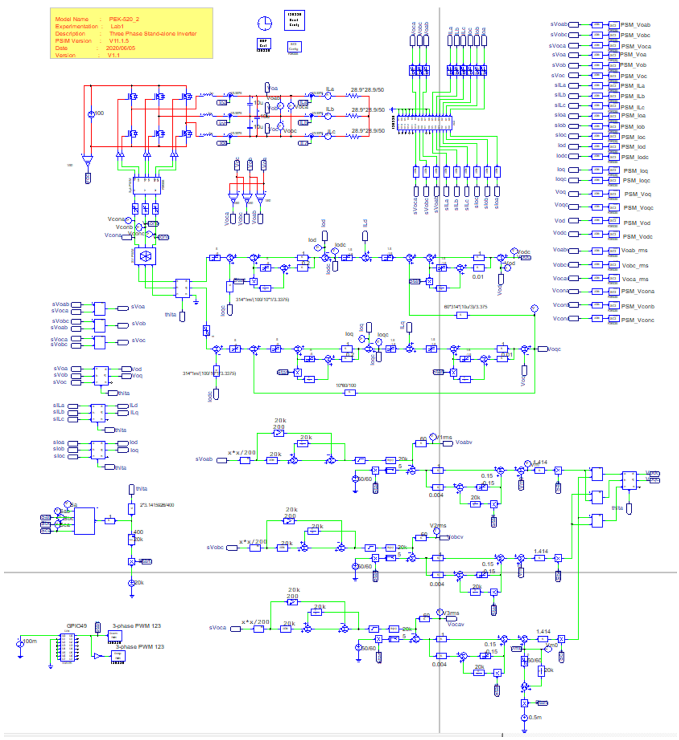


Figure 1.4 Experiment 1 digital circuit diagram

The simulation result is shown within the figure 1.5 and 1.6:

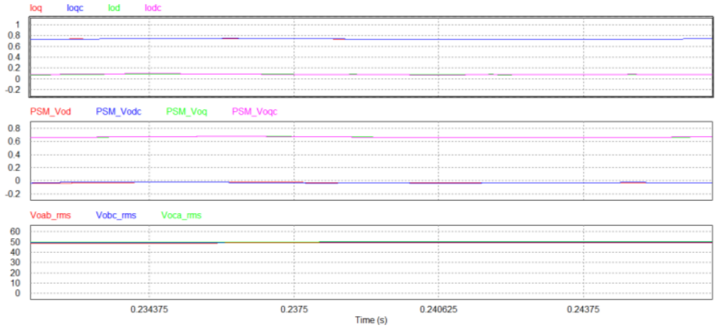


Figure 1.5 Experiment 1 digital circuit simulation waveforms

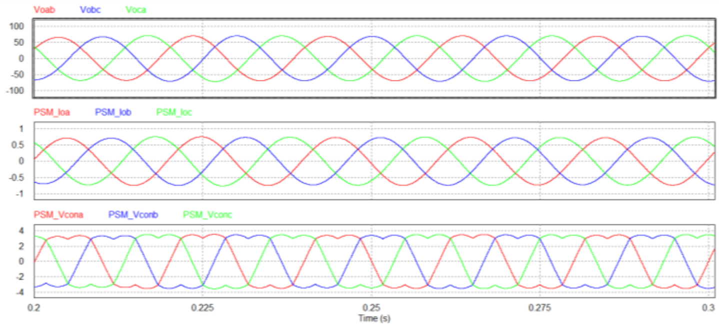


Figure 1.6 Experiment 1 digital circuit simulation waveforms

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-520_2 * 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 1.7. Please follow it to complete wiring.

Figure 1.7 Experiment 1 wiring figure

2. After wiring, make sure the PEK-520_2 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 1.8 shown, which means the DSP power is steadily normal.

Figure 1.8 DSP normal status with light on

3. Refer to the appendix B for burning procedure.

4. Connect the test leads of oscilloscope to IO-A, IO-B and IO-C of PEK-520_2, respectively, and connect the GND of test leads to the GND of module as the figure 1.9 shown.

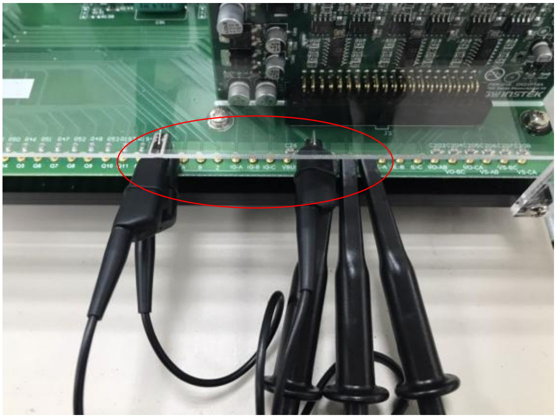


Figure 1.9
Oscilloscope test leads wiring

5. Click Set key to check set voltage and current values. Set voltage 100V with voltage scroll knob and current 3A with current scroll knob for PSW 160-7.2 as the figure 1.10 shown.

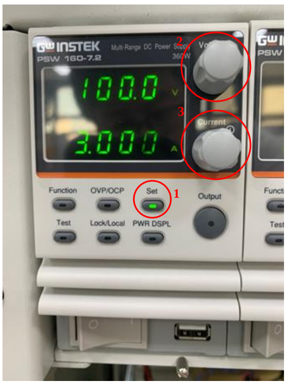
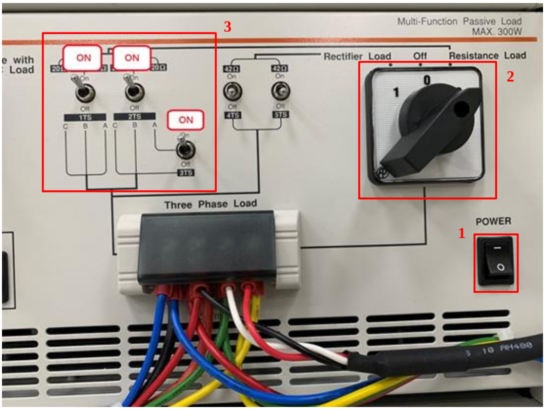


Figure 1.10
The settings of PSW 160-7.2

6. As the figure 1.11 shown, follow the steps below for GPL-500 operation. Power on GPL-500 → Rotate the Three Phase Load knob to 2 (Resistance Load) → Set 1TS, 2TS and 3TS as ON, which indicates full-load mode.

Figure 1.11
The full-load setting of GPL-500



7. After setting up and turning on PSW power output, finally turn on the switch of PEK-520_2.

The purpose of experiment

It is to observe fluctuation of three phase voltage of PEK-520_2 in accord with changes of load condition from the Lab1 experiment.

The Experiment Result

(1) Full Laod (10Ω)

The figure 1.12 shows that when GPL-500 is set as full-load mode, IO-A three phase current RMS value is 1.36V (2.852A in actual value), IO-B is 1.38A (2.894A in actual value), and IO-C is 1.37A (2.873A in actual value). The figure 1.13 shows that, in the mean time, VO-AB three phase voltage RMS value is 1.40V (48.780V in actual value), VO-BC is 1.43V (49.826V in actual value), and VO-CA is 1.41V (49.129V in actual value).

Figure 1.12

Three phase current waveform under full-load condition

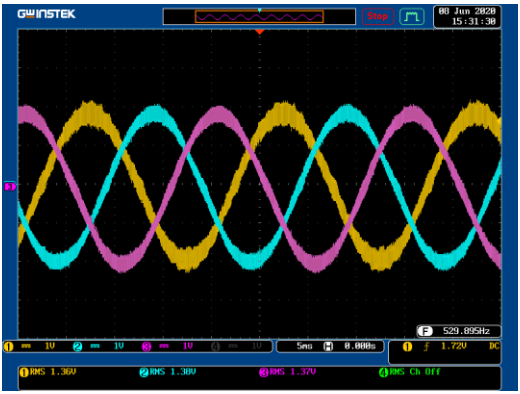
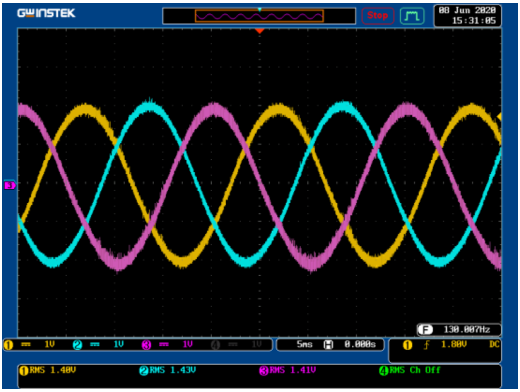


Figure 1.13

Three phase voltage waveform under full-load condition

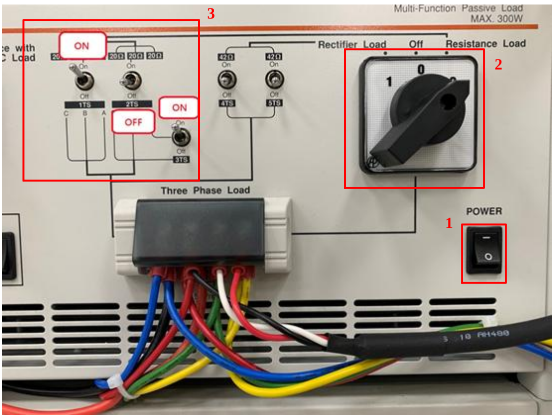


(2) Half Laod (20Ω)

As the figure 1.14 shown, follow the steps below for GPL-500 operation for half load. Power on GPL-500 → Rotate the Three Phase Load knob to 2 (Resistance Load) → Set 1TS and 3TS as ON, and 2TS as OFF, which indicates half-load mode.

Figure 1.14

GPL-500 half-load setting



The figure 1.15 shows that when GPL-500 is set as half-load mode, IO-A three phase current RMS value is 0.721A (1.512A in actual value), IO-B is 0.699A (1.466A in actual value), and IO-C is 0.694A (1.456A in actual value). The figure 1.16 shows that, in the mean time, VO-AB three phase voltage RMS value is 1.40V (48.780V in actual value), VO-BC is 1.43V (49.826V in actual value), and VO-CA is 1.41V (49.129V in actual value).

Figure 1.15

Three phase current waveform under half-load condition

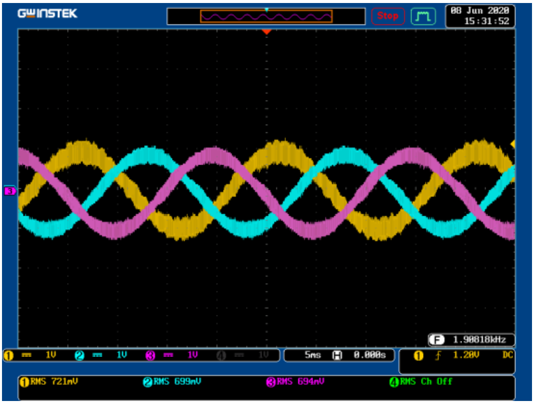
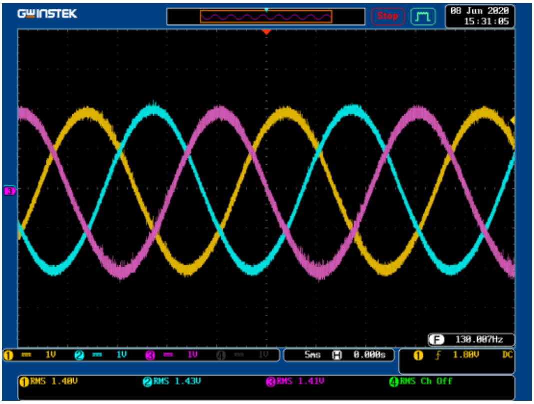


Figure 1.16

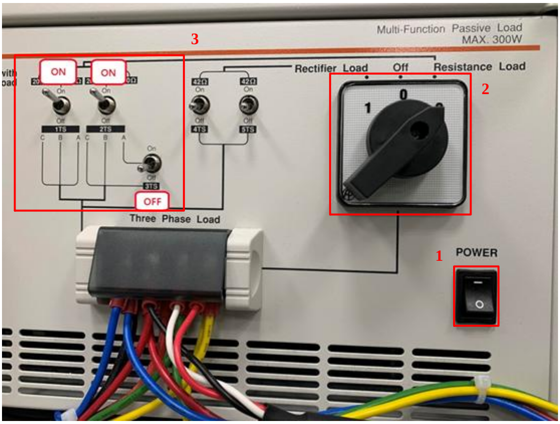
Three phase voltage waveform under half-load condition



(3) Unbalanced Laod (A phase 20Ω, B and C phase 10Ω)

As the figure 1.17 shown, follow the steps below for GPL-500 operation for unbalanced load. Power on GPL-500 → Rotate the Three Phase Load knob to 2 (Resistance Load) → Set 1TS and 2TS as ON, and 3TS as OFF, which indicates unbalanced-load mode.

Figure 1.17
GPL-500 unbalanced-load setting



The figure 1.18 shows that when GPL-500 is set as unbalanced-load mode, IO-A three phase current RMS value is 0.864A (1.812A in actual value), IO-B is 1.28A (2.684A in actual value), and IO-C is 1.26A (2.643A in actual value). The figure 1.19 shows that, in the mean time, VO-AB three phase voltage RMS value is 1.40V (48.780V in actual value), VO-BC is 1.43V (49.826V in actual value), and VO-CA is 1.41V (49.129V in actual value).

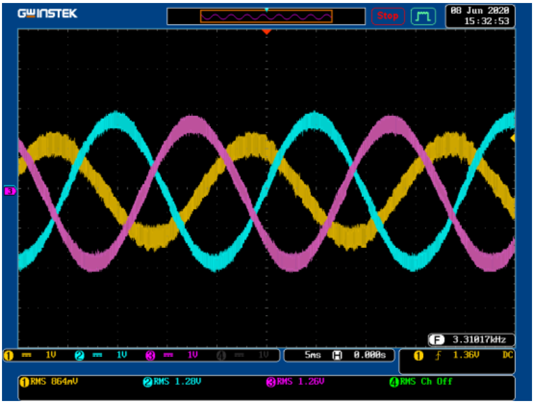


Figure 1.18

Three phase current waveform under unbalanced-load condition

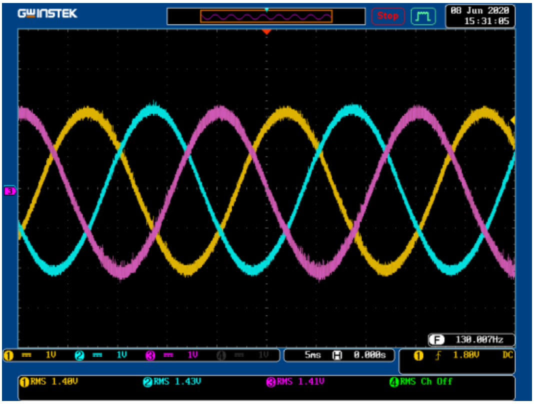


Figure 1.19

Three phase voltage waveform under unbalanced-load condition

Per different load operations, refer to the table 0.1 for the sensing ratio followed by filling in the table 1.1 with result in order.

Table 1.1 Three phase output voltage current measured values under varied loads

		IO-A (Arms)	IO-B (Arms)	IO-C (Arms)	VO-AB (Vrms)	VO-BC (Vrms)	VO-CA (Vrms)
No Load (10Ω)	Measured value	1.36A	1.38A	1.37A	1.4V	1.43V	1.41V
	Actual value	2.852A	2.894A	2.873A	48.780V	49.826V	49.129V
Half Load	Measured value	0.721A	0.699A	0.694A	1.4V	1.43V	1.41V

(20Ω)	Actual value	1.512A	1.466A	1.456A	48.780V	49.826V	49.129V
Unbalanced Load	Measured value	0.864A	1.28A	1.26A	1.4V	1.43V	1.41V
	Actual value	1.812A	2.648A	2.643A	48.780V	49.826V	49.129V

The conclusion

It has seen that, from the table 1.1, when load changes under the closed-circuit three phase inverter system, output current will fluctuate in accord with load changes, while output three phase voltage remains balanced.

Experiment 2 –Three Phase Grid-connected Inverter

Circuit Simulation

Inverter Specification

DC bus Voltage $V_{bus} = 100V$

AC Source Voltage $V_{LL} = 50V_{rms}$

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

$C_{Bus} = 400uF$, $L = 1.02uH$, $C = 10uF$

$K_s = 0.3$ (AC current sensing factor)

$K_v = 1/60$ (AC voltage sensing factor)

$K_v = 1/50$ (DC voltage sensing factor)

The analogue circuit diagram based on the parameters above is as the following figure 2.1 shown:
PSIM File: PEK-520_2_Sim2_3P_GC_Inv(50Hz)_V11.1.5_V1.1

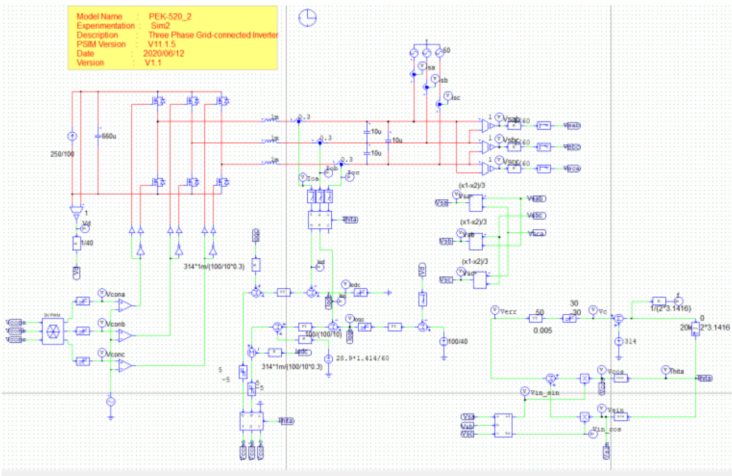


Figure 2.1 Experiment 2 PSIM analogue circuit diagram

The simulation result is shown within the figure 2.2:

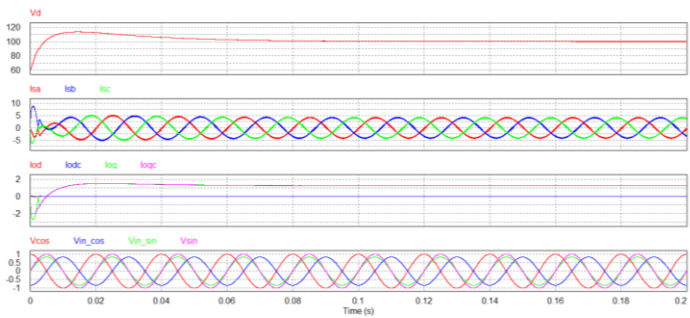


Figure 2.2 Experiment 2 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is shown as the figure 2.3:
PSIM File: PEK-520_2_Lab2_3P_GC_Inv(50Hz)_V11.1.5_V1.1

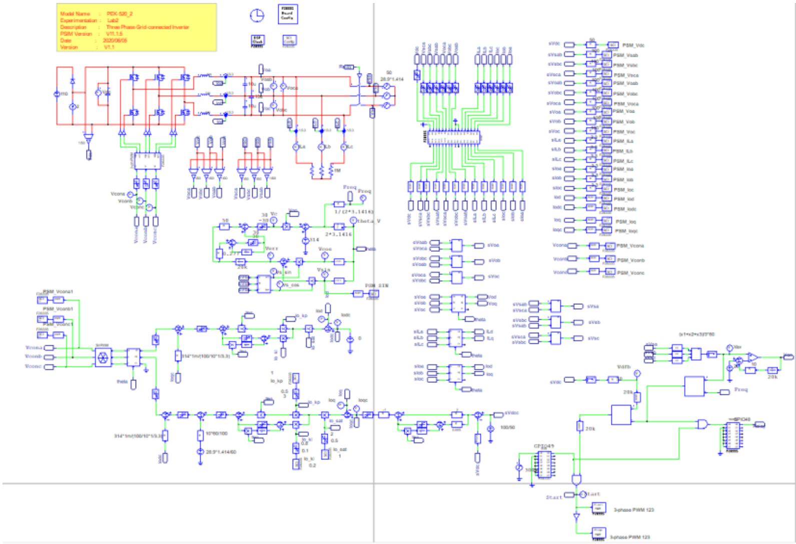


Figure 2.3 Experiment 2 PSIM digital circuit diagram

The simulation result is shown within the figure 2.4:

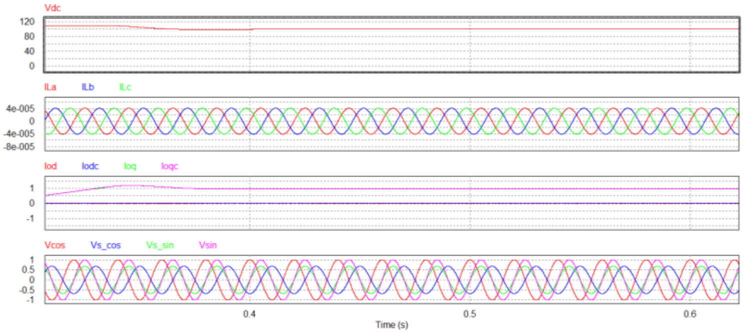


Figure 2.4 Experiment 2 digital circuit simulation waveforms

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. Refer to user manuals of each device before operation:

- PEK-520_2 * 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 2.5. Please follow it to complete wiring.

Figure 2.5 Experiment 2 wiring figure

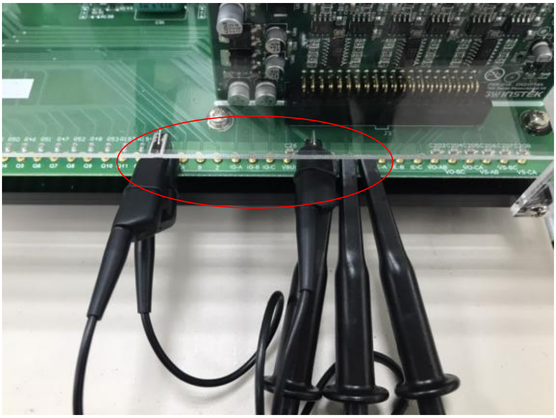
2. After wiring, make sure the PEK-520_2 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 2.6 shown, which means the DSP power is steadily normal.

Figure 2.6 DSP normal status with light on

3. Refer to the appendix B for burning procedure.

4. Connect the test leads of oscilloscope to IO-A, IO-B and IO-C of PEK-520_2, respectively, and connect the GND of test leads to the GND of module as the figure 2.7 shown. The measurement points within module are common ground.

Figure 2.7
Oscilloscope test leads wiring



5. Click Set key to check set voltage and current values. Set voltage 110V with voltage scroll knob and current 1A with current scroll knob for PSW 160-7.2 as the figure 2.8 shown.

Figure 2.8
The setting of PSW 160-7.2

6. As the figure 2.9 shown, power on APS-300 and set 50Hz for frequency, 3P4W for mode, 28.86V for output voltage.

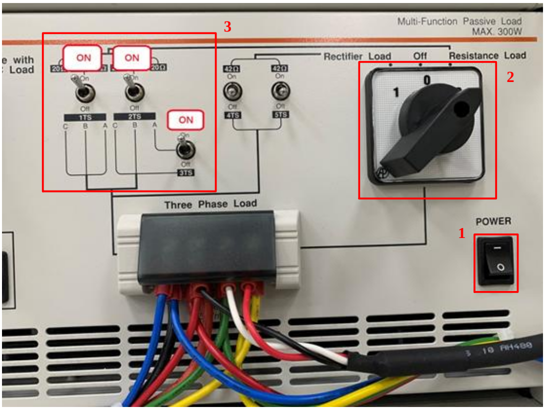
Figure 2.9

The setting of APS-300

7. As the figure 2.10 shown, follow the steps below for GPL-500 operation. Power on GPL-500 → Rotate the Three Phase Lord knob to Resistance Load → Set 1TS, 2TS and 3TS as ON, which indicates full-load mode.

Figure 2.10

The full-load setting of GPL-500



8. After setting up, turn on PSW and APS-300 power output followed by powering on PEK-520_2.

The purpose of experiment

It is to observe power fluctuations between inverter and power grid under varied inverter output powers.

The experiment result

(1) Inverter Output Power 100W

On the condition of full-load, the power required by load is 250W, which is provided by inverter and power grid commonly. Hence, when output power provided by inverter is 98.9W, the insufficient power 151.1W will be provided by power grid instead. As the figure 2.11 and 2.12 shown, because APS-300 displays single-phase power, the three-phase power will be 153.9W.

Figure 2.11

PSW output power

Figure 2.12

APS-300 output power

(2) Inverter Output Power 200W

Adjust output current to 2A via rotating the PSW current scroll knob. On the condition of full-load, when inverter provides 197.8W output power, the power required by load is 250W, which is provided by inverter and power grid commonly. The insufficient power 52.2W will be provided by power grid instead. As the figure 2.13 and 2.14 shown, because APS-300 displays single-phase power, the three-phase power will be 63.6W.

Figure 2.13

PSW output power

Figure 2.14

APS-300 output power

The Conclusion

From the experiment, it is evident that under the power grid-connected system the power from power grid, which is simulated by APS-300, will determine required power in accordance with fluctuation of system power in order to maintain the power balance of system.

Experiment 3 – Speed and Torque Control of PMSM

Circuit Simulation

The motor driver specification is as follows:

DC Voltage V_d = 130V

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

C_b = 330uF

K_s = 0.3 (Current sensing factor)

K_v = 1/50 (Voltage sensing factor)

The PMSM specification is as follows:

Rated Power: 400W

Rated Speed: 3000 rpm

Rated Current: 2.6A

Transient Max. Current: 7.8A

Counter EMF: 17.4 mV/min^{-1}

Electric Motor Resistance: 1.55 Ω

Electric Motor Inductive Reactance: 6.71mH

Motor Pole Number：10 poles

The analogue circuit diagram based on the parameters above is as the following figure 3.1 shown:
PSIM File:
PEK-520_1_Sim3_Speed_Torque_PMSM_V11.1.5_V1.1

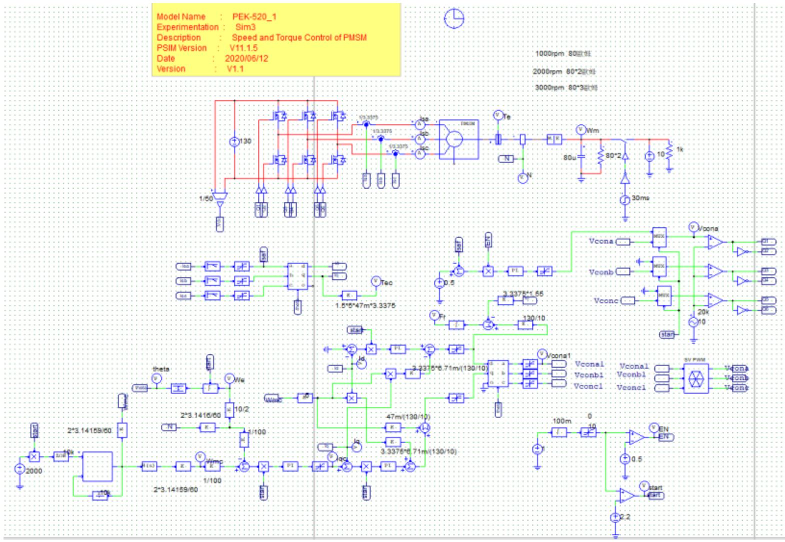


Figure 3.1 Experiment 3 - PSIM analogue circuit diagram

The simulation result is shown as the figure 3.2:

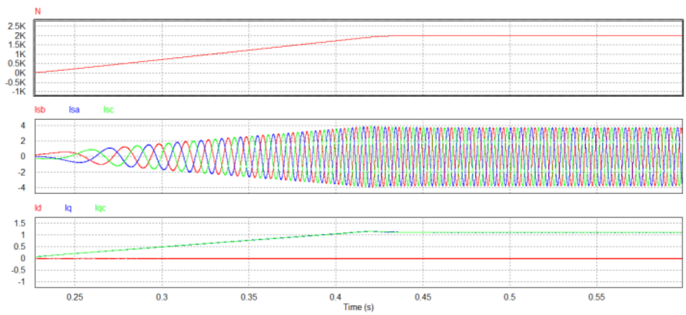


Figure 3.2 Experiment 3 analogue circuit simulation waveforms

The digital circuit diagram based on the analogue circuit is shown as the figure 3.3:
PSIM File: PEK-520_1_Lab3_Speed_Torque_PMSM_V11.1.5_V1.1

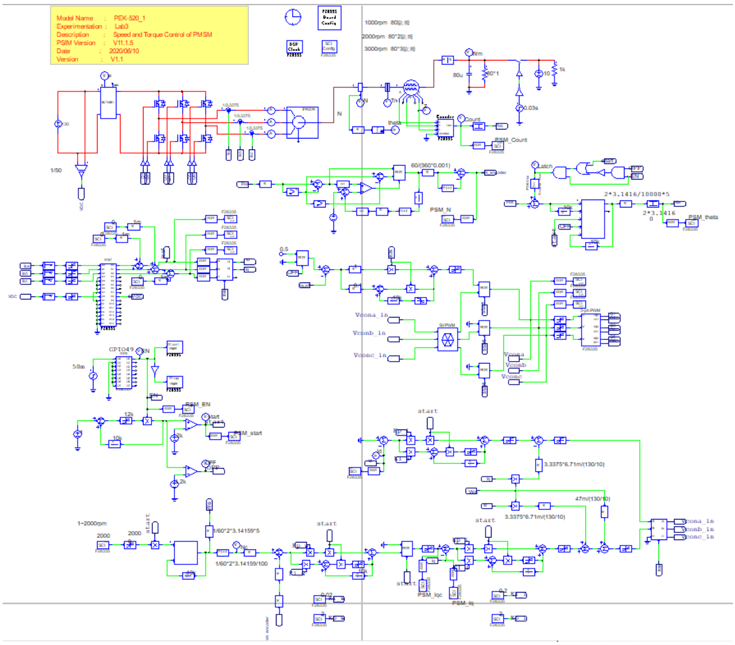


Figure 3.3 Experiment 3 PSIM digital circuit diagram

The simulation result is shown as the figure 3.4:

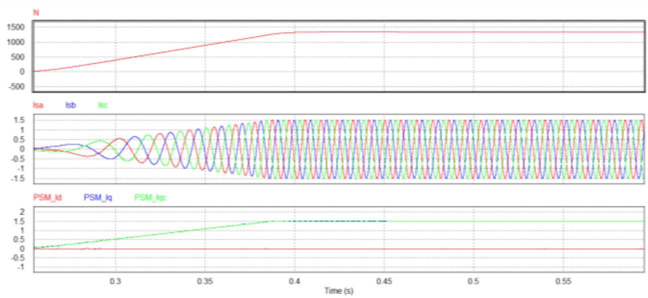


Figure 3.4 Experiment 3 digital circuit simulation waveforms

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-520_2 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2 and GPL-500)
- Motor Module * 1
- Power Cord * 1, Programming Cord * 1 and Load Cord * 1
- PC * 1

Experiment Procedure

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

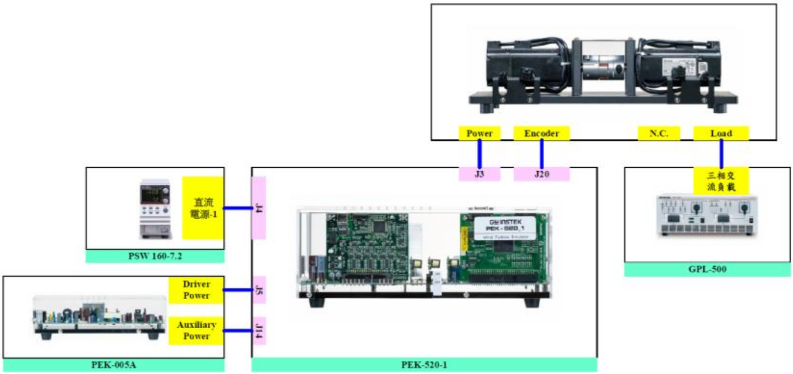


Figure 3.5 Experiment 3 wiring figure

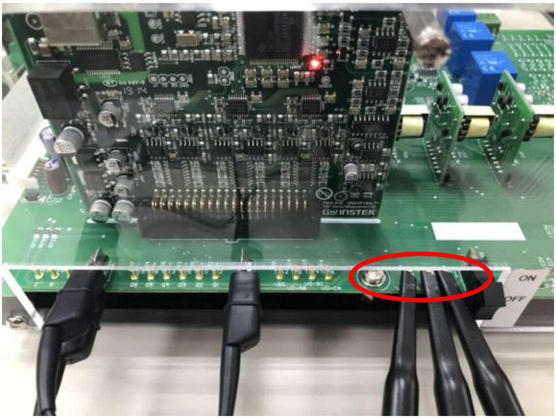
2. After wiring, make sure the PEK-520_1 switch is OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 3.6 shown, which means the DSP power is steadily normal.

Figure 3.6 DSP normal status with light on

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

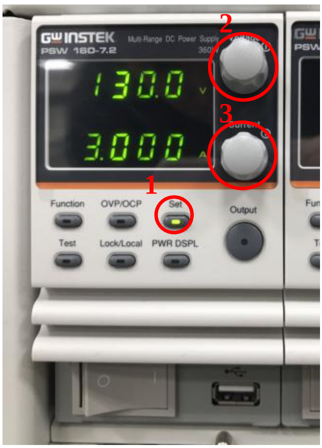
4. Connect the test leads of oscilloscope to IO-A, IO-B and IO-C of PEK-520_1, respectively, and connect the GND of test leads to the GND of module as the figure 3.7 shown. The measurement points within module are common ground.

Figure 3.7 Oscilloscope test leads wiring



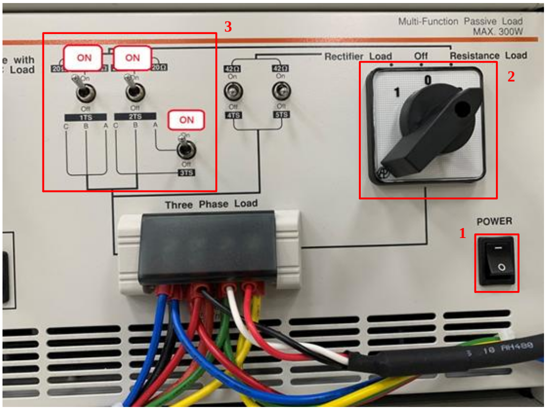
5. Click Set key to check set voltage and current values. Set voltage 130V with voltage scroll knob and current 3A with current scroll knob for PSW 160-7.2 as the figure 3.8 shown.

Figure 3.8 The setting of PSW 160-7.2



6. As the figure 3.9 shown, follow the steps below for GPL-500 operation. Power on GPL-500 → Rotate the Three Phase Lord knob to Resistance Load → Set 1TS, 2TS and 3TS as ON, which indicates full-load mode.

Figure 3.9
The full-load setting of GPL-500



7. After setting up and turning on PSW power output, turn on the switch of PEK-520_1.

The purpose of experiment

It is to observe fluctuations of driver output current when motor speed changes.

The experiment result

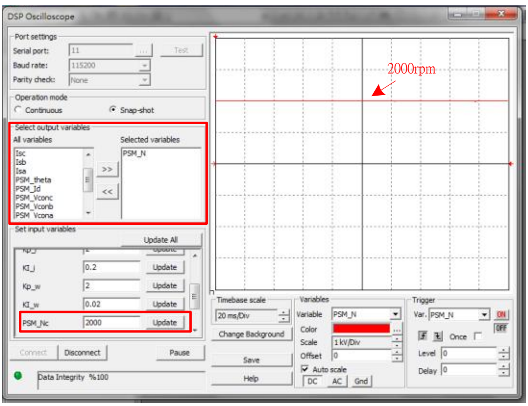
(3) Motor speed 2000 rpm

Motor speed can be modified via input parameter "PSM_Nc" of DSP oscilloscope and the initial setting is 2000 rpm. Also, it is available to use "PSM_N" of DSP oscilloscope to observe the current motor speed. As the figure 3.10 shown, the current speed is 2000 rpm.

The figure 3.11 shows that, from the oscilloscope observation, IO-A three phase current RMS value is 1.16V (2.433A in actual value), IO-B is 1.14A (2.391A in actual value), and IO-C is 1.12A (2.349A in actual value) with frequency 166.76Hz.

Figure 3.10

DSP oscilloscope motor speed measurement value



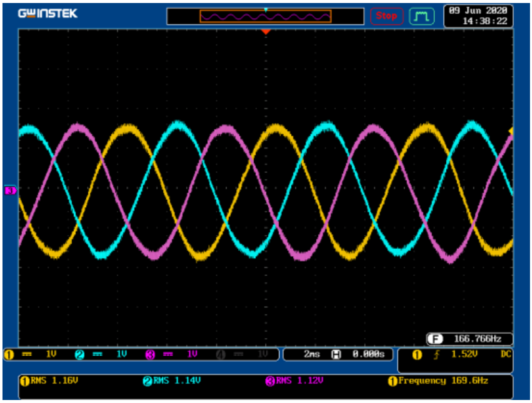


Figure 3.11

Motor three phase current waveform

(4) Motor speed 1000 rpm

After motor speed is modified from 2000rpm to 1000rpm via input parameter "PSM_Nc", click "Update" and the speed measurement (PSM_N) is in fact 1000rpm observed from DSP oscilloscope as the figure 3.12 shown.

The figure 3.13 shows that, from the oscilloscope observation, IO-A three phase current RMS value is 0.713A (1.495A in actual value), IO-B is 0.745A (1.563A in actual value), and IO-C is 0.756A (1.586A in actual value) with frequency 83.33Hz.

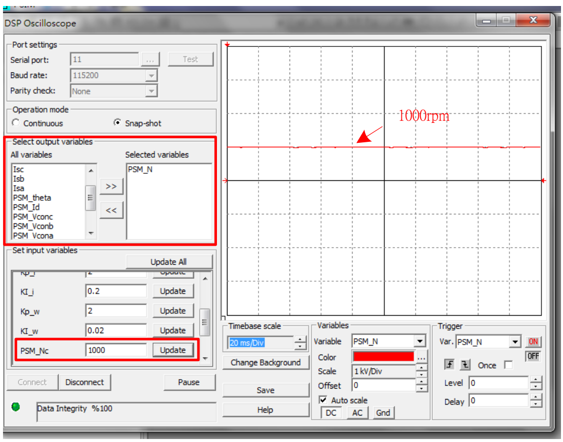
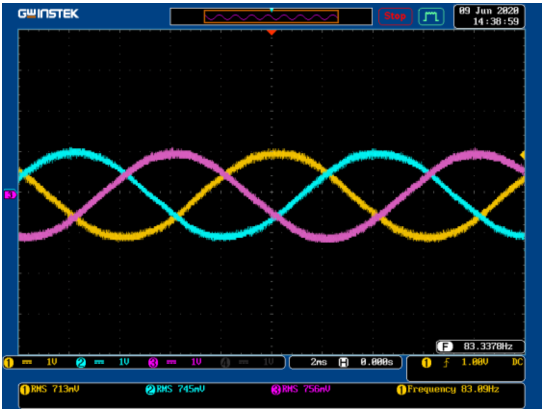


Figure 3.12

DSP oscilloscope motor speed measurement value

Figure 3.11

Motor three phase current waveform



Per different load operations, refer to the table 0.1 for the sensing ratio followed by filling in the table 3.1 with result in order.

Table 1.1 Three phase current measured values under varied motor speeds

RPM		IO-A(Arms)	IO-B(Arms)	IO-C(Arms)	Frequency(Hz)
2000rpm	Measured value	1.16A	1.14A	1.12A	166.76Hz
	Actual value	2.433A	2.391A	2.349A	
1000rpm	Measured value	0.713A	0.745A	0.756A	83.33Hz
	Actual value	1.495A	1.563A	1.586A	

The conclusion

It has seen that when motor speed increases, output current scale and frequency will increase accordingly. That is to say, motor speed is proportional to current scale and frequency.

Experiment 4 – Speed Control of PMSG

Circuit Simulation

The parameters of electric motor actuator:

DC Voltage V_d = 130V

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

C_b = 330uF

K_s = 0.3 (Current sensing factor)

K_v = 1/50 (Voltage sensing factor)

The parameters of generator actuator:

BUS Voltage V_{bus} = 130V

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

C_{bus} = 940uF

K_s = 0.3 (Current sensing factor)

K_v = 1/50 (Voltage sensing factor)

The parameters of permanent magnet synchronous motor:

Rated Power: 400W

Rated Speed: 3000rpm

Rated Current: 2.6A

Transient Max. Current: 7.8A

Counter emf: 17.4 mV/min^{-1}

Electric Motor Impedance: 1.55 Ω

Electric Motor Reactance: 6.71mH

Rotor Inertia: 27.7u kg · m²

Mechanical Constant: 0.53 ms

Motor Pole Number: 10 poles

The wind turbine and generator analogue circuit diagrams based on the parameters above are as the following figures 4.1 and 4.2 shown:

Wind Turbine PSIM File: PEK-520_1_Sim4_Torque_PMSM_V11.1.5_V1.1

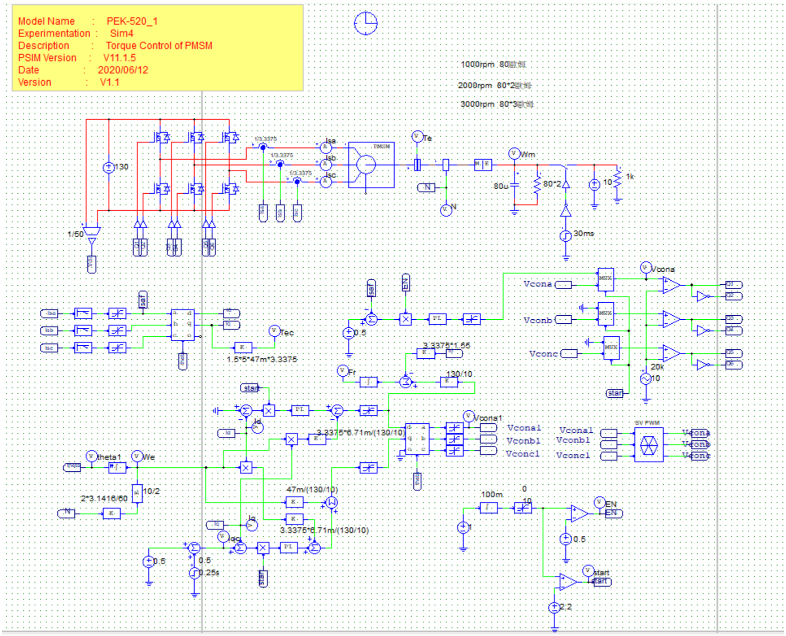


Figure 4.1 Experiment 4 Wind Turbine PSIM analogue circuit diagram

Generator PSIM File: PEK-520_2_Sim4_Speed_PMSG_V11.1.5_V1.1

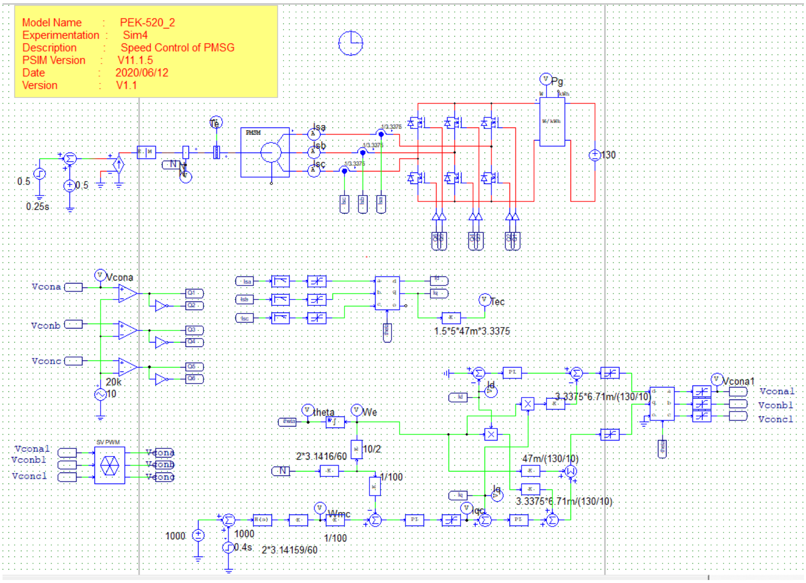


Figure 4.2 Experiment 4 Generator PSIM analogue circuit diagram

The wind turbine simulation result is shown as the figure 4.3:

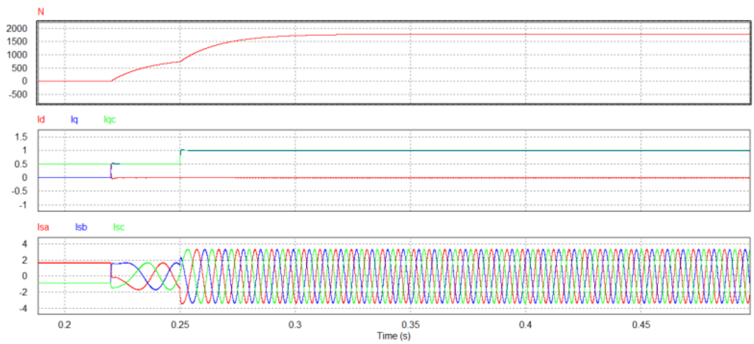


Figure 4.3 Experiment 4 Wind Turbine analogue circuit simulation waveforms

The generator simulation result is shown within the figure 4.4:

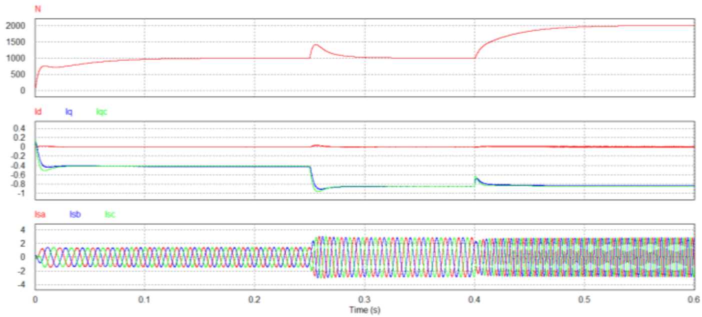


Figure 4.4 Generator analogue circuit simulation waveforms

The wind turbine and generator digital circuit diagrams based on the analogue circuit are as the following figures 4.5 and 4.6 shown:

Wind Turbine PSIM File: PEK-520_1_Lab4_Torque_PMSM_V11.1.5_V1.1

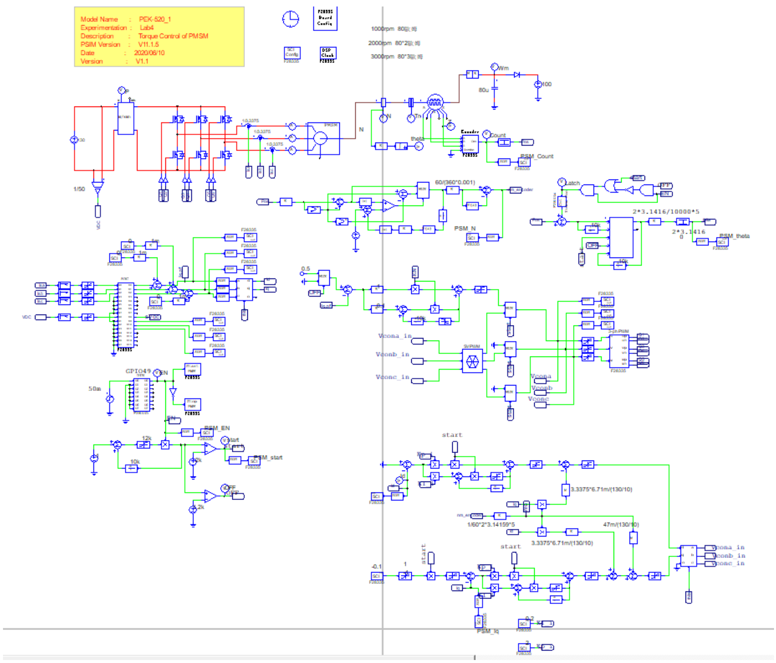


Figure 4.5 Experiment 4 Wind Turbine PSIM analogue circuit diagram

Generator PSIM File:
PEK-520_2_Lab4_Speed_PMSG_V11.1.5_V1.11

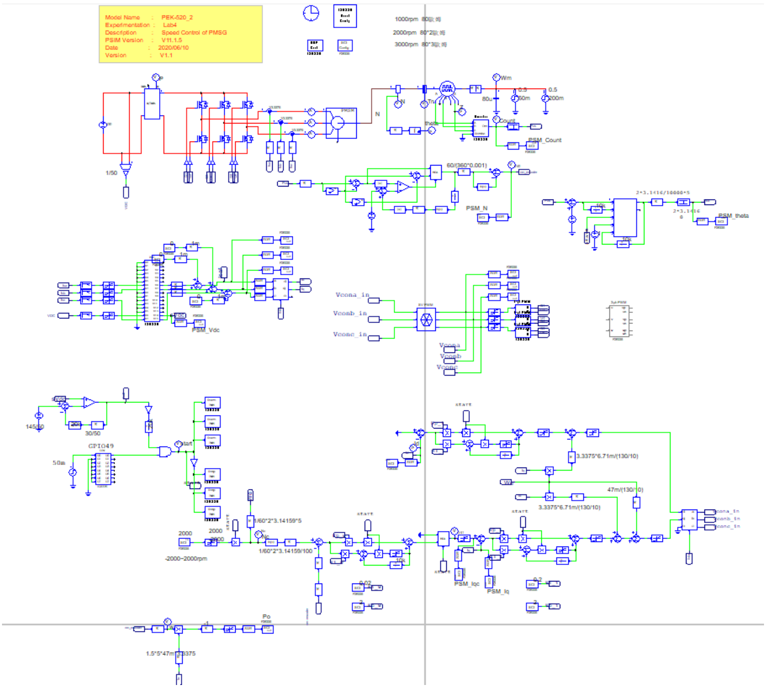


Figure 4.6 Experiment 4 Generator PSIM analogue circuit diagram

The wind turbine simulation result is shown as the figure 4.7:

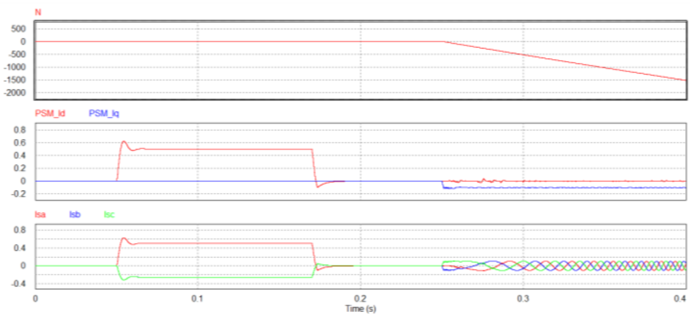


Figure 4.7 Experiment 4 Wind Turbine digital circuit simulation waveforms

The generator simulation result is shown as the figure 4.8:

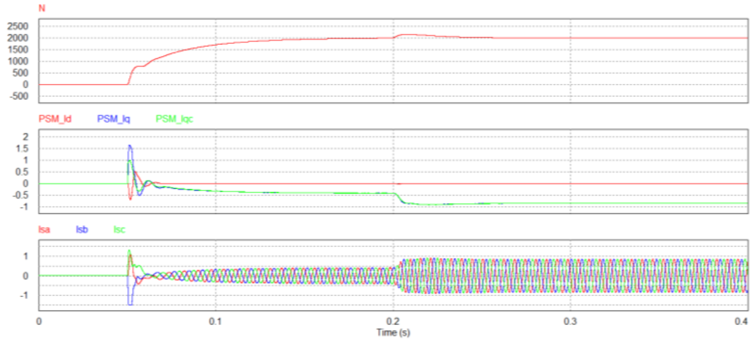


Figure 4.8 Experiment 4 Generator digital circuit simulation waveforms

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-520_1 * 1
- PEK-520_2 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E and PSW160-7.2)
- Motor Module * 1
- Power Cord * 2
- Coding Cord * 2
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 4.9. Please follow it to complete wiring.

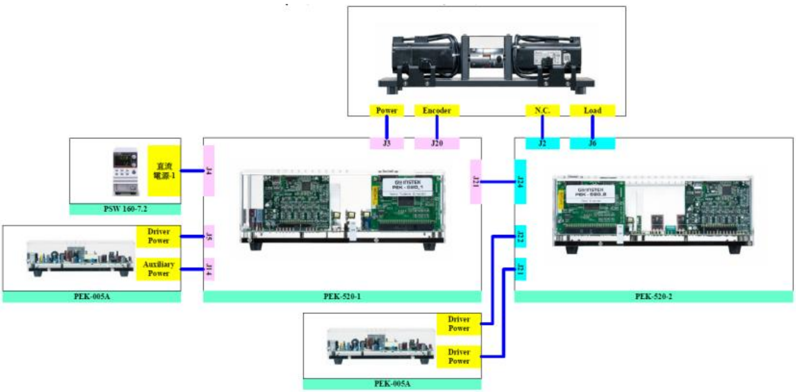
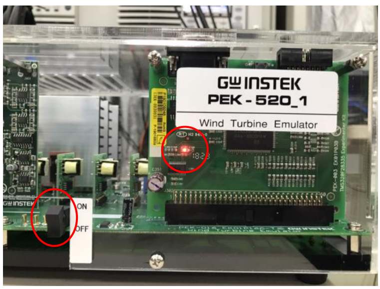


Figure 4.9 Experiment 4 wiring figure

2. After wiring, make sure the PEK-520_1 and PEK-520_2 switch are OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 4.10 shown, which means the DSP power is steadily normal.

Figure 4.10 DSP normal status with light on

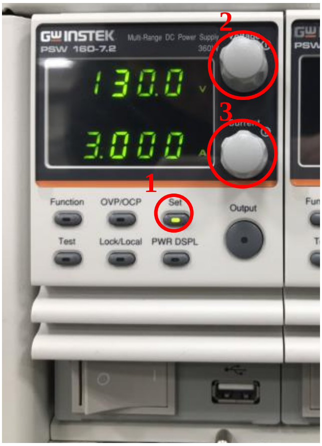


3. Refer to the appendix B for burning procedure and appendix C for RS232 connection. Because both PEK-520_1 and PEK-520_2 are required to utilize RS232 connection, the 2 separate PSIM windows are necessary for connection with PEK individually.
4. Connect the test leads of oscilloscope to IO-A, IO-B and IO-C of PEK-520_1, respectively, and connect the GND of test leads to the GND of module as the figure 4.11 shown.

Figure 4.11
Oscilloscope test leads wiring

5. Click Set key to check set voltage and current values. Set voltage 130V with voltage scroll knob and current 3A with current scroll knob for PSW 160-7.2 as the figure 4.12 shown.

Figure 4.12
The settings of
PSW 160-7.2



6. After setting up and turning on PSW power output, finally turn on the switch of PEK-520_1 followed by PEK-520_2.

The purpose of experiment

This experiment contains the motor with generator system in which motor is torque control and torgue is changed by current command adjustment, while generator is speed control, observing inverter current amplitude and frequency fluctuation when torque and speed change.

The Experiment Result

(5) Generator speed 2000rpm; motor current command -0.1

When the default setting of motor (PEK-520_1) current command (PSM_Iqc) is -0.1 as the figure 4.13 shown, it is available to observe, from DSP oscilloscope, motor current (PSM_Iq) is -0.1A as the figure 4.14 shown. When the default command of of generator (PEK-520_2) speed (PSM_N) is 2000rpm as the figure 4.15, it is available to observe via DSP oscilloscope as the figure 4.16 shown. The figure 4.17 shows that, from the oscilloscope observation, IO-A three phase current RMS value is 0.233A (0.489A in actual value), IO-B is 0.239A (0.501A in actual value), and IO-C is 0.154A (0.323A in actual value) with frequency 166.7Hz.

Figure 4.13

DSP oscilloscope motor current command value

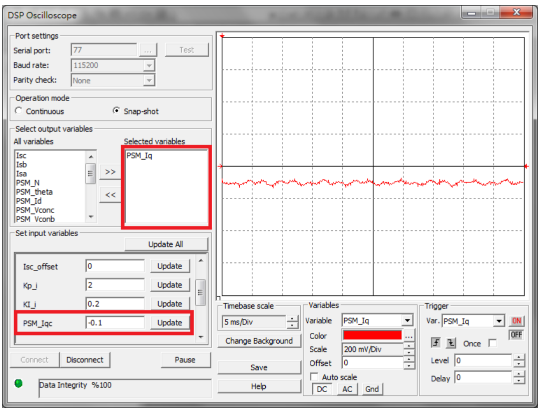


Figure 4.14

DSP oscilloscope motor current measured value

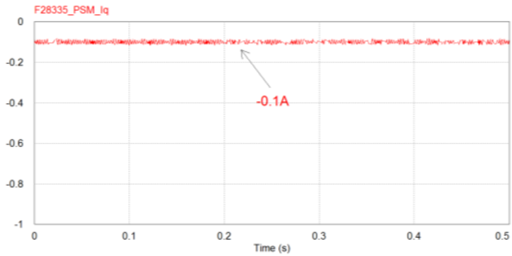


Figure 4.15

DSP oscilloscope generator speed command value

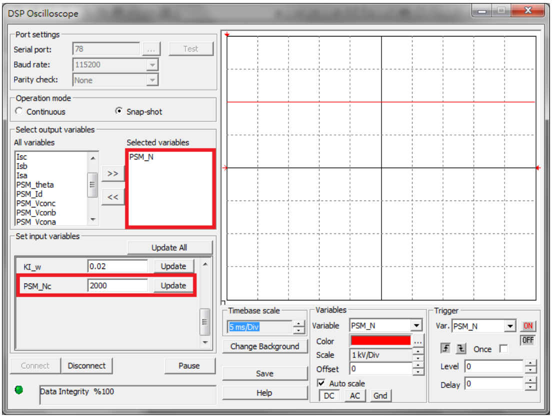


Figure 4.16

DSP oscilloscope generator speed measured value

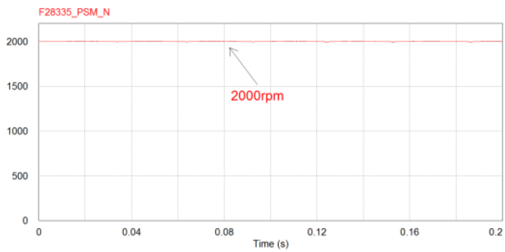
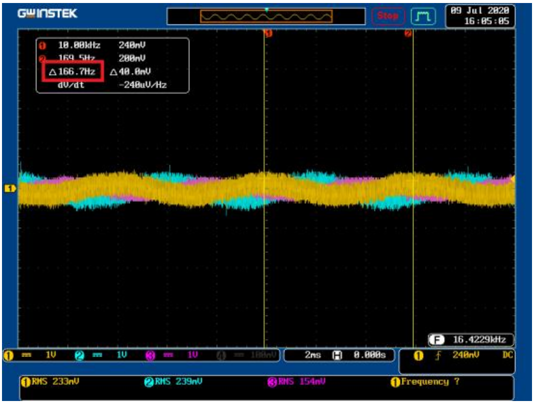


Figure 4.17

Motor three phase current waveform



(6) Generator speed 2000rpm; motor current command -0.5

After motor current command (PSM_Iqc) is modified from -0.1 to -0.5 as the figure 4.18 shown, click "Update" and the motor current (PSM_Iq) is in fact -0.5A observed from DSP oscilloscope as the figure 4.19 shown.

The figure 4.20 shows that, from the oscilloscope observation, IO-A three phase current RMS value is 0.572A (1.200A in actual value), IO-B is 0.602A (1.263A in actual value), and IO-C is 0.581A (1.219A in actual value) with frequency 166.7Hz.

Figure 4.18

DSP oscilloscope motor current command value

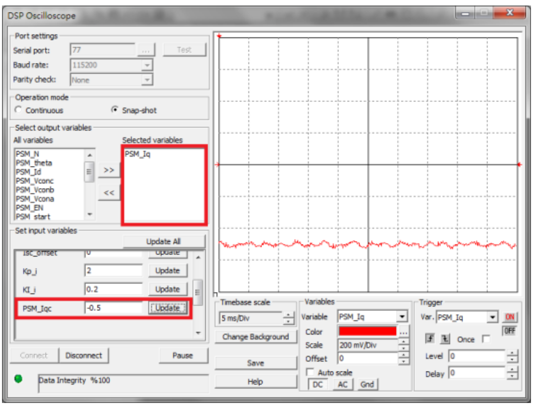


Figure 4.19

DSP oscilloscope motor current measured value

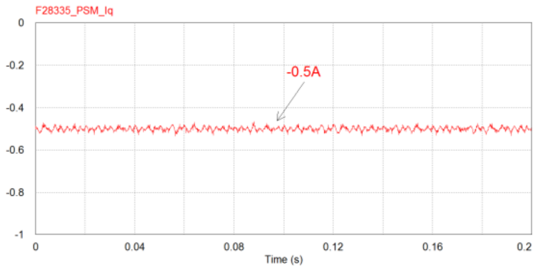
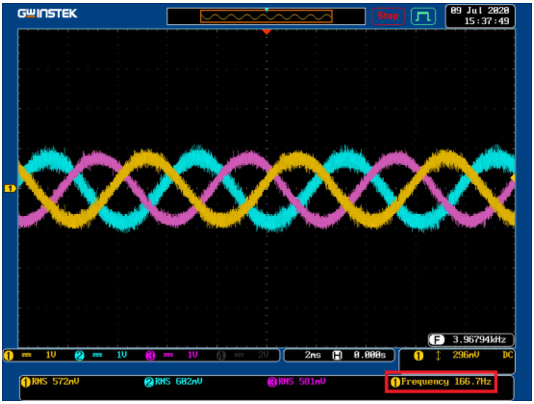


Figure 4.20

Motor three phase current waveform



(7) Generator speed 1000rpm; motor current command -0.5

After generator speed (PSM_Nc) is modified from 2000rpm to 1000rpm as the figure 4.21 shown, click "Update" and the generator speed (PSM_N) is in fact 1000rpm observed from DSP oscilloscope as the figure 4.22 shown.

The figure 4.23 shows that, from the oscilloscope observation, IO-A three phase current RMS value is 0.596A (1.25A in actual value), IO-B is 0.600A (1.258A in actual value), and IO-C is 0.547A (1.147A in actual value) with frequency 83.33Hz.

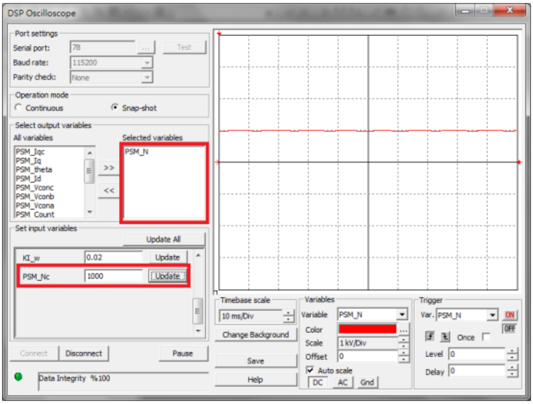


Figure 4.21

DSP oscilloscope generator speed command value

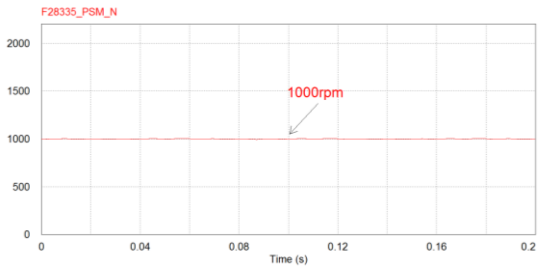


Figure 4.22

DSP oscilloscope generator speed measured value

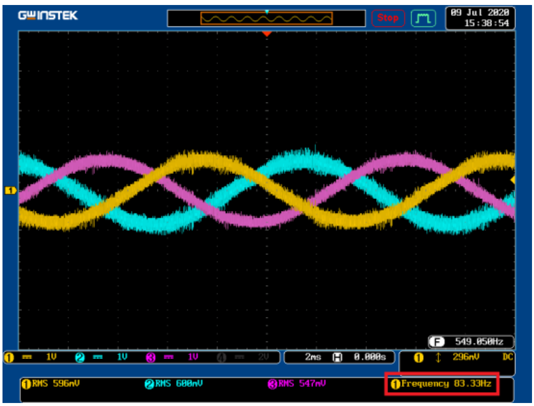


Figure 4.23

DSP oscilloscope motor three phase current waveform

Per different motor speeds and current commands, refer to the tables 0.1 and 0.2 for the sensing ratio followed by filling in the table 4.1 with result in order.

Table 4.1 Output three phase current measured values under varied motor speeds and current commands

Current Command	Motor Speed		IO-A(Arms)	IO-B(Arms)	IO-C(Arms)	Frequency(Hz)
-0.1A	2000rpm	Measured value	0.233A	0.239A	0.154A	166.7Hz
		Actual value	0.489A	0.510A	0.323A	
-0.5A	2000rpm	Measured value	0.572A	0.602A	0.581A	166.7Hz
		Actual value	1.200A	1.263A	1.219A	
-0.5A	1000rpm	Measured value	0.596A	0.600A	0.547A	83.33Hz
		Actual value	1.25A	1.258A	1.147A	

The conclusion

It has seen that when adjusting motor torque, the inverter output current amplitude changes accordingly. Also, when adjusting generator speed, the output current frequency fluctuates accordingly.

Experiment 5 –Wind Turbine Generator (WTG) Emulation

Circuit Simulation

The parameters of WTG actuator:

DC Voltage $V_d = 130V$

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

$C_b = 330uF$

$K_s = 0.3$ (Current sensing factor)

$K_v = 1/50$ (Voltage sensing factor)

The parameters of generator actuator:

BUS Voltage $V_{bus} = 130V$

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

$C_{bus} = 940uF$

$K_s = 0.3$ (Current sensing factor)

$K_v = 1/50$ (Voltage sensing factor)

The parameters of permanent magnet synchronous motor:

Rated Power: 400W

Rated Speed: 3000rpm

Rated Current: 2.6A

Transient Max. Current: 7.8A

Counter emf: 17.4 mV/min^{-1}

Electric Motor Impedance: 1.55 Ω

Electric Motor Reactance: 6.71mH

Rotor Inertia: 27.7u kg · m^2

Mechanical Constant: 0.53 ms

Motor Pole Number: 10 poles

The WTG analogue circuit diagram based on the parameters above is as the following figure 5.1 shown (generator utilizes Sim4 analogue program):

WTG PSIM File: PEK-520_1_Sim5_WTG_PMSM_V11.1.5_V1.1

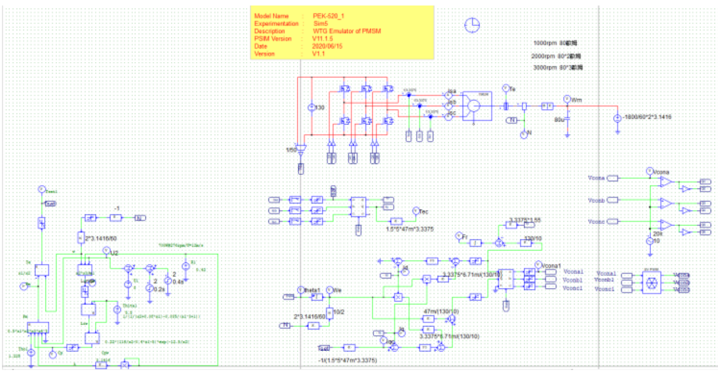


Figure 5.1 Experiment 5 PSIM analogue WTG circuit diagram

The WTG simulation result is shown within the figure 5.2:

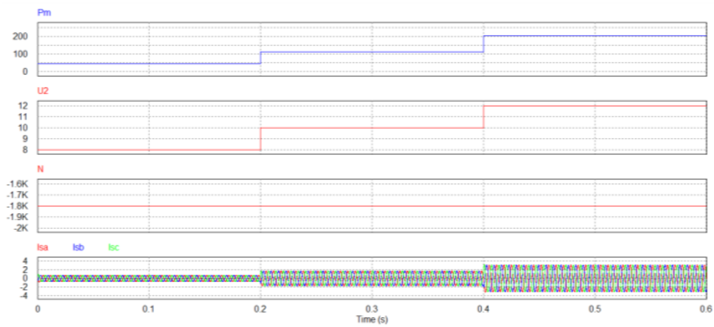


Figure 5.2 Experiment 5 Simulation waveform of analogue WTG circuit diagram

The WTG digital circuit diagram based on the analogue circuit diagram is as the following figure 5.3 shown (generator utilizes Lab4 digital program):

PSIM File: PEK-520_1_Lab5_WTG_PMSM_V11.1.5_V1.1

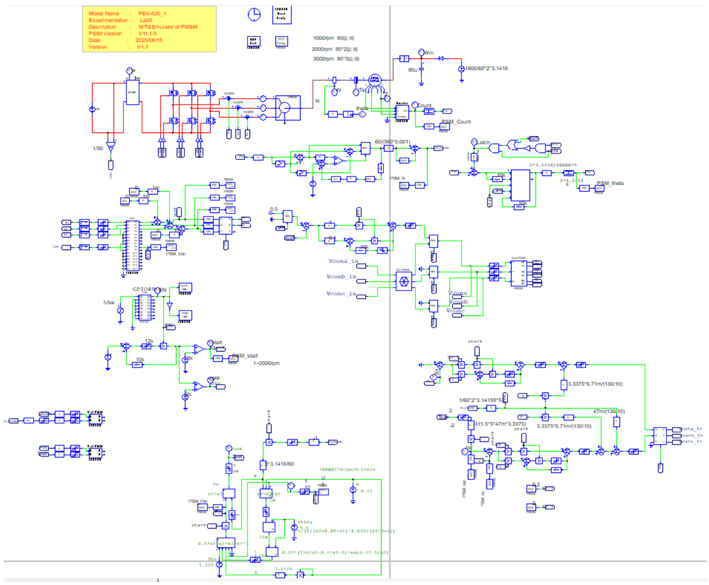


Figure 5.3 Experiment 5 PSIM digital WTG circuit diagram

The WTG simulation result is shown as the figure 5.4:

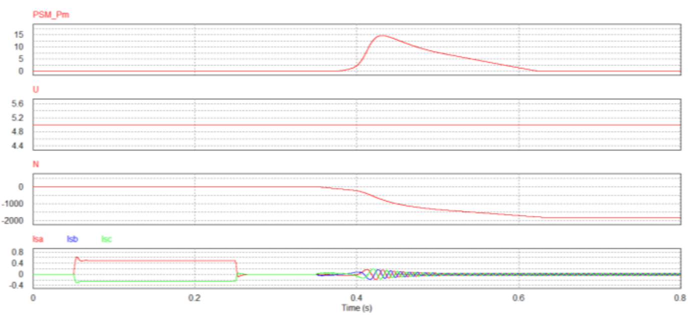


Figure 5.4 Experiment 5 digital WTG circuit simulation waveforms

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-520_1 * 1
- PEK-520_2 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E and PSW160-7.2)
- Motor Module * 1
- Power Cord * 2
- Coding Cord * 2
- PC * 1

Experiment Procedure

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

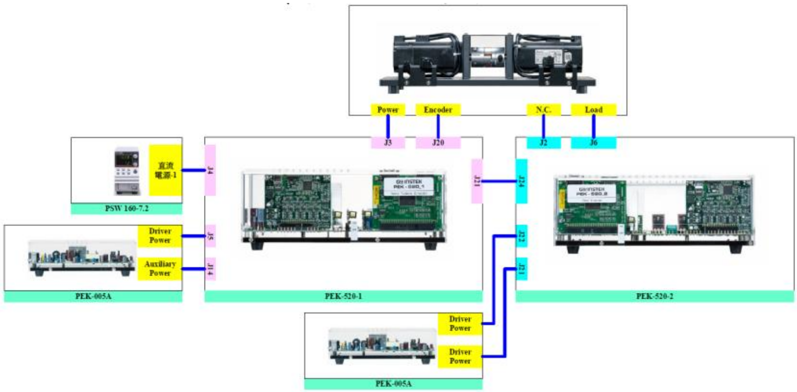
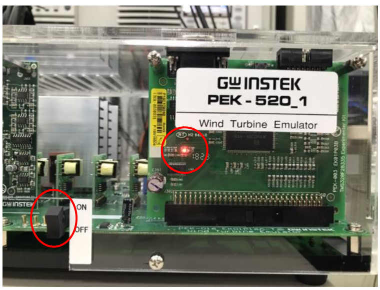


Figure 5.5 Experiment 5 wiring figure

2. After wiring, make sure the PEK-520_1 and PEK-520_2 switch are 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

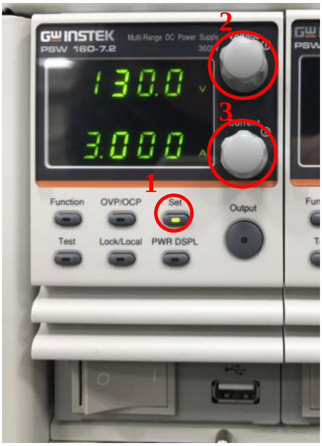


3. Refer to the appendix B for burning procedure and appendix C for RS232 connection. Because both PEK-520_1 and PEK-520_2 are required to utilize RS232 connection, the 2 separate PSIM windows are necessary for connection with PEK individually.
4. Connect the test leads of oscilloscope to IO-A, IO-B and IO-C of PEK-520_1, respectively, and connect the GND of test leads to the GND of module as the figure 5.7 shown.

Figure 5.7 Oscilloscope test leads wiring

5. Click Set key to check set voltage and current values. Set voltage 130V with voltage scroll knob and current 3A with current scroll knob for PSW 160-7.2 as the figure 5.8 shown.

Figure 5.8
The settings of PSW 160-7.2



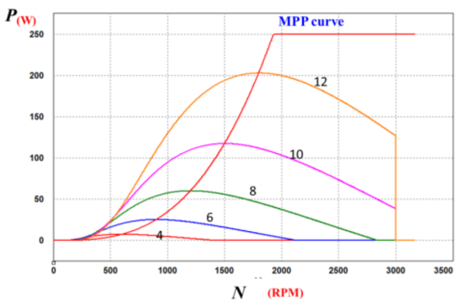
6. After setting up and turning on PSW power output, finally turn on the switch of PEK-520_1 followed by PEK-520_2.

The purpose of experiment

Within the Lab5 experiment following the Lab4 experiment, the motor torque command is determined by wind speed and motor speed, by doing which the corresponding power speed curve (PN Curve) can be mapped out to simulate the pattern of WTG as the figure 5.9 shown. When WTG changes its speed, observe if output power of WTG is in accord with power curve output.

Figure 5.9

PN cureve from varied wind speeds



The Experiment Result

(8) Wind speed (U) 10; generator speed 2000rpm

After WTG (PEK-520_1) wind speed (U) is modified from 5 to 10, click "Update" as the figure 5.10 shown. And after generator (PEK-520_2) speed command (PSM_Nc) is 2000rpm as the figure 5.11 shown, it is available to observe, from DSP oscilloscope, that WTG power (PSM_Pm) is 102W as the figure 5.12 shown.

Figure 5.10

WTG wind speed command modified from 5 to 10

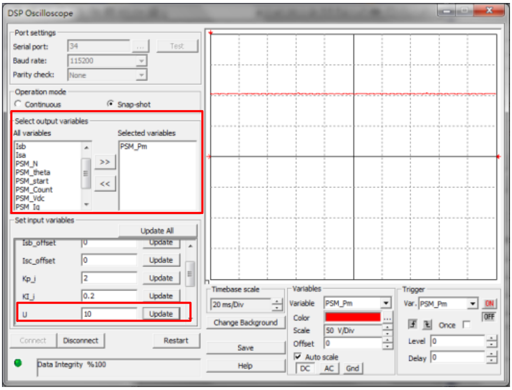


Figure 5.11

Generator speed command value

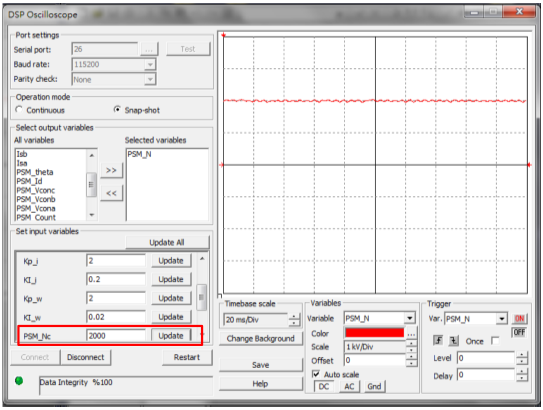
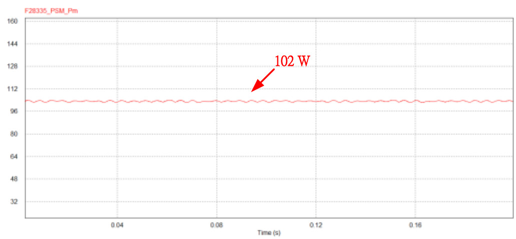


Figure 5.12

Generator speed measured value from DSP oscilloscope



(9) Wind speed (U) 10; generator speed 1000rpm

When wind speed (U) is maintained 10, adjust the generator speed command (PSM_Nc) from 2000rpm to 1000rpm followed by clicking "Update" as the figure 5.13 shown. It is available to observe, from DSP oscilloscope, that WTG power (PSM_Pm) is 95W as the figure 5.14 shown.

Figure 5.13

Generator speed command modified from 2000 to 1000

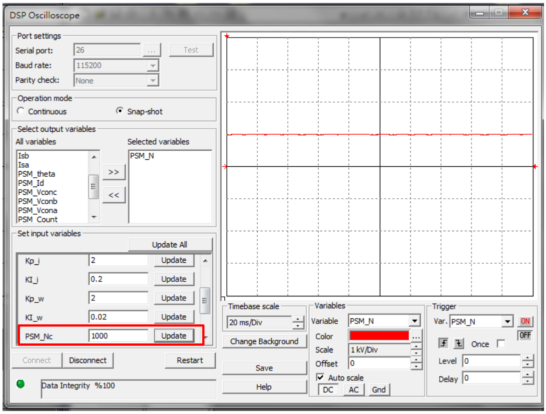
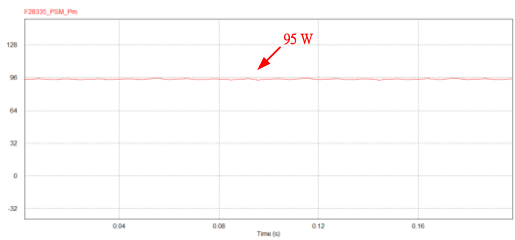


Figure 5.14

WTG power measured value from DSP oscilloscope



(10) Wind speed (U) 10; generator speed 1498rpm

When wind speed (U) is maintained 10, adjust the generator speed command (PSM_Nc) from 1000rpm to 1498rpm followed by clicking "Update" as the figure 5.15 shown. It is available to observe, from DSP oscilloscope, that WTG power (PSM_Pm) is 117W as the figure 5.16 shown.

Figure 5.15

Generator speed command modified from 1000 to 1498

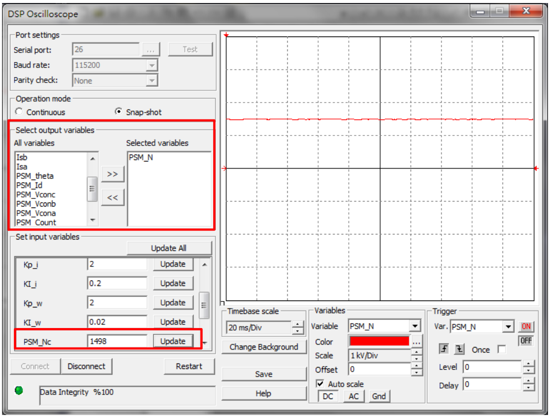
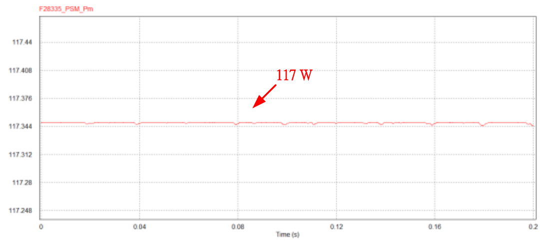


Figure 5.16

WTG power measured value from DSP oscilloscope



Per different measured powers from varied speeds, fill in the table 5.1 with results in order and compare them with certain PN Curve.

Table 5.1 WTG power theory and actual data under varied speeds

Wind Speed	Motor Speed		WTG Power(PSM_Pm)
10	2000rpm	Measured value	102 W
		Actual value	103 W
10	1000rpm	Measured value	95 W
		Actual value	94 W
10	1498rpm	Measured value	117 W
		Actual value	117.3 W

The conclusion

It has seen that, from the table 5.1, when wind speed is 10, the WTG output power, via speed adjustment, is corresponding to the PN curve of the figure 5.9 and therefore WTG power is practically outputing in accordance with power curve.

Experiment 6 – Maximum Power Point Tracking of WTG

Circuit Simulation

The parameters of WTG actuator:

DC Voltage V_d = 130V

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

C_b = 330uF

K_s = 0.3 (Current sensing factor)

K_v = 1/50 (Voltage sensing factor)

The parameters of generator actuator:

BUS Voltage V_{bus} = 130V

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

C_{bus} = 940uF

K_s = 0.3 (Current sensing factor)

K_v = 1/50 (Voltage sensing factor)

The parameters of permanent synchronous motor:

Rated Power: 400W

Rated Speed: 3000rpm

Rated Current: 2.6A

Transient Max. Current: 7.8A

Counter emf: 17.4 mV/min^{-1}

Electric Motor Impedance: 1.55 Ω

Electric Motor Reactance: 6.71mH

Rotor Inertia: 27.7u kg · m^2

Mechanical Constant: 0.53 ms

Motor Pole Number: 10 poles

The generator analogue circuit diagram based on the parameters above is as the following figure 6.1 shown (WTG utilizes Sim5 analogue circuit diagram program):

Generator PSIM File: PEK-520_2_Sim6_MPPT_PMSG_V11.1.5_V1.1

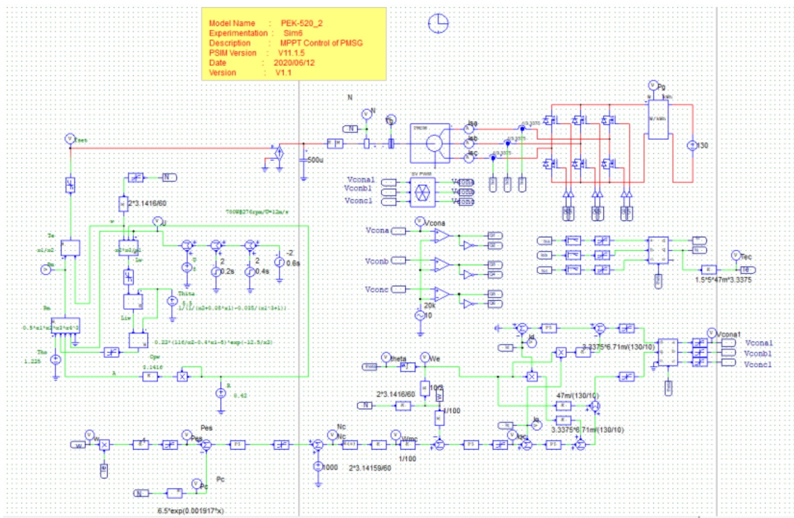


Figure 6.1 Experiment 6 PSIM generator analogue circuit diagram

The generator simulation result is shown within the figure 6.2:

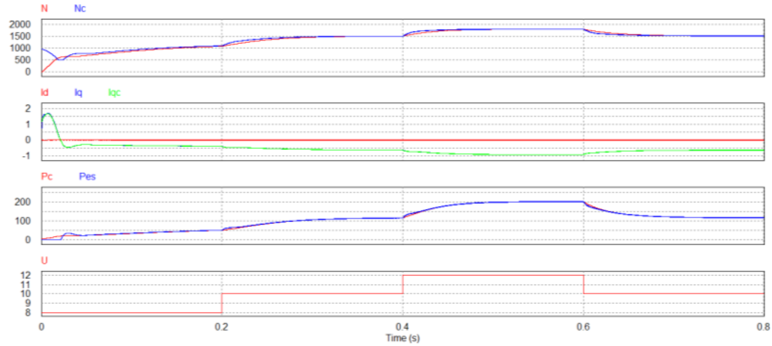


Figure 6.2 Experiment 6 analogue generator circuit simulation waveforms

The generator digital circuit diagram based on the analogue circuit diagram is as the following figure 6.3 shown (WTG utilizes Lab5 digital circuit program):
Generator PSIM File: PEK-520_2_Lab6_MPPT_PMSG_V11.1.5_V1.1

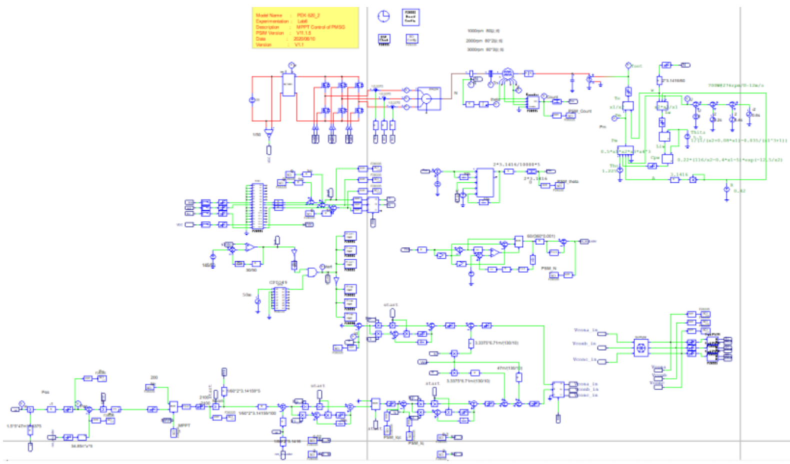


Figure 6.3 Experiment 6 PSIM generator digital circuit diagram

The generator simulation result is shown as the figure 6.4:

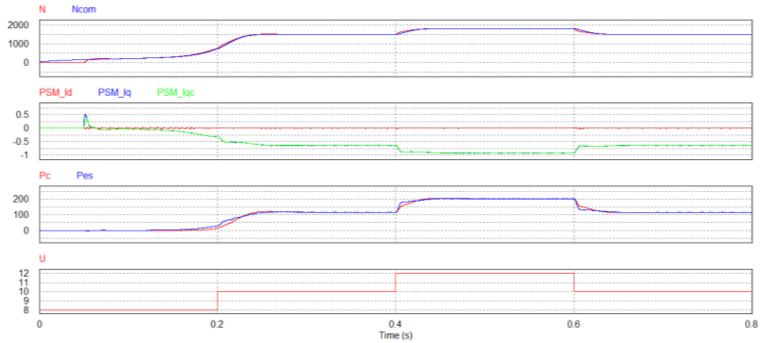


Figure 6.4 Experiment 6 digital generator circuit simulation waveforms

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-520_1 * 1
- PEK-520_2 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E and PSW160-7.2)
- Motor Module * 1
- Power Cord * 2
- Coding Cord * 2
- PC * 1

Experiment Procedure

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

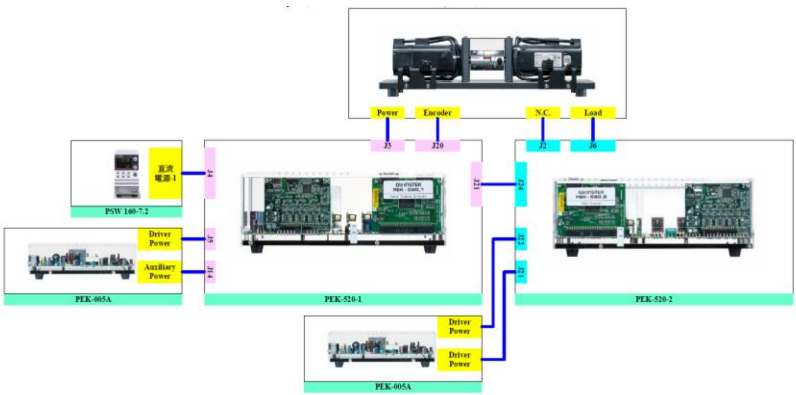


Figure 6.5 Experiment 6 wiring figure

2. After wiring, make sure the PEK-520_1 and PEK-520_2 switch are 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.

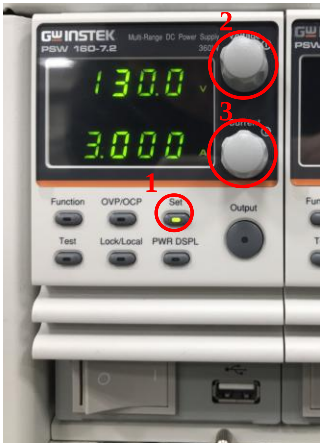
Figure 6.6 DSP normal status with light on

3. Refer to the appendix B for burning procedure and appendix C for RS232 connection. Because both PEK-520_1 and PEK-520_2 are required to utilize RS232 connection, the 2 separate PSIM windows are necessary for connection with PEK individually.
4. Connect the test leads of oscilloscope to IO-A, IO-B and IO-C of PEK-520_1, respectively, and connect the GND of test leads to the GND of module as the figure 6.7 shown.

Figure 6.7 Oscilloscope test leads wiring

5. Click Set key to check set voltage and current values. Set voltage 130V with voltage scroll knob and current 3A with current scroll knob for PSW 160-7.2 as the figure 6.8 shown.

Figure 6.8
The settings of
PSW 160-7.2



6. After setting up and turning on PSW power output, finally turn on the switch of PEK-520_1 followed by PEK-520_2.

The purpose of experiment

When wind speed changes, power curve of WTG changes accordingly in which the maximum power point will vary as well. As the figure 6.9 shown, plot a line of maximum power point curve (MPP Curve) under varied wind speed, the maximum power with corresponding motor speed under different wind speeds is shown as the figure 6.1. Try to alter wind speed and observe if WTG output power is maintained within the maximum power point currently.

Figure 6.9

PN Curve under varied wind speeds

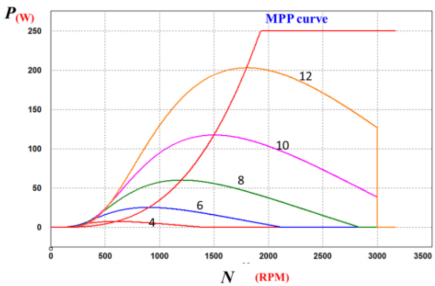


Table 6.1 Corresponding motor speeds relative to maximum power points under different wind speeds

Wind Speed (U)	Motor Speed (N)	Power (P)
1	145	0.11
2	300	0.93
3	449	3.16
4	599	7.51
5	749	14.6
6	898	25.3
7	1048	40.2
8	1198	60
9	1348	85.5
10	1198	117.3
11	1647	156.2
12	1797	202.7

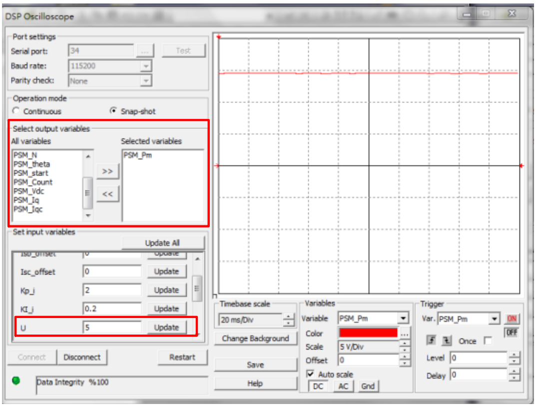
The Experiment Result

(11) Wind Speed (U) 5

When wind speed command (U) of WTG (PEK-520_1) is 5, it is available to observe, from DSP oscilloscope, that WTG power (PSM_Pm) is 14.5W as the figure 6.10 shown and generator (PEK-520_2) speed (PSM_N) is 691rpm as the figure 6.11 shown.

Figure 6.10

WTG power measured value from DSP oscilloscope



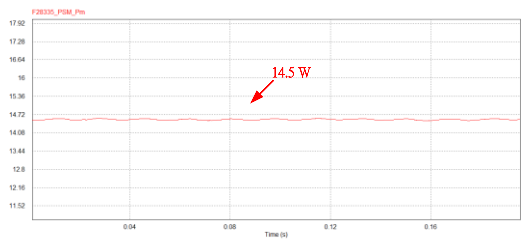
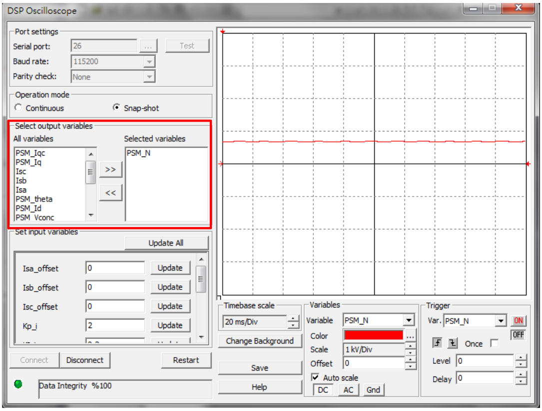
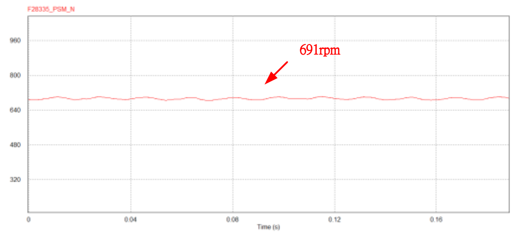


Figure 6.11

Generator speed measured value from DSP oscilloscope



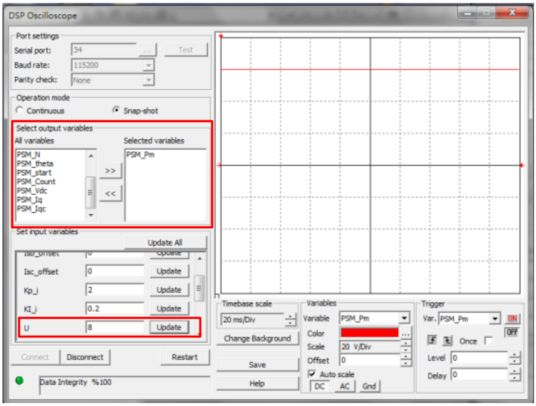


(12) Wind Speed (U) 8

When wind speed command (U) of WTG is adjusted from 5 to 8, it is available to observe, from DSP oscilloscope, that WTG power (PSM_Pm) is 60W as the figure 6.12 shown and generator speed (PSM_N) is 1161rpm as the figure 6.13 shown.

Figure 6.12

WTG power measured value from DSP oscilloscope



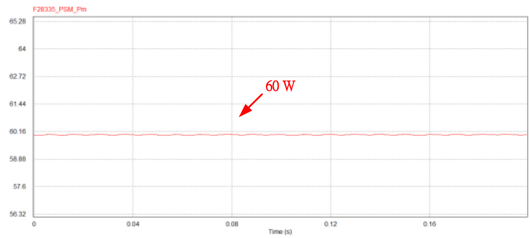
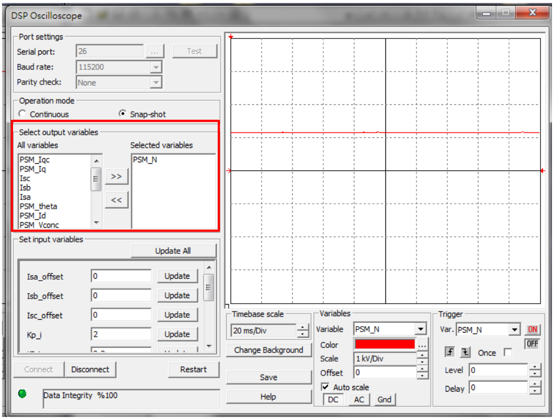
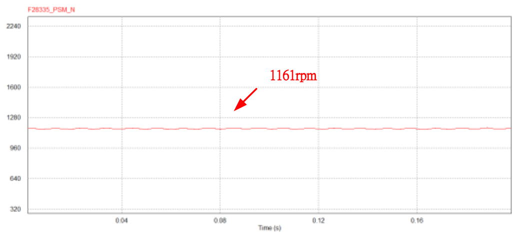


Figure 6.13

Generator speed measured value from DSP oscilloscope



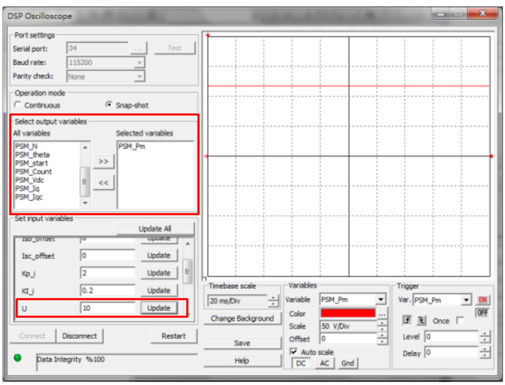


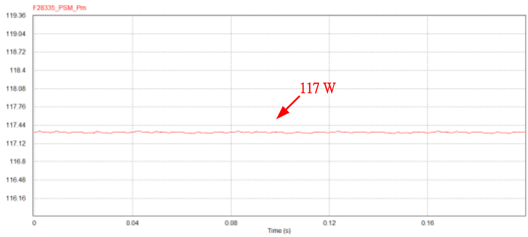
(13) Wind Speed (U) 10

When wind speed command (U) of WTG is adjusted from 8 to 10, click "Update" and it is available to observe, from DSP oscilloscope, that WTG power (PSM_Pm) is 117W as the figure 6.14 shown and generator speed (PSM_N) is 1474rpm as the figure 6.15 shown.

Figure 6.14

WTG power measured value from DSP oscilloscope





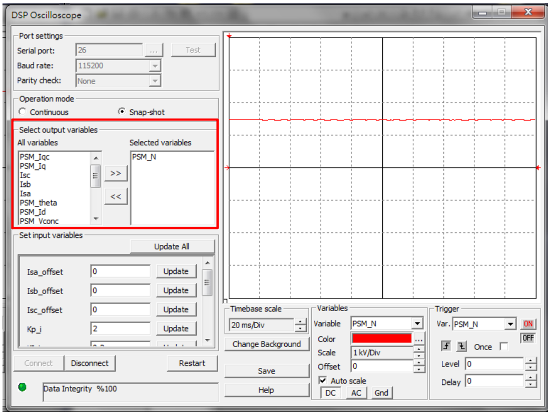
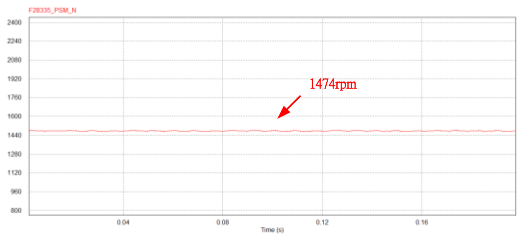


Figure 6.15

Generator speed measured value from DSP oscilloscope



Per different wind speeds, fill in the table 6.2 with results in order.

Table 6.2 WTG power measured values under varied wind speeds

Wind Speed		Motor Speed	WTG Power (PSM_Pm)
5	Measured value	691rpm	14.5 W
	Actual value	749rpm	14.6 W
8	Measured value	1161rpm	60 W
	Actual value	1198rpm	60 W
10	Measured value	1474rpm	117 W
	Actual value	1498rpm	117.3 W

The conclusion

It has seen that when wind speed changes, adjust generator motor speed, via maximum power point tracking control, to achieve the maximum power point of wind speed currently.

Experiment 7 – PMSG Wind Power Generation System)

Circuit Simulation

The parameters of WTG actuator:

DC Voltage $V_d = 130V$

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

$C_b = 330uF$

$K_s = 0.3$ (Current sensing factor)

$K_v = 1/50$ (Voltage sensing factor)

The parameters of generator actuator:

BUS Voltage $V_{bus} = 100V$

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

$C_{bus} = 940uF$

$K_s = 0.3$ (Current sensing factor)

$K_v = 1/50$ (Voltage sensing factor)

The parameters of grid-connected inverter:

BUS Voltage $V_{bus} = 100V$

AC Source Voltage $V_{LL} = 50V_{rms}$

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

C_d = 940uF, L = 1.02mH, C = 10uF

K_s = 0.3 (Current sensing factor)

K_v = 1/60 (AC Voltage sensing factor)

K_v = 1/50 (DC Voltage sensing factor)

The parameters of permanent magnet synchronous motor:

Rated Power: 400W

Rated Speed: 3000rpm

Rated Current: 2.6A

Transient Max. Current: 7.8A

Counter emf: 17.4 mV/min^{-1}

Electric Motor Impedance: 1.55 Ω

Electric Motor Reactance: 6.71mH

Rotor Inertia: 27.7u kg · m^2

Mechanical Constant: 0.53 ms

Motor Pole Number: 10 poles

The generator analogue circuit diagram based on the parameters above is as the following figure 7.1 shown (WTG utilizes Sim5 analogue circuit program):
Generator PSIM File: PEK-520_2_Sim7_3P_MPPT_GC_Inv(50Hz)_V11.1.5_V1.1

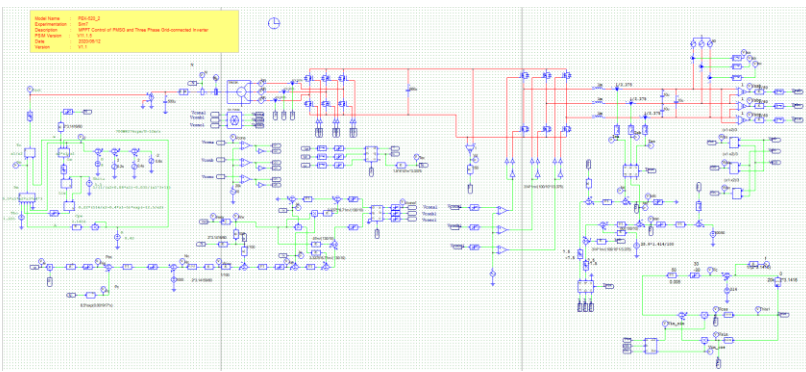


Figure 7.1 Experiment 7 PSIM analogue generator circuit diagram

The generator simulation result is shown within the figure 7.2:

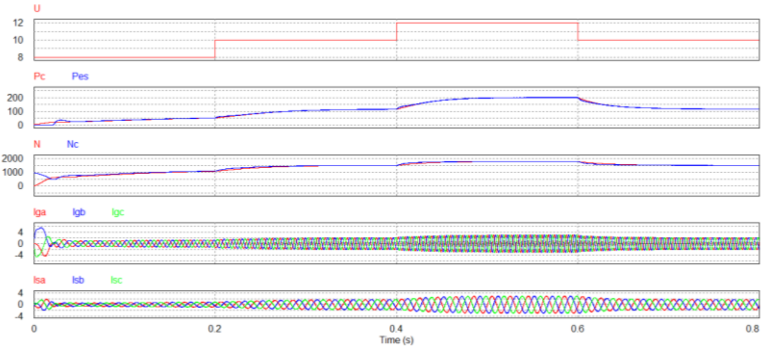


Figure 7.2 Experiment 7 analogue generator circuit simulation waveforms

The digital generator circuit diagram based on the analogue circuit diagram is as the following figure 7.3 shown:
Generator PSIM File: PEK-520_2_Lab7_3P_MPPT_GC_Inv(50Hz)_V11.1.5_V1.1

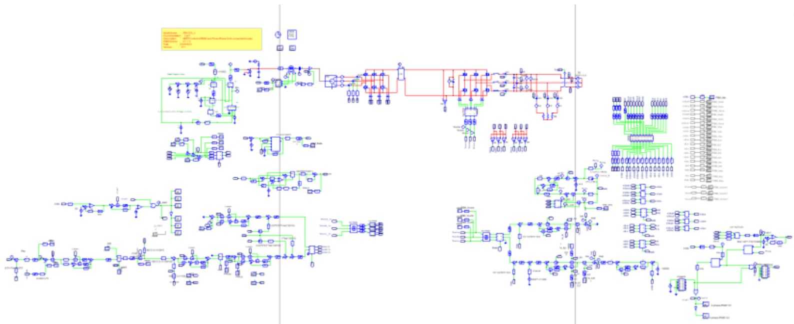


Figure 7.3 Experiment 7 PSIM digital generator circuit diagram

The generator simulation result is shown as the figure 7.4:

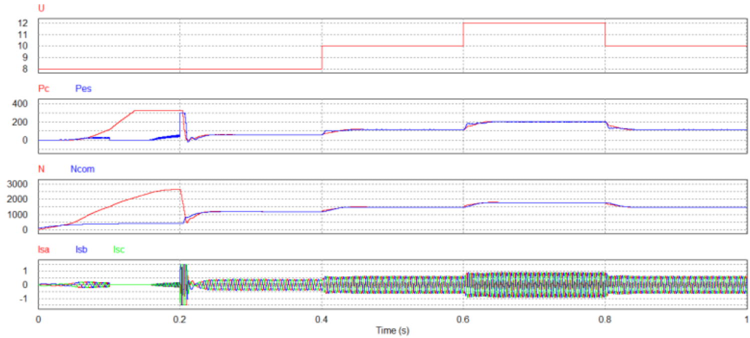


Figure 7.4 Experiment 7 digital generator circuit simulation waveforms

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-520_1 * 1
- PEK-520_2 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2, GPL-500 and APS-300)
- Motor Module * 1
- Power Cord * 2
- Coding Cord * 2
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 7.5. Please follow it to complete wiring.

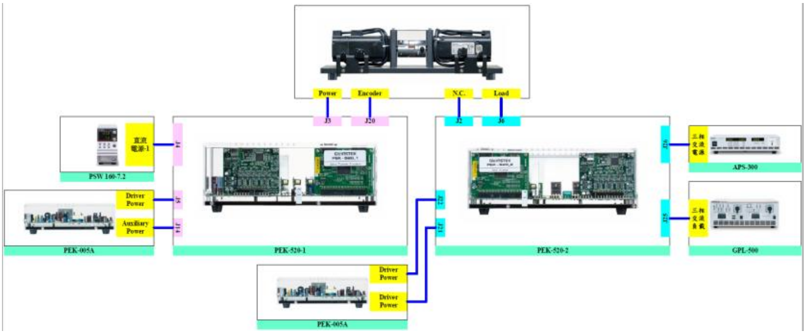


Figure 7.5 Experiment 7 wiring figure

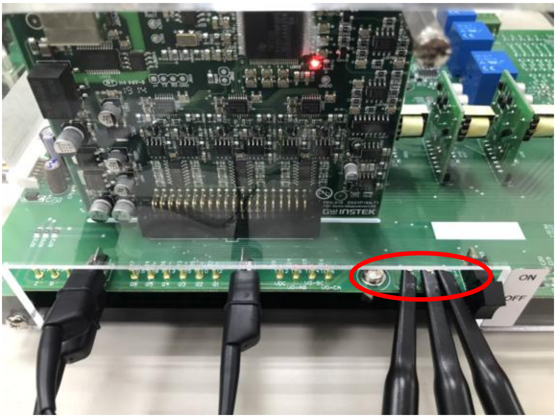
2. After wiring, make sure the PEK-520_1 and PEK-520_2 switch are OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 7.6 shown, which means the DSP power is steadily normal.

Figure 7.6 DSP normal status with light on


GW INSTEK
PEK-520_2
Grid Inverter
ON
OFF

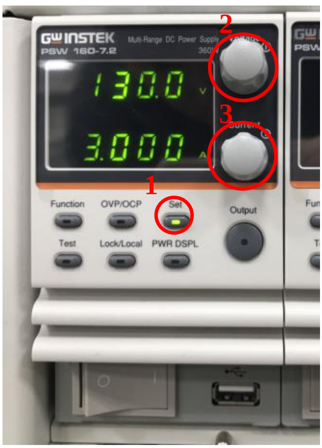
3. Refer to the appendix B for burning procedure and appendix C for RS232 connection. Because both PEK-520_1 and PEK-520_2 are required to utilize RS232 connection, the 2 separate PSIM windows are necessary for connection with PEK individually.
4. Connect the test leads of oscilloscope to IO-A, IO-B and IO-C of PEK-520_1, respectively, and connect the GND of test leads to the GND of module as the figure 7.77 shown.

Figure 7.7 Oscilloscope test leads wiring



5. Click Set key to check set voltage and current values. Set voltage 130V with voltage scroll knob and current 3A with current scroll knob for PSW 160-7.2 as the figure 7.8 shown.

Figure 7.8 The settings of PSW 160-7.2



6. As the figure 7.9 shown, power on APS-300 and set 50Hz for frequency, 3P4W for mode, 28.86V for output voltage.

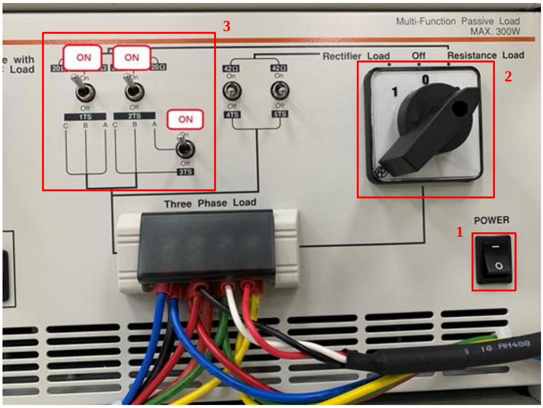
Figure 7.9

APS-300 setting

7. Power on GPL-500 → Rotate the Three Phase Load knob to 2 (Resistance Load) → Set 1TS, 2TS and 3TS as ON, which indicates full-load mode as the figure 7.10 shown.

Figure 7.10

GPL-500 full-load setting



8. After setting up and turning on PSW power output, finally turn on the switch of PEK-520_1 followed by PEK-520_2.

The purpose of experiment

Observe power changes between inverter and grid power when WTG output power changes due to wind speed flucturations.

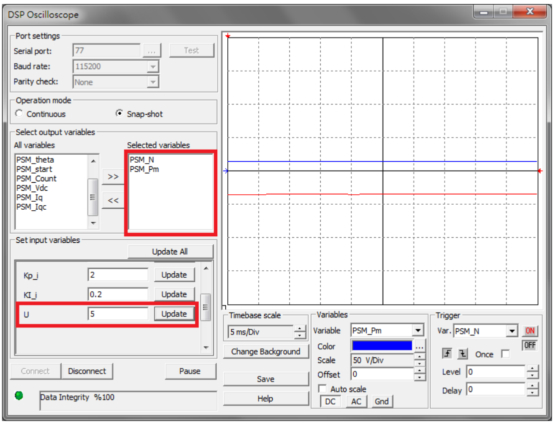
The experiment result

(14) Wind speed (U) 5

When the default setting of WTG (PEK-520_1) wind speed command (U) is 5, it is available to observe, from DSP oscilloscope, WTF power (PSM_Pm) is 15W and motor speed (PSM_N) is -689rpm as the figure 7.11 shown. In the meantime, it is available to observe that, via DSP oscilloscope, generator (PEK-520_2) power (PSM_Po) is 12W and motor speed (PSM_N) is 694 rpm as the figure 7.12 shown. The required power, when load is full-load, is 250W and the insufficient 238W power will be provided by grid power (APS-300). Since APS-300 displays single-phase power, the three-phase power will be 237.9W as the figure 7.13 shown.

Figure 7.11

DSP oscilloscope WTG power and motor speed measured value



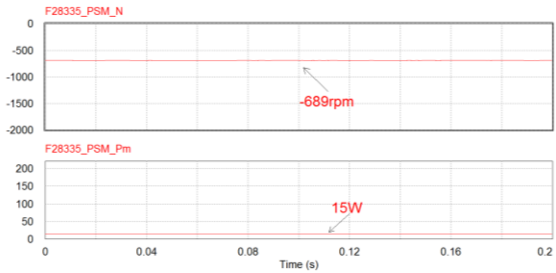
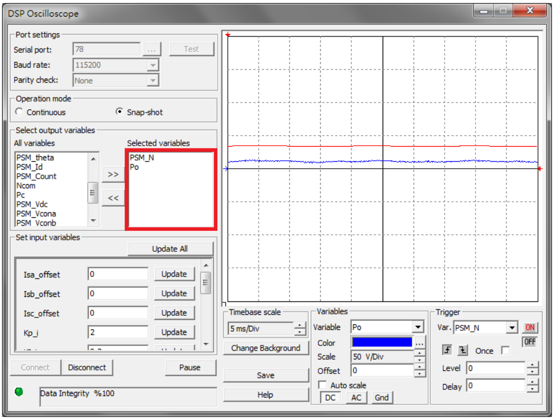


Figure 7.12

DSP oscilloscope generator power and motor speed measured value



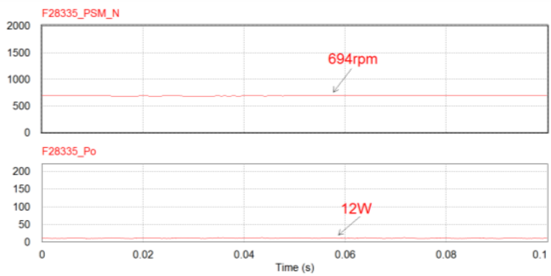


Figure 7.13
APS-300 output power

(15) Wind speed (U) 8

Adjust the wind speed command from 5 to 8 via DSP oscilloscope of WTG and it is available to observe that WTG power (PSM_Pm) is 60W and motor speed (PSM_N) is -1160 rpm as the figure 7.14 shown. The generator power (PSM_Po) will be 56W and motor speed (PSM_N) will be 1153 rpm as the figure 7.15 shown.

The required power, when load is full-load, is 250W and the insufficient 194W power will be provided by grid power (APS-300). Since APS-300 displays single-phase power, the three-phase power will be 201.6W as the figure 7.16 shown.

Figure 7.14

DSP oscilloscope WTG power and motor speed measured value

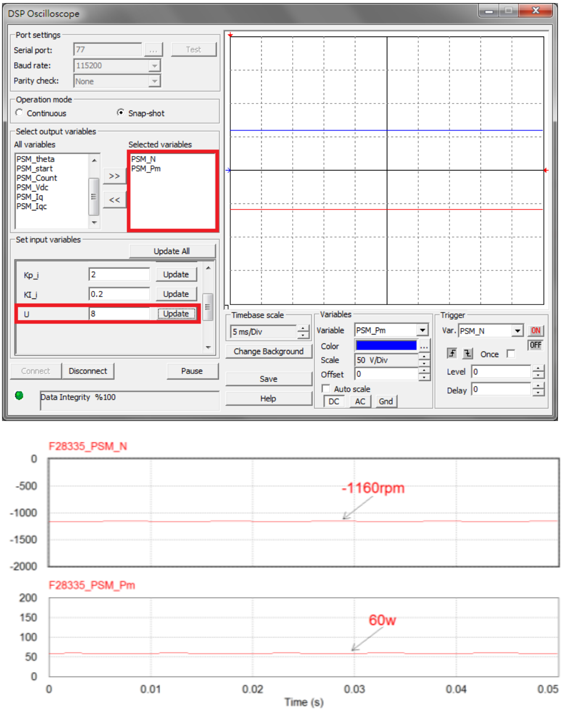
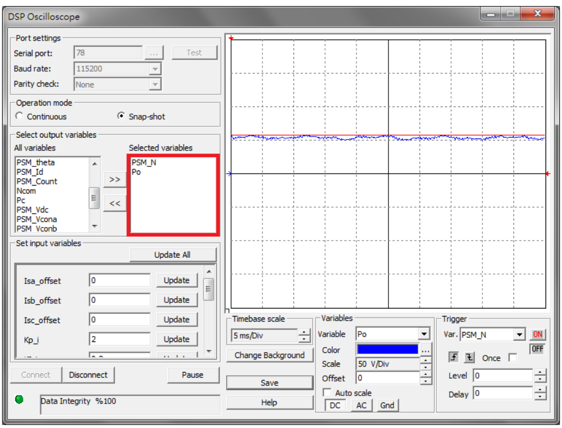


Figure 7.15

DSP oscilloscope generator power and motor speed measured value



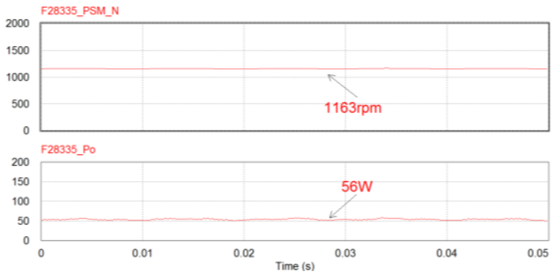


Figure 7.16 APS-300 output power

(16) Wind speed (U) 10

Adjust the wind speed command from 8 to 10 via DSP oscilloscope of WTG and it is available to observe that WTG power (PSM_Pm) is 117W and motor speed (PSM_N) is -1462 rpm as the figure 7.17 shown. The generator power (PSM_Po) will be 109W and motor speed (PSM_N) will be 1462 rpm as the figure 7.18 shown.

The required power, when load is full-load, is 250W and the insufficient 141W power will be provided by grid power (APS-300). Since APS-300 displays single-phase power, the three-phase power will be 158.7W as the figure 7.19 shown.

Figure 7.17

DSP oscilloscope WTG power and motor speed measured value

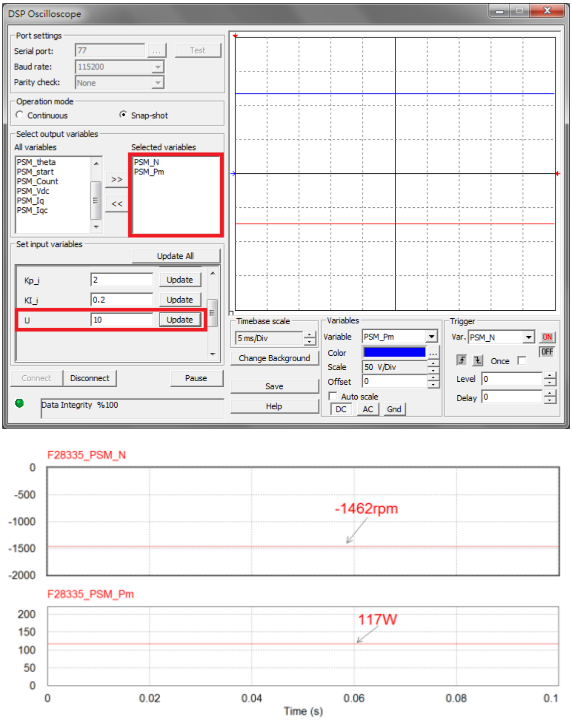
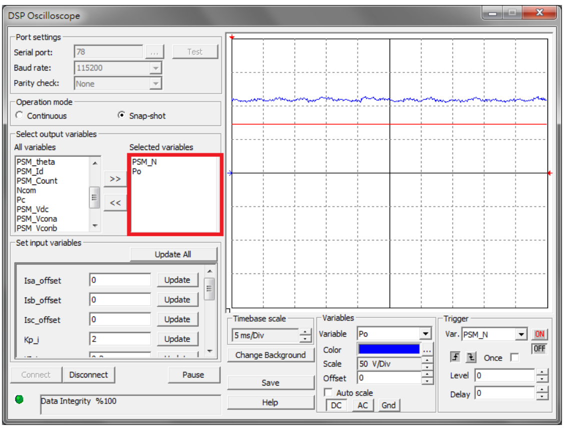


Figure 7.18

DSP oscilloscope generator power and motor speed measured value



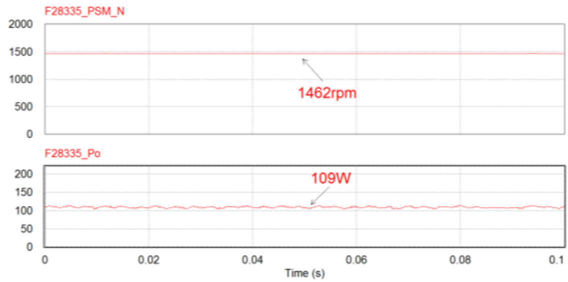


Figure 7.19
APS-300 output power

Fill in the table 7.1 with results in order.

Table 7.1 The power fluctuations of generator and grid power under varied wind speeds

Wind speed	Generator motor speed (rpm)	Generator power(W)	Power of grid power(W)	Power of load(W)
5	694	12	237.9	250
8	1163	56	201.6	250
10	1462	109	158.7	250

The conclusion

It has seen that, from the experiment, the power of power grid (simulation based on APS-300) regulates required power in accordance with varied powers of generator under the grid-connected system to maintain power balance of system.

Experiment 8 – Low Voltage Ride Through (LVRT) of PMSG WTG System

Circuit Simulation

The WTG actuator specification is as follows:

DC Voltage V_d = 130V

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

C_b = 330uF

K_s = 0.3 (Current sensing factor)

K_v = 1/50 (Voltage sensing factor)

The generator actuator specification is as follows:

BUS Voltage V_{bus} = 130V

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

C_{bus} = 940uF

K_s = 0.3 (Current sensing factor)

K_v = 1/50 (Voltage sensing factor)

The grid-connected inverter specification is as follows:

BUS Voltage V_{bus} = 100V

AC Source Voltage V_{LL}= 50V_{rms}

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

C_d = 940uF, L = 1.02mH, C = 10uF

K_s = 0.3 (Current sensing factor)

K_v = 1/60 (AC Voltage sensing factor)

K_v = 1/50 (DC Voltage sensing factor)

The PMSM specification is as follows:

Rated Power: 400W

Rated Speed: 3000rpm

Rated Current: 2.6A

Transient Max. Current: 7.8A

Counter emf: 17.4 mV/min^{-1}

Electric Motor Impedance: 1.55 Ω

Electric Motor Reactance: 6.71mH

Rotor Inertia: 27.7u kg · m^2

Mechanical Constant: 0.53 ms

Motor Pole Number: 10 poles

The generator analogue circuit diagrams based on the parameters above are as the following figure 8.1 shown (WTG utilizes Sim5 analogue circuit program instead):
Generator PSIM File: PEK-520_2_Sim8_3P_MPPT_GC_Inv_LVRT(50Hz)_V11.1.5_V1.1

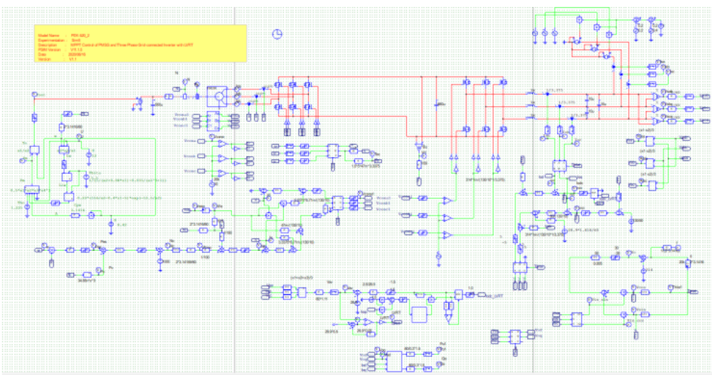


Figure 8.1 Experiment 8 PSIM analogue generator circuit diagram

The generator simulation result is shown within the figure 8.1:

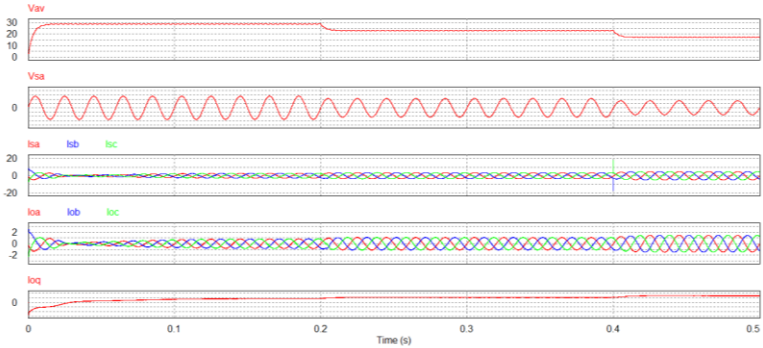


Figure 8.2 Experiment 8 analogue generator circuit simulation waveforms

The digital generator circuit diagram based on the analogue circuit is shown as the figure 8.3:
PSIM File: PEK-520_2_Lab8_3P_MPPT_GC_Inv_LVRT(50Hz)_V11.1.5_V1.1

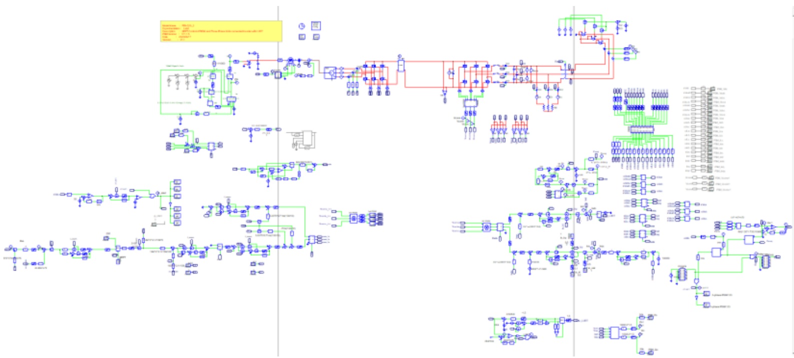


Figure 8.3 Experiment 8 PSIM digital generator circuit diagram

The generator simulation result is shown within the figure 8.4:

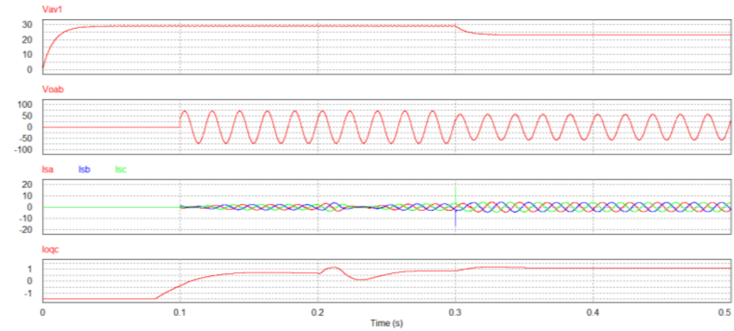


Figure 8.4 Experiment 8 digital generator circuit simulation waveforms

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-520_1 * 1
- PEK-520_2 * 1
- PEK-005A * 1
- PEK-006 * 1
- PTS-5000 * 1 (with GDS-2204E, PSW160-7.2, GPL-500 and APS-300)
- Motor Module * 1
- Power Cord * 2
- Coding Cord * 2
- PC * 1

Experiment Procedure

1. The experiment wiring is shown as the figure 8.5. Please follow it to complete wiring.

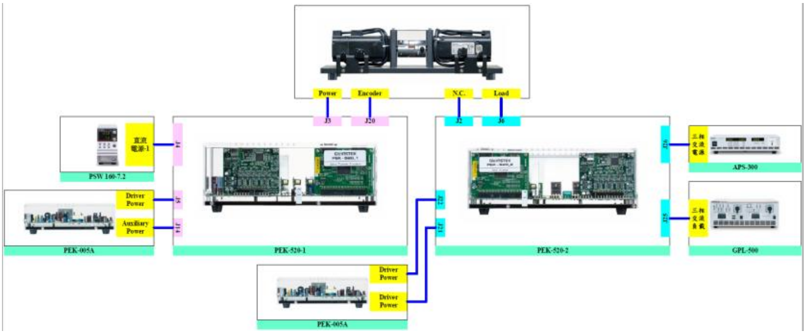


Figure 8.5 Experiment 8 wiring figure

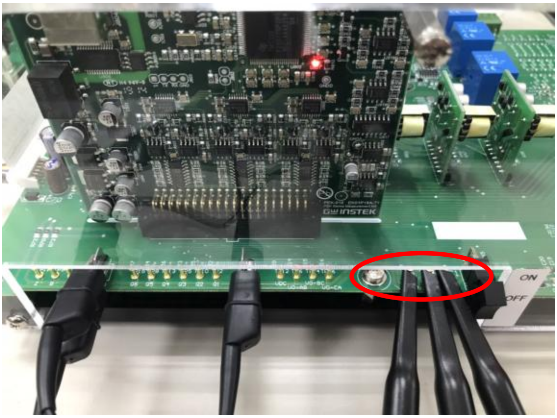
2. After wiring, make sure the PEK-520_1 and PEK-520_2 switch are OFF followed by turning the PEK-005A switch ON. The DSP red indicator lights on as the figure 8.6 shown, which means the DSP power is steadily normal.

Figure 8.6 DSP normal status with light on


GW INSTEK
PEK - 520_2
Grid Inverter
ON
OFF

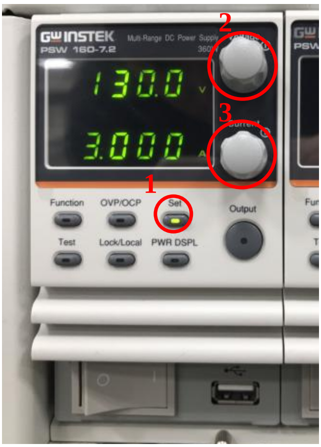
3. Refer to the appendix B for burning procedure and appendix C for RS232 connection. Because both PEK-520_1 and PEK-520_2 are required to utilize RS232 connection, the 2 separate PSIM windows are necessary for connection with PEK individually.
4. Connect the test leads of oscilloscope to IO-A, IO-B and IO-C of PEK-520_1, respectively, and connect the GND of test leads to the GND of module as the figure 8.7 shown.

Figure 8.7
Oscilloscope test leads wiring



5. Click Set key to check set voltage and current values. Set voltage 130V with voltage scroll knob and current 3A with current scroll knob for PSW 160-7.2 as the figure 8.8 shown.

Figure 8.8
The settings of PSW 160-7.2



6. As the figure 8.9 shown, power on APS-300 and set 50Hz for frequency, 3P4W for mode, 28.86V for output voltage.

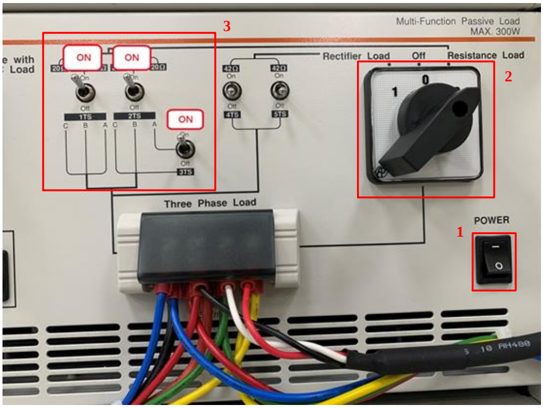
Figure 8.9

APS-300 setting

7. Power on GPL-500 → Rotate the Three Phase Load knob to 2 (Resistance Load) → Set 1TS, 2TS and 3TS as ON, which indicates full-load mode as the figure 8.10 shown.

Figure 8.10

GPL-500 full-load setting



8. After setting up and turning on PSW power output, finally turn on the switch of PEK-520_1 followed by PEK-520_2.

The purpose of experiment

If grid power voltage is dropping when wind generator system is running, inverter is required to enter the LVRT (Low Voltage Ride Through) mode in order to maintain gird power voltage. Also, we are going to observe output power fluctuation of inverter when grid power voltage is dropping.

The Experiment Result

(17) Wind speed (U) 5; grid power voltage 28.86V

Wind speed command (U) of WTG (PEK-520_1) is 5 by default, and the speed of WTG is -694rpm as the figures 8.11 and 8.12 shown. Also, it is available to observe that, via another DSP oscilloscope, generator (PEK-520_2) output power (PSM_Po) is 15W and PSM_Qo is 0W as the figures 8.13 and 8.14 shown.

Figure 8.11 WTG speed from DSP oscilloscope when wind speed is 5

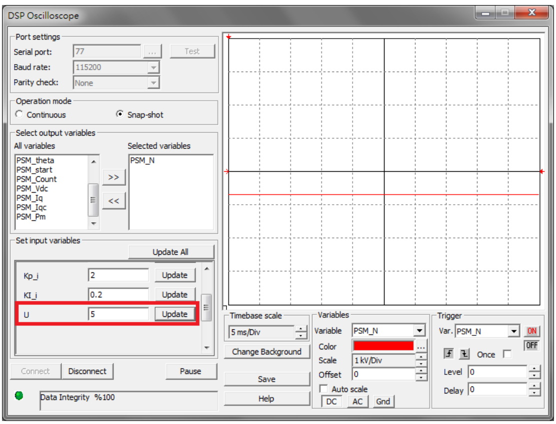
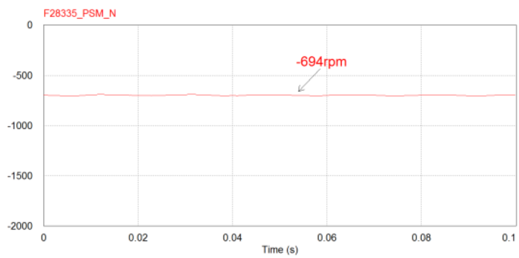


Figure 8.12 WTG speed measured by Simview



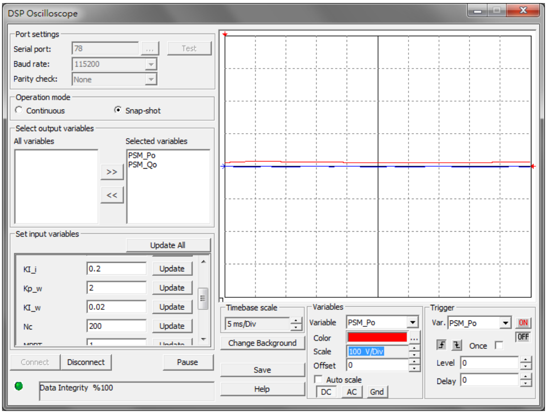


Figure 8.13 Generator output power from DSP oscilloscope when wind speed is 5

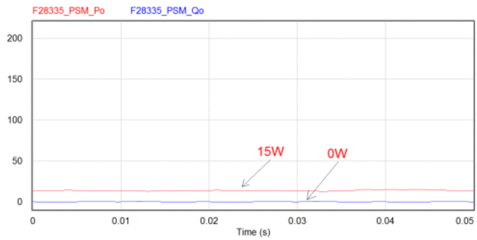


Figure 8.14 Generator output real power and virtual power measured by Simview

(18) Wind speed (U) 10; grid power voltage 28.86V

Wind speed command (U) of WTG DSP oscilloscope is adjusted from 5 to 10, and the speed of WTG is -1453rpm as the figures 8.15 and 8.16 shown. Also, it is available to observe that, via another DSP oscilloscope, generator output power (PSM_Po) is 147W and PSM_Qo is 0W as the figures 8.17 and 8.18 shown.

Figure 8.15
WTG speed from DSP oscilloscope when wind speed is 10

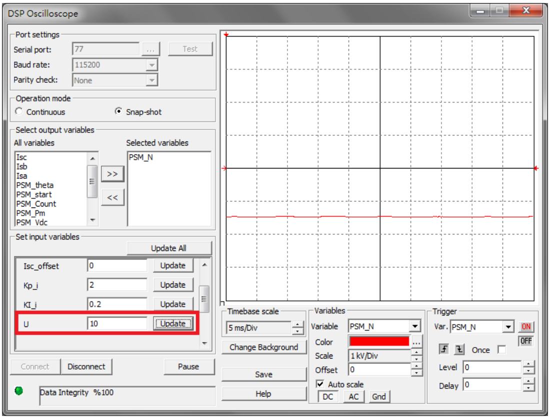


Figure 8.16
WTG speed measured by Simview

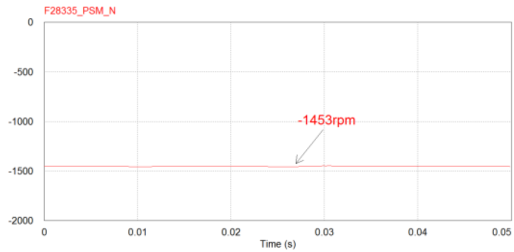


Figure 8.17
Generator output power from DSP oscilloscope when wind speed is 10

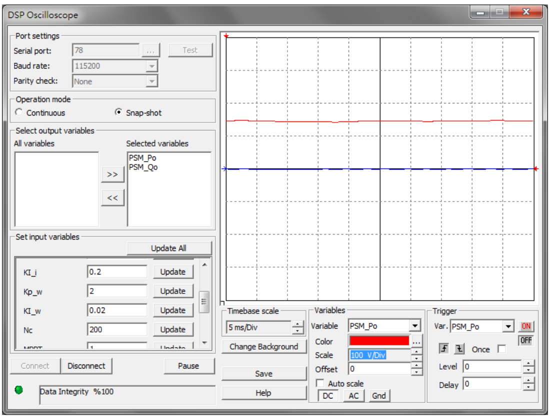
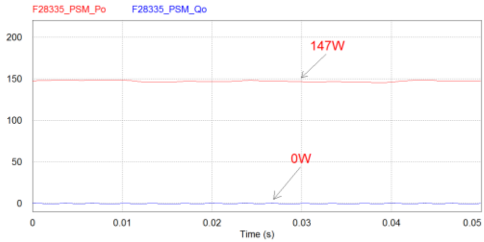


Figure 8.18 Generator output real power and virtual power measured by Simview



(19) Wind speed (U) 10; grid power voltage 24.66V

Wind speed command (U) is 10, and the grid power voltage is bucked down to 24.66V as the figures 8.19 shown. Also, it is available to observe that, via another DSP oscilloscope of generator, output power (PSM_Po) is 140W and PSM_Qo is 101W as the figures 8.20 and 8.21 shown.

Figure 8.19 APS-300 voltage is bucked down to 24.66V

Figure 8.20 The generator output power from DSP oscilloscope when APS-300 voltage is 24.66V

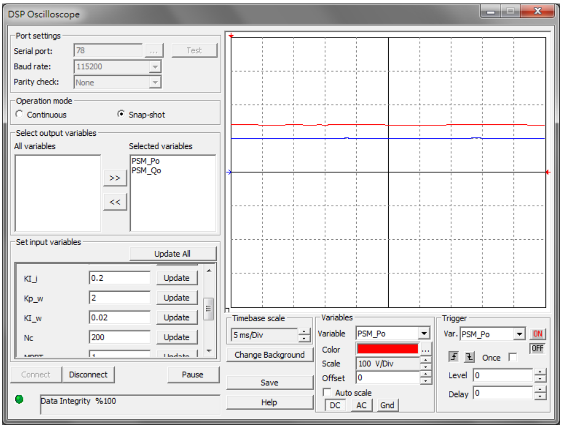
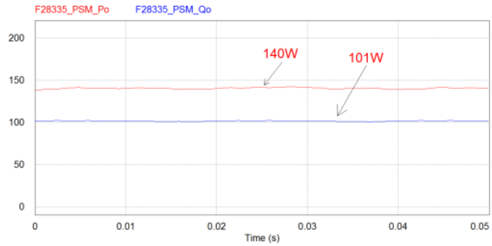


Figure 8.21 Generator output real power and virtual power measured by Simview



(20) Wind speed (U) 10; grid power voltage 14.86V

Wind speed command (U) is 10, and the grid power voltage is bucked down to 14.86V as the figures 8.22 shown. Also, it is available to observe that, via another DSP oscilloscope of generator, output power (PSM_Po) is 112W and PSM_Qo is 212W as the figures 8.22 and 8.23 shown.

Figure 8.22 APS-300 voltage is bucked down to 24.66V

Figure 8.23 The generator output power from DSP oscilloscope when APS-300 voltage is 14.86V

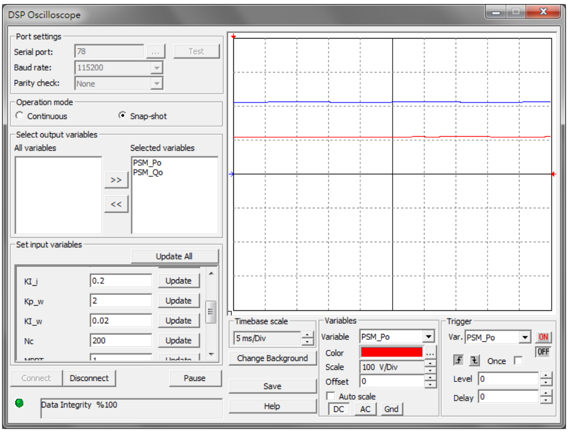
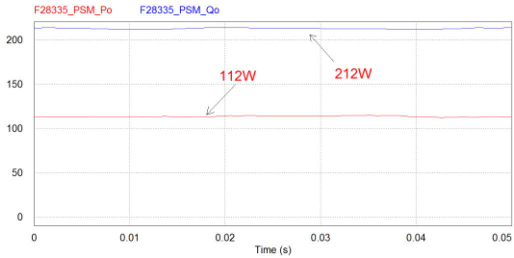


Figure 8.24
Generator output real power and virtual power measured by Simview

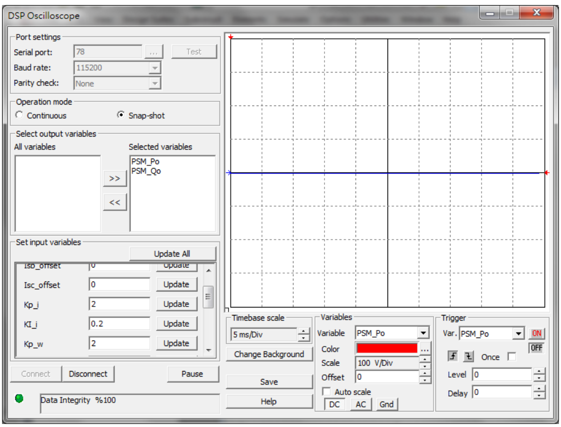


(21) Wind speed (U) 10; grid power voltage 13V

Wind speed command (U) is 10, and the grid power voltage is bucked down to 13V as the figures 8.25 shown. Also, it is available to observe that, via another DSP oscilloscope of generator, output power (PSM_Po) is 0W and PSM_Qo is 0W as the figures 8.26 shown.

Figure 8.25
APS-300 voltage is bucked down to 13V

Figure 8.26
The generator output power from DSP oscilloscope when APS-300 voltage is 13V



Fill in the table 8.1 with the power by generator under the above several conditions.

Table 8.1 WTG output power under varied grid power voltage

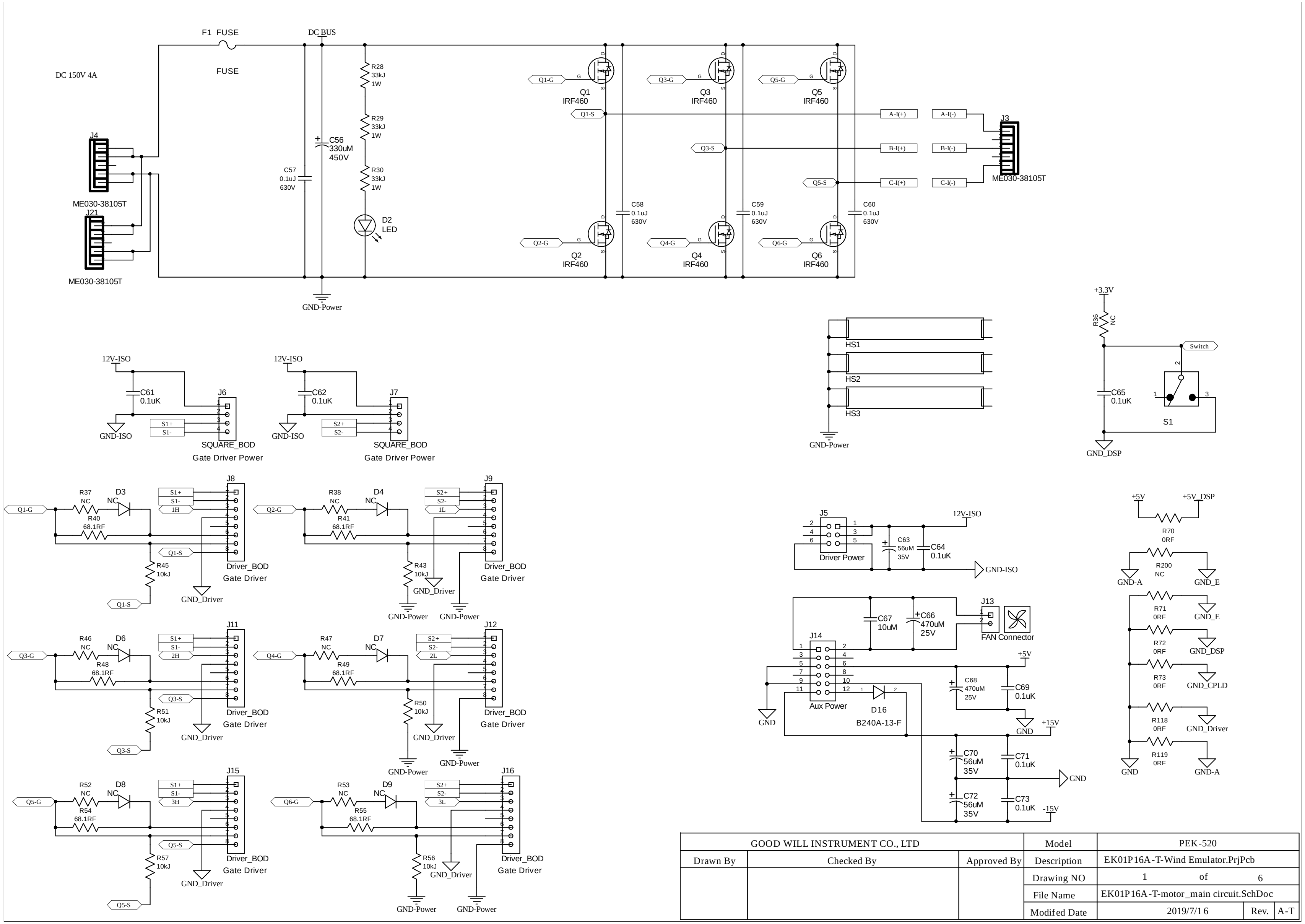
Wind Speed	Grid Power Voltage (V)	Generator Real Power(W)	Generator Reactive Power (W)
5	28.86	15	0
8	28.86	147	0
	24.66	140	101
	14.86	112	212
	13	0	0

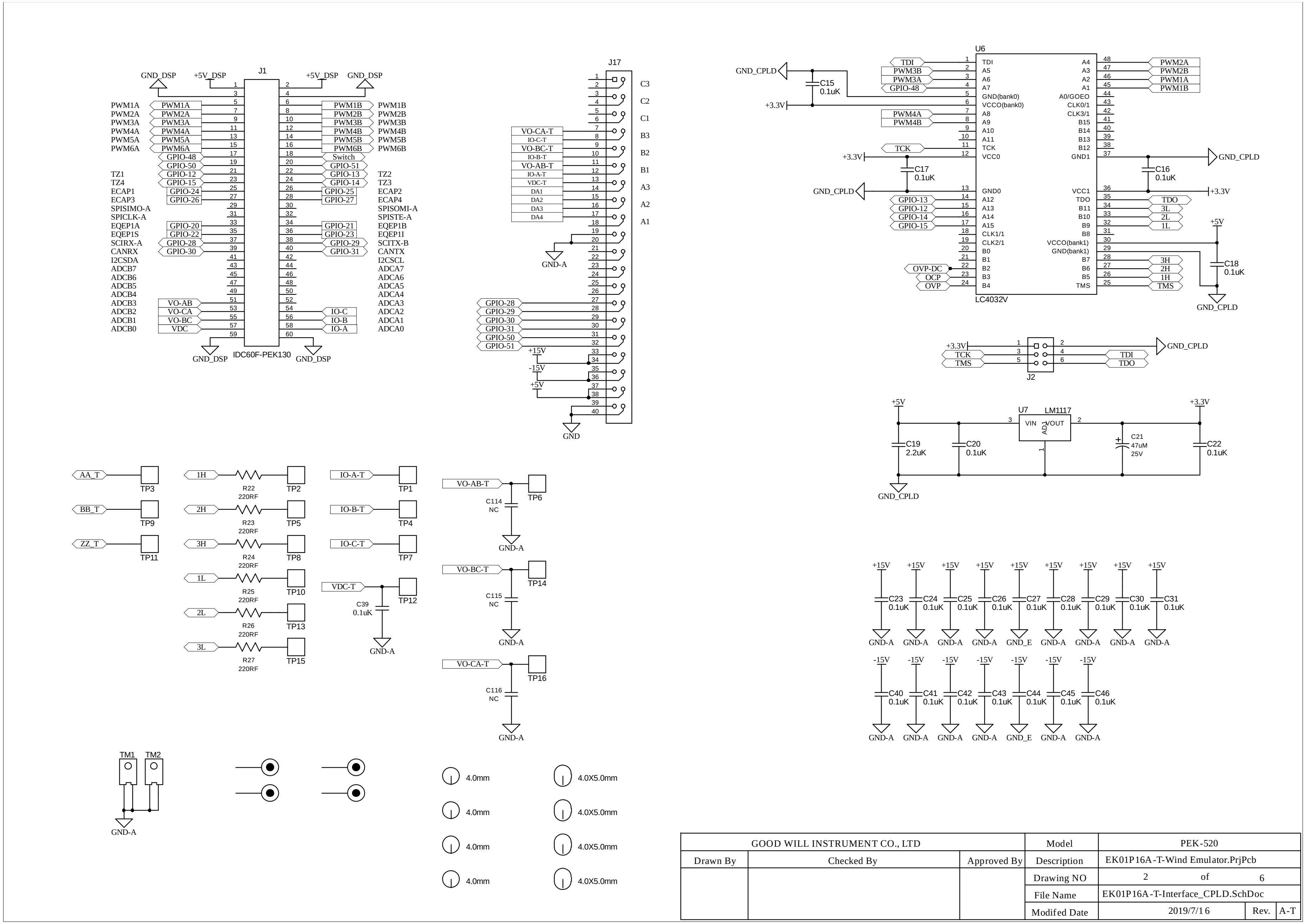
The conclusion

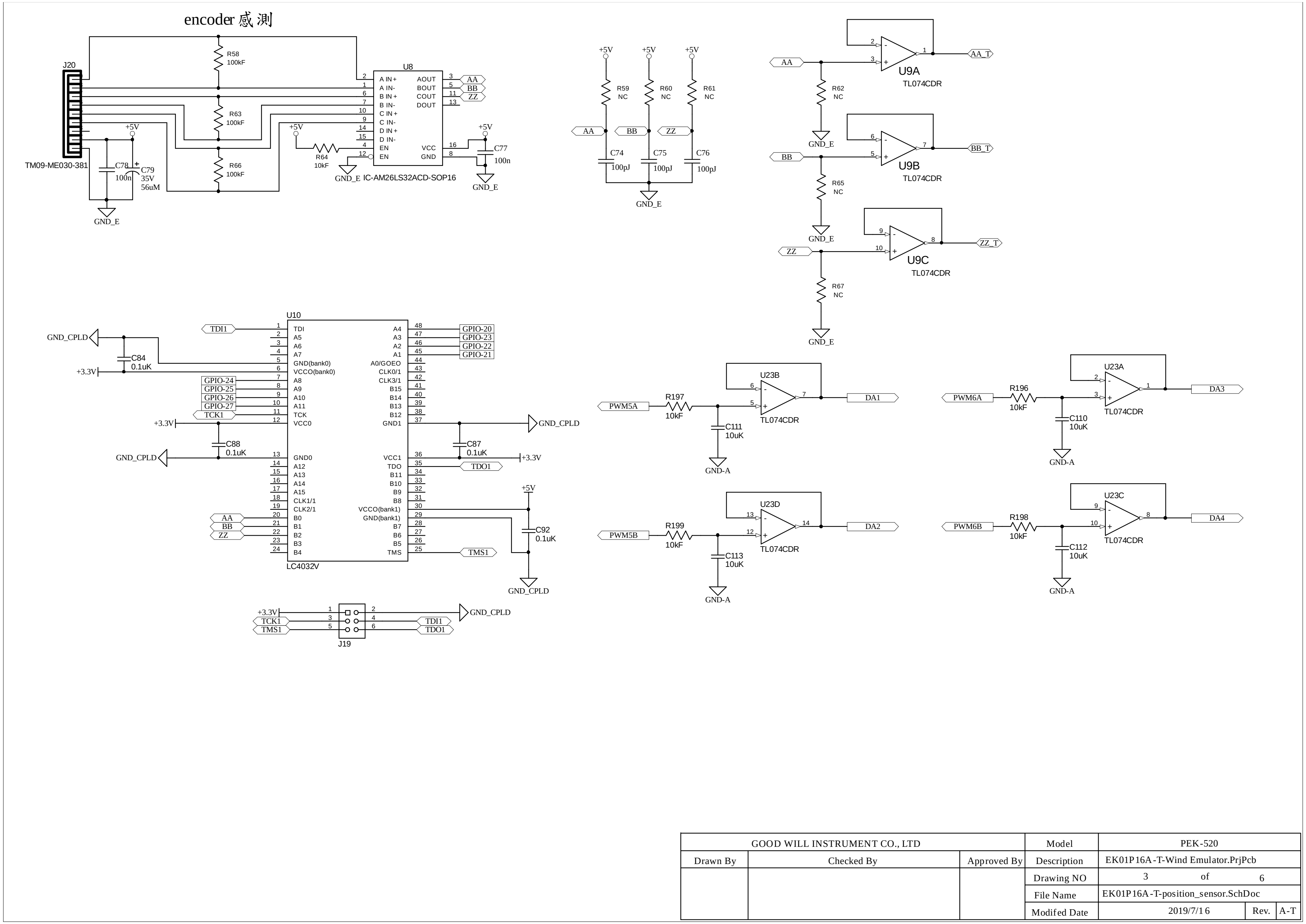
From the table 8.1, it is observed that within the power grid-connected system, when grid power voltage keeps lowering down to 24.7V, the inverter enters LVRT mode and provides reactive power in the meantime. In accord with voltage dropping down to 13V, the inverter trips and the system shuts down.

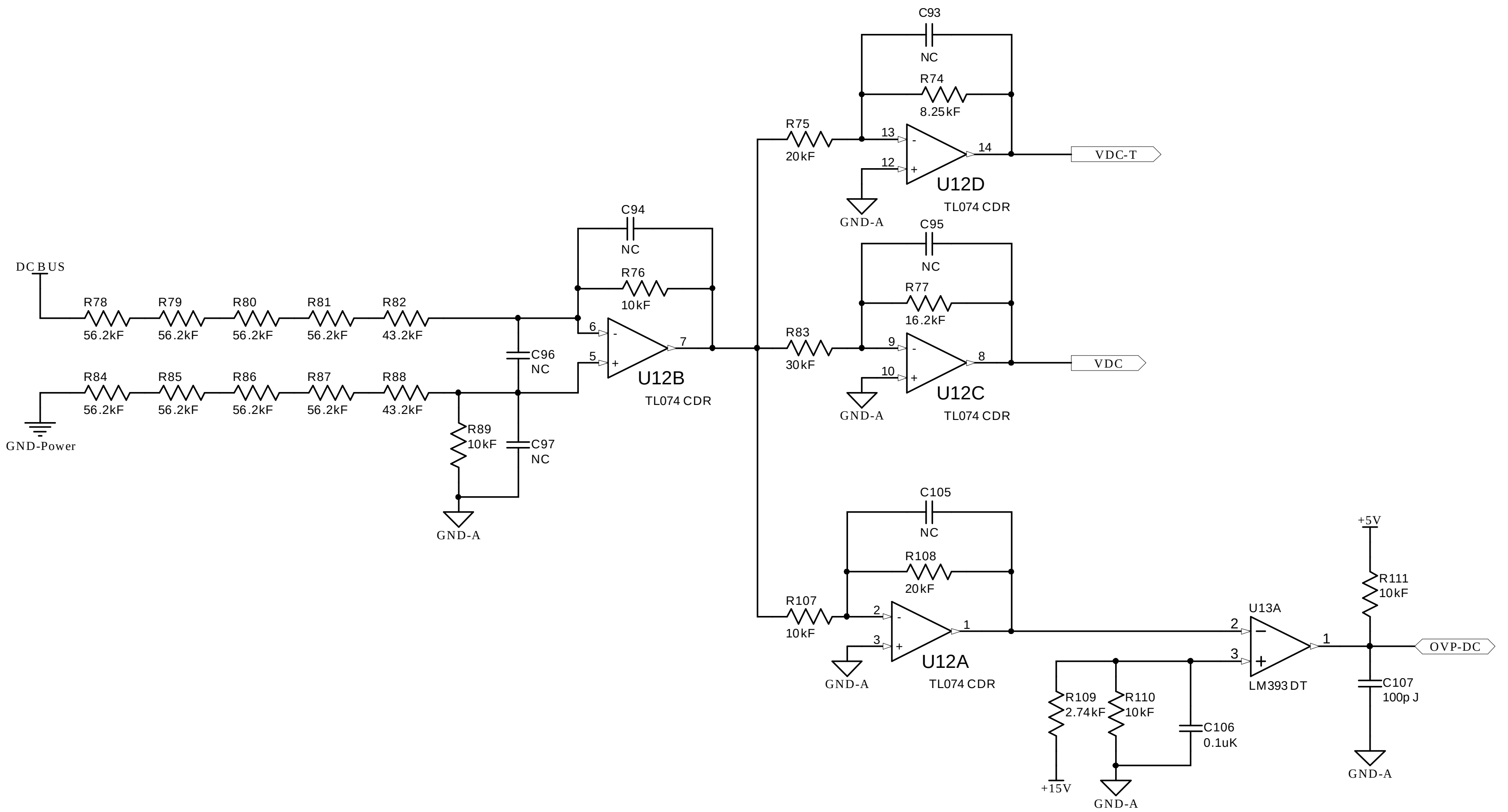
Appendix A – PEK-520 Circuit Diagram

T-Wind Emulator

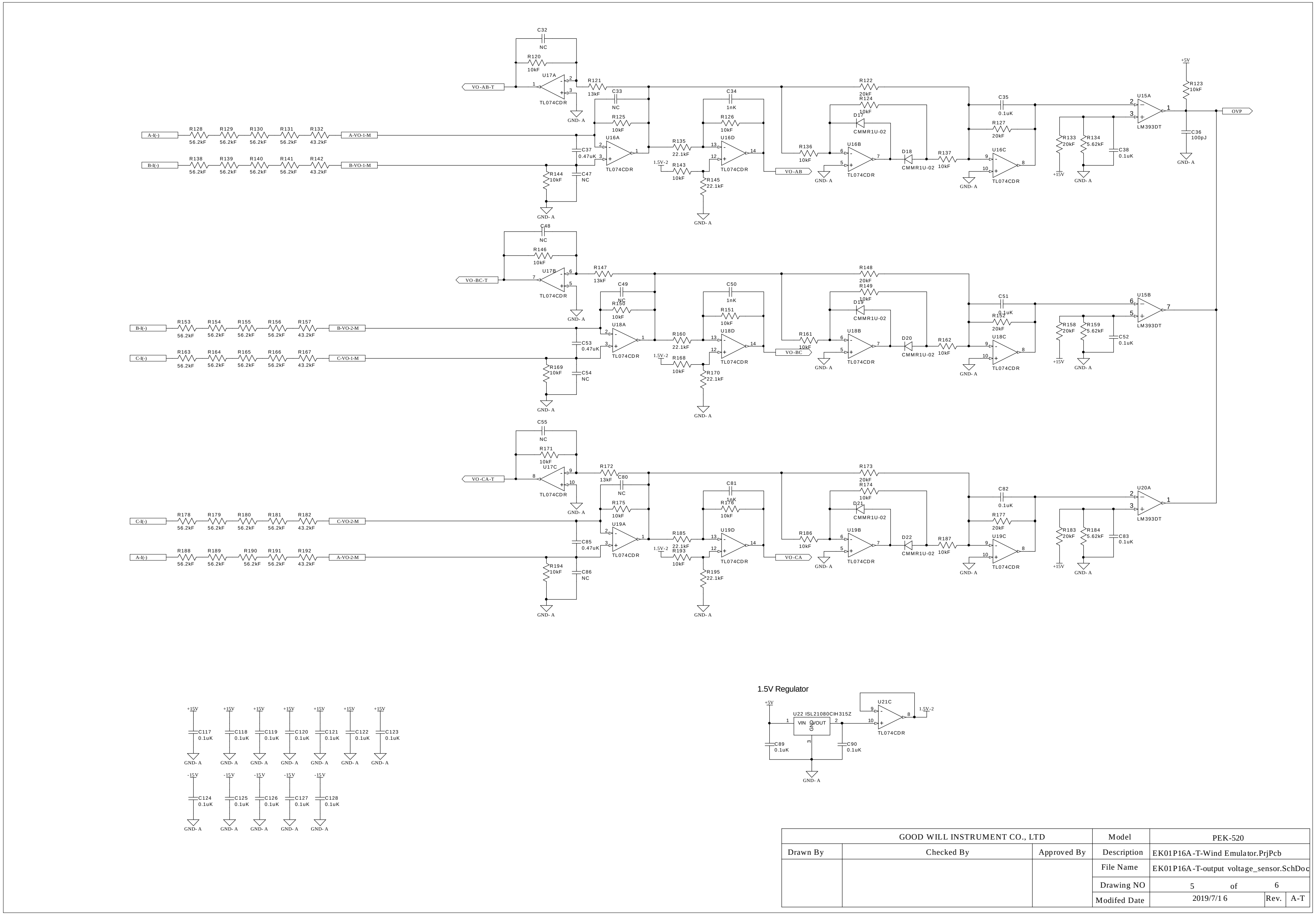


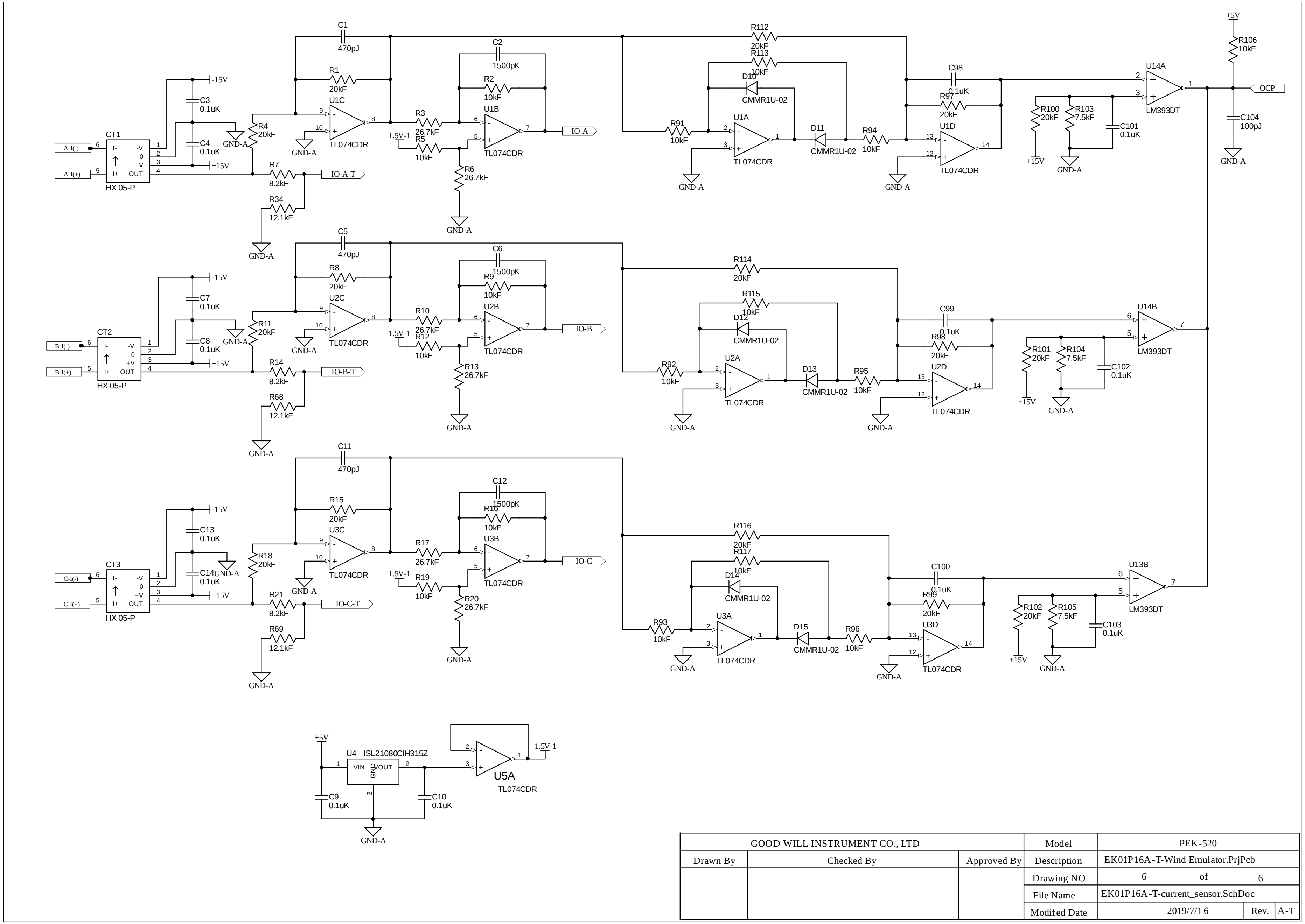

J1
IDC60F-PEK130
GND_DSP
+5V_DSP
J17
C3
C2
C1
B3
B2
B1
A3
A2
A1
GND-A
GND
U6
LC4032V
GND_CPLD
+3.3V
C15
0.1uK
C16
0.1uK
C17
0.1uK
C18
0.1uK
J2
U7
LM1117
C19
2.2uK
C20
0.1uK
C21
47uM
25V
C22
0.1uK
TP1
TP2
TP3
TP4
TP5
TP6
TP7
TP8
TP9
TP10
TP11
TP12
TP13
TP14
TP15
TP16
R22
220RF
C39
0.1uK
C114
NC
C115
NC
C116
NC
TM1
TM2
4.0mm
4.0X5.0mm
GOOD WILL INSTRUMENT CO., LTD
Model
PEK-520
Drawn By
Checked By
Approved By
Description
EK01P16A-T-Wind Emulator.PrjPcb
Drawing NO
2
of
6
File Name
EK01P16A-T-Interface_CPLD.SchDoc
Modifed Date
2019/7/16
Rev.
A-T


encoder 感測
J20
TM09-ME030-381
R58 100kF
R63 100kF
R66 100kF
C78 100n
C79 35V 56uM
R64 10kF
U8
A IN+
A IN-
B IN+
B IN-
C IN+
C IN-
D IN+
D IN-
EN
EN
AOUT
BOUT
COUT
DOUT
VCC
GND
IC-AM26LS32ACD-SOP16
C77 100n
GND_E
+5V
AA
BB
ZZ
R59 NC
R60 NC
R61 NC
C74 100pJ
C75 100pJ
C76 100pJ
U9A TL074CDR
U9B TL074CDR
U9C TL074CDR
R62 NC
R65 NC
R67 NC
AA_T
BB_T
ZZ_T
U10
LC4032V
TDI
A5
A6
A7
GND(bank0)
VCCO(bank0)
A8
A9
A10
A11
TCK
VCC0
GND0
A12
A13
A14
A15
CLK1/1
CLK2/1
B0
B1
B2
B3
B4
A4
A3
A2
A1
A0/GOEO
CLK0/1
CLK3/1
B15
B14
B13
B12
GND1
VCC1
TDO
B11
B10
B9
B8
VCCO(bank1)
GND(bank1)
B7
B6
B5
TMS
TDI1
TCK1
TDO1
TMS1
GPIO-20
GPIO-23
GPIO-22
GPIO-21
GPIO-24
GPIO-25
GPIO-26
GPIO-27
GND_CPLD
+3.3V
C84 0.1uK
C88 0.1uK
C87 0.1uK
C92 0.1uK
J19
U23B TL074CDR
U23D TL074CDR
U23A TL074CDR
U23C TL074CDR
PWM5A
PWM5B
PWM6A
PWM6B
R197 10kF
R199 10kF
R196 10kF
R198 10kF
C111 10uK
C113 10uK
C110 10uK
C112 10uK
DA1
DA2
DA3
DA4
GND-A
GOOD WILL INSTRUMENT CO., LTD
Model PEK-520
Drawn By
Checked By
Approved By
Description EK01P16A-T-Wind Emulator.PrjPcb
Drawing NO 3 of 6
File Name EK01P16A-T-position_sensor.SchDoc
Modifed Date 2019/7/16
Rev. A-T

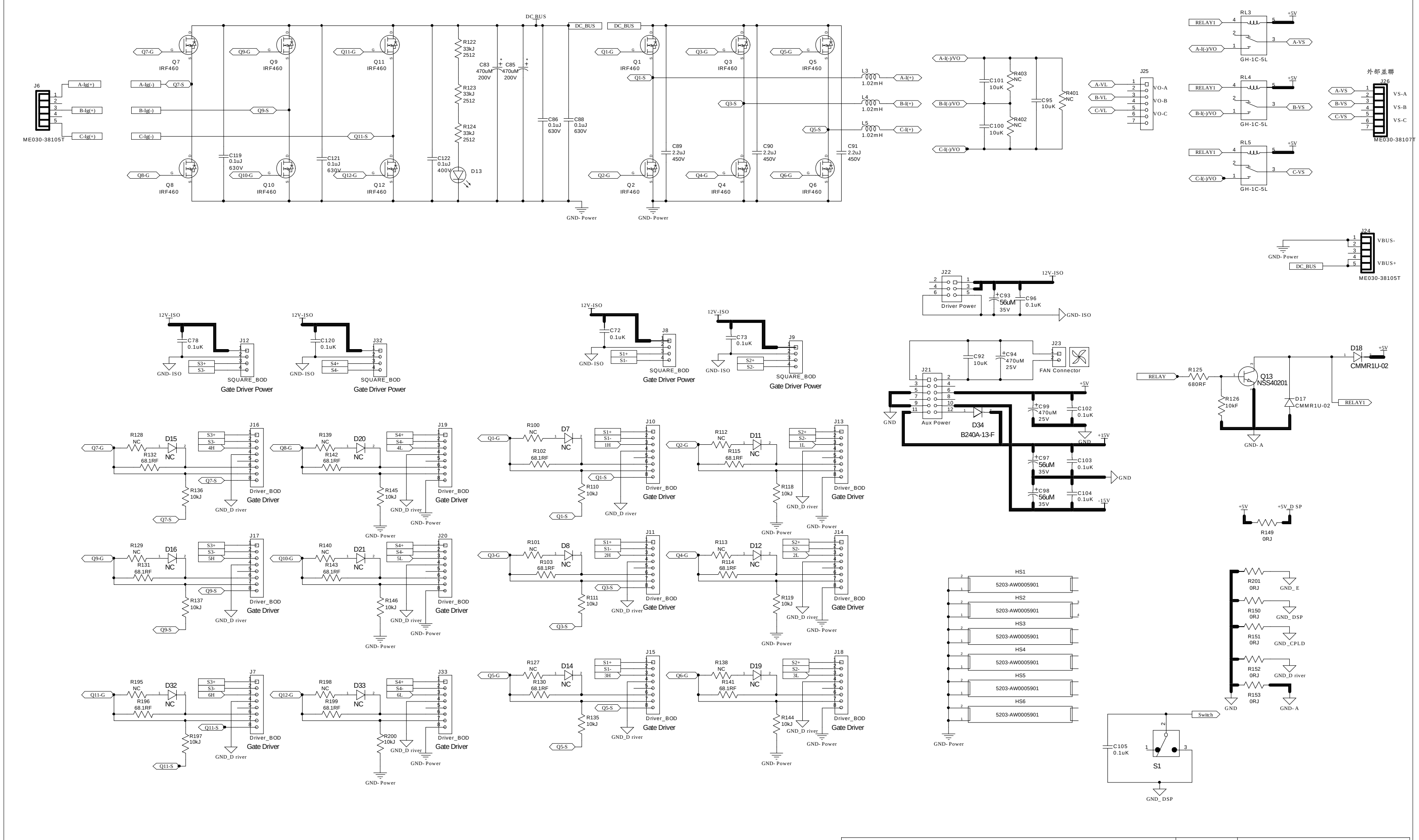


GOOD WILL INSTRUMENT CO., LTD			Model	PEK-520		
Drawn By	Checked By	Approved By	Description	EK01P16A-T-Wind Emulator.Prj		
			Drawing NO	4 of 6		
			File Name	EK01P16A-T-voltage_sensor.SchDoc		
			Modifed Date	2019/7/16	Rev.	A-T

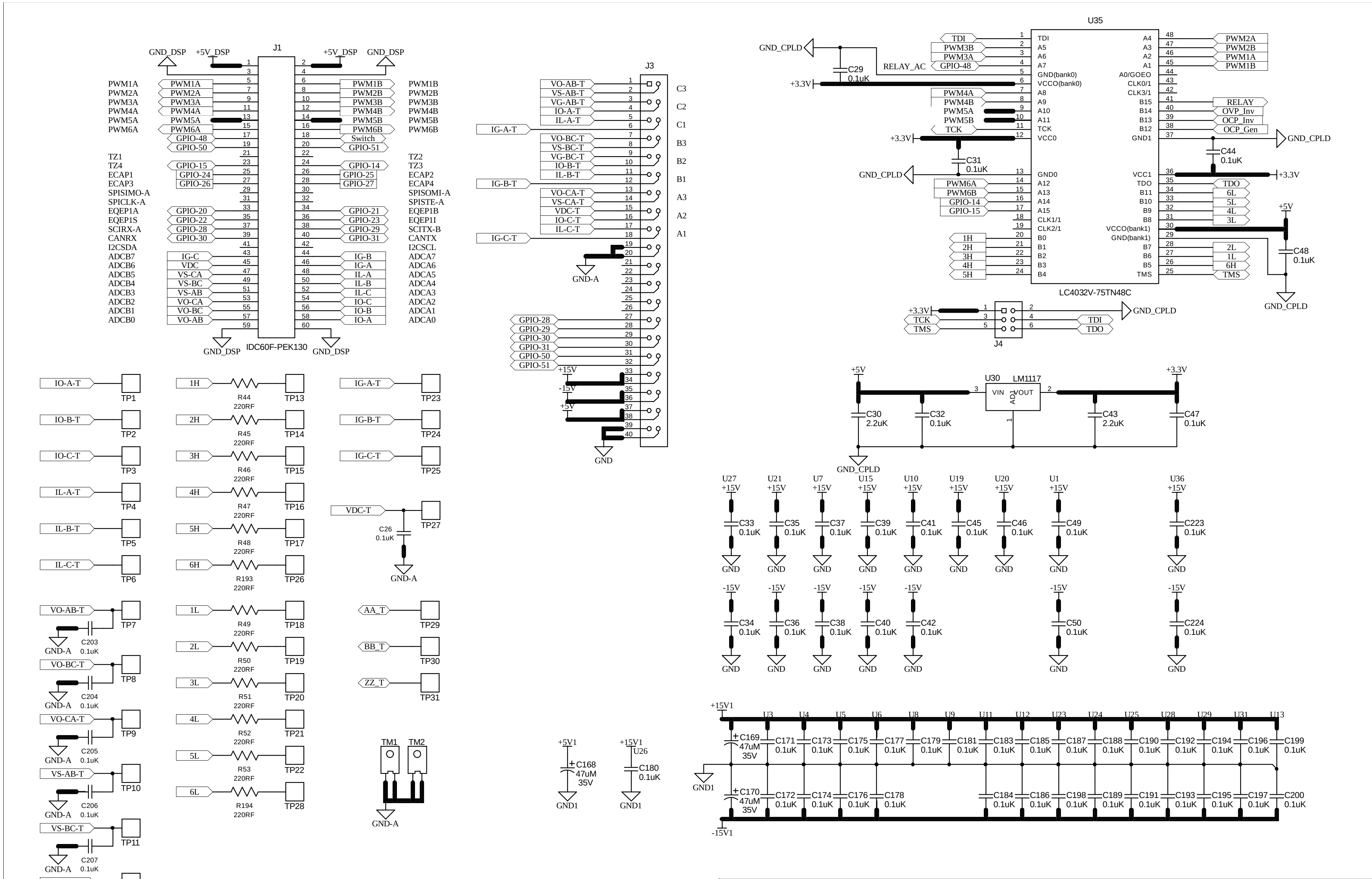

VO-AB-T
VO-BC-T
VO-CA-T
A-I(-)
B-I(-)
C-I(-)
A-VO-1-M
B-VO-1-M
B-VO-2-M
C-VO-1-M
C-VO-2-M
A-VO-2-M
VO-AB
VO-BC
VO-CA
OVP
TL074CDR
LM393DT
CMMR1U-02
GND- A
1.5V Regulator
U22 ISL21080CIH315Z
GOOD WILL INSTRUMENT CO., LTD
Model
PEK-520
Drawn By
Checked By
Approved By
Description
EK01P16A-T-Wind Emulator.PrjPcb
File Name
EK01P16A-T-output voltage_sensor.SchDoc
Drawing NO
5 of 6
Modifed Date
2019/7/16
Rev.
A-T


CT1
HX 05-P
A-I(-)
A-I(+)
-15V
+15V
C3 0.1uK
C4 0.1uK
R4 20kF
R7 8.2kF
R34 12.1kF
IO-A-T
C1 470pJ
R1 20kF
U1C TL074CDR
R3 26.7kF
R5 10kF
1.5V-1
C2 1500pK
R2 10kF
U1B TL074CDR
R6 26.7kF
IO-A
GND-A
R112 20kF
R113 10kF
D10 CMMR1U-02
R91 10kF
U1A TL074CDR
D11 CMMR1U-02
R94 10kF
C98 0.1uK
R97 20kF
U1D TL074CDR
U14A LM393DT
R100 20kF
R103 7.5kF
C101 0.1uK
+5V
R106 10kF
C104 100pJ
OCP
CT2
HX 05-P
B-I(-)
B-I(+)
C7 0.1uK
C8 0.1uK
R11 20kF
R14 8.2kF
R68 12.1kF
IO-B-T
C5 470pJ
R8 20kF
U2C TL074CDR
R10 26.7kF
R12 10kF
C6 1500pK
R9 10kF
U2B TL074CDR
R13 26.7kF
IO-B
R114 20kF
R115 10kF
D12 CMMR1U-02
R92 10kF
U2A TL074CDR
D13 CMMR1U-02
R95 10kF
C99 0.1uK
R98 20kF
U2D TL074CDR
U14B LM393DT
R101 20kF
R104 7.5kF
C102 0.1uK
CT3
HX 05-P
C-I(-)
C-I(+)
C13 0.1uK
C14 0.1uK
R18 20kF
R21 8.2kF
R69 12.1kF
IO-C-T
C11 470pJ
R15 20kF
U3C TL074CDR
R17 26.7kF
R19 10kF
C12 1500pK
R16 10kF
U3B TL074CDR
R20 26.7kF
IO-C
R116 20kF
R117 10kF
D14 CMMR1U-02
R93 10kF
U3A TL074CDR
D15 CMMR1U-02
R96 10kF
C100 0.1uK
R99 20kF
U3D TL074CDR
U13B LM393DT
R102 20kF
R105 7.5kF
C103 0.1uK
U4 ISL21080CIH315Z
VIN VOUT GND
C9 0.1uK
C10 0.1uK
U5A TL074CDR
1.5V-1
GOOD WILL INSTRUMENT CO., LTD
Model PEK-520
Drawn By
Checked By
Approved By
Description EK01P16A-T-Wind Emulator.PrjPcb
Drawing NO 6 of 6
File Name EK01P16A-T-current_sensor.SchDoc
Modifed Date 2019/7/16
Rev. A-T

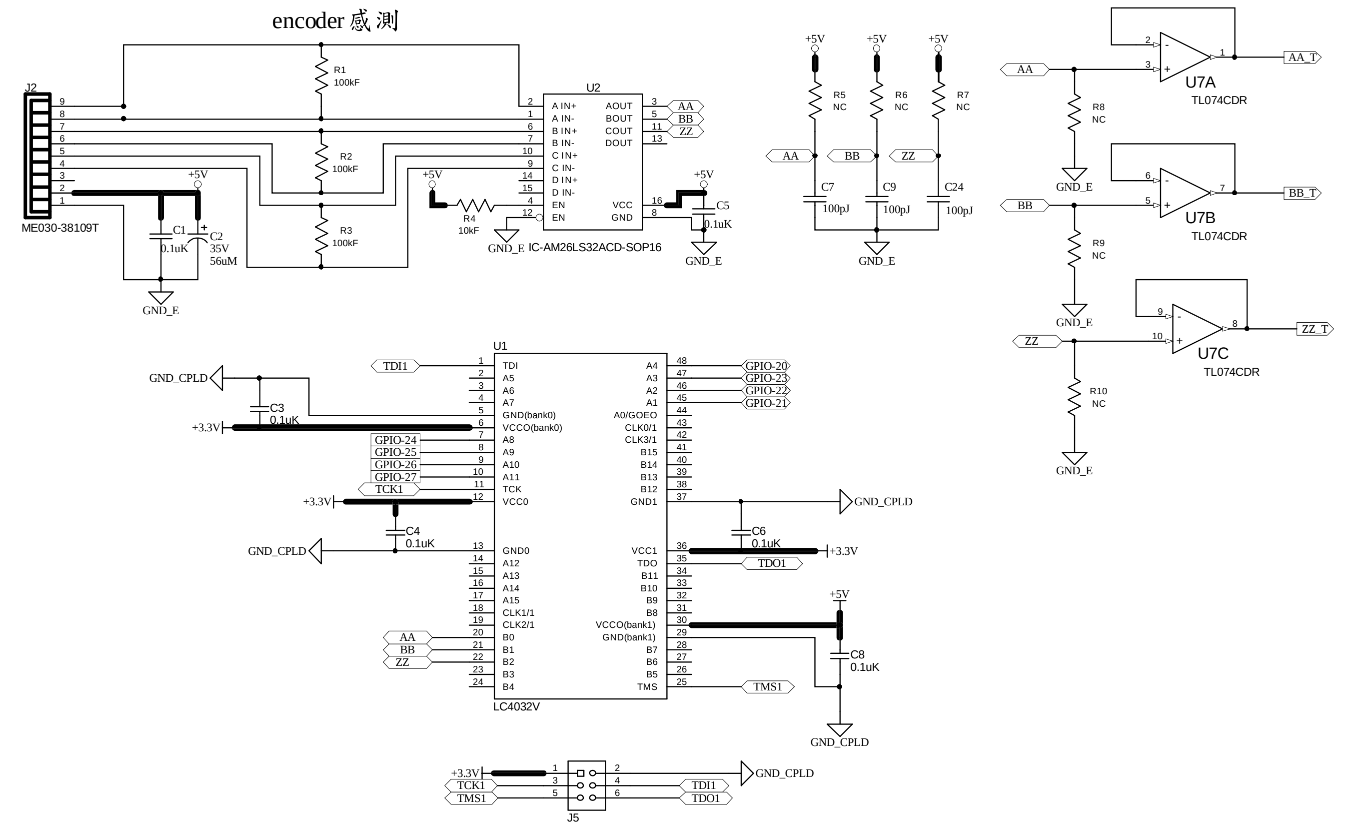
Grid Inverter



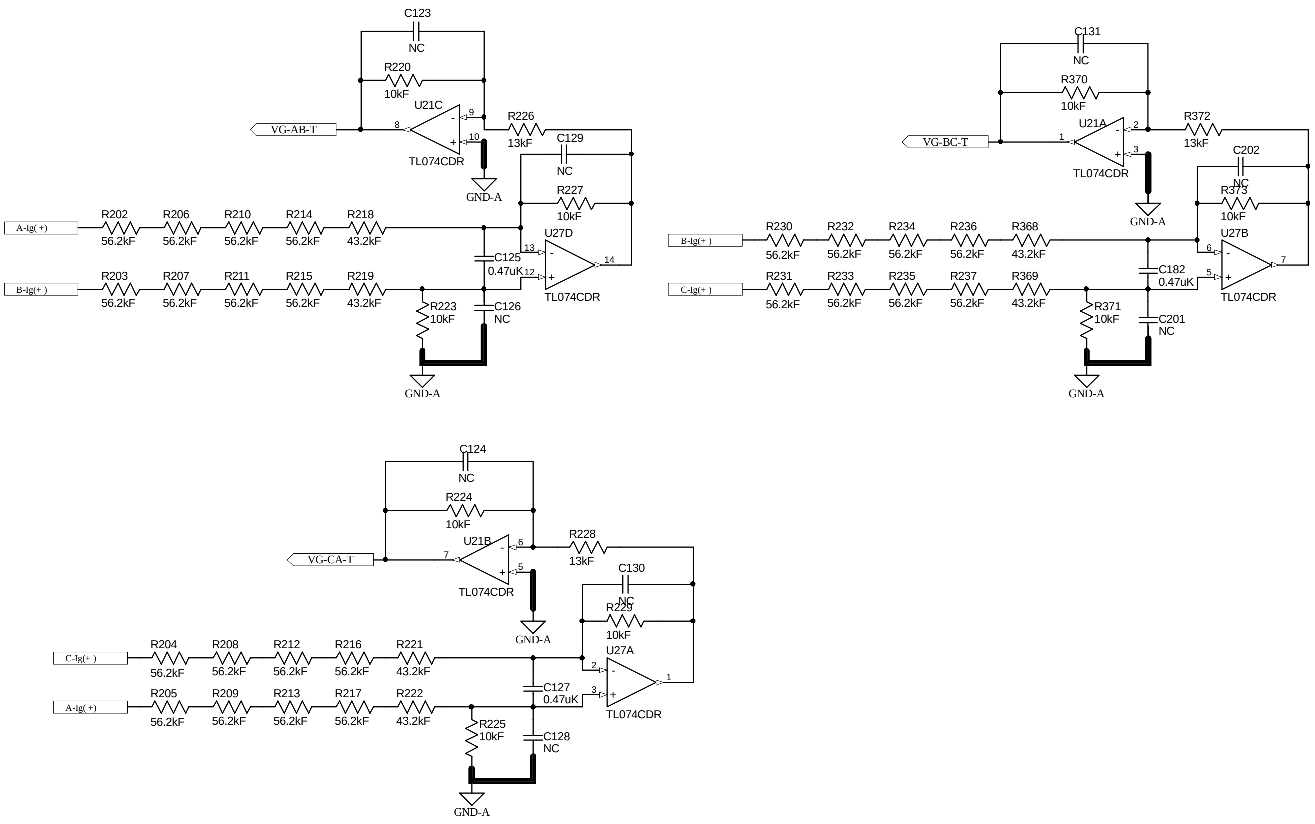
GOOD WILL INSTRUMENT CO., LTD			Model	PEK-520(Grid Inverter)		
Drawn By	Checked By	Approved By	Description	PEK-520_Grid Inverter.PrjPcb		
			File Name	EK01S17A-T_Power Stage.SchDoc		
			Drawing NO	1 of 10		
			Modifed Date	2019/7/24	Rev.	0



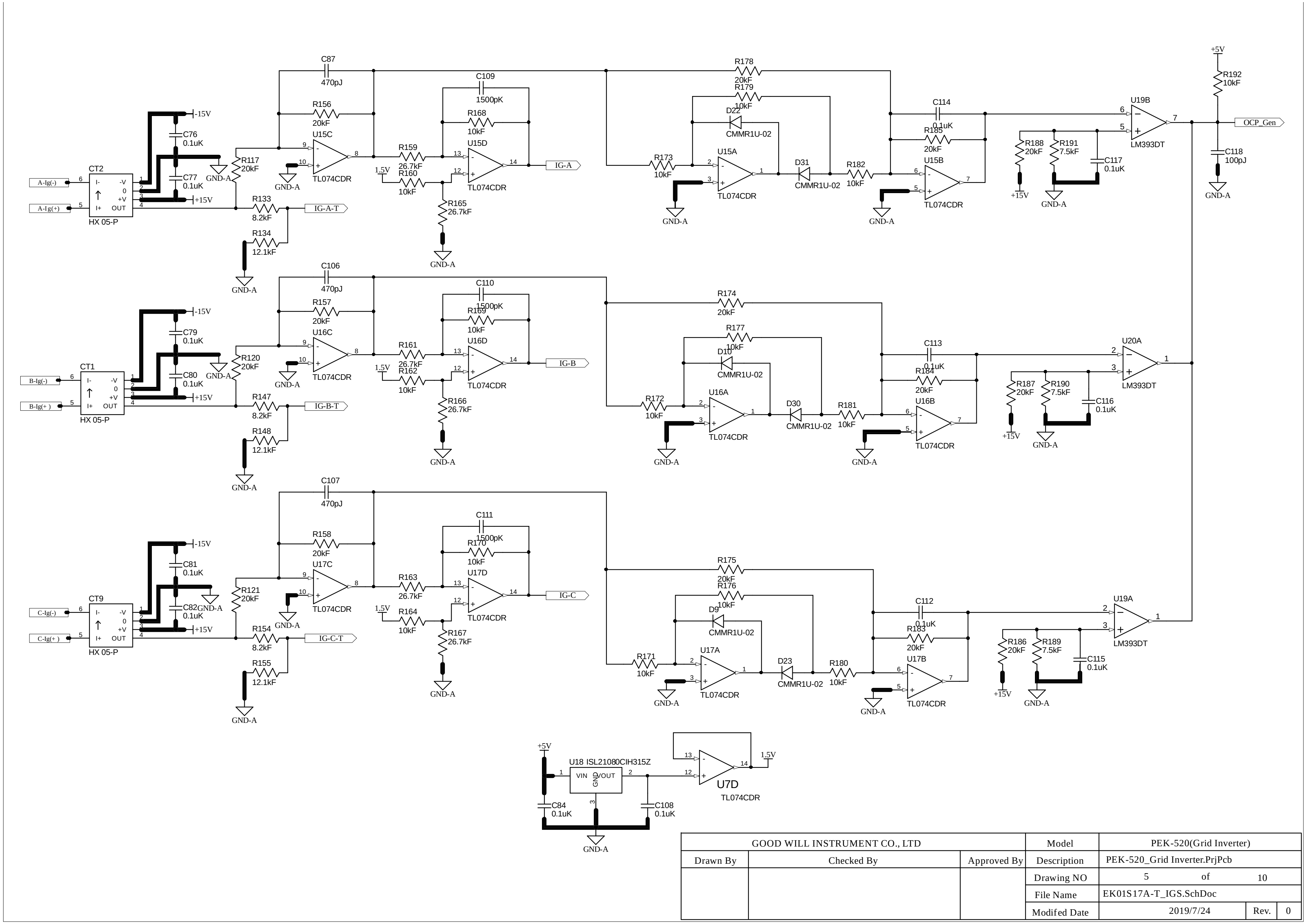
GOOD WILL INSTRUMENT CO., LTD			Model	PEK-520(Grid Inverter)	
Drawn By	Checked By	Approved By	Description	PEK-520_Grid Inverter.PrjPcb	
			Drawing NO	2 of 10	
			File Name	EK01S17A-T_Interface.SchDoc	
			Modifed Date	2019/7/24	Rev. 0

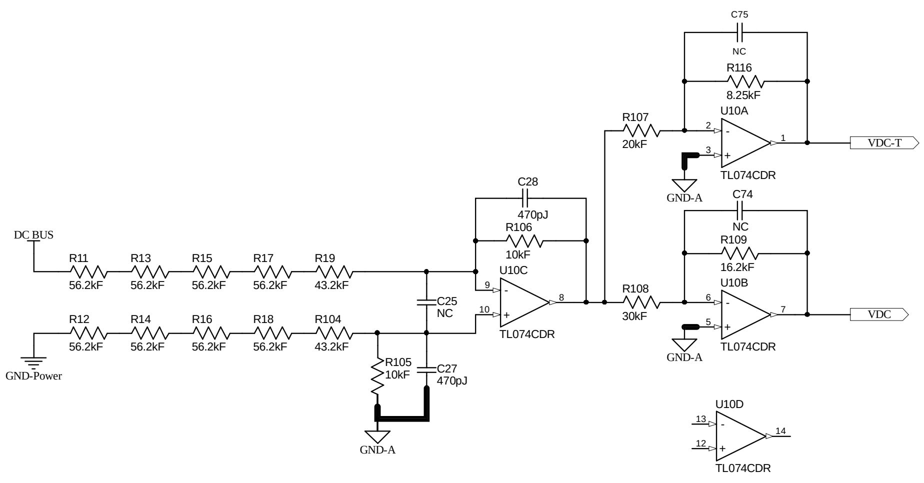


GOOD WILL INSTRUMENT CO., LTD			Model	PEK-520(Grid Inverter)
Drawn By	Checked By	Approved By	Description	PEK-520_Grid Inverter.PrjPcb
			Drawing NO	3 of 10
			File Name	EK01S17A-T_Encoder.SchDoc
			Modifed Date	2019/7/24 Rev. *

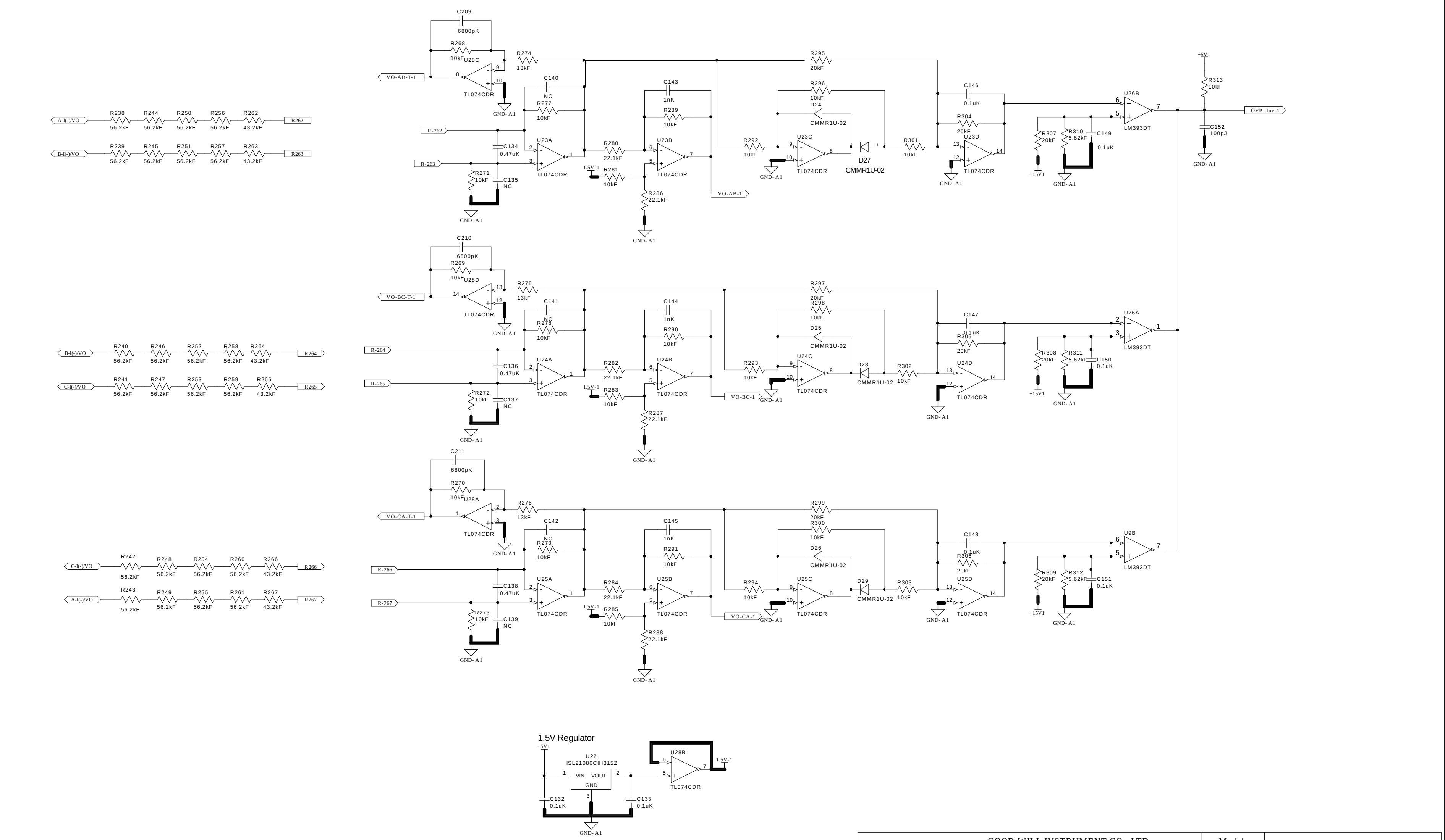


GOOD WILL INSTRUMENT CO., LTD			Model	PEK-520(Grid Inverter)		
Drawn By	Checked By	Approved By	Description	PEK-520_Grid Inverter.PrjPcb		
			Drawing NO	4 of 10		
			File Name	EK01S17A-T_VIS.SchDoc		
			Modifed Date	2019/7/24	Rev.	0

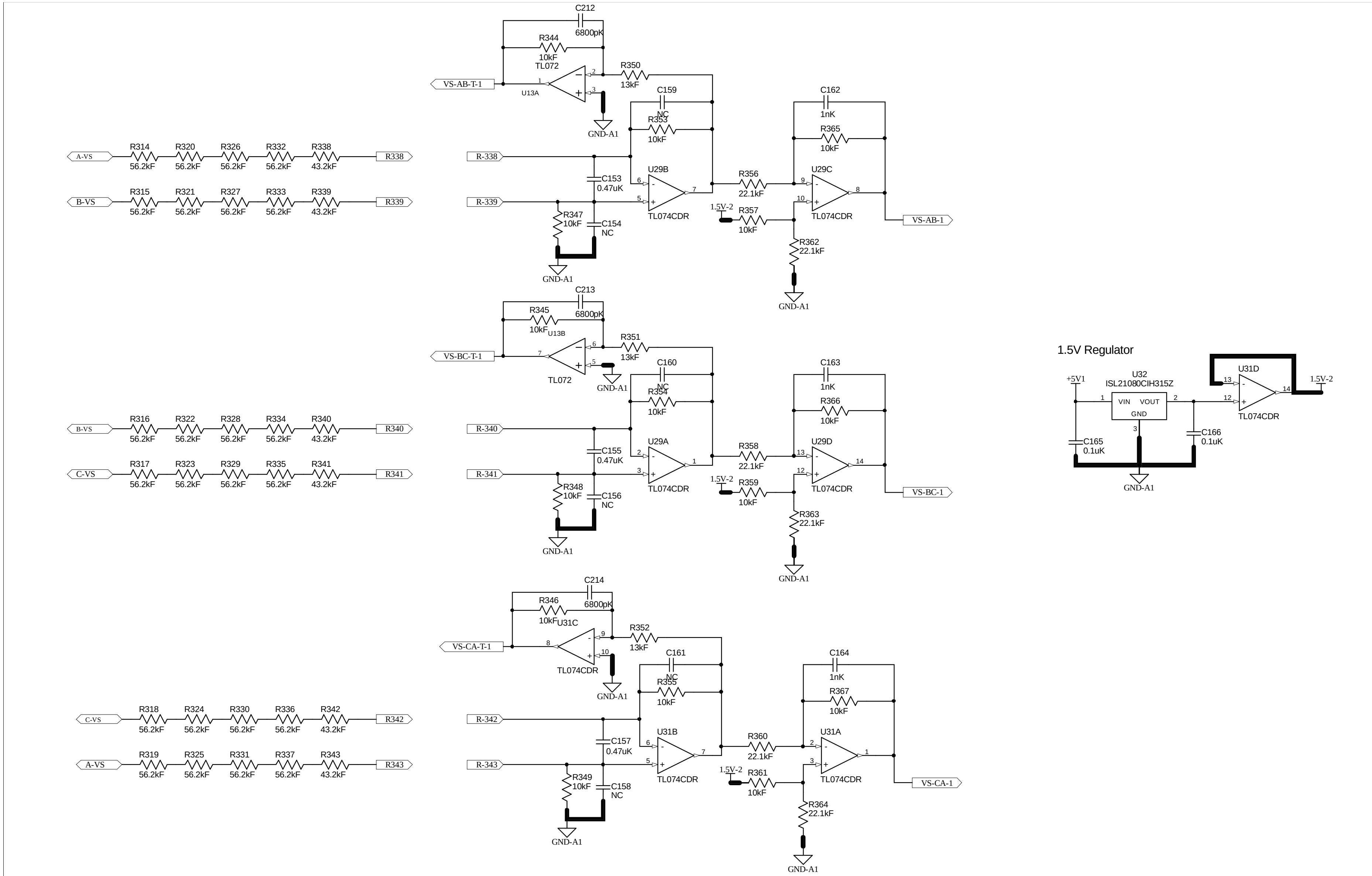

A-Ig(-)
A-Ig(+)
CT2
HX 05-P
-15V
+15V
C76
0.1uK
C77
0.1uK
GND-A
R117
20kF
C87
470pJ
R156
20kF
U15C
TL074CDR
R133
8.2kF
R134
12.1kF
IG-A-T
R159
26.7kF
R160
10kF
1.5V
C109
1500pK
R168
10kF
U15D
TL074CDR
R165
26.7kF
IG-A
R178
20kF
R179
10kF
D22
CMMR1U-02
R173
10kF
U15A
TL074CDR
D31
CMMR1U-02
R182
10kF
C114
0.1uK
R185
20kF
U15B
TL074CDR
R188
20kF
R191
7.5kF
C117
0.1uK
U19B
LM393DT
+5V
R192
10kF
C118
100pJ
OCP_Gen
B-Ig(-)
B-Ig(+)
CT1
HX 05-P
C79
0.1uK
C80
0.1uK
R120
20kF
C106
470pJ
R157
20kF
U16C
TL074CDR
R147
8.2kF
R148
12.1kF
IG-B-T
R161
26.7kF
R162
10kF
C110
1500pK
R169
10kF
U16D
TL074CDR
R166
26.7kF
IG-B
R174
20kF
R177
10kF
D10
CMMR1U-02
R172
10kF
U16A
TL074CDR
D30
CMMR1U-02
R181
10kF
C113
0.1uK
R184
20kF
U16B
TL074CDR
R187
20kF
R190
7.5kF
C116
0.1uK
U20A
LM393DT
C-Ig(-)
C-Ig(+)
CT9
HX 05-P
C81
0.1uK
C82
0.1uK
R121
20kF
C107
470pJ
R158
20kF
U17C
TL074CDR
R154
8.2kF
R155
12.1kF
IG-C-T
R163
26.7kF
R164
10kF
C111
1500pK
R170
10kF
U17D
TL074CDR
R167
26.7kF
IG-C
R175
20kF
R176
10kF
D9
CMMR1U-02
R171
10kF
U17A
TL074CDR
D23
CMMR1U-02
R180
10kF
C112
0.1uK
R183
20kF
U17B
TL074CDR
R186
20kF
R189
7.5kF
C115
0.1uK
U19A
LM393DT
U18 ISL21080CIH315Z
VIN
GND
VOUT
C84
0.1uK
C108
0.1uK
U7D
TL074CDR
GOOD WILL INSTRUMENT CO., LTD
Model
PEK-520(Grid Inverter)
Drawn By
Checked By
Approved By
Description
PEK-520_Grid Inverter.PrjPcb
Drawing NO
5 of 10
File Name
EK01S17A-T_IGS.SchDoc
Modifed Date
2019/7/24
Rev.
0



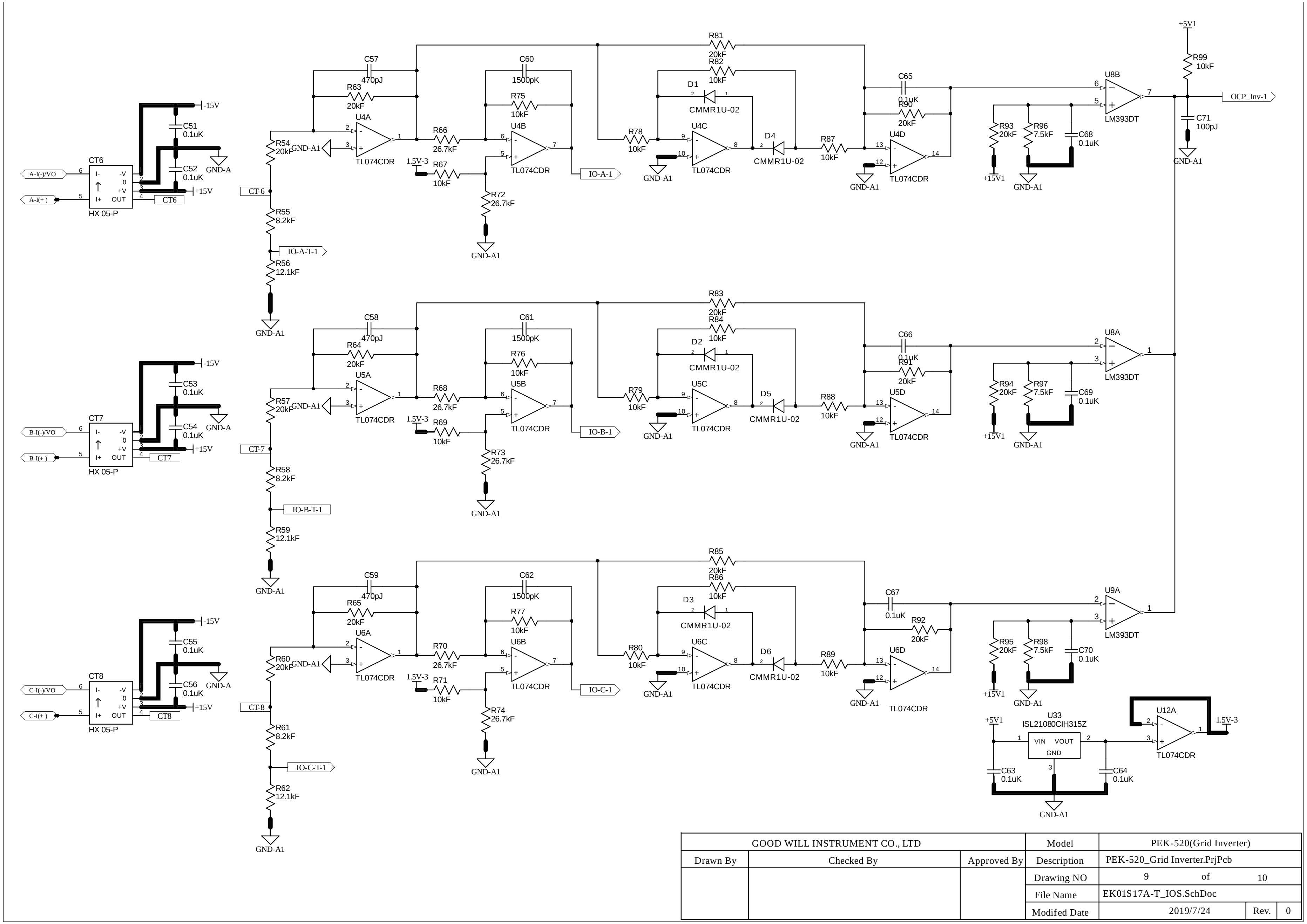
GOOD WILL INSTRUMENT CO., LTD			Model	*	
Drawn By	Checked By	Approved By	Description	PEK-520_Grid Inverter.PrjPcb	
			Drawing NO	6 of 10	
			File Name	EK01S17A-T_VBS.SchDoc	
			Modifed Date	2019/7/24	Rev. *

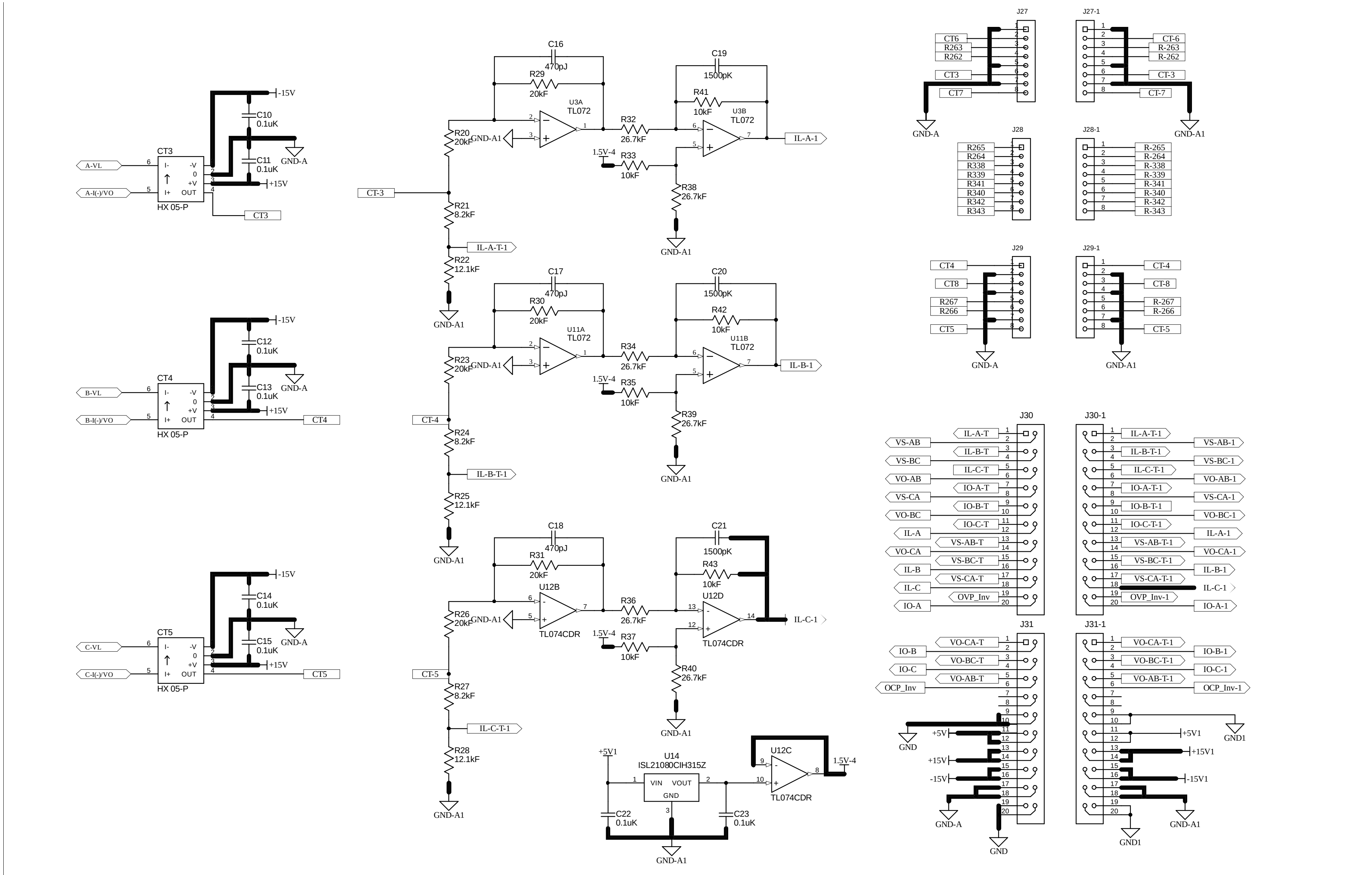


GOOD WILL INSTRUMENT CO., LTD			Model	PEK-520(Grid Inverter)
Drawn By	Checked By	Approved By	Description	PEK-520_Grid Inverter.PrjPcb
			File Name	EK01S17A-T_VOS.SchDoc
			Drawing NO	7 of 10
			Modifed Date	2019/7/2 4 Rev. 0



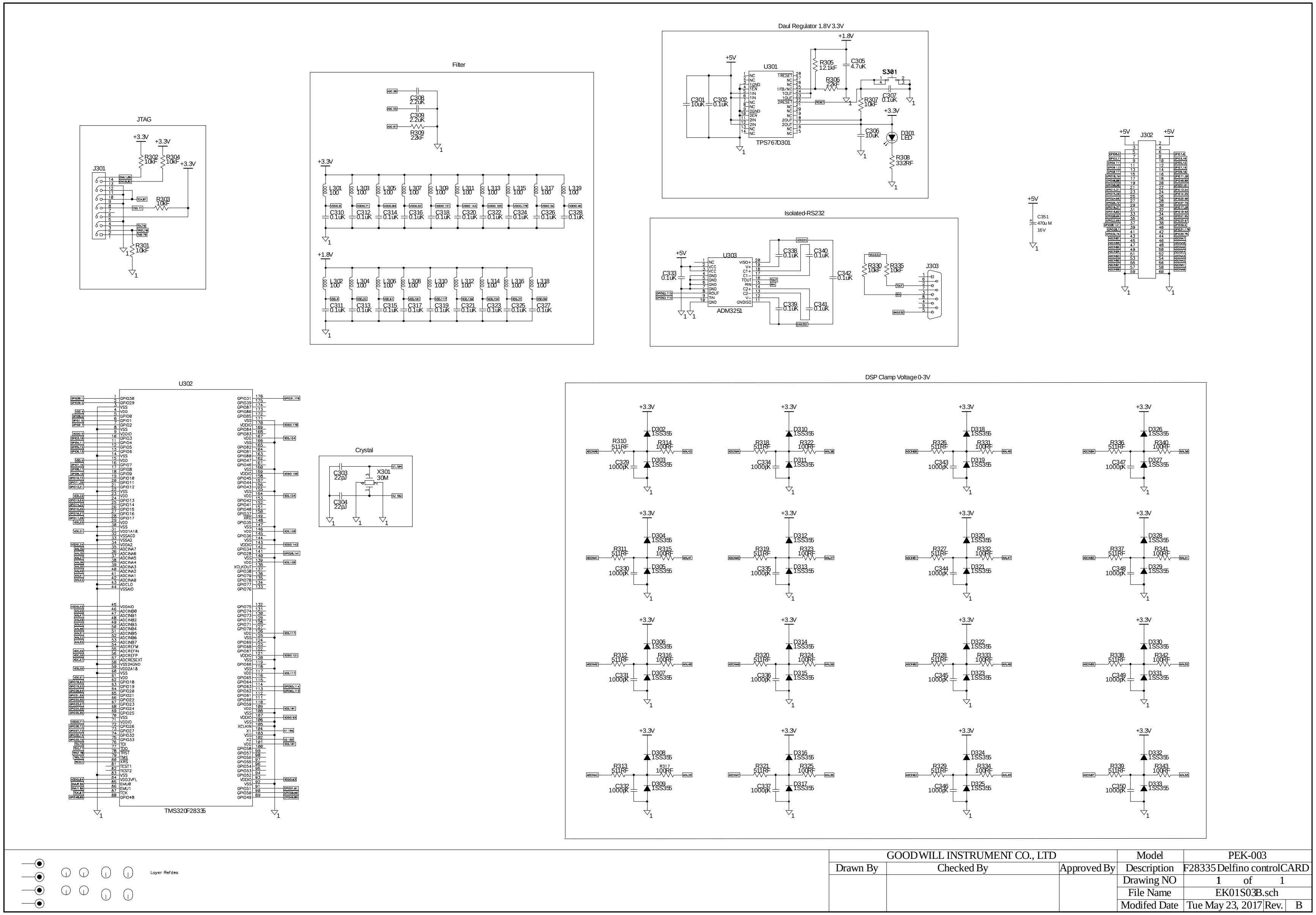
GOOD WILL INSTRUMENT CO., LTD			Model	PEK-520(Grid Inverter)		
Drawn By	Checked By	Approved By	Description	PEK-520_Grid Inverter.PrjPcb		
			Drawing NO	8 of 10		
			File Name	EK01S17A-T__VSS.SchDoc		
			Modifed Date	2019/7/24	Rev.	0


A-I(-)/VO
A-I(+)
B-I(-)/VO
B-I(+)
C-I(-)/VO
C-I(+)
CT6
CT7
CT8
HX 05-P
-15V
+15V
GND-A
GND-A1
C51 0.1uK
C52 0.1uK
C53 0.1uK
C54 0.1uK
C55 0.1uK
C56 0.1uK
CT-6
CT-7
CT-8
R54 20kF
R55 8.2kF
R56 12.1kF
R57 20kF
R58 8.2kF
R59 12.1kF
R60 20kF
R61 8.2kF
R62 12.1kF
IO-A-T-1
IO-B-T-1
IO-C-T-1
C57 470pJ
C58 470pJ
C59 470pJ
R63 20kF
R64 20kF
R65 20kF
U4A
U5A
U6A
TL074CDR
R66 26.7kF
R68 26.7kF
R70 26.7kF
1.5V-3
R67 10kF
R69 10kF
R71 10kF
C60 1500pK
C61 1500pK
C62 1500pK
R75 10kF
R76 10kF
R77 10kF
U4B
U5B
U6B
R72 26.7kF
R73 26.7kF
R74 26.7kF
IO-A-1
IO-B-1
IO-C-1
R81 20kF
R82 10kF
R83 20kF
R84 10kF
R85 20kF
R86 10kF
D1
D2
D3
D4
D5
D6
CMMR1U-02
R78 10kF
R79 10kF
R80 10kF
U4C
U5C
U6C
R87 10kF
R88 10kF
R89 10kF
C65 0.1uK
C66 0.1uK
C67 0.1uK
R90 20kF
R91 20kF
R92 20kF
U4D
U5D
U6D
+5V1
R99 10kF
U8B
U8A
U9A
LM393DT
OCP_Inv-1
C71 100pJ
R93 20kF
R94 20kF
R95 20kF
R96 7.5kF
R97 7.5kF
R98 7.5kF
C68 0.1uK
C69 0.1uK
C70 0.1uK
+15V1
U33
ISL21080CIH315Z
VIN
VOUT
GND
C63 0.1uK
C64 0.1uK
U12A
1.5V-3
GOOD WILL INSTRUMENT CO., LTD
Model
PEK-520(Grid Inverter)
Drawn By
Checked By
Approved By
Description
PEK-520_Grid Inverter.PrjPcb
Drawing NO
9 of 10
File Name
EK01S17A-T_IOS.SchDoc
Modifed Date
2019/7/24
Rev.
0

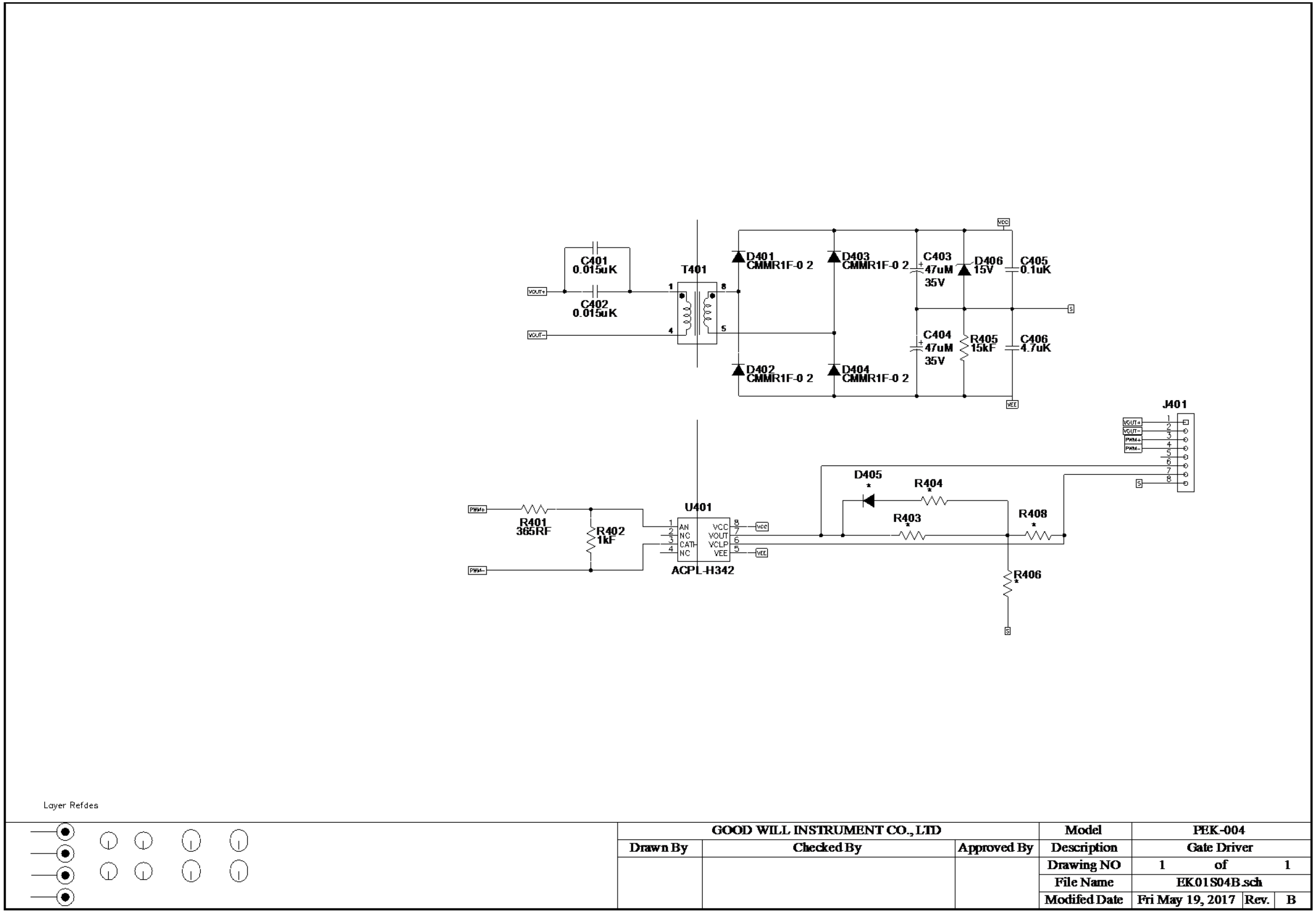


GOOD WILL INSTRUMENT CO., LTD			Model	PEK-520(Grid Inverter)		
Drawn By	Checked By	Approved By	Description	PEK-520_Grid Inverter.PrjPcb		
			Drawing NO	10 of 10		
			File Name	EK01S17A-T_ILS.SchDoc		
			Modifed Date	2019/7/24	Rev.	0

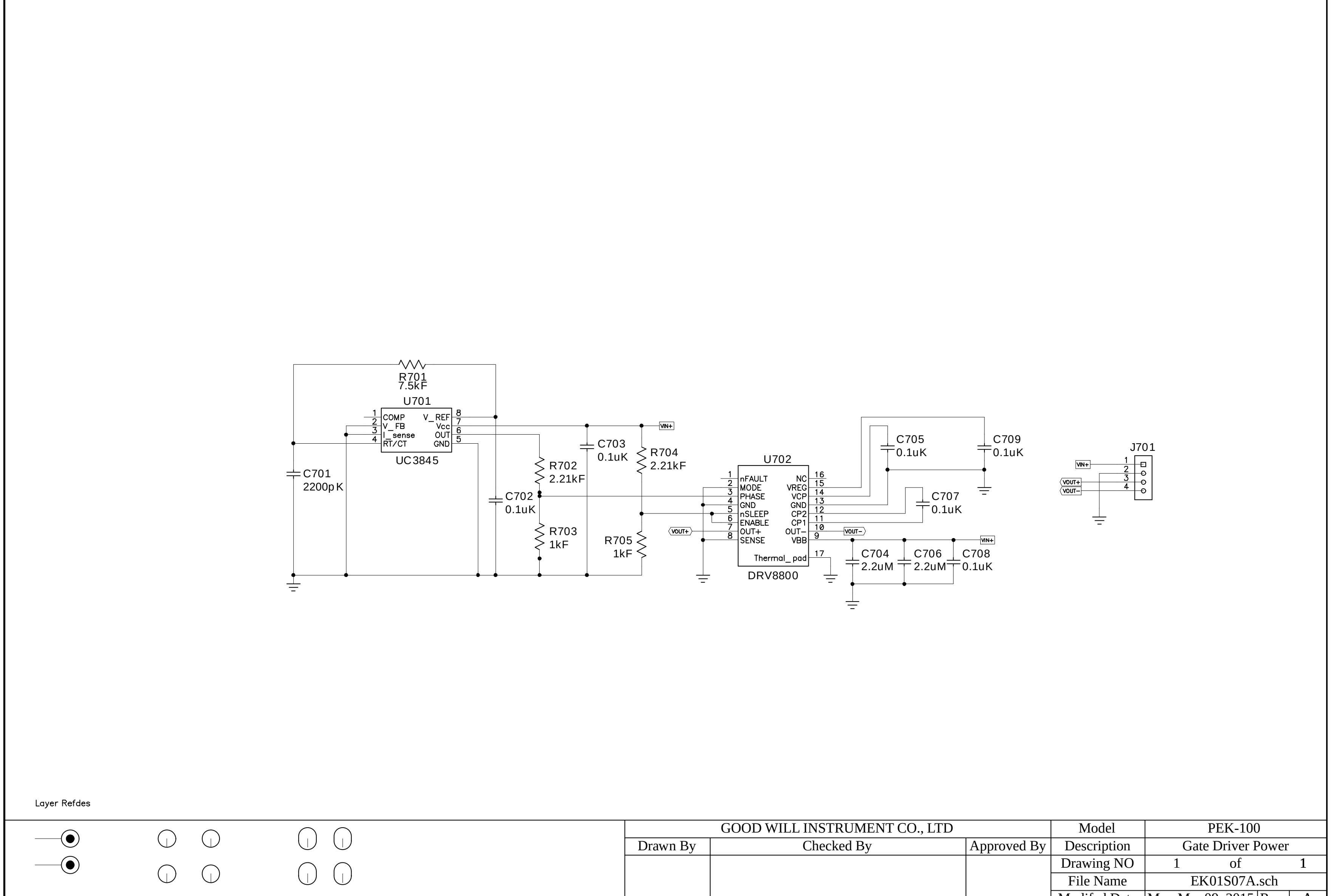
F28335 Delfino control CARD



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
R405
15kF
C405
0.1uK
C406
4.7uK
VCC
VEE
S
J401
PWM+
PWM-
R401
365RF
R402
1kF
U401
ACPL-H342
AN
NC
CATH
NC
VCC
VOUT
VCLP
VEE
D405
R404
R403
R408
R406
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



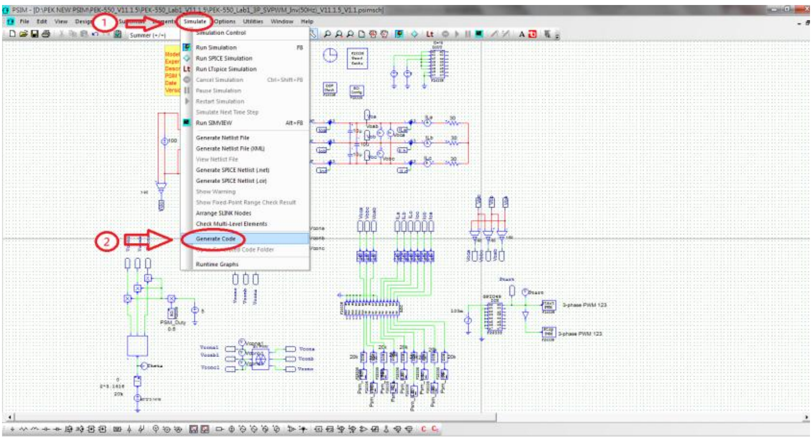
GOOD WILL INSTRUMENT CO., LTD			Model	PEK-100
Drawn By	Checked By	Approved By	Description	Gate Driver Power
			Drawing NO	1 of 1
			File Name	EK01S07A.sch
			Modifed Date	Mon Mar 09, 2015 Rev. A

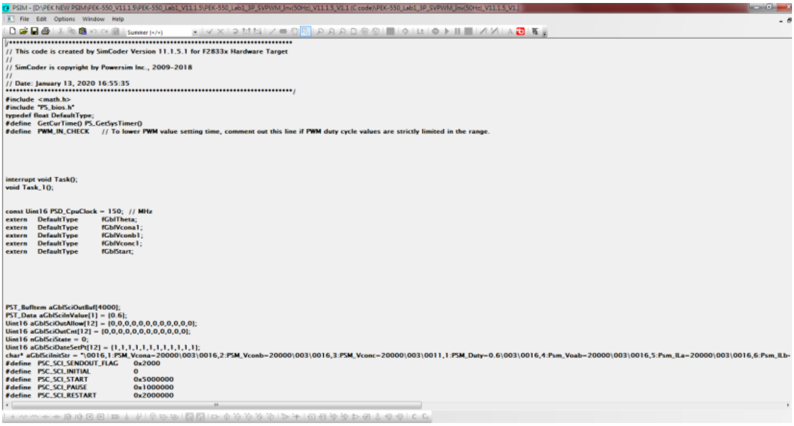
Appendix B – C Code Burning Procedure

This appendix takes "PEK-520_Lab1_3P_SVPWM_Inv (50Hz)_V11.1.5_V1.1" as an example for the instruction. See the detailed steps below.

Operating steps

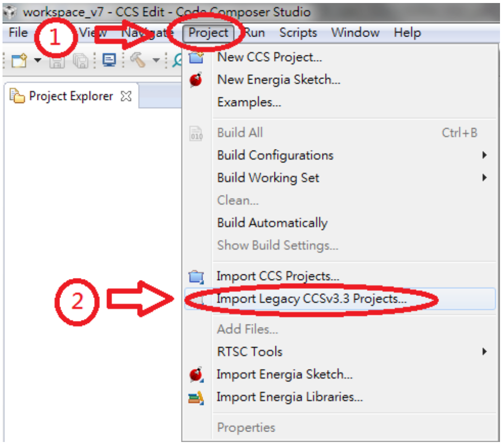
1. Open the digital circuit file "PEK-520_ Lab1_3P_SVPWM_Inv(50Hz)_V11.1.5_V1.1" within the PSIM program followed by clicking "Generate Code" from "Simulate" tab. The PSIM will generate C Code automatically as shown below.



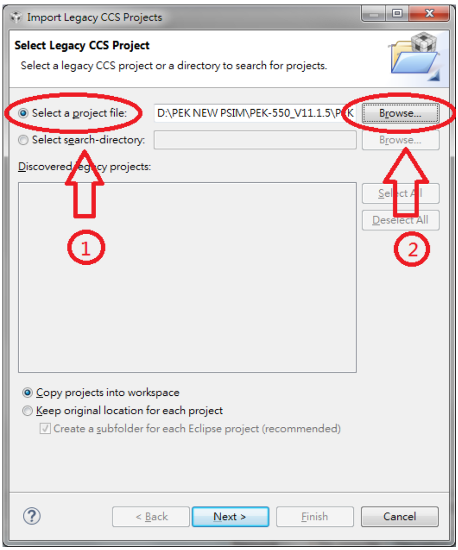


2. A folder of identical name with the PSIM circuit file in which the required files for burning and C Code are well saved will be generated in the location of PSIM circuit file by system.

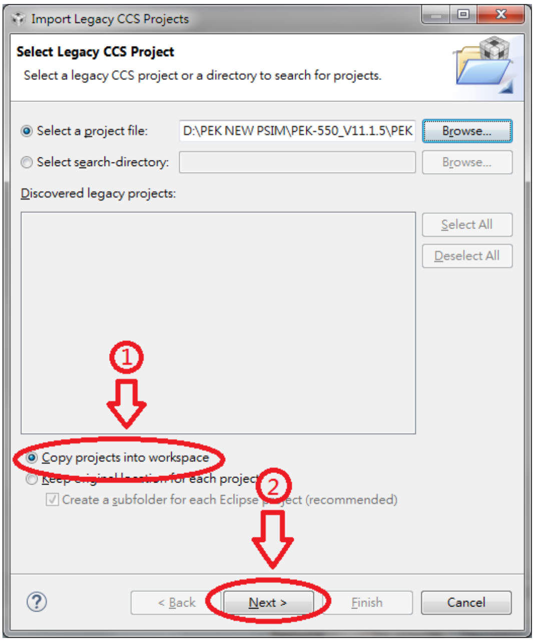
3. Open CCS and select "Project" tab followed by clicking "Import Legacy CCSv3.3 Projects" as the figure below.

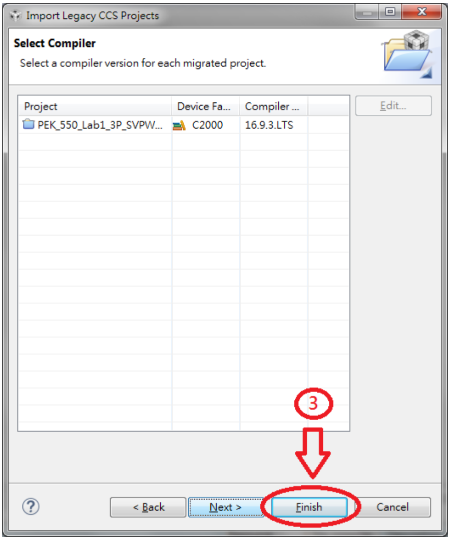


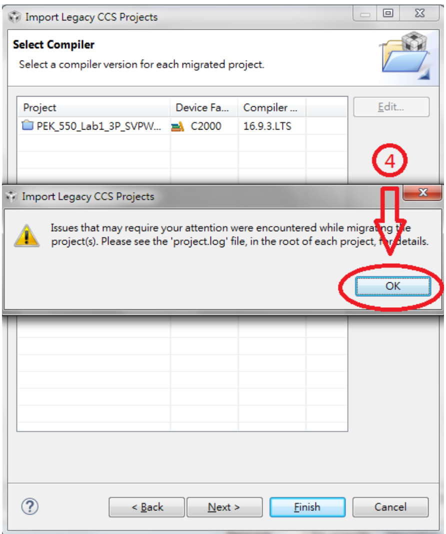
4. Go to "Select a project file" and click "Browser" followed by searching the folder where C Code is located and selecting the file with name extension ".pjt" as the following figure shown.



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 ...
Edit...
PEK_550_Lab1_3P_SVPW...
C2000
16.9.3.LTS
3
< Back
Next >
Finish
Cancel


Import Legacy CCS Projects
Select Compiler
Select a compiler version for each migrated project.
Project
Device Fa...
Compiler ...
Edit...
PEK_550_Lab1_3P_SVPW...
C2000
16.9.3.LTS
4
Import Legacy CCS Projects
OK
< Back
Next >
Finish
Cancel

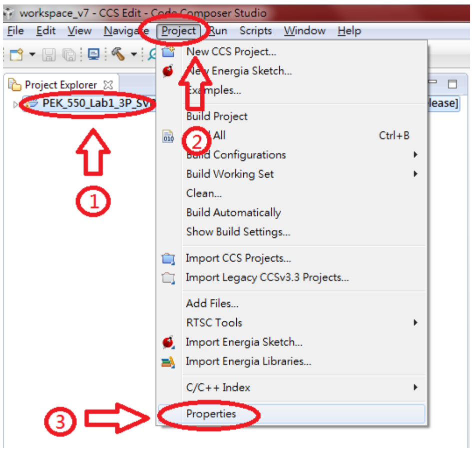
6. Select C Code file and choose “Properties” from “Project” tab. The setting steps are as follows.

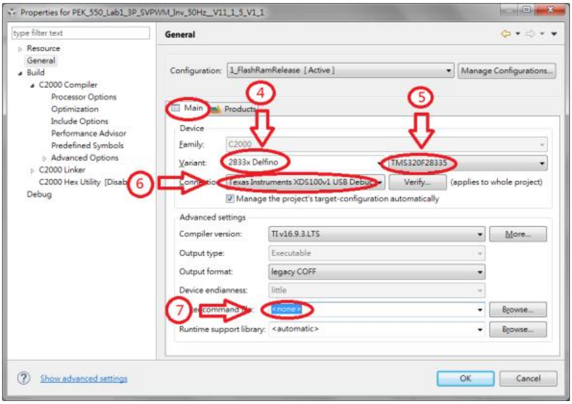
   1) Select “TMS320F28335” of “2833X Delfino” from Variant under Main tab.

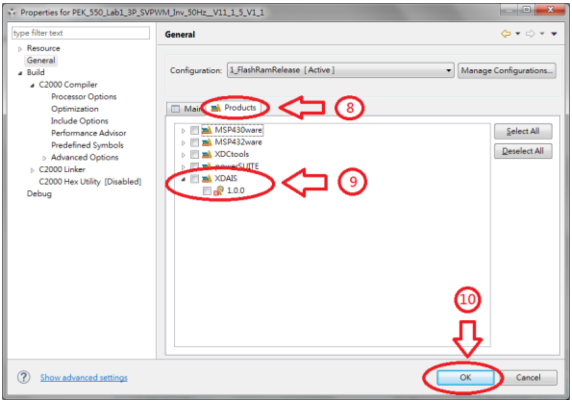
   2) Select “Texas Instruments XDS100v1 USB Debug Probe” from Connection under Main tab.

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

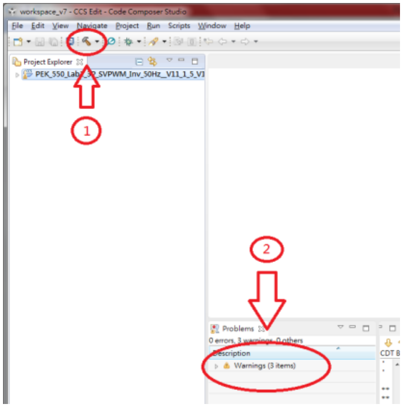
   4) Deselect “XDAIS” under Project tab. (Ignore this step if your CCS version doesn’t provide this option.



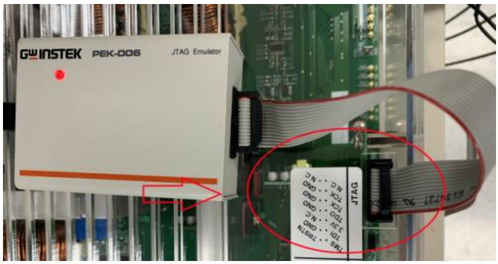


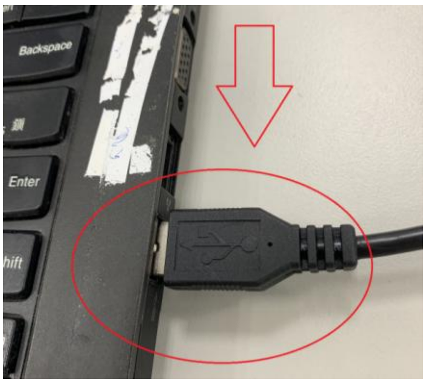


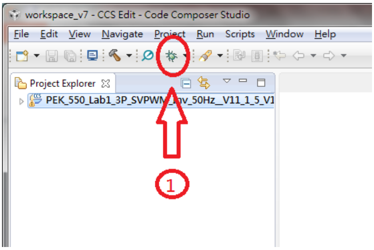
7. After the setting, click "Build" for compilation. If no errors occur after compiling, the program is eligible for burning. Simply ignore the warnings, which have no impact on burning process.



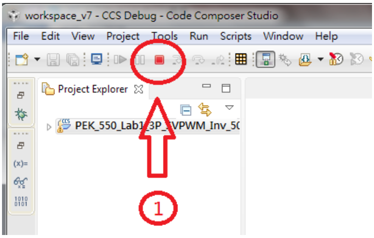
8. Connect PEK-006 to PC and PEK module respectively followed by clicking "Debug" to proceed to burning process.



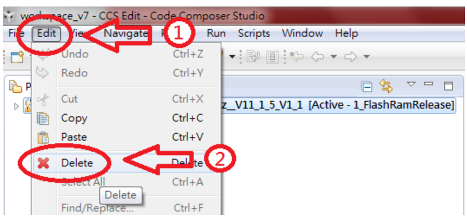


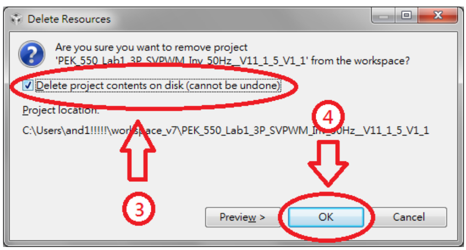


9. After the burning process, click "Terminate" and remove "PEK-006"to finish the entire procedure.



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.



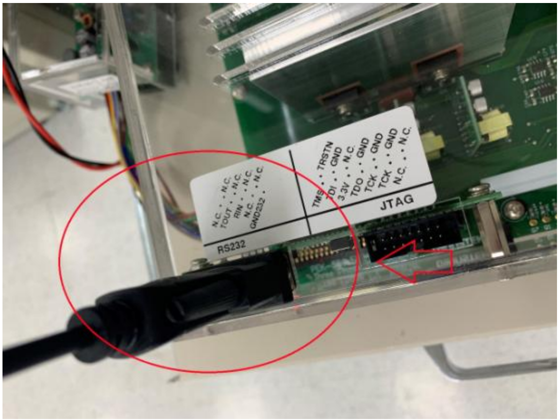


Appendix C – RS232 Connection

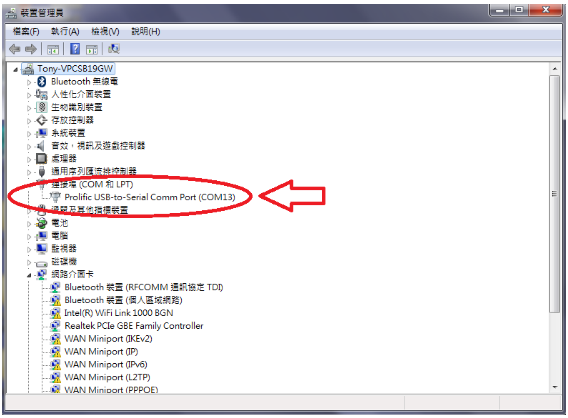
Operating steps

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

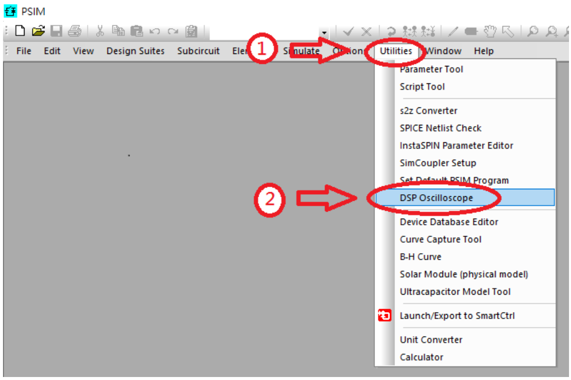
2. Connect one end of RS232 cable to PC, and the other end to the RS232 connector of PEK module.



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.

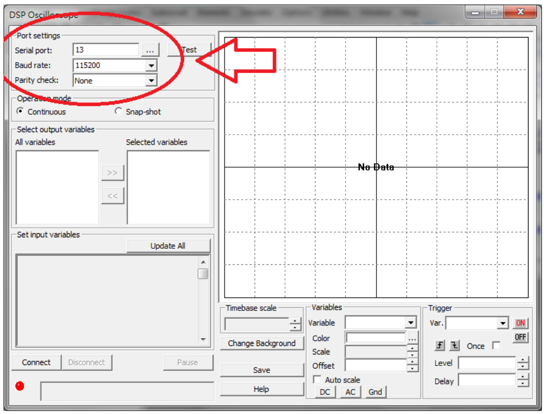


5. The Port settings are as follows.

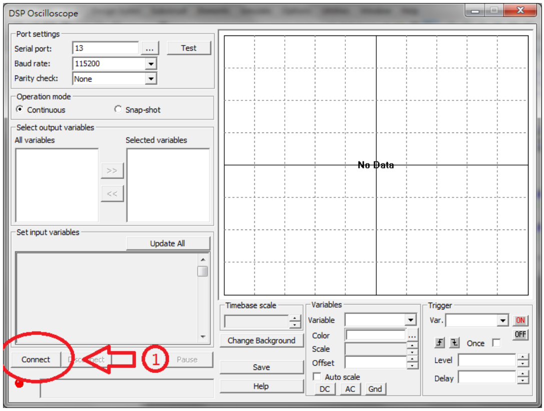
   1) Select the COM port being used by RS232.

   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.